Northeast Fisheries Science Center Reference Document 96-05d

A Report of the 21st Northeast Regional Stock Assessment Workshop

21st Northeast Regional Stock Assessment Workshop (21st SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

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

June 1996

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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 the distribution and catches of yellowtail flounder, Atlantic cod, and haddock in the NEFSC bottom trawl survey

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

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MEETING OVERVIEW

The Stock Assessment Review Committee (SARC) Meeting of the 21st Northeast Regional Stock Assessment Workshop (21st SAW) was held at the Northeast Fisheries Science Center (NEFSC), Woods Hole, Massachusetts during 27 November -1 December 1995. SARC Chairman was Dr. Terrence P. Smith (NEFSC). Members of the SARC included scientists from NMFS/NEFSC, NERO and NWFSC, Mid-Atlantic (MAFMC) and New England (NEFMC) Fishery Management Councils, Atlantic States Marine Fisheries Commission (ASMFC), the States of MA and NY, and Canada (Table 1). In addition, more than 30 other persons attended all or part of the meeting (Table 2). The meeting agenda is presented in Table 3.

Table 1. Composition of the SARC.

Chair:
Terry Smith, NEFSC
(SAW Chairman)

Four ad hoc experts chosen by the Chair:

Jon Brodziak, NMFS, Hatfield Marine Science Center
John Kocik, NEFSC
Loretta O'Brien, NEFSC
William Overholtz, NEFSC

One person from NMFS, Northeast Regional Office:

Peter Colosi, NERO

One person from each Regional Management Council:

Andy Applegate, NEFMC
Richard Seagraves, MAFMC

Atlantic States Marine Fisheries Commission/State personnel:

Steve Cadrin, MA DMR
Frank Lockhart, ASMFC
Kim McKown, NY DEC

One scientist from Canada:
Mark Showell, DFO
Academia - No participation
Other Region - No participation

Table 2. List of participants.

National Marine Fisheries Service
Northeast Fisheries Science Center
Frank Almeida
Marinelle Basson
John Boreman
Russell Brown
Stephen Clark
Kevin Friedland
Wendy Gabriel
Tom Helser
Lisa Hendrickson
Josef Idoine
Shih-Wei Ling
Ralph Mayo
Steve Murawski
Helen Mustafa
Paul Rago
Fred Serchuk
Gary Shepherd
Katherine Sosebee
Mark Terceiro
Jim Weinberg
Susan Wigley
NMFS Headquarters
John Witzig

Mid -Atlantic Fishery Management Council
Alan Weiss
Connecticut Department of Environmental Protection
Penny Howell
Massachusetts Department of Marine Fisheries
Steve Correia
Tom Currier
Arnold Howe
Jeremy King
Dan McKiernan
David Pierce
Maine Department of Marine Resources
David Stevenson
Rhode Island Department of Fish and Wildlife
Mark Gibson
Conservation Law Foundation
Ellie Dorsey
Manomet Bird Observatory
Dave Martins
University of Massachusetts
Paul Nitschke
Cape Oceanic
Peter Spalt

Table 3. Agenda of the 21st Northeast Regional Stock Assessment Workshop (SAW-21) Stock Assessment Review Committee (SARC) Meeting.

NEFSC Aquarium Conference Room
166 Water Street
Woods Hole , Massachusetts
Telephone: 508-548-5123
27 November (1:00 PM) - 1 December (6:00 PM)1995

AGENDA

SPECIES/STOCK	SUBCOMMITTEE & PRESENTER	SARC LEADER	RAPPORTEUR
MONDAY, November 27 (1:00 PM - 7:30 PM)			
Opening		T.P. Smith, Chairman	H. Mustafa
Welcome			
Agenda			
Conduct of Meeting			
Long-finned Squid (A)	Invertebrate P. Rago	J. Brodziak	J.Weinberg
Discuss Advisory Report			
TUESDAY, November 28 (9:00 AM - 6:00 PM)			
Short-finned Squid (B)	Invertebrate P. Rago	W. Overholtz	L. Hendrickson
Discuss Advisory Report			
Atlantic Herring (C))	Coastal/Pelagic D. Stevenson K. Friedland	S. Cadrin	K. Friedland M. Terceiro
Discuss Advisory Report			
Review available drafts			
WEDNESDAY, November 29 (9:00 AM - 6:00 PM)			
Report of the Ad Hoc Working Group on Sea- Port-Sampling (F)	D. Pierce		H. Mustafa
Winter Flounder (D)	So. Demersal W. Gabriel	R. Seagraves	G. Shepherd
Discuss Advisory Report			
Review available draft report sections			
Complete Review/Discussion of above species			

Table 3. (Continued)

THURSDAY, November 30 (9:00 AM - 6:00 PM)			
Northeast Groundfish Complex (E)	No. Demersal		
Discuss Advisory Report	R. Mayo K. Sosebee T. Helser L. O'Brien S. Wigley S. Cadrin	A. Applegate	R. Brown/R. Mayo
Review all Research Recommendations			
Review list of publications for the SAW-21 series			
FRIDAY, December 1 (9:00 AM - 6:00 PM)			
Complete SARC Report sections			H. Mustafa (Coordinator)
Finalize sections and review final draft Advisory Report			
Other Business			H. Mustafa

Opening

Chairman Terry Smith welcomed the meeting participants and introduced the members of the SARC. He reviewed the SAW process and the composition and duties of the SAW Steering Committee, as well as the responsibilities of the SARC meeting participants (Subcommittee chairs, SARC leaders, and rapporteurs) and the SARC documentation. The Subcommittee report on each species/stock will form the basis of the SARC Consensus Summary of Assessments. Other working papers will be candidates for publication in the SAW-21 series of the Center Reference Documents. Dr. Smith outlined the general flow of the meeting, including the preparation of the SARC and Advisory reports. The agenda, he indicated, is intentionally front loaded to allow time for additional discussion, document preparation, and analyses that might be recommended by the SARC after each presentation.

The Chairman reviewed the recommended species on the agenda for this meeting and dates of other meetings in the SAW-22 cycle. Although lobster was recommended for review at SAW-22, the Steering Committee concluded that there is a need to review lobster productivity and overfishing definitions prior to another stock assessment. NMFS will convene an international review panel to address the issue and suggest terms of reference for the next Lobster assessment. The Invertebrate Subcommittee and the SARC will meet following the Review Panel to discuss and respond to the Panel report.

Agenda and Reports

The SARC Agenda included four species from the waters off the Northeast U.S. coast (short- and long-finned squids, Atlantic herring and winter flounder), the Northeast groundfish complex, and a report of the Ad hoc Sea Sampling Working Group. A chart of U.S. commercial statistical areas used to report landings in the Northwest Atlantic is presented in Figure 1. Area of the Northwest Atlantic showing NMFS/NEFSC bottom trawl offshore survey strata is presented in Figure 2.

Table 4. NEFSC Reference Documents associated with the 21st Northeast Regional Stock Assessment Workshop (21st SAW)

Title/Author(s)
Stock assessment of Short Finned Squid, *Illex illecebrosus*, in the Northwest Atlantic during 1993 by L. Hendrickson, et al.
Assessment of Winter Flounder, *Pleuronectes americanus*, in Southern New England and the Mid-Atlantic by G. Shepherd, et al.
An Index Based Assessment of Winter Flounder, *Pleuronectes americanus*, Populations in the Gulf of Maine by S. Cadrin, et al.
Influence of Temperature and Depth on the Distribution and Catches of Yellowtail Flounder, Cod, and Haddock in the NEFSC Trawl Survey by T. Helser and J. Brodziak
Preliminary Results of a Spatial Analysis of Haddock Distribution Applying a Generalized Additive Model by L. O'Brien
The Lorenz Curve Method Applied to NEFSC Bottom Trawl Survey Data by S. Wigley
Predicting Spawning Stock Biomass for Georges Bank and Gulf of Maine Cod Stocks with Research Vessel Survey Data by S. Cadrin and R. Mayo
Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW), Stock Assessment Review Committee (SARC) Consensus Summary of Assessments
Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW), Public Review Workshop

The SARC reviewed a total of 19 working papers, seven papers were recommended to be upgraded to NEFSC Reference Documents in the SAW-21 series (Table 4). Subcommittee reports were prepared in a number of meetings (Table 5) and are the basis of the species sections in this report. The SARC Consensus Summary of Assessments, with SARC comments and research recommendations, and the draft "Advisory Report on Stock Status" will be available at the SAW-21 Public Review Workshop and will be published in the NEFSC Reference Document series after the SAW-21/22 Steering Committee Meeting.

Presentations and Discussion

Highlights of Presentations

As assessment methods for both the long- and short-finned squids have changed since these species were last assessed during SAW-17, the SARC focused on the differences in assessment methodology between the previous and current assessments. Real-time management was recommended for both squids, as the highly variable recruitment of these species with an annual life span makes their populations susceptible to recruitment overfishing. This form of management would permit in-season adjustment to maintain precautionary levels of spawning potential. Presented was an exploratory analysis in real-time management options for squid stocks based on the example of the squid fishery in Falkland Islands. The Committee requested that a summary of this analysis (Working Paper B2) be presented to the MAFMC and concluded that a detailed data collection plan and cost-benefit analysis should be drafted to determine the feasibility of implementing real-time management for the two squids. As current data availability, including survey data, is not adequate for real-time management, data inadequacy is reflected in the research recommendations under both species. Among the recommendations under the short-finned squid, a transboundary stock, is development of a joint U.S. and Canada research program to improve the biological basis for management and assessment.

Table 5. SAW-21 Subcommittee meetings.

Subcommittee - Species Analysis **Attendance**	**Meeting Date** **and Place**
Invertebrate Subcommittee	10 - 12 October 1995
- LONG-FINNED SQUID	Woods Hole, MA
M. Basson, NEFSC/NMFS	
J. Brodziak, NEFSC/NMFS	
R. Hanlon, MBL	
L. Hendrickson, NEFSC/NMFS	
W. Macy, URI	
P. Rago, NEFSC/NMFS (Chair)	
R. Seagraves, MAFMC	
- SHORT-FINNED SQUID	
All above, and -	
James Weinberg, NEFSC/NMFS	
Southern Demersal Subcommittee	16 - 20 October 1995
- WINTER FLOUNDER	Woods Hole, MA
S. Cadrin, MA DMF	
S. Correia, MA DMF	
W. Gabriel, NEFSC/NMFS (Chair)	
M. Gibson, RI DFW	
A. Howe, MA DMF	
P. Howell, CT DEP	
D. Grout, NH FG	
N. Lazar, ASMFC	
M. Lambert, NEFSC/NMFS	
W. Ling, NEFSC/NMFS	
P. Scarlett, NJ DEP	
G. Shepherd, NEFSC/NMFS	
Northern Demersal Subcommittee	14 September 1995[1]
- NORTHEAST GROUNDFISH COMPLEX	29 September 1995[2]
A. Apllegate, NEFMC ([3 part-time])	30 October - 3 November 1995[3]
R. Brown, NEFSC/NMFS ([1,2,3])	Woods Hole, MA
S. Cadrin, MA DMF ([3])	
T. Helser, NEFSC/NMFS ([1,3])	
R. Mayo, NEFSC/NMFS (Chair) ([1,2,3])	
L. O'Brien, NEFSC/NMFS ([1,2,3])	
K. Sosebee, NEFSC/NMFS ([1,2,3])	
S. Wigley, NEFSC/NMFS ([1,2,3])	
Coastal Pelagic Subcommittee	7 - 9 November 1995
- ATLANTIC HERRING	Boothbay Harbor, ME
K. Friedland, NEFSC/NMFS	
D. Libby, ME DMR	
D. Stevenson, ME DMR	
[E. Anderson, NEFSC/NMFS (Chair) was unable to attend]	

During the review of the herring coastal stock complex assessment, discussion focused on VPA calibrations in both ADAPT and ICA (Integrated Catch Analysis) assessment programs. Additional ADAPT and ICA runs were carried out during the meeting and the SARC chose to base the current assessment on VPA results from the ADAPT. The remarkable shift in the growth rate and weight of herring observed in the presented analyses may be a result of a large biomass. A major research recommendation of the SARC is to develop a long-term strategy for assessing individual spawning stocks as a basis for more effective management of any heavily exploited portions (s) of the herring stock complex.

Dr. David Pierce presented the Report of the Ad Hoc Sea- Sampling Working Group which included several preliminary products (tables). A summary of this presentation appears in this report.

The SARC agreed with the Southern Demersal Subcommittee's reasoning for changing the winter flounder stock structure from four to three stock complexes (Southern New England - Middle Atlantic, Georges Bank, and Gulf of Maine). Large differences were found in the growth and maturity rates among the complexes. Discussion of the species centered around estimation of discards, implications of projections, and the implication of management measures.

The analysis of the Northeast Demersal Complex included 16 species, or 25 stocks, (10 regulated large mesh species in the Northeast Multispecies Fishery Management Plan, three small mesh species in the Plan, and three additional species, often taken in the Northeast demersal fishery). Reviewed was a summary of recent and historical temporal and spatial trends for aggregated species, as well as several technical papers on methods used to address the terms of reference for the Northern Demersal Complex. The Subcommittee addressed all terms of reference, with the exception of the fourth, "Evaluate the by-catch implications of the multispecies trawl and fixed gear fisheries for Northeast groundfish on the ability to meet fishing mortality rate (F) goals for individual species/stocks." To address this term of reference would be a long-term project which would require a a research recommendation from the SARC and a scoping document. The analytical methods described by members of the Subcommittee may be applied to a number of species and include: a habitat preference analysis to test species affinity to temperature and depth; a General Additive Models approach for smoothing data collected with measurement error and to stabilize variance used to analyze the distribution of haddock; an econometrics method (Lorenz Curve Method), developed to study the distribution of income, applied to NEFSC bottom trawl survey data; and, an objective statistical method (ARIMA approach) for selecting smoothing parameters to stabilize variance caused by measurement error used for predicting spawning stock biomass for Georges Bank and Gulf of Maine cod stocks using research vessel survey data. The SARC complimented members of the Northern Demersal Subcommittee on the quality of their work and the production of original and integrative approaches in addressing the terms of reference. Meeting participants indicated that dealing with a complex of species was interesting to the SARC and informative to the audience and suggested that future SAWs include subject oriented terms of reference that incorporate analyses from several species or take a multispecies approach to addressing certain questions.

Before the meeting adjourned, participants discussed the SAW process and the SARC meeting schedule, the need to continue the Assessment Methods Subcommittee and to replace its chair, as well as a number of possible theme topics for SAW-22. This discussion is summarized in the Other Business section of this report.

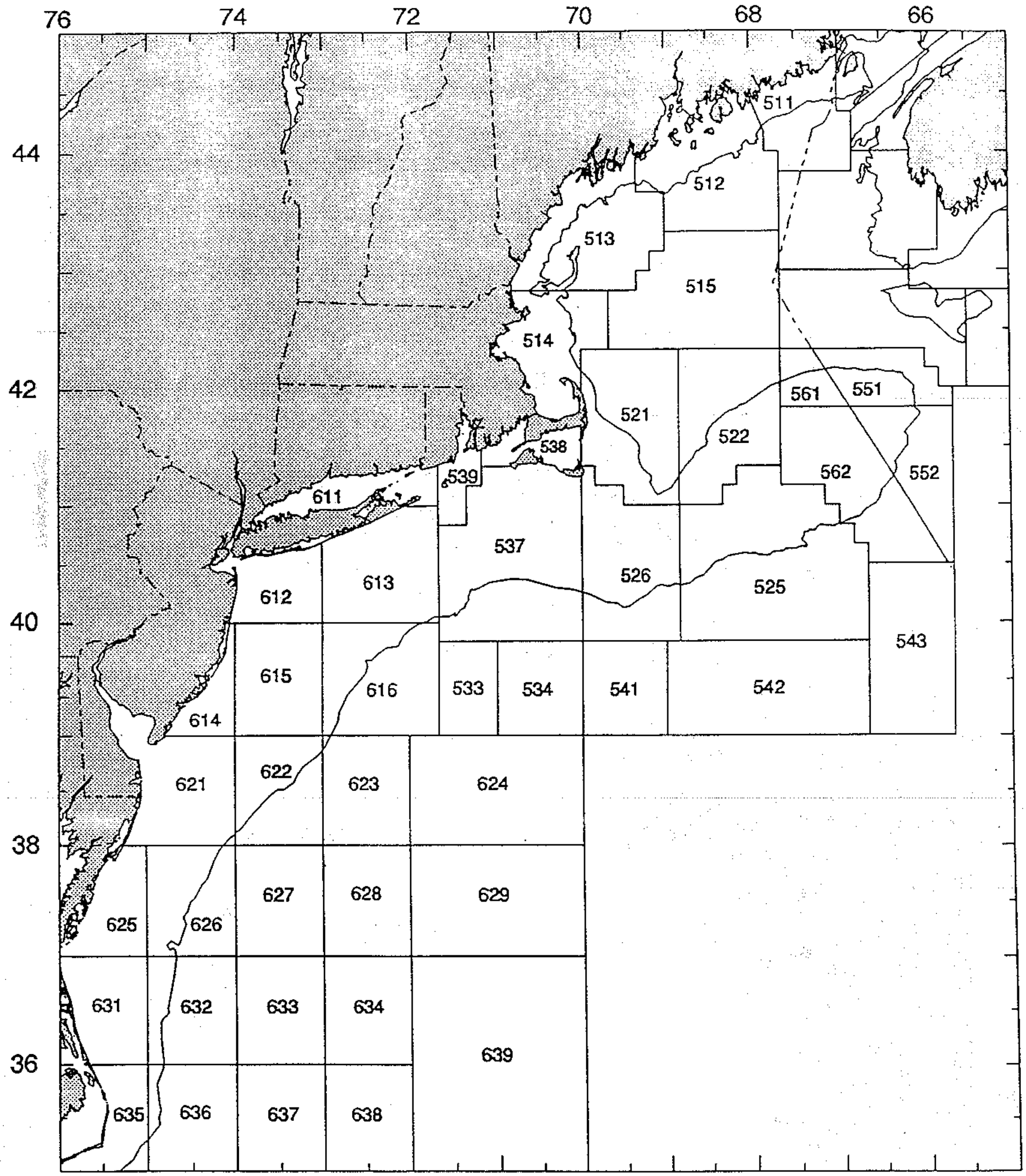

Figure 1. Statistical areas used for catch monitoring in offshore fisheries in the Northeast United States.

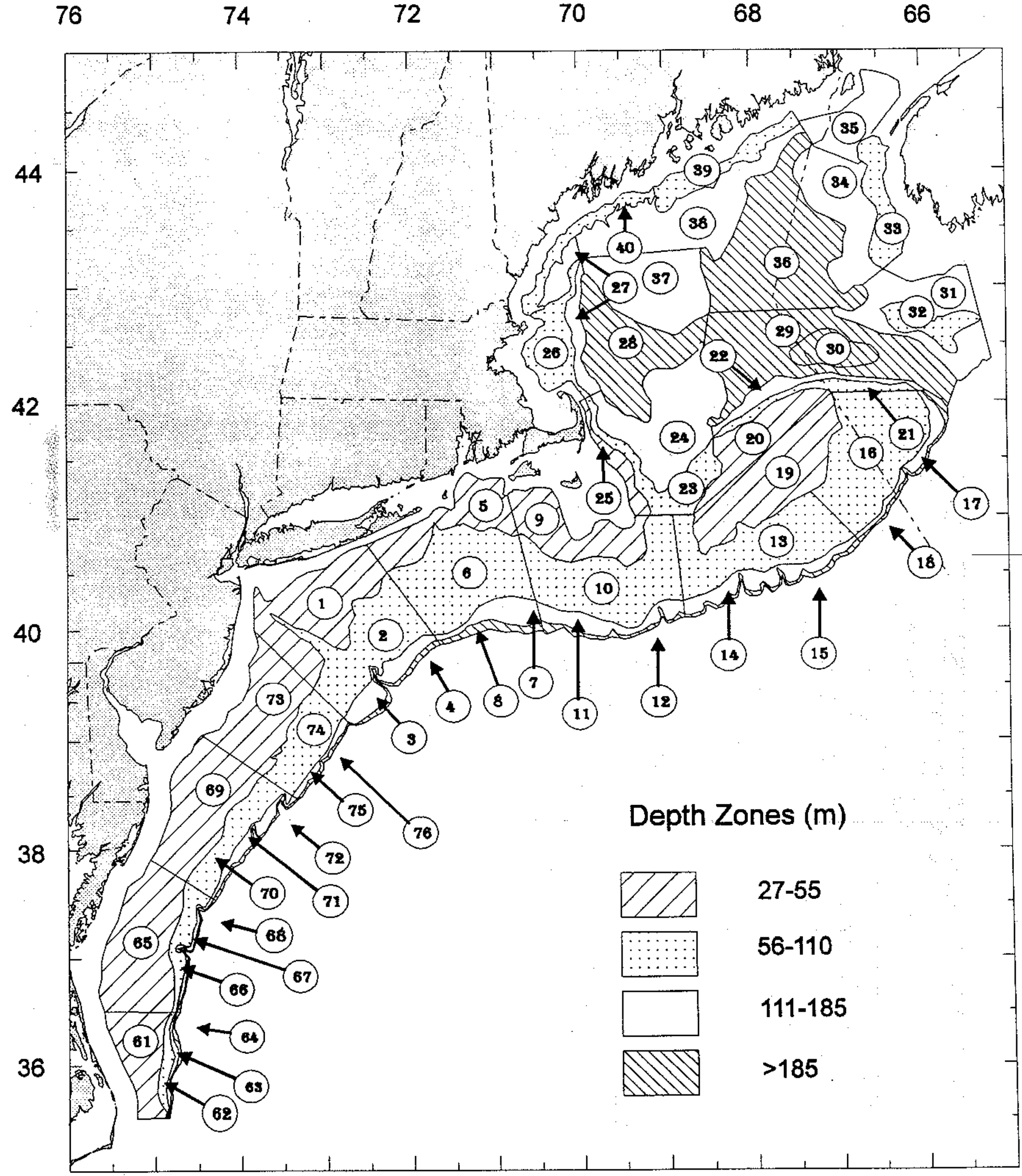

Figure 2. Area of the Northwest Atlantic showing NMFS/NEFSC bottom trawl offshore survey strata.

B. SHORT-FINNED (*Illex*) SQUID

Terms of Reference

The following Terms of Reference were addressed for short-finned squid:

a. Examine the seasonal and annual distribution patterns and relationship to environmental parameters, especially temperature.

b. Estimate relative abundance and mortality rates.

c. Review overfishing definition.

Introduction

An assessment of the *Illex illecebrosus* stock was last conducted for review by the 17th Stock Assessment Review Committee (SARC), in December, 1993 (NEFSC 1994). The SARC found that the stock was under-exploited and was at a medium biomass level. This report presents an updated and revised analytical assessment of the U.S. EEZ portion of the stock, for the period 1967-1993, based on analyses of statolith ageing, commercial fishery, and research survey data.

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, in NAFO Subareas 2, 3 and 4, by the Northwest Atlantic Fisheries Organization (NAFO). The current NAFO total allowable catch (TAC) is 150,000 mt (NAFO 1980, cited by O'Dor and Dawe *in press*). Annual levels of allowable biological catch and domestic allowable harvest 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 on the current status of the stock. In 1995, the allowable biological catch and domestic allowable harvest were 30,000 mt. The proposed domestic allowable harvest has been decreased to 21,000 mt for 1996. In recognition that the domestic resource is rapidly approaching full utilization and that expansion of the U.S. fleet would lead to overcapitalization, Amendment 5 (MAFMC 1995) to this FMP was developed and recently submitted for NMFS Secretarial approval. 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 engaged in the *Illex* fishery.

Stock Structure

The short-finned 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 B1). Regardless of this speculation, the proportion of tows capturing *Illex* during the 1967-1994 NEFSC autumn surveys (Figure B1), 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.

The Fishery

Commercial Landings

Domestic and foreign landings (mt) of *Illex* during 1963-1994 (Table B1) were collected from various sources. U.S. EEZ landings for 1963-1988 were taken from the Report of the 10th SAW (NEFSC 1990), while the NEFSC (NEMFIS) database provided domestic landings for 1989-1994. Landings for NAFO Subareas 2, 3 and 4, during 1973-1993, were taken from NAFO Scientific Council Summary reports.

The magnitude and spatial pattern of *Illex* landings has varied considerably during 1963-1993. During 1973-1982, total landings averaged 70,954 mt and were predominately taken from NAFO Subareas 2, 3 and 4 (73%) (Figure B2A). Following the collapse of the fishery in NAFO Subareas 3 and 4, total landings during 1983-89 averaged only 9,179 mt. Since 1983, total landings have been dominated by the domestic fishery, which averaged 6,956 mt (76% total landings) and 14,766 mt (75% total landings) during 1983-1989 and 1990-1993, respectively. Since 1987, there has been no foreign participation in the *Illex* fishery within the U.S. EEZ (Cape Hatteras to the Gulf of Maine).

Domestic *Illex* landings have increased every year since 1988, to a record high of 18,012 in 1993 (Figure B2B). This represented 87% of total landings and a 2% increase over the 1992 domestic landings. Preliminary estimates of 1994 domestic landings are 18,322 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 1) and month, were collected from the NEFSC weigh-out database (Table B2). 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.

Commercial Discards

Discard data were not available for directed *Illex* trips, although anecdotal reports by some fishermen have suggested that *Illex* discard was minimal. Confidential bycatch observations collected during foreign and Joint Venture fishing operations have indicated that discarding of *Illex* was negligible in comparison to landings. In general, the tendency of *Illex* to school by size, and targetting of larger squid by the fishery (16-28 cm), suggests low discard rates of smaller squid.

Recreational Landings

There are no known recreational landings of *Illex* squid.

Commercial Fishery Sampling Intensity

The annual number of U.S. commercial length samples, trips, landings and sampling intensity (length samples per metric ton of *Illex* landed), during 1982-1993, are presented in Table B3. Commercial length composition was assessed for all sizes combined since there are no market categories for this species. A total of 1,154 squid lengths were collected in 1993; this constituted roughly 23 length frequency samples of 50 squid each. Overall, sampling intensity in 1993 was relatively low with roughly 1 length frequency sample collected for every 780 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.

Commercial Length and Age Composition

Monthly mean weights in the U.S. catch were obtained by pooling commercial length-frequency samples by month, then applying the length-weight equation for combined areas, seasons and sizes (ln(weight) = -3.03444 + 2.71990 ln(length), weight in g and length in cm) which was derived from NEFSC survey data (Lange and Johnson 1981). Month-specific averages for the 1982-92 time series were substituted as mean weights for months in which no length samples were collected during 1993. An estimate of the annual mean weight of harvested *Illex* (W_a), stratified by month, was computed as the weighted average of these monthly mean weights (W_m), where the weighting coefficient was the fraction of the annual landings which occurred during that month (f_m):

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

Total numbers of *Illex* squid landed by the domestic fishery, during 1982-1993, were then computed by dividing annual mean weights into annual yields (Table B4). Similar to landed weight, the numbers of *Illex* squid landed have been increasing since 1988, reaching a time series peak in 1993.

Stock Abundance Indices

Commercial LPUE

Standardized fishing effort and 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 vessel 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 targetting *Illex* were used while trips that landed minor amounts of *Illex* were excluded; (2) a finer 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 B5).

Standardized effort for the domestic fishery declined to a low of 29 days fished in 1988, but has been increasing markedly since then (Table B6, Figure B3A). 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, since 1988, LPUE has been gradually declining (Figure B3B). Standardized LPUE remained stable in 1993 at 46 mt/day fished; slightly below the 1982-1993 average (47 mt/day fished).

Spatial patterns in nominal LPUE by quarter-degree square, for 4-year time blocks during 1982-1993, were depicted using a geographic information system (GIS) (Figures B4-B6). 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 1982-85, 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 1990-93, areas of high LPUE extended throughout most of southern New England, particularly in waters deeper than 500 fathoms. High LPUE levels occurred throughout most of the offshore shelf waters between Cape Hatteras and Cape Cod. Fishing on Georges Bank was still sparse, 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

Relative indices of *Illex* abundance and biomass, within the U.S. EEZ from Cape Hatteras to the Gulf of Maine, were computed from NEFSC spring and autumn bottom trawl surveys. The 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 B1) showed that *Illex* consistently utilized this habitat, and for this reason, in contrast to previous assessments, Gulf of Maine strata were included in the computation of relative abundance indices . Overall, standard survey tows in offshore strata 1-40 and 61-76 (Figure 2) were used to compute indices of relative abundance.

A vessel catchability analysis presented at SAW 12 (NEFSC 1991) suggested that the *Delaware II* exhibited greater fishing power than the *Albatross IV* research vessel. 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 (≤ 10 cm) and recruits (≥ 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 ration 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 signed rank test of the paired difference in catch per tow also indicated that the median difference was not 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 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 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 signed rank 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 signed rank 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 in order to standardize these tows to *Albatross IV* catches.

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, WP A2), 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*.

The results also indicated that *Illex* catches were significantly associated with time of day during roughly half of the years analyzed, 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 this 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.

Vessel-adjusted, stratified mean numbers per tow and mean weights (kg) per tow from the autumn and spring bottom trawl surveys exhibit considerable annual variability (Tables B7 and 8, Figure B6). Although high inter-annual variability might be expected for an annual species if fluctuations in recruitment were substantial, 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. Further 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 (≤ 10 cm) abundance very well, the autumn survey appears to provide a better measure of relative abundance of recruited squid (≥ 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 taken from the autumn survey provide a more consistent measure of relative *Illex* abundance in the U.S. EEZ due to higher overlap between stock distribution and survey coverage.

The autumn number per tow and weight per tow indices both indicate two distinct periods of high abundance which were well above the long-term average; during 1976-1981 and during 1987-1090. 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 1993). 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, WP A2). *Illex* undergo a lengthy southward migration to spawn south of Cape Hatteras, with a spawning peak during winter, after which 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) (Figures B8-B11) and recruits (≥ 11 cm) (Figures B12-B15) was characterized from NEFSC research surveys. Survey strata are 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 survey time series. Although the number of years of survey data depicted differ by season due to fewer winter and summer surveys, a seasonal distribution pattern is evident from these figures. Although the Gulf of Maine was not sampled during the winter survey (Figure B9), *Illex* pre-recruits appear to be beyond survey coverage either further offshore or south of Cape Hatteras. During the spring (Figure B10), 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 suggest a northerly migration of juveniles. During the peak of the summer fishery (Figures B11 and B15), the stock becomes dispersed over a broader geographic region throughout the continental shelf, generally moving further inshore. By autumn (Figures B12 and B16), *Illex* have generally begun to move offshore and migrate south.

Life History Parameters

<u>Growth</u>

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 and length-at-age curve were estimated for *Illex* using techniques described in Brodziak and Macy (*in press*), based on size-at-age data (N=202) collected from the Newfoundland jigging fishery and reported in Dawe and Beck (1992). *Illex* growth in length and weight is very rapid and can be described as exponential for both length and weight (Figure B16). The maximum age reported in this data set was 250 days. The growth curve for weight (W) in grams at age (d) in days is:

$$W(d)=20.003509 \cdot \exp(0.012555 \cdot d)$$

while the growth curve for mantle length (L) in cm at age (d) is:

$$L(d)=11.56955 \cdot \exp(0.00347 \cdot d)$$

Natural Mortality

Short-finned 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*. As for *Loligo* squid (see previous section), this value represents 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 Wroblenski 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. Applied to a length-at-age equation for *Illex* (refer to Growth section), 50% maturity for males occurs at approximately 6 months of age.

Estimates of Stock Size and Fishing Mortality

Surplus Production Analysis

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. The form of the difference equation was:

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

where B_t is stock biomass at the beginning of year t, C_t was the catch biomass harvested in year t, E_t is standardized fishing effort in year t, q is the biomass catchability coefficient, r is the intrinsic rate of biomass growth, and K is the carrying capacity of the stock. The parameters (q, r, and K) of this model were estimated using the regression method described in Hilborn and Walters (1992, see Eq. 8.4.10, p. 308) where standarized LPUE from the domestic fishery during 1982-1993, was the relative abundance index proportional to stock biomass and the catch and effort totals 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 $E[B_t]$. Results of this model are summarized in Table B9.

Bootstrapping procedures were applied to estimate the uncertainty of model parameters. A total of 1,000 bootstrap replicates were applied to 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 (Hillborn and Walters 1992).

Standard deviations of the parameter estimates were estimated from the bootstrap replicates. The parameter estimates were $q=1.537 \cdot 10^{-3}$ ($\sigma_q=0.786 \cdot 10^{-3}$), $r=2.44$ ($\sigma_r=0.56$), 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 parameters estimates by first computing B_{82} and $E[B_{82}]$ and then iterating the process equation for each triplet of parameters. Based on these computations, 50% CI's for fishing mortality and stock biomass were derived (Figure B17A and B).

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 B9. 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 B17A). Monthly F decreased steadily from a 1982 peak of 0.13 to 0.04 in 1986. Monthly fishing mortality rates have been increasing since 1988, from 0.01 to 0.12 in 1993. During 1992, the monthly fishing mortality rate was equal to the $F_{50\%}$ target ($F_{50\%}=0.11$) (refer to **Biological Reference Points** below) 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 B17C) suggested that landings exceeded annual production during 1991-1993.

Biological Reference Points

The overfishing definition for *Illex*, as defined in the MAFMC Atlantic Mackerel, Squid and Butterfish Fishery Management Plan, 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. According to this 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 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). This suggests that *Illex* has the potential to be overfished in 1995.

However, 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. Moreover, 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. 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 its one-year life cycle. 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 (Figure B18) for this species, an appropriate threshold would be a monthly $F_{20\%}$ (0.28), with fishing intensity such that escapement is above this threshold, and 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 to ensure a high probabilty 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 Subareas 5 and 6 (O'Dor and Coelho 1993) and a monthly natural mortality rate of 0.30. Results (Table B10) indicated that the fishing mortality that maximized yield per recruit (F_{max}) was 0.61, while $F_{20\%}$= 0.28 and $F_{50\%}$= 0.11 (Figure B18).

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:

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 with the inclusion of post-spawning mortality:

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 comparison to the analyses without post-spawning mortality, it was evident that the inclusion of post-spawning mortality would generally increase the values of F_{max} and $F_{20\%}$. The increase in F_{max} would be due to the fact that less yield could be taken from the plus-group, forcing more yield to be taken from younger, recruited age classes. The increase in $F_{20\%}$ would be due to the fact that there would be 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 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 the 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. 1) can be re-expressed as:

$$B_{t+1} = B_t + rB_t\left(1-\frac{B_t}{K}\right) - F_{ref}\,B_t \quad \textbf{(2)}$$

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:

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

The initial condition, B_0, for Eq. 2 was estimated as the CPUE value in 1982 divided by the estimated catchability parameter (q) from Eq. 1. 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 condition for 1982 as 38.5/0.001537 = 25,049 mt where 38.5 (mt/dfay fished) is the GLM-adjusted LPUE (Table B6).

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. 2 and Eq. 3 to each bootstrap realization of r, q, and K.

The point estimate of the long-term potential yield for the target fishing mortality rate, $F_{50\%}$,was 15,392 mt and was 24,272 mt for the threshold fishing rate of $F_{20\%}$. 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 were:

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}
Threshhold: $F_{20\%} = 0.28$	21,325	{18,150,28,183}

Cumulative distribution plots for expected yields in Figure B18 illustrate the substantial overlap between yields for the two reference points. Average landings for 1988-1993 of 11,305 mt were below the target median level. Average landings for 1992-1994 (Table B1), of 18,053 mt, exceeded the target level but were within the predicted interquartile yield range for the target fishing mortality rate.

It should be noted that the long-term potential yields from the biomass dynamics model are consistent with the recent history of resource productivity but could vary 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 population abundance can be highly variable and a single recruitment failure could imply 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, no advantage can be taken of periods of good recruitment.

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 were selected rather than catch quotas because effort management allows catches to vary with population size, which permits taking advantage of good recruitment. The *Illex argentinus* management plan is based on ensuring that proportional escapement remains at a selected target level which is above a threshold minimum spawning stock biomass. 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:

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

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. This proportional escapement target (in this case, 40%) was used to set fishing effort limitations prior to the start of the fishing season, which is when population abundance is unknown. For example, the number of licenses was determined via the target fishing mortality using effort and estimates of catchability:

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

Once the fishing season started, catch (in weight) and effort data were radioed in on a daily basis and weekly biological data were collected from a subset of vessels, by observers at sea, as part of fishing license agreements. The biological data is critical to the conversion of catch weight to numbers, due to the rapid growth of *Illex* during the fishing season. After several weeks of data collection, these data were then incorporated in 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, under different fishing effort scenarios, levels of effort through the end of the fishing season. If the projected absolute escapement was below the threshold, an early closure was considered. If escapement was above the threshold, then in-season adjustments were considered in order to take advantage of good recruitment.

Given the similar life history of *Illex illecebrosus*, a single fishing season, and 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 details of a specific real-time management plan for the U.S. *Illex* fishery would require further research and should be specified prior to implementation. The basics of establishing such a plan are presented in Table B11. Based on preliminary analyses, using a Leslie-Delury assessment model with standardized monthly LPUE data appeared to be a useful method for measuring in-season population abundance. These results agreed well with the surplus production model results from the current assessment. The long autumn survey time series might be useful in setting a threshold spawning biomass level. Since this survey is conducted following the fishing season, it should provide a good index of relative spawning biomass. However, absolute measures of biomass (i.e. swept area estimates) from the autumn survey data should also be investigated. An LPUE index could be used to predict the autumn level of abundance since LPUE and these survey indices show a high correlation, particularly for tonnage class 4 vessels. The results of the preliminary Delury model analysis and additional real-time management information can be found in Basson (WP B2).

Summary and Conclusions

(1) The U.S. EEZ portion of this transboundary stock is fully-exploited and probably at a medium biomass level. Spatial expansion of the fishery has occurred since 1982. Since 1988, effort has been increasing to a near-record high in 1993, while LPUE has been gradually decreasing. The potential consequences of increased effort should be evaluated before further effort is directed toward the U.S. EEZ portion of this stock.

(2) The current NAFO (Subareas 2-4) TAC of 150,000 mt 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 entire *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.

(3) The current overfishing definition does not provide adequate protection for this species given its annual life cycle. Instead, an appropriate threshold would be a monthly $F_{20\%}$ (0.28), due to the flat-topped nature of the yield-per-recruit curve, with a monthly fishing mortality rate target of $F_{50\%}$ (0.11). Landings in excess of the threshold may jeopardize the stock and have deleterious ecosystem-level effects. Fishing mortality has been increasing since 1988 and, in 1993 (F_{93}=0.12 per month), exceeded the $F_{50\%}$ target.

(4) Provisional estimates of long-term potential yield (LTPY) were derived from the expected yields, during 1982-1993, which were predicted by a biomass dynamics model with 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, of 11,305 mt, were below the target midian yield. Landings during 1992-1994 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.

(5) Recruitment for this annual species may vary substantially between years due to natural environmental variation. *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 extremely cold conditions (Beck et al., 1994). In addition to commercial resource value, the significant ecosystem role of *Illex*, as both predator and prey, is an 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*). Real-time management for an annual species with highly variable recruitment and no overlap of generations would permit in-season adjustments via catch or 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* and preliminary analyses which utilized LPUE data from the U.S. *Illex illecebrosus* fishery appear to agree well with the results of the Hilborn-Walters production model. This suggests that a similar type of management plan may be possible for the U.S. EEZ *Illex illecebrosus* fishery.

SARC Comments

Most of the discussion of the SARC members focused on the differences between this assessment and that of the SAW 17. Minimum biomass estimates were derived, during SAW 17, from area-swept calculations using autumn survey indices. However, due to *Illex*'s offshore distribution during NEFSC surveys, stock abundance is not accurately characterized by either the spring or autumn research survey. Rather, the autumn survey provides only a measure of spawning biomass escapement. The current assessment utilized the standardized LPUE indices (GLM output) as a measure of abundance which was incorporated into a surplus production model to derive annual biomass estimates and fishing mortality rates. This method was accepted by the SARC, but due to concerns about the termination of the LPUE time series, with the 1994 implementation of effort data collection from logbooks, it was recommended that other measures of population abundance be investigated for the next assessment.

In addition, interpretation of the surplus production model results given that 22% of the bootstrap replicates produced either negative q values or negative biomass estimates is problematic. Infeasible estimates may be attributable to the lack of sufficient range in the magnitude of the LPUE time series. It was also noted that surplus production models are generally designed for species with overlapping generations.

The importance of continuing to collect, or even increasing, the number of commercial length-frequency samples was also emphasized as a necessity for converting catch biomass into numbers. Commercial discarding practices, particularly aboard freezer trawlers, should be characterized by placing at-sea observers aboard vessels targetting *Illex*. Additionally, the amount of *Illex* bycatch occurring, in the silver hake and other non-directed fisheries, should be determined.

The SARC agreed that the new GLM effort

standardization method represented an improvement over that from the last assessment. This new method included only those trips which targetted *Illex* (*Illex* comprised 25% or greater of total trip weight) and accounted for finer scale changes in spatial and temporal patterns. Although catches from NAFO Subareas 2-4 represented only a minor portion of the total catch during 1982-1993, catch from these areas should be included in the next assessment. The SARC recommended that effort standardization by individual vessel, instead of by tonclass, be investigated.

Another change from the previous assessment involved the application of vessel standardization coefficients to stratified mean number and weight per tow values from the NEFSC autumn survey. The SARC accepted these coefficients, and requested that the details of the vessel fishing power analysis be included in the final SARC document. In addition, the SARC requested further investigation of applying diurnal adjustment factors to autumn research survey catches of *Illex*, since the results of a habitat study (Brodziak and Hendrickson, WP A2) showed that the relationship between time of day and catch per tow from the autumn survey was significant in some years.

The appropriateness of various targets and overfishing definitions were discussed at length. It was agreed that the current overfishing definition does not offer adequate protection for the stock since the autumn survey does not track pre-recruits well and that either a rate-based or biomass-based definition might offer better protection for this annual species. One proposal was an F_{max} overfishing definition and $F_{20\%}$ target. A more risk-averse quota-based method which could utilize the lower quartile from the MSY model, in combination with $F_{20\%}$, was also proposed. However, caution was urged in using a yield-per-recruit reference point and associated estimate of average recruitment since the autumn survey only provides an approximate measure of escapement from the fishery. Given the variability in abundance for this annual species, the lower quartile of the MSY series might turn out to be too conservative in some years.

The appropriateness of selecting $F_{20\%}$ as a biological reference point by analogy to another *Illex* species was questioned given the lack of knowledge about *Illex* recruitment. It was agreed that substantiating any %MSP value would be difficult, but that choosing F_{50}% would be more precautionary and similar to the Falkland Islands reference point (40% proportional escapement) used for real-time management of the *Illex argentinus* fishery. Further, it was noted that $F_{20\%}$ might be a reasonable reference point given that female *Illex* produce 20 times as many eggs as *Loligo*, for which a target of $F_{50\%}$ was selected. In conclusion, the SARC decided on a threshold monthly fishing mortality rate of $F_{20\%}$ (0.28) and a target of $F_{50\%}$ (0.11) for the U.S. EEZ *Illex* fishery.

Real-time management methods presented in Working Paper B2 were also discussed. SARC members felt real-time management was critical for annual species such as the squids, given the fact that a single recruitment failure could imply stock collapse and that stock size is generally unknown before the start of the fishing season and highly variable between years. Preliminary analyses utilizing the monthly coefficients from the standardized LPUE model suggest that there is good agreement between the Leslie-Delury depletion model and the 1982-1993 surplus production model values from the current assessment. The pros and cons of effort versus catch quota controls were discussed. Concerns about adequate data collection methods, including at-sea observers, and their costs were expressed. It was noted that catch information from dealer reports would be easier to extract than the use of effort data from logbooks and that the collection of early-season catch and effort data, for only a representative portion of the fleet, might be more cost-effective for determining in-season effort or catch quota adjustments. The SARC requested the summarization and presentation of the real-time management information in Working Paper B2 to the MAFMC. They also determined that a detailed data collection plan and a cost-benefit analysis should be drafted to determine the feasibility of implementing real-time management measures for *Loligo* and *Illex* squid. It was recommended that the *Illex* fishery, due to it's single-season and small number of vessels, be used as a test case.

Research Recommendations

- o Total catch (U.S. EEZ and NAFO Subareas 2-4) should be incorporated into future surplus production model analyses for this unit stock.

- o Investigate effort standardization for individual vessels, or 2-digit vessel size classes.

- o A joint research program for this transboundary stock, involving US and Canadian scientists, would improve the biological basis for management and assessment.

- o Joint transboundary management measures should be considered.

- o The level of length frequency sampling is low (1 sample of 50 lengths per 800 mt landed) and should be increased. Given the variability in mean weights, by month and statistical area, increased sampling effort is recommended to characterize the fishery, particularly if real-time management measures are implemented. Mean weights would be necessary to convert catch biomass to numbers for input to a Leslie-DeLury model. Industry participation in the collection of length frequency data should be explored through provisions of the mandatory logbook requirement. Voluntary collection of biological data at sea would help address sampling needs and foster industry/scientist communication.

- o Examine factors related to the formation of daily growth increments, such as temperature, light and vertical migration.

- o Increase knowledge of the stock structure by studying the range of the population throughout the year and determining spawning locations.

- o Establish a pilot study to collect *Illex* statoliths during research surveys to determine length-at-age and weight-at-age relationships for squid from Cape Hatteras to the Gulf of Maine.

- o Schedule the collection of at-sea observer data for trips targetting *Illex,* particularly aboard freezer boats, to evaluate fishery catch and discarding practices. Also investigate *Illex* bycatch in the silver hake fishery and other fisheries.

- o Determine whether abundance indices require adjustment factors for time of day in all survey years.

- o *Illex* has been reported to school by sex and size. Record the sex and sexual maturity of squid caught during research surveys for use in determining differences in growth rates, and timing of spawning and mean length at sexual maturity of females, respectively, in the U.S. EEZ.

- o If an *Illex* fishery develops south of Cape Hatteras, it would be desirable to characterize the species composition of the catch and to identify the extent of co-occurrence of other *Illex* species off the southeastern U.S. coast.

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Table B1. 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 1973-1994[1,2,3,5]

	Cape Hatteras to the Gulf of Maine			NAFO Subareas 2, 3 and 4	All Areas
Year	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	5,422	111	5,533
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	18,322[4]	0	18,322	-[5]	-[5]
AVERAGES					
1963-93	4,006	6,794	10,774	-[1]	28,429[1,2,5]
1973-82	1,109	18,306	19,414	51,540	70,954
1983-89	6,956	537	7,492	1,687	9,179
1990-93	14,766	0	14,766	4823[2,4,5]	19,589[2,5]

[1] ICNAF squid landings were not reported by species before 1973.
[2] *Illex* landings from NAFO Subareas 2, 3 and 4 in 1992 and 1993 are provisional.
[3] Landings during 1982-1992 have been updated by NAFO.
[4] Landings for 1994 are preliminary.
[5] Landings from NAFO Subareas 2, 3 and 4 in 1994 are unavailable.

Table B2. Landings (mt) of *Illex* squid (*Illex illecebrosus*) by 3-digit US statistical area and month during 1993.

	MONTH														
AREA	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	35.4	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 B3. Summary of Illex squid commercial fishery sampling, during 1982-1993, in the U.S. EEZ.

YEAR	SAMPLE SIZE	TRIPS SAMPLED	U.S. LANDINGS (mt)	SAMPLES PER TON LANDED
1982	2961	59	5,902	2
1983	920	18	9,944	11
1984	1690	33	9,547	6
1985	411	8	4,997	12
1986	866	17	5,176	6
1987	600	12	10,260	17
1988	759	15	1,966	3
1989	159	3	6,801	43
1990	324	6	11,316	35
1991	751	15	11,908	16
1992	800	16	17,827	22
1993	1154	23	18,012	16

Table B4. Total numbers of *Illex illecebrosus* landed (millions) 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	5,422	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 1982-93	131	10,813	82.5

Table B5. Results of General Linear Model for the domestic *Illex* squid fishery during 1982-1993.

Dependent Variable: LNCPUEDF

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
982	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
9622	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
98	0.000000000	B	.	.	.

Table B6. Standardized fishing effort and LPUE for *Illex* squid (*Illex illecebrosus*) 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] (daysfished)
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	5,422	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 1982-93			47.3	10,813		263

[1] Effort for 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 B7. All sizes, pre-recruit (≤ 10 cm), and recruit (> 10 cm) stratified mean numbers per tow and mean weights per tow (kg) of *Illex illecebrosus* from the NEFSC fall bottom trawl survey (offshore strata 1-40 and 61-76, Cape Hatteras to the Gulf of Maine) during 1967-94.

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 B8. All sizes, pre-recruit (≤ 10 cm), and recruit (> 10 cm) stratified mean numbers per tow and mean weights per tow (kg) of *Illex illecebrosus* from the NEFSC spring bottom trawl survey (offshore strata 1-40 and 61-76, Cape Hatteras to the Gulf of Maine) during 1967-95.

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 B9. Results of the surplus production model, for *Illex* squid landed in theU.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	5,422	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

Table B10. Yield and spawning stock biomass per recruit estimates for *Illex illecebrosus*.

Yield and Spawning Stock Biomass per Recruit

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	TOTCTHN	TOTCTHW	TOTSTKN	TOTSTKW	SPNSTKN	SPNSTKW	% 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

Table B11. The basics of real-time management of *Illex illecebrosus*.

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

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

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

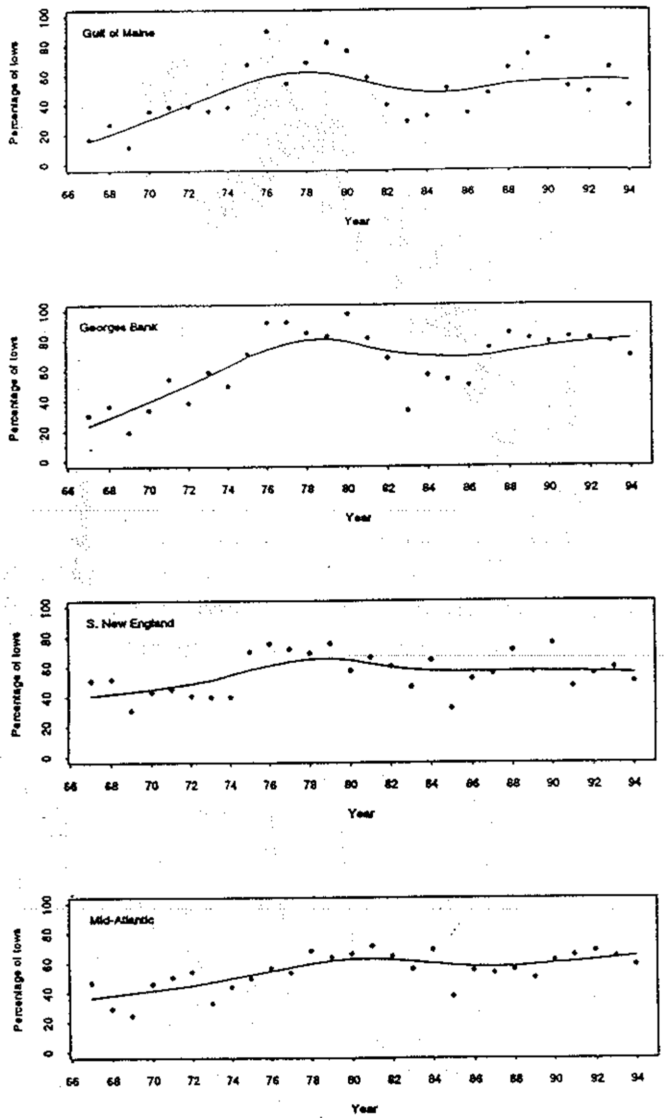

Figure B1. Proportion of tows, by region, in which *Illex illecebrosus* were caught during NEFSC autumn bottom trawl surveys, 1967-1994. Line represents LOWESS smoothed estimate with tension parameter of 0.5.

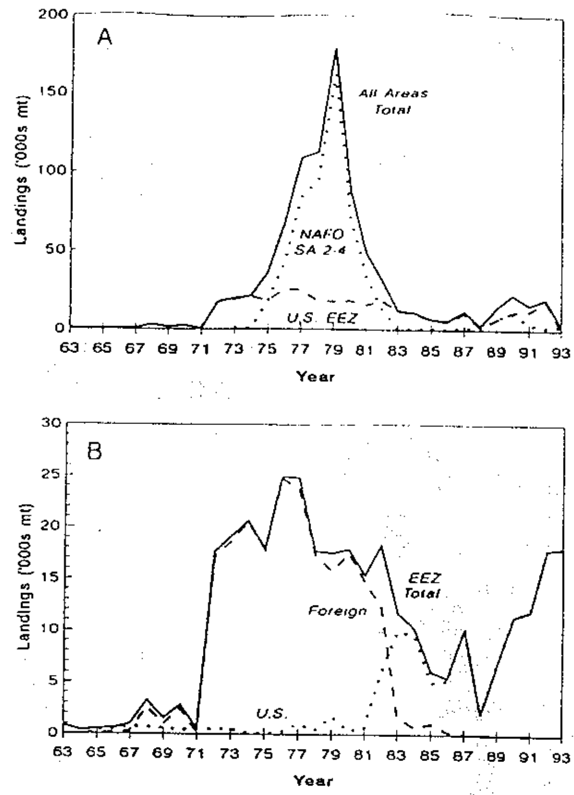

Figure B2. Trends in *Illex* squid landings for (A) total US EEZ, NAFO Subareas 2-4 (1973-1993) and landings for all areas combined and (B) US, foreign, and total US EEZ during 1963-1993.

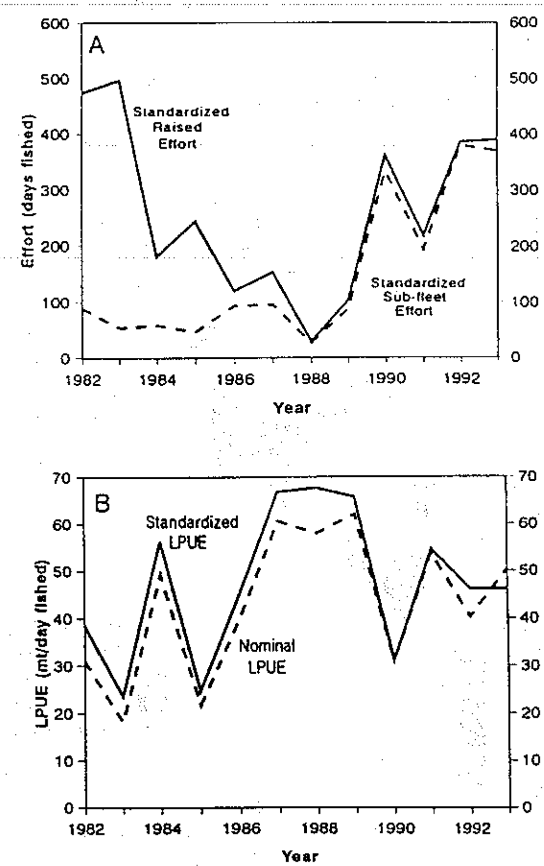

Figure B3. Trends in standardized and nominal (A) effort (days fished) and (B) LPUE (mt/day fished) for vessels whose landings of *Illex* squid exceeded 25% (by weight) of their trip landings, 1982-1993.

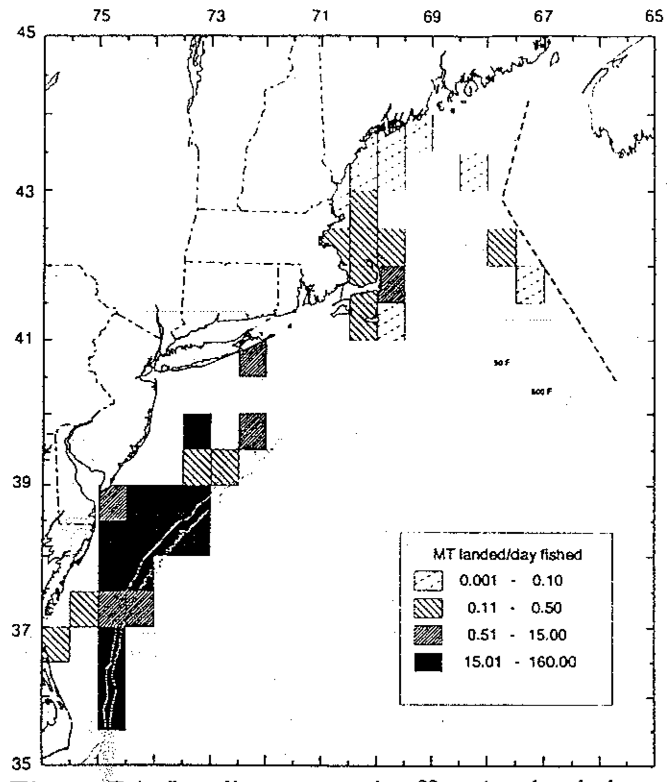

Figure B4. Landings per unit effort (mt landed per day fished) of *Illex illecebrosus* caught by the domestic bottom trawl fishery during 1982-985.

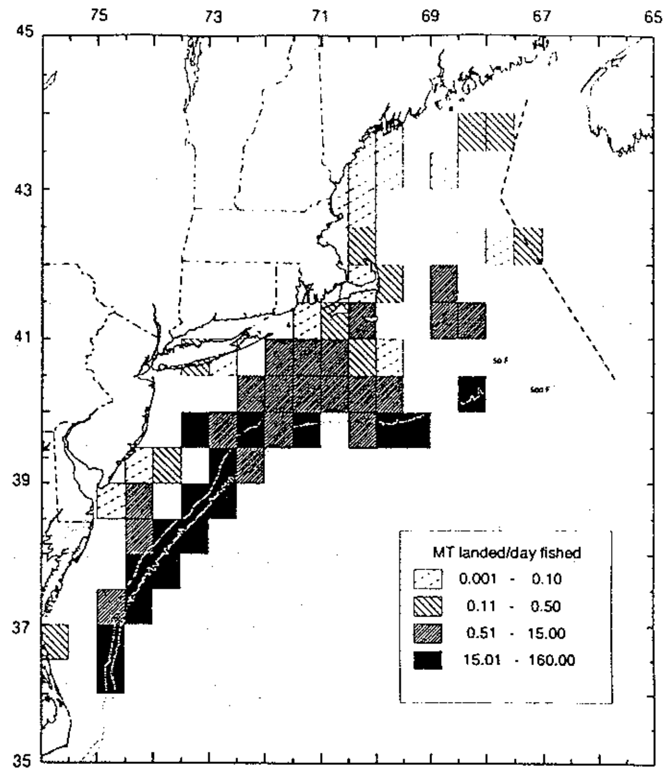

Figure B6. Landings per unit effort (mt landed per day fished) of *Illex illecebrosus* caught by the domestic bottom trawl fishery during 1990-1993.

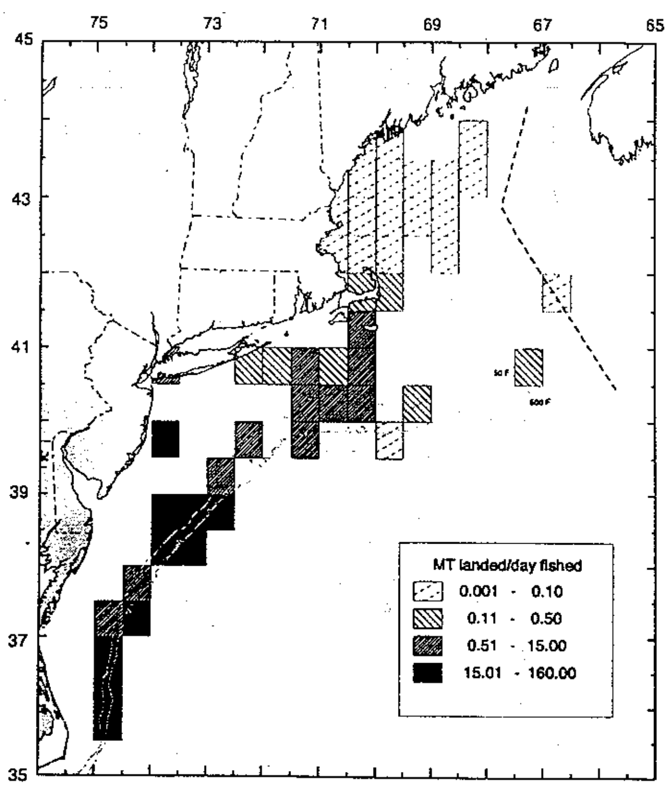

Figure B5. Landings per unit effort (mt landed per day fished) of *Illex illecebrosus* caught by the domestic bottom trawl fishery during 1986-1989.

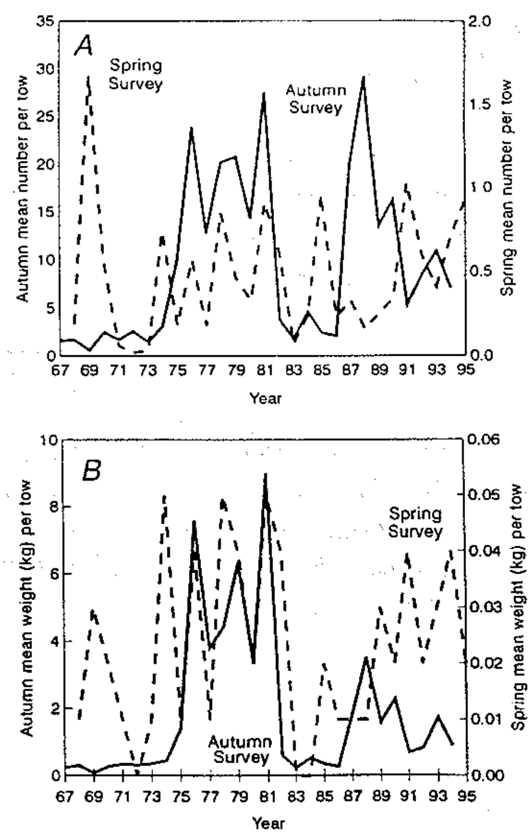

Figure B7. Stratified mean number per tow (A) and mean weight per tow (kg) (B) of *Illex illecebrosus* from the NEFSC autumn (1967-1994) and spring (1968-1995) bottom trawl surveys.

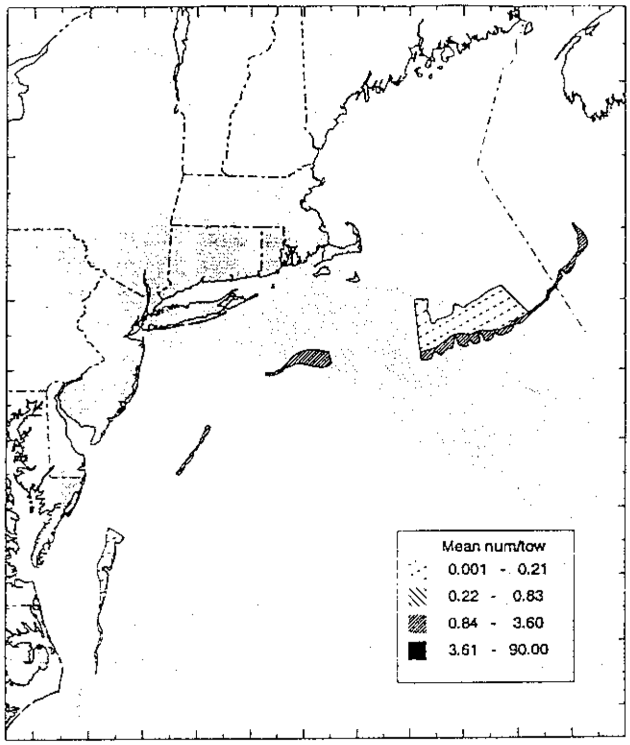

Figure B8. Mean number per tow of *Illex illecebrosus* pre-recruits (≤ 10 cm), by survey stratum, during NEFSC winter surveys, 1992-1994.

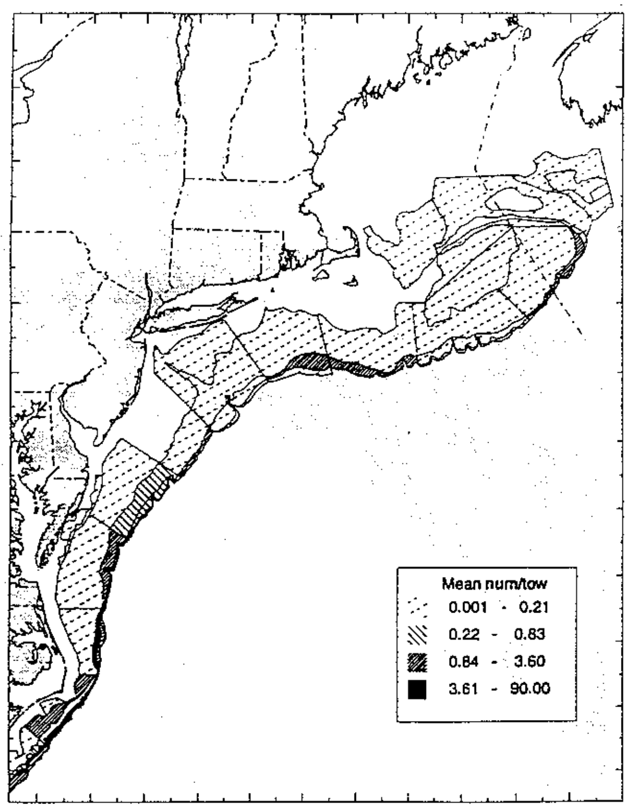

Figure B9. Mean number per tow of *Illex illecebrosus* per-recruits (≤ 10 cm), by survey stratum, during NEFSC spring surveys, 1968-1994.

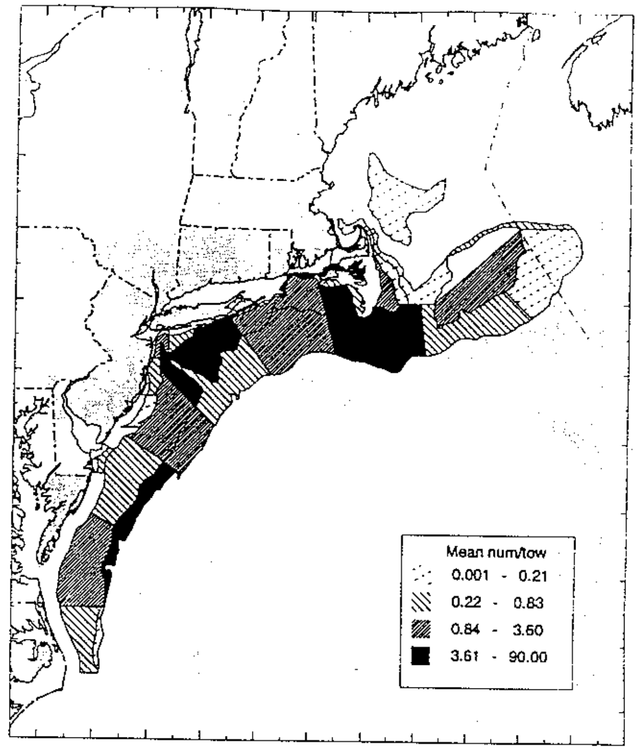

Figure B10. Mean number per tow of *Illex illecebrosus* pre-recruits (≤ 10 cm), by survey stratum, during NEFSC summer surveys, 1977-1980.

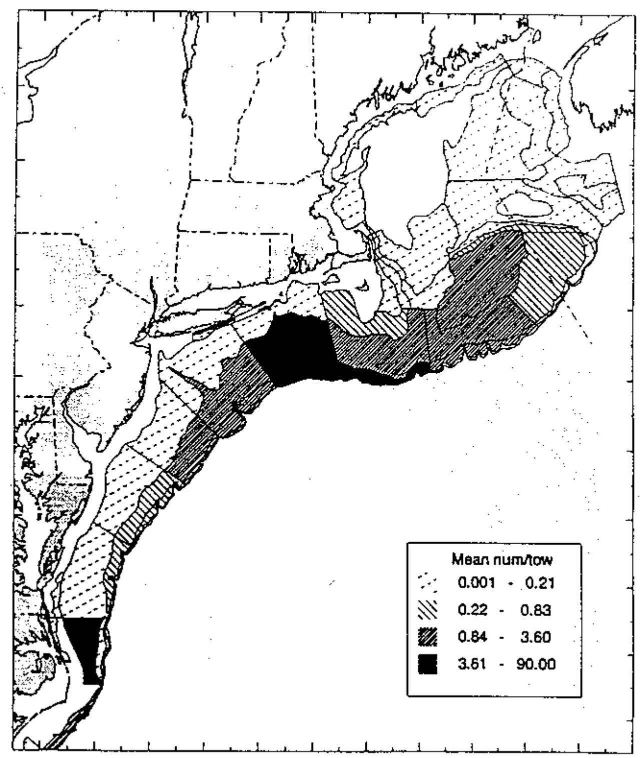

Figure B11. Mean number per tow of *Illex illecebrosus* pre-recruits (≤ 10 cm), by survey stratum during NEFSC autumn surveys, 1967-1994.

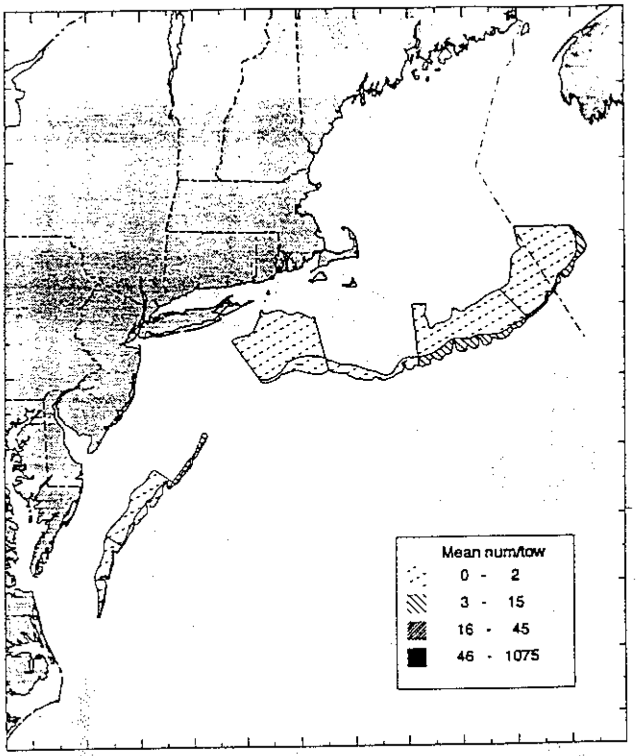

Figure B12. Mean number per tow of *Illex illecebrosus* pre-recruits (≥ 11 cm), by survey stratum, during NEFSC winter surveys, 1992-1994.

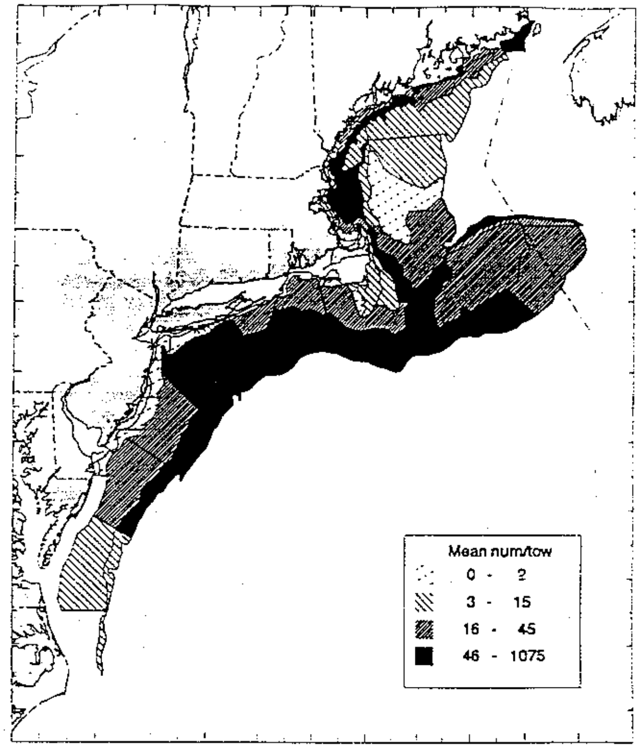

Figure B14. Mean number per tow of *Illex illecebrosus* pre-recruits (≥ 11 cm), by survey stratum, during NEFSC summer surveys, 1977-1980.

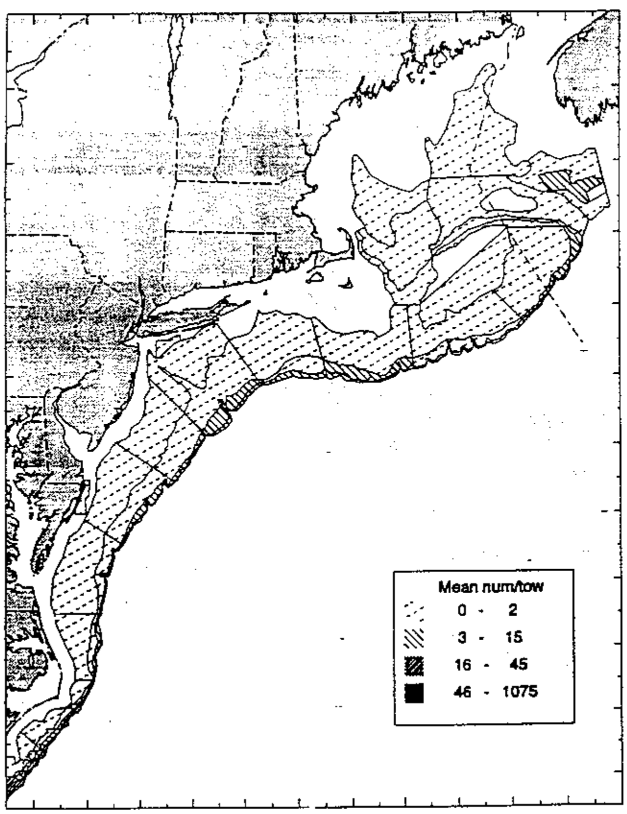

Figure B13. Mean number per tow of *Illex illecebrosus* pre-recruits (≥ 11 cm), by survey stratum, during NEFSC spring surveys, 1968-1994.

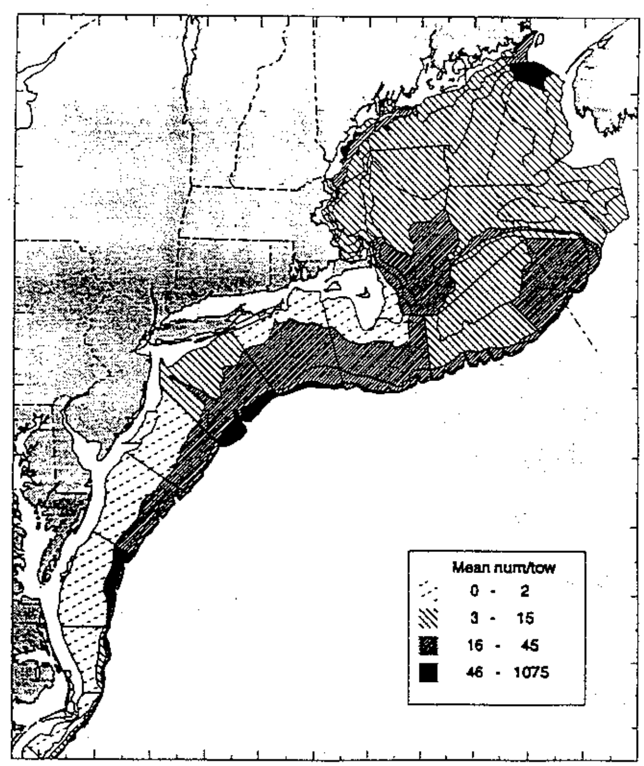

Figure B15. Mean number per tow of *Illex illecebrosus* pre-recruits (≥ 11 cm), by survey stratum, during NEFSC autumn surveys, 1967-1994.

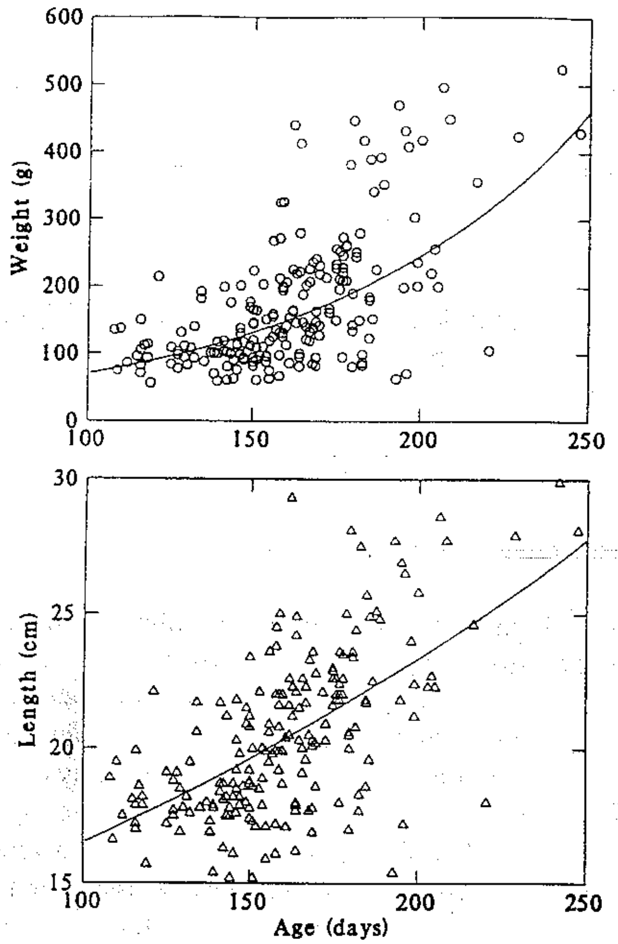

Figure B16. Observed and predicted weight-at-age (top) and length-at-age (bottom), for *Illex illecebrosus*. Weight = 20.exp(0.01255 d) and length = 11.64.exp(0.00348 d). Raw data from E. Dowe (ers. comm., DFO, St. John's).

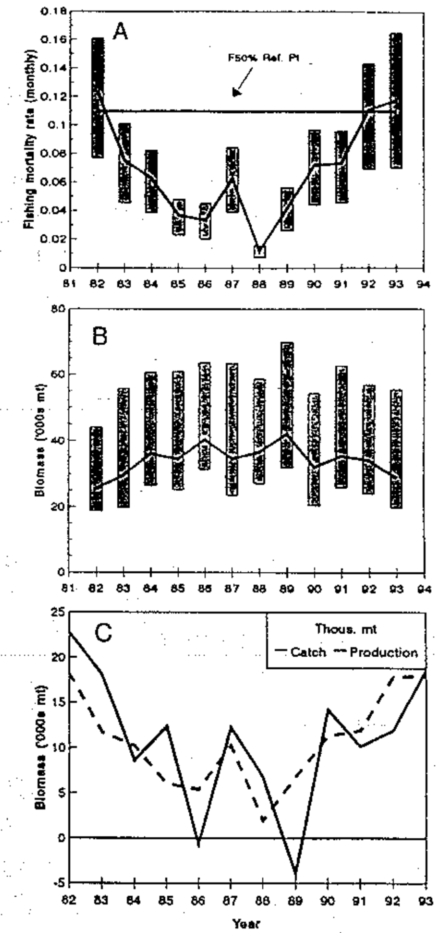

Figure B17. Median annual fishing mortality estimates, for *Illex* squid, with interquartile range derived from bootstrap estimation method (A); median initial biomass estimates with interquartile range (B) and comparison of annual catch with estimated median annual production (C). Negative production in year t implies a decrease in initial biomass in year t+1.

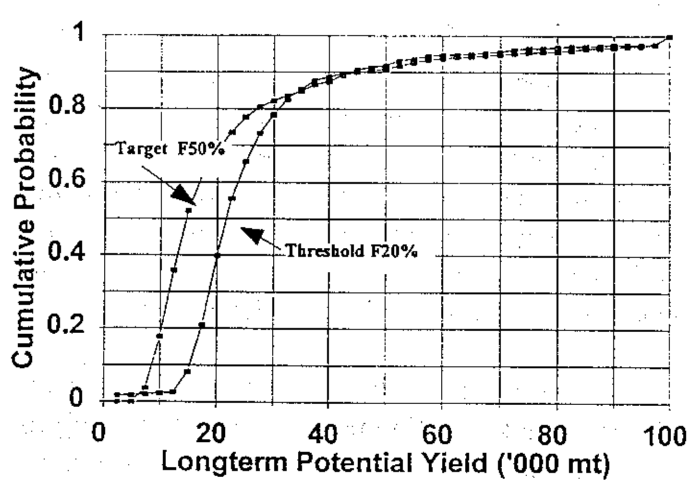

Figure B18. Distribution of long-term potential yields expected from the U.S. EEZ *Illex illecebrosus* fishery for target (F50%) and threshold (F20%) fishing mortality rates.