Northeast Fisheries Science Center Reference Document 96-05g

A Report of the 21st Northeast Regional Stock Assessment Workshop

Stock Assessment of Northern Shortfin Squid in the Northwest Atlantic during 1993

by

L.C. Hendrickson, J. Brodziak, M. Basson, and P. Rago

National Marine Fisheries Serv., Woods Hole, MA 02543

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

August 1996

The *Northeast Fisheries Science Center Reference Document* series comprises informal reports produced by the Center for timely transmission of results obtained through work at various Center laboratories. The reports are reviewed internally before publication, but are not considered formal literature. The National Marine Fisheries Service does not endorse any proprietary material, process, or product mentioned in these reports. To obtain additional copies of this report, contact: Research Communications Unit, Northeast Fisheries Science Center, Woods Hole, MA 02543-1026 (508-548-5123 x 260).

This report may be cited as: Hendrickson, L.C.; Brodziak, J.; Basson, M.; Rago, P. 1996. Stock assessment of northern shortfin squid in the Northwest Atlantic during 1993. *Northeast Fish. Sci. Cent. Ref. Doc.* 96-05g; 63 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

This report is a product of the 21st Northeast Regional Stock Assessment Workshop (21st SAW). Proceedings and products of the 21st SAW are scheduled to be documented and released as subissues (denoted by a lower case letter) of *Northeast Fisheries Science Center Reference Document* 96-05 (*e.g.*, 96-05a) . Tentative titles for the 21st SAW are:

An index-based assessment of winter flounder populations in the Gulf of Maine

Assessment of winter flounder in Southern New England and the Mid-Atlantic

Influence of temperature and depth on distribution and catches of yellowtail flounder, Atlantic cod, and haddock in NEFSC bottom trawl surveys

Predicting spawning stock biomass for Georges Bank and Gulf of Maine Atlantic cod stocks with research vessel survey data

Preliminary results of a spatial analysis of haddock distribution applying a generalized additive model

Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW): Public Review Workshop

Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments

Stock assessment of northern shortfin squid in the Northwest Atlantic during 1993

The Lorenz curve method applied to NEFSC bottom trawl survey data

TABLE OF CONTENTS

List of Figures iv
List of Tables v
Abstract vii

Introduction 1

Stock Structure 1

Management 1

The Fishery 2
- Landings and Discards 2
- Length Frequency Sampling 3
- Catch in Numbers 3

Stock Abundance and Biomass Indices 4
- Commercial Catch Rates 4
- Research Vessel Survey Indices 5

Stock Distribution 8

Life History Parameters 9
- Growth 9
- Natural Mortality 9
- Sexual Maturity 9

Estimation of Stock Size and Fishing Mortality Rates 10
- Stock Size Estimates 10
- Fishing Mortality Estimates 11

Biological Reference Points 12
- Yield and Spawning Stock Biomass per Recruit 12

Long-Term Potential Yield 13

Real-Time Management 15
- Example of Falkland Islands *Illex* Fishery 15
- Plan Considerations for U.S. EEZ *Illex* Fishery 17

Summary and Conclusions 22

References 25

LIST OF FIGURES

Figure 1. Proportion of tows, by region, in which *Illex illecebrosus* were caught during NEFSC autumn bottom trawl surveys, 1967-1994.

Figure 2. Trends in *Illex* squid landings from (A) the U.S. EEZ, NAFO Subareas 2-4 (1973-1993), and all areas combined and (B) U.S., foreign, and total U.S. EEZ landings during 1963-1993.

Figure 3. U.S. commercial statistical areas used to report landings in the northwest Atlantic.

Figure 4. Trends in (A) standardized effort (days fished) and (B) standardized and nominal LPUE (mt/day fished), during 1982-1993, for vessels with landings of *Illex* squid that exceeded 25% of their total trip weight.

Figure 5. Landings per unit of effort (mt landed per day fished) of *Illex illecebrosus* for the domestic bottom trawl fishery during 1982-1993.

Figure 6. Northwest Atlantic offshore strata sampled during NEFSC bottom trawl surveys.

Figure 7. Standardized, stratified mean number per tow (A) and mean weight per tow (kg) (B) of *Illex illecebrosus* in NEFSC research vessel bottom trawl surveys during autumn (1967-1994) and spring (1968-1995).

Figure 8. Mean number per tow of *Illex illecebrosus* pre-recruits ($\leq$ 10 cm), by survey stratum, during NEFSC research vessel bottom trawl surveys.

Figure 9. Mean number per tow of *Illex illecebrosus* recruits ($\geq$ 11 cm), by survey stratum, during NEFSC research vessel bottom trawl surveys.

Figure10. Observed and predicted weight-at-age (top) and length-at-age (bottom), for *Illex illecebrosus.*

Figure11. Median fishing mortality rates for the U.S. EEZ *Illex* fishery with interquartile ranges derived from bootstrap estimation (A), median initial biomass estimates with interquartile ranges (B), and annual catch vs. estimated median annual production (C).

Figure12. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for *Illex illecebrosus.*

Figure13. Distribution of long-term potential yields expected from the U.S. EEZ *Illex illecebrosus* fishery for the target ($F_{50\%}$) and threshold ($F_{20\%}$) fishing mortality rates.

FigureB1. Trends in nominal LPUE (numbers per day fished) for tonnage class 4 vessels, in the U.S. EEZ *Illex* squid fishery, during May - November, 1982-1993.

FigureB2. Comparison of average biomass estimates (solid circles), of *Illex illecebrosus* during the fishing season, and peak to end-of-season biomass estimates (triangles) resulting from the Leslie-DeLury model with biomass estimates (open circles) from the Hilborn-Walters model (annual, standardized LPUE indices divided by catchability coefficient (q), during 1982-1993.

FigureC1. NEFSC autumn research survey biomass indices (mean kg/tow) of *Illex illecebrosus,* in year t+1 (1968-1994, labelled in figure), plotted against the same indices in year t (1967-1993). Medians are represented by solid lines and upper and lower quartiles are represented by dotted lines.

FigureD1. Monthly LPUE (mt/day fished), for tonnage class 4 vessels involved in the U.S. EEZ *Illex* squid fishery, plotted against autumn research survey biomass indices (kg/tow) in the same year during May (5), June (6) and July (7), 1982-1993.

LIST OF TABLES

Table 1. Northern shortfin squid (*Illex illecebrosus*) landings (mt) from Cape Hatteras to the Gulf of Maine, during 1963-1994, and from NAFO Subareas 2, 3 and 4 during 1973-1993.

Table 2. U.S. EEZ landings (mt) of *Illex* squid, during 1993, by 3-digit statistical area and month.

Table 3. Length-frequency sampling intensity of *Illex* squid landed in the U.S. EEZ during 1982-1993.

Table 4. Total numbers (millions) of *Illex illecebrosus* landed, from Cape Hatteras to the Gulf of Maine, during 1982-1993.

Table 5. General Linear Model analysis of LPUE for trips targeting *Illex* squid in the U.S. EEZ during 1982-1993.

Table 6. Standardized fishing effort and LPUE for *Illex* squid landed in the U.S. EEZ, between Cape Hatteras and the Gulf of Maine, during 1982-1993.

Table 7. All sizes, pre-recruit (≤ 10 cm), and recruit (≥ 11 cm) standardized, stratified mean catch per tow, in numbers and weight (kg), of *Illex illecebrosus* from NEFSC autumn research vessel bottom trawl surveys (offshore strata 1-40 and 61-76, Cape Hatteras to the Gulf of Maine) during 1967-1994.

Table 8. All sizes, pre-recruit (≤ 10 cm), and recruit (≥ 11 cm) standardized, stratified mean catch per tow, in numbers and weight (kg), of *Illex illecebrosus* from NEFSC spring research vessel bottom trawl surveys (offshore strata 1-40 and 61-76, Cape Hatteras to the Gulf of Maine) during 1968-1995.

Table 9. Surplus production model results for the *Illex* squid fishery in the U.S. EEZ during 1982-1993.

Table 10. Yield and spawning stock biomass per recruit estimates for *Illex illecebrosus* landed in the U.S. EEZ.

Table B1. Preliminary results from a Leslie-Delury model applied to monthly LPUE (numbers/day fished) for tonnage class 4 vessels, in the U.S. EEZ *Illex illecebrosus* fishery, during 1982-1993.

ABSTRACT

The status of the northern shortfin squid (*Illex illecebrosus*) stock in the northwest Atlantic, during 1982-1993, is assessed and new life history information is used to compute estimates of fishing mortality, stock biomass and spawning stock biomass. An overfishing definition which is more appropriate for this annual species is recommended. A spawning stock biomass threshold of $F_{20\%}$ (0.28 per month) is proposed, given the flat-topped nature of the yield-per-recruit curve, with a target fishing mortality rate of $F_{50\%}$ (0.11 per month).

During 1973-1981, total NAFO landings from Cape Hatteras to Newfoundland were predominately from NAFO Subareas 2-4 and averaged 75,400 mt. Following a 1979 peak in landings from these Subareas, of 162,100 mt, the foreign fishery collapsed and recruitment has since remained poor. Total NAFO landings have been dominated by the domestic fishery since 1983 and there has been no foreign participation in the U.S. EEZ fishery since 1987. During 1982-1993, total landings averaged only 14,500 mt, of which U.S. EEZ landings comprised 75%. Since 1988, domestic landings have been increasing annually and reached a record high of 18,000 mt (87% of total NAFO landings) in 1993.

The U.S. EEZ portion of this transboundary stock is fully-exploited and probably at a medium level of biomass. Since 1988, standardized fishing effort has been increasing while landings per unit of standardized effort (LPUE) have generally been decreasing. Standardized LPUE indices were used as a relative abundance index in a surplus production model to estimate annual fishing mortality rates, initial and average stock biomass, and MSY. Fishing mortality rates have been increasing since 1988, reaching 0.12 per month in 1993. During 1992, the fishing mortality rate was equal to the proposed $F_{50\%}$ target of 0.11 and was just above it in 1993. The probability that F_{93} exceeded $F_{50\%}$ was 0.54.

The allowable biological catch (ABC), established by the Mid-Atlantic Fishery Management Council, was 30,000 mt during 1993-1996. During this time, the domestic annual harvest (DAH) was also 30,000 mt, but was reduced to 21,000 mt in 1996. Median long-term potential yields of 14,579 mt and 21,325 mt, for the target ($F_{50\%}$) and threshold ($F_{20\%}$) fishing mortality rates, respectively, were computed from the model bootstrap estimates of *r*, *q* and *K*. Average landings during 1988-1993 (11,305 mt) were below the target median yield. However, average landings during 1992-1994 (18,063 mt) exceeded this target but lie within the predicted interquartile yield range for $F_{50\%}$. These LTPY estimates are consistent with recent resource productivity, but could vary depending on the favorability of environmental conditions for recruitment and growth.

Implementation of a real-time management plan is recommended for this annual species and the general components of such a plan are presented for the U.S. EEZ *Illex illecebrosus* fishery. Weekly or biweekly monitoring of fishery landings and effort data, would allow estimations of stock size during the fishing season. In-season adjustments of catch or effort could be implemented to preserve adequate levels of spawning stock biomass, to avoid overfishing during periods of poor recruitment, and to increase landings during periods of good recruitment.

INTRODUCTION

This report represents a revised analytical assessment of the northern shortfin squid *(Illex illecebrosus)* stock in the northwest Atlantic during 1982-1993, based on analyses of statolith ageing, commercial fishery data and research survey data. New and updated information and analyses are provided from those presented in the 1992 assessment (NEFSC 1994, Brodziak and Hendrickson (1996)).

STOCK STRUCTURE

The shortfin squid is a highly-migratory ommastrephid that tends to school by sex and size and lives for up to one year (Dawe *et al.* 1985, Dawe and Beck 1992, O'Dor and Dawe *In Press*). The *Illex* population is assumed to constitute a unit stock throughout its range of commercial exploitation from Cape Hatteras to Newfoundland. Coelho and O'Dor (1993) found that determination of *Illex* stock structure may be complicated by the overlap of seasonal cohorts. They found that mean size at sexual maturity varied between northern and southern geographic regions in some years. However, it was unknown whether these differences were due to inherent population structure. O'Dor and Coelho (1993) speculated that changes in the seasonal breeding patterns of the *Illex* population could have played a role in the collapse of the Canadian fishery during the early 1980's (Table 1). Regardless of this speculation, the proportion of tows capturing *Illex*, during the 1967-1994 Northeast Fisheries Science Center (NEFSC) autumn surveys (Figure 1), showed a synchronous pattern of changes in relative abundance across broad geographic regions within the U.S. EEZ. Further, all six possible pairings of the regional proportion of tows capturing *Illex* were significantly positively correlated at the α=0.01 significance level. These significant associations suggested that *Illex* recruitment from Cape Hatteras to the Gulf of Maine was affected by similar processes, as expected under the hypothesis of a unit stock.

MANAGEMENT

A commercial fishery for *Illex illecebrosus* occurs from Newfoundland to Cape Hatteras. The fishery is managed in the U.S. EEZ (NAFO Subareas 5 and 6) by the Mid-Atlantic Fishery Management Council (MAFMC) and by the Northwest Atlantic Fisheries Organization (NAFO) in NAFO Subareas 2, 3 and 4. Since 1980, the annual total allowable catch (TAC) established by NAFO for Subareas 2-4 has been 150,000 mt (NAFO 1995). 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 (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 has been decreased to 21,000 mt for 1996 (MAFMC 1995a). In recognition that the domestic resource is rapidly approaching full utilization and that expansion of the U.S. fleet may lead to overcapitalization, Amendment 5 (MAFMC 1995b) to this FMP was developed and recently submitted for NMFS Secretarial approval. If adopted, Amendment 5 would limit entry into the directed fishery, establish trip limits for non-moratorium vessels, and require mandatory logbook reporting by all permitted vessels in the *Illex* fishery.

THE FISHERY

Landings and Discards

Domestic and foreign landings (mt) of *Illex*, during 1963-1994 (Table 1), were collected from various sources. U.S. EEZ landings for 1963-1988 were taken from the Report of the Spring 1990 NEFC Stock Assessment Workshop (NEFC 1990) and landings for 1989-1994 were taken from the NEFSC commercial fisheries weighout database. Landings from NAFO Subareas 2, 3, and 4, during 1973-1993, were taken from NAFO Scientific Council Summary reports (NAFO 1986, 1994a and 1994b). Landings for 1994 were reported by E. Dawe, Department of Fisheries and Oceans, Newfoundland (pers. comm. 1996). There were no known recreational landings of *Illex* squid.

The magnitude and spatial pattern of *Illex* landings varied considerably during 1963-1993. During 1973-1981, total landings averaged 75,376 mt and were predominately (74%) taken from NAFO Subareas 2, 3 and 4 (Figure 2A). Following a 1979 peak in landings from these Subareas, of 162,092 mt, this fishery collapsed. During 1982-1993, total landings averaged only 14,481 mt and landings from NAFO Subareas 2-4 averaged only 3,668 mt. Recruitment has remained poor and the fishery has not returned since its collapse. In recent years, the majority of landings in these Subareas occurred as directed catch and bycatch in the Subarea 4 silver hake fishery (NAFO 1995). Preliminary landings during 1994 from Subareas 3 and 4 were 5,985 mt.

Since 1983, total landings have been dominated by the domestic fishery, which averaged 7,638 mt (58% of the total landings) and 11,305 mt (71% of the total landings) during 1982-1987 and 1988-1993, respectively. Since 1987, there has been no foreign participation in the *Illex* fishery within the U.S. EEZ. Domestic landings have increased every year since 1988, to a record high of 18,012 in 1993 (Figure 2B). This represented 87% of the total landings in 1993 and a 2% increase over the 1992 domestic landings. Preliminary estimates of the 1994 domestic landings were 18,350 mt. In 1993, domestic landings were reported for a total of 438 trips made by 53 vessels. Otter trawl gear was used to harvest 99.9% of this total during 428 trips made by 49 vessels.

The pattern of domestic *Illex* landings in 1993, by statistical reporting area (Figure 3) and month, were collected from the NEFSC commercial fisheries database (Table 2). Since 1982, this fishery has occurred primarily in offshore areas during the summer and early fall. Similar to recent years, most of the 1993 landings (84%) occurred during July-September and were predominately taken from statistical area 622 (73%). Based on a monthly proration of the 1993 domestic landings of *Illex* and *Loligo* squid, by month and 2-digit statistical area, an additional 13 mt of unclassified squid were considered likely to have been *Illex* squid.

Since discard data were not available for directed *Illex* trips, discarding of *Illex* was not incorporated into the assessment analyses. However, based on confidential bycatch observations collected during foreign and Joint Venture fishing operations, the weight of *Illex* discarded was negligible in comparison to the landings. In general, the tendency of *Illex* to school by size, and targeting of larger squid by the fishery (16-28 cm), suggests that discard rates of small *Illex* may be low.

Length Frequency Sampling

Length frequency sampling of *Illex* squid landings from the U.S. EEZ, during 1982-1993, is summarized in Table 3. The distribution of commercial length samples, by month and statistical area, is presented in Appendix A. Commercial length composition was assessed for all sizes combined since there are no market categories for this species. A total of 1,154 squid were sampled for mantle length in 1993; comprising 23 length-frequency samples of 50 squid each. Overall, sampling intensity in 1993 was relatively low with one length frequency sample collected for every 783 mt of *Illex* landed. Length samples were collected during all months of the fishing season, with the exception of June. Overall, the monthly distribution of length samples were generally concordant with the monthly landings distribution; 92% of the length samples were collected during July-October when 90% of the landings occurred.

Catch in Numbers

Monthly mean weights in the U.S. catch were computed by pooling commercial length-frequency samples by month, for each year, then applying a length-weight equation to compute weights at length. The length-weight equation used in these computations was derived from NEFSC survey data for combined areas, seasons and sizes ($\ln(\text{weight}) = -3.03444 + 2.71990 \ln(\text{length})$, weight in g and length in cm) (Lange and Johnson 1981). Weight at length values were then summed by month to compute monthly mean weights in the catch for each year. Month-specific averages for the preceding years of the time series were substituted as mean weights for months in which no length samples were collected. Annual mean weight estimates of harvested *Illex* (W_a) were then computed as weighted averages of these monthly mean weights (W_m), where the weighting coefficient was the fraction of the annual landings which occurred during each month (f_m):

$$W_a = \sum_{m=1}^{12} f_m W_m \tag{1}$$

Total numbers of *Illex* squid landed annually by the domestic fishery, during 1982-1993, were then computed by dividing annual mean weights into annual yields (Table 4). Similar to landed weight, the numbers of *Illex* squid landed annually have been increasing since 1988, reaching a time series peak in 1993.

STOCK ABUNDANCE AND BIOMASS INDICES

Commercial Catch Rates

Standardized fishing effort and landings per unit of effort (LPUE) (metric tons landed per standard day fished), during 1982-1993, were estimated for the domestic fishery with a four-factor (year, month, area, and vessel tonnage class) main effects General Linear Model (GLM) applied to log-transformed LPUE data. Otter trawl trips landing at least 25%, by weight, of *Illex* squid during May-November were partitioned by vessel tonnage class according to their Gross Registered Tonnage (GRT) designation. The GLM included trips that targeted *Illex*; Class 3 (51-150 GRT) and Class 4 (151-500 GRT) vessels fishing in statistical areas (SAs) 526, 616, 622, 626 and 632. Although some trips that landed *Illex* were excluded based on these criteria, in particular Class 2 vessel trips in the Gulf of Maine, the trips included in the GLM accounted for 92% of the total domestic landings during 1982-1993. This analysis was considered to be an improvement over the GLM analysis used in SARC 17 because: (1) only trips targeting *Illex* were used while trips that landed minor amounts of *Illex* were excluded; (2) a finer spatial scale was used to evaluate the area effect (3-digit SAs instead of 2-digit SAs); (3) a significant month effect was added to characterize in-season fishing success. These improvements reduced the mean square error (MSE) and coefficient of variation (CV) from MSE=2.83 and CV=195% in the previous model to MSE=0.60 and CV=21% (Table 5).

Standardized effort for the domestic fishery declined to a low of 29 days fished in 1988, but has been increasing markedly since then (Table 6, Figure 4A). Standardized fishing effort has been above the 1982-1993 average (225 days fished) since 1990 and reached a near-record 390 days fished in 1993. Concurrently, LPUE has been gradually declining since 1988 (Figure 4B). Standardized LPUE remained stable in 1993 at 46 mt/day fished; slightly below the 1982-1993 average of 47 mt/day fished.

Spatial patterns in nominal LPUE during 1982-1993 were depicted in 4-year time blocks, by quarter-degree square, using a geographic information system (GIS) (Figure 5). Weighted LPUE values were computed as a ratio of the sum of the metric tons landed within each quarter-degree square to the sum of the days fished within each quarter-degree square. During 1982-1985, the bottom trawl fishery predominately took place in the offshore waters of the Mid-Atlantic region, with a minor component occurring along the western Gulf of Maine; the latter being comprised of Class 2 and Class 3 vessels. During 1986-1989, a period of declining fishing effort, the fishery expanded into southern New England (primarily SA 537), at fairly high LPUE levels, with minor activity on Georges Bank. During 1990-1993, areas of high LPUE extended throughout most of southern New England, particularly in waters deeper than 50 fathoms. The highest LPUE levels occurred in offshore shelf waters between Cape Hatteras and Cape Cod. Fishing activity on Georges Bank was still limited, but LPUE in these areas increased. This progressive increase in the number and size of areas of high LPUE indicates a northward expansion of the fishery, from the Mid-Atlantic region, since 1982.

Research Vessel Survey Indices

Annual indices of *Illex* relative abundance (stratified mean catch per tow, in numbers) and biomass (stratified mean weight per tow, in kilograms), within the U.S. EEZ from Cape Hatteras to the Gulf of Maine, were computed from NEFSC spring (1968-1995) and autumn (1967-1994) bottom trawl surveys. Survey procedures and details of the stratified random sampling design are provided in Azarovitz (1981). A review of the percentage of tows catching *Illex* in the Gulf of Maine (Figure 1) showed that *Illex* consistently utilized this habitat. Accordingly, Gulf of Maine strata were included in the computation of relative abundance indices in contrast to previous assessments. Overall, standard survey tows in offshore strata 1-40 and 61-76 (Figure 6) were used to compute indices of relative abundance.

Vessel Catchability Analysis

A vessel catchability analysis presented at SAW 12 (NEFSC, 1991) suggested that the *Delaware II* research vessel exhibited greater fishing power than the *Albatross IV*. Potential differences in the catchability of *Illex* by these two research vessels were re-examined, in the current assessment, by analyzing catch data from paired tows (the vessels fished side by side) from NEFSC gear comparison cruises in 1982, 1983, 1987 and 1988. Total number per tow, number per tow of *Illex* pre-recruits ($\leq$ 10 cm) and recruits ($\geq$ 11 cm), and weight per tow were compared to determine whether there was a difference in average catch per tow between the two vessels. Only tows where both vessels caught both recruits and pre-recruits (N=38) were used in the size-based analysis, whereas only tows with positive *Illex* catch by both vessels were used in the total number per tow (N=226) and weight per tow (N=205) analyses.

The ratios of the mean number per tow and log-transformed mean number per tow were examined first, where N_{AL} and N_{DE} were the number per tow for the *Albatross IV* and the *Delaware II*. These ratios were: $E[N_{AL}]/E[N_{DE}] = 0.79$ and $E[\ln(N_{AL})/E[\ln(N_{DE})] = 0.78$. Both, the ratio and log-transformed ratio of mean catches were less than 1 and suggested greater fishing power for the *Delaware II.* We also computed the mean of the ratio of the number per tow to be $E[N_{AL}/N_{DE}] = 1.09$, which suggested slightly higher fishing power for the *Albatross IV.* The mean paired difference in catch per tow was also computed to be $E[N_{AL} - N_{DE}] = -9.5$ and a t-test indicated that this mean was not significantly different from 0 ($P=0.43$). A Wilcoxon's signed-ranks test (Sokal and Rohlf 1981) of the paired difference in catch per tow indicated that the median difference was significantly different from 0 ($P=0.0001$). When a logarithmic transformation was applied to the catches, significant differences were detected with the t-test ($P=0.001$) and Wilcoxon's test ($P=0.0001$). The results of these comparisons and the mean ratios of catch per tow suggested that the *Albatross IV* was not as powerful as the *Delaware II* for catching total numbers of *Illex* and that a vessel conversion factor for numbers was necessary. Thus, a vessel conversion coefficient of 0.78 was applied to the *Delaware II* stratified mean number per tow values prior to computing the autumn survey indices in order to standardize these tows to *Albatross IV* catches.

A similar examination of the catch rates of numbers of pre-recruits (P_{AL} and P_{DE}) and recruits (R_{AL} and R_{DE}) was performed. The ratios of mean number per tow were $E[P_{AL}]/E[P_{DE}] = 0.45$ and $E[\ln(P_{AL})/E[\ln(P_{DE})] = 0.67$ for pre-recruits, and $E[R_{AL}]/E[R_{DE}] = 0.38$ and $E[\ln(R_{AL})/E[\ln(R_{DE})] = 0.79$ for recruits. Mean paired differences in the log-transformed catch per tow were computed to be $E[\ln(P_{AL})) - \ln(P_{DE})] = -0.539$ for pre-recruits and $E[\ln(R_{AL})) - \ln(R_{DE})] = -0.497$ for recruits, and the t-test indicated that these means were significantly different from 0 ($P=0.006$ and $P=0.037$, respectively). A Wilcoxon's signed- ranks test of the paired difference in log-transformed catch per tow also indicated that the median difference for pre-recruits was significantly different from 0 ($P=0.004$) while the median difference was for recruits was likely different from 0 ($P=0.051$). It appeared that the *Albatross IV* was not as powerful as the *Delaware II* for catching both pre-recruits and recruits.

For weight per tow (W_{AL} and W_{DE}), the ratio of mean catch per tow was $E[W_{AL}]/E[W_{DE}] = 0.81$ and the mean ratio was $E[W_{AL}/W_{DE}] = 1.34$. The mean paired difference in catch per tow was also computed to be $E[W_{AL} - W_{DE}] = -1.05$ and a t-test indicated that this mean was not significantly different from 0 ($P=0.436$). A Wilcoxon's signed-ranks test of the paired difference in weight per tow indicated that the median difference was significantly different from 0 ($P=0.0001$). The results for weight per tow were similar to those for numbers per tow and it appeared that the *Albatross IV* was probably not as powerful as the *Delaware II* in catching *Illex* by weight. Thus, 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 these tows to *Albatross IV* catches.

Habitat Analysis

The effects of depth, surface temperature, bottom temperature, and time of day on *Illex* catches during the NEFSC fall survey were also examined (Brodziak and Hendrickson

In Prep.), based on the univariate habitat association test of Perry and Smith (1994). The results indicated that *Illex* catches were moderately associated with depth, with highest catches occurring in shelf edge waters greater than 185 m deep, and that the current survey design of stratification by depth was appropriate for *Illex*. The results also indicated that *Illex* catches were significantly associated with surface temperature during roughly half of the years examined and generally occurred in waters with surface temperatures of 13-20°C. Bottom temperature had a lesser influence on *Illex* distribution during the autumn survey, with most catches occurring in waters with bottom temperatures of 9-13°C. This suggested that *Illex* catches were associated with cooler water temperatures in comparison to *Loligo*.

During half of the years analyzed, the results also indicated that *Illex* catches were significantly associated with time of day and appeared to be size-specific. Catch per tow of pre-recruits was highest during the day, while catch per tow of recruits was highest during dawn/dusk. The relationship between catch per tow and time of day was significant at the $\alpha = 0.05$ level for 13 out of the 28 years in the time series. These results differed from similar analyses for *Loligo* squid where the relationship was significant for all years of the time series. Diurnal catch rate adjustment factors were not applied to compute abundance indices because the indices were not used to estimate absolute population size and because it was assumed that stations were randomly distributed by time period among survey strata during the 24-hour continuous operation of the NEFSC bottom trawl survey. Whether the application of diurnal adjustment factors are warranted for *Illex* catch rates requires further investigation.

Relative Abundance and Biomass Indices

Vessel-adjusted, stratified mean numbers per tow and mean weights (kg) per tow from the autumn and spring bottom trawl surveys exhibited considerable annual variability (Tables 7 and 8, Figure 7). Although high inter-annual variability might be expected for an annual species if fluctuations in recruitment were substantial, it should be noted that the outer shelf and continental slope are important *Illex* habitats (O'Dor and Dawe *In Press*) that are not intensively sampled by NEFSC bottom trawl surveys. Furthermore, it should be noted that bottom otter trawl gear is not likely to be an efficient sampling gear for *Illex* distributed vertically in the water column. Although neither survey tracks pre-recruit ($\leq$ 10 cm) abundance very well, the autumn survey appears to provide a better measure of relative abundance of recruited squid ($\geq$ 11 cm) than the spring survey. The CVs for the spring number per tow indices were much higher than those from the autumn survey and no significant autocorrelation in biomass was evident for the total weight per tow index. Lower catch rates and lower precision of the spring survey estimates occur primarily because the distribution of *Illex* extends beyond the range of the survey. No significant cross-correlation was detected at any lag between the stratified mean weight per tow values of the spring and fall series. However, a significant positive correlation ($r = 0.3805$, $p < 0.05$) did exist between the autumn biomass index for the current year and the previous year. Overall, indices from the autumn survey provide a more consistent measure of *Illex* relative abundance, in the U.S. EEZ, due to greater overlap between the stock distribution and survey coverage.

The autumn number per tow (Figure 7A) and weight per tow (Figure 7B) indices both indicate two distinct periods of high abundance, 1976-1981 and 1987-1990, which were well above the long-term average. Although the stratified mean numbers per tow during this earlier period were similar to those from the latter period, individual mean weights of animals from the earlier period were more than double those from the latter period. The observed difference in mean weights may be due to differing contributions of seasonal breeding components or differing growth conditions during these periods. More recently, the numbers per tow index was slightly above the long-term average (9.6 squid/tow) during 1993 and slightly below it during 1994.

STOCK DISTRIBUTION

Offshore shelf and continental slope waters are primary habitat for *Illex* during most of its life (O'Dor and Dawe *In Press*). Consistent with Lange *et al.* (1984), the highest catch rates during the autumn survey occurred in the shelf-slope convergence zone at depths greater than 185 m (Brodziak and Hendrickson *In Prep.*). *Illex* undergo a lengthy southward migration to spawn south of Cape Hatteras, with a spawning peak during winter, after which time the spent squid reportedly die (Trites 1983, Rowell *et al.* 1985, O'Dor and Dawe *In Press*).

The seasonal spatial distribution of *Illex* pre-recruits (≤ 10 cm) (Figure 8) and recruits (≥ 11 cm) (Figure 9) was characterized from NEFSC research surveys. Survey strata were shaded according to the density of squid (mean number/tow) captured in each stratum. Shading categories were based on the number per tow quartiles for the entire summer survey time series. Although the number of years of survey data depicted differed by season, primarily a result of fewer winter and summer surveys, a seasonal distribution pattern was evident. Although the Gulf of Maine was not sampled during the winter survey (Figure 8), *Illex* pre-recruits appeared to be beyond survey coverage; either further offshore or south of Cape Hatteras. During the spring, pre-recruit densities were highest in the southernmost offshore strata, with very low densities occurring further inshore and in the northern areas of their range. These results suggested a northerly migration of juveniles in the spring. During the peak of the summer fishery (Figures 8 and 9), the stock became dispersed over a broader geographic region, throughout the continental shelf, generally moving further inshore. By autumn, *Illex* have generally begun to move offshore and migrate south.

LIFE HISTORY PARAMETERS

Growth

Statolith aging methods have been validated for this species (Dawe *et al.* 1985, Hurley *et al.* 1985). Dawe and Beck (1992) applied statolith increment analysis to *Illex* squid and found that this species appears to live for up to roughly one year. Weight-at-age and length-at-age curves were estimated for *Illex* by fitting size-at-age data to Schnute growth models (1981) using methods described in Brodziak and Macy (1996) to select the models representing the best relationships for weight-at-age and length-at-age. The source of the size-at-age data (N=202) was the Newfoundland jigging fishery as reported in Dawe and Beck (1992) (E. Dawe, DFO, St. John's, Newfoundland, pers. comm.). The maximum age reported in this data set was 250 days. The analyses indicated that *Illex* growth in terms of length and weight is rapid and can be described as exponential for both factors (Figure 10). Based on examination of the variance ratio described by Schnute (1981), the growth curve representing the best relationship describing weight (W), in grams, at age (d), in days, was:

$$W(d) = 20.003509e^{(0.0125554d)} \tag{2}$$

while the growth curve representing the best relationship describing mantle length (L), in cm, at age (d) was:

$$L(d) = 11.56955e^{(0.003474d)} \tag{3}$$

Natural Mortality

Shortfin squid are highly migratory, school by size, exhibit cannibalism and live less than one year (Dawe and Beck 1992, O'Dor and Dawe *In press*). As a result, a high natural mortality rate is expected. A monthly instantaneous natural mortality rate (M_m) of M_m= 0.30 (M_d=0.01) has been used in this assessment of *Illex*. This value represented the average of three estimates. First, Hoenig's (1983) regression method, applying a maximum age of 250 days to his predictive equation for mollusks, results in a monthly instantaneous natural mortality rate of M_m= 0.39. A second method, based on animal size and bioenergetic constraints (Peterson and Wroblewski 1984), gave an estimate of M_m = 0.22 for an animal weighing 20 grams. A third method, by analogy with another commercially-exploited *Illex* species (*Illex argentinus*), gave a value of M_m = 0.26 (Rosenberg *et al.* 1990).

Sexual Maturity

Spawning probably occurs throughout the year, with a strong peak during the winter and a secondary peak during the summer (Coelho and O'Dor 1993, Dawe *et al.* 1985). Summer spawning appears to be more important in the southern portion of the stock's range, where it may contribute to the greater stability of stock abundance within the Mid-Atlantic Bight (Lange and Sissenwine 1981). Sexual maturity stages have been described for male *Illex* squid (Mercer 1973) and a nidamental gland index has been derived for females (Durward *et al.* 1979). However, sexual maturity observations are not regularly made at sea during NEFSC research survey cruises. Coelho and O'Dor (1993) found that mean size at maturity varies latitudinally and interannually. They gave a range of mean sizes at sexual maturity for male squid from NAFO Subareas 5 and 6 as 200-215 mm. When applied to a length-at-age equation for *Illex* (refer to Growth section), this results in 50% maturity for males at approximately 6 months of age.

ESTIMATION OF STOCK SIZE AND FISHING MORTALITY RATES

Stock Size Estimates

Parameters of the difference equation form of the Schaefer surplus production model (Walters and Hilborn 1976) were estimated for the *Illex* fishery within the U.S. EEZ, during 1982-1993, using:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - qE_tB_t \qquad \textbf{(4)}$$

where B_t was stock biomass at the beginning of year t, C_t was the catch biomass harvested in year t, E_t was standardized fishing effort in year t, q was the biomass catchability coefficient, r was the intrinsic rate of biomass growth, and K is the carrying capacity of the stock. The parameters (r, q and K) of this model were estimated using the regression method described in Hilborn and Walters (1992, refer to Eq. 8.4.10, p. 308) where standardized LPUE from the domestic fishery, during 1982-1993, was input as the relative abundance index proportional to stock biomass and total catch and effort inputs were total landed biomass and expanded standardized effort within the U.S. EEZ.

The regression was significant ($F=7.16$, $P=0.017$, $R^2=0.64$) and the residuals were normally distributed. The point estimate of q was used to estimate the stock biomass at the beginning of 1982 (B_{82}=25,049 mt) and the process equation was used to calculate B_{83} to B_{93}. Average annual stock biomass ($E[B_t]$) was computed as the initial stock biomass plus one-half the surplus production for that year. Annual fishing mortality rates were estimated as the total landings, in weight, divided by $E[B_t]$. The results of this model are summarized in Table 9.

Bootstrapping procedures were applied to estimate the uncertainty of model parameters. A total of 1,000 bootstrap replicates were calculated based on the residuals of the regression model. Of these replicates, a total of 221 estimates resulted in either infeasible q estimates (i.e. negative) or generated negative biomass estimates at some point in the time series. Infeasible estimates were excluded from further consideration although they do provide some insight into the model fit. Infeasible estimates in surplus production models are often due to a lack of sufficient range in the time series values, rather than inappropriateness of the model (Hilborn and Walters 1992).

Standard deviations of the parameter estimates were estimated from the bootstrap replicates. The parameter estimates were q=1.537·10^{-3} (σ_q=0.786·10^{-3}), r=2.44 (σ_r=0.56), and K=39,793 (σ_K=129,129), where the standard deviations are reported for values of q, r, and K that led to feasible population sizes throughout 1982-1993 (N=779). Comparison of median bootstrap estimates of r, q and K with the original point estimates suggested a maximum bias of less than 2.1 %.

Uncertainty in the initial stock biomass and average stock biomass series was characterized with the bootstrapped parameter estimates by first computing B_{82} and $E[B_{82}]$ and then iterating the process equation for each triplet of parameters (r, q and K). Based on these computations, 50% CIs for fishing mortality and stock biomass were derived (Figures 11A and B).

The results indicated that stock biomass was lowest in 1982 and highest in 1986 and that there was considerable uncertainty in the estimates of stock biomass. Average stock biomass was lowest in 1982 and highest in 1988 and was also imprecisely estimated.

Fishing Mortality Estimates

Estimated annual and monthly fishing mortality rates, during 1982-1993, are presented in Table 9. Monthly values were computed by dividing the annual fishing mortality rates by the number of months comprising the fishing season. The four months of June-September were used in this computation, since most (81%) of the 1982-1993 landings occurred during these months. Estimated monthly fishing mortality rates ranged from 0.01 to 0.13 during 1982-1993 with an average monthly F of 0.07 (Figure 11A). F decreased steadily from a 1982 peak of 0.13 to 0.04 in 1986. Fishing mortality rates have been increasing since 1988, from 0.01 to 0.12 in 1993. During 1992, the fishing mortality rate was equal to the $F_{50\%}$ target ($F_{50\%}$=0.11) (refer to BIOLOGICAL REFERENCE POINTS section) and was just above it during 1993. The probability that F_{93} exceeded the $F_{50\%}$ target was 0.54 and the probability that it exceeded the $F_{20\%}$ threshold was 0.01. The average coefficient of variation of fishing mortality was roughly 55% during 1982-1993.

A comparison of model derived estimates of annual production and catch (Figure 11C) suggested that landings exceeded annual production during 1991 and 1992.

BIOLOGICAL REFERENCE POINTS

The current overfishing definition for *Illex* has been characterized as 'risky' by a scientific review panel (Rosenberg *et al.* 1994) and should be changed to reflect the one-year life cycle of this species. The overfishing definition for *Illex*, as defined in the current FMP, occurs when the three-year moving average of pre-recruits from the NEFSC autumn bottom trawl survey is within the first quartile of this series. However, the use of a three-year moving average is inappropriate for a species with a lifespan of less than one year. Given the highly variable recruitment of this species, recruitment failure in a single year could lead to stock collapse. Furthermore, because the NEFSC autumn survey does not provide reliable indices of *Illex* pre-recruit abundance, the current overfishing definition does not provide an adequate measure of recruitment overfishing.

According to the current overfishing definition, *Illex* was not overfished in 1993, since the largest index in the first quartile of the pre-recruit time series was 0.19, which is less then the three-year moving average of the pre-recruit index (0.72). During 1994, the largest index in the first quartile was also 0.19 and the three-year moving average was 0.72, suggesting that *Illex* was not overfished in 1994. Assuming a pre-recruit index of zero in 1995, the three-year moving average of the pre-recruit index would be 0.12, which is less than the largest index in the first quartile (0.19 number per tow). Therefore, based on this overfishing definition, *Illex* has the potential to be overfished in 1995.

A more appropriate overfishing definition should minimize the risk of recruitment overfishing, by ensuring that escapement exceeds a threshold minimum spawning stock biomass (SSB_{min}). Given the flat-topped nature of the yield-per-recruit curve for this species (Figure 12), an appropriate threshold would be a monthly $F_{20\%}$ (0.28), with fishing intensity such that escapement is above this threshold, at a monthly target level of $F_{50\%}$ (0.11). Although environmental factors also affect the recruitment process, they cannot be predicted or controlled. These biological reference points should allow sufficient spawning biomass to survive each year in order to ensure a high probability of successful recruitment in the following year. A similar target of 40% proportional escapement was set for the Falkland Islands *Illex argentinus* fishery (Beddington *et. al.* 1990).

YIELD AND SPAWNING STOCK BIOMASS PER RECRUIT

A monthly yield and spawning stock biomass per recruit analysis was conducted based on the estimated growth curves. A plus-group of squid 8 months and older was used. Based on the observed mean weight in the fishery and the mean weight at age taken from the estimated growth curve, the mean age at exploitation in the commercial fishery was approximately 4.5 months during 1982-1993. This indicated that an age of 4 months would be a reasonable value to assume for knife-edged recruitment to the fishery. This analysis incorporated an age at 50% maturity of 6 months, based on a mean length at maturity for *Illex* squid collected from NAFO Subareas 5 and 6 (O'Dor and Coelho, 1993) and a monthly natural mortality rate of 0.30. Results (Table 10) indicated that the monthly fishing mortality that maximized yield per recruit (F_{max}) was 0.61, while $F_{20\%}$= 0.28 and $F_{50\%}$= 0.11 (Figure 12).

Sensitivity analyses were conducted to evaluate the importance of monthly natural mortality, M_m, in the determination of F_{max} and $F_{20\%}$. These reference points were recalculated based on three point estimates of M_m and compared with the results for the value of M_m = 0.30 used in the assessment. Clearly, the F_{max} reference point was much more sensitive to changes in the value of M_m than the $F_{20\%}$ reference point:

M_m	F_{max}	$F_{20\%}$
0.22	0.38	0.25
0.26	0.47	0.27
0.30	0.61	0.28
0.39	> 4.00	0.31

A similar analysis was conducted to evaluate the potential importance of post-spawning mortality through the application of a non-constant instantaneous natural mortality rate to calculate F_{max} and $F_{20\%}$ values. Post-spawning mortality was assumed to occur one month after the attainment of full maturity and consisted of a doubling of the natural mortality rate for squid in the plus-group (8+ months old). Again, the F_{max} reference point was much more sensitive to changes in the value of M_m than the $F_{20\%}$ reference point:

M_m	F_{max}	$F_{20\%}$
0.22	0.56	0.32
0.26	0.69	0.33
0.30	0.91	0.35
0.39	> 4.00	0.37

In summary, the inclusion of post-spawning mortality will generally increase the values of F_{max} and $F_{20\%}$. The increase in F_{max} is due to the fact that less yield can be taken from the plus-group, forcing more yield to be taken from younger, recruited age classes. The increase in $F_{20\%}$ is due to the fact that there is a reduced contribution of spawning stock from the plus-group, thereby reducing the importance of substantial survival to the plus-group age.

LONG-TERM POTENTIAL YIELD

Provisional estimates of long-term potential yield (LTPY) were derived from the expected yields predicted by the biomass dynamics model with respect to the biological reference point F levels. These estimates differ from earlier ones in that the annual life cycle of *Illex* and the seasonal distribution of current fishing effort are addressed. The monthly target fishing mortality rate of $F_{50\%} = 0.11$ was converted to an annual rate by adjusting for the average seasonal distribution of landings. During 1982-1993, approximately 91% of the landings occurred between June and September. Applying $F_{50\%}$ for four months and allowing for additional mortality outside this period, the effective annual F was computed as 4(0.11)/0.91 = 0.4835. Applying the same method to the threshold monthly fishing mortality rate of $F_{20\%}= 0.28$ resulted in an annual threshold F of 1.2308.

The yield that would be realized under these fishing mortality rates is dependent upon the structural form of the biomass dynamics equation and the parameter estimates. The biomass dynamics equation (Eq. 4) can be re-expressed as:

$$B_{t+1} = B_t + rB_t\left(1-\frac{B_t}{K}\right) - F_{ref}\,B_t \tag{5}$$

where F_{ref} represents the biological reference point. The expected yield ($E[C_t]$) is the product of the reference fishing mortality rate and the average biomass during the year. Average biomass was defined as the initial biomass plus one half of the production elaborated during the year. Expected catch biomass ($E[C_t]$) was thus defined as:

$$E\left[C_t\right] = F_{ref}\left[B_t + \left(\frac{rB_t}{2}\right)\left(1-\frac{B_t}{K}\right)\right] \tag{6}$$

The initial condition, B_0, for Eq. 5 was estimated as the CPUE value in 1982 divided by the estimated catchability parameter (q) from Eq. 4. As long as F_{ref} is less than the parameter r, the population will stabilize to an equilibrium level unless B_0 greatly exceeds K. The long-term yield for the point estimates of r, q, and K was defined as the average yield for the time period 2000 to 2018 given an initial (1982) biomass condition of 38.5/0.001537 = 25,049 mt where 38.5 (mt/day fished) is the GLM-adjusted LPUE (Table 6).

Bootstrapping was applied to characterize the empirical distribution of long-term yield for the biomass dynamics model. The empirical distribution of long-term yield was computed by applying Eq. 5 and Eq. 6 to each bootstrap realization of r, q, and K.

The point estimates of LTPY for the target fishing mortality rate, $F_{50\%}$, and the threshold fishing mortality rate, $F_{20\%}$, were 15,392 mt and 24,272 mt, respectively. Median long-term yields from the bootstrap estimates, for $F_{50\%}$ and $F_{20\%}$, were 14,579 mt and

21,325 mt, respectively. Interquartile ranges for the target and threshold fishing rates are shown below:

Fishing Mortality Rate (per month)	Median Long-term Yield (mt)	Interquartile Range of Yield (mt)
Target: $F_{50\%} = 0.11$	14,579	{10,754 , 23,237}
Threshold: $F_{20\%} = 0.28$	21,325	{18,150, 28,183}

Cumulative distribution plots of expected yields (Figure 13) for the two reference points illustrate substantial overlap. Average landings for 1988-1993 of 11,305 mt were below the median target yield. Average landings for 1992-1994 (Table 1) of 18,063 mt exceed the target yield but lie within the predicted interquartile range for the target fishing mortality rate.

These long-term potential yields are consistent with the recent history of resource productivity but may vary in the future depending on the favorability of environmental conditions for recruitment and growth.

REAL-TIME MANAGEMENT

Real-time management is particularly desirable for annual stocks such as *Illex* and *Loligo* squid because annual population abundance can be highly variable and a single recruitment failure could lead to stock collapse. Stock size is generally unknown before the start of the fishing season and can only be estimated once the fishing season is underway. In-season adjustments of catch or effort could provide biological and economic benefits such as the preservation of adequate spawning biomass each year, avoidance of overfishing during periods of poor recruitment, and increased landings during periods of good recruitment. Under the existing quota-based management system, the catch limit would have to be set ultraconservatively in order to avoid reducing spawning biomass to a dangerously low level. Furthermore, under the current system, no advantage can be taken of periods of good recruitment.

Example of Falkland Islands *Illex* Fishery

A real-time management plan which incorporates effort controls has been implemented in the Falkland Islands for the *Illex argentinus* fishery (Basson *et al. In Press*; Beddington *et al.* 1990; Rosenberg *et al.* 1990). Effort controls, in the form of limiting the number of licenses and fishing season duration, were selected rather than catch quotas for two reasons. First, effort management does not require a pre-season estimate of recruitment for the calculation of a TAC. Second, effort management allows catches to vary with population size, which permits taking advantage of good recruitment. There is also less incentive to mis-report catches, since in-season catch is not limited, which suggests that catch per unit effort data should be more reliable. The number of recruits from this annual species, in any given year, are produced by survivors from the previous year. Therefore, the *Illex argentinus* management plan was based on ensuring that proportional escapement remained at a selected target level which, under average recruitment, implied absolute escapement above a threshold minimum spawning stock biomass. It is possible, with effort limitation, to compute a pre-season level of effort required to meet this proportional escapement target. Proportional escapement, P, is defined as the ratio between the number of spawners surviving under a given level of fishing mortality and the number of spawners with no fishing mortality:

$$P=\frac{N_0 e^{-mT-F}}{N_0 e^{-mT}}=e^{-F} \tag{7}$$

where N_0 is the number of recruits at the start of the season, m is the natural mortality rate per week, T is the total number of weeks to the end of the fishing season and the start of the spawning period, and F is total fishing mortality over the entire fishing season. A proportional escapement target of 40% was used to set fishing effort limitations prior to the start of the fishing season, which is when population abundance is unknown. This approach does not explicitly require an estimate or prediction of recruitment for the upcoming season. In-season stock assessments can be used to make adjustments to effort controls and avoid causing spawning biomass levels to fall below SSB_{min}. The number of licenses was determined via the target fishing mortality rate using effort and estimates of catchability, where $F=qE$. For example, if the target proportional escapement is 40%, then the total fishing mortality would be:

$$F_{target}=-\ln(0.40) \tag{8}$$

Once the fishing season started, catch (in weight) and effort data were radioed in on a daily basis and weekly biological data were collected by at-sea observers, from a subset of vessels which fished throughout the fishing season, as part of fishing license agreements. The biological data are critical to the conversion of catch weight to numbers in the Leslie-DeLury assessment model. The weekly time scale is also essential due to the rapid growth of *Illex* during the fishing season. After several weeks of data collection, these data were incorporated into a Leslie-Delury model to compute in-season estimates of initial population size (or recruitment), current population size and catchability coefficients. These results were used to project population size, with regards to current fishing effort, through the end of the fishing season. If the projected absolute escapement was below the threshold, an early closure was considered.

In-season adjustments, in the form of early closures, are disruptive to the fishery and, at best, would allow for a spawning stock biomass close to the threshold. In-season adjustments were therefore viewed as emergency measures which could, for example, be implemented in cases where recruitment was particularly low.

Plan Considerations for U.S. EEZ *Illex* Fishery

Given the similar life history of *Illex illecebrosus*, the fact that harvesting occurs during a single season, and given the small number of vessels participating in the domestic fishery, the U.S. *Illex* fishery would be a feasible test case for implementing a similar real-time management plan. The design and details of a specific real-time management plan, including a cost-to-benefit analysis, for the this fishery would require further research prior to implementation.

Setting a Target

There are many well-documented approaches to setting an appropriate target level of exploitation (Smith *et al.* 1993). Possibilities include targets set in terms of fishing mortality (e.g. $F_{20\%}$) or in terms of yield. Regardless, it is important to consider the potentially large inter-annual variability in recruitment and the annual life cycle of *Illex* when defining reference points. For example, stock-production model results should be interpreted with caution, since these types of models were designed for populations with overlapping generations.

Another method might involve setting a fishing mortality target which incorporates a pre-determined, low probability of reaching or exceeding the threshold, since even if an in-season adjustment is made, spawning biomass will only be at or just above the threshold. However, this method can be used to avoid a disruptive, in-season closure or reduction in the TAC. Furthermore, if interannual variability in catch is reduced by this approach, it may be favored by the fishing industry. The probability level could be calculated based on an assumed recruitment distribution and a range of fishing mortality rates.

Setting a Threshold Spawning Biomass

In addition, a threshold spawning biomass should be established which minimizes the probability of very low subsequent recruitment. This would require estimates or indices of spawning stock biomass (absolute escapement) and recruitment. The NEFSC autumn research survey may be useful in determining a threshold spawning biomass since it is conducted at the end of the fishing season, covers a majority of *Illex* habitat in the U.S.

EEZ, and has been conducted over a long time period. Both absolute (i.e. swept area estimates as minimum spawning biomass estimates) and relative estimates of spawning biomass should be examined from this survey data. Recruitment is more difficult to estimate, but the following four approaches were examined: Leslie-Delury models, spring survey indices, autumn survey indices and an indirect, Markov-type approach. At this time, the spring survey indices do not appear to be a good index of *Illex* abundance for reasons previously discussed. Preliminary investigations of the other three approaches were conducted. However, further analyses would be required to determine the appropriateness of applying any of these methods.

The approach of fitting a Leslie-Delury model to monthly LPUE data, for each year independently, was examined for the period 1982-1993. Based on these preliminary analyses, the model could only be fit successfully to data for 1983 when utilizing the standardized monthly LPUE data from the current assessment. However, when the model was fit without effort standardization, to monthly LPUE data for tonnage class 4 vessels, the results proved to be more promising. The methodology assumptions and results of this analysis are presented in Appendix B (Figures B1and B2, Table B1). Realistic biomass estimates occurred for 7 of the 12 seasons analyzed and low R^2 values, implying unrealistically high population abundance, occurred for 3 of the 12 seasons. Although the resulting R^2 values appear high (Table B1), these should be interpreted with caution since the use of monthly LPUE values makes each annual time series very short (Figure B1). Ideally, the number of points in the time series should be increased through the collection of daily or weekly data for each fleet. As indicated in Figure B2, the Leslie-DeLury biomass estimates and those computed from the Hilborn-Walters model (standardized LPUE, in year *t*, divided by *q*) are of a similar order of magnitude. In addition, the Leslie-DeLury biomass estimates are more variable over time and, since the *q* value was allowed to vary from year to year, some estimates are much lower than those from the Hilborn-Walters model. The Leslie-DeLury approach appears to be promising. However, the inputs and constraints applied to the model in this test case do not provide a good series of spawning biomass and subsequent recruitment estimates, for use in setting a threshold, because of the gaps which occur in the time series. If weekly LPUE data become available in the future, and with variations to the inputs and constraints of the model, these results may improve.

A second approach which could be used in conjunction with the Leslie-DeLury model would be to set a threshold level of spawning biomass using indices of relative abundance from the autumn survey. It would be reasonable to assume that the autumn survey index in year *t* is proportional to the spawning biomass in year *t*. A naive index of recruitment would be the autumn index with an index of the catches in year *t* added back on. In this case, 'recruitment' is closer to a measure of the exploitable biomass, or peak biomass, rather than population size in numbers at the start of the fishing season. Assume that:

$$\mathbf{u^*_t = u_t + qC} \qquad \mathbf{(9)}$$

where u^*_t is the index of recruitment in year t, u_t is the autumn survey index (in kg/tow), C_t is the landings during the fishing season (May-September) in year t, and q is like a catchability coefficient which allows for the conversion of landings (mt or kg) to a survey index equivalent in kg/tow units. Appendix Figure C1 suggests that a Ricker-like, stock-recruitment relationship exists when $q = 0$. As previously discussed, there is also some serial correlation present between these two variables. When the non-linear Ricker model was fitted by log transformation, using the autumn survey indices (in kg/tow) and the catches (in weight) for the entire U.S. EEZ, the result was a negative estimate of q. Thus, an improved analytical model is necessary in order to pursue this approach to setting a threshold. One approach might involve using monthly catches, in terms of numbers instead of weight, appropriately discounted for the effects of natural mortality.

A third, indirect approach would involve a simulation study to determine the implications of different threshold levels. The simulation model could, for example, make different assumptions about the distribution of recruitment at levels of escapement above and below the median (or lower quartile) of the autumn survey time series. Although the *Illex* stock-recruitment relationship requires further investigation, Figure C1 highlights two important points. First, at the low end of the range, the results for different assumptions about q are very similar. Second, the mean and variance of the index were greatly reduced when the previous index was a very low value; one that was below the median or first quartile of the time series. Thus, the probability of high recruitment seems to be reduced at low values of the autumn survey index (u_t). The variance of u_t was only 0.264 for values of u_t below the median, but was 7.304 for values of u_t above the median. Irrespective of which q-value is used and whether or not catches are included, this pattern for the mean and variance of expected recruitment at low or high u_t values would hold true for the current data set. This information could be used to set a threshold in terms of the autumn survey index, which could then be converted to an absolute estimate of spawning biomass. As an example, a reasonable threshold might lie around the lower quartile, but further investigations are warranted.

In-season Monitoring

Once a threshold has been selected, either in terms of absolute biomass or in terms of a survey index (in kg/tow), methods for in-season monitoring of population abundance and effort control adjustments should be determined. The feasibility of using a Leslie-DeLury type of assessment appears promising, but would require the collection of LPUE data on a shorter time scale than a month, as well as the collection of biological data. During the first few weeks of the fishing season, an estimate of catchability from the previous year could be applied to the LPUE time series in order to give an indication of absolute population abundance. In addition, comparisons with historic LPUE indices during the same part of the fishing season may be helpful in highlighting periods of low LPUE. The validity of the assumptions for the Leslie-DeLury approach should be carefully checked prior to its application. For example, the validity of the assumption of no migration during the main part of the fishing season should be examined, perhaps through a study of the residuals, once weekly data are available. If some of the model assumptions are violated and can't be fixed, sensitivity analyses may suffice for the purpose of making management decisions.

An alternative approach to an in-season assessment might involve the use of an LPUE index to predict the autumn index of abundance at the end of the season, since a reasonably good correlation exists between raw monthly LPUE values and the autumn survey index in each year, particularly for tonnage class 4 vessels during June and July. Raw LPUE indices were used since a valid standardization may not be possible early in the season when only limited data are available. Furthermore, only a limited number of 3-digit statistical areas are relevant to this fishery and monthly LPUE values, by tonnage class, are easily calculated. The correlation results for tonclass 3 and tonclass 4 vessels were:

Month	Tonclass	
	3	4
May	0.26	0.13
June	0.09	0.59
July	0.13	0.55
August	0.01	0.30
September	0.69	0.64
October	0.27	0.74

The correlation for tonnage class 3 vessels was more variable and not as high as for tonclass 4 vessels during June and July. It is interesting to note that the relationship between monthly LPUE values and the autumn survey indices is linear at the origin, but the curve flattens out at higher values (Appendix Figure D1). This effect could be real, for example, as a result of operational constraints, like "saturation effects" or trip time limits, or as a result of the measure of effort used. This warrants further investigation since it could have implications for the Leslie-DeLury assessments.

If it is not possible to get an estimate of population abundance during the early part of the fishing season, LPUE in June could be used to predict an autumn survey index which could be compared to a threshold set on the same scale. For example, a threshold set at the lower quartile of the autumn survey indices could be used to decide whether an in-season adjustment would be required.

In-season adjustment

The determination of whether to conduct an in-season adjustment to catch or effort limitations, and the magnitude of such an adjustment, is of primary importance in the management planning process. If the threshold is in terms of absolute biomass, the magnitude of an adjustment is difficult to determine without an estimate of absolute abundance during the season. In such a case, alternative methods for performing in-season adjustments, summarized in Appendix E, would have to be investigated.

However, with an in-season estimate of absolute abundance, obtained either by direct assessment or by using LPUE/q (for example, q being estimated from a previous fishing season), adjustments to catch or effort can be determined.

We have already noted why effort limitation is preferable to catch limitation. Since catches will fluctuate with trends in recruitment, with effort limitation, in-season adjustments need only be made in unusual circumstances, for example, when recruitment is particularly poor. If total catch limits are used, in-season adjustments may serve a dual function: (1) to prevent the reduction of spawning biomass to a level below the threshold and (2) to take advantage of good recruitment. In this case, the management plan should identify another set of rules which define when and how increases in allowable catches should be made.

The probability of detecting the need for an in-season adjustment to reduce catch or effort when there is no need, and vice versa (not detecting the need for an adjustment where there really is a need), cannot be established *a priori*, because the probabilities depend on the quality and quantity of data, the assessment model(s), and the degree to which the model assumptions are met. Therefore, the only feasible approach to estimating these probabilities is via simulation modelling which would be used to project absolute escapement at the end of the fishing season to determine the appropriate levels of effort or catch which are likely to result in escapement above the threshold.

Data Requirements

Real-time management of this fishery would require mandatory reporting and sampling during the fishing season. Similar to the Gulf of Maine northern shrimp fishery (ASMFC 1994) and the *Illex illecebrosus* fishery in NAFO Subareas 3 and 4 (NAFO 1980), establishing a fixed fishing season for the U.S. EEZ *Illex* fishery makes sense, since most of the landings (91%) consistently occurred between June and September during 1982-1993. A fixed season would be beneficial in terms of reducing fishing on small squid early in the season and reducing costs associated with real-time monitoring of the fishery since data collection would occur during a shorter time window. Furthermore, a limited season may allow more vessels to fish than would be the case for fishing throughout the year. At a minimum, mandatory reporting of total removals (kept and discarded squid) in terms of weight, by 3-digit statistical area, would be required on a daily or weekly basis for individual vessels in the fishery. Recently, *Illex* has been classified by multiple market categories. If there are large size differences between these categories, it would also be useful to collect this information by market category.

Ideally, mandatory reporting of daily or weekly effort data, by 3-digit statistical area, would be required for each of the 45 or so vessels in the fishery. However, a subset of vessels (e.g. from various tonclass categories) could be selected for this purpose. The appropriate measures of effort require further investigation as do factors associated with vessel type, such as freezer capacity, which are invaluable when estimating catchability coefficients for vessels and detecting reasons for large changes in catchability.

The existing port sampling program, which involves the collection of commercial length and weight data, could be used to fulfill some of these data collection requirements. However, this sampling would have to be mandatory for the selected subset of vessels from this fishery and the sampling intensity would have to be increased at the ports where these vessels land their catch. When considering sample distribution by statistical reporting area, it should be noted that most of the *Illex* landings (74%) during 1982-1993 were from a single statistical area (SA 622).

In addition, mandatory sampling at sea would be required on a weekly basis, for a selected subset of vessels, in order to verify port sampling data, discarding practices and sexual maturation for SSB calculations. This biological data would also be used for monitoring purposes, such as detecting growth and maturation anomalies. Similar to the protocol of the existing sea sampling program, biological sampling would include the collection of length-frequency data of the catch, but possibly subsampled by market category. Since discarding practices may vary from year-to-year, depending on market conditions and other factors, monitoring of this fraction of the catch should be conducted, but may not require the same sampling intensity. Individual weight measurements from these subsamples could be taken at a laboratory, along with sex and sexual maturity information. Although sex and sexual maturity information is preferred it is not a necessity. However, the length and weight data is critical to deriving in-season, length-weight equations used to convert the catch weights to numbers for use in the Leslie-DeLury assessments. At the start of the fishing season, observed length-frequency data may be used with a length-weight equation derived from the NEFSC spring bottom trawl survey data or the previous year's fishery.

Summary

In summary, the basic components of a real-time management plan include: a target level of exploitation, a threshold spawning biomass to be avoided, and a method of monitoring where the population level is with regard to the target and, in particular, the threshold. The approaches to establishing a real-time management plan for the U.S. EEZ *Illex* squid fishery are summarized in Appendix F. Although further investigations would be required to determine the details of such a plan, the preliminary analyses described in this section may serve as a starting point.

SUMMARY AND CONCLUSIONS

The U.S. EEZ portion of this transboundary stock is fully-exploited and probably at a medium biomass level. Total landings have been dominated by the domestic fishery since 1983 and there has been no foreign participation in this fishery since 1987.

Domestic landings have been increasing every year since 1988, reaching a peak of 18,012 mt in 1993, and spatial expansion of the fishery has occurred since 1982. Since 1988, effort has also been increasing, to a near-record high in 1993, while LPUE has been gradually decreasing. Therefore, the potential consequences of increased effort should be evaluated before further effort is directed toward the U.S. EEZ portion of this stock.

The current overfishing definition does not provide adequate protection for this species given its annual life cycle. A more appropriate overfishing definition should minimize the risk of recruitment overfishing by ensuring that escapement during the current year exceeds a threshold minimum spawning stock biomass (SSB_{min}) which is sufficient to ensure a high probability of successful recruitment in the subsequent year. Given the flat-topped nature of the yield-per-recruit curve for this species, $F_{20\%}$ (0.28 per month) would represent an appropriate threshold, with fishing intensity such that escapement is above this threshold, at a monthly target level of $F_{50\%}$ (0.11 per month). A similar target of 40% proportional escapement has been applied to the *Illex argentinus* fishery in the Falkland Islands. Fishing mortality rates in the U.S. EEZ have steadily been increasing since 1988 and exceeded the $F_{50\%}$ target in 1993 (F_{93}= 0.12 per month). The probability that F_{93} exceeded the $F_{50\%}$ target was 0.54 and the probability that it exceeded the $F_{20\%}$ threshold was 0.01. Landings in excess of the threshold may jeopardize the stock and have deleterious ecosystem-level effects.

Provisional estimates of LTPY were derived from expected yields, for the period 1982-1993, which were predicted by a biomass dynamics model with respect to the biological reference point F levels. Median long-term potential yields of 14,579 mt and 21,325 mt, for the target ($F_{50\%}$) and threshold ($F_{20\%}$) fishing mortality rates, respectively, were computed from the model bootstrap estimates of *r*, *q* and *K*. Average landings during 1988-1993 (11,305 mt) were below the target median yield. Although average landings during 1992-1994 (18,063 mt) exceeded this target, they lie within the predicted interquartile yield range for $F_{50\%}$. These LTPY estimates are consistent with recent resource productivity, but could vary depending on the favorability of environmental conditions for recruitment and growth.

Recruitment for this annual species may vary substantially due to natural environmental variability. *Illex* recruitment in the northern portion of its range appears to be related to ocean climate (Dawe and Warren, 1992), with poor recruitment coinciding with cold conditions (Beck *et al.*, 1994). In addition to its value as a commercial resource, the important ecosystem role of *Illex* as both predator and prey is another important reason for understanding the population dynamics of this species. For example, *Illex* abundance may increase when niche space becomes available, due to decreases in predators and competitors or increases in prey (Dawe and Brodziak, *In Press*). Environmental factors cannot be predicted or controlled. However, real-time management of a species with highly variable recruitment and no overlap of generations would permit in-season adjustments of catch, or preferably, effort limitations. These adjustments would ensure preservation of adequate levels of spawning biomass each year, avoidance of overfishing during periods of poor recruitment, and increased landings during periods of good recruitment. A real-time management plan has been implemented in the Falkland Islands for *Illex argentinus*. Good agreement between the fitting of a Leslie-DeLury model to monthly LPUE data, from the U.S. EEZ *Illex* fishery, and the results obtained from the Hilborn-Walters production model suggests that a similar type of management plan may be possible for this fishery.

In addition, the current NAFO (Subareas 2-4) TAC of 150,000 mt, if taken, may not be sustainable. Landings of this magnitude were achieved only once, in 1979, during a period of exceptional *Illex* abundance. During the historic peak of the *Illex* fishery, 1976-1980, average landings of only 90,000 mt were sustained. The fact that landings and apparent abundance declined markedly following this peak suggests that landings above 90,000 mt may not, in fact, be sustainable either. Return of the *Illex illecebrosus* fishery in NAFO Subareas 3 and 4 (Beck *et al.* 1994) has not yet occurred for unknown reasons. It has been speculated that the relative contribution of seasonal breeding components within the stock may have been altered through intensive harvest (O'Dor and Coelho 1993). The NAFO TAC should be reconsidered along with additional management measures. *Illex illecebrosus* is a highly-migratory, transboundary species and a joint assessment between U.S. and Canadian scientists is critical to resolving management differences between NAFO Subareas 2-4 and the U.S. EEZ.

REFERENCES

ASMFC [Atlantic States Marine Fisheries Commission]. 1994. Assessment report for Gulf of Maine northern shrimp, 1994.

Azarovitz, T.R. 1981. A brief historical review of the Woods Hole Laboratory trawl survey time series. In: Doubleday, W.G. and Rivard, D. (Eds.) Bottom trawl surveys. *Canadian Special Publication of Fisheries and Aquatic Sciences* 58, p. 62-67.

Basson, M., J.R. Beddington, J.A. Crombie, S.J. Holden, L.V. Purchase and G.A. Tingely. *In Press.* Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the southwest Atlantic as an example. Fish. Res.

Beck, P.C., E.G. Dawe and J. Drew. 1994. An update of the fishery for short-finned squid (*Illex illecebrosus*) in the Newfoundland area during 1989-93 with descriptions of some biological characteristics and temperature trends. NAFO SCR Doc. No. 94/37.

Beddington, J.R., A.A. Rosenberg., J.A. Crombie and G.P. Kirkwood. 1990. Stock assessment and the provision of management advice for the short fin squid fishery in Falkland Island waters. Fish. Res. , 8:351-365.

Brodziak, J. and L.C. Hendrickson. (1996). Stock assessment of short-finned squid, *Illex illecebrosus*, in the Northwest Atlantic during 1992. NOAA/NMFS/NEFSC: Woods Hole,MA. NEFSC [Northeast Fisheries Science Center] Ref. Doc. 94-05.

Brodziak, J. and L.C. Hendrickson. *In Prep.* An analysis of some factors affecting survey catches of squids, *Loligo pealei* and *Illex illecebrosus* in the Northwest Atlantic.

Brodziak, J.K.T. and W.K. Macy III. 1996. Growth of long-finned squid, *Loligo pealei*, in the northwest Atlantic. Fish. Bull. 94:212-236.

Coelho M.L. and R.K. O'Dor. 1993. Maturation, spawning patterns and mean size at maturity in the short-finned squid *Illex illecebrosus*. p. 81-91. *In:* Okutani T., O'Dor R.K. and Kubodera T. (eds.) *Recent Advances in Cephalopod Fisheries Biology*. Takai University Press, Tokyo, XV + 752 p.

Dawe, E.G., R.K. O'Dor, P.H. Odense, and G.V. Hurley. 1985. Validation and application of an ageing technique for short-finned squid (*Illex illecebrosus*). J. Northw. Atl. Fish. Sci. 6:107-116.

Dawe, E.G. and P.C. Beck. 1992. Population structure, growth, and sexual maturation of short-finned squid at Newfoundland, Canada, based on statolith analysis. ICES C.M. Shellfish Committee/K:33.

Dawe, E.G. and W. Warren. 1992. Recruitment of short-finned squid in the Northwest Atlantic Ocean and some environmental relationships. J. Ceph. Biol. 2(2): 1-21.

Dawe, E.G. and J. Brodziak. *In Press*. Trophic relationships and possible effects of ecosystem variability on recruitment in short-finned squid of the genus *Illex*. *In:* O'Dor, R.K., P.G. Rodhouse and E.G. Dawe (Eds.). A review of the recruitment dynamics in the squid genus *Illex*. FAO Fish. Tech. Paper.

Dawe, E.G. 1996. Personal communication. Department of Fisheries and Oceans. St. John's, Newfoundland.

Durward, R.D., T. AMARATUNGA and R.K. O'Dor. 1979. Maturation index and fecundity for female squid, *Illex illecebrosus* (LeSueur, 1821). ICNAF Res. Bull. 14:67-72.

Hilborn, R. and C.J. Walters. 1992. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty.* Chapman and Hall, New York, 570 p.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 81:898-903.

Hurley, G.V., P. Odense, R.K. O'Dor and E.G. Dawe. 1985. Strontium labelling for verifying daily growth increments in the statoliths of the short-finned squid (*Illex illecebrosus*). Can. J. Fish. Aquat. Sci. 42:380-383.

Lange A.M.T. and M. P. Sissenwine. 1981. Evidence of summer spawning of *Illex illecebrosus* (LeSueur) off the Northeastern United States. NAFO SCR Doc. 81/VI/33.

Lange, A.M.T., and K. Johnson. 1981. Dorsal mantle length-total weight relationships of squids *Loligo pealei* and *Illex illecebrosus* from the Atlantic Coast of the United States. NOAA Tech. Rep. NMFS/SSRF 745.

Lange, A.M.T., M.C. Ingham and C.A. Price. 1984. Distribution of maturing Illex illecebrosus relative to the shelf-slope fromt of the northeastern United States. NAFO SCR Doc. 84/IX/109, Ser. No. N906. 18 p.

Mercer, M.C. 1973. Sexual maturity and sex ratios of the ommastrephid squid *Illex illecebrosus* (LeSueur) at Newfoundland (Subarea 3). ICNAF Res. Doc. 73/71, Ser. No. 3024. 14 p.

Mid-Atlantic Fishery Management Council. 1994. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1995.

Mid-Atlantic Fishery Management Council. 1995a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1996.

Mid-Atlantic Fishery Management Council. 1995b. *Draft*: Amendment 5 to the Fishery Management Plan and the Final Environmental Imapct Statement for the Atlantic Mackerel, Squid and Butterfish Fisheries. 201 pp.

NAFO [Northwest Atlantic Fisheries Organization] 1980. Canadian proposal for international regulation of the fisheries for squid (*Illex*) on Subareas 3 and 4 of the Convention Area. NAFO Fisheries Commission Document 80/III/4, Ser. No. N085.

NAFO [Northwest Atlantic Fisheries Organization] 1986. Historical Catches of Selected Species by Stock Area and Country for the Period 1963-84. NAFO SCS Doc. 86/2, Ser. No. N1112.

NAFO [Northwest Atlantic Fisheries Organization] 1994a. Historical Catches of Selected Species by Stock Area and Country for the Period 1982-92. NAFO SCS Doc. 94/1, Ser. No. N2351.

NAFO [Northwest Atlantic Fisheries Organization] 1994b. Provisional Nominal Catches in the Northwest Atlantic, 1993. NAFO SCS Doc. 94/24. Ser. No. N2487.

NAFO [Northwest Atlantic Fisheries Organization] 1995. Scientific Council Reports, 1994. pp. 116-117.

NEFC. 1990. Report of the Spring 1990 NEFC Stock Assessment Workshop (Tenth SAW). NOAA\NMFS\NEFC: Woods Hole, MA. NEFC [Northeast Fisheries Center] Ref. Doc. 90-07.

NEFSC. 1991. Report of the Twelfth Northeast Regional Stock Assessment Workshop, Spring, 1991. NOAA\NMFS\NEFC: Woods Hole, MA. NEFSC [Northeast Fisheries Center] Ref. Doc. 91-03.

NEFSC. 1992. Report of the Fourteenth Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NOAA\NMFS\NEFC: Woods Hole, MA. NEFSC [Northeast Fisheries Center] Ref. Doc. 92-07.

NEFSC. 1994. Report of the Seventeenth Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. NOAA/NMFS/NEFSC: Woods Hole, MA. NEFSC [Northeast Fisheries Science Center] Ref. Doc. 94-06.

O'Dor R.K. and Coelho M.L. 1993. Big squid, big currents and big fisheries. p. 385-396. *In:* Okutani T., O'Dor R.K. & Kubodera T. (Eds.) *Recent Advances in Cephalopod Fisheries Biology.* Takai University Press, Tokyo, XV + 752 p.

O'Dor, R.K. and E.G. Dawe. *In press.* Chapter 4. *Illex illecebrosus. In:* O'Dor, R.K., P.G. Rodhouse and E.G. Dawe (Eds.). A review of the recruitment dynamics in the squid genus *Illex.* FAO Fish. Tech. Paper.

Perry, R.I. and S.J. Smith. 1994. Identifying habitat associations of marine fishes using survey data: an application to the northwest Atlantic. Can. J. Fish. Aquat. Sci. 51:589-602.

Peterson, I. and J. S. Wroblewski. 1984. Mortality rates of fishes in the pelagic ecosystem. Can. J. Fish. Aquat. Sci. 41:1117-1120.

Rosenberg, A. A, P. Mace, G. Thompson, G. Darcy, W. Clark, J. Collie, W. Gabriel, A. MacCall, R. Methot, J. Powers, V. Restrepo, T. Wainwright, L. Botsford, and K. Stokes. 1994. Scientific review of definitions of overfishing in U.S. fishery management plans. NOAA Tech. Mem. NMFS-F/SPO-17.

Rosenberg, A.A., Kirkwood, G.P., Crombie, J. and Beddington, J.R. 1990. The assessment of stocks of annual squid species. Fish. Res. 8:335-350.

Rowell T.W., Trites R.W. and Dawe E.G. 1985. Distribution of short-finned squid larvae and juveniles in relation to the Gulf Stream Frontal Zone between Florida and Cape Hatteras. NAFO Sci. Coun. Studies 9: 77-92.

Schnute, J. 1981. A versatile growth model with statistically stable parameters. Can. J. Fish. Aquat. Sci. 38:1128-1140.

Smith S.J., J.J. Hunt and D. Rivard (Eds). 1993. Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. fish. Aquat. Sci. 120 p.

Sokal R. R., and J.F. Rohlf. 1981. *Biometry: the principles and practice of statistics in biological research.* Second Edition. W.H. Freeman and Company. 859 p.

Trites R.W. 1983. Physical oceanographic features and processes relevant to *Illex illecebrosus* spawning in the western North Atlantic and subsequent larval distribution, NAFO Sci. Studies 6:39-55.

Walters, C.J. and R. Hilborn. 1976. Adaptive control of fishing systems. J. Fish. Res. Bd. Can. 33:145-149.

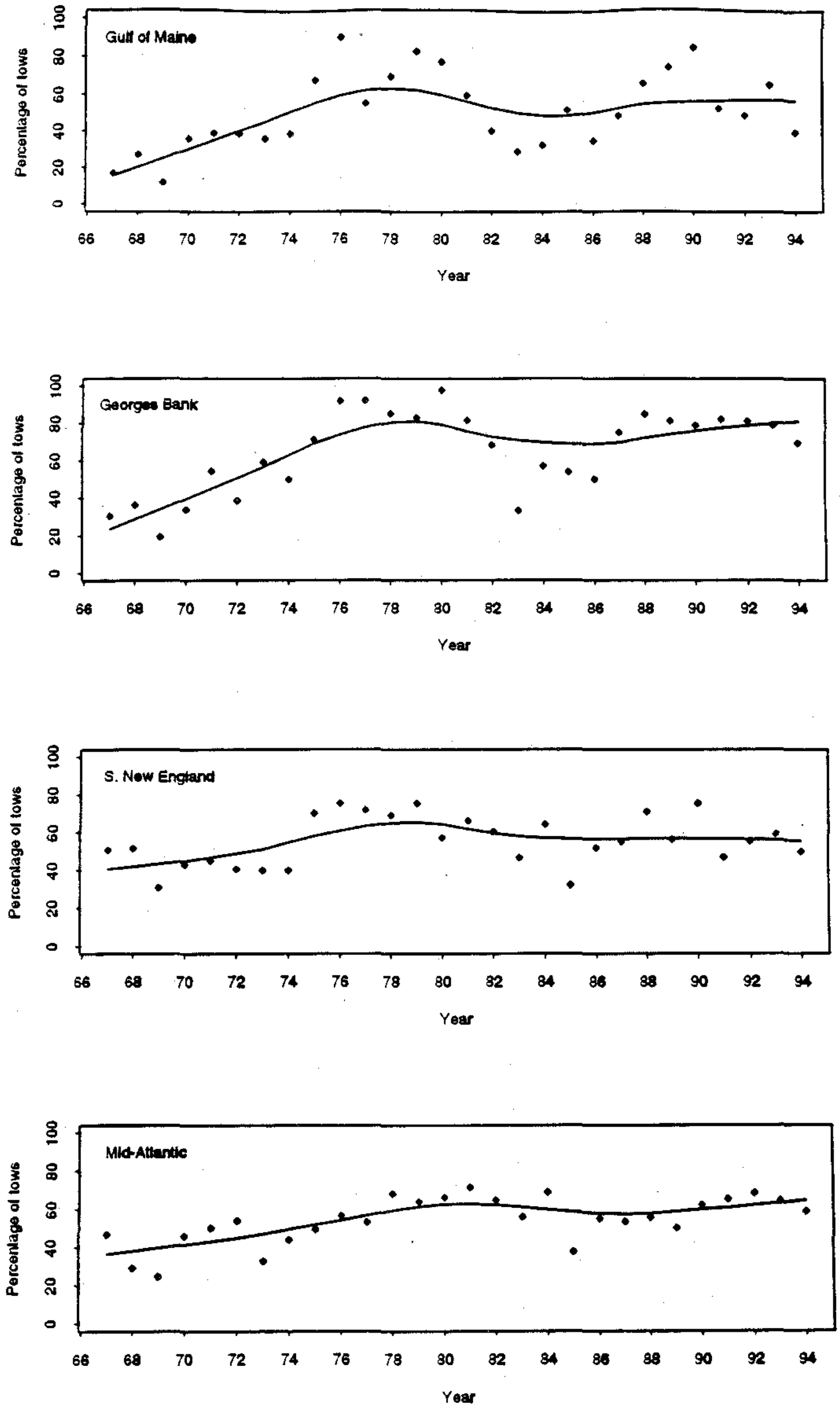


Figure 1. Proportion of tows, by region, in which Illex illecebrosus were caught during NEFSC autumn bottom trawl surveys, 1967-1994. Line represenets LOWESS smoothed estimate with tension parameter of 0.5.

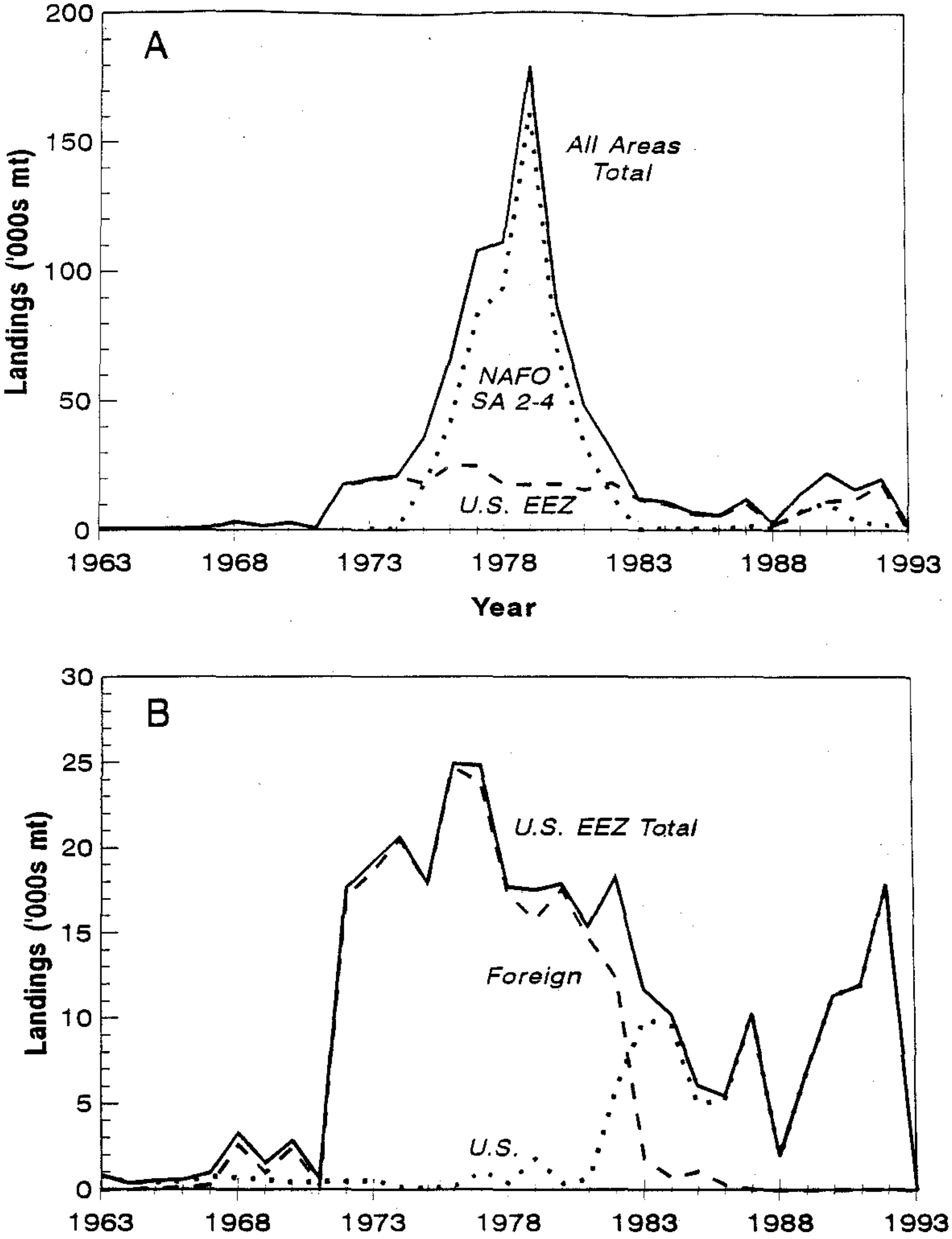


Figure 2. Trends in *Illex* squid landings from (A) the U.S. EEZ, NAFO Subareas 2-4 (1973-1993), and all areas combined and (B) U.S., foreign and total U.S. EEZ landings during 1963-1993.

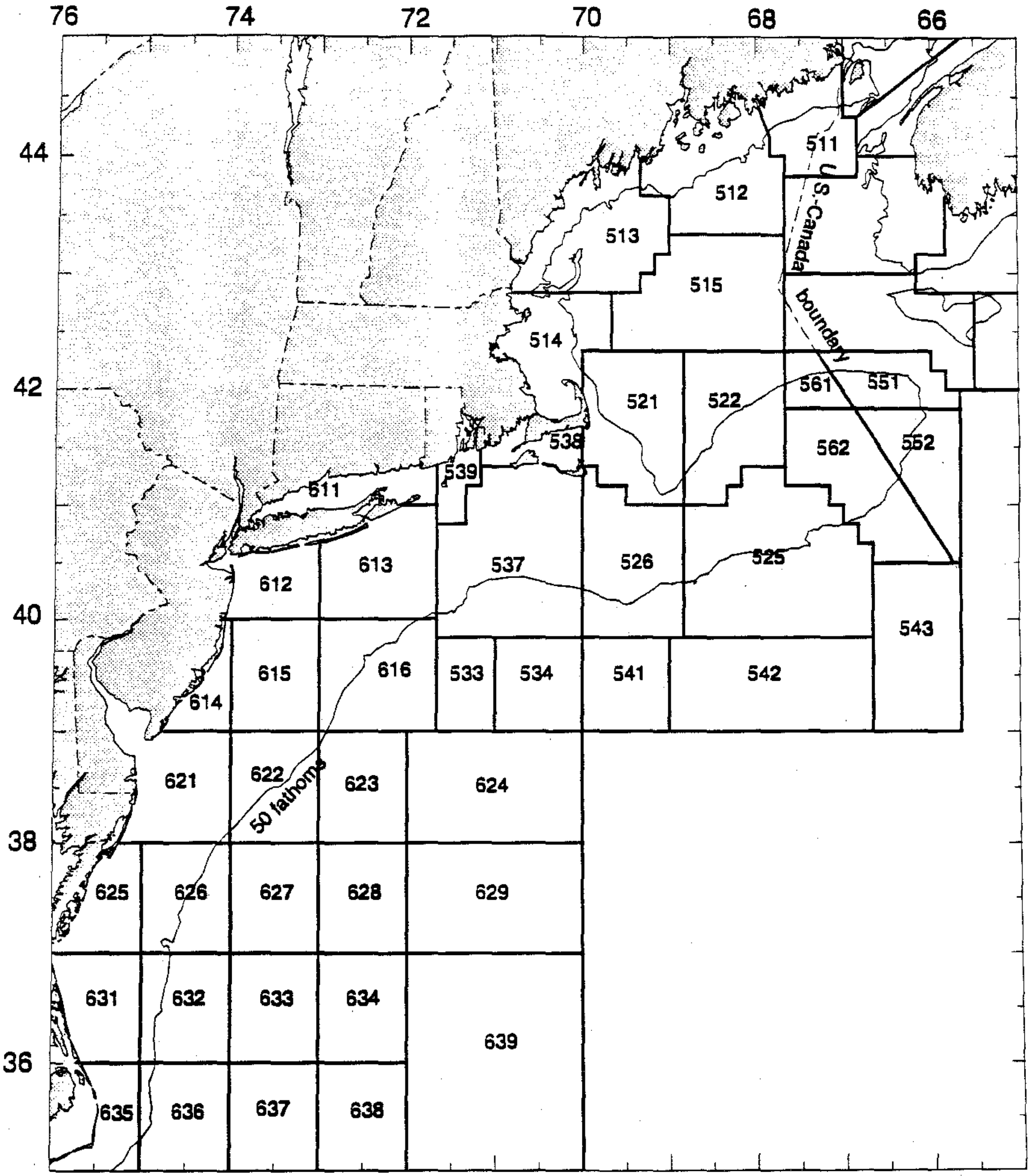


Figure 3. U.S. commercial statistical areas used to report landings in the northwest Atlantic.

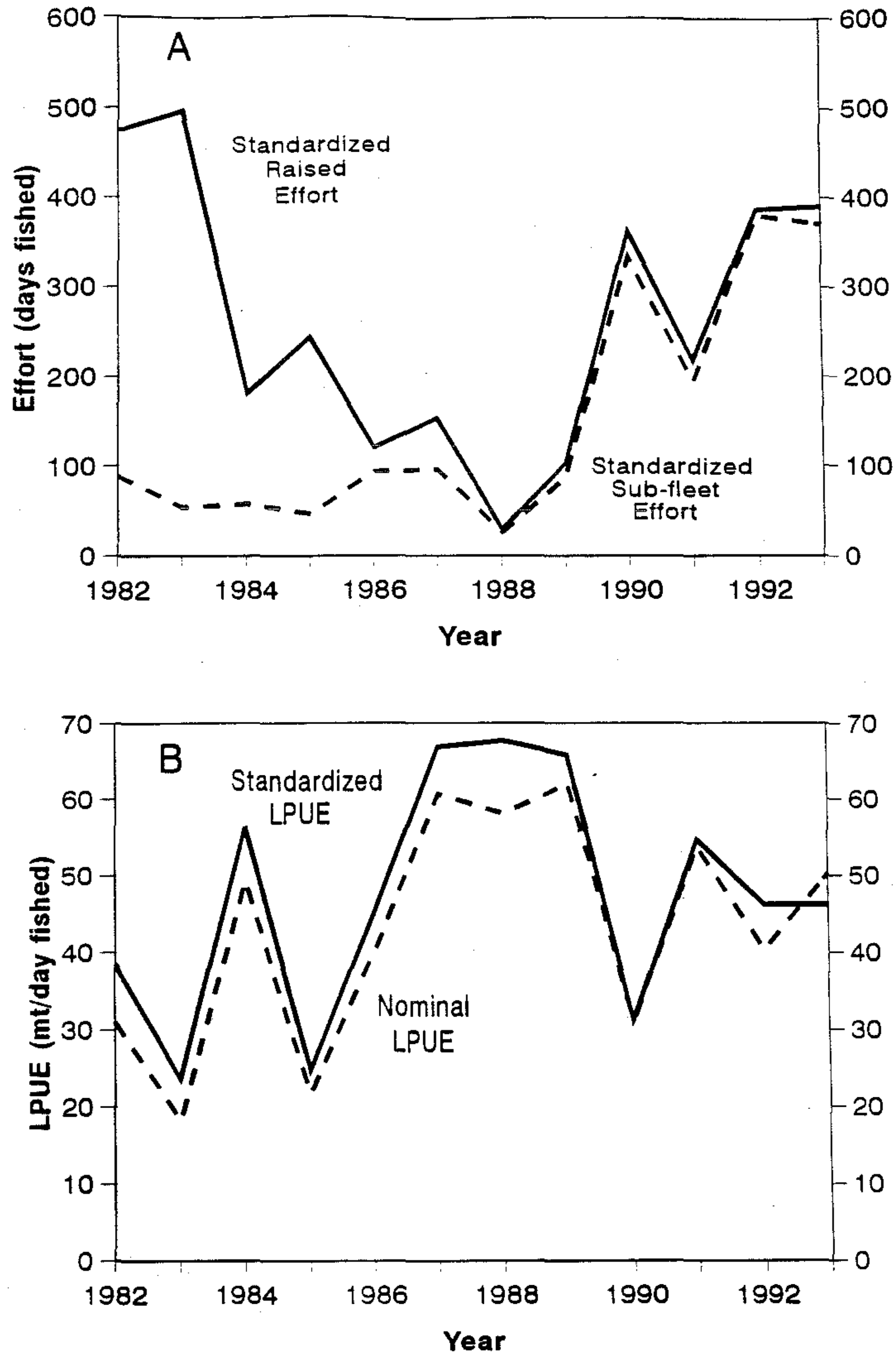


Figure 4. Trends in (A) standardized effort (days fished) and (B) standardized and nominal LPUE (mt/day fished), during 1982-1993, for vessels with landings of *Illex* squid that exceeded 25% of their total trip weight.

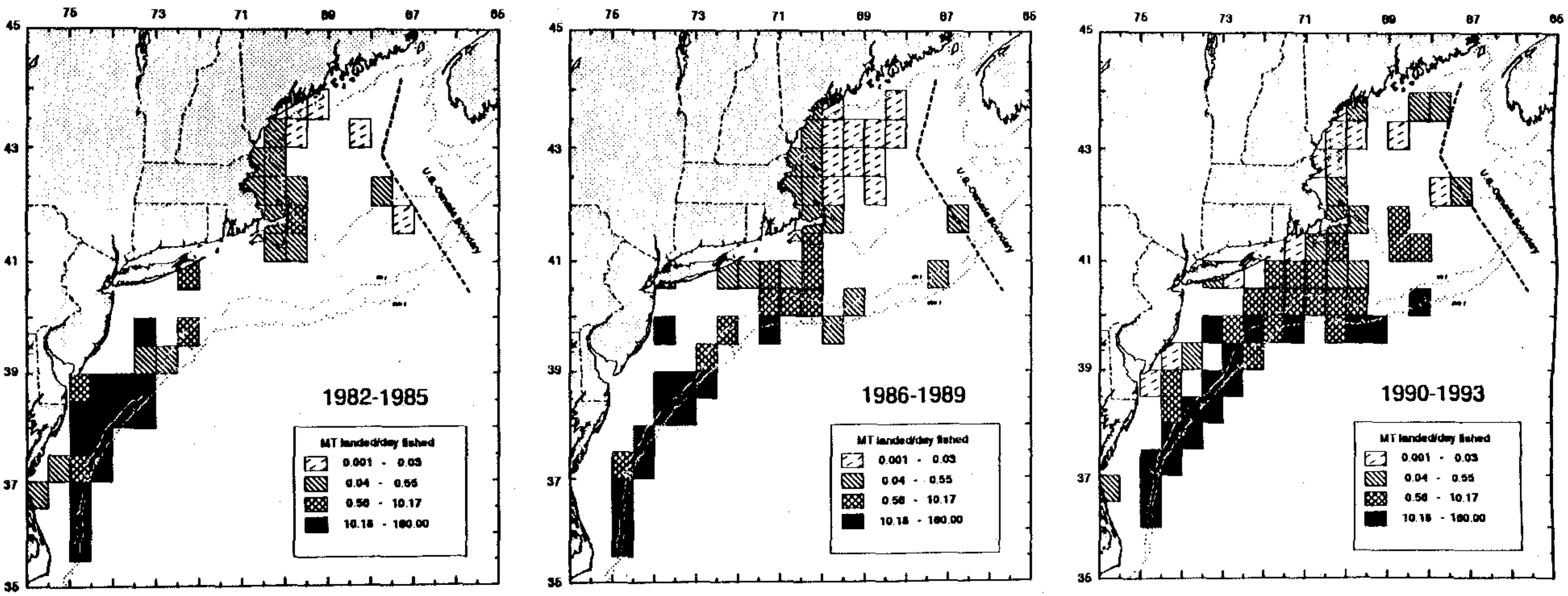


Figure 5. Landings per unit of effort (mt landed per day fished) of *Illex illecebrosus* for the domestic bottom trawl fishery during 1982-1993.

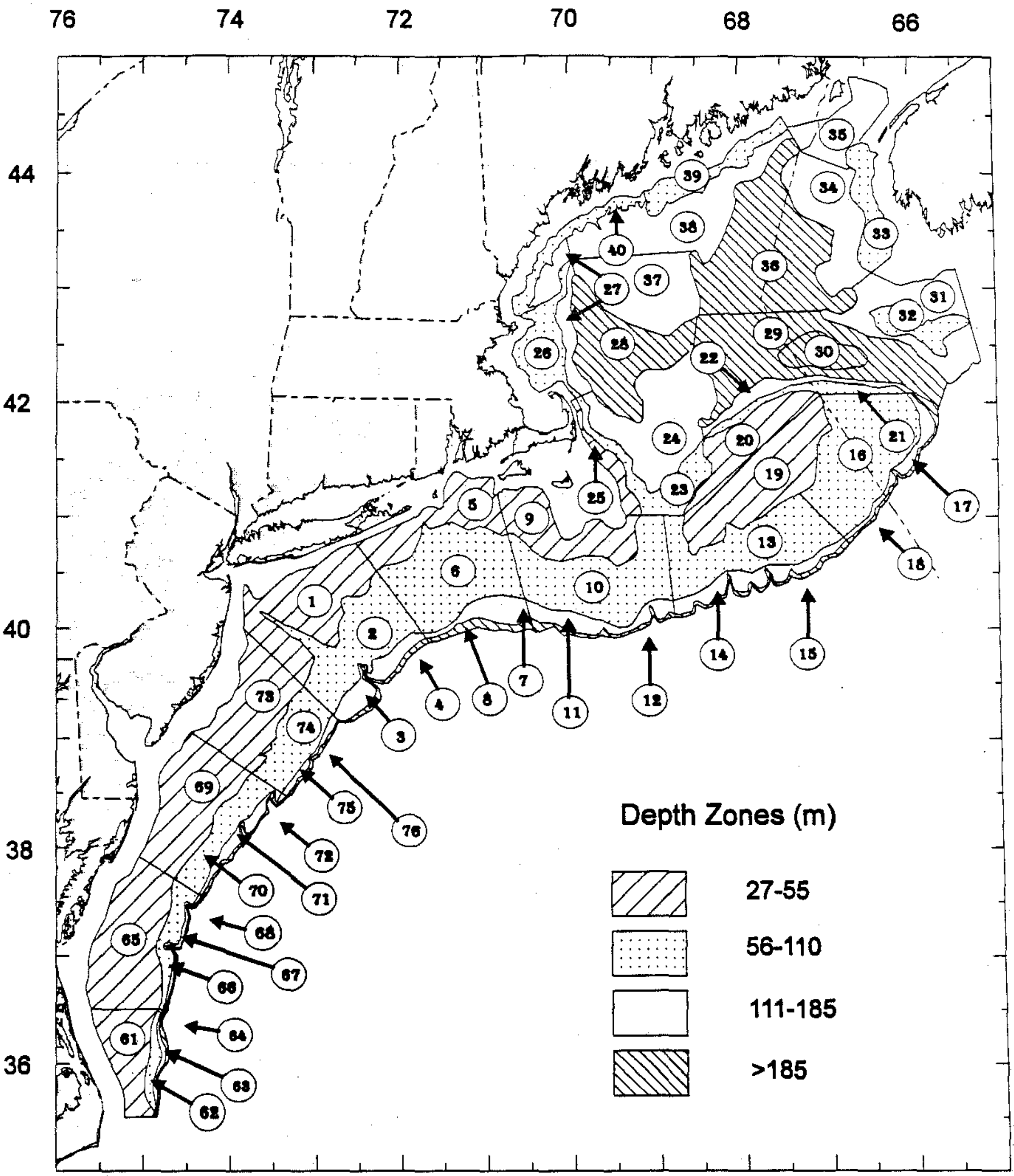


Figure 6. Northwest Atlantic offshore strata sampled during NEFSC bottom trawl surveys.

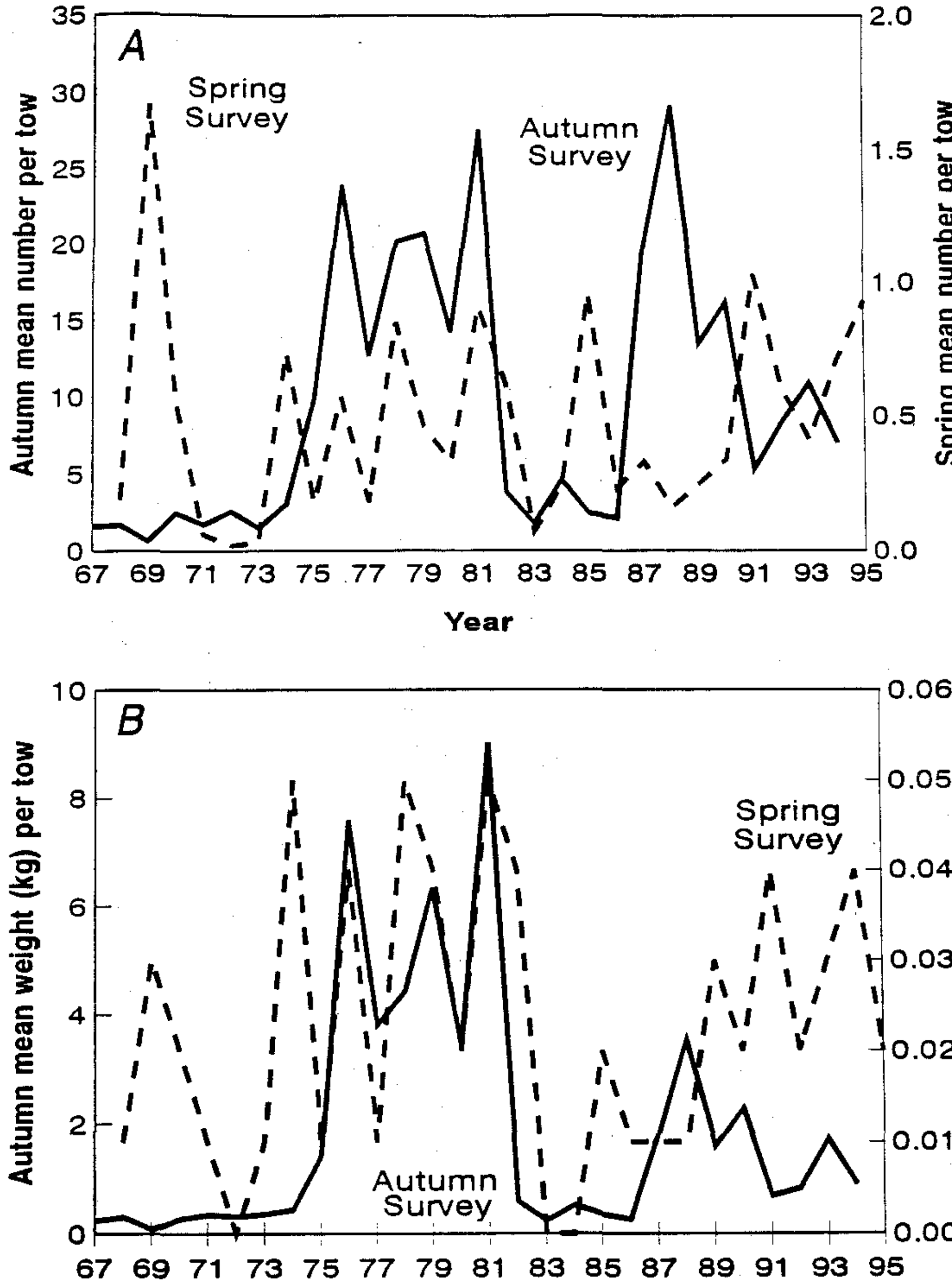


Figure 7. Standardized, stratified mean number per tow (A) and mean weight per tow (kg) (B) of *Illex illecebrosus* in NEFSC research bottom trawl surveys during autumn (1967-1994) and spring (1968-1995).

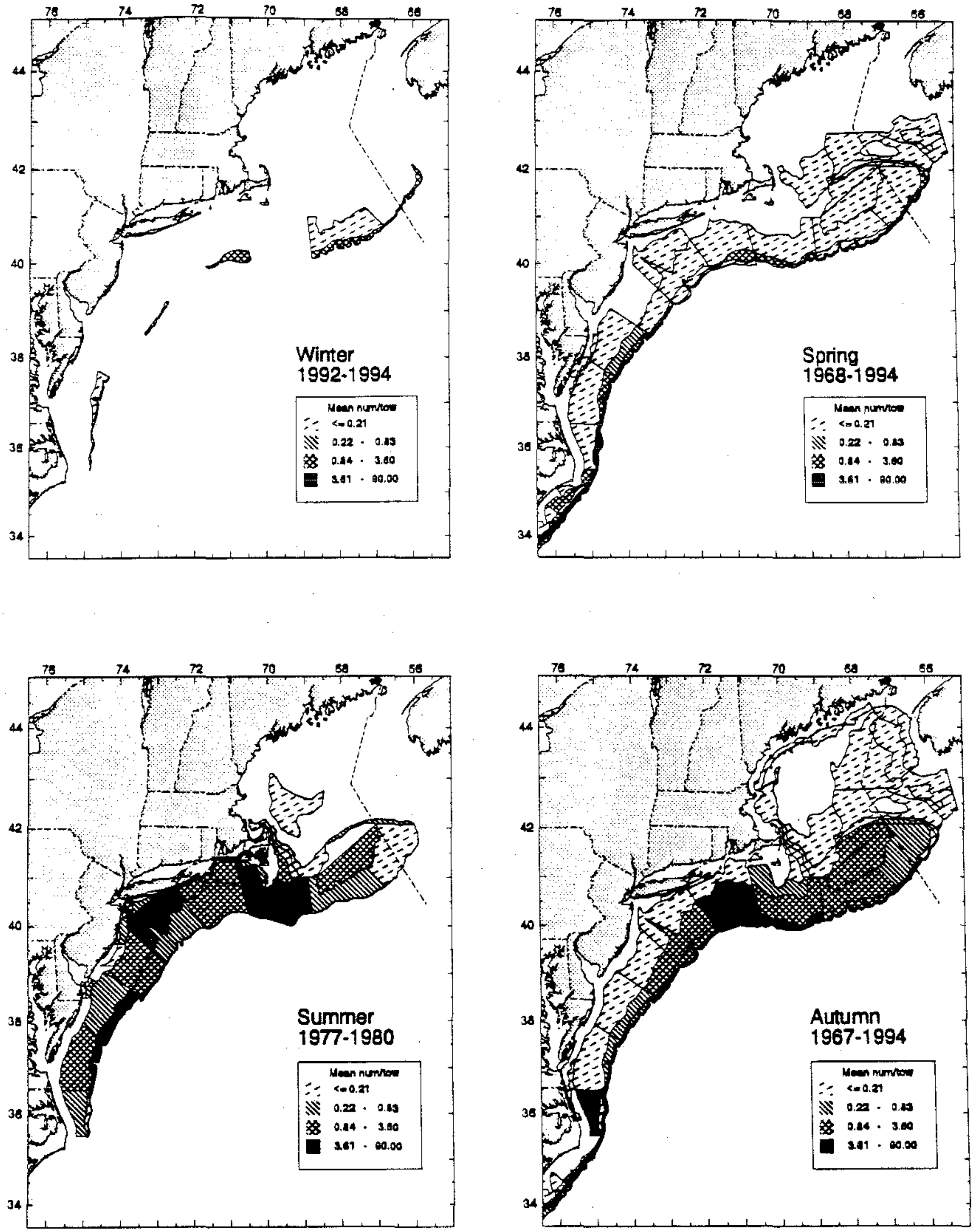


Figure 8. Mean number per tow of *Illex illecebrosus* pre-recruits (≤ 10 cm), by survey stratum, during NEFSC research vessel bottom trawl surveys.

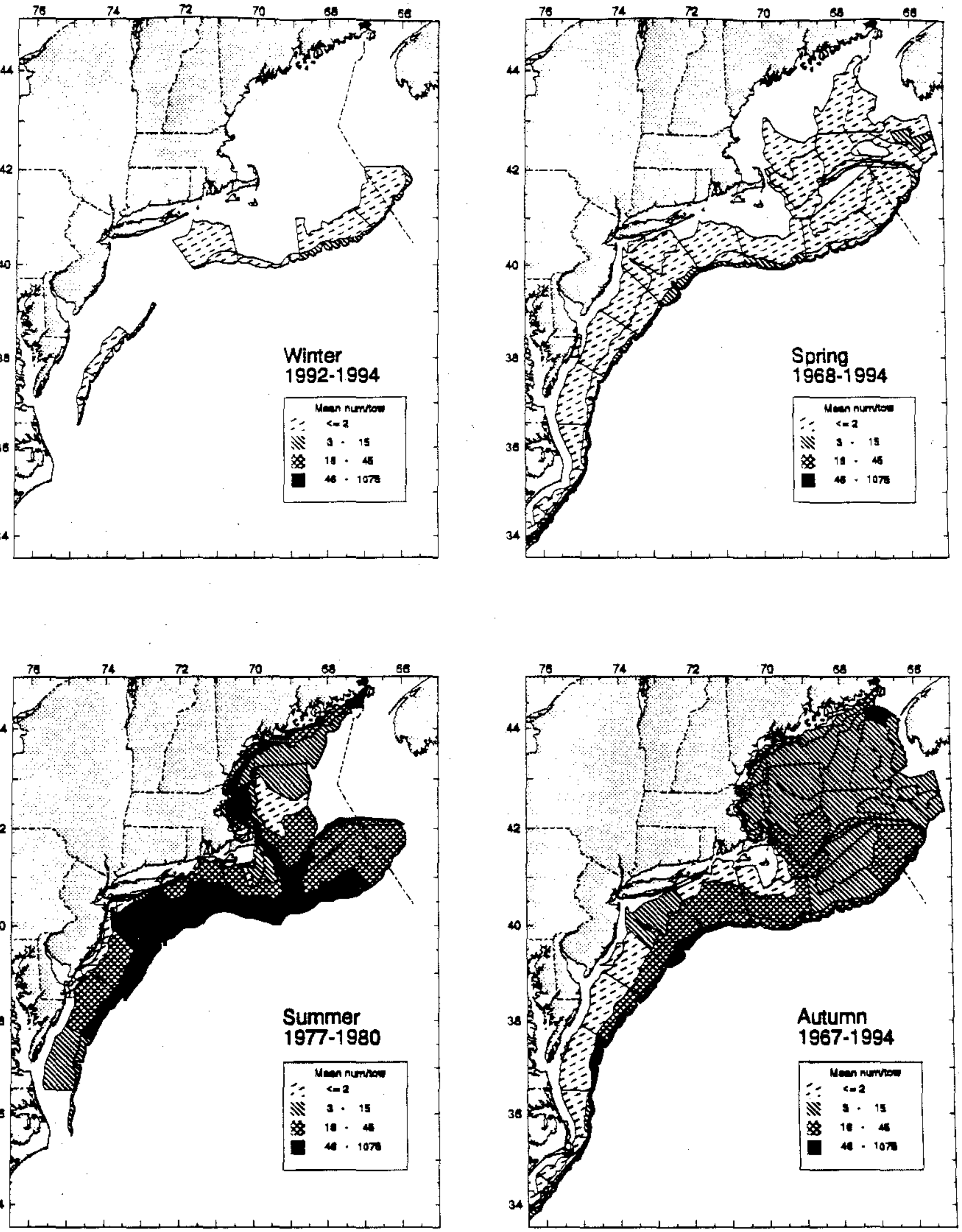


Figure 9. Mean number per tow of *Illex illecebrosus* recruits (≥ 11 cm), by survey stratum, during NEFSC research vessel bottom trawl surveys.

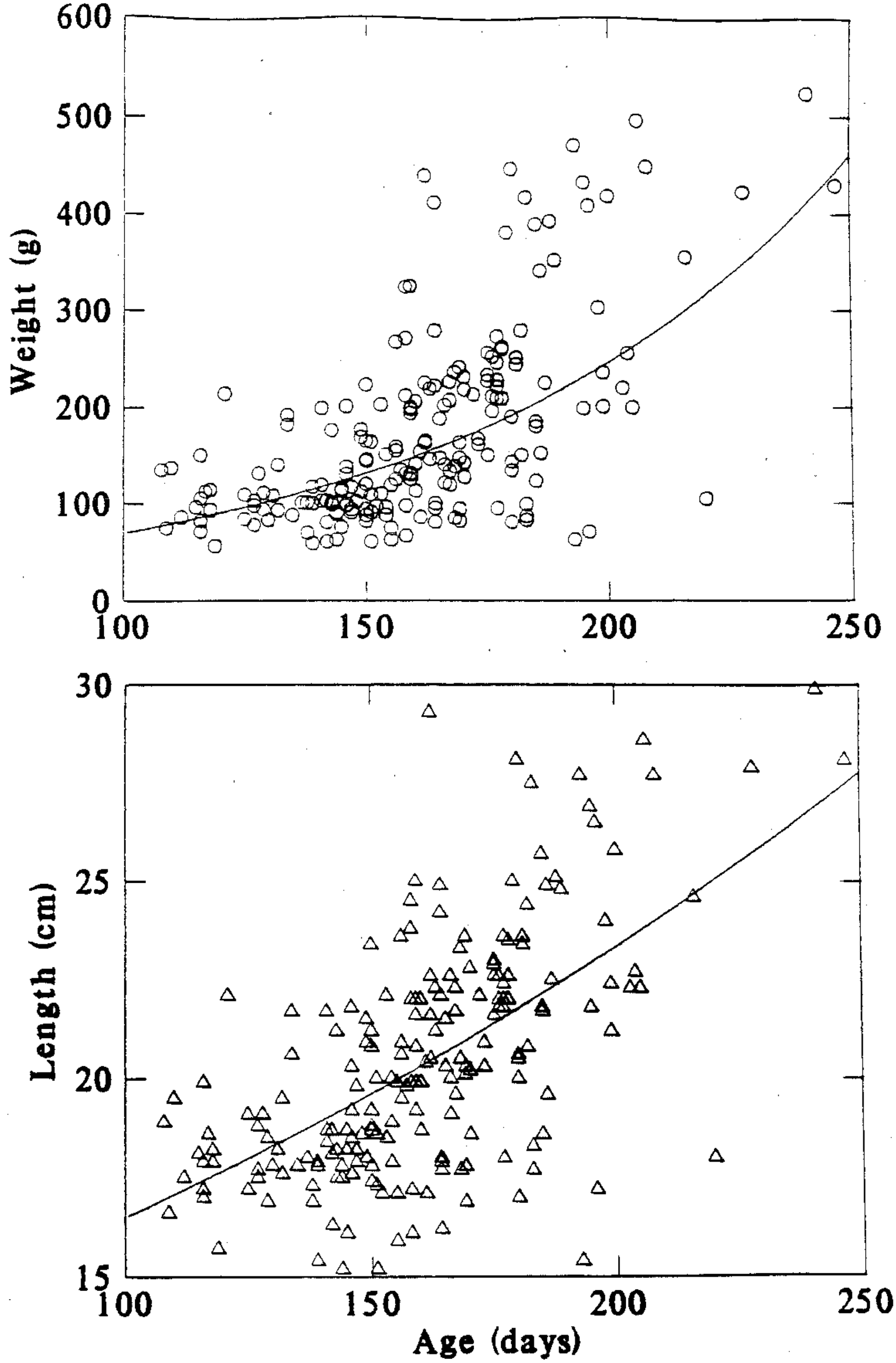


Figure 10. Observed and predicted weight-at-age (top) and length-at-age (bottom), for *Illex illecebrosus*. Weight = 20·exp(0.01255 d)) and length = 11.64·exp(0.00348 d). Raw data from E. Dawe (pers. comm., DFO, St. John's).

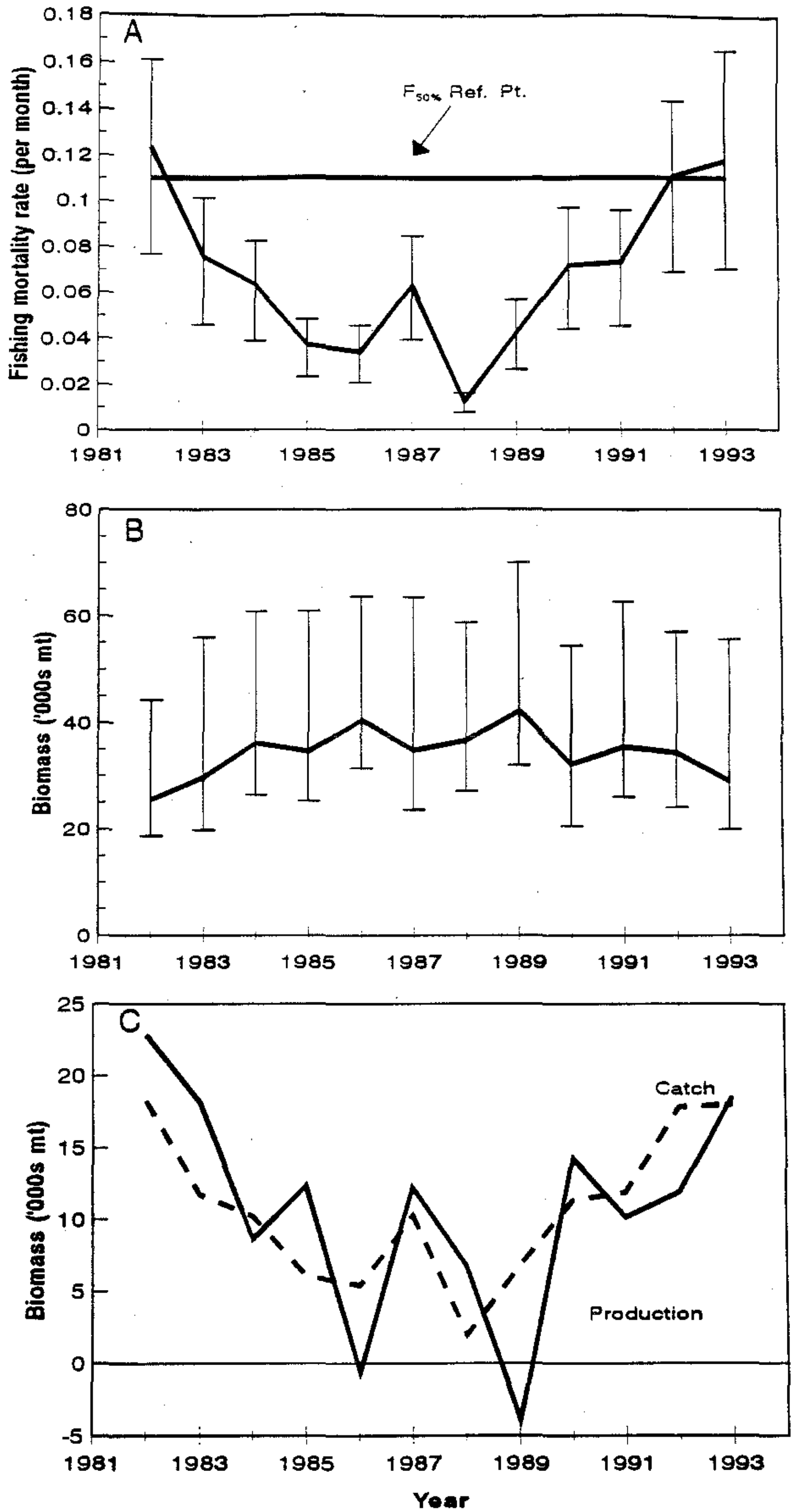


Figure 11. Median fishing mortality rates, in the U.S. EEZ *Illex illecebrosus* fishery, with interquartile ranges derived from bootstrap estimation (A), median initial biomass estimates with interquartile ranges (B), and annual catches with estimated median annual production (C). Negative production in year t implies a decrease in initial biomass in year t+1.

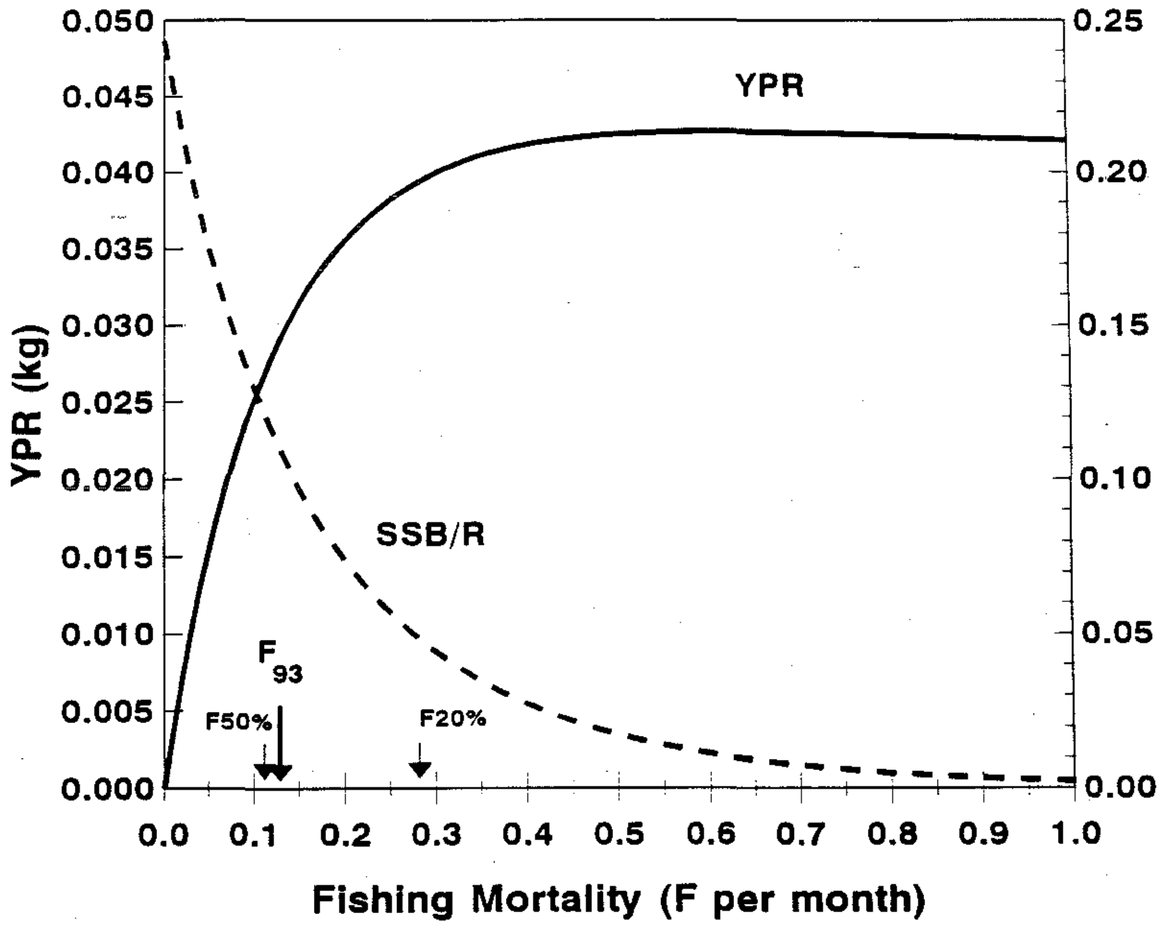


Figure 12. Yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) for *Illex illecebrosus*.

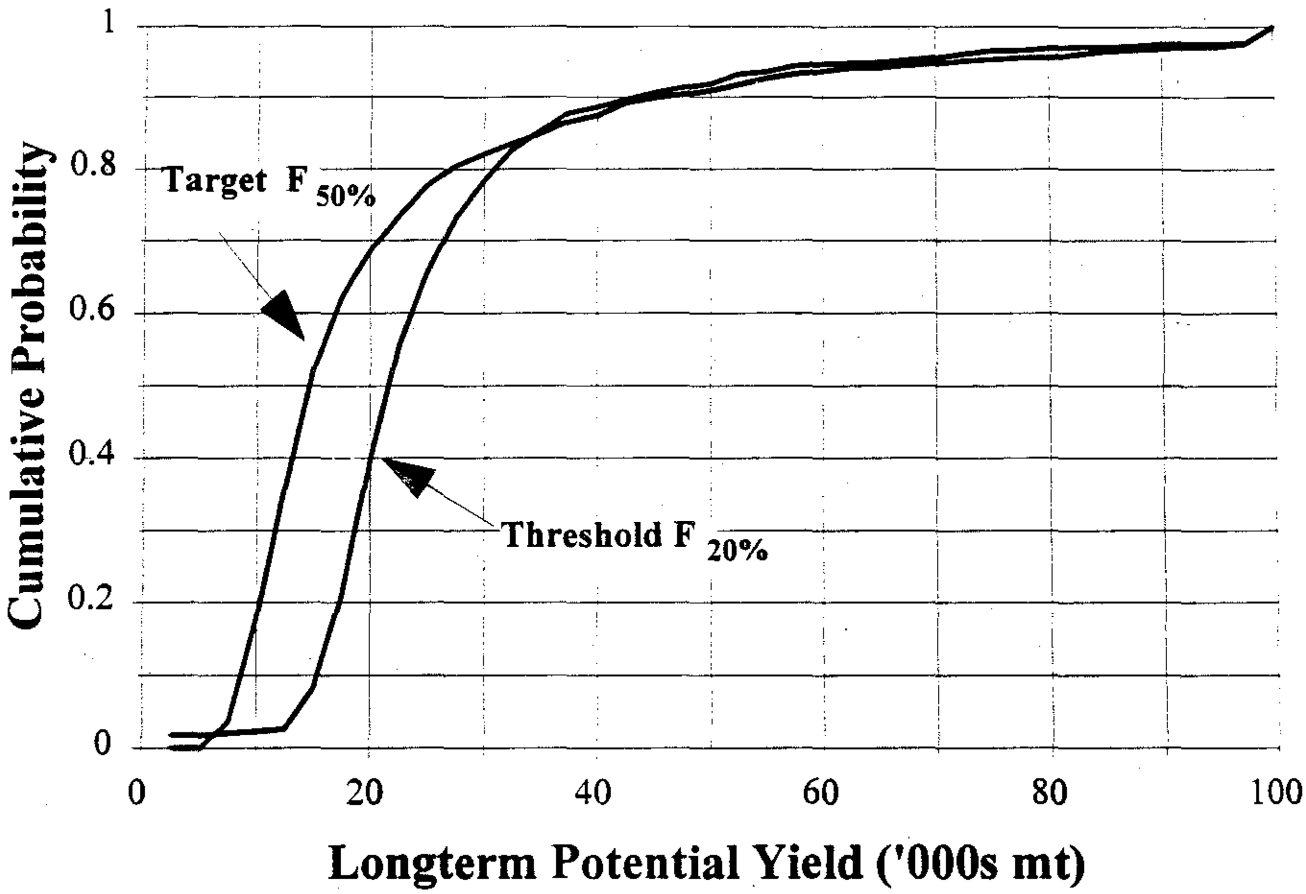


Figure 13. Distribution of long-term potential yields expected from the U.S. EEZ *Illex illecebrosus* fishery for target ($F_{50\%}$) and threshold ($F_{20\%}$) fishing mortality rates.

Table 1. Short-finned squid (*Illex illecebrosus*) landings (mt) from Cape Hatteras to the Gulf of Maine, during 1963-1994, and from NAFO Subareas 2, 3, and 4 during 1973-1993.[1,2,3]

Year	Cape Hatteras to the Gulf of Maine			NAFO Subareas 2, 3 and 4	All Areas
	Domestic	Foreign	Subtotal	Subtotal	Total
1963	810	0	810	- [1]	810
1964	358	2	360	- [1]	360
1965	444	78	522	- [1]	522
1966	452	118	570	- [1]	570
1967	707	285	992	- [1]	992
1968	678	2,593	3,271	- [1]	3,271
1969	562	975	1,537	- [1]	1,537
1970	408	2,418	2,826	- [1]	2,826
1971	455	159	614	- [1]	614
1972	472	17,169	17,641	- [1]	17,641
1973	530	18,625	19,155	641	19,796
1974	148	20,480	20,628	283	20,911
1975	107	17,819	17,926	17,696	35,622
1976	229	24,707	24,936	41,767	66,703
1977	1,024	23,771	24,795	83,480	108,275
1978	385	17,310	17,695	94,064	111,759
1979	1,780	15,742	17,522	162,092	179,614
1980	349	17,529	17,878	69,606	87,484
1981	631	14,723	15,354	32,862	48,216
1982	5,902	12,350	18,252	12,908 [3]	31,160
1983	9,944	1,776	11,720	421	12,141
1984	9,547	676	10,223	715	10,938
1985	4,997	1,053	6,050	673	6,723
1986	5,176	250	5,426	111	5,537
1987	10,260	0	10,260	1,718	11,978
1988	1,966	1	1,967	846	2,813
1989	6,801	0	6,801	7,327	14,128
1990	11,316	0	11,316	10,843	22,159
1991	11,908	0	11,908	3,838	15,746
1992	17,827	0	17,827	1,851 [2]	19,678 [2]
1993	18,012	0	18,012	2,759 [2]	20,771 [2]
1994	18,350 [2]	0	18,350	5,985 [2]	24,335 [2]
AVERAGES					
1963-1993	4,006	6,794	10,800	26,024 [1,2]	28,429 [2]
1973-1981	576	18,967	19,543	55,832	75,376
1982-1987	7,638	2,684	10,322	2,758	13,080
1988-1993	11,305	1	11,305	4,577 [2]	15,883 [2]

[1] NAFO squid landings were not reported by species prior to 1973, so average is given for 1973-1993.
[2] Provisional landings
[3] Landings during 1982-1992 have been updated by NAFO.

Table 2. U.S. EEZ landings (mt) of *Illex* squid , during 1993, by 3-digit statistical area and month.

AREA	MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	AVG % 1993	AVG % 1982-93
512	-	-	-	-	-	-	-	-	-	0.1	-	-	0.1	<1	<1
513	-	-	-	-	-	-	-	-	0.3	-	-	-	0.3	<1	<1
514	-	-	-	-	-	-	-	0.3	0.1	-	-	-	0.4	<1	<1
521	-	-	-	-	-	-	-	-	0.2	-	-	-	0.2	<1	<1
522	-	-	-	-	-	-	0.4	8.4	-	-	-	-	8.8	<1	<1
526	-	-	-	0.1	-	-	0.3	-	1966.0	681.7	-	-	2648.1	15	4
537	1.3	-	-	-	-	0.8	4.9	10.3	162.7	-	-	2.9	182.9	1	<1
538	-	-	-	-	0.1	-	0.3	-	-	-	-	-	0.4	<1	<1
561	-	-	-	-	-	-	-	0.4	-	-	-	-	0.4	<1	<1
616	33.3	0.3	-	1.7	0.1	-	159.8	1186.9	57.4	2.7	55.1	-	1497.3	8	4
621	-	-	-	-	-	-	0.1	-	-	-	-	-	0.1	<1	<1
622	6.4	3.8	1.8	3.0	5.2	1525.9	4690.8	4442.2	1925.9	349.5	85.4	14.8	13054.7	73	74
623	-	-	-	-	-	-	105.3	22.4	-	-	-	-	127.8	<1	1
626	-	-	-	0.4	3.6	-	199.3	46.6	117.3	40.7	24.4	3.0	435.3	2	9
627	-	-	-	-	-	-	-	-	-	15.7	-	-	15.7	<1	1
631	-	-	-	-	-	-	-	-	-	-	0.3	-	0.3	<1	<1
632	-	-	-	-	-	21.9	-	-	-	17.5	0.1	-	39.5	<1	4
TOTAL	41.0	4.1	1.8	5.2	9.0	1548.6	5161.2	5717.5	4229.9	1107.9	165.3	20.7	18,012.2		
AVG %	<1	<1	<1	<1	<1	9	29	32	23	6	<1	<1			
AVG % 1989-93	<1	<1	<1	<1	1	12	28	30	20	7	1	<1			
AVG % 1982-93	<1	<1	<1	<1	4	15	27	27	22	5	<1	<1			

Table 3. Length-frequency sampling intensity of *Illex* squid landed in the U.S. EEZ during 1982-1993.

YEAR	SQUID SAMPLED	LENGTH FREQUENCY SAMPLES	U.S. EEZ DOMESTIC LANDINGS (mt)	TONS LANDED PER SAMPLE
1982	2,961	59	5,902	100
1983	920	18	9,944	552
1984	1,690	33	9,547	289
1985	411	8	4,997	625
1986	866	17	5,176	304
1987	600	12	10,260	855
1988	759	15	1,966	131
1989	159	3	6,801	2,267
1990	324	6	11,316	1,886
1991	751	15	11,908	794
1992	800	16	17,827	1,114
1993	1,154	23	18,012	783

Table 4. Total numbers (millions) of *Illex illecebrosus* landed from Cape Hatteras to the Gulf of Maine during 1982-1993.

Year	Mean Weight (g)	Total Landings (mt)	Number of Squid Landed ($x10^6$)
1982	154	18,252	118.6
1983	130	11,720	90.2
1984	128	10,223	79.8
1985	130	6,050	46.4
1986	110	5,426	49.4
1987	132	10,260	77.4
1988	139	1,967	14.1
1989	126	6,801	54.0
1990	126	11,316	89.7
1991	140	11,908	85.1
1992	128	17,827	139.3
1993	123	18,012	146.4
AVERAGE 1982-1993	131	10,813	82.5

Table 5. General Linear Model analysis of LPUE for directed *Illex* squid trips in the U.S. EEZ during 1982-1993.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	342.13836128	15.55174369	26.12	0.0001
Error	1579	940.18543422	0.59543093		
Corrected Total	1601	1282.32379550			

R-Square	C.V.	Root MSE	LNCPUEDF Mean
0.266811	21.34403	0.7716417	3.6152583

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	11	168.67814841	15.33437713	25.75	0.0001
TONCLASS	1	15.92235389	15.92235389	26.74	0.0001
AREA	4	59.63406930	14.90851733	25.04	0.0001
MONTH	6	97.90378968	16.31729828	27.40	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	11	127.40487918	11.58226174	19.45	0.0001
TONCLASS	1	8.83076436	8.83076436	14.83	0.0001
AREA	4	52.70598304	13.17649576	22.13	0.0001
MONTH	6	97.90378968	16.31729828	27.40	0.0001

Parameter	Estimate		T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	3.724923867	B	50.64	0.0001	0.07355282
YEAR					
83	-0.715042849	B	-6.78	0.0001	0.10549186
84	0.383029198	B	4.32	0.0001	0.08869290
85	-0.576149911	B	-4.84	0.0001	0.11894811
86	-0.091549845	B	-0.99	0.3199	0.09201788
87	0.469253839	B	4.76	0.0001	0.09850293
88	0.430926944	B	3.23	0.0013	0.13347011
89	0.350937135	B	3.03	0.0025	0.11588224
90	-0.396321637	B	-4.10	0.0001	0.09663468
91	0.142449705	B	1.55	0.1213	0.09188585
92	0.027741936	B	0.36	0.7154	0.07607145
93	-0.004786929	B	-0.06	0.9491	0.07498800
82	0.000000000	B	.	.	.
TONCLASS					
3	0.163917128	B	3.85	0.0001	0.04256385
4	0.000000000	B	.	.	.
AREA					
526	1.390260548	B	8.22	0.0001	0.16916136
616	-0.005269795	B	-0.05	0.9640	0.11670176
626	-0.158211407	B	-2.36	0.0184	0.06703520
632	-0.309451927	B	-3.67	0.0002	0.08421010
622	0.000000000	B	.	.	.
MONTH					
5	-0.884058218	B	-9.25	0.0001	0.09554736
6	-0.033911156	B	-0.53	0.5992	0.06451520
7	-0.114140530	B	-2.04	0.0414	0.05591629
9	-0.161420188	B	-2.70	0.0069	0.05969926
10	-0.679510681	B	-7.30	0.0001	0.09313807
11	-1.246089309	B	-6.02	0.0001	0.20695364
8	0.000000000	B	.	.	.

Table 6. Standardized fishing effort and LPUE for *Illex* squid landed in the U.S. EEZ, between Cape Hatteras and the Gulf of Maine, during 1982-1993.

	GLM Model Results (Sub-fleet)					
Year	Landings (mt)	Standardized Effort[1] (days fished)	Domestic LPUE[2] (mt/df)	Total Landings (mt)	Ratio Total Landings/ Model Landings	U.S. Standardized Effort[3] (days fished)
1982	3,412	88.6	38.5	18,252	5.3	474
1983	1,266	53.7	23.6	11,720	9.3	497
1984	3,262	57.8	56.4	10,223	3.1	181
1985	1,154	46.6	24.8	6,050	5.2	244
1986	4,210	93.2	45.2	5,426	1.3	120
1987	6,403	95.6	66.9	10,260	1.6	153
1988	1,749	25.8	67.7	1,967	1.1	29
1989	5,769	87.7	65.8	6,801	1.2	103
1990	10,401	333.2	31.2	11,316	1.1	362
1991	10,599	193.7	54.7	11,908	1.1	218
1992	17,530	379.4	46.2	17,827	1.0	386
1993	17,078	369.7	46.2	18,012	1.1	390
AVERAGE 1982-1993			47.3	10,813		263

[1] Effort in 1982-1987 has been prorated to account for joint venture landings.
[2] Ratio of total landings (mt) to standardized effort for *Illex* trips used in the GLM.
[3] Calculated total standardized effort for the domestic fishery.

Table 7. All sizes, pre-recruit (≤ 10 cm), and recruit (≥ 11 cm) standardized, stratified mean catch per tow, in numbers and weight (kg), of *Illex illecebrosus* caught in NEFSC autumn research vessel bottom trawl surveys (offshore strata 1-40 and 61-76, Cape Hatteras to the Gulf of Maine) during 1967-1994.

Year	All sizes Number/tow	CV[1] (%)	All sizes Kg/tow	Individual Mean Weight (g)	Pre-recruits Number/tow	Recruits Number/tow
1967	1.64	19	0.24	147	0.04	1.56
1968	1.66	21	0.31	186	0.10	1.56
1969	0.61	25	0.07	121	0.09	0.52
1970	2.45	26	0.27	110	0.93	1.51
1971	1.69	12	0.35	206	0.19	1.50
1972	2.57	25	0.32	123	0.68	1.89
1973	1.46	23	0.35	242	0.04	1.42
1974	3.06	41	0.44	145	1.20	1.87
1975	9.85	43	1.41	143	3.98	5.87
1976	23.94	22	7.59	317	0.42	23.52
1977	12.72	19	3.80	299	0.72	12.00
1978	20.18	20	4.43	219	3.29	16.89
1979	20.75	13	6.34	305	1.31	19.44
1980	14.24	16	3.38	238	0.43	13.81
1981	27.62	34	9.02	327	0.22	27.40
1982	3.80	13	0.59	155	0.71	3.09
1983	1.75	15	0.23	134	0.16	1.58
1984	4.61	17	0.52	113	0.32	4.28
1985	2.37	16	0.35	147	0.19	2.21
1986	2.14	16	0.25	119	0.26	1.84
1987	19.97	40	1.84	92	0.89	19.11
1988	29.18	43	3.53	121	0.43	28.77
1989	13.47	24	1.59	118	1.04	12.46
1990	16.19	9	2.29	141	0.61	15.58
1991	5.33	13	0.69	129	0.23	5.07
1992	8.42	14	0.83	98	1.78	6.62
1993	10.87	21	1.73	159	0.15	10.76
1994	6.99	24	0.89	128	0.22	6.78
Average 1967-1994	9.63	22	1.92	171	0.74	8.89

[1] Coefficient of variation for the all sizes index.

Table 8. All sizes, pre-recruit (≤ 10 cm), and recruit (≥ 11 cm) standardized, stratified mean catch per tow, in numbers and weight (kg), of *Illex illecebrosus* caught in NEFSC spring research vessel bottom trawl surveys (offshore strata 1-40 and 61-76, Cape Hatteras to the Gulf of Maine) during 1967-1995.

Year	All sizes Number/tow	CV[1] (%)	All sizes Kg/tow	Individual Mean Weight (g)	Pre-recruits Number/tow	Recruits Number/tow
1968	0.19	42	0.010	54	0.019	0.17
1969	1.67	50	0.027	16	1.457	0.21
1970	0.56	43	0.023	41	0.150	0.41
1971	0.06	37	0.009	138	0.008	0.06
1972	0.02	39	0.001	53	0.004	0.02
1973	0.03	52	0.007	196	0.000	0.03
1974	0.74	39	0.045	60	0.066	0.68
1975	0.18	33	0.012	70	0.087	0.09
1976	0.57	52	0.035	62	0.007	0.56
1977	0.18	18	0.010	57	0.035	0.15
1978	0.85	46	0.045	52	0.014	0.84
1979	0.46	25	0.041	88	0.078	0.38
1980	0.33	22	0.021	65	0.107	0.22
1981	0.91	30	0.053	58	0.045	0.87
1982	0.62	26	0.039	63	0.050	0.57
1983	0.07	29	0.003	41	0.011	0.06
1984	0.24	69	0.004	17	0.210	0.03
1985	0.96	78	0.023	24	0.824	0.14
1986	0.23	69	0.007	29	0.190	0.04
1987	0.33	45	0.012	36	0.187	0.14
1988	0.16	40	0.010	66	0.066	0.09
1989	0.25	30	0.028	111	0.004	0.25
1990	0.34	36	0.019	55	0.019	0.32
1991	1.03	41	0.043	42	0.233	0.80
1992	0.60	31	0.022	37	0.112	0.49
1993	0.41	23	0.030	74	0.010	0.40
1994	0.71	41	0.038	54	0.188	0.52
1995	0.93	29	0.020	22	0.592	0.34
Average 1968-1995	0.5	40	0.023	60	0.170	0.3

[1]Coefficient of variation for the all sizes index.

Table 9. Surplus production model results for the *Illex* squid fishery in the U.S. EEZ during 1982-1993.

Year	Calculated Biomass (mt)	Biomass Production (mt)	Catch (mt)	Average Biomass (mt)	Annual Fishing Mortality Rate	Monthly Fishing Mortality Rate[1]
1982	25,049	22,649	18,252	36,373	0.50	0.13
1983	29,446	18,685	11,720	38,789	0.30	0.08
1984	36,411	7,553	10,223	40,187	0.25	0.06
1985	33,741	12,524	6,050	40,003	0.15	0.04
1986	40,215	-1,039	5,426	39,695	0.14	0.04
1987	33,754	12,502	10,260	40,005	0.26	0.07
1988	35,995	8,384	1,967	40,187	0.05	0.01
1989	42,412	-6,811	6,801	39,007	0.17	0.04
1990	28,800	19,416	11,316	38,508	0.29	0.07
1991	36,900	6,547	11,908	40,174	0.30	0.08
1992	31,539	15,964	17,827	39,522	0.45	0.11
1993	29,677	18,411	18,012	38,883	0.46	0.12

[1] Assumes a 4-month fishing season (June-September)

Table 10. Yield and spawning stock biomass per recruit estimates for *Illex illecebrosus* landed in the U.S. EEZ.

Proportion of F before spawning: 1.0000
Proportion of M before spawning: 1.0000
Natural mortality is constant at: 0.3000
Initial age (months) is: 1 Last age is: 8
Last age is a PLUS group
Input data from file named: illypr.in

Age-specific Input data for Yield per Recruit Analysis:

Age (mos)	Fish Mort Pattern	Nat Mort Pattern	Proportion Mature	Average Stock	Weights Catch
1	0.0000	1.0000	0.0000	0.0355	0.0355
2	0.0000	1.0000	0.0000	0.0520	0.0520
3	0.0000	1.0000	0.0000	0.0762	0.0762
4	1.0000	1.0000	0.0000	0.1117	0.1117
5	1.0000	1.0000	0.0000	0.1636	0.1636
6	1.0000	1.0000	0.5000	0.2398	0.2398
7	1.0000	1.0000	1.0000	0.3514	0.3514
8+	1.0000	1.0000	1.0000	0.5149	0.5149

Summary of Yield per Recruit Analysis:

The slope of the yield per recruit curve at F=0: 0.388391
F level at slope=1/10 of the above slope (F0.1): 0.262287
Yield/Recruit corresponding to F0.1: 0.038676
F level to produce Maximum Yield/Recruit (Fmax): 0.609939
Yield/Recruit corresponding to Fmax: 0.042654
F level at 0.20 of max spawning potential: 0.280629
SSB/Recruit corresponding to F=0.280629: 0.048615

Yield per Recruit Results:

FMORT	TOTCATCHNUM	TOTCATCHWT	TOTSTOCKNUM	TOTSTOCKWT	SPNSTOCKNUM	SPNSTOCKWT	% MSP
0.000	0.00000	0.00000	3.8583	0.5654	0.5551	0.2431	100.00
0.050	0.05808	0.01542	3.6664	0.4813	0.4106	0.1755	72.19
0.100	0.10164	0.02514	3.5229	0.4209	0.3102	0.1295	53.26
0.150	0.13552	0.03140	3.4116	0.3758	0.2382	0.0971	39.96
0.200	0.16263	0.03549	3.3229	0.3413	0.1852	0.0739	30.40
0.250	0.18480	0.03817	3.2507	0.3144	0.1455	0.0568	23.38
0.300	0.20328	0.03993	3.1907	0.2928	0.1153	0.0441	18.15
0.350	0.21892	0.04107	3.1403	0.2754	0.0921	0.0345	14.21
0.400	0.23233	0.04179	3.0973	0.2611	0.0740	0.0272	11.20
0.450	0.24394	0.04223	3.0602	0.2492	0.0598	0.0216	8.88
0.500	0.25411	0.04248	3.0279	0.2393	0.0485	0.0172	7.08
0.550	0.26307	0.04261	2.9997	0.2309	0.0396	0.0138	5.67
0.600	0.27105	0.04265	2.9747	0.2237	0.0324	0.0111	4.57
0.650	0.27818	0.04264	2.9526	0.2175	0.0266	0.0090	3.69
0.700	0.28460	0.04259	2.9328	0.2121	0.0219	0.0073	2.99
0.750	0.29041	0.04252	2.9151	0.2074	0.0181	0.0059	2.44
0.800	0.29569	0.04244	2.8991	0.2033	0.0150	0.0048	1.99
0.850	0.30051	0.04236	2.8846	0.1997	0.0124	0.0040	1.63
0.900	0.30493	0.04227	2.8714	0.1965	0.0103	0.0033	1.34
0.950	0.30899	0.04219	2.8595	0.1937	0.0086	0.0027	1.10
1.000	0.31275	0.04212	2.8485	0.1911	0.0072	0.0022	0.91

Appendix A. Summary of U.S. EEZ *Illex* squid commercial length-frequency sampling and mean weights, by month and statistical area, during 1982-1993.

YEAR	MONTH	AREA	MEAN WEIGHT (grams)	SQUID SAMPLED	ANNUAL SAMPLE TOTAL	LENGTH-FREQUENCY SAMPLES
82	6	622	179	2,020	2,961	59
82	7	514	107	54		
82	7	521	115	172		
82	7	622	185	257		
82	8	515	120	53		
82	8	521	137	58		
82	8	522	134	56		
82	8	622	222	241		
82	10	626	185	50		
83	6	513	164	149	920	18
83	6	636	89	52		
83	7	622	88	67		
83	7	626	98	54		
83	7	632	113	55		
83	7	636	104	53		
83	8	626	157	51		
83	8	632	125	53		
83	8	636	151	52		
83	9	622	143	168		
83	9	626	159	105		
83	11	513	216	61		
84	4	626	71	45	1,690	33
84	5	622	85	163		
84	6	513	47	51		
84	6	622	120	605		
84	6	632	126	57		
84	7	622	164	361		
84	8	622	174	56		
84	8	626	120	17		
84	8	632	144	116		
84	9	632	155	114		
84	11	513	140	53		
84	12	622	139	52		
85	4	622	84	54	411	8
85	4	626	43	7		
85	5	622	79	50		
85	6	626	124	53		
85	8	626	128	30		
85	9	626	139	57		
85	9	632	143	112		
85	12	513	212	48		

YEAR	MONTH	AREA	MEAN WEIGHT (grams)	SQUID SAMPLED	ANNUAL SAMPLE TOTAL	LENGTH-FREQUENCY SAMPLES
86	5	622	56	137	866	17
86	5	632	52	52		
86	6	513	87	48		
86	7	622	90	307		
86	7	626	104	54		
86	8	622	104	107		
86	9	622	133	56		
86	9	632	125	52		
86	12	616	79	53		
87	5	622	64	65	600	12
87	6	622	113	435		
87	6	632	152	53		
87	7	622	140	47		
88	1	622	91	58	759	15
88	5	626	76	53		
88	6	622	86	62		
88	7	622	137	57		
88	7	632	120	54		
88	8	632	132	264		
88	9	632	145	211		
89	6	622	74	51	159	3
89	8	626	121	108		
90	6	626	107	56	324	6
90	7	626	114	160		
90	8	632	125	52		
90	9	626	116	56		
91	6	616	104	100	751	15
91	6	632	96	50		
91	7	622	149	100		
91	7	626	148	150		
91	8	616	158	101		
91	8	622	150	200		
91	8	626	139	50		

YEAR	MONTH	AREA	MEAN WEIGHT (grams)	SQUID SAMPLED	ANNUAL SAMPLE TOTAL	LENGTH-FREQUENCY SAMPLES
92	6	622	90	50	800	16
92	7	622	103	50		
92	7	622	115	50		
92	7	626	105	50		
92	7	622	115	50		
92	7	622	91	50		
92	7	622	108	50		
92	7	622	111	50		
92	7	622	120	50		
92	7	622	116	50		
92	7	622	121	50		
92	7	622	106	50		
92	7	622	142	50		
92	9	626	164	50		
92	9	622	183	50		
92	10	622	171	50		
93	5	622	69	50	1,154	23
93	7	622	109	51		
93	7	622	117	50		
93	7	622	150	50		
93	7	622	139	50		
93	7	622	127	50		
93	7	622	126	50		
93	7	622	131	50		
93	7	622	124	50		
93	7	622	131	50		
93	7	626	129	50		
93	7	626	125	50		
93	8	522	114	50		
93	8	616	129	50		
93	8	616	53	53		
93	9	626	152	50		
93	9	626	124	50		
93	10	622	150	50		
93	10	622	165	50		
93	10	622	179	50		
93	10	622	165	50		
93	10	622	142	50		
93	11	626	182	50		

Appendix B. Methodology used for *Illex illecebrosus* recruitment estimation using a Leslie-DeLury model applied to monthly LPUE values for tonnage class 4 vessels.

Model assumptions:

(1) the fished population consists of a single cohort (e.g. winter spawners) with recruitment occurring before the start of the fishing season

(2) LPUE is assumed proportional to population size during the fishing season, May-November

(3) no recruitment or migration occurs during the fishing season (closed population)

(4) discarding of *Illex* is negligible.

The population dynamics equation is:

$$\mathbf{N_{t+1} = e^{-M} N_t - e^{-1/2M} C_t}$$

where $\mathbf{N_t}$ is the population size, in numbers, at the start of time period t (used raw monthly LPUE indices, numbers per day fished, from statistical areas 526, 616, 622, 626 and 632), $\mathbf{C_t}$ is the catch during time period t (total landings from Cape Hatteras to the Gulf of Maine were converted to approximate monthly catch weights, by using the observed proportions of catch taken in each month, based on annual LPUE data), and $\mathbf{M}$ is the natural mortality rate per time period (M=0.24 per month).

The following log-normal error model was used:

$$\mathbf{\ln(LPUE_t) \sim N(\ln(qN_{t+1/2}),\ s^2)}$$

where q is the catchability coefficient allowed to vary between years and

$$\mathbf{N_{t+1/2} = e^{-1/2M} N_t - C_t/2.}$$

The fitting procedure assumes that LPUE is proportional to population size, in the middle of the month, and uses LPUE values from the peak to the end of each time series.

Table B1. Preliminary results from a Leslie-DeLury model applied to monthly LPUE (numbers/day fished) for tonnage class 4 vessels, in the U.S. EEZ *Illex illecebrosus* fishery, during 1982-1993.

Year	N_0 [1] (000's)	N_T [2] (000's)	q	R^2 [3]	Biomass[4] (mt)	Average[5] Biomass	Peak Biomass
82							
83	615,526	116,428	0.00056	0.819	22,121	39,218	69,576
84	336,562	44,207	0.00193	0.610	8,399	18,178	28,495
85							
86							
87	598,448	99,484	0.00186	0.859	18,902	34,389	53,840
88							
89	185,735	9,663	0.00958	0.719	1,836	7,198	14,127
90	403,520	29,784	0.00227	0.786	5,659	18,136	33,965
91	264,245	29,001	0.00288	0.787	5,510	16,059	27,518
92	721,709	69,938	0.00121	0.929	13,288	33,395	51,642
93							

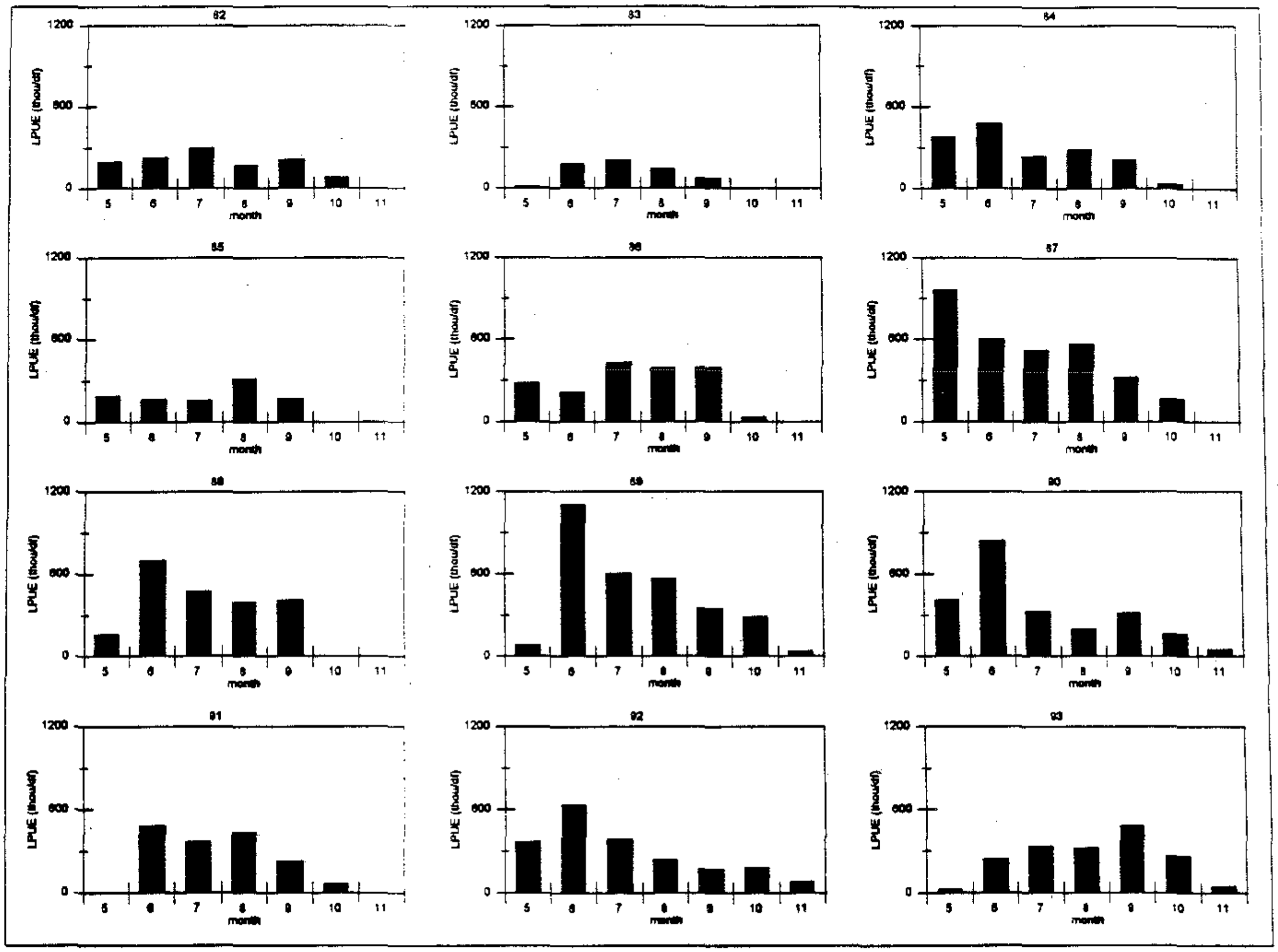
1 N_0 is the population size, in numbers, at the start of May.

2 N_T is the population size, in numbers, at the end of the series where T varied slightly from year to year: 1983 = end of Sept, 1984 = Oct, 1987 = Oct, 1989 = Nov, 1990 = Nov, 1991 = Oct and 1992 = Nov. Ideally N_T should be standardized to reflect population size during the same month of each year.

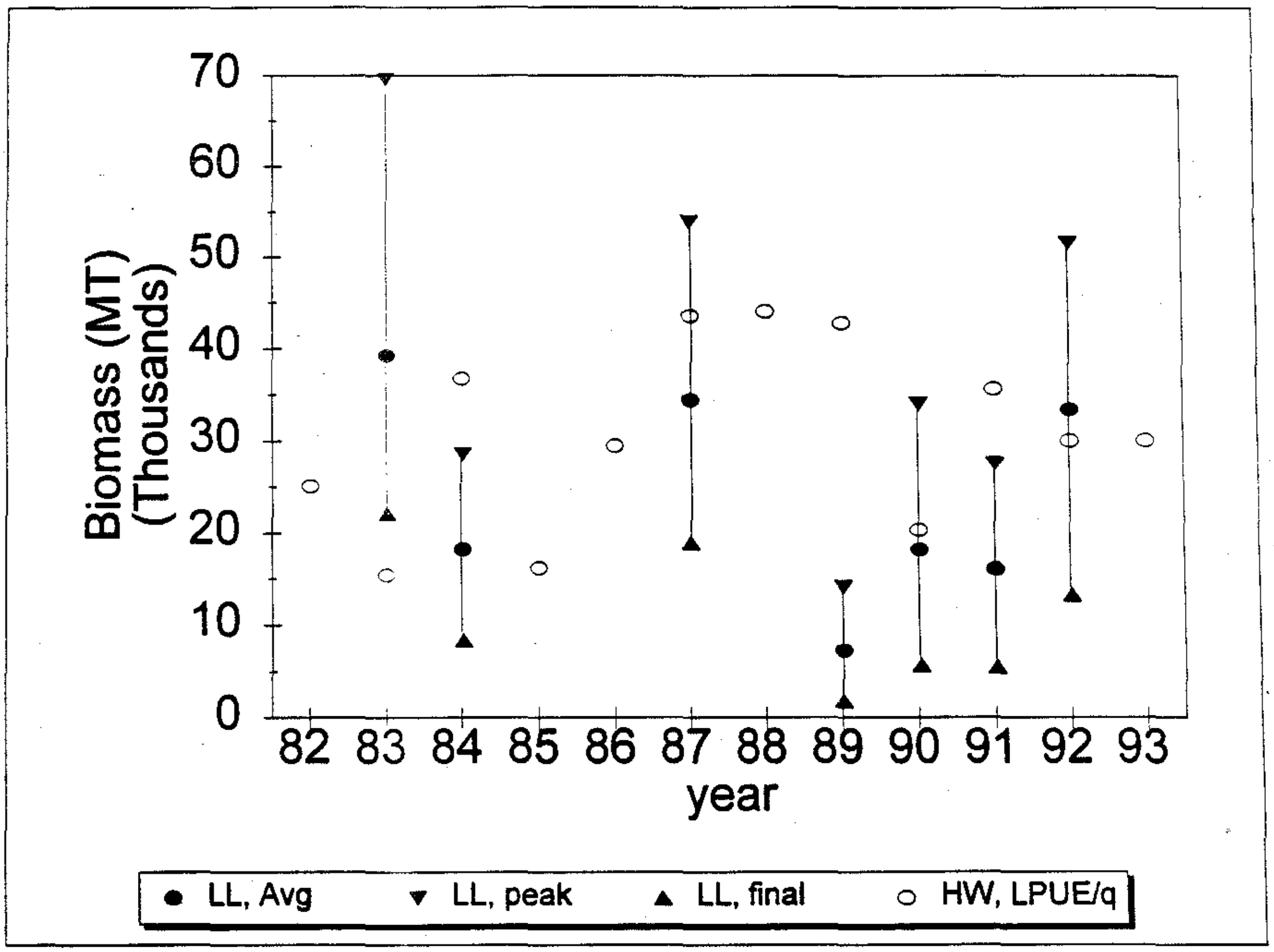
3 R^2 is the r-square value of the fit and blank boxes indicate that no sensible fit could be obtained. Although these values are high, they should be interpreted with caution since the number of points in the regressions were limited.

4 Biomass is N_T multiplied by a mean weight, during the last month of the fishery, of 0.19 kg (used mean weight from September of 1972-1982).

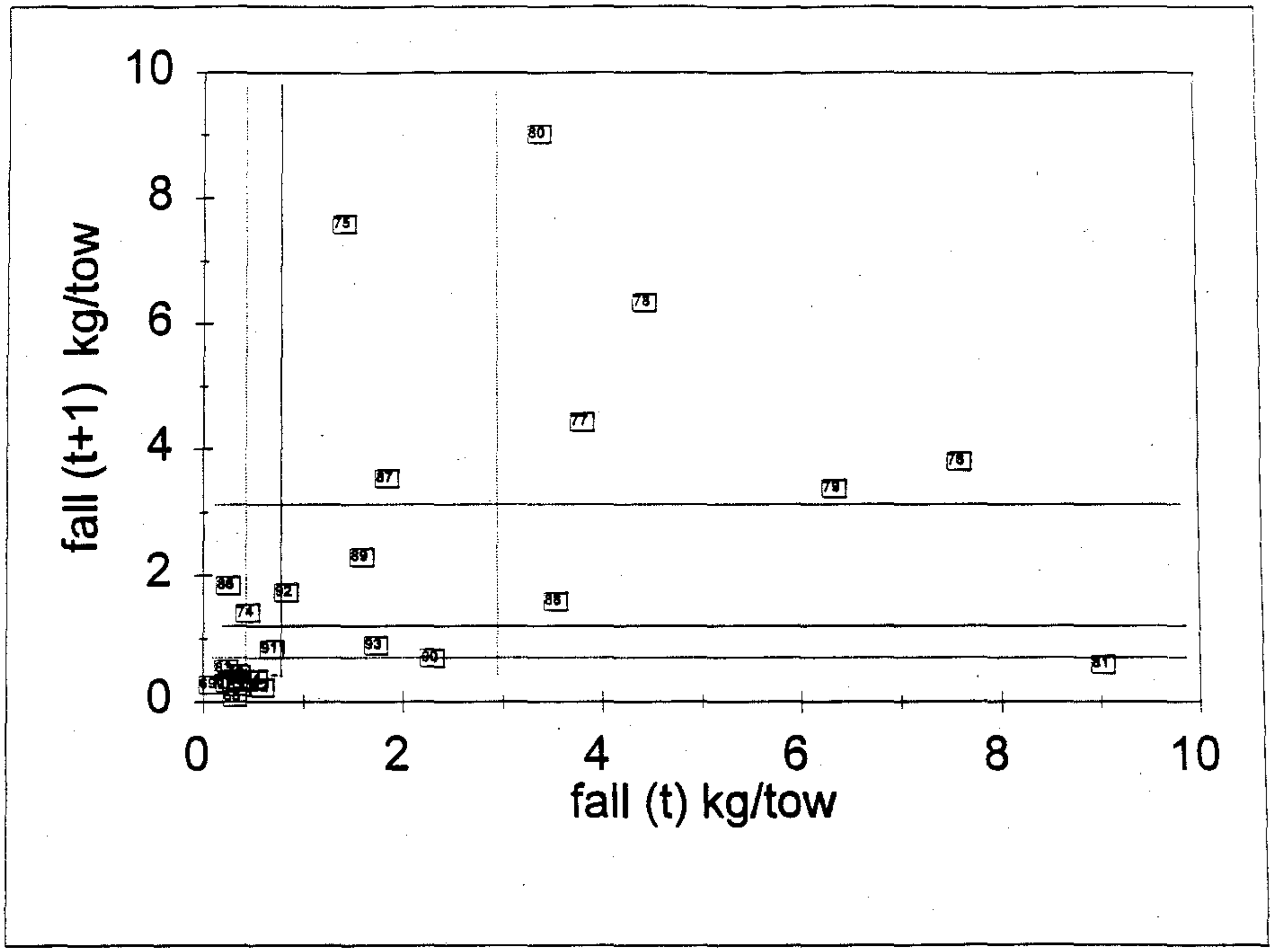
5 Average and peak biomass were calculated from monthly biomass estimates which were the products of the numbers and the mean weight in a given month.



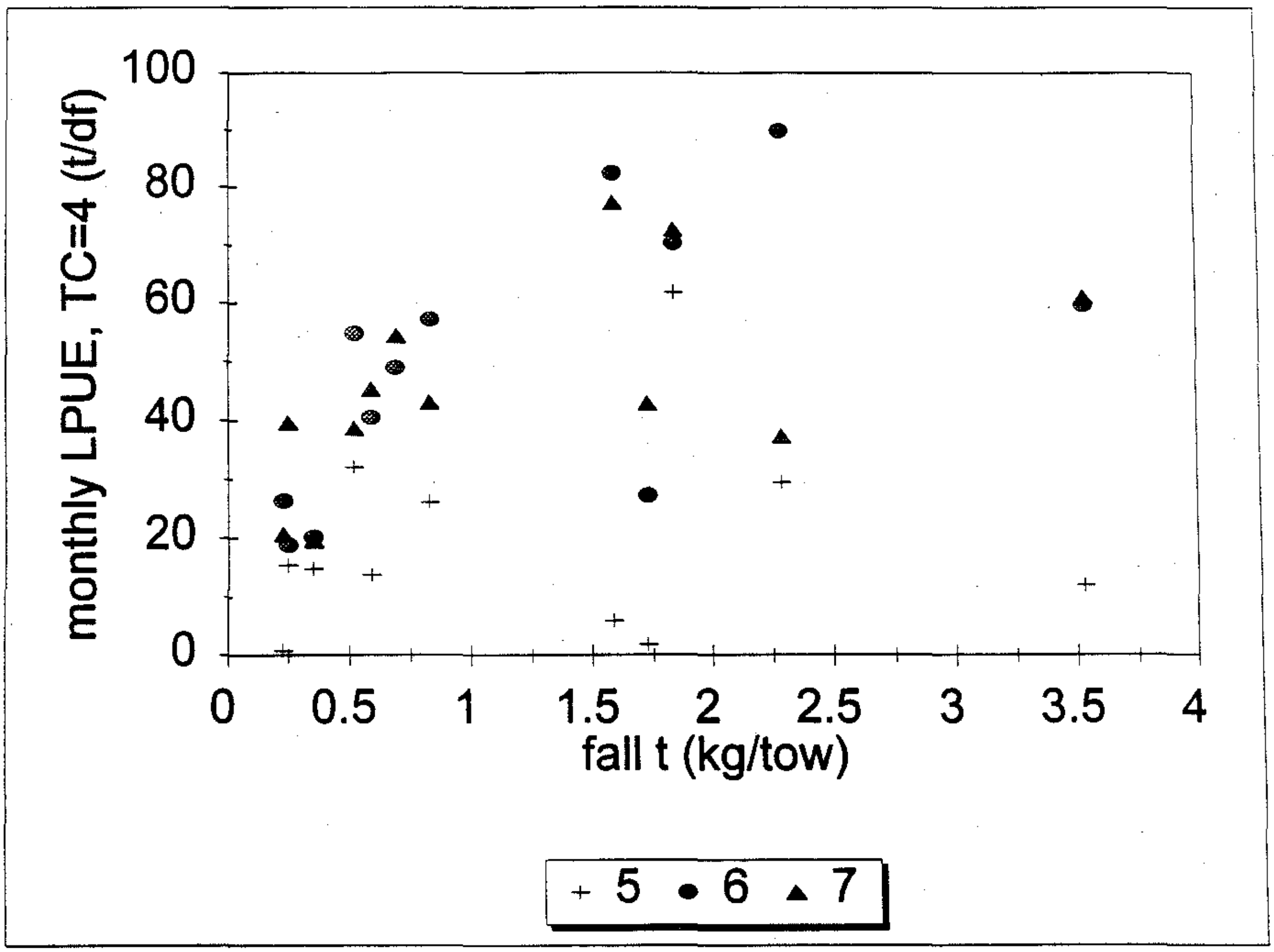
FigureB1. Trends in nominal LPUE (numbers per day fished) for tonnage class 4 vessels, in the U.S. EEZ *Illex* squid fishery, during May - November, 1982-1993.



FigureB2. Comparison of average biomass estimates (solid circles), of *Illex illecebrosus* during the fishing season, and peak to end-of-season biomass estimates (triangles) resulting from the Leslie-DeLury model with biomass estimates (open circles) from the Hilborn-Walters model (annual, standardized LPUE indices divided by catchability coefficient q), during 1982-1993.



FigureC1. NEFSC autumn research survey biomass indices (mean kg/tow), of *Illex illecebrosus*, in year t+1 (1968-1994, labelled in figure) plotted against the same indices in year t (1967-1993). Medians are represented by solid lines and upper and lower quartiles are represented by dotted lines.



FigureD1. Monthly LPUE (mt/day fished), for tonnage class 4 vessels involved in the U.S. EEZ *Illex* squid fishery, plotted against autumn research survey biomass indices (kg/tow) in the same year during May (5), June (6) and July (7), 1982-1993.

Appendix E. Examples of alternative methods for setting pre-season catch or effort limits and deciding when and how to perform in-season adjustments.

REFERENCE POINTS

TARGET

Aim to keep the fishing mortality (F) at or below some sustainable level (e.g. via a fishing mortality value such as $F_{20\%}$) or some proxy for this (e.g. defined in terms of yield)

THRESHOLD

Also aim to keep the stock well above some threshold spawning biomass (or escapement level), because below that level, the probability of good recruitment in the following year is reduced.

1. Setting a pre-season TAC or total effort level

(a) Based on fishing mortality

For example, directly from YPR or use a relationship between I_t (index of escapement from previous year) and fishing mortality to establish a target F, then compute a TAC by multiplying by some measure of biomass (e.g. avg. recent biomass; low, med or high biomass associated with I_t). Effort can be obtained from F using an estimate of catchability.

(b) Based on historic landings

For example, low, medium and high yields associated with low, medium and high I_t

(c) Based on probabilities

For example, $P(F > F_{crit})$ is small or P(Escapement < Threshold) is small, where F_{crit} is the fishing mortality that would drive spawning biomass below the threshold when recruitment is average. This would be a good approach once a better idea of the statistical distribution of recruitment or stock size has been obtained.

The initial TAC or effort level should be set conservatively so that the probability of the need for an in-season adjustment is small. This could be built-in via Fand/or biomass.

2. Monitoring abundance and deciding when to perform an in-season adjustment

The exact timing of this process would depend on the nature and quality of the data and assessment procedure.

(a) Ideally, perform an in-season assessment to estimate current abundance and project absolute escapement under initial TAC or current effort level, then compare with threshold escapement (and historic distribution of escapement/recruitment) to determine whether an adjustment is required.

(b) Use LPUE to compare with (statistical) distribution of historic LPUE and determine whether it is above the mean/median or below the lower quantile, in order to decide whether an adjustment is required. It may also be possible to relate LPUE to absolute biomass via an assessment model, in order to assess the effect of the given TAC or effort on expected absolute escapement.

3. Adjusting the TAC or effort

The main objective is to keep spawning biomass above the threshold. An in-season adjustment, if applied, would generally result in spawning biomass at or just above the threshold. When making an adjustment:

(a) reduce the TAC or effort so that the expected escapement would be above the threshold (e.g. Escapement = $1.05 * B_{threshold}$) or

(b) so that that P(Escapement $\leq$ Threshold) is very close to zero.

Effort limitation is preferable to catch limitation, since upward adjustments are not necesssary because it permits taking advantage of good recruitment. However, when catch limits are used there may be a demand for upward adjustment of the TAC in years when recruitment is particularly good. This could be accomplished, along with meeting management objectives, as follows:

(a) adjust the TAC upward so that the expected escapement would still be above the threshold, and possibly, so that fishing mortality is not above a certain level (e.g. $F < F_{max}$; or Proportional Escapement > $\exp(F_{max})$)

(b) adjust TAC upward so that P(Escapement <= Threshold) is 'closer to' the nominal target. Since other factors may come into play (e.g. to avoid very large variations in catches from year to year), one may want to limit the percentage increase in the adjusted TAC to some percentage.

Appendix F. The basics of real-time management of the Illex illecebrosus fishery.

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

** Requirements for catch and effort data collection:

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

Requirements for weekly biological data collection, by at-sea observers, on selected vessels:

- Length frequency of the catch (usually by sex)
- Weight-length sub-samples (usually by sex) (Essential!)
- Sexual maturity
- Sex ratio