C. ASSESSMENT OF NORTHERN SHORTFIN SQUID ON THE EASTERN USA SHELF DURING 2003 and 2004

A Report of the
SARC 42 Assessment Working Group
National Marine Fisheries Service
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EXECUTIVE SUMMARY

The northern shortfin squid, *Illex illecebosus*, inhabits the continental shelf and slope waters of the Northwest Atlantic Ocean between Iceland and the east coast of Florida and constitutes a unit stock throughout its range. The species is highly migratory, growth is rapid and the lifespan is short, up to 215 days for individuals inhabiting the USA shelf. *I. illecebrosus* is semelparous and females spawn and die within several days of mating. Thus, natural mortality increases with age for the age range where spawning occurs. Fishing mortality and spawning mortality occur simultaneously. Stock structure is complicated by the overlap of seasonal cohorts. Age data indicate that spawning occurs throughout the year and that the first several months of the US fishery are supported by the winter cohort. The onset and duration of the fisheries occur in relation to annual migration patterns on and off the continental shelf which appear to be highly influenced by environmental conditions. On the USA shelf, a bottom trawl fishery generally occurs during June through October. Since its inception in 1987, the domestic fishery has taken a majority of the total annual landings. In recent years, there has been no fishery on the Scotian Shelf and landings from the Newfoundland jig fishery have been very low. There are no stock-wide research surveys and it is unknown whether NEFSC research bottom trawl surveys track *Illex* abundance or its availability on the shelf because these surveys cover only a portion of the *Illex* habitat and they occur during migration periods.

The northern stock component, extending from Newfoundland to the Scotian Shelf, is assessed annually and managed by the Northwest Atlantic Fisheries Organization (NAFO) based on a total allowable catch (TAC). The southern stock component, extending from the Gulf of Maine to the east coast of Florida, is managed by the Mid-Atlantic Fisheries Management Council (MAFMC) based on an annual TAC. According to the regulations, closure of the directed fishery occurs when 95% of the quota has been landed. At that time, a trip limit of 4.5 mt (10,000 lbs) takes effect. The stock was last assessed in 2003, at SAW 37, and updated fishery and survey data for 1999-2002. At SAW 37, it was not possible to evaluate stock status because there were no reliable estimates of stock biomass or fishing mortality rates. However, based on qualitative information, it was determined that overfishing was not likely to have occurred during 1999-2002. Stock status with respect to biomass was unknown.

The current assessment focuses on the southern stock component, particularly during 2003 and 2004, but survey indices and landings from the northern stock component are also presented. This is a data-poor stock, and because there are no reliable research survey indices for *Illex* inhabiting the U.S. Shelf, the assessment relies on fisheries data, in particular, catch per unit

effort (CPUE) indices and biological data collected during prior cooperative research projects. Due to its short lifespan and the short fishing season, *Illex* was assessed using an in-season (weekly) model. Estimates of natural mortality were included in the in-season model and in a weekly per-recruit model. Although the Working Groups felt the model formulations were sound, it was decided that the use of the results from the three models was premature, mainly due to a lack of seasonal age, growth and maturity data which greatly affect the model results. Due to the lack of adequate data regarding fishing mortality rates and absolute biomass, stock status could not be determined for 2003 or 2004.

TERMS OF REFERENCE

The following Terms of Reference were addressed and are summarized below:

1.) *Characterize the commercial and recreational catch including landings and discards.*

    There is no recreational fishery for *Illex*. Landings and discards from the USA fishery were updated for 2003 and 2004. Landings from the fisheries involving the northern stock component (Scotian Shelf and Newfoundland) were also updated for 2003 and 2004. Refer to Section 3.0.

2.) *Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates.*

    A revised version of the SARC 37 in-season assessment model was run using data for 2003 and 2004. However, the model estimates of fishing mortality and stock size were not reliable because new data on seasonal growth rates and maturity are required for the model. Refer to Section 7.0.

3.) *Evaluate and either update or re-estimate biological reference points as appropriate.*

    A revised version of the SARC 37 maturation-natural mortality model was presented but the results were not considered reliable because new data on seasonal growth rates and maturity are required for the model. Because the preliminary natural mortality estimates are a data input to the per-recruit models that were used to estimate biological reference points, the reference point estimates from the per-recruit models were also considered preliminary. In addition, seasonal changes in growth rates are likely for this species and this will affect the reference point estimates. Therefore, seasonal growth rate data are required to test the sensitivity of the per-recruit models to growth rates. Refer to Section 6.0.

4.) *Where appropriate, estimate a TAC and/or TAL based on stock status and target fishing mortality rate for the year following the terminal assessment year.*

5.) *If possible,*

    a. *provide short term projections (2-3 years) of stock status under various TAC/F strategies and*

    b. *evaluate current and projected stock status against existing rebuilding or recovery schedules, as appropriate.*

As *Illex* is a sub-annual species, assessments should be based on data from the current year. However, stock assessments are prepared for the previous year because data for the current year are unavailable at the time of the assessment and/or the current year's fishery is ongoing at the time of the SARC. Consideration of the timing of the *Illex* assessment and the collection of in-season assessment data are needed to remedy these issues.

6.) *Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in previous SARC-reviewed assessments.*

The accomplishment of many of the previous SARC research recommendations, as a result of external grant funds obtained by the lead assessment scientist and cooperative research projects, has resulted in an increased understanding of the complex life history of this species and has allowed the development and testing of new models which appear promising. This information has been documented in several journal and report publications. Refer to Section 9.0 for the status of the SARC 37 research recommendations.

1.0 INTRODUCTION

An initial review of the *Illex illecebrosus* assessment was conducted on October 3, 2005 at a meeting of the Invertebrate Working Group held at the Northeast Fisheries Science Center in Woods Hole, Massachusetts. Lynne Purchase, a squid assessment scientist from the Renewable Resources Assessment Group (RRAG), at Imperial College in London, attended the meeting as an external reviewer. Ms. Purchase's comments are presented in Appendix C1. The assessment was revised according to the recommendations made at the October 3 meeting and was reviewed again at a second Working Group meeting held during October 24-28 in Woods Hole, MA. The comments from second Working Group meeting are included in Appendix C2. The follows persons attended the second meeting:

Name	Organization
Jay Burnett	NMFS/NEFSC
Ralph Mayo	NMFS/NEFSC
Larry Jacobsen	NMFS/NEFSC
Chris Legault	NMFS/NEFSC
Susan Wigley	NMFS/NEFSC
Laurel Col	NMFS/NEFSC
Jim Weinberg	NMFS/NEFSC
Mark Terceiro	NMFS/NEFSC
Azure Westwood	NMFS/NEFSC
Dan Farnham	Industry Advisor
Kathy Lang	NMFS/NEFSC
Paul Rago	NMFS/NEFSC
Bill Overholtz	NMFS/NEFSC
Vidar Wespestad	Industry Consultant
Jim Ruhle	Industry Advisor
Dvora Hart	NMFS/NEFSC
Mauricio Ortiz	NMFS/SEFSC

Dana Hanselman	NMFS/AFSC
Eric Powell	Rutgers University
Francois Gregoire	DFO, Canada
Lisa Hendrickson	NMFS/NEFSC
Rich Seagraves	MAFMC
Marybeth Tooley	ECPH
Paul Nitschke	NMFS/NEFSC
Steve Cadrin	NMFS/NEFSC/SMAST
Mary Radlinski	SMAST

The *Illex illecebrosus* stock was last assessed in 2003 at the 37th Stock Assessment Workshop (SAW) (NEFSC 2003). The assessment included updates of fisheries and research survey data for 1999 through 2002. An in-season (weekly) assessment model that incorporated recruitment, landings and effort data, mean body weights from the fishery, and natural mortality rates computed from a maturation-natural mortality model were used to estimate initial stock size and fishing mortality rates in the U.S. fishing area during 1999 but the model was considered preliminary because additional testing was required (NEFSC 2003). The SARC 37 assessment also included a weekly yield-per-recruit (YPR) and egg-per-recruit (EPR) analysis which was also considered premature. With respect to stock status, SARC 37 concluded that it was not possible to evaluate the current stock status because there are no reliable estimates of absolute stock biomass or fishing mortality rate.

The current assessment pertains to the southern stock component (US EEZ, from the Gulf of Maine to Cape Hatteras, NC), but also summarizes landings and research survey data from the northern stock component (Newfoundland and the Scotian Shelf). Fisheries data and research survey biomass and abundance indices were updated to include 2003 and 2004. *Illex illecebrosus* is a semelparous species and an age-based maturation-natural mortality model that estimates spawning mortality rates was presented during the last assessment. The model has been reformulated, changing from a discrete time step to a continuous process. Output from the reformulated model, including the probability of spawning at age and spawning mortality rate estimates, are incorporated in yield-per-recruit and egg-per-recruit analyses along with fishery selectivity estimates and catch mean weights, during 1999-2002, to estimate biological reference points. Results from the reformulated maturation-natural mortality model and the per-recruit models are taken from a journal publication (Hendrickson and Hart 2006) prepared by the *Illex* assessment scientists. The in-season stock assessment model that was considered preliminary during the last assessment was further developed and tested using simulation analyses. Simulation analysis results are presented herein.

2.0 BACKGROUND

The northern shortfin squid, *Illex illecebosus*, inhabits the continental shelf and slope waters of the Northwest Atlantic Ocean between Iceland and the east coast of Florida and is assumed to constitute a unit stock throughout its range (Dawe and Hendrickson 1998). The northern stock component, extending from Newfoundland to the Scotian Shelf, is assessed annually and managed by the Northwest Atlantic Fisheries Organization (NAFO) based on a total allowable catch (TAC). The southern stock component, extending from the Gulf of Maine to the east coast of Florida, is managed by the Mid-Atlantic Fisheries Management Council (MAFMC) based on an annual TAC.

The life history and habitat requirements of *I. illecebrosus* are summarized in Hendrickson and Holmes (2004). The northern shortfin squid is a highly-migratory ommastrephid that lives for up to one year (Dawe et al. 1985; Dawe and Beck 1997; O'Dor and Dawe 1998; Hendrickson 2004). Temporal and spatial distribution patterns are highly variable at the northern limit of this species' range (Newfoundland) and are associated with environmental factors (Dawe et al. 1998). Recruitment dynamics are complex and have not been fully elucidated for the U.S. EEZ component of the stock, so reliable predictions of annual recruitment levels are not currently possible. Stock structure is complex and, in Newfoundland waters, is complicated by overlapping seasonal cohorts that migrate through the fishing grounds (Dawe and Beck 1997). Mean size at maturity varies between northern and southern geographic regions in some years (Coelho and O'Dor 1993). However, it is not known whether these differences are due to inherent population structure. O'Dor and Coelho (1993) speculated that changes in the seasonal spawning patterns could have played a role in the collapse of the Canadian fishery during the early 1980's.

The *Illex* stock is fished on the continental shelf from Newfoundland, Canada to Cape Hatteras, North Carolina. However, there are no stock-wide indices of relative abundance or biomass. The NEFSC bottom trawl surveys do not cover the entire habitat range of the species and it is unknown whether the survey indices measure relative abundance or availability to the survey gear. In addition, CPUE data for the US fishery is of coarse temporal and spatial resolution and age and growth information for the U.S. stock component is limited to data from a single pre-fishery survey (Hendrickson 2004). As a result, research recommendations in previous assessments have emphasized the need for improved stock assessment data, particularly given the short lifespan and short fishing season (4-5 months on average for the US fishery).

Since 1997, the NEFSC has conducted multiple cooperative research projects with the *Illex* fishing industry that have increased our knowledge about the age, growth and life history of *Illex* in US waters (Hendrickson 2004) and that have improved the spatial and temporal resolution of fisheries catch, effort and biological data in real-time via electronic logbook reporting (Hendrickson et al. 2003). The products of these research projects have been used extensively in new assessment models that take into account the semelparous life history of *I. illecebrosus*.

Commercial fisheries for *I. illecebrosus* occur from Newfoundland to Cape Hatteras, North Carolina. The bottom trawl fishery operating within the U.S. EEZ (Northwest Atlantic Fisheries Organization Subareas 5 and 6) is managed by the Mid-Atlantic Fishery Management Council (MAFMC) and fisheries operating within Northwest Atlantic Fisheries Organization (NAFO) Subareas 2, 3 and 4 are managed by NAFO (Fig. C1). During 1980-1998, the annual total allowable catch (TAC) established by NAFO for Subareas 2-4 was 150,000 mt (NAFO 1995). The NAFO TAC was reduced to 75,000 mt in 1999 (NAFO 2000) and has been 34,000 mt since 2000 (Hendrickson et al. 2005). Annual levels of allowable biological catch (ABC) and domestic annual harvest (DAH) in the U.S. EEZ are determined in accordance with the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan (SMB FMP) and are based on the best available information about the current status of the stock. During 1991-1995, the optimum yield (OY), ABC and DAH were 30,000 mt (MAFMC 1994). The DAH was reduced to 21,000 mt in 1996 (MAFMC 1995a) and 19,000 mt during the 1997-1999 fishing seasons (MAFMC 1996a; 1997a;

1998a). The DAH has been 24,000 mt since 2000 and was set at 24,000 for 2006 (MAFMC 2000; 2001; 2002).

Amendment 5 of the SMB FMP was enacted (MAFMC 1995b; 1996b) in recognition that the domestic resource was approaching full utilization and that expansion of the U.S. fleet might lead to overcapitalization. Amendment 5 established a permit moratorium to limit entry into the directed fishery, required mandatory logbook and dealer reporting as of January 1, 1997, and established a 5,000-pound trip limit for incidental catches of *Illex* by non-moratorium vessels. Amendment 6 (MAFMC 1996c) provided a mechanism for in-season closures of the *Illex* fishery, and established an overfishing definition of $F_{20\%}$ and procedures for the specification of annual quotas based on $F_{50\%.}$ Amendment 7 (MAFMC 1998b) was enacted to achieve consistency between FMP's with regards to Limited Access Federal permits. Based on the requirements of the Sustainable Fisheries Act (SFA), Amendment 8 (MAFMC 1998c) established MSY-based biological reference points. Threshold and target fishing mortality rates were specified as F_{MSY} and 75% of F_{MSY}, respectively. In addition, a biomass target and minimum biomass threshold were specified as B_{MSY} and 50% of B_{MSY}, respectively. Amendment 8 also defined the essential habitat of *Illex* in the U.S. EEZ and established a framework adjustment process for specific management measures. Amendment 9 is still in draft form, and with respect to *Illex*, could extend the moratorium on entry to the commercial fishery, allow for specification of management measures covering multiple years, require electronic daily reporting, modify the exemption from the *Loligo* minimum mesh size requirement for vessels in the *Illex* fishery, implement closures to reduce gear impact on habitat, and modify the *Loligo* possession imit by *Illex* fishery vessels during *Loligo* fishery closures..

3.0 LANDINGS AND DISCARDS

Landings

A bottom trawl fishery for *I. illecebrosus* occurs on the USA shelf (NAFO Subareas 5+6) and an artisanal jig fishery occurs in inshore Newfoundland waters (NAFO Subarea 3). Historically, a bottom trawl fishery also occurred on the Scotian Shelf in NAFO Subarea 4 (Hendrickson et al. 2005). The timing and duration of the fisheries are determined primarily by the migration of the species through the fishing grounds on the continental shelf. The inshore migration into Subarea 3 generally occurs during July, approximately three months later than it occurs on the continental shelf in Subareas 4, 5 and 6. This delay in the arrival of squid on the fishing grounds is presumably a result of the position of the Gulf Stream, the hypothesized transport mechanism for paralarvae hatched during the winter (Trites 1983), being located further from shore in this northern region. An unusually early inshore arrival of squid occurred in Subarea 3 during June of 1987, when 78% of the landings for that year were taken. *Illex* remains on the shelf longer in Subarea 3 so the fishing season often extends into November after landings reach a peak in September (NEFSC 1999). Since 1992, the U.S. fishery and the Subarea 4 fishery have generally occurred during June through October with a peak in July (NEFSC 1999). Historically, foreign trawlers involved in the silver hake and argentine fishery in Subarea 4 also targeted *Illex* if it became available before the July closure of the silver hake fishing season (Mark Showell, pers. comm. 1999). However, the mixed fishery for silver hake, argentine and *Illex* has not operated in Subarea 4 since 2000 (Hendrickson et al. 2004).

Illex landings (mt) during 1963-2005 are presented for the southern stock component inhabiting the US EEZ (NAFO Subareas 5+6) as well as the northern stock component (NAFO Subareas 3+4, Table C1, Fig. C2). US EEZ landings are partitioned into foreign and domestic components and the total allowable catches (TACs) for Subareas 3+4 and Subareas 5+6 are also presented. During 1963-1976, U.S. EEZ landings of squid by distant water fleets (foreign landings) were not consistently reported by species. In addition, domestic landings of squid were not recorded by species in the commercial fisheries dealer database until 1979. As a result, U.S. EEZ landings during 1963-1978 were derived from prorations based on the temporal and spatial landings patterns of *Illex illecebrosus* and *Loligo pealeii*, by country, from fisheries observer data (Lange and Sissenwine 1980). U.S. EEZ landings for 1979-2005 were obtained from the Weighout Database, which consists of fish purchases by dealers, and also include landings from joint ventures that occurred during 1982-1990 between U.S. and foreign fishing vessels. Dealer reporting of *Illex* purchases has been mandatory since January 1, 1997. Since April of 2004, dealers have been required to enter their fish purchases electronically in the Weighout Database these data are considered preliminary. Landings from NAFO Subareas 3+4, during 1963-2004, were obtained from Hendrickson et al. (2005).

Total *Illex* landings have varied considerably since 1963 and have consisted of three distinct levels of magnitude (Fig. C2A). A period of high landings, which occurred during 1976-1981 when distant water fleets were active in all NAFO fishing areas, was bracketed by periods of substantially lower landings. During 1963-1967, total landings were low, averaging 7,354 mt, and were primarily from the Subarea 3 inshore jig fishery. During 1968-1974, total landings averaged 13,470 mt and were predominately from distant water fleets that had begun fishing in Subareas 5+6. However, this trend was reversed during 1976-1981, when landings were predominately from Subareas 3+4. During this time, total landings averaged 100,300 mt, and in 1979, reached the highest level on record (179,333 mt). Thereafter, landings from Subareas 3+4 declined rapidly from 162,092 mt in 1979 to 426 mt in 1983. However, landings from Subareas 5+6 remained stable and did not exceed 25,000 mt, in part, due to effort limitations placed on the distant water fleets. Since its inception in 1987, landings from the domestic bottom trawl fishery have comprised a majority of the total landings. The exception occurred in 1997, when landings from Subareas 3+4 (15,485 mt) exceeded U.S. EEZ landings (13,629 mt) and were at their highest level since 1982. Landings from Subareas 3+4 declined to 57 mt in 2001, and then gradually increased to 2,034 mt in 2004. Since 2000, landings from Subareas 3+4 have primarily been from the Newfoundland jig fishery (Hendrickson et al. 2004).

U.S. EEZ landings have been characterized by two distinct periods (Fig. C2B). During 1968-1982, U.S. EEZ landings were predominately taken by distant water fleets, and in 1976, reached a peak of 24,936 mt. U.S. EEZ landings subsequently declined to 1,958 mt in 1988 (Fig. C2B) when foreign participation in the U.S. *Illex* fishery became prohibited in order to foster development of a domestic fishery. During 1998-1994, landings from the domestic fishery increased from 1,958 mt to 18,350 mt, then reached a peak of 23,597 mt in 1998. This 1998 peak led to a closure of the fishery because the quota (19,000 mt) was reached. During 1999-2002, U.S. landings declined and reached their lowest level in 2002 (2,750 mt) since the 1987 inception of the domestic fishery. U.S. landings increased to 6, 389 mt in 2003 then reached their highest level on record in 2004 (26, 087 mt) which resulted in a closure of the fishery because the quota (24,000 mt) was reached. A preliminary estimate of the U.S. landings for 2005 is 11,429 mt.

A majority (≥ 98%) of the annual landings from the U.S. EEZ are taken with bottom trawls (Table C2). Domestic fishing effort is greatly influenced by the global market demand for squid and is limited by onshore and at-sea freezer storage capacity as well as the availability of *Illex* to the bottom trawl fishery. The Vessel Trip Report (VTR) database and NEFSC Sea Sampling database indicate that the U.S. EEZ *Illex* fishery occurs primarily at depths between 128 and 366 m. Gear limitations prevent fishing in waters deeper than 457 m (Glenn Goodwin, pers. comm. 1999).

Since January 1, 1997, *Illex* moratorium permit holders have been required to report catch, effort and fishing location data to NMFS on Vessel Trip Reports from which the data are entered into the Vessel Trip Report (VTR) Database. Landings recorded in the Weighout Database are considered more accurate than the kept fraction of the catch reported on the VTRs because the latter represent estimates made by vessel captains. However, the fishing effort and location data required to compute landings per unit of effort (LPUE) are only recorded in the VTR Database and there is no single field that directly links trips from the WO Database with those from the VTR Database. Therefore, in order to avoid the use of prorated landings to compute weekly LPUE, weekly trends in landings were compared between the VTR and Weighout Databases to determine whether the VTR landings could be used to compute LPUE.

Trends in weekly *Illex* landings and the duration of the fishing season vary by year. During 1999-2004, trends in weekly *Illex* landings were similar for the VTR and WO Databases. During 1999-2002, the fishery began during weeks 23 or 24 and lasted for a period of 16 to 21 weeks (Fig. C3). During 2003, weekly landings varied without trend, which is characteristic of years with low fishing effort, such as 2001 and 2002 (NEFSC 2003), and the duration of the fishing season was longer than normal (23 weeks). The variability in weekly landings trends is partly attributable to the coarse temporal resolution of the WO and VTR Databases, which necessitates assigning week of the year by the date landed instead of the tow date. Tow-based data associated with real-time fisheries data reporting show less variability (NEFSC 2003; Hendrickson et al. 2003). Some of the variability in the weekly landings trends for both databases is attributable to the coarse resolution of the landings data (trip-based rather than tow-based) which requires trips to be assigned to weeks based on the date landed rather than the date caught. During the Working Group meeting, the weekly landings figure for 2004 suggested that *Illex* landings reported in the VTR Database underestimated the landings in the WO Database. This discrepancy was subsequently re-examined and Figure C3 has been revised to reflect the updated WO data for 2004, which now indicates similar trends in magnitude between weekly landings from the two databases. This data revision does not impact any other assessment computations. The WO and VTR Databases indicate that the weekly landings during 2004 were more than double the weekly landings obtained during 1999-2003. Weekly landings during 2004 show an increasing trend followed by a decreasing trend, with an inflection point at week 35. Landings increased rapidly between weeks 20 and 24, and then stabilized at about 1,600 mt per week through week 32. Thereafter, landings increased further and reached a peak of 2,730 mt in week 35. The fishery was closed after week 38 because the quota was taken, but landings declined prior to this time, between weeks 35 and 38.

Discards

Two sources of data are available for estimating *Illex* discards, data from the NEFSC Observer Program Database and the VTR Database. Although reporting of discards is required on VTRs, reporting of *Illex* discards is inconsistent. Therefore, *Illex* discards were quantified, by month, based on data from fishing trips monitored at sea by NEFSC fishery observers.

In addition to the *Illex* fishery, which is characterized by 34.9-60.3 mm diamond mesh codends, other fisheries likely to incur *Illex* bycatch are those that utilize bottom trawls of similarly small mesh and that occur during May-November, when *Illex* is present on the U.S. continental shelf. The offshore *Loligo* fishery meets both criteria and catch data from observed trips from the NEFSC Observer Program database indicate that a majority of the *Illex* bycatch, during 1995-2004, occurred in the offshore *Loligo* fishery.

Illex discards (mt) in the *Illex* and *Loligo* fisheries were estimated, by month and year, from catch data collected during trips sampled by observers from the NEFSC Sea Sampling Program during 1995-2004. The *Illex* fishery was defined as bottom trawl trips that occurred during May-October in which *Illex* landings comprised ≥ 25% of the total trip weight. The *Loligo* fishery was defined as bottom trawl trips that occurred during November-April in which *Loligo* landings comprised ≥ 25% of the total trip weight. Annual estimates of *Illex* discards in the *Illex* fishery were computed by multiplying the annual discard ratio (annual *Illex* discards/annual *Illex* kept, mt) by the annual *Illex* landings. Annual estimates of *Illex* discards in the *Loligo* fishery were computed by multiplying the annual discard ratio (annual *Illex* discards/annual *Loligo* kept, mt) by the annual *Illex* landings. Annual estimates for each of the two fisheries were summed to obtain the total amount of annual discards.

The annual sampling intensity of trips observed in the *Illex* fishery was low during 1995-2003, ranging between 2 and 15 trips (Table C3). There were no *Illex* trips sampled during 2001 or 2002. During 2004, 33 trips were sampled and most trips occurred during July and August, the peak of the fishing season. Temporal discarding patterns during 1995-2004 could not be discerned because the number of trips sampled by month was not representative of the seasonal landings pattern. The amount of *Illex* discarded by the *Illex* fishery during 1995-2004 ranged between 29 mt and 344 mt per year (Table C3).

The annual sampling intensity of trips observed in the *Loligo* fishery during 1995-2003 was also low, ranging between 3 and 18 trips (Table C4). During 2004, 54 trips were sampled primarily in the offshore, winter fishery. During 1995-2004, monthly sampling coverage was inconsistent during the year-round fishing season, so monthly discarding trends could not be discerned. During January of 2001, Gear Restriction Areas (GRAs) were established to reduce scup bycatch. The Southern GRA is closed to small-mesh (< 4.5 inch codend mesh) fisheries during January through March 15. NEFSC spring survey data indicate that *Illex* migration onto the U.S. continental shelf generally begins in March, during the latter part of the closure period. However, observer data were inadequate to evaluate whether this closure area also aided in the reduction of *Illex* discarding by the *Loligo* fishery. The amount of *Illex* discarded by the *Loligo* fishery during 1995-2004 ranged between 1 mt and 1,222 mt per year and was highest in 2004.

In summary, *Illex* discard estimates are imprecise but the overall level of discards in recent years was likely low in comparison to the *Illex* landings. Most of the *Illex* discards occur in the winter offshore *Loligo* fishery (Table C5). During 1995-2004, the combined *Illex* discards from both squid fisheries ranged between 53 mt and 1,556 mt and comprised 0.5-6.0% of the annual *Illex* landings by the U.S. fishery (Table C5). *Illex* discarding in both squid fisheries was higher during 1998 and 2004, when *Illex* abundance was higher. However, a quantitative comparison of discarding between years and months is difficult due to low sampling intensity, by month and year, in both fisheries.

Mean Body Size

For the northern stock component, trends in annual average body size are associated with annual trends in *Illex* relative abundance (Hendrickson et al. 2004). In-season changes in *Illex* body size reflect the combined effects of growth, mortality (from fishing and natural mortality), and emigration and immigration from the fishing grounds. Therefore, annual and in-season trends in *Illex* mantle length (cm) and body weight (g) were assessed for *Illex* samples obtained from the landings by squid processors and NMFS port samplers during 1994-2004. With the exception of 1996, *Illex* landed during 1999-2003 were smaller than in other years during 1994-2004. Median mantle lengths were highest during 1994 and 2004 and were lowest in 1996 (Fig. C4). Median body weight was highest during 1994 and lowest in 2001 (Fig. C4). Median mantle length and body weight during 2003 were similar to those from 2002. The median weight of squid in 2004 was the highest since 1998 and the median mantle length in 2004 was as high as in 1994. Median mantle length and body weight were significantly lower in 2001 than for most years during 1994-2004. Interannual trends in squid size are likely attributable to environmental conditions, particularly if they persist across multiple years, but size trends may also reflect fishing in different geographic areas. A review of bottom water temperature anomalies in the Mid-Atlantic Bight indicated that bottom temperatures near the shelf edge were warmer than average during large portions of the year in 1999-2002 (Jossi and Benway 2003) when *Illex* mean body size was small and catches were low.

The Lowess-smoothed trend line of a composite of the average body weights of squid landed during 1994-1998 indicated a steady increase in average size from 50-175 g during weeks 20 through 34, but the trend for smaller squid that were landed during 1999-2002 indicated an increase in body size that was more gradual, from 70 to 110g between weeks 22 through 30 (NEFSC 2003). Thereafter, average body size was generally stable. The attainment of an asymptotic average size may be partially driven by the recruitment of smaller squid, but most likely reflects the emigration of larger squid. In autumn, the density of large squid increases with depth and is highest in the deepest strata (186-366 m) during this offshore migration period (Brodziak and Hendrickson 1999). Maximum average size in the fishery during 1999-2002 occurred one month earlier, at week 30, than during 1994-1998 and was only 60% (110 g) of the 1994-1998 value (NEFSC 2003). In comparison, weekly increases in mean mantle length occurred more rapidly in 2004 than in 2003 (Fig. C5) and the weekly trends in mean body weight during 2003 resemble those from 1999-2002 while the 2004 trends are more similar to the trends observed for 1994-1998. During 2004, *Illex* mean body weights increased from 100 to 200 g between weeks 21 and 34 then declined thereafter (Fig. C6). The decline in mean body weight after week 34 may be due to recruitment, the annual offshore migration, or both factors.

4.0 RELATIVE ABUNDANCE AND BIOMASS INDICES

Research Surveys

Although there are no stock-wide indices of abundance or biomass for the *Illex* stock, several seasonal research surveys provide some information about local abundance trends on the USA

Shelf and the Scotian Shelf. The NEFSC spring bottom trawl survey occurs in March, prior to the USA fishery, but captures low densities of squid at few stations in comparison to the autumn survey because the spring survey occurs at a time when *Illex* are migrating onto the continental shelf (Hendrickson 2004). *Illex* are caught at 5-10% of the offshore stations sampled during spring surveys and at 30-80% of the offshore stations during autumn surveys (Fig. C7). The NEFSC autumn survey occurs when *Illex* are migrating off the shelf. The autumn survey indices can be considered as an index of spawner escapement because the survey occurs near the end of the fishing season. A portion of the *Illex* stock resides outside the range of the NEFSC surveys. The outer shelf and continental slope are important *Illex* habitats (Lange 1981) that are not intensively sampled during NEFSC bottom trawl surveys. In addition, the survey bottom trawl gear is not likely to sample pelagic species efficiently. Therefore, survey indices may represent the on-shelf availability of *Illex* rather than a measure of relative abundance or biomass. A Canadian bottom trawl survey occurs on the Scotian Shelf (NAFO Divisions 4VWX) during July. Since the Scotian Shelf survey occurs near the start of the directed fisheries, it can be considered as a pre-fishery relative abundance index for the area surveyed.

NEFSC survey procedures and details of the stratified random sampling design are provided in Azarovitz (1981). Standard survey tows in offshore strata 1-40 and 61-76 (Fig. C8) were used to compute relative abundance and biomass indices which were adjusted for differences in research vessel effects. A vessel conversion coefficient of 0.81 was applied to the *Delaware II* stratified mean weight per tow values, prior to computing the autumn survey indices, to standardize *Delaware II* catches to the *Albatross IV* catches (Hendrickson et al. 1996). Indices of relative abundance (stratified mean number per tow) and biomass (stratified mean weight per tow, in kg) from NEFSC autumn bottom trawl surveys, conducted during 1967-2004 are presented in Figure C9 and Table C6. Indices from NEFSC spring surveys, conducted during March, were also computed for the same strata set used to derive the autumn survey indices. Relative abundance and biomass indices from the Canadian bottom trawl survey, conducted on the Scotian Shelf (NAFO Division 4VWX) during July, are presented with the autumn survey indices for comparative purposes. All survey strata were used in the computations and the indices could not be standardized for gear and vessel changes that occurred in 1982, 1983 and 2004 due a lack of data from comparative fishing experiments (Hendrickson et al 2005).

As might be expected for a sub-annual species with environmental effects on availability and recruitment, all of the survey indices show a large degree of interannual variability. Autumn survey indices suggest that *Illex* relative abundance on the U.S. shelf was high during 1976-1981 and during 1987-1990 (Fig. C9). Autumn survey abundance indices were at or below the 1982-2003 average during 1991-1997. Abundance indices increased in 1998, but then declined to the second lowest level on record in 1999 (Table C6), following the high level of landings taken in 1998 (Table C1). During 1999-2002, abundance indices increased gradually during a period of low fishing effort (NEFSC 2003). Relative abundance reached the highest level on record in 2003 (28 squid per tow), then declined to below the 1982-2003 average in 2004, coincident with the highest landings on record for the U.S. stock component.

NEFSC spring survey indices are more variable than those from the autumn survey due to variability in the timing of *Illex* migrations onto the shelf in the spring. However, a notable trend is the spike in abundance and biomass indices that occurred during 1997 and 1998. Although this spike coincided with a 1998 spike in domestic landings, a similar spike in the spring abundance index did not occur in 2004, the year of the highest U.S. landings on record (Fig. C10A, Table C1). The 2005 spring survey index was very low and similar to the 2003 level.

The Canadian Scotian Shelf survey indices do not appear to track either the spring or autumn surveys of the USA Shelf. Similar to the NEFSC autumn survey indices, the Canadian survey indices also showed a peak in abundance and biomass during 1976, but not for an extended period of time (Figs. C10B and C10C). Based on an extended period of low *Illex* biomass in the July Scotian Shelf surveys and smaller than average body size (Fig. C11A), since 1982, the SA 3+4 component of the stock has been characterized as being in a low productivity regime (Hendrickson et al. 2005). The average body size of *Illex* caught in the NEFSC autumn surveys has also been much lower since 1982 and was below the 1982-2003 average during 2000-2004 (Fig. C11B). Average body size in the NEFSC spring survey was at or below the 1982-2003 average during 1995-2004 (Fig. C11C). These long-term observed difference in mean weights may be due to differing contributions of seasonal cohorts or differing growth conditions during these periods.

The migration of *Illex* squid into northern fishing areas off Newfoundland is affected by oceanographic conditions (Rowell et al. 1985; Dawe and Warren 1992; Dawe et. al. 1998). The autumn distribution of *Illex* on the U.S. shelf is also affected by water temperature conditions and bottom temperatures ranging from 9-13°C are preferred (Brodziak and Hendrickson 1999). The Mid-Atlantic Bight serves as important *Illex* habitat during spring through autumn (Hendrickson and Holmes 2004). Areal average surface and bottom temperature anomalies indicate that spring and autumn water temperatures in the Mid-Atlantic Bight have generally been warmer during 1982-2003 than during the reference period of 1977-1987 (Fig. C12) (Holzwarth and Mountain 1990; Holzwarth-Davis and Taylor 1992, 1993 and 1994; Taylor and Almgren 1996a and 1996b; Taylor and Kalidas 1997; Taylor and Bascunan 1998, 1999, 2000 and 2001; Taylor et. al. 2002). *Illex* relative abundance and biomass indices from the autumn surveys and spring average body weights, for 1982-2002, are significantly negatively correlated with bottom water temperature anomalies from the autumn surveys (NEFSC 2003). However, interpretation of these results is complicated because spring and autumn bottom water temperature anomalies are correlated so additional research on this topic is needed.

Depth transect surveys were conducted seasonally during 2003-2005 by Rutgers University with funding from the Research Set-aside Program of the Mid-Atlantic Fishery Management Council (MAFMC). Survey data were available for January (2004 and 2005), March (2003-2005), May (2003 and 2004) and November (2004). However, only the May data are relevant to the *Illex* stock because *Illex* does not consistently inhabit the U.S. Shelf during the other survey months (Black *et al.* 1987; Hendrickson 2004). *Illex* catch rates were examined from the May bottom trawl surveys, conducted along two transects located near Hudson and Baltimore Canyons, to determine what proportion of the survey catches occurred at depths beyond the limit of the majority of the NEFSC autumn survey stations (about 185 m). However, the data could not be used to evaluate *Illex* abundance by depth because declines in catch rates coincided with the depth beyond which sampling occurred at night (274 m), when *Illex* is distributed in the upper layer of the water column and not available to bottom trawl gear (Brodziak and Hendrickson 1999).

Fishery Catch per Unit of Effort Indices

The in-season pattern of CPUE reflects the balance of recruitment, fishing and natural mortality, and emigration from the fishing area (Caddy 1991). In Caddy's formulation, the boundaries between these processes are sharp and are assumed to induce point changes in the slope of log CPUE versus time. Implementation of an in-season depletion model would require an ability to detect such point changes in the CPUE trends. However, a declining trend in weekly LPUE data from the U.S. *Illex* fishery is not detectable in some years (NEFSC 1999). In order to better understand LPUE trends, spatial changes in fishing patterns were evaluated and the effects of various factors on the standardization of fishing effort were assessed. Since *Illex* discards for the U.S. fishery are low in comparison to *Illex* landings (refer to the above section on discards), LPUE is considered to be representative of CPUE.

Fishing Effort

Fishing effort in the *Illex* illecebrosus fishery is affected by catch values determined largely by the global squid market, particularly the Falklands squid fisheries, and the abundance of *Illex* on the U.S. Shelf. The *Illex* fishery is a volume-based fishery and effort patterns vary for the two fleet sectors involved in the directed fishery, refrigerated seawater system trawlers (RSW vessels) and freezer trawlers (FT vessels). The RSW vessels tend to be of smaller size than the freezer trawlers and store their catches in chilled seawater. Both factors result in shorter trips, generally less than four days, than those made by FT vessels (up to 14 days) which are larger and freeze their catches at sea. The home ports for FT vessels are North Kingston and Point Judith, Rhode Island and Cape May, New Jersey. Effort patterns for the RSW fleet are primarily determined by the travel distance between a shoreside processing facility and the offshore fishing grounds. The home port for most of the RSW vessels is Cape May, New Jersey, where there is a major *Illex* processing facility, but other home ports include Wanchese, North Carolina, Hampton Roads, Virginia and several Rhode Island ports (MAFMC 1998c).

The fleet size is small, generally less than 30 vessels, but the number of vessels participating in the fishery is highly variable from year-to-year. During 1999 and 2004, participation in the fishery was high (27-28 vessels) and during 2000-2003 participation was much lower (10-14 vessels, Fig. C13A). During 1999-2003, most of the annual landings (> 75%) were from freezer trawlers. However, in 2004, the proportion of annual landings for each fleet sector was nearly equal (Fig. C13B). This was primarily a result of an increased number of short duration trips (355 trips lasting 1.8 days on average) conducted by RSW vessels (Table C7, Fig. C13C).

Total nominal effort for both fleet sectors combined was twice as high in 2004 as in 2003, despite a shorter fishing season (five fewer weeks), and may have been higher if the fishery was not closed on September 21 (Table C7). In-season trends in weekly effort were different for the two fleet sectors during 2003 and 2004. During 2003, only three freezer trawlers fished for *Illex*, so the number of FT trips was fairly constant throughout the fishing season (Fig. C14A). The weekly trend in the number of days fished by FT vessels varied without trend in 2003 and was very erratic due to the duration (8.2 days on average) and timing of the trips which tend to start and end on the same day of the week (Fig. C14B). During 2004, twelve FT fished and the number of trips gradually increased throughout the fishing season until the fishery was closed (Fig. C14C). The number of days fished by FTs in 2004 increased between weeks 20-30 then varied without trend until the fishery closure (Fig. C14D). In contrast, weekly trends in the number of RSW trips was similar to weekly trends in the number of days fished, for 2003 and 2004, due to the short trip durations (1.8-2.8 days). During both years, a definite trend of increasing effort, which peaked at week 35, was followed by a decline. In 2003, a second rise and fall pattern was observed between weeks 37 the end of the RSW fishery (week 44). It was suggested at the Working Group meeting, that the decline in RSW effort (trips and days fished) which occurred three weeks prior to the fishery closure, during week 35, was a result of a unimplemented plan for an early-season closure of the Cap May processing facility.

A geographic information system (GIS) was used to examine the spatial distribution of effort in the *Illex* fishery, by quarter-degree square (QDSQ), during 2003 and 2004. The spatial distribution of fishing effort also varied by fleet sector. During 2003, freezer trawler effort was concentrated in several QDSQs, while RSW effort occurred across a broader area. In 2003, there was little spatial overlap between the most heavily fished QDSQs by the two fleet sectors (Fig. C15). For QDSQs that were consistently fished in 2003, the monthly effort pattern showed a rise and fall trend (Fig. C16). In contrast to 2003, fishing effort by both fleet sectors was concentrated off Cape May, New Jersey in 2004 (Fig. C17). Effort that occurred further south was primarily attributable to RSW vessels. In 2004, there was a high degree of spatial overlap between the most heavily-fished QDSQs of both fleet sectors. Within the three QDSQs with the highest effort concentrations, a monthly rise and fall pattern of effort is observed for the RSW vessels. FT effort was more constant throughout the season in QDSQs 38731 and 38733 (Fig. C18).

Trends in LPUE

As discussed in the Landings section, trends in weekly landings from the Weighout database closely matched those from the VTR database for 2003 and 2004. As a result, nominal LPUE was computed as the sum of the weekly effort (days fished) from the VTR Database divided by the sum of the weekly landings (mt) from the VTR Database. Weekly trends in nominal LPUE for RSW vessels showed a clear rise and fall pattern during 2003 and 2004, but weekly catch rates of FT vessels did not (Fig. C19). During 2003 (a year of low FT effort), FT catch rates showed several rise and fall periods with a peak during week 31, while RSW catch rates gradually increased during weeks 24-38, then declined thereafter. During 2004, RSW vessels began fishing one week earlier than FT vessels. RSW catch rates increased rapidly during weeks 20-23, then gradually increased between weeks 24 and 34. After week 34, but prior to closure of the fishery (week 38), there was a decline in RSW catch rates which occurred one week prior to the decline in the number of RSW trips and days fished (Fig. C14). FT catch rates reached a peak during the first few weeks of the fishery (week 22) then remained fairly constant during weeks 23-34. After week 34, FT catch rates also declined. However, it cannot be assumed that the decline in catch rates after week 34 were due to declining *Illex* abundance because of the confounding of reduced fishing effort during this time as a result of the proposed processing facility closure.

Spatial trends in nominal LPUE, for the entire *Illex* fleet, were very different between 2003 and 2004. High catch rates occurred across a larger area in 2004 than in 2003 and this may suggest much higher *Illex* abundance in 2004 (Fig. C20). Fairly high catch rates also occurred neat the shelf edge located off southern New England. During 2003, monthly catch rates were highest in July and were consistently high in southern areas (35º 30′ to 37º N), and (Fig. C21). During 2004, monthly catch rates were consistently high near the shelf edge off Cape May, and the area of high catch rates increased in size during July and August (Fig. C22). Fishing in the southern New England area occurred in August. A sequential rise and fall pattern in the combined catch rates of all vessels occurred in three different QDSQs during the 2003 fishing season, but it is unclear whether this represented localized depletion (Fig. C23A). During 2004, weekly trends in catch rates were similar for three FTs fishing in two different QDSQs (Fig. C24B) and the catch rates of several RSW vessels and a FT fishing within the same QDSQ all showed similar trends (Fig. C24C). These trends suggest that depletion may be possible within QDSQs during periods of high effort by both fleet sectors.

Standardization of the effort used to compute LPUE was conducted in order to determine whether this would improve the ability to detect a declining trend in weekly catch rates. A three-factor, main effects General Linear Model (GLM) was applied to log-transformed LPUE data (mt per day fished) for 2003 and 2004. LPUE was computed using the VTR landings for 2003. The WO landings were used to compute LPUE for 2004 because weekly landings data presented during the Working Group meeting suggested underreporting of VTR landings for 2004. For 2004, the VTR and WO data were matched by hull number, month and day (using the date sold field) and the VTR landings were replaced with the WO landings. This matched data set accounted for 72% of the WO landings. The trips that did not match were prorated to week of the year and QDSQ based on the ratios of the matched trips. The proration accounted for an additional 16% of the WO landings. The remainder of the trips could not be used because they had missing effort values, QDSQs, or both. As in previous assessments, directed trips used in the GLM were defined as otter trawl trips that occurred during May through November and that landed at least 25%, by weight, of *Illex*. Factors included in the GLM included: week of the year, quarter-degree, and either vessel type (RSW or freezer trawler) or hull number. Final model runs included the factors: vessel type, quarter-degree square and week of the year (Table C8 and C9). A summary of the various GLM runs is presented in Table C10. For the final 2004 models run, all three model effects were highly significant ($p < 0.0001$), but the influence of spatial effects (quarter-degree square) on LPUE was not significant in 2003. Weekly standardized fishing effort was highly variable in 2003 (Fig. C24A) and standardized LPUE did not show a rise and fall trend. Standardized effort for 2004 indicated an increasing trend which reached a peak in week 35 then declined (Fig. C24B). Nominal LPUE showed a similar trend (Fig. C25A), but the trend was removed when LPUE was computed using standardized effort (Fig. C25B).

5.0 ESTIMATION OF NATURAL MORTALITY

Maturation-Natural Mortality Model

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT REFERS TO APPENDIX C3 WHICH HAS BEEN OMITTED. REFER TO HENDRICKSON AND HART [2006], FOR MODEL RESULTS).

Based on a review of the model results, the Working Group decided that the estimates of natural mortality were preliminary. They acknowledged that the model formulation was sound and appropriate given the semelparous life history of the species, but that natural mortality estimates may vary during the fishing season because growth rates increase seasonally for squid from the northern stock component (Dawe and Beck 1997). The Working Group recommended that new data on growth and maturity be obtained for inclusion in future model runs.

6.0 BIOLOGICAL REFERENCE POINTS

The Amendment 8 control rule states that when the stock biomass exceeds B_{MSY}, the overfishing threshold is F_{MSY}, and target F is 75% of F_{MSY}. Below B_{MSY}, target F decreases linearly and is set to zero when stock size is at the biomass threshold of $\frac{1}{2}B_{MSY}$. Amendment 8 specifies B_{MSY} as 39,300 mt and F_{MSY} as 1.22 per year.

Reference points that minimize the risk of recruitment overfishing, by ensuring that escapement exceeds a threshold minimum spawning stock biomass or number of eggs per recruit, have been considered to be the most appropriate for annual squid stocks that exhibit highly variable trends in interannual recruitment (Beddington et al. 1990). The current MSY-based biological reference points were based on a biomass dynamics model which estimated MSY at 24, 274 mt (NEFSC 1996). However, bootstrap analyses indicated poor precision of *r*, *q* and *K* estimates and the model assumption of constant natural mortality rate is invalid for *I. illecebrosus*. Given these considerations, %MSP-based proxies for MSY-based reference points are recommended. Further, the source of the reference point proxies should be derived from a model that accounts for the semelparous life history of *Illex*.

Yield-per-recruit and egg-per-recruit models

A semelparous life history model was derived to estimate yield-per-recruit (YPR) and the number of eggs-per-recruit (EPR) for a cohort of female squid as a function of fishing mortality (Hendrickson and Hart 2006). Consistent with the maturation-mortality model, the YPR and EPR models track females in two bins: the number of immature females, N_t, and the number of mature females, S_t. At each weekly time step, immature individuals have four possible fates: (1) death due to either non-spawning natural mortality, M_{NS}, (e.g., from predation, which is assumed to occur at a constant rate) or (2) death due to fishing mortality (calculated as $F_t = F\theta_t$, where θ_t is the fishery selectivity of the individuals of age t weeks); (3) survival to the next week either as an immature individual; or (4) survive and mature at rate P_t.

Biological reference point estimates derived from the egg-per-recruit and yield-per-recruit models were presented. However, the potential reference point proxies estimated using the EPR model were considered preliminary by the SARC 42 Working Group because they included estimates of natural mortality that were considered preliminary. In addition, seasonal changes in growth rates are likely for this species and this will affect the reference point estimates (Figure C26). Therefore, seasonal growth rate data are required to test the sensitivity of the per-recruit models to growth rates.

(EDITOR'S NOTE: THIS PART OF THE WORKING GROUP REPORT REFERS TO APPENDIX C4 WHICH HAS BEEN OMITTED) (see Hendrickson and Hart 2006).

7.0 STOCK SIZE AND FISHING MORTALITY RATES

In-season Assessment Model

The short life cycles, rapid growth rates, highly variable population abundance, high natural mortality rates and semelparous breeding strategies of most cephalopod species render many of the traditional annual-based approaches to stock assessment inappropriate (Caddy 1983). This is certainly the case for the *I. illecebrosus* stock, for which biomass dynamics models provide very imprecise estimates of stock size and fishing mortality rates (NEFSC 1996; Hendrickson et. al. 1996) which is likely attributable to the fact that cephalopod population dynamics do not conform to the underlying model assumptions (Pierce and Guerra 1994). Assessment of the *Illex* stock is hindered by the lack of research survey biomass and abundance indices for the USA stock component and the stock as a whole. Annual-based modeling approaches are inappropriate for a species with a lifespan of less than one year.

Within-season depletion models have been found to offer the most promise for assessing ommastrephid and loliginid squid stocks (Anon. 1999; Pierce and Guerra 1994) and have been used since 1987 to assess the Falkland Islands stocks of *Illex argentinus* and *Loligo gahi* (Rosenberg et. al. 1990; Agnew et al. 1998). Depletion estimation requires data consisting of: total catch, mean body weights, an abundance index (e.g., CPUE), a recruitment index proportional to the number of recruits, and an estimate of natural mortality. In addition, these data must be of appropriate temporal and spatial resolution, tow-based, and available throughout the fishing season.

During the previous *Illex* assessment at SARC 37 (NEFSC 2003), the in-season assessment model developed for SARC 29 (NEFSC 1999) was revised to include a recruitment index and an objective function. The model, which estimates weekly fishing mortality rates and initial stock size, was run using tow-based catch, effort and fishing location data instead of VTR data. During the current assessment, the SARC 37 model was further revised to allow for the possibility of fitting one of the maturity ogive parameters, α, together with F_{TOT} and N_0.

Both Working Groups felt that the SARC 42 model formulation (Appendix C5) was sound but that the model results should not be used to update fishing mortality and stock size estimates because:

1. A major model uncertainty is the use of a May growth curve which underestimates growth later in the fishing season. Despite scaling up the asymptotic length by using a percentile of the observed lengths from the fishery data, empirical length-at-age data must be collected and analyzed to determine seasonal changes in growth rate

2. The method of computing the weekly recruitment indices requires further investigation

3. Sensitivity analyses for various values of initial stock size, using 1999 and 2003 data, indicated that a broad range of N_0 and F_{TOT} values were plausible, suggesting a flat estimation surface. The Working Group felt that additional simulation testing would be beneficial in understanding how varying the model parameters affect the model results.

8.0 CONCLUSIONS

Abundance and biomass indices

Seasonal bottom trawl surveys of the USA shelf do not cover the geographic distribution of the USA stock component. *Illex* inhabit areas outside the range of the USA surveys based on data from other research surveys and fisheries data. The USA autumn survey may serve as an index of spawner escapement but for a cohort other than that which is fished at the start of the *Illex* fishing season. Furthermore, it is unknown whether autumn survey trends are due to low abundance, low availability or both. The relative abundance index for the US autumn survey was the highest on record in 2003 and very low in 2004 following the highest landings on record. Further research is needed to determine the association between fishery catch rates and *Illex* abundance.

Fishery Characteristics

Body size is likely related to productivity. *Illex* landed during 2004 were larger in size than those landed during most years since 1994. The number of vessels and trips that occurred in 2004 were much higher than any year since 2000 and landings reached a record high of 26,087 mt, which exceeded the quota and resulted in an early closure of the fishery. Landings and effort in 2003 were much lower than in 2004 and body size (an indicator of productivity) was also smaller, similar to the trends for 1999-2002. Preliminary U.S. fishery landings for 2005 are 11, 429 mt.

Estimation of fishing mortality and stock size

The in-season model estimates of fishing mortality and stock size were not considered reliable because new data on seasonal growth rates and maturity are required for the model. Use of the May growth curve underestimates growth later in the season.

Stock status

Stock status cannot be determined because adequate data are not available to estimate fishing mortality rates and absolute stock size.

9.0 RESEARCH RECOMMENDATIONS PAST AND PRESENT

The status of research recommendations from the previous *Illex* assessment, conducted at SARC 37, is presented in Table C11. Based on reviews of the current assessment, it was concluded at both Subcommittee meetings that the most important research recommendation involves the collection and analysis of seasonal age and maturity. Without these data, assessment of the stock using the models contained herein will not be possible. In order of priority, specific research recommendations from the current assessment are as follows:

1. All of the models presented require additional data collection. Maturity and age data should be collected throughout the fishing season to evaluate the effects of differential growth and maturity within seasons and between years. Emphasis should be placed on the

collection of weekly data. The in-season model would be improved with tow-based catch, effort and fishing location data, particularly if collected electronically in real-time.

2. Re-estimate M_{ns} and M_{sp} for females from each seasonal cohort and determine whether M_{ns} and M_{sp} estimates for males are similar to those of females.

3. Re-estimate biological reference points for each seasonal cohort by incorporating seasonal information regarding growth, selectivity, and natural mortality.

4. The in-season assessment model results show a high sensitivity to parameters such as growth and recruitment, so additional simulation analyses are needed to determine the range of possible responses by the model. The simulation analyses should reflect the actual reality of the fishery and data input/output (such as fishery length frequencies for estimating partial recruitment). Length data rather than age data should be utilized in the simulation model so that the simulation formulation is identical to that used in the in-season model.

5. Further exploration of relationships between oceanographic conditions and abundance and body size of squid on the US Shelf is needed to determine whether a pre-season predictor variable for abundance or stock productivity can be found.

6. It is important to know what fraction of the stock inhabits waters deeper than 185 m, particularly during May and in the fall. Seasonal transect surveys are conducted by Rutgers University with Mid-Atlantic research funds in order to monitor the seasonal depth distribution of Mid-Atlantic species. Although *Illex* is not a “target” species, abundance and length frequency data are collected. However *Illex* abundance by depth could not be determined from these surveys because diel migration patterns were confounded with the sampling protocol. Therefore, it would be useful to conduct some adaptive or fixed stations for determining *Illex* abundance and length composition, during daylight hours, at depths beyond 185 m during May and in the fall.

7. A pre-fishery, stratified random survey would be useful to estimate initial stock size.

8. Evaluate the utility of relative abundance and biomass indices from the NEFSC winter survey.

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***ILLEX* TABLES:**

Table C1. *Illex illecebrosus* landings (mt) in NAFO Subareas 5+6 (U.S. EEZ) and Subareas 3 and 4 during 1963-2005 [1,2,3,4,5,6] and total allowable catches (TACs).

	Cape Hatteras to the Gulf of Maine (Subareas 5+6)			Subareas (3+4)	All Subareas (3-6)	TAC (000's mt) 3+4	TAC (000's mt) 5+6	
Year	Domestic (mt)	Foreign (mt)	Total (mt)	Total (mt)	Total (mt)			Percent US Landings
1963	810		810	2,222	3,032			
1964	358	2	360	10,777	11,137			
1965	444	78	522	8,264	8,786			
1966	452	118	570	5,218	5,788			
1967	707	288	995	7,033	8,028			
1968	678	2,593	3,271	56	3,327			
1969	562	975	1,537	86	1,623			
1970	408	2,418	2,826	1,385	4,211			
1971	455	6,159	6,614	8,906	15,520			
1972	472	17,169	17,641	1,868	19,509			
1973	530	18,625	19,155	9,877	29,032			
1974	148	20,480	20,628	437	21,065		71	98
1975	107	17,819	17,926	17,696	35,622	25	71	50
1976	229	24,707	24,936	41,767	66,703	25	30	37
1977	1,024	23,771	24,795	83,480	108,275	25	35	23
1978	385	17,207	17,592	94,064	111,656	100	30	16
1979	1,493	15,748	17,241	162,092	179,333	120	30	10
1980	299	17,529	17,828	69,606	87,434	150	30	20
1981	615	14,956	15,571	32,862	48,433	150	30	32
1982	5,871	12,762	18,633	12,908	31,541	150	30	59
1983	9,775	1,809	11,584	426	12,010	150	30	96
1984	9,343	576	9,919	715	10,634	150	30	93
1985	5,033	1,082	6,115	673	6,788	150	30	90
1986	6,493	977	7,470	111	7,581	150	30	99
1987	10,102	0	10,102	562	10,664	150	30	95
1988	1,958	0	1,958	811	2,769	150	30	71
1989	6,801	0	6,801	5,971	12,772	150	30	53
1990	11,670	0	11,670	10,975	22,645	150	30	52
1991	11,908	0	11,908	2,913	14,821	150	30	80
1992	17,827	0	17,827	1,578	19,405	150	30	92
1993	18,012	0	18,012	2,686	20,698	150	30	87
1994	18,350	0	18,350	5,951	24,301	150	30	76
1995	14,058	0	14,058	1,055	15,113	150	30	93
1996	16,969	0	16,969	8,742	25,711	150	21	66
1997	13,629	0	13,629	15,614	29,243	150	19	47
1998	23,597	0	23,597	1,902	25,499	150	19	93
1999	7,388	0	7,388	305	7,693	75	19	96
2000	9,011	0	9,011	366	9,377	34	24	96
2001	4,009	0	4,009	57	4,066	34	24	99
2002	2,750	0	2,750	258	3,008	34	24	91

Table C1. cont.

Year	Cape Hatteras to the Gulf of Maine (Subareas 5+6) Domestic (mt)	Foreign (mt)	Total (mt)	Subareas (3+4) Total (mt)	All Subareas (3-6) Total (mt)	TAC (mt) 3+4	5+6	Percent US Landings
2003	6,389	0	6,389	1,128	7,517	34	24	85
2004	26,087	0	26,087	2,034	28,121	34	24	93
2005	11,429	0	11,429	Not available	11,429	34	24	
Averages								
1976-1981	674	18,986	19,661	80,645	100,306			
1982-1987	7,770	2,868	10,637	2,566	13,203			
1988-1993	11,363	0	11,363	4,156	15,518			
1994-1999	15,665	0	15,665	5,595	21,260			
2000-2003	5,540	0	5,540	452	5,992			

[1] Landings during 1963-1978 were not reported by species, but are proration-based estimates by Lange and Sissenwine (1980)

[2] Landings during 1979-2003 are from the NEFSC Weighout Database

[3] Domestic landings during 1982-1991 include Joint-Venture landings

[4] Includes landings from Subarea 2

[5] Landings during 2004 are preliminary for all Subareas; USA landings were reported electronically by dealers during April 2004-2005

[6] Landings for 2005 include preliminary dealer reports as of 11/2/2005

Table C2. Landings (mt) of *Illex illecebrosus* recorded in the Weighout Database, by gear type, during 1998-2004.

Year	Bottom Trawl	Other[1] and Unknown	Midwater Pair Trawl	Total	Percent Bottom Trawl
1998	23,567.6	0.5		23,568	100.00
1999	7,387.4	1.2		7,389	99.98
2000	9,011.2	0.1		9,011	100.00
2001	4,008.6	0.0		4,009	100.00
2002	2,724.4	0.0	25.1	2,750	99.09
2003	6,364.4	0.1	26.9	6,391	99.58
2004	25,483.1	546.6		26,030	97.90

[1] As of April 2004, gear type data were reported by dealers

Table C3. Estimates of kept weight (mt), discarded weight (mt) and discard ratios (discard/kept weight) of *Illex illecebrosus* sampled in the *Illex* fishery, by observers from the NEFSC Observer Program, during 1995-2004. *Illex* trips were defined as trips where *Illex* landings were ≥ 25%, by weight, of the total trip landings. Total discard estimates are the product of discard ratios and total *Illex* andings, for *Illex* trips in the Weighout database, for all months sampled.

	May	**June**	**July**	**Aug**	**Sept**	**Oct**	**Total**
1995							
Trips	0	0	0	0	1	1	2
Total Kept (mt)					0.902	0.113	1.015
Total Discards (mt)					0.007	0.023	0.030
Ratio discard/kept					0.008	0.204	0.030
Total Landings (mt)					1,263.819	905.822	2,169.641
Total Discards (mt)					9.808	184.371	64.127
1996							
Trips	0	4	3	6	1	1	15
Total Kept (mt)		112.696	236.297	182.447	136.617	166.106	834.163
Total Discards (mt)		0.769	3.499	0.045	0.163	0.000	4.476
Ratio discard/kept		0.007	0.015	0.000	0.001	0.000	0.005
Total Landings (mt)		3,817.659	2,736.593	3,787.278	2,455.642	2,436.032	15,233.204
Total Discards (mt)		26.050	40.522	0.936	2.930	0.000	81.741
1997							
Trips	0	0	7	3	0	0	10
Total Kept (mt)			773.388	343.904			1,117.292
Total Discards (mt)			1.941	5.286			7.227
Ratio discard/kept			0.003	0.015			0.006
Total Landings (mt)			5,077.722	3,600.592			8,678.314
Total Discards (mt)			12.744	55.343			56.134

Table C3. cont.

	May	June	July	Aug	Sept	Oct	Total
1998							
Trips	0	0	2	2	0	0	4
Total Kept (mt)			106.141	48.761			154.902
Total Discards (mt)			1.656	0.000			1.656
Ratio discard/kept			0.016	0.000			0.011
Total Landings (mt)			7,526.991	6,501.153			14,028.144
Total Discards (mt)			117.435	0.000			149.970
1999							
Trips	0	0	1	2	1	0	4
Total Kept (mt)			26.218	50.723	14.011		90.952
Total Discards (mt)			0.000	0.907	0.068		0.975
Ratio discard/kept			0.000	0.018	0.005		0.011
Total Landings (mt)			2,249.614	2,550.402	596.029		5,396.045
Total Discards (mt)			0.000	45.605	2.893		57.845
2000							
Trips	0	2	4	7	0	0	13
Total Kept (mt)		85.820	135.459	182.796			404.075
Total Discards (mt)		0.000	0.680	1.198			1.878
Ratio discard/kept		0.000	0.005	0.007			0.005
Total Landings (mt)		1,409.981	2,753.821	2,122.142			6,285.944
Total Discards (mt)		0.000	13.824	13.908			29.215
2001							
Trips	0	0	0	0	0	0	0

Table C3. cont.

	May	June	July	Aug	Sept	Oct	Total
2002							
Trips	0	0	0	0	0	0	0
2003							
Trips	0	1	5	2	1	1	10
Total Kept (mt)		1.950	667.788	294.246	8.393	276.739	1,249.116
Total Discards (mt)		0	2.330	0	00.006	0.232	2.568
Ratio discard/kept		0	0.0003	0	0.001	0.001	0.002
Total Landings (mt)		1,108.513	1,196.377	1,123.499	526.248	1,931.618	5,886.256
Total Discards (mt)		0	4.174	0	0.376	1.619	6.170
2004							
Trips	1	3	12	9	7	1	33
Total Kept (mt)	24.948	89.132	327.945	378.682	342.689	0.102	1,163.498
Total Discards (mt)	0	0.907	12.774	0	2.287	0.519	16.487
Ratio discard/kept	0	0.01	0.039	0	0.007	5.088	0.014
Total Landings (mt)	1,527.714	5,646.571	6,664.912	8,184.790	3,987.020	0	26,011.007
Total Discards (mt)	0	57.459	259.609	0	26.608	0	343.676

Table C4. Estimates of kept weight (mt), discarded weight (mt) and discard ratios (discard/kept weight) of *Illex illecebrosus* sampled in the *Loligo* fishery, by observers from the NEFSC Observer Program, during 1995-2004. *Loligo* trips were defined as trips where *Loligo* landings were ≥ 25%, by weight, of the total trip landings. Estimates of total discards are based the product of discard ratios and reported *Loligo* landings, by month, for *Loligo* trips in the Weighout database.

	Nov	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Total**
1995							
Trips	0	1	1	1	0	0	3
Total Kept (mt)		1.195	0.513	2.971			4.679
Total Discard (mt)		0.000	0.000	0.002			0.002
Ratio discard/kept		0.000	0.000	0.001			0.000
Total Landings (mt)		537.991	981.273	1,407.113			2,926.377
Total Discards (mt)		0.000	0.000	0.947			1.251
1996							
Trips	1	1	1	2	1	0	6
Total Kept (mt)	3.009	0.335	0.760	11.952	10.972		27.028
Total Discard (mt)	1.100	0.000	0.000	0.068	0.069		1.237
Ratio discard/kept	0.366	0.000	0.000	0.006	0.006		0.046
Total Landings (mt)	347.441	306.178	2,077.435	1,933.899	1,462.509		6,127.462
Total Discards (mt)	127.014	0.000	0.000	11.003	9.197		280.438
1997							
Trips	0	0	1	2	1	1	5
Total Kept (mt)			2.220	23.071	8.137	12.084	45.512
Total Discard (mt)			0.318	0.206	0.278	0.687	1.489
Ratio discard/kept			0.143	0.009	0.034	0.057	0.033
Total Landings (mt)			602.383	1,192.511	752.883	735.620	3,283.397
Total Discards (mt)			86.287	10.648	25.722	41.821	107.422

Table C4. cont.

	Nov	Dec	Jan	Feb	Mar	Apr	Total
1998							
Trips	2	0	3	3	7	3	18
Total Kept (mt)	3.629		21.514	25.045	100.520	25.540	176.248
Total Discard (mt)	0.003		0.372	0.078	0.976	3.395	4.824
Ratio discard/kept	0.001		0.017	0.003	0.010	0.133	0.027
Total Landings (mt)	1,442.321		1,202.271	3,697.553	3,720.621	1,009.754	11,072.520
Total Discards (mt)	1.192		20.789	11.516	36.125	134.225	303.061
1999							
Trips	2	3	0	0	4	5	14
Total Kept (mt)	40.183	14.411			31.508	37.670	123.772
Total Discard (mt)	0.032	0.155			2.015	2.376	4.578
Ratio discard/kept	0.001	0.011			0.064	0.063	0.037
Total Landings (mt)	1,783.164	1,286.115			1,197.348	1,343.383	5,610.010
Total Discards (mt)	1.420	13.833			76.573	84.733	207.499
2000							
Trips	1	0	4	5	5	0	15
Total Kept (mt)	0.429		14.527	63.171	53.083		131.210
Total Discard (mt)	0.000		0.005	0.492	0.530		1.027
Ratio discard/kept	0.000		0.000	0.008	0.010		0.008
Total Landings (mt)	292.562		1,232.910	2,182.140	1,769.293		5,476.905
Total Discards (mt)	0.000		0.424	16.995	17.665		42.869

Table C4. cont.

	Nov	Dec	Jan	Feb	Mar	Apr	Total
2001							
Trips	2	1	1	4	5	1	14
Total Kept (mt)	21.32	11.05	2.864	29.828	61.793	23.918	150.773
Total Discard (mt)	0.227	0	0.906	1.789	0.402	0.228	3.552
Ratio discard/kept	0.011	0.000	0.316	0.060	0.007	0.010	0.024
Total Landings (mt)	1,908.420	1,691.437	519.057	850.685	1,557.575	979.096	7,506.270
Total Discards (mt)	20.319	0.000	164.199	51.022	10.133	9.333	176.837
2002							
Trips	0	0	1	3	0	3	7
Total Kept (mt)			20.117	24.937		15.183	60.237
Total Discard (mt)			0.15	1.026		0	1.176
Ratio discard/kept			0.007	0.041		0	0.020
Total Landings (mt)			1,272.791	1,338.373		111.488	2,722.652
Total Discards (mt)			9.490	55.066		0	53.154
2003							
Trips	4	2	0	0	0	2	8
Total Kept (mt)	9.734				18.673	13.290	41.697
Total Discard (mt)	0.412				0.027	2.702	3.141
Ratio discard/kept	0.042				0.001	0.203	0.075
Total Landings (mt)	348.863				2,050.161	1,602.186	4,001.210
Total Discards (mt)	14.766				2.964	325.742	343.472
2004							
Trips	10	21	3	15	0	5	54
Total Kept (mt)	7.188	207.010	12.416	156.471		265.424	648.509
Total Discard (mt)	2.750	3.050	2.693	23.371		12.537	44.401
Ratio discard/kept	0.383	0.015	0.217	0.149		0.047	0.068
Total Landings (mt)	1,651.820	2,585.834	979.853	1,355.578		2,892.108	9,465.194
Total Discards (mt)	631.957	38.099	212.528	202.473		136.605	1,221.662

Table C5. Summary of *Illex* discards (mt), by year and fishery, estimated from data collected by observers from the NEFSC Observer Program during 1995-2004.

	Percentage of landings sampled for *Illex* discards										
	Illex Fishery		*Loligo* Fishery		***Illex* Discards (mt)**						
Year	*Illex* Landings (May-Oct, mt)	%	*Loligo* Landings (Nov-April, mt)	%	*Illex* Fishery	%	*Loligo* Fishery	%	Total	**Total *Illex* Landings (mt)**	***Illex* Discards (% of *Illex* landings)**
1995	13,494	0.01%	6,702	0.07%	64	98	1	2	65	14,058	0.5%
1996	15,563	5.36%	7,070	0.38%	82	23	280	77	362	16,969	2.1%
1997	12,709	8.79%	6,484	0.69%	56	34	107	66	163	13,629	1.2%
1998	23,091	0.67%	12,755	1.38%	150	33	303	67	453	23,597	1.9%
1999	7,115	1.28%	7,811	1.59%	58	22	207	78	265	7,388	3.6%
2000	8,901	4.54%	5,810	2.25%	29	40	43	60	72	9,011	0.8%
2001	3,452	0.00%	7,506	2.01%	No data		177		177	4,009	4.4%
2002	2,342	0.00%	6,107	0.98%	No data		53		53	2,750	2.0%
2003	5,887	21.22%	8,804	0.47%	6	2	344	98	350	6,389	5.5%
2004	26,011	4.47%	10,350	6.27%	344	22	1,222	78	1,566	26,087	6.0%

Table C6. Standardized, stratified mean catch per tow (delta-transformed) in numbers/tow, and kg/tow of *Illex illecebrosus,* pre-recruits (≤ 10 cm) and recruits (≥ 11 cm), caught during autumn research bottom trawl surveys in offshore strata 1-40 and 61-76 from Cape Hatteras to the Gulf of Maine during 1967-2004.

Year	All sizes (no./tow)	CV (%)	All sizes (kg/tow)	CV (%)	Individual Mean Weight (g)	Pre-recruits (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	0.50
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	1.71
1973	1.47	24	0.353	25	242	0.04	1.43
1974	2.82	40	0.392	30	145	1.20	1.62
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
1998	14.60	51	1.400	50	94	1.18	13.42
1999	1.39	16	0.192	17	136	0.15	1.24
2000	7.41	28	0.706	22	94	0.95	6.46
2001	4.49	27	0.323	23	72	0.46	4.03
2002	6.36	20	0.444	19	70	1.01	5.35
2003	28.46	61	1.946	67	69	3.12	25.34
2004	5.06	24	0.412	22	82	1.09	3.97
Average							
1967-1981	9.05	22	2.510	21	209	0.89	8.16
1982-2003	9.58	25	1.06	25	111	0.73	8.86
1967-2003	9.36	24	1.65	23	151	0.79	8.57
1999-2003	9.62	30	0.72	29	88	1.14	8.48

Table C7. Summary of data from Vessel Trip Reports submitted by fishermen participating in the *Illex illecebrosus* fishery during 2003 and 2004. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

	2003			2004		
	FT	RSW	Total	FT	RSW	Total
N vessels	3	11	14	12	16	28
N trips	32	80	112	92	355	447
Average trip duration (days absent from port)	8.2	2.8	4.4	6.5	1.8	2.8
Average nominal effort (days fished) per trip	2.1	0.8	1.2	1.1	0.5	0.6
Average landings (mt)	152	17	55	122	34	52
Average nominal LPUE (mt/df)	71	22	48	111	76	89
Total fishery landings (mt)	4,859	1,337	6,195	12,174	11,198	23,372
Proportion of total annual landings	0.78	0.22		0.52	0.48	
Total nominal effort (days fished)	69	61	130	101	161	262
Proportion of total annual effort	0.53	0.47		0.39	0.61	
Duration of fishing season (weeks) [1]			23			18
Timing of fishing season			weeks 24-46			weeks 21-38

[1] Fishery closed on 9/21/2004 because quota of 24,000 mt was landed

Table C8. Results of a General Linear Model with log-transformed landings per unit effort from the 2003 U.S. *Illex illecebrosus* fishery as the dependent variable and week of year, vessel type (freezer or RSW trawler), and quarter-degree square fishing area as class effects in the model.

Source	DF	Sum of Squares	Mean Square	F	Pr > F
Model	28	64.92159721	2.31862847	3.35	< 0.0001
Error	50	34.60964687	0.69219294		
Corrected Total	78	99.53124408			
R-Square	CV	Root MSE	ln (lpuemt) Mean		
0.652274	25.36757	0.831981	3.279705		
Source	DF	Type I SS	Mean Square	F	Pr > F
wkofyr	21	43.71807976	2.08181332	3.01	0.0007
vessel type	1	16.85165507	16.85165507	24.35	<.0001
quarter-degree square	6	4.35186239	0.7253104	1.05	0.4062
Source	DF	Type III SS	Mean Square	F	Pr > F
wkofyr	21	28.38454289	1.3516449	1.95	0.0271
vessel type	1	16.32903841	16.32903841	23.59	<.0001
quarter-degree square	6	4.35186239	0.7253104	1.05	0.4062
Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		2.892167156	0.65598996	4.41	<.0001
wkofyr	23	-0.83677222	1.09519873	-0.76	0.4484
	26	0.025684254	0.85545884	0.03	0.9762
	27	-0.556877471	0.80031553	-0.70	0.4898
	28	0.727561846	0.7656278	0.95	0.3465
	29	-1.057333371	0.80031553	-1.32	0.1925
	30	0.050102596	0.8073132	0.06	0.9508
	31	0.820210337	0.87588503	0.94	0.3535
	32	0.174250298	0.79740912	0.22	0.8279
	33	-0.810892382	0.71768494	-1.13	0.2639
	34	0.326811416	0.85266844	0.38	0.7031
	35	0.473101326	0.74953597	0.63	0.5308
	36	-0.192868857	0.72695638	-0.27	0.7919
	37	-0.448380259	0.89406911	-0.50	0.6182
	38	0.773904369	0.74364221	1.04	0.3030
	39	0.74920603	0.74830111	1.00	0.3215
	40	0.564620776	0.71213424	0.79	0.4316

	41	0.303483041	0.73487454	0.41	0.6814
	42	-0.252719536	0.7925821	-0.32	0.7512
	44	0.06387861	1.03822267	0.06	0.9512
	45	-0.87454083	1.03822267	-0.84	0.4036
	46	-2.196469961	1.09814748	-2.00	0.0509
	924	0			
vessel type	freezer	1.38042707	0.28421484	4.86	<.0001
	90	0			
quarter-degree square	35744	-0.251695345	0.48585275	-0.52	0.6067
	36744	-0.051855303	0.39807988	-0.13	0.8969
	37741	-0.554991953	0.47689578	-1.16	0.2500
	38731	-0.248242504	0.44571473	-0.56	0.5800
	38732	-0.361044568	0.33103193	-1.09	0.2806
	38734	0.673924219	0.51879469	1.30	0.1999
	936742	0			

Table C9. Results of a General Linear Model with log-transformed landings per unit effort from the 2004 U.S. *Illex illecebrosus* fishery as the dependent variable and week of year, vessel type (freezer or RSW trawler), and quarter-degree square fishing area as class effects in the model.

Source	DF	Sum of Squares	Mean Square	F	Pr > F
Model	30	31	56.7928322	1.8320268	< 0.0001
Error	340	368	167.8628528	0.4561491	
Corrected Total	370	399	224.655685		

R-Square	Coeff Var	Root MSE	lnlpuemt Mean
0.252799	15.43396	0.675388	4.375987

Source	DF	Type I SS	Mean Square	F	Pr > F
wkofyr	19	24.77420331	1.30390544	2.86	<.0001
vessel type	1	12.40259859	12.40259859	27.19	<.0001
quarter-degree square	11	19.61603029	1.78327548	3.91	<.0001

Source	DF	Type III SS	Mean Square	F	Pr > F
wkofyr	19	30.60929990	1.61101578	3.53	<.0001
vessel type	1	17.81584700	17.81584700	39.06	<.0001
quarter-degree square	11	19.61603029	1.78327548	3.91	<.0001

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		4.260992	0.232047	18.36	<.0001
wkofyr	20	0.280698	0.508075	0.55	0.581
	21	-0.395540	0.243112	-1.63	0.1046
	22	0.482445	0.254427	1.9	0.0587
	23	0.346848	0.238090	1.46	0.146
	25	-0.244626	0.211317	-1.16	0.2478
	26	0.016649	0.207027	0.08	0.9359
	27	-0.015857	0.217309	-0.07	0.9419
	28	0.340708	0.203401	1.68	0.0948
	29	-0.161689	0.210484	-0.77	0.4429
	30	-0.000075	0.220173	0.00	0.9997
	31	0.157004	0.238182	0.66	0.5102
	32	0.141091	0.228924	0.62	0.5381
	33	0.320713	0.206790	1.55	0.1218
	34	0.688085	0.215205	3.20	0.0015
	35	0.551480	0.199831	2.76	0.0061
	36	0.023374	0.213164	0.11	0.9127
	37	0.188770	0.240686	0.78	0.4334

	38	0.070158	0.236524	0.30	0.7669
	39	-0.971570	0.454831	-2.14	0.0333
	924	0			
vessel type	freezer	0.634100	0.101463	6.25	<.0001
	90	0			
quarter-degree square	37734	0.037820	0.372147	0.10	0.9191
	37741	-0.098423	0.277586	-0.35	0.7231
	37742	-0.804485	0.276812	-2.91	0.0039
	37743	0.216598	0.298521	0.73	0.4686
	38724	0.101493	0.210326	0.48	0.6297
	38731	-0.298963	0.183363	-1.63	0.1039
	38732	-0.077336	0.173498	-0.45	0.6561
	38733	-0.031082	0.188733	-0.16	0.8693
	39693	0.858187	0.701742	1.22	0.2222
	39721	-1.453390	0.236918	-6.13	<.0001
	39722	-0.806836	0.381026	-2.12	0.0349
	999999	0			

Table C10. Probability values ($\alpha = 0.05$) from General Linear Models used to standardize catch rates in the *Illex illecebrosus* fishery during 2003 and 2004. Vessel types were characterized as freezer trawler (FT) or refrigerated seawater system (RSW) trawler.

Effect	**2003**		**2004**					
					RSW		FT	
Week of year	**0.0271**	0.1230	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0025**
Quarter-degree square	0.4062	0.9807	**0.0001**	0.0737	0.0588	**0.0177**	0.7251	**0.0001**
Vessel type	**0.0001**		**0.0001**					
Hull Number		**0.0008**		**0.0001**	**0.0001**		**0.0001**	
Model	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
R^2	0.65	0.75	0.25	0.67	0.65	0.20	0.72	0.28
df	28	38	31	52	45	25	47	24

Table C11. Status of research recommendations from the previous *Illex* stock assessment (SARC 37).

Research Recommendation	Status
Continue model development, with the objective of producing sound statistical models for stock assessment purposes	All three models presented at SARC 37 were improved upon and tested further. These models require seasonal age and maturity data before further model testing can be done.
Consider the development of "operating models" which can be used to test the effectiveness of alternative management strategies	This research recommendation cannot be accomplished until a reliable stock assessment model is available.
Evaluate the relationship between growth rates and sea temperature to define possible changes in stock productivity associated with environmental conditions.	Not completed. Requires a funding source for the collection and analysis of growth rate data.
Define biological indicators of low or high productivity regimes.	In progress. There is a relationship between *Illex* body size, autumn survey relative abundance indices, and bottom temperature anomalies on the US Shelf. However, further investigation of these relationships is needed.
Evaluate seasonal and latitudinal clines in growth rates.	Not completed. Requires a funding source for the collection and analysis of growth rate data.
Evaluate and design cooperative research programs with commercial vessels for sampling of size, weight and possible age of *Illex* during the fishing season	Completed. Length and weight data from the fishery are collected by the *Illex* processors/dealers and sent to the NEFSC for use in the assessments.
Continue with cooperative ventures for pre-season survey to obtain possible indices of upcoming stock abundance and productivity.	A pre-season *Illex* survey was conducted using commercial vessels in 2000 with funds from an external grant and these data were used in the assessments (SARC 37 and current). External funding is needed to conduct a second *Illex* pre-season survey to assess the inter-annual variability of the data.
Evaluate catch rates by vessel by using VTR and Weighout databases to improve procedures for standardization of nominal LPUE.	Completed during the current assessment.

ILLEX FIGURES

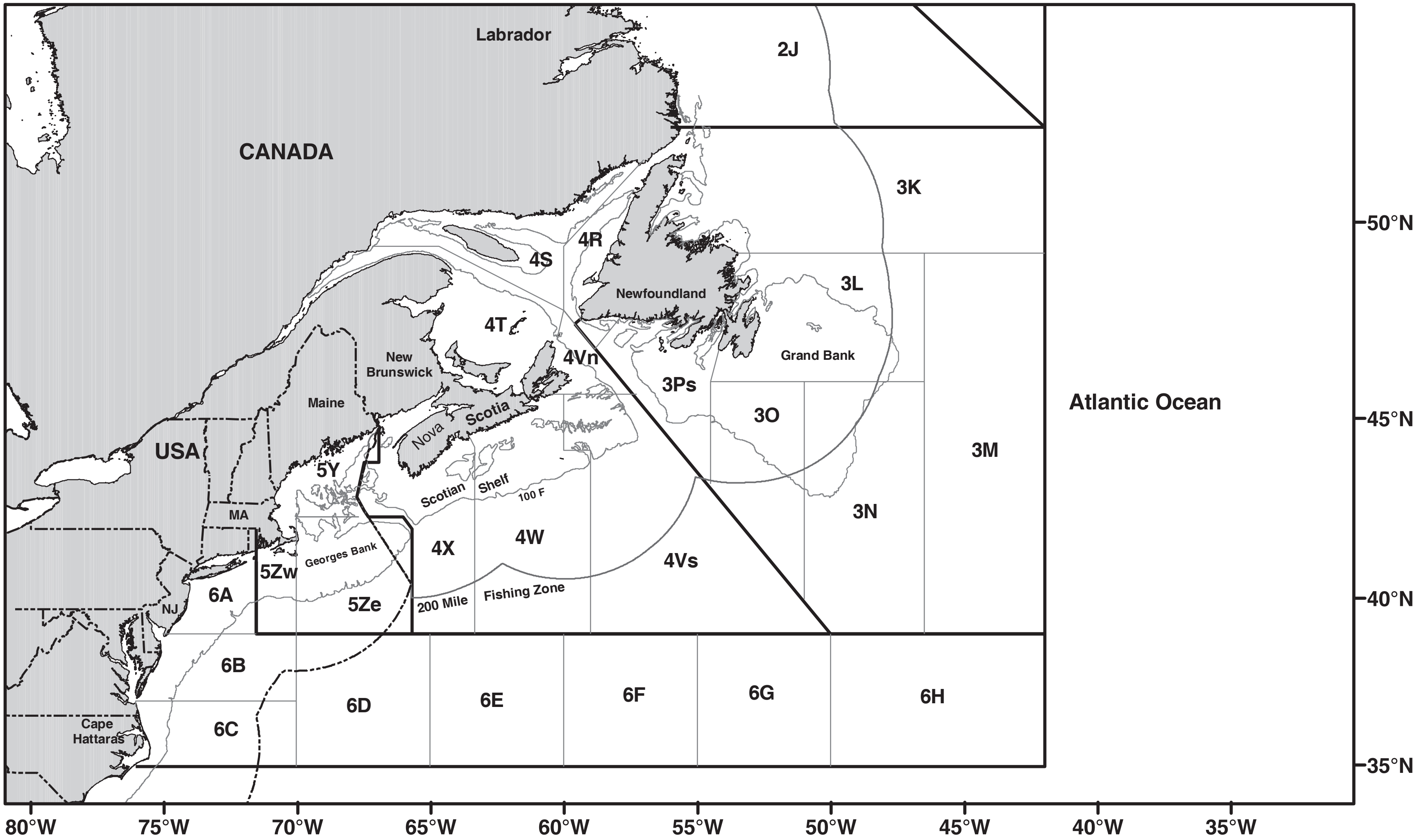

Figure C1. Catch reporting areas of the Northwest Atlantic Fisheries Organization (NAFO) for Subareas 3-6.

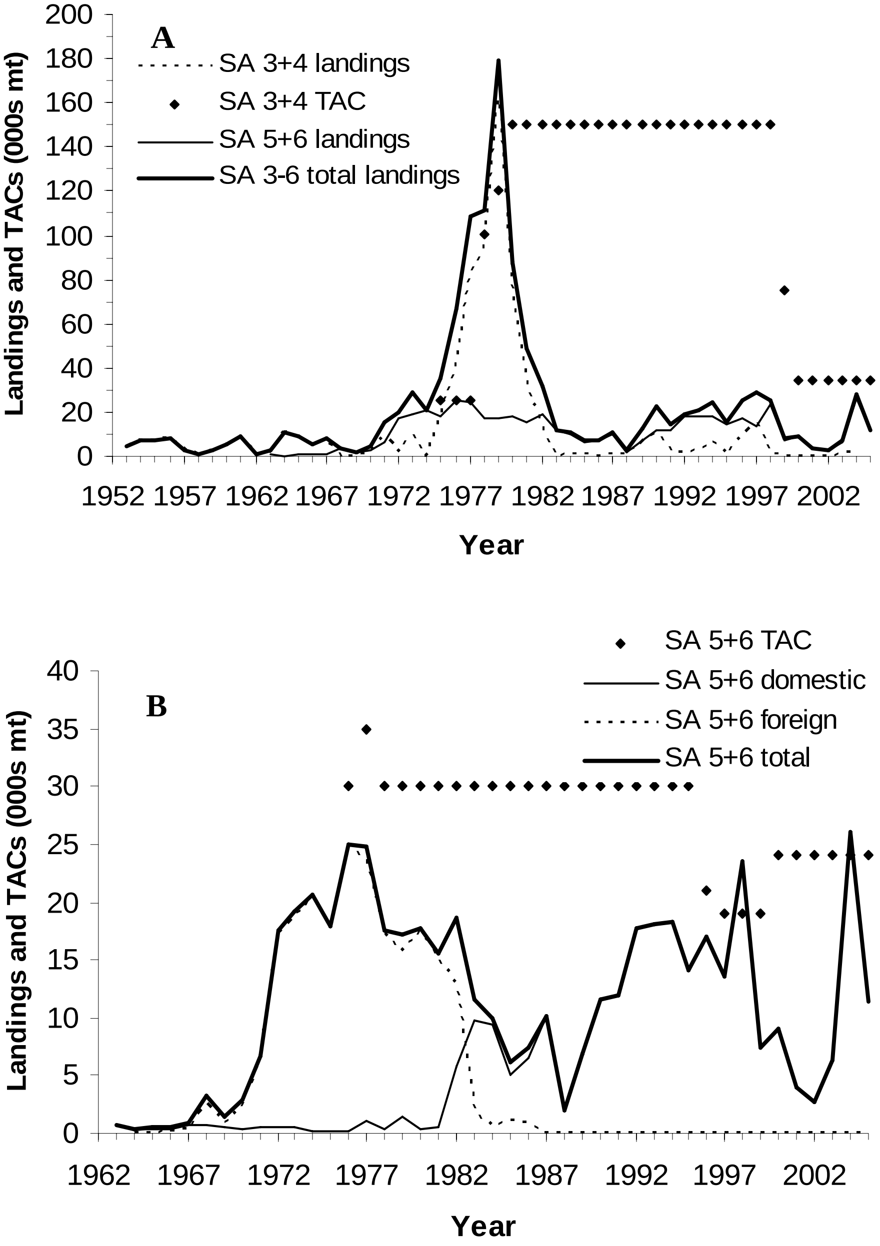

Figure C2. Total landings of *Illex illecebrosus* in (A) NAFO Subareas 3-6 and (B) in the US EEZ (NAFO Subareas 5+6), with respect to annual TACs, during 1963-2005.

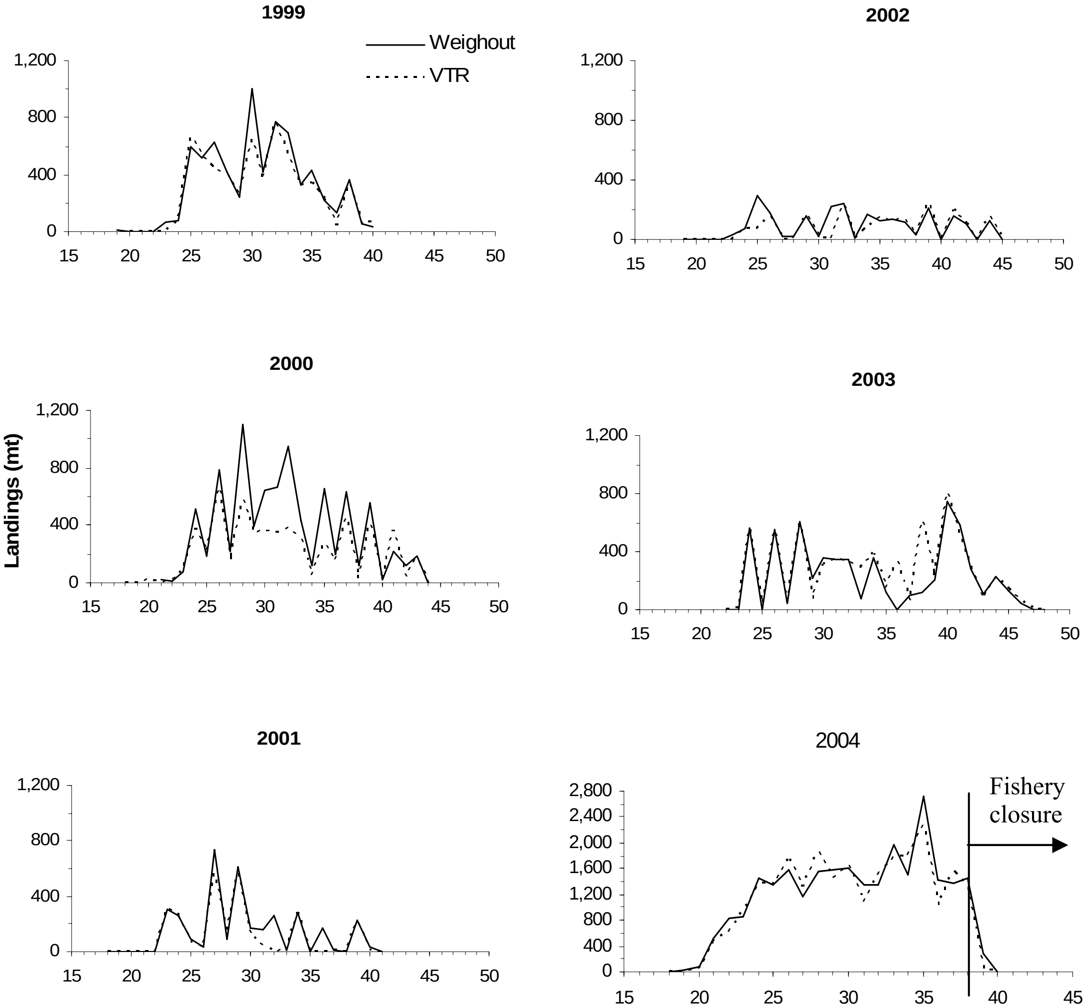

Figure C3. Trends in weekly *Illex illecebrosus* landings from the Weighout database versus the Vessel Trip Report database during 1999-2004.

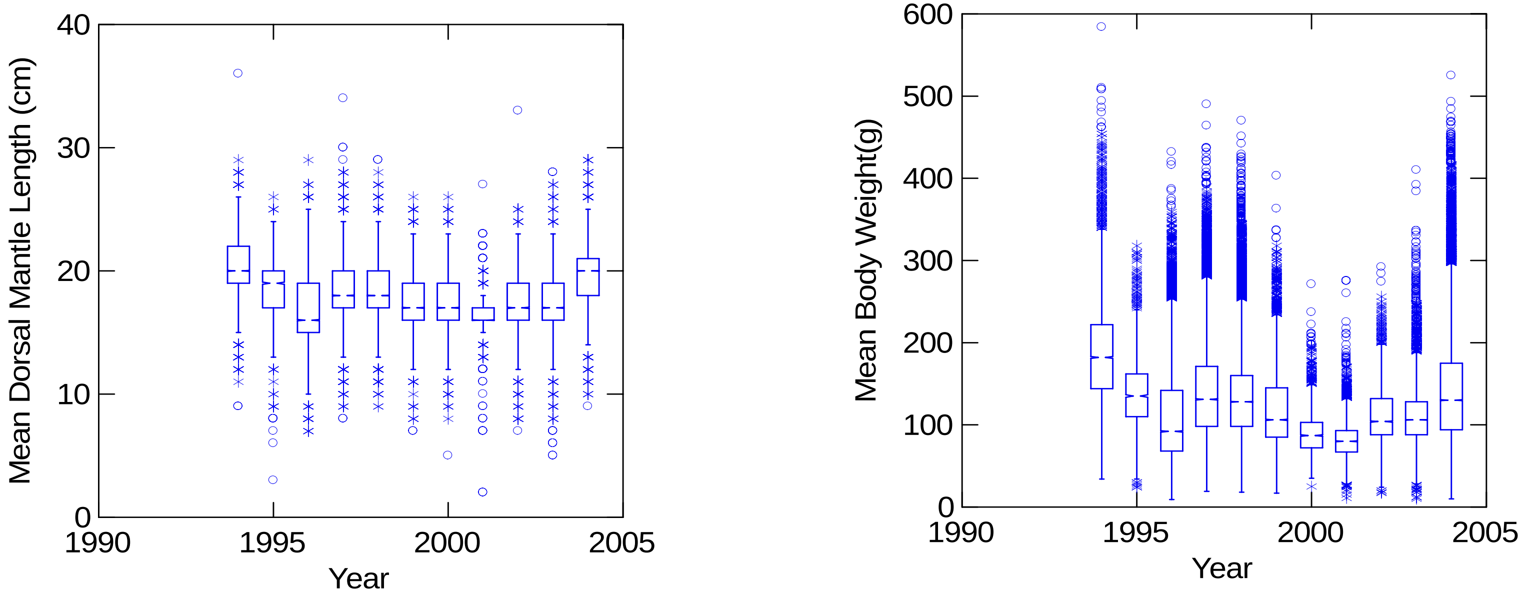

Figure C4. Annual trends in the dorsal mantle length (cm) and body weight (g) of *Illex illecebrosus* landed during 1994-2004. The boxes represent the boundaries of the interquartile range and the notch within the box represents the median.

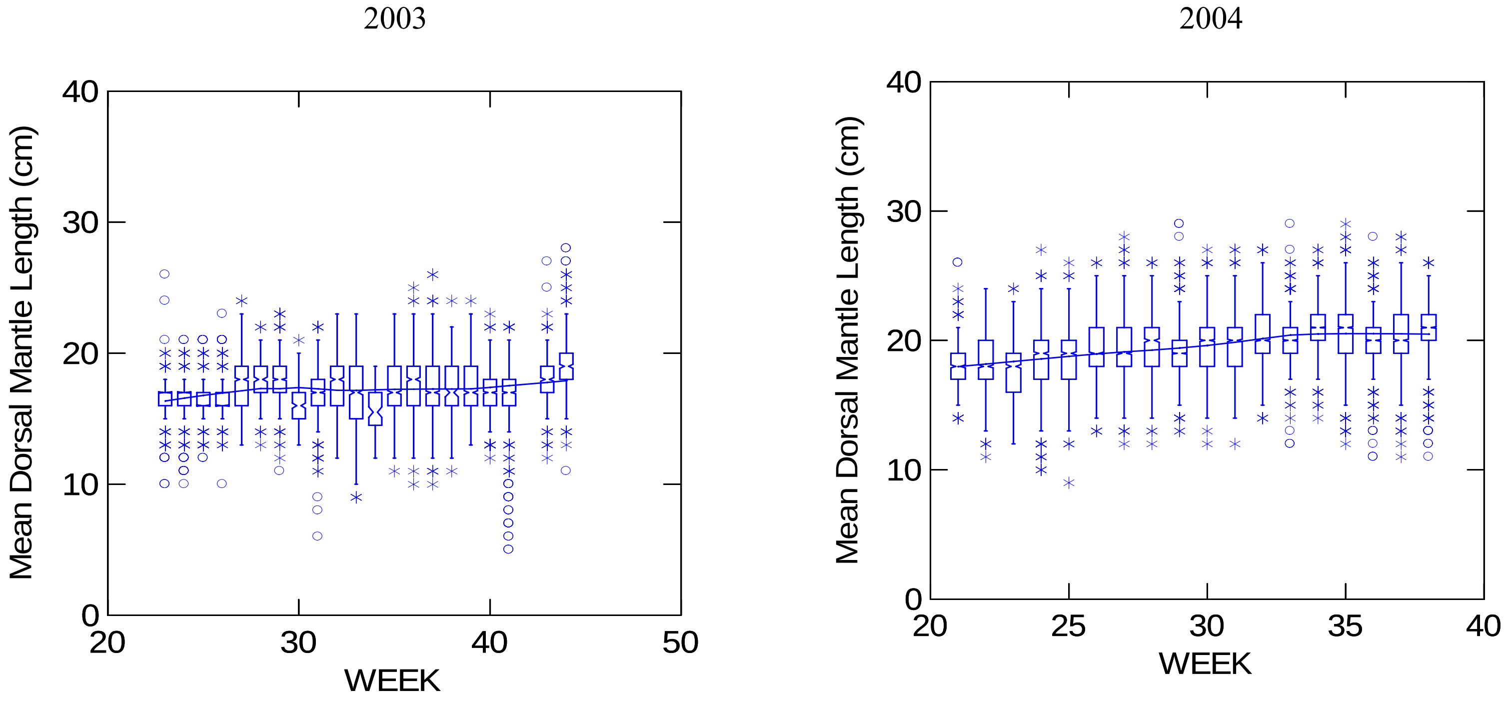

Figure C5. Weekly trends in the dorsal mantle length (cm) of *Illex illecebrosus* landings during 2003 and 2004. The solid line represents a loess smooth of the observed values with a tension factor of 0.5.

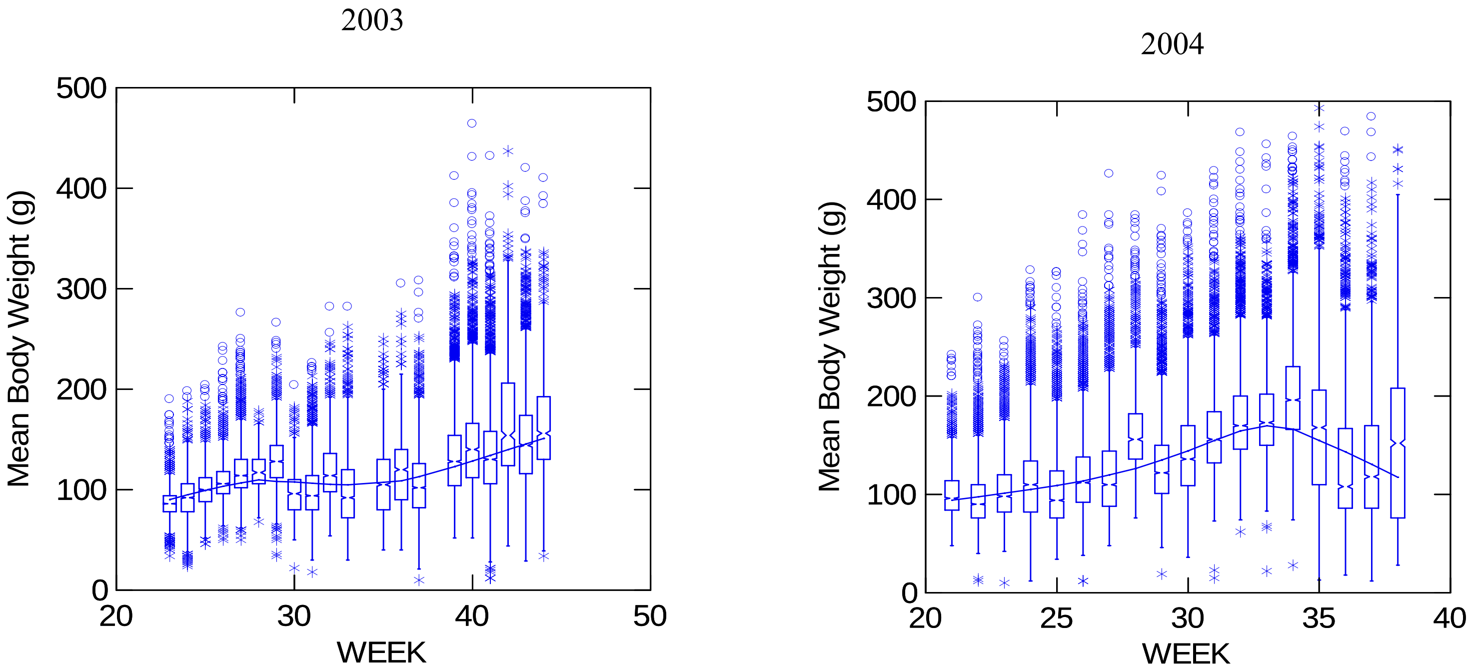

Figure C6. Weekly trends in the body weight (g) of *Illex illecebrosus* landings during 2003 and 2004. The solid line represents a loess smooth of the observed values with a tension factor of 0.5.

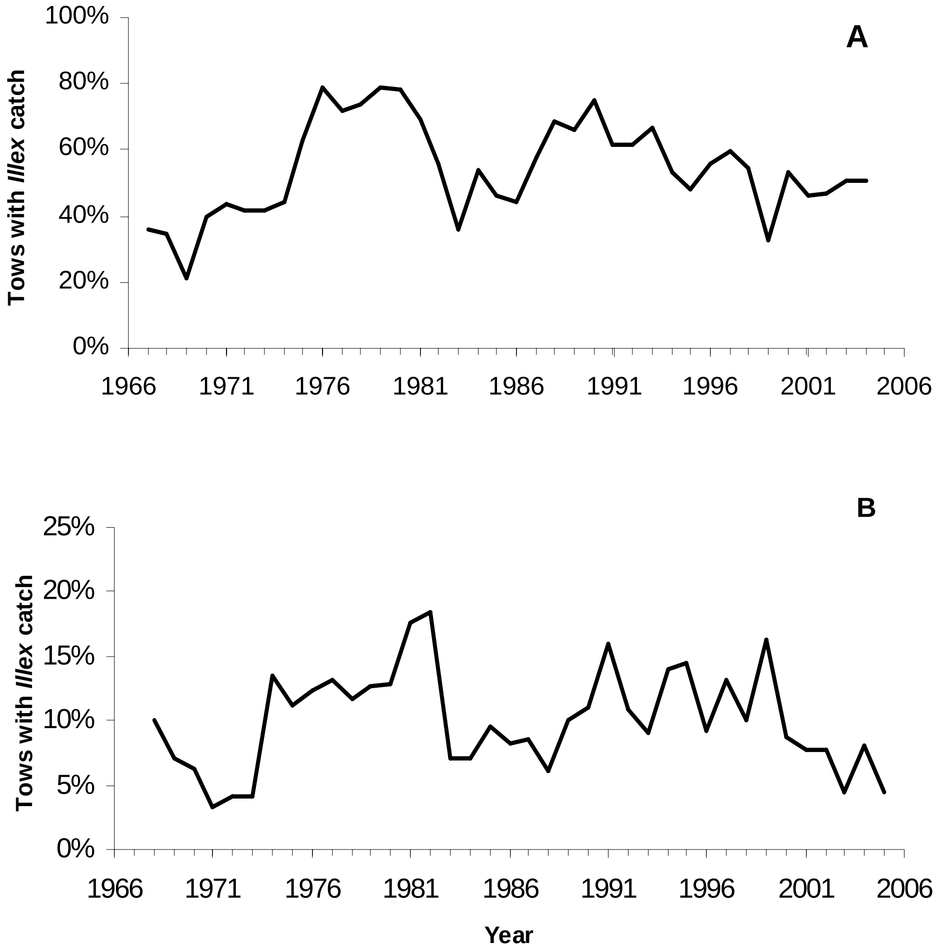

Figure C7. Annual trends in the percentage of tows with *Illex* catch, in offshore strata sampled during the (A) NEFSC autumn (1967-2004) and (B) spring (1968-2005) research bottom trawl surveys.

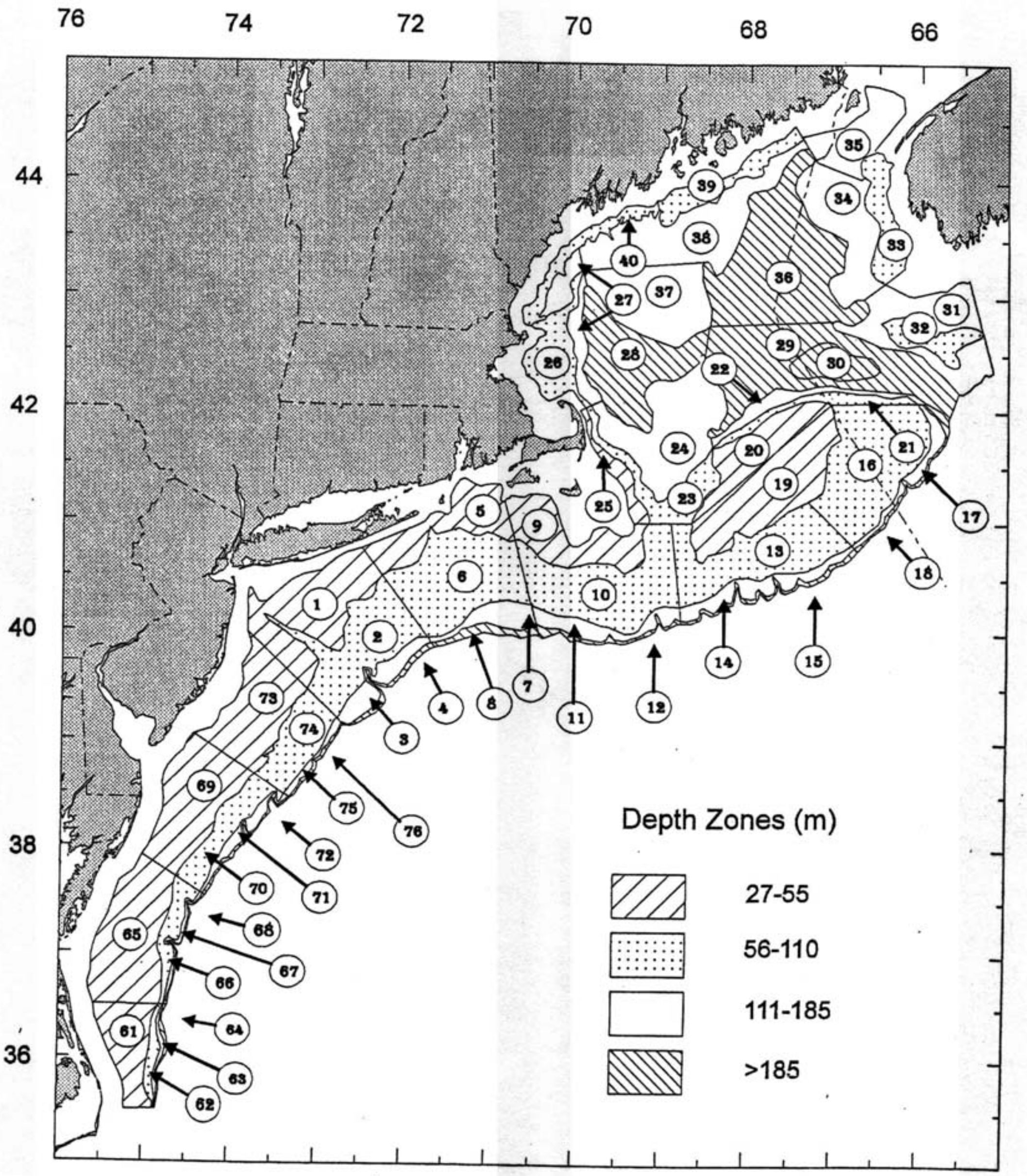

Figure C8. Offshore depth strata sampled during Northeast Fisheries Science Center bottom trawl research surveys.

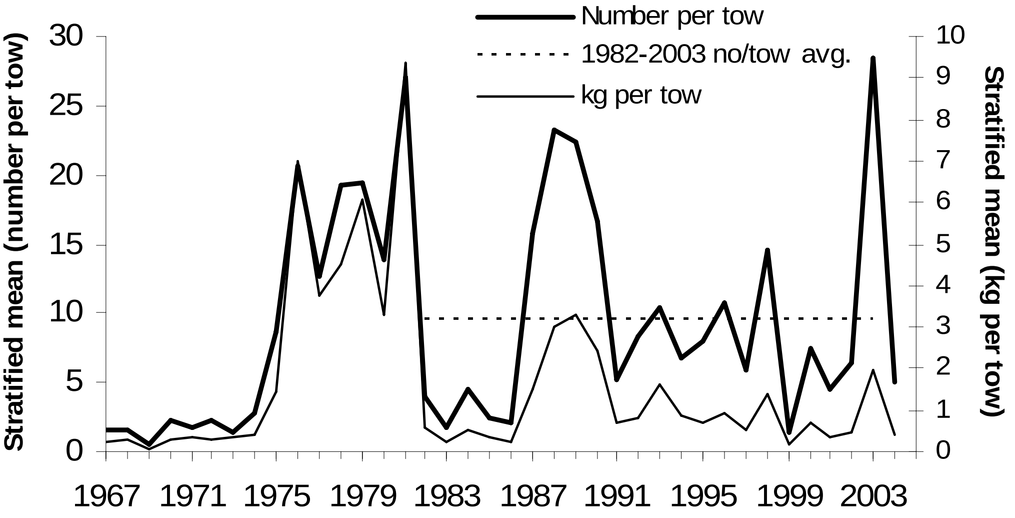

Figure C9. Trends in *Illex illecebrosus* relative abundance (stratified mean number tow) and biomass (stratified mean kg per tow) indices based on data from NEFSC autumn bottom trawl surveys conducted on the USA shelf during 1967-2004.

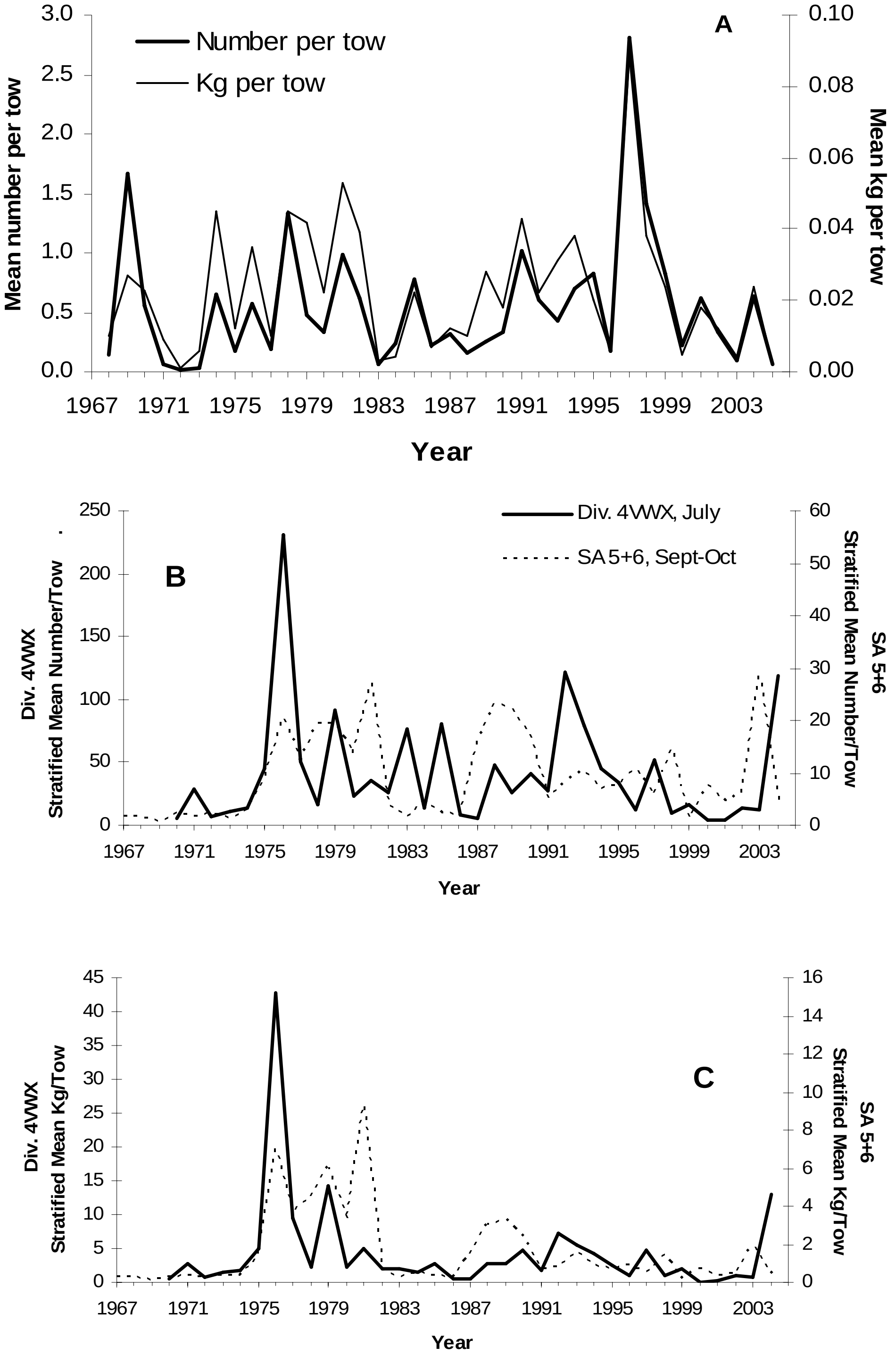

Figure C10. Trends in *Illex illecebrosus* relative abundance (stratified mean number per tow) and biomass (stratified mean kg per tow) based on bottom trawl surveys of (A) the USA shelf during March and (B and C) the USA shelf in September/October and the Scotian Shelf in July. Scotian Shelf survey indices could not be standardized for gear and vessel changes that occurred in 1982, 1983 and 2004.

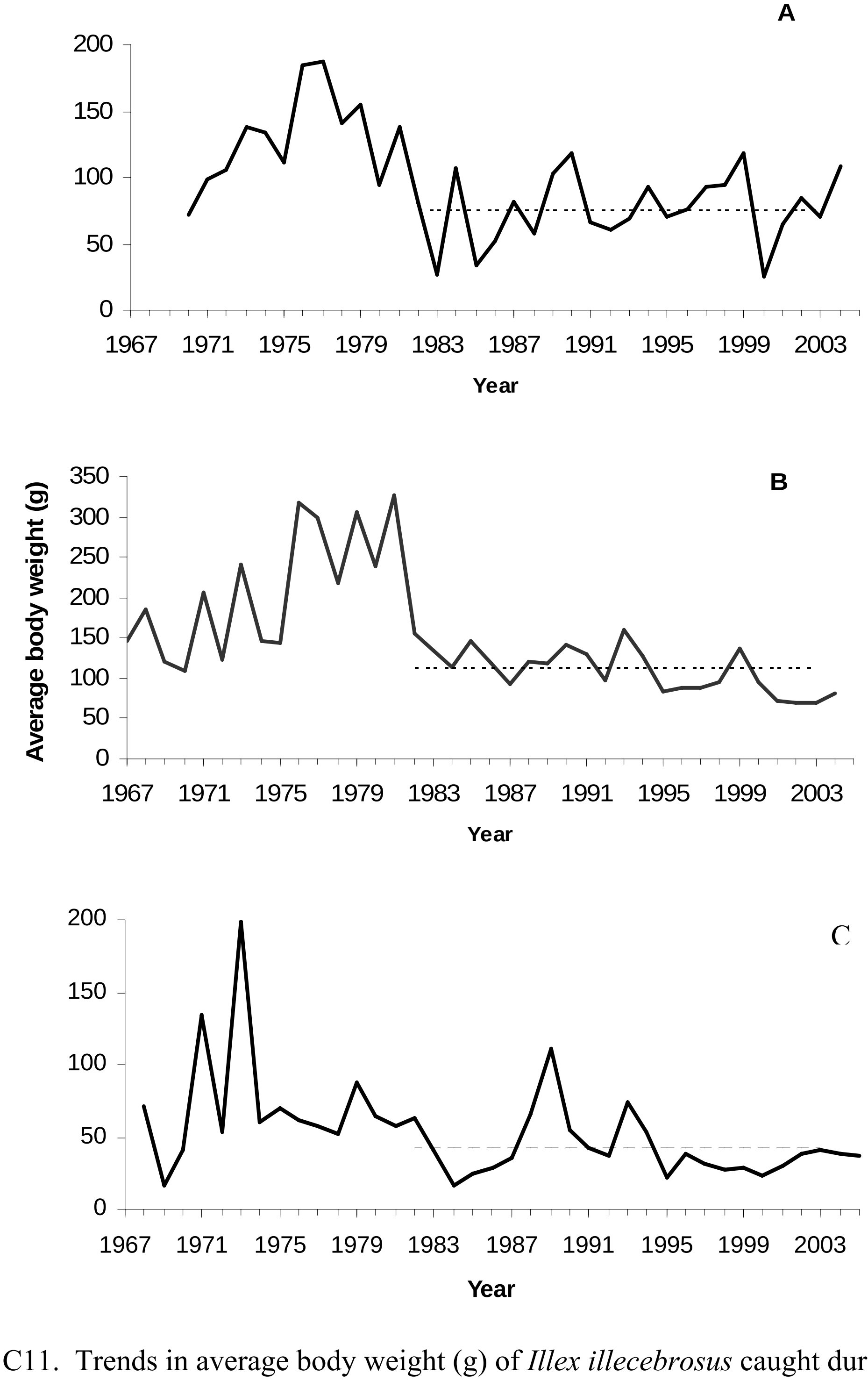

Figure C11. Trends in average body weight (g) of *Illex illecebrosus* caught during (A) Canadian research bottom trawl surveys conducted in July on the Scotian Shelf (1970-2004) and NEFSC (B) autumn (1967-2004) and (C) spring (1968-2005) research bottom trawl surveys of the U. S Shelf. The dashed line represents the 1982-2003 average body weight.

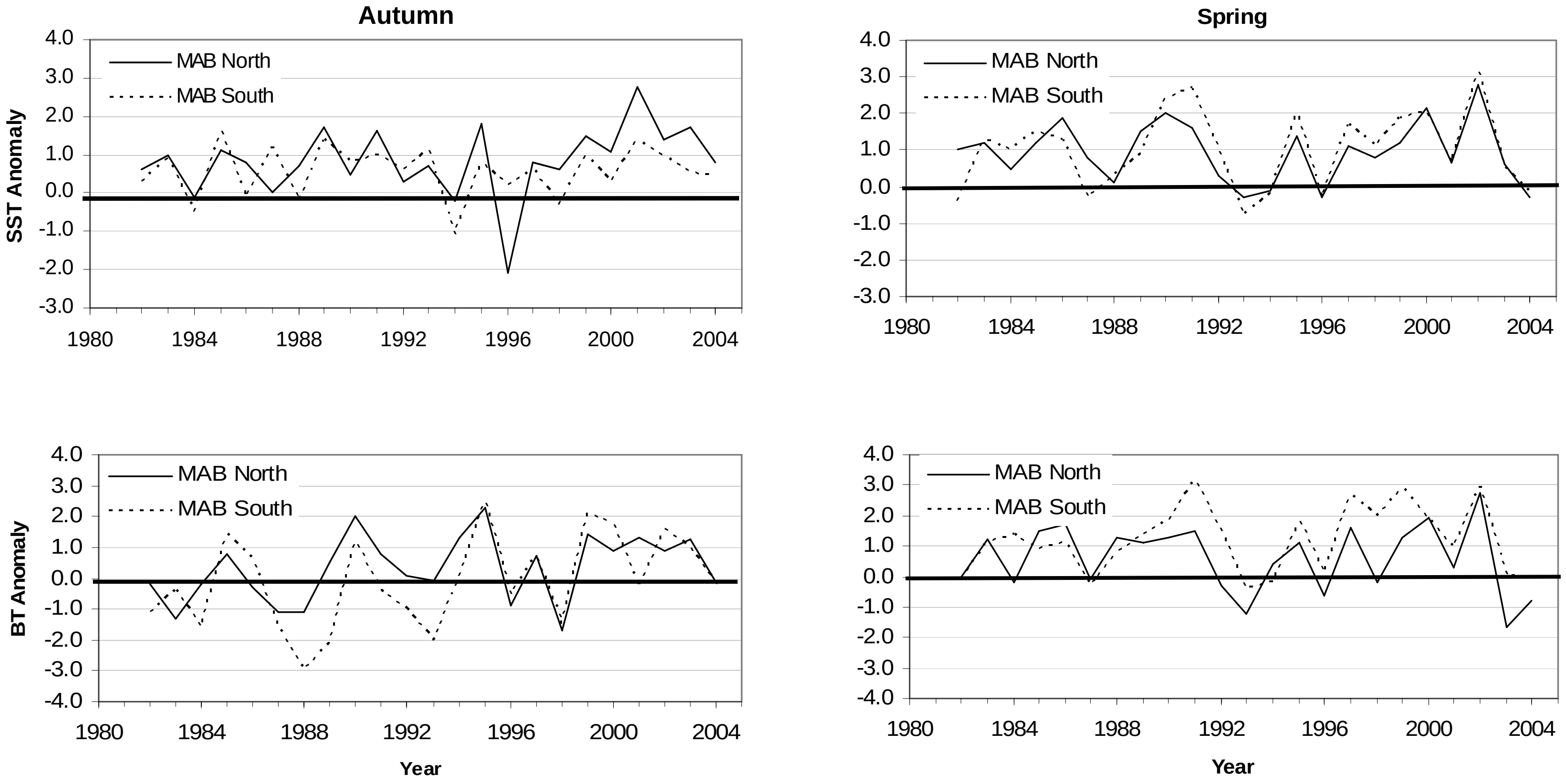

Figure C12. Sea surface temperature and bottom temperature anomalies in the Mid-Atlantic Bight, north versus south, during NEFSC autumn and spring research bottom trawl surveys, 1982-2004. The reference period is 1977-1987.

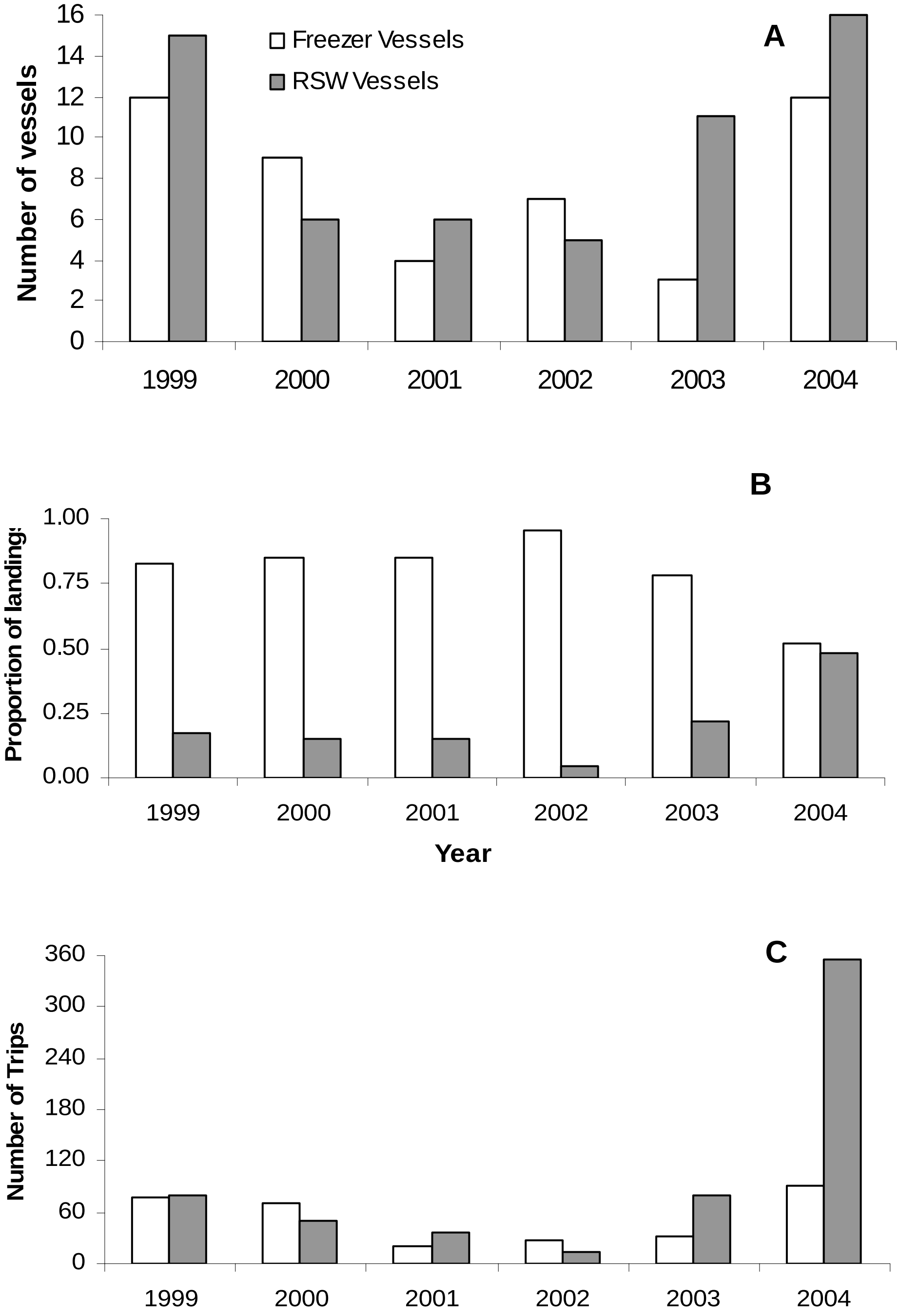

Figure C13. Number of (A) vessels, (B) proportion of annual landings and (C) number of trips, by fleet sector, in the directed fishery during 1999-2004.

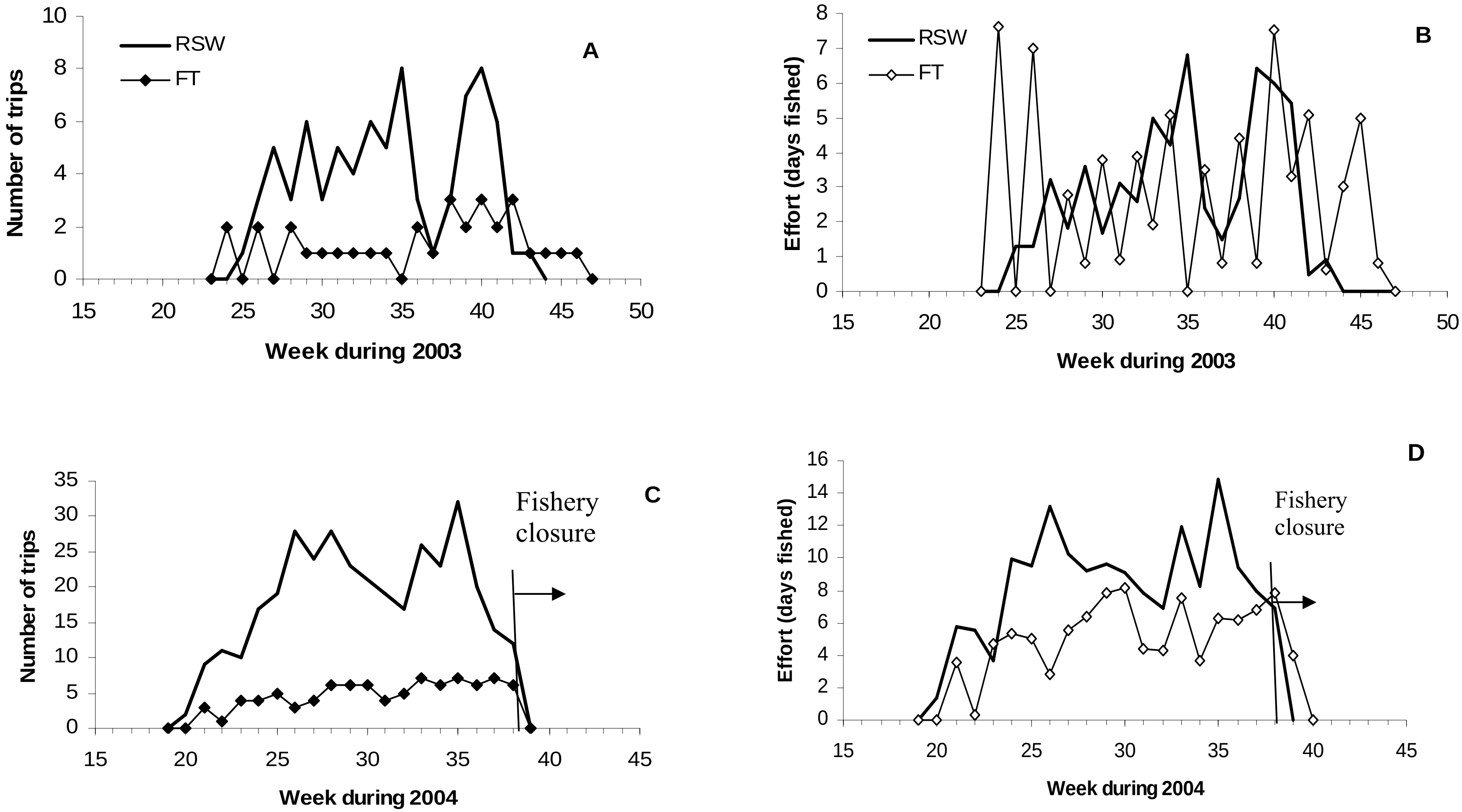

Figure C14. Number of fishing trips and nominal effort (days fished) for freezer trawlers (FT) and refrigerated seawater system (RSW) trawlers, by week, during 2003 (A and B) and 2004 (C and D).

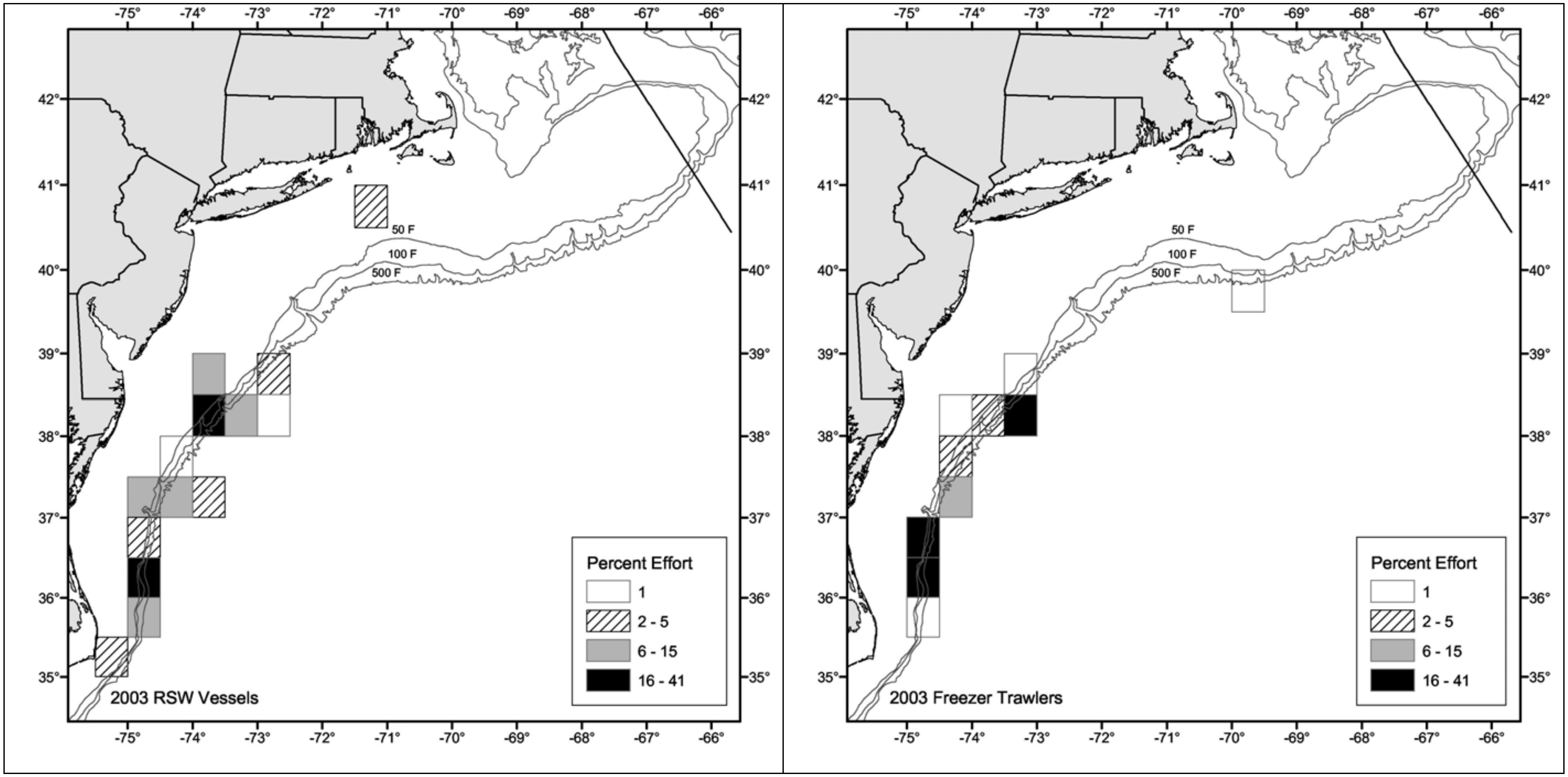

Figure C15. Percentage of nominal annual effort, by quarter-degree square, for refrigerated seawater system (RSW) trawlers and freezer trawlers participating in the *Illex illecebrosus* fishery during 2003.

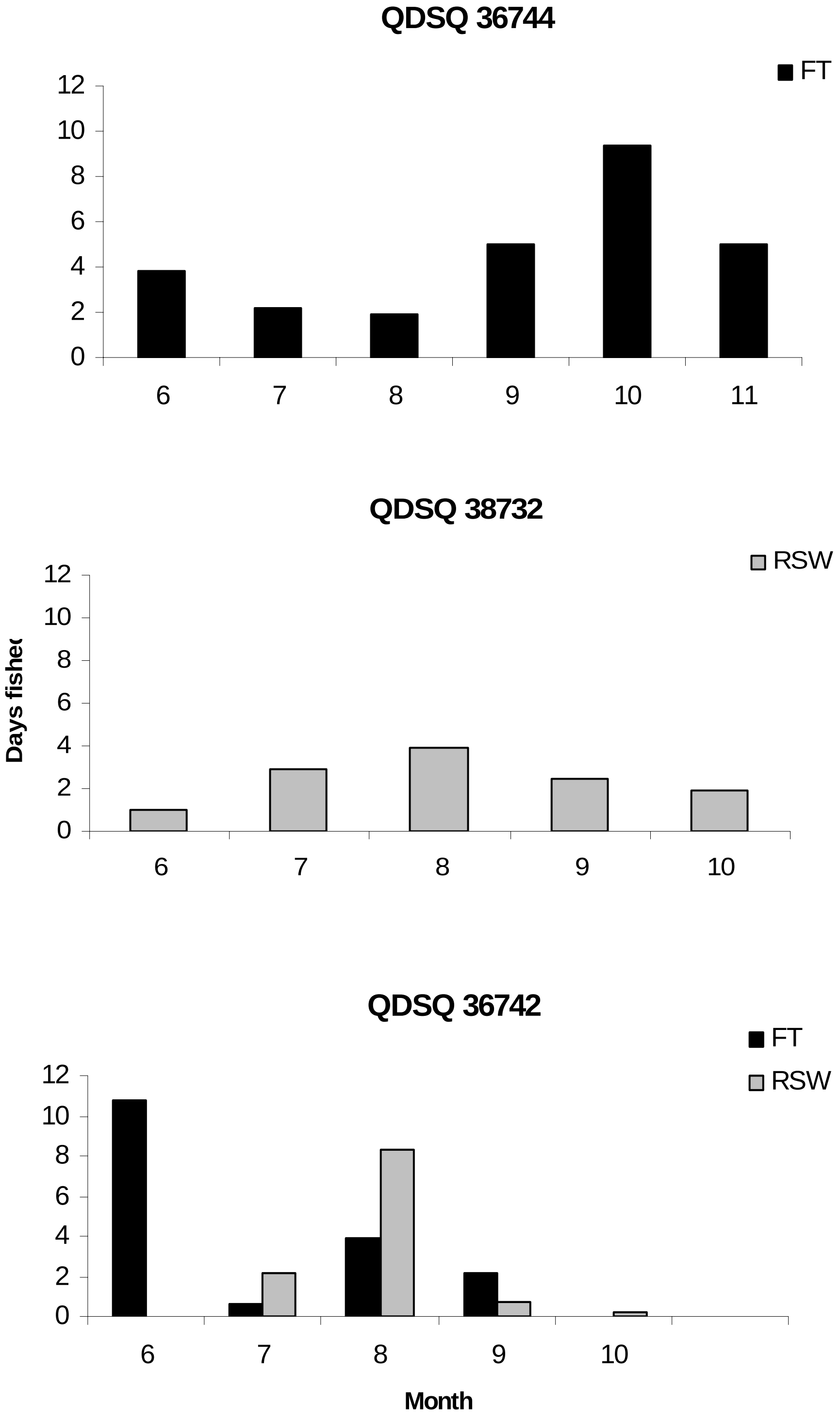

Figure C16. Effort (days fished), by fleet sector and month, in quarter-degree squares that were consistently fished during the 2003 *Illex* fishery. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

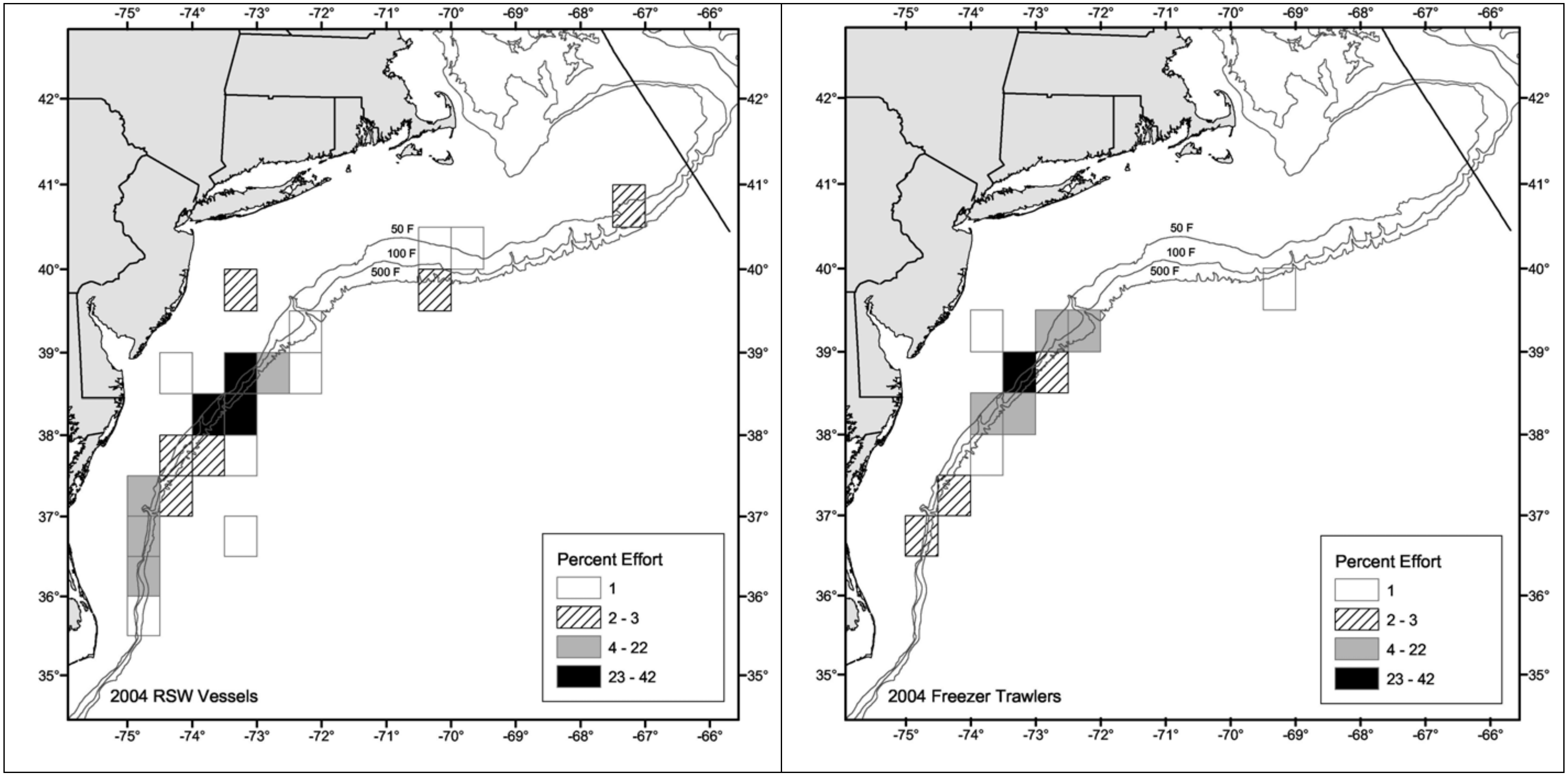

Figure C17. Percentage of nominal annual effort, by quarter-degree square, for refrigerated seawater system (RSW) trawlers and freezer trawlers participating in the *Illex illecebrosus* fishery during 2004.

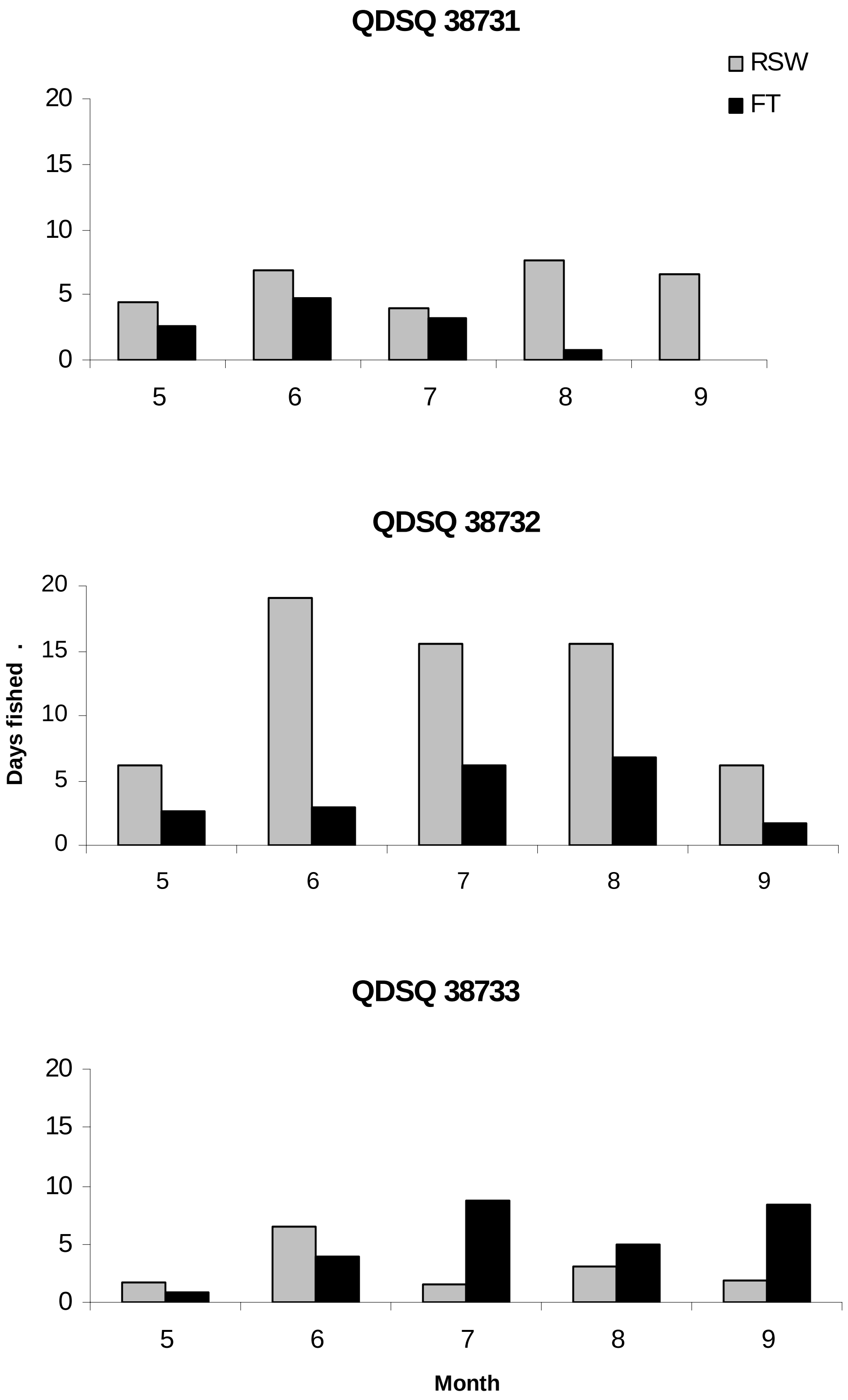

Figure C18. Effort (days fished), by fleet sector and month, in quarter-degree squares that were consistently fished during the 2004 *Illex* fishery. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

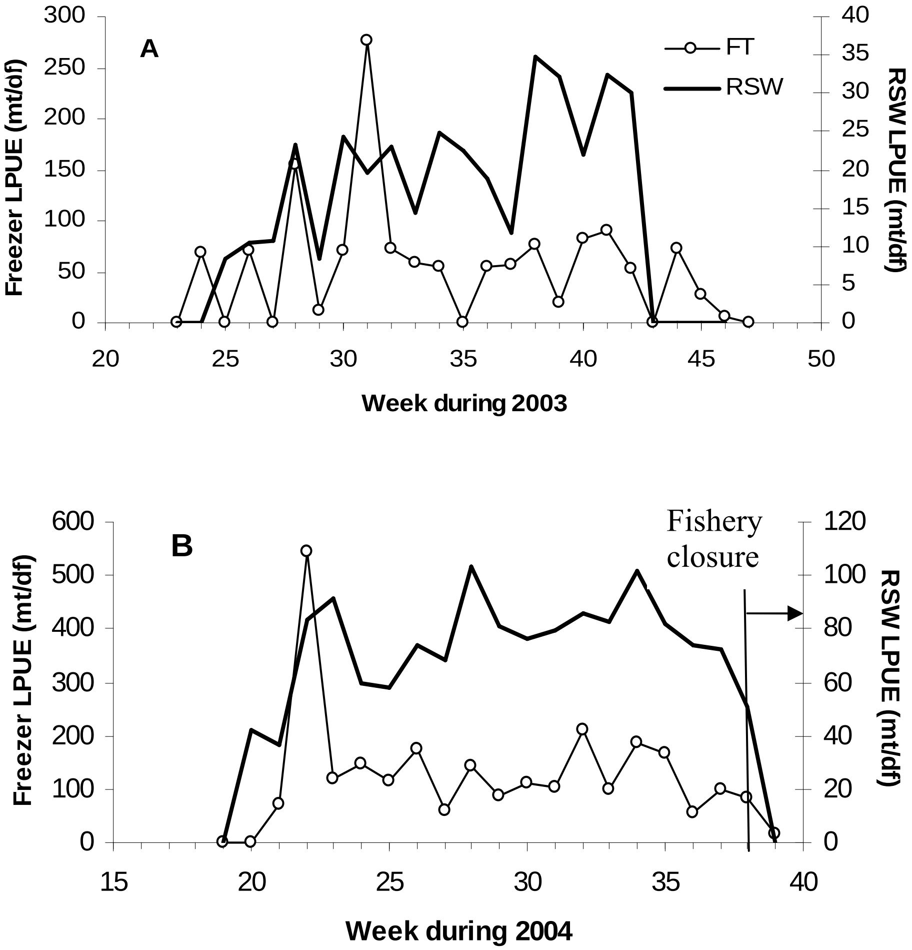

Figure C19. Weekly trends in nominal landings per unit effort (mt/day fished), by fleet sector, in the *Illex illecebrosus* fishery during (A) 2003 and (B) 2004. FT represents freezer trawlers and RSW represents refrigerated seawater system trawlers.

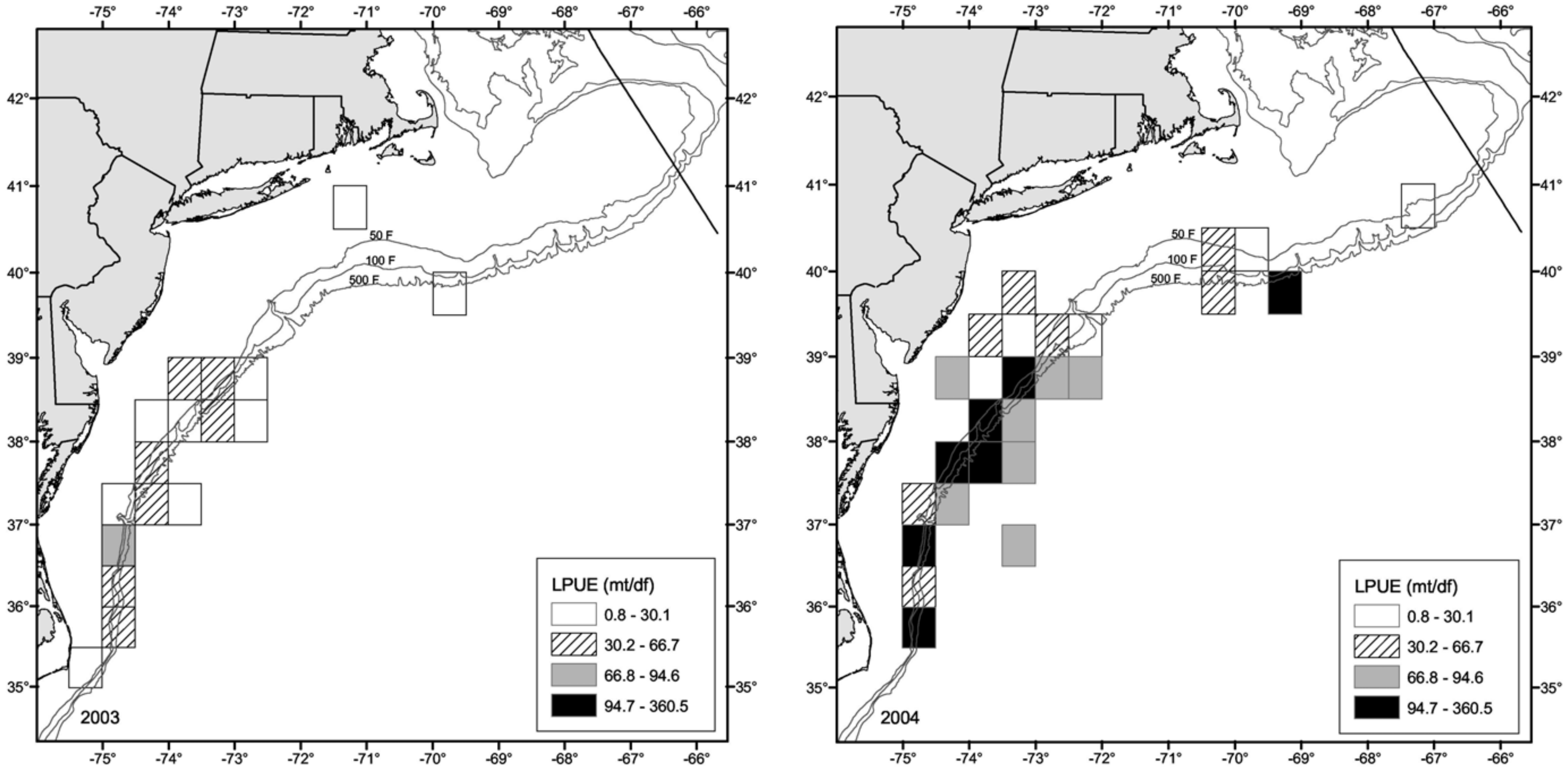

Figure C20. Nominal landings per unit of effort (mt/day fished), by quarter-degree square, for bottom trawlers participating in the *Illex illecebrosus* fishery during 2003 and 2004.

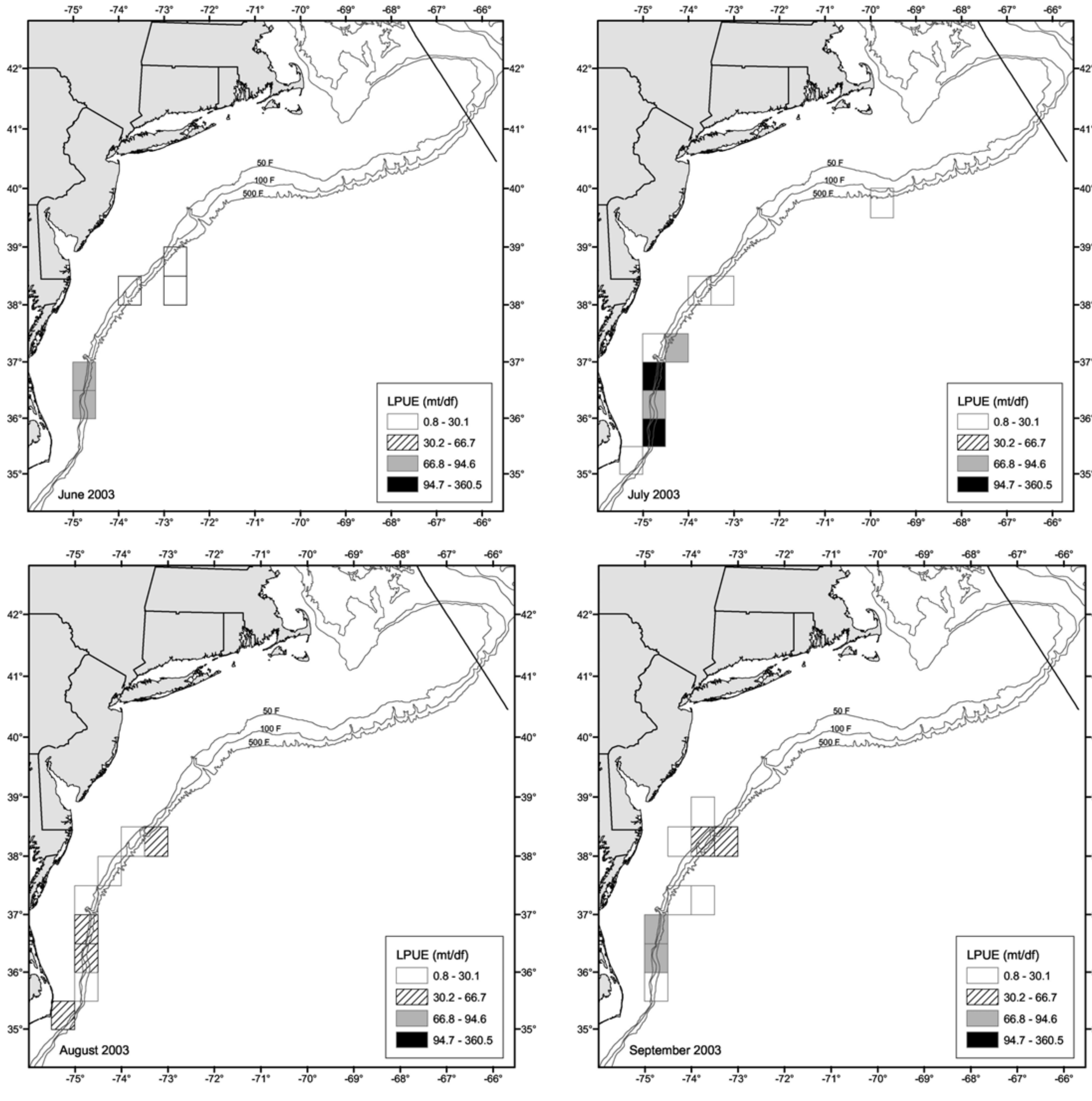

Figure C21. Monthly distribution of nominal landings per unit of effort (mt/days fished), by quarter-degree square, for bottom trawlers participating in the *Illex illecebrosus* fishery during June-October, 2003.

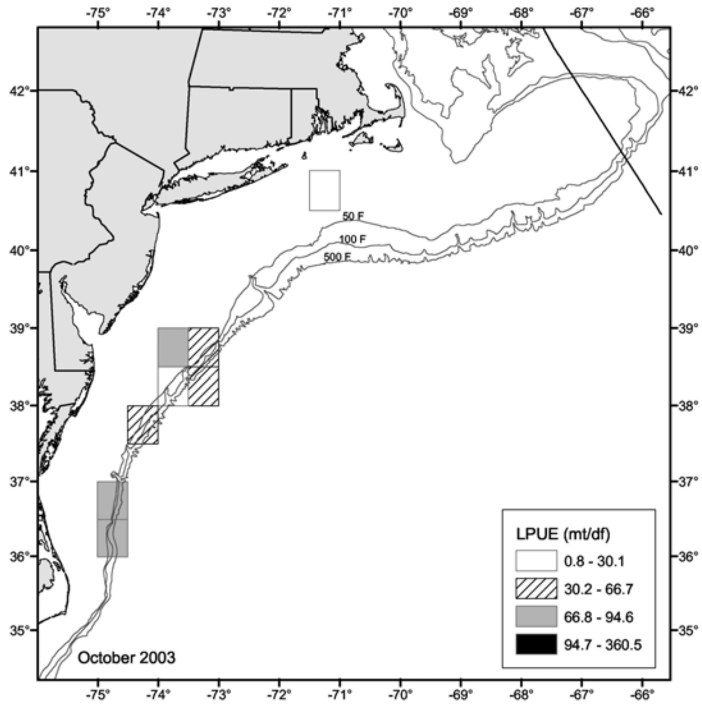

Figure C21. continued

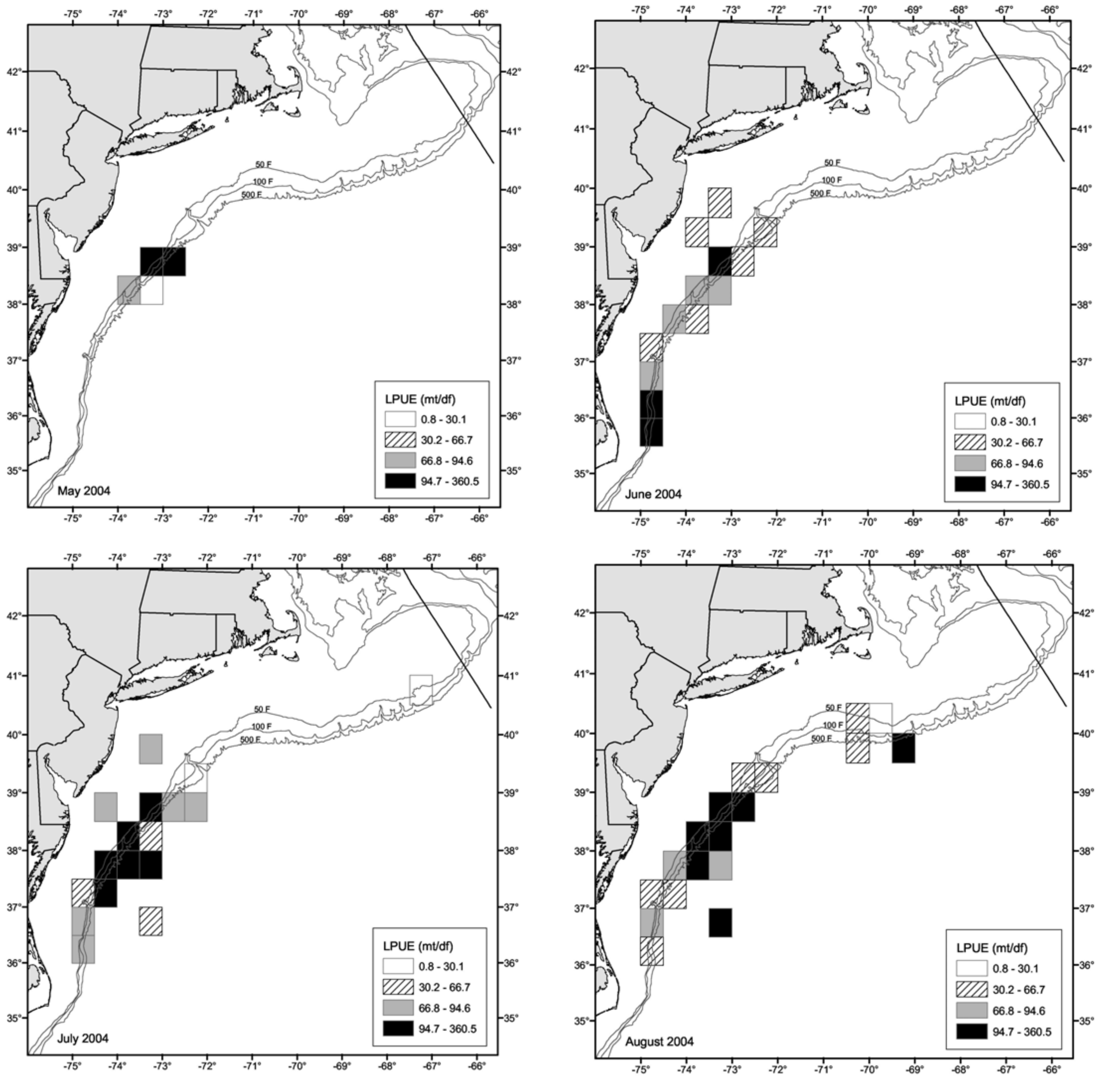

Figure C22. Monthly distribution of nominal landings per unit of effort (mt/days fished), by quarter-degree square, for bottom trawlers participating in the *Illex illecebrosus* fishery during May-September, 2004.

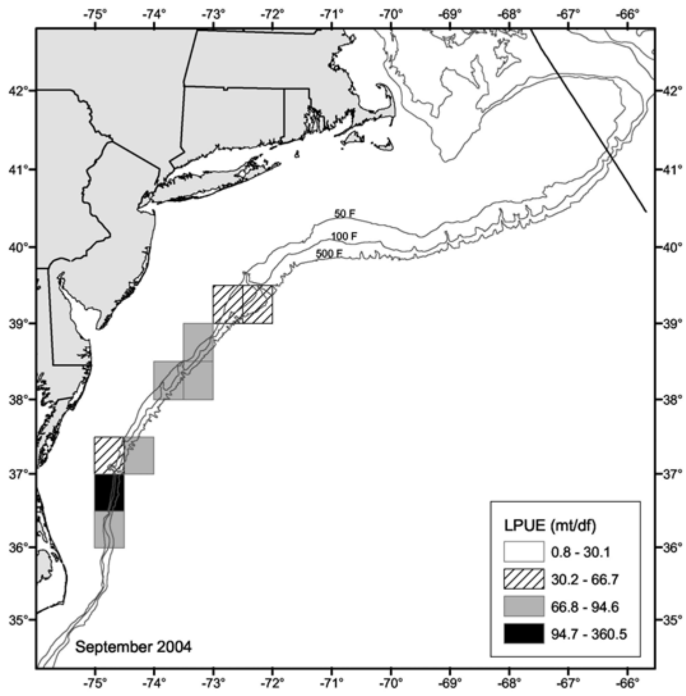

Figure C22. continued

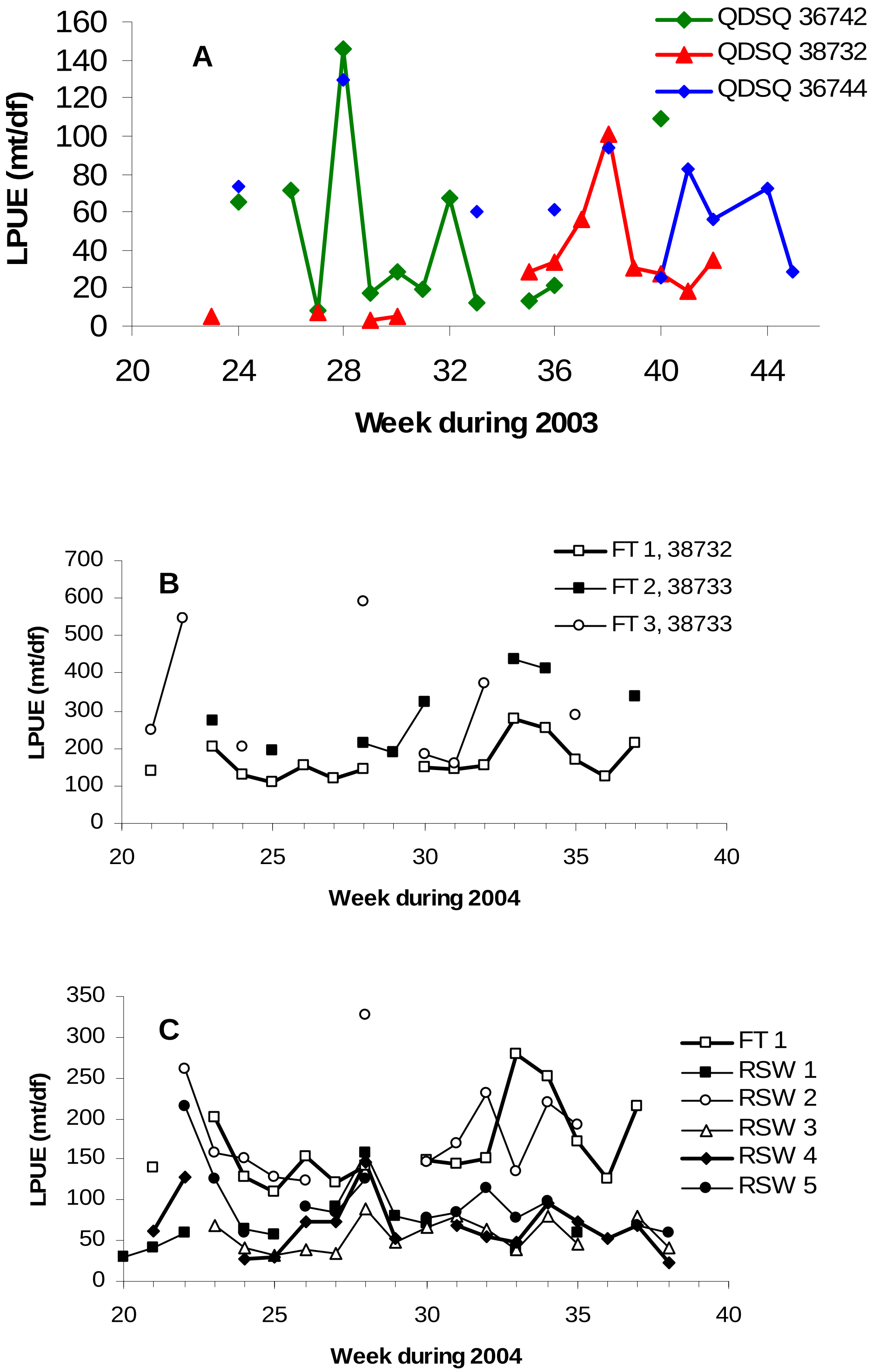

Figure C23. Example of (A) a sequential rise and fall pattern indicated by nominal LPUE for three quarter-degree squares fished by the *Illex* fleet during 2003 and examples of weekly fishing patterns (B) for freezer trawlers quarter-degree squares 38733 and 38732, and (C) for freezer trawlers versus RSW boats in square 38733 during 2004.

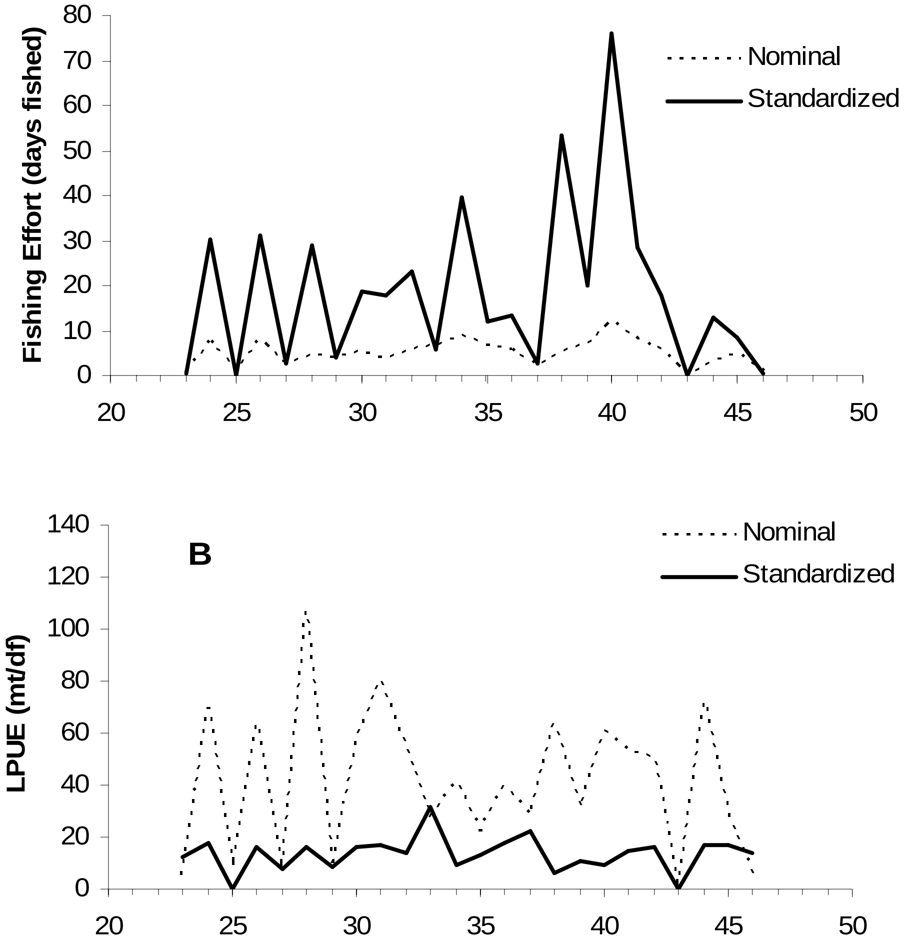

Figure C24. Weekly trends in nominal and standardized (A) fishing effort (df) based on Vessel Trip Report data and (B) LPUE (mt/df) computed from landings and effort data from the VTR Database for 2003.

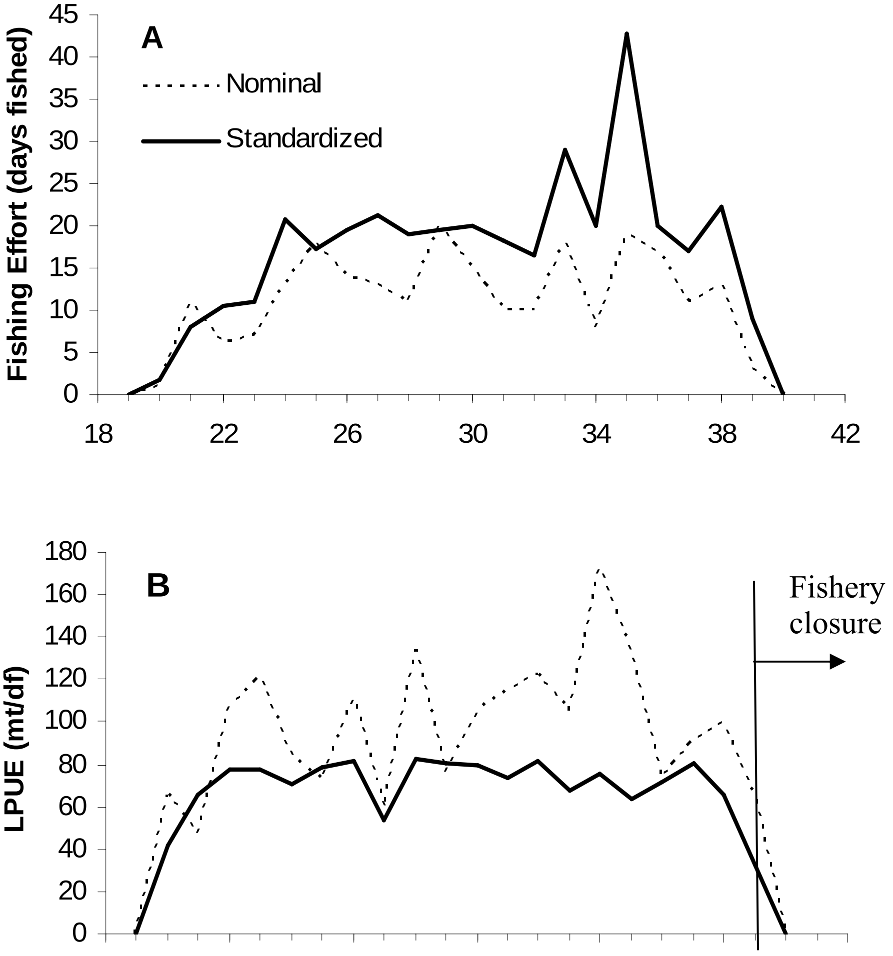

Figure C25. Weekly trends in nominal and standardized (A) fishing effort (df) based on Vessel Trip Report data and (B) LPUE (mt/df) computed from prorated landings from the Weighout Database and effort data from the VTR Database for 2004.

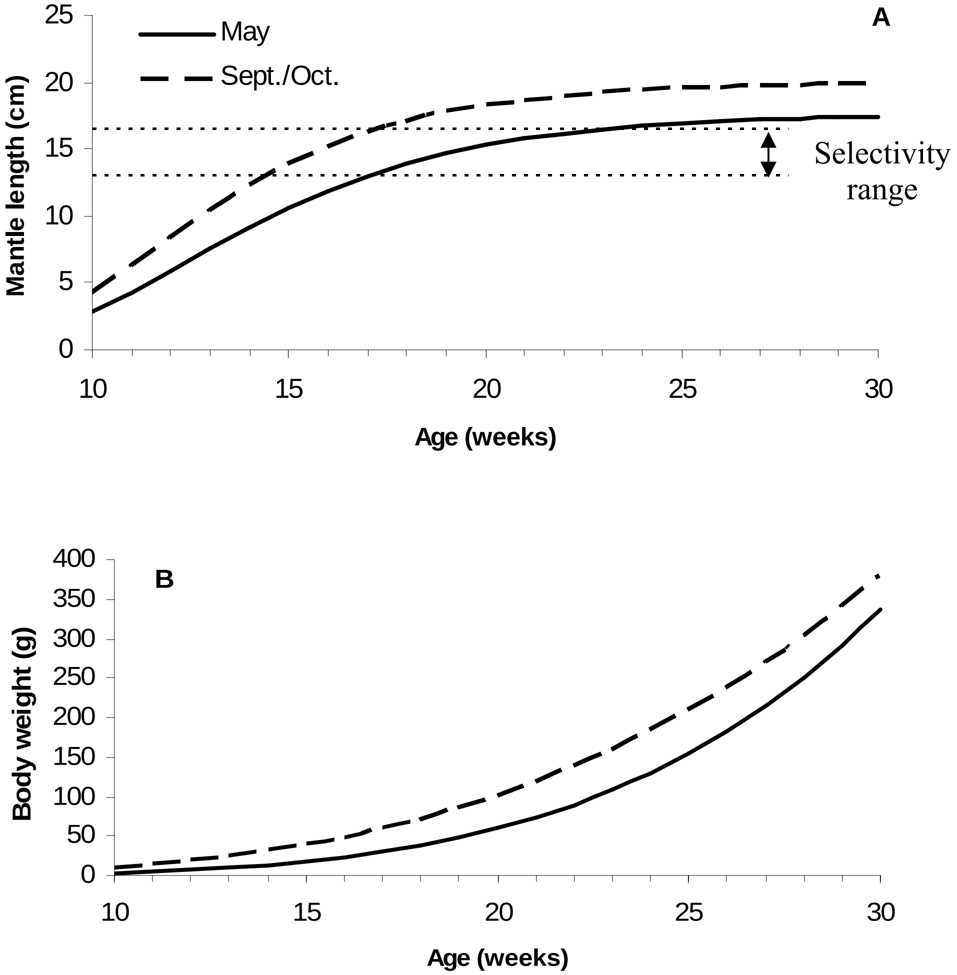

Figure C26 Growth rates of female *Illex illecebrosus* in May versus September/October, during 2000, in terms of (A) length and (B) body weight. The selectivity range shown represents the length range encompassing partial to full selectivity by the fishery and was derived by converting *Illex* lengths from the directed fishery, during 1999-2002, to ages using a weight-at-age relationship from a May 2000 *Illex* survey (Hendrickson 2004).

APPENDIX C1: Comments from external reviewer, Lynne Purchase (Renewable Resources Assessment Group, Imperial College London, England), 10/3/05 Working Group meeting

General Comments

The purpose of this workshop was to review data and methodology available for an assessment the *Illex illecebrosus* stock in advance of the future SARC 42 meeting. This document records my observations as an outside observer on the conduct, conclusions drawn and recommendations for future work made from this working group in order to finalise the assessment and supporting data at the next subcommittee stage. Whilst noting that the data from this fishery does not lend itself to the 'standard' squid assessment methodologies, what emerged from presentation and discussion between scientists and representatives of the industry at the working group meeting was a comprehensive, coherent and rigorous synthesis of both commercial and research data in order to summarise and report on current understanding of stock status within a precautionary approach to the fishery.

Specific comments - data characteristics of fishery

Stock distribution, its range, and environmental factors affecting both were clearly defined and presented. The performance pattern within the fishery is a result of the timing and extent of the feeding migration into shelf waters and subsequent spawning migration off the shelf into deeper waters. (A spawning site for the stock was found during the May 2000 survey on the continental shelf.)

The position of the US EEZ stock (NAFO subareas 5 and 6) as a component of a larger management unit encompassing NAFO subareas 3 to 6 was apparent from landings statistics summarised over the history of the fishery since 1963. It was noted that a closure had occurred in the 2004 fishery since the TAC (24,000mt) was reached and that in order to ensure continued sustainability of the stock, adequate spawner escapement from all fishery areas is required.

Length and weight of samples from landings appear to indicate and increasing trend since 2000 when it was noted that animals were smaller and weighed less than in earlier years. It would be beneficial to obtain corresponding information on maturity from these samples in order to ascertain the presence of more than one cohort in the fishery since it is known that recruitment occurs in most months. This could be facilitated either by the training of observers and/or provision of frozen samples to NEFSC for analysis.

Specific comments - assessment models

Assessment of this stock in the context of estimation of absolute stock biomass or fishing mortality rate has not been possible; this is because the DeLury depletion-'no recruitment' type model has proven inappropriate, given observed trends in LPUE within the data from the fisheries. The autumn bottom trawl surveys do not cover the entire habitat range for the stock and so survey indices are not representative, although they do indicate a relative index of spawner escapement. Accordingly, per-recruit models and supporting analyses have and continue to be developed in order to provide biological reference points in order to minimise recruitment overfishing and to ensure sufficient escapement. Key to this development are egg- and yield-per-recruit models in which non-spawning and spawning natural mortality is accounted for explicitly.

This represents a new approach compared to the assumption of constant natural mortality for animals of all ages adopted in most other cephalopod assessments in which fishing takes place on a spawning population. Whilst the ‘trigger’ for onset of spawning maturity remains largely unknown, this approach reflects the observation that within semelparous species, such as *Illex*, it is the older individuals that are most likely to become mature, to spawn and then die. Far from being constant, it is much more the case that natural mortality increases over the range of ages at which spawning occurs.

The age-based cohort model developed for estimating spawning mortality (maturation-mortality model) and application of these mortalities within per-recruit models (which are highly sensitive to assumptions about natural mortality) for *Illex illecobrosus* was presented comprehensively with detailed supporting analysis.

Whilst it was noted that this model has also been peer reviewed prior to publication, in the context of testing its overall robustness and general applicability, it is worth underlining the caveat that this model has been developed on the basis of age and maturity data from one survey (May, 2000). Analyses from other squid fisheries indicate that there is often significant intra- and interannual variation in growth and maturation rates. As indicated in the course of the workgroup meeting, the effect of this on the model needs further study and, in this context, it may be worth seeking out data
(*ie.,.*biological data in which age has been recorded in addition to the more usual sex, maturity, length and weight) from other, similar cephalopod fisheries. This would extend testing of this model in a cost-effective and timely manner.

The estimates of non- and spawning mortalities have been used within the ‘in-season’ model developed to estimate initial abundance and total fishing mortality from real-time data. Again, it appears that the use of growth and age data from the May survey is a major source of uncertainty in this method. It was noted that current simulation analyses of this ‘in-season’ stock assessment model should be extended to assess its performance and to highlight the need for any additional data.

A better understanding of trends in ‘in-season’ LPUE are important if LPUE is to be used in future monitoring of the fishery as an indicator of abundance of squid within a given fishing area. It was noted that GLM analysis undertaken to standardise effort data within the model required further development and investigation; problematic in this case was the differing behaviour of the two vessel types in terms of trip duration and attributing landings to specific dates; it is possible that repeating this analysis on a time-scale of two- rather than one week periods as main effects may improve the standardisation process in terms of smoothing the data. It is worth noting that effort data may not be smooth over time.

APPENDIX C2: Comments from SARC 42 Working Group meeting 2 (October 24-28, 2005)

The Working Group (WG) reviewed a comparison of the weekly *Illex* landings from the Dealer Weighout database versus the Vessel Trip Report (VTR) database for 1999-2004. During all years except 2004, the weekly landings reported in the VTR database were of similar magnitude. The WG discussed the discrepancy between the weekly landings reported in the two databases for 2004 and noted that one possible reason for the discrepancy is the increase in effort by RSW boats in 2004 in comparison to 2003. Reporting of the kept fraction of the catch by RSW captains is likely to be less accurate, because unlike freezer boats, catches are not boxed and weighed at sea. However, it was unknown whether underreporting in 2004 was greater for RSW vessels than freezer trawlers and the number of vessels from both fleet sectors increased between 2003 and 2004.

The WG noted that fewer vessels were involved in the 2003 fishery and suggested a comparison of VTR landings by vessel during 2003 and 2004 to determine whether underreporting in 2004 was due in part to a change in behavior of captains who reported accurately in 2003 or due to the addition of RSW vessels with poorer reporting accuracy.

The WG noted the possibility that part of the 2004 end-of-season decline in the number of trips after week 34 was due to a temporary shut down at one of the main *Illex* processing plants, Lund's Fisheries, for maintenance.

The WG discussed the trends in the percentage of survey tows in which *Illex* was caught with respect to whether increases in relative abundance were associated with increases in dispersion indices. The WG noted the importance of distinguishing between changes in geographic distribution that may affect the number of positive tows and changes in abundance that would also influence the number of positive tows particularly given that the NEFSC surveys only cover a portion of *Illex* habitat.

The WG noted that R^2 value from the General Linear Models (GLM) were relatively high in comparison to GLM runs for groundfish fleets. It was suggested that a histogram or other plot of the catch rate data would be useful to judge how well the *Illex* fishery data conform to the GLM model assumption of log-normality.

The WG noted that some of the weekly and bi-weekly variability in nominal landings per unit effort (LPUE) was due to the duration of freezer trawler trips which tend to be of one to two weeks in duration with trip departure and return days that consistently occur on similar days of the week (e.g., Monday and Saturday). A suggestion was made to evaluate the use of a running average of LPUE to minimize the week-to-week noise, especially in 2003, when the catch was dominated by freezer trawlers who employ this fishing strategy.

The Working Group was concerned that the underreporting of landings in the 2004 VTR reports affect might affect the LPUE estimates for 2004 and suggested the use of the 'week' coefficients from the GLM to back-calculate standardized model effort.

Several models were improved and carried forward from the last assessment. These models showed improvement over the last assessment but issues of data availability and model formulation still remain. The WG agreed that continued development of the models presented is important because the approaches being used appear to be valid for this semelparous species.

The WG expressed concern about the representativeness of the maturity ogive given that it was derived from data collected in May and therefore may not describe maturity trends throughout the course of the entire fishing season The WG recommended collecting in-season age and maturity data to assess how changes in growth, maturity and recruitment t influence model output.

The WG noted that the in-season assessment model has a basic assumption that maturity is age-dependent and that selectivity is length-dependent and expressed concern about whether the age- and length-based assumptions were compatible.

The WG noted that selectivity is complicated, particularly during the latter part of the fishing season due to emigration of large females to spawn, recruitment, cannibalism, and possible increases in growth rates. This might result in a dome-shaped selectivity curve at that time. The WG noted that the late-season decline in squid size/weight has a number of competing explanations that may influence the model differentially depending on, for example, the relative importance of off-shelf migration versus spawning mortality.

The WG discussed the possibility that the in-season model may not be formulated correctly for recruitment during the fishing season and suggested that alternative methods of quantifying recruitment be examined. For example, the model could be allowed to estimate recruitment by subtracting M plus F from the initial stock size and assuming that F equals zero.

APPENDIX C3: Maturation-Natural Mortality Model

See Hendrickson and Hart (*2006*).

APPENDIX C4: Per-recruit Models

See Hendrickson and Hart (*2006*).

APPENDIX C5: In-season Assessment Model

In-season assessment model formulation and input data

An in-season stock assessment model that was reviewed at SARC 37 was deemed preliminary and subject to further testing. Additional testing of a revised version of the SARC 37 model was conducted during the current assessment using input data for 2003 and 2004 in addition to output data from simulation analyses. The model revision involved a change to the objective function as described below.

The model was designed to estimate weekly stock size and fishing mortality rates of the *Illex* population (in numbers) on the U.S. shelf according to the equation:

$$N_{t+1} = N_t \exp(-Z) + r_t \exp(-M_{NS}),$$

where N_t is the population numbers in week t, Z is total mortality, r_t is recruitment to the exploitable size classes in week t, and M_{NS} is natural mortality due to causes other than spawning (e.g., predation). The predicted catch $\hat{C}_t$ (in numbers) in week t was calculated using the catch equation:

$$\hat{C}_{t+1} = N_t F_t \, [1\text{-}\exp(-Z)]/Z$$

The weekly fishing mortality rate, $F_{t,}$ was calculated as:

$$F_t = qS_tE_t$$

where S_t represents the proportion of N_t that is selected by the fishery, E_t is the estimated effort in week t, and q is a constant. Weekly effort (days fished) was computed as the sum of the product of the average tow duration and the number of tows conducted per trip based on data reported by fishermen in the Vessel Trip Report database. Effort was assumed to be proportional to fishing mortality and was standardized according to the methods described in the above section on fishery LPUE. The aggregated length composition from the landings was used in the calculations presented above.

Individual squid lengths were used for the following purposes:

(a) to calculate the selectivity function S_t (Fig. C5.1) via the equation:

$$S_t = \frac{\sum_L s_L n_{L,t}}{\sum_L n_{L,t}}$$

where s_L is the estimated selectivity of the length group L, and $n_{L,t}$ is the number of squid of length group L in week t;

(b) to estimate recruitment, which was done by applying the May 2000 growth rate for combined sexes (Hendrickson 2004) to the numbers of 13-cm squid observed in the landings (the smallest size retained by the fishery) to estimate one week of growth for these individuals. Thereafter, these lengths were divided by the proportion selected by the fishing gear.

(c) and to estimate natural mortality, where the number, $n_{a,t}$, at each age group a and week t was back-calculated from the length composition using the May 2000 growth rate for combined sexes (Hendrickson 2004). Total natural mortality, m_a (both spawning and non-spawning mortality), for each age group (in weeks) was estimated from the maturation-natural mortality model. Total natural mortality was computed as:

$$M_t = \frac{\sum_a m_a n_{a,t}}{\sum_a n_{a,t}}$$

The Gompertz growth curve used in the calculation of equations (b) and (c) above was computed from data collected during a pre-fishery *Illex* survey conducted in May 2000. However, since *Illex* grow larger as the season progresses, the asymptotic size of the May growth curve was exceeded. Nearly all of the squid caught during the last few weeks of the season consisted of lengths that exceeded the estimated maximum length observed in May. In order to address the seasonal growth issue, the maximum (asymptotic) mantle length, *a*, from the May growth curve was adjusted upward each week and estimated as the 95th percentile of the length-frequency distribution of the weekly landings.

The model estimates the initial abundance, N_0, and total fishing mortality, F_{TOT}. F_{TOT} is the sum of the weekly fishing mortality rates of fully-recruited squid for the entire fishing season and was computed as:

$$F_{TOT} = \sum_t qE_t$$

The SARC 37 version of the model estimated the values of these two quantities by minimizing a chi-square statistic:

$$\chi^2 = \sum_t (C_t - \hat{C}_t)^2 / \hat{C}_t$$

subject to the constraint

$$\sum_t C_t = \sum_t \hat{C}_t$$

where C_t is the observed catch in week t.

The revised version of the model allows for the possibility of fitting one of the maturity ogive parameters, α, together with F_{TOT} and N_0. Because there may be prior information regarding these parameters (in particular, α), and because there may be insufficient information to freely fit all three parameters simultaneously, penalty terms were added to allow for deviations from the originally estimated values, so that the new objective function is:

$$\sum_t (C_t - \hat{C}_t)^2 / \hat{C}_t + k_1 (N_0 - \hat{N}_0)^2 + k_2 (F_0 - \hat{F}_0)^2 + k_3 (\alpha - \hat{\alpha})^2 + k_4 [\sum_t C_t - \sum_t \hat{C}_t]^2$$

where N_0, F_0, and α are the prior estimates of these parameters, with posterior estimates denoted by circumflexes, and the k_i terms are weightings reflective of the confidence in these values.

In-season model results

Model runs using the 2003 data indicated that the results were sensitive to varying the initial guesses of $\mathrm{N_0}$ and $\mathrm{F_{TOT}}$. The results also indicated that a broad range of $\mathrm{N_0}$ and $\mathrm{F_{TOT}}$ values were plausible because the χ^2 statistic was relatively flat over large portions of parameter space. Thus, there is considerable model uncertainty regarding the exact values of these parameters. The model fits were poor for both 2003 and 2004 and are not presented herein.

Simulation model formulation and input data

A simulation model was developed to output simulated data sets to test and calibrate the in-season assessment model. The simulation model works similarly to the per-recruit model that takes into account maturity and spawning mortality, but the simulation model also includes a term for recruitment and is a discrete (weekly) model structured by age and maturity status.

The dynamics of non-mature squid [$N_{\mathrm{t}}(a)$] and mature squid [$S_{\mathrm{t}}(a)$] at week t and age a (in weeks) is (excluding the plus age group):

$$N_{\mathrm{t+1}}(a+1) = N_{\mathrm{t}}(a)\exp(-M_{\mathrm{ns}}-F_{\mathrm{t}}(a)-R(a)) + r_{\mathrm{t}}$$

$$S_{t+1}(a+1) = S_t(a)\exp(-M_{ns}-M_{sp}-F_t(a)) \\ + N_t(a)R(a)[(1-\exp(-M_{ns}-F_n-R(a)))/(M_{ns}+F+R(a))][(1-\exp(-M_{ns} - M_{sp}))/(M_{sp}+M_{ns})]$$

where r_t is recruitment in week t, F_t(a) is fishing mortality in week t on the age a squid, and M_{ns} and M_{sp} are the non-spawning and spawning natural mortality rates, and R is the maturation rate. For the plus group (age a_p),

$$N_{t+1}(a_p) = N_t(a_{p-1}) \exp(-M_{ns}-F_t(a_{p-1})-R(a_{p-1}))+ N_t(a_p)\exp(-M_{ns}-F_t(a_p)-R(a_p)) + r_t$$

$$S_{t+1}(a_p) = S_t(a_p)\exp(-M_{ns}-M_{sp}-F_t(a_p) + S_t(a_{p-1})\exp(-M_{ns}-M_{sp}-F_t(\mathrm{a}_{p-1}) \\ + N_t(a_p)R(a_p)[(1-\exp(-M_{ns}-F_t(a_p)-R(a_p))/(M_{ns}+F(a_p)+R(a_p))][(1-\exp(-M_{ns} - M_{sp}))/(M_{sp}+M_{ns})] + \\ N_t(a_{p-1})R(a_{p-1})[(1-\exp(-M_{ns}- F_t(a_{p-1})-R(a_{p-1}))/(M_{ns}+F(\mathrm{a}_{p-1})+R(\mathrm{a}_{p-1}))][(1-\exp(-M_{ns} - M_{sp})/(M_{sp}+M_{ns})]$$

Non-spawning and spawning natural mortality parameters were taken from the maturity-natural mortality model (Hendrickson and Hart, 2006) and set to $M_{ns} = 0.06$ and $M_{sp} = 0.55$ for all model runs. Fishing mortality varies by age and the same selectivity-at-age ogive used in the per-recruit models was applied in the simulation models. Landings (in numbers) C_t were calculated from the catch equation:

$$C_t\,(a) = \Sigma_a\ \{N_t(a)F_t(a)[1-\exp(-M_{ns}-F_t(a)]/\ [M_{ns}+F_t(a)] + \\ S_t(a)F_t(a)[1-\exp(-M_{ns}- M_{sp}\ -\underline{F}_t(a))]/\ [M_{ns} + M_{sp}+F_t(a)]\}$$

Catches in numbers were converted to weights using a weight-at-age relationship, for combined sexes, from the May 2000 *Illex* survey (Hendrickson 2004):

$$W(a) = \varepsilon a^{\phi},\ 1.12\mathrm{x}10^{-6},\ \phi = 3.6.$$

Simulation model runs were conducted for a fishing season of 19 weeks at various levels of constant fishing mortality, various trends in fishing mortality (increasing, decreasing, and increasing then decreasing), various levels of recruitment, and with observation noise for all variables set to 10%. With the exception of model runs 10 and 11, recruitment was assumed to be constant except for a pulse of recruits which assumed to be twice as large in weeks 7-9 as during other weeks. The outputs from the simulation model were input into the in-season assessment model to evaluate the ability of the in-season model to recover the fishing mortality and N_0 estimates from the simulations.

Simulation model results

In most cases, the in-season model was able to find excellent fits to the data. As often is the case with forward-projecting models, the estimated values of F_{TOT} and N_0 were often estimated with some error, though the product of these two quantities was typically estimated close to the simulated values (Table C5.1). Allowing the in-season model to estimate the maturity parameter with a Bayesian penalty function did not consistently improve the estimates, possibly because the model was already achieving a good fit to the simulated data. Adding noise to the simulated data only mildly worsened the ability of the in-season model to recover the original parameter estimates.

It can be concluded that if the biological and fishing processes are being modeled correctly, the in-season model can usually estimate total fishing mortality and initial abundance to within 50%, and the product of these two quantities is more accurately estimated than either of them individually.

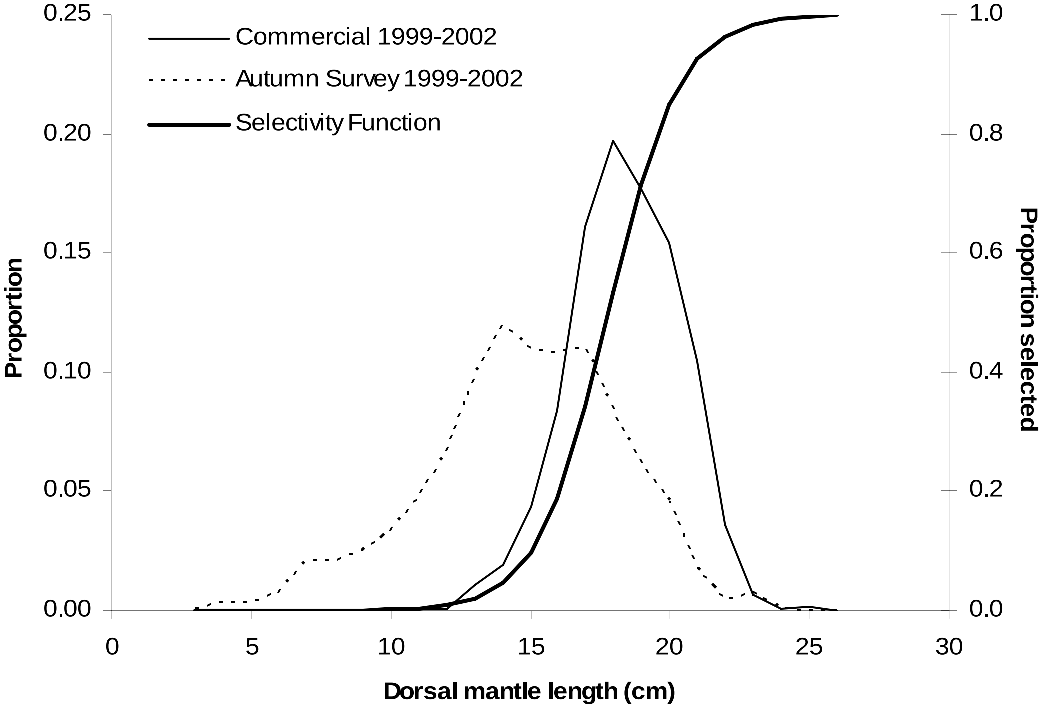

Figure C5.1. Composite length compositions, for 1999-2002, of *Illex illecebrosus* from the NEFSC autumn bottom trawl surveys (strata 1-12 and 61-76) and directed fishery landings.

Length samples from the two sources were subset to include data from similar time periods and geographic areas during each year to derive the selectivity curve shown.

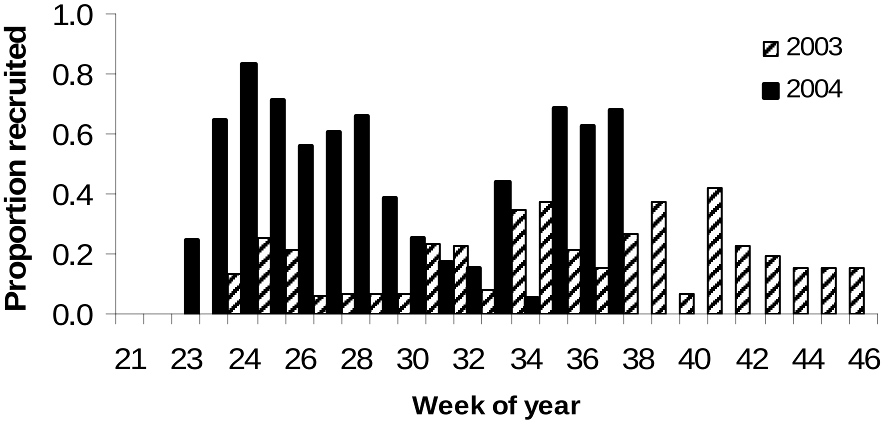

Figure C5.2. Proportion of *Illex illecebrosus* recruitment, by week, during 2003 and 2004.

Table C5.1. Results of simulation model runs under various input scenarios that included maturity ogive parameters of $\alpha = -7.93$ and $\beta = 0.0435$ (Hendrickson, 2004). F_{TOT} is the fishing mortality rate for fully-recruited squid over the entire fishing season.

Model Run	**Scenario**	**Alpha Maturity Parameter**	**Penalty**	**F_{TOT}**	**Estimated** F_{TOT}	**Estimated** N_0	χ^2	**% Error** F	**% Error** N_0	**% Error** $F*N_0$
1	Constant F	Baseline		0.95	2.53	95,428	45	166.3	61.8	1.7
	N0 = 250 mill.	alpha = -7.95	10	0.95	2.58	93,510	45	171.6	62.6	1.6
2	Constant F	Baseline		1.9	2.49	192,393	89	31.1	23.0	0.9
	N0 = 250 mill.	alpha = -8.056	10	1.9	2.88	166,668	88	51.6	33.3	1.1
3	Constant F	Baseline		3.8	4.33	219,018	178	13.9	12.4	0.2
	N0 = 250 mill.	alpha = -8.03	10	3.8	4.62	205,320	178	21.6	17.9	0.1
4	Constant F	Baseline		5.7	5.52	254,412	262	3.2	1.8	1.4
	N0 = 250 mill.	alpha = -8.09	10	5.7	5.97	235,641	261	4.7	5.7	1.3
5	Constant F	Baseline		11.4	7.92	290,473	402	30.5	16.2	19.3
	N0 = 250 mill.	alpha = -8.67	10	11.4	8.67	256,606	399	23.9	2.6	21.9
6	Constant F	Baseline-Run1		3.8	5.54	166,142	70512	45.8	33.5	3.1
	with noise	Baseline-Run2		3.8	4.59	279,201	121739	20.8	11.7	34.9
	N0 = 250 mill.	Baseline-Run3		3.8	2.71	346,602	63375	28.7	38.6	1.1
		Mean		3.8	4.28	263,982	85209	31.8	28.0	13.0
7	Two-way ramp	Baseline		5.7	5.40	244,486	649	5.3	2.2	7.4
	N0 = 250 mill.	alpha = -6.99	10	5.7	2.22	685,485	357	61.1	174.2	6.8
8	Ramp up	Baseline		5.7	5.17	213,293	502	9.3	14.7	22.6
	N0 = 250 mill.	alpha = -7.25	10	5.7	2.90	451,533	164	49.1	80.6	8.1
9	Ramp down	Baseline		5.7	5.43	285,165	294	4.7	14.1	8.7
	N0 = 250 mill.	alpha = -7.84	10	5.7	5.17	297,526	290	9.3	19.0	7.9
10	Constant F	Baseline		5.7	7.05	190,362	347	23.7	23.9	5.8
	Low recruits	alpha = -8.89	10	5.7	8.99	150,206	304	57.7	39.9	5.2
11	Constant F	Baseline		5.7	4.55	448,721	3093	20.2	79.5	43.3
	High recruits	alpha = -10.55	10	5.7	7.86	252,476	2607	37.9	1.0	39.3