D. Northern Shortfin Squid (*Illex illecebrosus*)

TERMS OF REFERENCE

The following Terms of Reference were addressed:

1. Characterize fishery performance since the last assessment based on landings, discards, fishing effort and other relevant data.
2. Estimate fishing mortality and stock biomass in absolute or relative terms, as appropriate, and characterize uncertainty of estimates.
3. Evaluate stock status relative to current reference points. Using new biological information, update or re-estimate biological reference points as appropriate.
4. Evaluate new assessment approaches potentially useful for short-lived *Illex* squid. In particular, characterize performance of the new stock assessment model developed for SARC-29; propose improvements as appropriate. Evaluate recent experimental tow-by-tow fisheries data collection programs for use in real-time management. If possible, evaluate environmental indices that might be used to predict availability or productivity.

INTRODUCTION

The *Illex illecebrosus* stock was last assessed in 1999 at the 29th Stock Assessment Workshop (SAW) (NEFSC 1999a). The assessment included updates of fisheries and research survey data for 1994 through 1998. A DeLury depletion-type model that assumed no recruitment, incorporated weekly landings and effort data from the Vessel Trip Report (VTR) database, mean body weights in the landings and a constant, weekly natural mortality rate of 0.06, were used to estimate initial stock size and fishing mortality in the U.S. fishing area during 1994-1998 (NEFSC 1999b). The fishing mortality estimate was interpreted as an upper bound for the U.S. stock component. An imprecise, lower bound on fishing mortality was computed by reducing the upper bound to account for unfished habitat in U.S. waters. The latter, lower bound estimate was considered the most appropriate metric for determining stock status because Northeast Fisheries Science Center (NEFSC) spring and autumn survey distribution maps indicated that *Illex* migrates through the fishing grounds in a "wave" pattern rather than a "gauntlet" pattern. However, the collection of tow-based fisheries data was recommended to better understand in-season LPUE trends and to assess the appropriateness of utilizing a DeLury depletion model for in-season stock assessment.

The SARC 29 assessment also included a weekly yield-per-recruit (YPR) and spawning stock biomass-per-recruit (SSB/R) analysis that incorporated a 1994-1998 composite exploitation pattern, a constant natural mortality rate of 0.06 per week, and input data from SARC 21 (NEFSC 1996) that was converted to weekly values. Growth and maturity of *Illex* were among the major model uncertainties because growth and maturity data were from *Illex* in the 1990 Newfoundland jig fishery where biological characteristics are substantially different. SARC-29 recommended a target fishing mortality rate of $F_{50\%}$ as an F_{MSY} proxy in order to minimize the potential for recruitment overfishing. In addition, a constant escapement harvest policy and in-season stock assessment approaches were recommended to minimize recruitment overfishing and maximize yield. In addition, a constant escapement harvest policy and in-season stock assessment approaches were recommended to minimize recruitment overfishing and maximize yield.

With respect to stock status, SARC 29 concluded that overfishing was not likely to have occurred during 1994-1998 because the upper and lower bounds on fishing mortality estimates were below potential F_{MSY} proxies. However, an evaluation of whether the stock was overfished was not possible because no representative measure of stock biomass and corresponding reference point were available.

The current assessment pertains to the U.S. EEZ portion of the stock and updates fisheries data and indices of relative abundance and biomass during 1999-2002. A new maturation model that incorporates the semelparous life history of *Illex*, allows for estimation of spawning mortality rates and new information regarding the age composition, growth and maturity of *Illex* inhabiting U.S. waters is presented. Output from the maturation model, including the probability of spawning at age and spawning mortality rate estimates, are incorporated into yield-per-recruit and egg-per-recruit analyses along with revised selectivity estimates and mean weights in the catch, during 1999-2002, to derive new biological reference points that may serve as F_{MSY} proxies. Tow-based fisheries data from a real-time data collection program were utilized in a preliminary model which may be useful in future assessments for in-season estimation of stock size and fishing mortality rates.

BACKGROUND

A review of the biology, population dynamics and exploitation of the *Illex illecebrosus* stock in the northwest Atlantic Ocean, in relation to stock assessment and management, is presented in Dawe and Hendrickson (1998). The Northern shortfin squid is a highly-migratory ommastrephid that tends to school by sex and size and lives for up to one year (Dawe et al. 1985; Dawe and Beck 1997; O'Dor and Dawe, 1998; Hendrickson *In Review*). The *Illex* population is assumed to constitute a unit stock throughout its range of commercial exploitation from Cape Hatteras to Newfoundland (Dawe and Hendrickson 1998). Temporal and spatial distribution patterns are highly variable and are associated with environmental factors at the northern limit of this species' range (Dawe et al. 1998). Recruitment dynamics are complex and have not been fully elucidated for the U.S. EEZ component of the stock, so that reliable predictions of annual recruitment levels are not currently possible. Stock structure is complex and, in Newfoundland waters, is complicated by overlapping seasonal cohorts that migrate through the fishing grounds (Dawe and Beck 1997). Mean size at sexual maturity varies between northern and southern geographic regions in some years (Coelho and O'Dor 1993). However, it is not known whether these differences were due to inherent population structure. O'Dor and Coelho (1993) speculated that changes in the seasonal spawning patterns could have played a role in the collapse of the Canadian fishery during the early 1980's.

The *Illex* stock is transboundary in nature and is fished on the continental shelf from Newfoundland, Canada to Cape Hatteras, North Carolina. However, there are no stock-wide indices of relative abundance or biomass. The NEFSC bottom trawl surveys do not cover the entire habitat range of this species and it is unknown whether the survey indices measure relative abundance or availability to the survey gear. In addition, U.S. fisheries data is of coarse temporal and spatial resolution and age and growth information is lacking for the U.S. stock component. As a result, research recommendations in previous assessments have emphasized the need for improved stock assessment data, particularly since *Illex* lives for less than one year and the U.S. fishing season is of short duration (4-5 months on average). As a result, the NEFSC has conducted several cooperative research projects with the *Illex* fishing industry that have resulted in: (1) improved spatial and temporal resolution of fisheries catch, effort and biological data; (2) characterization of the age composition, growth, and maturity of *Illex* inhabiting U.S. waters prior to the start of the fishery; and (3) the collection of fisheries data, in real-time, via electronic logbook reporting. The products of these research projects are used extensively in the current assessment.

During 1999, a large portion of the *Illex* fleet participated in a real-time data collection study that involved recording tow-based catch, effort and fishing location data, in hardcopy form, with weekly submittals of these data to the NEFSC. In addition, squid processors provided mantle length and body weight data from squid collected daily during each trip. Study participants attended a workshop at which the results were presented and improvements for future data collection activities were recommended. The study results were also posted on an NEFSC website.

Data collection from the *Illex* fishery continued during 2000-2001 in hard copy format. In 2002, tow-based, data were collected electronically in real-time, via e-mail, and automatically loaded into Oracle tables (Hendrickson et al. 2003). Vessel operators were able to log on to secure, personal web sites to edit and confirm their fisheries data collected at sea, and to incorporate additional vessel data required for logbooks. The web site also allowed fishermen to view their personal catch and oceanographic data through the use of an interactive mapping tool and print hardcopy logbooks for their records. The study demonstrated that electronic logbook reporting offers an efficient, cost-effective means of collecting accurate, high resolution fisheries and oceanographic data that can rapidly be made available to fishermen and stock assessments scientists.

During May 2000, a pre-fishery bottom trawl survey was conducted with two squid vessels, chartered by the NEFSC, to assess initial stock size and distribution and to collect biological data for age, growth and maturity analyses (Hendrickson *In Review*).

MANAGEMENT

Commercial fisheries for *I. illecebrosus* occur from Newfoundland to Cape Hatteras, North Carolina. The fishery operating within the U.S. EEZ (Northwest Atlantic Fisheries Organization Subareas 5 and 6) is managed by the Mid-Atlantic Fishery Management Council (MAFMC) and fisheries operating within Northwest Atlantic Fisheries Organization (NAFO) Subareas 2, 3 and

4 are managed by NAFO (Figure D1). During 1980-1998, the annual total allowable catch (TAC) established by NAFO for Subareas 2-4 was 150,000 mt (NAFO 1995). The NAFO TAC was reduced to 75,000 mt in 1999 (NAFO 1998) and has been 34,000 mt since 2000 (Hendrickson *et al.* 2003). Annual levels of allowable biological catch (ABC) and domestic annual harvest (DAH) in the U.S. EEZ are determined in accordance with the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan (SMB FMP) and are based on the best available information about the current status of the stock. During 1991-1995, the optimum yield (OY), ABC and DAH were 30,000 mt (MAFMC 1994). The DAH was reduced to 21,000 mt in 1996 (MAFMC 1995a) and 19,000 mt during the 1997-1999 fishing seasons (MAFMC 1996a; 1997a; 1998a). The DAH has been 24,000 mt since 2000 (MAFMC 2000; 2001; 2002).

Amendment 5 of the SMB FMP was enacted (MAFMC 1995b; 1996b) in recognition that the domestic resource was approaching full utilization and that expansion of the U.S. fleet might lead to overcapitalization. Amendment 5 established a permit moratorium to limit entry into the directed fishery, required mandatory logbook and dealer reporting as of January 1, 1997, and established a 5,000-pound trip limit for incidental catches of *Illex* by non-moratorium vessels. Amendment 6 (MAFMC 1996c) allowed for the potential to establish seasonal closures of the *Illex* fishery and set the current overfishing definition of $F_{20\%}$ and established procedures for the specification of annual quotas based on $F_{50\%.}$ Amendment 7 (MAFMC 1998b) was enacted to achieve consistency between FMP's with regards to Limited Access Federal permits. Based on the requirements of the Sustainable Fisheries Act (SFA), Amendment 8 (MAFMC 1998c) established a new overfishing definition and F target defined as the catch associated with F_{MSY} and 75% of F_{MSY}, respectively. In addition, a biomass target and minimum biomass threshold were specified as B_{MSY} and 50% of B_{MSY}, respectively. Amendment 8 also defined the essential habitat of *Illex* in the U.S. EEZ and established a framework adjustment process for specific management measures. Amendment 9 is currently in draft form, and with respect to *Illex*, could: 1) extend the moratorium on entry to the commercial *Illex* fishery, 2) allow for specification of management measures covering multiple years, 3) allow for the transit of vessels through the U.S. EEZ which possess greater than 5,000 pounds of *Illex* caught outside the U.S. EEZ when a trip limit is in effect, 4) implement management alternatives for Atlantic mackerel, squid, and butterfish to prevent, mitigate or minimize adverse effects from fishing which would bring the FMP into compliance with Section 303(a)(7) of the SFA, and 5) implement measures to reduce discards in the *Illex* fishery.

THE FISHERIES

Landings

Illex landings (mt) during 1963-2002 are presented by NAFO Subarea (Figure D1). Subareas 5+6 (U.S. EEZ) landings are partitioned into foreign and domestic components (Table D1). Total allowable catches (TACs) established for NAFO Subareas 3+4 and Subareas 5+6 during 1974-2002 are also presented in Table D1. Prior to 1976, U.S. EEZ landings of squid by distant water fleets were not consistently reported by species. As a result, *Loligo pealeii* landings are included with *Illex* landings prior to 1976. In addition, squid landings were not recorded by species in the NEFSC commercial fisheries "Weighout" database until 1979. As a result, U.S. EEZ landings during 1963-1978 were derived from prorations based on the temporal and spatial landings patterns of *Illex illecebrosus* and *Loligo pealeii*, by country, from fisheries observer data (Lange and Sissenwine 1980). U.S. EEZ landings during 1979-2002 are from the Weighout database and include landings from joint ventures that occurred during 1982-1990 between U.S. and foreign fishing vessels. Landings from NAFO Subareas 3+4, during 1963-2002, were taken from Hendrickson et al. (2002) and 2003 landings were reported by E. Dawe, Canada Department of Fisheries and Oceans (pers. comm. 2003).

Historically, total *Illex* landings have varied considerably and consisted of three distinct levels of magnitude (Figure D2A). A period of high landings occurred during 1976-1981, when distant water fleets were active in all NAFO fishing areas, which was preceeded and followed by periods of substantially lower landings. During 1963-1967, total landings were low, averaging 7,354 mt, and were primarily from the Subarea 3 inshore hand jig fishery. During 1968-1974, total landings averaged 13,470 mt and were predominately from distant water fleets fishing in Subareas 5+6. However, this trend was reversed during 1976-1981, when landings were predominately from Subareas 3+4. During this time, total landings averaged 100,300 mt, and in 1979, reached the highest level on record (179,333 mt). During 1979-1983, landings from Subareas 3+4 declined rapidly from 162,092 mt to 426 mt. However, landings from Subareas 5+6 remained stable, in part, due to effort limitations placed on the distant water fleets fishing in U.S. waters. Total landings have been dominated by the U.S. domestic bottom trawl fishery since its inception in 1982. The exception occurred in 1997, when landings from Subareas 3+4 (15,485 mt) exceeded U.S. EEZ landings (13,629 mt) and were at their highest levels since 1982. Landings from Subareas 3+4 declined to 1,902 mt in 1998 and have been less than 400 mt since then. The decline in landings was primarily due to the lack of a bycatch fishery for *Illex* in Subarea 4 since 2000 (Hendrickson et al. 2002).

U.S. EEZ landings were characterized by two distinct periods (Figure D2B). During 1968-1982, U.S. EEZ landings were predominately taken by distant water fleets, and in 1976, reached a peak of 24,936 mt. U.S. EEZ landings subsequently declined to 1,958 mt in 1988 (Figure D2B). There has been no foreign participation permitted in the U.S. *Illex* fishery since 1987 in order to foster development of a domestic fishery. During 1998-1994, landings from the domestic fishery increased from 1,958 mt to 18,350 mt, then reached a peak of 23,597 mt in 1998. This 1998 peak led to an early closure of the fishery because the landings quota was exceeded. Since 1998, U.S. EEZ landings have been below the 1982-2002 average, and in 2002, reached their lowest level since 1988 (2,723 mt).

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

The temporal patterns of fisheries in U.S. and Canadian waters are determined primarily by the timing of this species' feeding migration onto and spawning migration off of the continental shelf, although worldwide squid market conditions also influence the timing of the fishing season in the U.S. EEZ. Inshore migration in Subarea 3 generally occurs during July, approximately three months later than it occurs on the continental shelf in Subareas 4, 5 and 6. This delay in the arrival of juveniles on the fishing grounds is presumably a result of the position of the Gulf Stream being located further from shore in this northern region. An unusually early inshore arrival of squid occurred in Subarea 3 during June of 1987, when 78% of the landings for that year were taken. This species also remains on the shelf longer in Subarea 3, where fishing extends into November, particularly since 1992. Since 1992, the U.S. EEZ fishery and the bycatch of *Illex* taken in the Subarea 4 silver hake fishery have begun in May or June. Although the silver hake fishery in Subarea 4 closes in July, it is apparent from the Canadian observer program that these vessels target *Illex* when it is available (Mark Showell, pers. comm. 1998). Since 1992, peak landings have occurred during July, in Subareas 4, 5, and 6, during September in Subarea 3 (NEFSC 1999b).

In-season trends in *Illex* landings and the duration of the fishing season vary by year (NEFSC 1999b). Since 1987, the U.S. fishery has occurred between May and November, but most of the landings (90%) are taken between June and September (NEFSC 1999b). Weekly trends in *Illex* landings from the VTR database are similar to those from the Weighout database, with the exception of weeks 30 through 33 in 2000. A comparison of landings by vessel and trip in both databases confirmed missing VTR data for one vessel during those weeks. During 1999-2002, the fishery began during weeks 22 or 23 and lasted for a period of 17 to 21 weeks (Figure D3). Weekly landings were highly variable, which made it difficult to detect the inflection point after which landings declined, particularly in 2001 and 2002. This variability is partly attributable to the coarser temporal resolution of the VTR database, which necessitates assigning week of the year by the date landed instead of the tow date, as is possible with use of the real-time reporting data (Figure D4). In-season landings variability is also attributable to a reduction in the number of tows across weeks due to reduced participation in the fishery during 1999-2002 (see section Landings per Unit Effort below).

<u>Discard Estimation</u>

In addition to the *Illex* fishery, which is characterized by a codend mesh size of approximately 38.1 mm, other fisheries likely to incur *Illex* bycatch are those that utilize bottom trawls of similarly small mesh and that occur during May-November, when *Illex* is present on the U.S. continental shelf. The offshore *Loligo* fishery meets both criteria and catch data from observed trips from the NEFSC Observer Program database indicate that a majority of the *Illex* bycatch, during 1995-2002, occurred in the offshore *Loligo* fishery.

Illex discards (mt) in the *Illex* and *Loligo* fisheries were estimated, by month and year, from catch data collected during trips sampled by observers from the NEFSC Sea Sampling Program during 1995-2002. The *Illex* fishery was defined as bottom trawl trips that occurred during May-October in which *Illex* landings comprised ≥ 25% of the total trip weight. The *Loligo* fishery was defined as bottom trawl trips that occurred during November-April in which *Loligo* landings comprised ≥ 25% of the total trip weight. Annual estimates of *Illex* discards were computed by multiplying the discard ratio (*Illex* discarded/*Illex* or *Loligo* kept, mt) by either the *Illex* or *Loligo* landings.

The annual sampling intensity of trips observed in the *Illex* fishery was low, ranging between 2 and 15 trips (Table D2), and represented 0.01-4.54% of the annual *Illex* landings (Table D3). There were no *Illex* trips sampled during 2001 or 2002. Temporal discarding patterns could not be discerned because the number of trips sampled by month was not representative of the seasonal landings pattern. The amount of *Illex* discarded in the *Illex* fishery, during 1995-2000, ranged between 29 mt and 150 mt per year.

The annual sampling intensity of trips observed in the *Loligo* fishery was also low, ranging between 3 and 18 trips (Table D4), and represented 0.07-2.25% of the annual *Loligo* landings (Table D3). Sampling coverage was inconsistent during the fishing season, so monthly trends in discarding could not be discerned. Inconsistent sampling may also be reflected in the spatial patterns of discarding which varied greatly during 1999-2001 (Figures D5A and B). During 2001, Gear Restriction Areas (GRA's) were established to reduce scup bycatch. The Southern GRA is closed to small-mesh (< 4.5 inch codend mesh) fisheries during January through March 15 (Figure D6). NEFSC spring survey data indicate that *Illex* migration onto the U.S. continental shelf generally begins in March, during the latter part of the closure period. However, observer data were inadequate to evaluate whether this closure area will also aid in the reduction of *Illex* discarding in the *Loligo* fishery. The amount of *Illex* discarded in the *Loligo* fishery, during 1995-2002, ranged between 1 mt and 303 mt per year.

In summary, *Illex* discard estimates are imprecise but the overall level of discard in recent years was likely small. During 1995-2002, *Illex* discarded in the two squid fisheries ranged between 53 mt and 453 mt and comprised 0.5-4.4% of the total *Illex* landings during this time period (Table D3). *Illex* discarding in both squid fisheries was highest during 1998, when *Illex* abundance was highest. However, a quantitative comparison of discarding between years and months was difficult due to low sampling intensity, by month and year, in both fisheries.

Mean Size of *Illex* in the Fishery

Average body size and within season trends in average size are potentially important for *Illex* because changes in size reflect the combined effects of growth, mortality, emigration and immigration from fishing grounds. Consequently, mean size data likely contain information useful in stock assessment modeling (NEFSC 1999b). *Illex* landings were sampled by squid processors, for mantle length (cm) and body weight (g), during 1999-2002 (Table D5) and during 1994-1998 (NEFSC 1999b). *Illex* landed during 1999-2002 were smaller and weighed less than in most years since 1994. Median mantle lengths were highest during 1994 and lowest in 1996 and 2001 (Figure D7A). Likewise, median body weight was highest during 1994 and lowest in 2001 (Figure D7B). Median mantle length and body weight, during 2001, was significantly lower than during 1994-1998, with the exception of 1996. Interannual trends in squid size are likely attributable to environmental conditions, particularly if they persist across multiple years, but size trends may also reflect fishing in different geographic areas. A review of bottom water temperature anomalies in the Mid-Atlantic Bight indicated that bottom temperatures near the shelf edge were warmer than average during large portions of the year in 1999-2002 (Jossi and Benway 2003) when *Illex* mean body size was small and fishing success was low.

The Lowess-smoothed trend line of average weight in the landings during 1994-1998 show a steady increase in average size from 50-175 g between week 20 and 34 (Figure D8A). A 1999-

2002 composite of average body weights indicated a different pattern of seasonal change in average body size. During weeks 22 through 30, the increase in average body weight was more gradual and average body size was smaller, an increase from 70 to 110 g (Figure D8B). Thereafter, average size was generally stable. The attainment of an asymptotic average size may be partially driven by the recruitment of smaller squid, but most likely reflects the emigration of larger squid. In autumn, the density of large squid increases with depth and is highest in the deepest strata (186-366 m) during this offshore migration period (Brodziak and Hendrickson 1999). Maximum average size in the fishery during 1999-2002 occurred one month earlier, at week 30, than during 1994-1998 and was only 60% (110 g) of the 1994-1998 value.

ABUNDANCE AND BIOMASS INDICES

Research Vessel Survey Indices

Although there are no stock-wide indices of abundance or biomass for the *Illex* stock, a number of surveys may provide some information about local abundance of trends. The NEFSC spring bottom trawl survey occurs at a time when *Illex* are migrating onto the U.S. continental shelf and the autumn survey occurs during an offshore migration period (Hendrickson et al. 1996). A portion of the stock may reside outside the range of the surveys and the fishery, and therefore, LPUE and survey indices may represent the on-shelf availability of *Illex* rather than abundance or biomass indices. The outer shelf and continental slope are important *Illex* habitats (Lange 1981) that are not intensively sampled during NEFSC bottom trawl surveys (Figure D9). In addition, the survey bottom trawl gear is not likely to sample pelagic species efficiently.

The NEFSC autumn bottom trawl survey occurs near the end of the fishing season and approximates a post-fishery index for the area surveyed. Indices of relative abundance (stratified mean number per tow) and biomass (stratified mean weight per tow, in kg) from NEFSC autumn bottom trawl surveys, conducted during 1967-2002, are the best abundance information available for *Illex* in U.S. waters. Survey procedures and details of the stratified random sampling design are provided in Azarovitz (1981). Standard survey tows in offshore strata 1-40 and 61-76 (Figure D10) were used to compute abundance and biomass indices, which were adjusted for differences in research vessel effects. A vessel conversion coefficient of 0.81 was applied to the *Delaware II* stratified mean weight per tow values, prior to computing the autumn survey indices, to standardize *Delaware II* catches to the *Albatross IV* catches (Hendrickson et al. 1996). Indices from NEFSC spring surveys, conducted during March, were also computed. Abundance and biomass indices from the Canadian bottom trawl survey, conducted on the Scotian Shelf (NAFO Division 4VWX) during July, are presented for comparative purposes. The Canadian survey occurs just after the start of the fishery and may approximate a pre-fishery index for the area surveyed.

As might be expected for an annual species with environmental effects on availability and recruitment, all of the survey indices show a large degree of interannual variability. Autumn survey indices indicate that *Illex* abundance on the U.S. shelf was high during 1976-1981 and during 1987-1990 (Figure D11A). However, autumn survey abundance indices have been below the 1982-2002 average since 1998, and in 1999, were the lowest on record (Table D6). NEFSC spring survey indices are more variable than those from the autumn survey due to variability in the timing of on-shelf migrations. However, a notable trend is the peak in abundance and biomass indices that occurred during 1997 and 1998, which coincides with the 1998 peak in domestic landings (Figure D11B). Canadian survey indices also show a peak in abundance and biomass during 1976, but not for an extended period of time. During 1992-1994, *Illex* were fairly abundant, but abundance has declined since 1997 and was at the lowest level on record during 2000 and 2001, with only a slight increase during 2002 (Figure D11A). Based on an extended period of low *Illex* biomass in the July 4VWX surveys (Figure D11C) and smaller than average body size, since 1982, the SA 3+4 component of the stock has been characterized as being in a low productivity regime (Hendrickson et al 2002). The average body size of *Illex* caught in the NEFSC autumn surveys has also been much lower since 1982 and below average during most years since (Figure D12A). Average body size in the NEFSC spring survey has been below average since 1995 (Figure D12B). This observed difference in mean weights may be due to differing contributions of seasonal breeding components or differing growth conditions during these periods.

The percentage of tows in which *Illex* were caught in all offshore strata, was computed from the NEFSC spring and autumn survey data to assess *Illex* availability on the U.S. continental shelf. *Illex* are generally caught at less than 10% of the offshore stations sampled during spring surveys, but both spring and autumn surveys suggest that the distribution of *Illex* is more dispersed during periods of high survey abundance (Figure D13).

The migration of *Illex* squid into northern fishing areas off Newfoundland is affected by oceanographic conditions (Rowell et al. 1985; Dawe and Warren 1992; Dawe et. al. 1998). The autumn distribution of adult *Illex* on the U.S. continental shelf is affected by water temperature conditions and bottom temperatures ranging from 9-13°C are preferred (Brodziak and Hendrickson 1999). An increasing trend in areal average surface and bottom temperature anomalies (warmer than average temperatures) has been occurring in the Mid-Atlantic Bight during the spring since 1996 (Figure D14) (Holzwarth and Taylor 1992, 1993 and 1994; Taylor and Almgren 1996a and 1996b; Taylor and Kalidas 1997; Taylor and Bascunan 1998, 1999, 2000 and 2001; Taylor et. al. 2002). Anomalies were computed in relation to a 1977-1987 reference period using the method of Holzwarth and Mountain (1990). Autumn surface and bottom temperature anomalies increased after 1998. A correlation analysis was used to investigate the relationships between environmental trends and trends in *Illex* abundance, biomass, and average body size in U.S. waters. The results indicated that abundance and biomass indices from the autumn surveys and spring average body weights were significantly negatively correlated with bottom water temperature anomalies from the autumn surveys (Table D7). Interpretation is complicated because spring and autumn bottom water temperature anomalies are correlated. However, relationships between environmental conditions and the availability of *Illex* to U.S. fisheries is an important topic for future research.

<u>Landings per Unit Effort</u>

During previous assessments, standardized LPUE indices for 1982-1993 were computed for the domestic *Illex* fleet (NEFSC 1996). However, this LPUE time series could not be updated because of methodological changes in data collection since 1993. The 1982-1993 time series consisted of fishing effort and location data collected by port agents during interviews with fishing vessel captains. This data collection method was changed in May of 1994, when fishing effort and location data were reported by vessel operators on Vessel Trip Reports (VTR). However, submittal of VTR data did not become mandatory for *Illex* squid moratorium permit holders until January 1, 1997. Consequently, fishing effort and location data for the *Illex* fishery are incomplete for the 1994-1996 fishing seasons (NEFSC 1999b).

Within season LPUE data are potentially important for *Illex* assessments because, as noted by Caddy (1991), the seasonal pattern of LPUE reflects the balance of immigration, fishing and natural mortality, and emigration from the fishing area. In Caddy's formulation, the boundaries between these processes are sharp and are assumed to induce point changes in the slope of log LPUE versus time. Implementation of in-season management would require an ability to detect such point changes in the LPUE slope. However, a declining trend in weekly LPUE data from the U.S. *Illex* fishery was not detectable in some years (NEFSC 1999b). In order to better understand the LPUE trends, spatial changes in fishing patterns were evaluated and the effects of various factors on the standardization of fishing effort were assessed.

<u>Fishing Effort</u>
A geographic information system (GIS) was used to examine the spatial distribution of effort in the *Illex* fishery, by quarter-degree square, during 1999-2002. A substantial decrease in the area fished by the *Illex* fleet occurred between 1999 and 2002 (Figure D15). During 2000-2002, fishing effort (days fished) became concentrated along the shelf edge in more southerly, localized areas (south of 38° N latitude). This spatial pattern is due to a feedback effect such that high catch rates lead to more tows in the same vicinity. Fishing locations varied between the two fleet sectors; freezer trawlers and recirculating seawater system (RSW) trawlers. An areal decrease in the area fished between 1999 and 2002 occurred in the RSW fleet (Figure D16), but the freezer trawlers consistently fished a core area during this time period (Figure D17). This difference in fishing patterns is attributable to the ability of freezer trawlers, with greater hold capacities, to make trips of longer duration. Freezer trawlers did not fish on the northernmost fishing grounds, near the shelf edge in southern New England, during 2001 or 2002.

Spatial patterns in fishing effort are partly due to a reduction in the number of vessels participating in the fishery during 1999-2002. A decline in the number of RSW vessels occurred between 1999 and 2000 then stabilized at a low level (Figure D18A). However, the number of RSW trips consistently declined during 1999-2002 (Figure D18B). Freezer trawler participation declined more rapidly, particularly between 1999 and 2001 (Figure D18A), yet the landings during 1999-2002 were predominately (82-96%) from the freezer trawler fleet (Figure D18C). This is explained by the fact that the average trip duration and the average effort (days fished) of freezer trawlers during this period was approximately three times that of RSW trawlers (Figure D19, Table D8).

As discussed in the Landings section, trends in weekly landings from the Weighout database closely match those from the VTR database. As a result, the VTR data were used in the current assessment to assess annual and in-season trends in LPUE, by assigning each subtrip to a week of the year based on the date landed. Subtrips in the *Illex* fishery are defined as fishing within different Statistical Areas (Figure D20). Nominal LPUE was estimated using a ratio estimator of total VTR landings divided by total VTR effort during each week in 1999-2002. Average LPUE for RSW vessels declined drastically during 1999-2002, from 23.9 mt to 7.3 mt, but freezer trawler LPUE was stable during this time period. Overall, total landings and effort declined during 1999-2002 and this resulted in a nominal LPUE trend that was low and stable (Table D9, Figure D21).

Similar to weekly landings trends, in-season trends in nominal LPUE were highly variable and this variability increased between 1999 and 2002. Standardization of catch rates was evaluated in order to determine whether this would improve the ability to detect a declining trend in weekly catch rates. A three-factor, main effects General Linear Model (GLM) was applied to log-transformed LPUE data (mt per day fished) for each year (1999-2002). As in previous assessments, directed trips used in the GLM were defined as otter trawl trips that occurred during May through November and that landed at least 25%, by weight, of *Illex*. Factors included in the initial model runs included: week of the year and either quarter-degree square or latitude and depth, and either vessel type (RSW or freezer trawler) or crew size. Final model runs included the factors: vessel type, quarter-degree square and week of the year, because initial model runs indicated that these factors were significant at the 5% level during most years. However, the significance of these effects varied between years (Table D10). Significant model results were obtained for 1999-2001 and indicated that week of the year and vessel type are important factors in explaining changes in LPUE. Vessel type was not significant during 1999 and week of year was not significant during 2002. The influence of spatial effects (quarter-degree square) on LPUE were less important and were only significant during 2000. GLM model results for 1999 are presented in Table D11 and indicated good fit (r^2 = 0.70). Standardized fishing effort and LPUE during 1999 are presented, by week, in Table D12. Standardized LPUE was not as variable as nominal LPUE, and in 1999, showed a general increase between weeks 25 and 32, followed by a decline (Figure D22B). The use of LPUE indices in future stock assessment models should include standardization.

LIFE HISTORY PARAMETERS

Previous *Illex* stock assessments (NEFSC 1996; NEFSC 1999b) incorporated growth and maturity data from a statolith-based aging study conducted on *Illex* sampled in the Newfoundland jig fishery during 1990 (Dawe and Beck 1992; Dawe and Beck 1997). The current assessment incorporates new information about the growth, maturity and age composition of *Illex* sampled from U.S. waters prior to the start of the fishery. The new data are the result of a statolith-based age analysis of squid caught during an *Illex* bottom trawl survey conducted by the NEFSC during May 19-29, 2000 (Hendrickson *In Review*). The age analysis was conducted using the method of Dawe and Beck (1997) and included a double-blind age analysis of 20 individuals in order to estimate aging error. Unlike the Newfoundland growth rate study (Dawe and Beck 1997), growth rates estimated from the May 2000 survey data included the full range of the maturity spectrum, including the largest number of mature females captured to date.

A major discovery during the May 2000 survey was in the initial documentation of a spawning site for the *Illex* stock, on the continental shelf in the Mid-Atlantic Bight, which was based on the distribution of mature and mated females (Figure D23).

Growth Rates
Weight-at-age relationships, for females and combined sexes, used in the assessment were for squid collected during the May 2000 *Illex* survey (Hendrickson *In Review*) and are shown in Figure D24.

Natural Mortality
Stock assessment models should account for the fact that *Illex illecebrosus* is a semelparous species with high post-spawning natural mortality rates. The maximum longevity of *Illex* inhabiting U.S. waters is about 215 days (Hendrickson *In Review*). Although the exact time span between spawning and death is unknown, it is probably several days. Female *Illex* held in captivity spawned multiple egg balloons then died shortly after spawning (O'Dor et al. 1980). A weekly time step was used for modeling in this assessment, with all individuals within a weekly time bin being assumed to be in the middle of their age bin. All mortality and maturity parameter estimates are in units of weeks.

Maturation-Natural Mortality Model
A maturation-mortality model was developed to estimate female maturation rates and natural mortality of females attributable to spawning. Because females die soon after spawning, natural mortality was partitioned into spawning (M_{SP}) and non-spawning (M_{NS}, due e.g., from predation) components, based on age and maturity data collected during a May 2000, pre-fishery survey of *Illex* inhabiting U.S. waters (Hendrickson *In Review*). The model tracks maturity and mortality in an unfished cohort of females as they begin to mature, spawn and die at a higher rate than non-mature females. The model incorporated female age composition data for spawners and non-spawners, with spawners defined as mature (Stage 5) females. The model also incorporated maturity at age data that was used to estimate the weekly probability of spawning at age to estimate a weekly probability of spawning throughout the lifespan of an individual. Because of substantial imprecision in ageing *Illex*, ageing error is incorporated explicitly in the model calculations. Corrections for ageing error are based on data from a double-blind aging precision study of 20 squid captured during the May 2000 *Illex* survey (Hendrickson *In Review*). In addition, model calculations deal explicitly with under-representation of spawning females in field samples due to their higher natural mortality rate. Sensitivity analysis was used to evaluate a range of model and parameter assumptions. The model was implimented in AD Model-Builder, allowing for parameters estimates and their standard deviations

The model starts with a cohort of females at age twelve weeks (one week younger than the youngest observed mature female). Let N_t and S_t be the number of immature and mature females in the cohort of age t during week t (where age and time are both given in weeks). Assuming no fishing (the data were collected prior to the start of the fishery), the number of immature females in the next age group at the beginning of the following week will be:

$$N_{t+1} = N_t[1\text{-}\exp(-M_{NS})\text{-}p_t],$$

where M_{NS} is the non-spawning natural mortality (assumed constant with age), and p_t is the probability that an immature female of age t will become mature at age t. The number of mature females at age t+1 will be:

$$S_{t+1} = \exp(-M_{SP})S_t + N_t p_t \exp(-M_{NS}).$$

It will be assumed that the probability of maturing is a logistic function of age:

$$p_t = p_\infty/[1+\exp(-a(t-h))],$$

where p_∞ is taken to be 1, a is the shape parameter, and h is the half-saturation age at which the probability of becoming mature is 50%. Note that the probability p_t of a female maturing in a given week is not equal to the probability that a female of age in field samples will be mature because the latter depends on the mortality rates of mature females.

The model is fit to two types of data. The first is the proportion of animals of age t weeks that are matur36e. Given that there are N_t individuals in the sample of age t weeks, and the probability of that age being mature is φ_t, the likelihood that k_t of them are mature is:

$$L_t = \binom{N_t}{k_t} \varphi_t^{k_t} (1-\varphi_t)^{N_t - k_t}$$

Using logarithmic transformation and summing over all age groups gives the log-likelihood function:

$$L_b = \sum_t \ln L_t$$

The second type of data is the proportion ρ_t of all individuals that are of a given age t. Because of trawl selectivity issues, this calculation is restricted to squid of estimated age 20 weeks or greater. If there are m mature individuals of these ages, and the probability of any of them being of age t is q_t, the likelihood that they will be $k_1,\ldots,k_n$ mature individuals in age classes 1,…,n is:

$$L_\omega = \binom{m}{k_1 \ldots k_n} \prod_{t=1}^{n} q_t^{k_t}$$

so that the log-likelihood function for these data is:

$$L_m = \ln \binom{m}{k_1 \ldots k_n} + \sum_{t=1}^{n} k_t \ln q_t$$

These two functions are combined to form a total log-likelihood function that is maximized by the software program:

$$L = \lambda_b L_b + \lambda_m L_m$$

For these runs, the weighting parameters λ_b and λ_m were both taken to be 0.5, so that the two types of data were given equal weight. Because of ageing error, an observation error term (normal with mean zero, standard deviation 13.14 days) was added to "true" ages in the model before predicted values of numbers at age and predicted proportions mature at age were compared in log likelihood calculations to the actual data (which contains measurement errors). This was accomplished by convolving the ageing error vector

e = (0.007, 0.024, 0.062, 0.122, 0.183, 0.122, 0.062, 0.024, 0.007), representing the probability of an ageing error of -4,-3,-2,-1,0,1,2,3, and 4 weeks, respectively, with the predicted age distribution without ageing error.

Results

As expected, the model results suggested that natural mortality rates of spawning females are substantially higher than for non-spawning females. Model fits were best at a relatively high level of spawning natural mortality (0.80 per week) and at relatively low values of non-spawning natural mortality (Table D13). However, M_{NS} was difficult to estimate in the model, probably because it is only a small portion of total mortality. In lieu of direct estimates, the model was run with M_{NS} values of 0.01, 0.03 and 0.06 per week (Figure D25). For each of these values of M_{NS}, maximal likelihood estimates of M_{SP} and the logistic parameters a and h were found. Model estimates for the "half" and "shape" parameters (Table D13) were relatively insensitive to assumptions about M_{NS}. In addition, the model was run with and without the inclusion of ageing error for each combination of M_{NS} and M_{SP} (Figure D25). Standard deviations for parameter estimates were about 0.1 for a, 2.9 for h and 0.3 for M_{SP} in most runs.

The inclusion of ageing error in model calculations improved the goodness of fit for all model scenarios (Figure D25). The model fit the age composition data well for non-spawning natural mortality rates M_{NS}=0.01 and 0.03 per week, but not for the highest level M_{NS}=0.06 (Figure D25). Fit to proportion mature-at-age data was mediocre (Figure D25). A second sensitivity analysis (not shown) indicated that model fit to maturity data was strongly influenced by the observation of a single, young (13 weeks old) mature female squid (Figure D25). The age and maturity stage of the observation was confirmed. It is not uncommon to sample precocious individuals of either sex (Hendrickson personal observation). Further aging studies will be needed to better estimate the maturity of young female squid.

Maturity and natural mortality estimates from the maturation-mortality model were used provisionally in per-recruit modeling described below, despite problems with goodness of fit to maturity data. This decision was made because the new per-recruit model for *Illex* represents a substantial improvement over traditional approaches, but requires estimates of natural mortality for both mature and immature females. Parameter estimates from the maturation-mortality model seemed reasonable on biological grounds and were estimated in a biologically plausible model. Moreover, they were based on all available data and constitute the best available information. Use of reasonable estimates from the model was preferable to using arbitrary values in per-recruit modeling (e.g., a total M value of 0.06 was used in previous assessments). However, it is important to acknowledge the uncertainty in the maturity and mortality parameters and to carry out sensitivity analyses in per-recruit and other modeling where the uncertainty is important with respect to providing management advice.

BIOLOGICAL REFERENCE POINTS

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

A semelparous life history model was derived to estimate yield-per-recruit (YPR) and the number of eggs-per-recruit (EPR) for a cohort of female squid as a function of fishing mortality.

Consistent with the maturation-mortality model, the YPR and EPR models track females in two bins: the number of immature females, N_t, and the number of mature females, S_t. At each weekly time step, immature individuals have four possible fates: (1) death due to either non-spawning natural mortality, M_{NS}, (e.g., from predation, which is assumed to occur at a constant rate) or (2) death due to fishing mortality (calculated as $F_t = F\theta_t$, where θ_t is the fishery selectivity of the individuals of age t weeks); (3) survival to the next week either as an immature individual; or (4) survive and mature at rate P_t. The instantaneous rate P_t is related to the probability of maturing within a week p_t by $P_t = -\ln(1- p_t)$. The population dynamics equation for immature squid is:

$$N_{t+1} = N_t \exp(-M_{NS} - F_t - P_t).$$

Mature individuals can: (1) die due to non-spawning natural mortality or (2) die due to fishing mortality, both of which are assumed to occur at the same rates, M_{NS} and F_t, as for immature squid; (3) spawn (at rate $R_t = Msp - M_{NS}$) and die; or (4) survive to the next week as mature individuals without spawning. The population equation for mature squid is:

$$S_{t+1} = S_t \exp(-M_{SP} - F_t) + N_t \exp(-M_{NS} - F_t)[1-\exp(-P_t)].$$

The number of eggs, E_t, produced during the t^{th} week per female recruit is:

$$E_t = V_t S_t R_t [1-\exp(-M_{NS} - F_t - R_t)]/(M_{NS} + F_t + R_t),$$

where V_t is the mean number of eggs produced by a female of age t weeks.

The yield, Y_t, produced in week t is:

$$Y_t = W_t F_t \{N_t[1-\exp(-M_{NS} - F_t - P_t)]/(M_{NS} + F_t + P_t) + S_t(1-\exp(-M_{NS} - F_t - R_t)]/(M_{NS} + F_t + R_t)]\},$$

where W_t is the mean weight of an individual at week t.

The total number of eggs-per-recruit and the yield-per-recruit, respectively, were computed as:

$$E = \Sigma_t E_t/N_0$$

and

$$Y = \Sigma_t Y_t/N_0$$

where N_0 is the initial cohort size.The calculations were started at week 12, (just prior to the youngest age at maturation and spawning) and ended at week 31, which was assumed to be a plus group. Model input data are presented in Table D14. The maturation rates, P_t, and spawning rates, R_t, were obtained from the maturation-mortality model described above. The mean weights at age in the catch (W_t) were based on a weight-at-age relationship, for combined sexes, from the May 2000 *Illex* survey (Figure D23) (Hendrickson *In Review*). Fishery selectivity at age (θ_t) was assumed to be piecewise-linear, between ages 17 and 23 weeks, based on a 1999-2002 composite age distribution of landings in the directed fishery (Figure D26). The composite age distribution was derived by converting body weights to ages using the May 2000 *Illex* survey weight-at-age relationship for combined sexes (Figure D23) (Hendrickson *In Review*).

The fecundity of *Illex* sp. increases with size (Laptikhovsky and Nigmatullin 1993). Therefore, the fecundity-at-age parameters (V_t) were assumed to be proportional to the predicted average body weights-at-age of females from the May 2000 *Illex* survey and multiplied by an estimate of fecundity per unit body weight. (Hendrickson *In Review*). The fecundity of a 31-week old female was fixed at 60,255 eggs. This value was determined based on fecundity values from the literature and the average weight (89 g) of mature females from the May 2000 *Illex* survey (Hendrickson *In Review*). The ovary weight of a mature *I. illecebrosus* female is 25% of the body weight and the average weight of a mature egg is 240 µg (Durward et al. 1978). Thus, based on an average body weight of 89g, for mature females, the predicted number of mature ova produced by each female would be 92,700 eggs. However, the actual fecundity for a congener, *I. argentinus*, represents only 65% of the potential fecundity (Laptikhovsky and Nigmatullin 1993). Therefore, on average, the actual fecundity of an 89 g female would be approximately 60,255 eggs.

<u>Results</u>
The results of per-recruit model sensitivity runs for the three pairs of M_{SP} and M_{NS} values are shown in Table D15 and Figure D27. Depending on assumptions about natural mortality rates for spawning and non-spawning females, the ranges of instantaneous, fully-recruited values for F0.1, $F_{50\%}$ and $F_{40\%}$ were: 0.21-0.24, and 0.27-0.33 per week, respectively (Table D16 and Figure D27).

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

Potential reference point proxies estimated using the new EPR model ($F_{40\%}$=0.27 and $F_{50\%}$=0.21 per week) were considered preliminary by the SARC 37 panel. A sensitivity analysis (Table D16 and Figure D27) showed that the reference point calculations were sensitive to changes in assumed natural mortality rates. In particular, a model run using the new input data and M_{TOT}=0.06 per week (the total natural mortality rate assumed for all individuals in the SARC 29 model) gave substantially lower F values for all per-recruit reference points (Table D16).

Per-recruit reference points from SARC 29 (NEFSC 1999b) are lower than reference points estimated with the new data and the new model (Table D16). However, the comparison is misleading due to differences in input data (Figure D28) and methods of calculation. The new model counts time as the age of a hypothetical cohort whereas the SARC 29 analysis counted time as week of the fishery without reference to age. The two conventions are related but it is difficult to compare one to the other. In the new model, stock weights represent female weight-at-age data based on statolith-derived ages and body weights from *Illex* sampled during the May

2000 *Illex* survey (Hendrickson *In Review*), while the SARC 29 model used the 1990 growth curve from squid collected in the Newfoundland jig fishery (Figure D28). The catch mean weights in the new model are based on statolith-derived ages and body weights for *Illex* of both sexes sampled during the May 2000 *Illex* survey (Hendrickson In Review). Catch mean weights in the SARC 29 model were weekly mean weights in the landings during 1994-1998. The latter are asymptotic, whereas weights-at-age from the May 2000 *Illex* survey increase exponentially with age (Figure D28). In the current assessment, fishery selectivity was an increasing asymptotic function of age, unlike SARC 29, where selectivity was approximated by using a variable, dome-shaped trend in weekly fishing effort (Figure D28). Selectivity and growth patterns assumed in SARC 29 were protracted relative to patterns estimated based on data for this assessment (Figure D28). Mean weights in the catch also varied between the two models. The F values for reference points in SARC 29 were expressed as seasonal totals computed as the sum of weekly fishing mortality rates during each week of a 31-week fishery. In contrast, F values for reference points in this assessment are maximum values for fully-recruited age groups.

<u>Uncertainties</u>

A significant seasonal increase in the growth rates, in terms of mantle length and body weight, of *I. illecebrosus* from Newfoundland waters occurs in both sexes (Dawe and Beck 1997). Similar growth trends are likely for *Illex* inhabiting U.S. waters, but this has not been verified. The YPR and EPR models incorporate spring growth rates and assume that growth rates are constant throughout the lifespan of an individual. As a result, estimates of yield-per-recruit and the number of eggs-per-recruit may be underestimated. However, if seasonal growth increases proportionately across all age groups, reference points such as $F_{0.1}$ and $F_{50\%}$ would remain unaffected.

The maturation-mortality model is based solely on females, but yield is obtained from both sexes. This could create error in the YPR (though not the EPR) estimates if growth, maturation or mortality of males differs substantially from that of females.

As described above, the maturity and natural mortality estimates of M_{NS} which were used in per-recruit modeling were imprecise. Fortunately, immature natural mortality is a relatively small portion of total natural mortality. Sensitivity analysis indicates that changes in M_{NS} had modest effects on reference point calculations.

STOCK SIZE AND FISHING MORTALITY RATES

<u>Relative Exploitation Indices</u>

Relative exploitation indices, computed as a ratio of U.S. landings to the NEFSC autumn survey biomass index, generally increased during 1988-1999 (Figure D29). After reaching the highest level since the inception of the domestic fishery, in 1999, relative exploitation indices declined drastically.

<u>In-season assessment modeling approaches</u>

The short life cycles, rapid growth rates, highly variable population abundance, high natural mortality rates and generally semelparous breeding strategies of most cephalopod species render many of the traditional annual-based approaches to stock assessment inappropriate (Caddy 1983). This has certainly been true for the *I. illecebrosus* stock, for which biomass dynamics models provide very imprecise estimates of stock size and fishing mortality rates (NEFSC 1996; Hendrickson et. al. 1996). At the 1998 NAFO Precautionary Approach NAFO Workshop, the ASPIC (A Surplus Production Model Including Covariates) (Prager 1994) biomass dynamics model was applied to the stock but resulted in poor model fit. Part of the problem with applying annual models to this stock lies in the fact there are no reliable indices of abundance or biomass for the stock as a whole. The very short life cycle (less than one year) is another significant problem with annual-based modeling approaches.

According to the ICES Working Group on Cephalopod Fisheries and Life History, within-season, "real-time" depletion methods have been found to offer the most promise for assessing ommastrephid and loliginid squid stocks (Pierce and Guerra 1994; ICES 1998; Rosenberg et. al. 1990). Depletion estimation requires data consisting of: total catch, mean body weights, an abundance index (catch and effort), a recruitment index proportional to the number of recruits, and an estimate of natural mortality. In addition, these data must be of appropriate temporal and spatial resolution, tow-based, and available throughout the fishing season.

The in-season assessment model from SARC 29 (NEFSC 1999b) was run with 1999 data that included: weekly VTR effort and landings data; total landings from the Weighout database; weekly, loess-smoothed mean body weights of landed *Illex*; and natural mortality rate estimates from the maturation model. The SARC 29 model used mean weight to estimate emigration from the fishing grounds, assuming a constant total natural mortality rate of 0.06 per week, and did not include recruitment during the fishing season. However, biological data collected as part of the 1999 real-time reporting study indicate that recruits entered the fishery continuously during the first ten weeks of the season. In addition to not accounting for in-season recruitment, application of the 1999 VTR data to the SARC 29 model resulted in unrealistic solutions. Thus, the Invertebrate Subcommittee decided not to accept the model results for use in the current assessment.

In order to address the data requirements for in-season modeling and the possibility of real-time management, the NEFSC collaborated with the *Illex* fishing industry and conducted a real-time fisheries data collection study in 1999 (refer to Background Section). The 1999 real-time data were used in the current assessment to further test and refine in-season modeling approaches. These 1999 data were considered the most representative of the real-time data sets because the 1999 data set consisted of the highest percentage of total annual landings (Table D17).

The results from the new model (Appendix A) were informative, but are considered preliminary and not yet recommended for management use because the model was not fully evaluated or rigorously tested due to lack of time.

CONCLUSIONS

Abundance and biomass indices

Seasonal bottom trawl surveys do not cover the whole range of the stock. *Illex* inhabit areas outside the range of the surveys based on survey data and anecdotal reports. Since 1999, NEFSC autumn survey abundance indices have been below the 1982-2002 average. However, it is unknown whether this trend is due to low abundance, low availability or both. Spring survey abundance indices and the proportion of spring and autumn survey tows with *Illex* catch has also been low in recent years. The July Scotian Shelf survey indices have been low since 1998.

Surface and bottom water temperatures in the Mid-Atlantic Bight have been warmer than average during recent years. *Illex* abundance and biomass indices from the autumn surveys and spring average body weights were significantly negatively correlated with bottom water temperature anomalies from the autumn surveys. Average body weights of *Illex* in multiple surveys have been low for an extended period of time. This likely represents another indication of an environmental effect on productivity.

The annual LPUE time series for 1999-2002 is too short to interpret and confounded by changes in fleet composition. In-season LPUE trends were generally flat during 2000-2002.

Fishery Characteristics

Illex landed during 1999-2002 were smaller and weighed less than in most years since 1994. This fact, coupled with a similar decrease observed in multiple surveys over an extended time period and increased bottom temperatures in recent years, is likely related to productivity. The number of vessels has declined since 1999, particularly the number of RSW vessels. The area fished also decreased in size, which may be due to the reduction in fishery participation. Landings have been below the 1982-2002 average since 1998 and this may due to the reduced effort observed during this time period, low biomass or both factors.

Stock status

It is unknown whether the stock is overfished because available survey indices do not include sampling of the entire habitat range. Consequently, an appropriate B_{MSY} proxy could be recommended and stock status relative to B_{MSY} could not be determined. However, the stock may be at a relatively low biomass level based on biomass indices from multiple surveys and poor fishery performance during 1999-2002. It is not clear whether recent low trends in LPUE and survey indices are due to reduced availability, reduced biomass or both.

An F_{MSY} estimate is not available. However, $F_{40\%}$ or $F_{50\%}$ have been recommended, based on previous SARC recommendations regarding the need to reduce the potential for recruitment overfishing. The best available estimates of $F_{40\%}$ and $F_{50\%}$ are from the new per-recruit model used in this assessment, although there is uncertainty regarding the underlying biological parameters which were estimated in the maturity-natural mortality model. The relationship of $F_{40\%}$ or $F_{50\%}$ reference points to F_{MSY} is unknown and an important topic for future research.

It was unlikely that overfishing occurred during 1999-2002 because:

1. The current small fleet size and effort levels make it is unlikely that the fishery could exert the very high fishing mortality rate required to exceed the new estimate of $F_{50\%}$.

2. The fishing season is short and recruitment appears to occur during most months, so fishing mortality estimates from any model for the fished portion of the stock represent a worst-case scenario or an upper bound on F for the stock in US waters over the entire year. The short fishing season makes high annual average F values unlikely.

3. The geographic range of the U.S. fishery is restricted by gear conflicts and depth limitations, although *Illex* inhabit waters to the north, south and offshore of the fishery. In addition, fishing mortality outside U.S. waters (e.g. in Canada) has been low in recent years. The restricted geographical distribution of the fishery makes high annual average F values for the entire stock unlikely.

4. Relative exploitation indices have declined considerably since 1999 and have been below the 1982-2002 median since then.

5. Preliminary model results (Appendix A) indicate that fishing mortality rates as high as $F_{50\%}$ are unlikely to have occurred during 1999, when relative F was the highest in recent years.

SARC COMMENTS

The WG and panel expressed the imperative need for a new management schema. Currently, management uses a fixed quota based on the catch associated with a F_{MSY} target (75% of F_{MSY}). The relative exploitation index for *Illex* may not be useful because it is based on the fall survey after most of the fishery has occurred. Also, the spring survey index is considered to track availability of the stock rather than stock abundance. In addition, the WG considered that the survey indexes do not encompass the entire habitat range for the *Illex* stock.

Management based on fixed quotas may be risk prone for this type of fishery, where recruitment is highly variable year to year. The WG and panel agreed that management targets should primarily avoid recruitment overfishing, either by an escapement spawning biomass target or another proxy to protect a minimum spawning success of the stock taking into consideration possible environmental constraint on the stock. The panel suggested evaluating weekly SSB fraction analysis over the fishing season as a proxy for spawning biomass targets. This will reiterate the need to move towards a scheme of in season stock management approaches. Another approach would be to control fishing effort rather than fixed quotas, due to the present lack of ability to determine if the current quota is too high or too low for the *Illex* stock in a given year. The WG also suggested adopting management schemes for the stock under conditions of high or low productivity of the stock as in the NAFO management plans. Although it recognized that this schema will require several years of evaluations before it can be decided if the stock has switched between a low or a high productivity regime, and this situation can be detrimental especially due to the fact that the successful recruitment depends exclusively in a single-prior year's spawning biomass.

The panel discussed the possible reasons for the lower asymptotic average mean size and weight trends of *Illex* from survey samples in the latest years (1999-2002) compared to corresponding values in 1994-1998 (Fig D7-D8). Possible causes include both environmental and non environmental effects. It was suggested that these plots of mean size or weight do reflect the net product of several factors including growth, mortality and availability, and that is unlikely to be able to discriminate any single cause beyond of the absence of larger size individuals in the latest years. These changes in asymptotic size and weight of *Illex* were not obvious in the average trends from the commercial catches.

The group pointed out that in the latest years the total catch has been as low as 10% of the quota. It was suggested that the low availability had caused a switch of fishing effort from squid to scallops. While the price for scallops remains high there is unlikely to be increased Illex effort, but future effort trends are of course difficult to predict accurately. The Group mentioned that *Illex* is available in the shelf and deep ocean, although possibly in lower densities than those required to sustain current commercial fishery operations, or beyond of the gear operability.

The panel commended the development of models that incorporate more realistic characteristic of the biology of *Illex* stocks, particularly ageing of US *Illex* samples, the distinction between mortality of pre and post spawners, and maturity at age relationship. These models are on the right track and further refinement and evaluation is highly recommended.

The WG expressed the importance of translate F weekly rates to some Management reference proxy, the WG articulated the need for directions on how to express weekly F estimates as seasonal or yearly F value.

The panel reviewed the correlation of environmental variables and *Illex* abundance and biomass indices. The results indicated an inverse correlation between bottom sea temperature and *Illex* abundance, corroborating that recent low density of *Illex* might be related to the positive anomalies (e.g. average temperatures above the average base line) of sea temperature in recent years. However, it is not possible to distinguish between overall reduction of *Illex* stock biomass or simply changes in the spatio-temporal distribution of the stock in response to the temperature changes. The panel recommended pursuing the evaluation of oceanographic conditions and *Illex* stock dynamics.

The panel expressed concern about the *Illex* stock status, in lieu of the recent severe declines of catches, shrinkage of the fishing grounds, reductions of maximum average size and weight of mature animals, as well low catch rates from the fall and spring surveys. Standardized LPUE had also decline although overall total fishing effort has by significantly reduced. However, at this point it is not possible to assess if declines of exploitable biomass are due to fishing mortality or other factors such as the shift of stock productivity towards a low regime or environmental related changes. It was mentioned that similar trends have been observed in the Illex NAFO management unit. Thus a precautionary management approach ought to be follow.

RESEARCH RECOMMENDATIONS

Stock assessment and modeling

- Model development should continue, with the objective of producing sound statistical models for stock assessment purposes.

- Consideration should be given to the development of "operating models" which can subsequently be used to test the effectiveness and robustness of alternative management strategies (i.e., Management Strategy Evaluation).

Biological Research

- Evaluate the relationship between growth rates and sea temperature to define possible changes in stock productivity associated with environmental conditions.
- Evaluate seasonal and latitudinal clines in growth rates.
- Define biological indicators of low or high productivity regimes.
- Explore food chain relationship for *Illex*, for what ?

Fisheries Research

- Evaluate and design cooperative research programs with commercial vessels for sampling of size, weight and possible age of *Illex* during the fishing season
- Continue with cooperative ventures for pre-season survey to obtain possible indices of upcoming stock abundance and productivity.
- Evaluate catch rates by vessel by using VTR and Weight out database to improve procedures for standardization of nominal LPUE.

ACKNOWLEDGEMENTS

Improvements in the quality of the *Illex* stock assessment would not have been possible without the participation of the *Illex* fleet in the real-time data collection process, data entry by industry consultants from Rutgers University and the collection of biological data by the squid processors. Many thanks go to Betty Holmes and Chris Pickett for technical support, particularly involving the preparation of the GIS maps. The May 2000 *Illex* survey was funded by the Marine Fisheries Initiativess (MARFIN) Program.

LITERATURE CITED

Agnew, D.J., J.R. Beddington, R. Baranowski, S. des Clers, and C.P. Nolan. 1998. Approaches to assessing stocks of *Loligo gahi* around the Falkland Islands. Fish. Res. 35: 155-169.

Applegate, A, S. Cadrin, J. Hoenig, C. Moore, S. Murawski and E. Pikitch. 1998. Evaluation of existing overfishing definitions and recommendations for new overfishing definitions to comply with the Sustainable Fisheries Act. Final Report. 179 p.

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

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

Basson, M., J.R. Beddington, J.A. Crombie, S.J. Holden, L.V. Purchase and G.A. Tingely. 1996. Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the southwest Atlantic as an example. Fish. Res., 28:3-27.

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

Black, G.A.P., T.W. Rowell, and E.G. Dawe. 1987. Atlas of the biology and distribution of the squids *Illex illecebrosus* and *Loligo pealei* in the Northwest Atlantic. Can. Spec. Publ. Fish. Aquat. Sci. 100: 62 p.

Brodziak, J. and L.C. Hendrickson. 1999. An analysis of environmental effects on survey catches of squids, *Loligo pealei* and *Illex illecebrosus,* in the Northwest Atlantic. Fish. Bull. 97:9-24.

Caddy, J. F. 1991. Daily rings on squid statoliths: an opportunity to test standard population models? *In*: Jereb, P.S., S. Ragonese, and S. von Boletzky. (Eds.) *Squid age determination using statoliths*. Proceedings of the International Workshop held in the Istituto di Tecnologia della Pesca e del Pescato (ITPP-CNR), Mazara del Vallo, Italy, 9-14 October, 1989. N.T.R.-I.T.P.P. Special Publication No. 1, pp. 53-66.

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

Dawe, E.G. 2003. Personal communication. Department of Fisheries and Oceans. St. John's, Newfoundland.

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

Dawe, E.G., and P.C. Beck. 1997. Population structure, growth and sexual maturation of short-finned squid (*Illex illecebrosus*) at Newfoundland. Can. J. Fish. Aquat. Sci., 54: 137-146.

Dawe, E.G., and L. C. Hendrickson. 1998. A review of the biology, population dynamics, and exploitation of short-finned squid in the Northwest Atlantic Ocean in relation to the assessment and management of the resource. NAFO SCR. Doc. 98/59, Ser. No. N3051.

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

Dawe, E.G., E.B. Colburne and K.F. Drinkwater. 1998. Environmental regulation on short-finned squid recruitment to Canadian fishing areas. NAFO SCR Doc. 98/54, Ser. N3045.

Durward, R.D., T. Amaratunga and R.K. O'Dor. 1978. Maturation index and fecundity for female squid, *Illex illecebrosus* (LeSueur, 1821). ICNAF Res. Doc. 78/II/1. 12 p.

Forsythe, J.W. and W.F. van Heukelem. 1987. Growth. *In*: P. R. Boyle (Ed.) *Cephalopod Life Cycles, Vol. II.* Acad. Press Inc. (London) Ltd. pp 135-156.

Goodwin, Glenn. 1999. Personal Communication. Captain of F/V *Relentless*. Davisville, RI.

Hendrickson, L.C. *In Review*. Population biology of northern shortfin squid (*Illex illecebrosus*) in the northwest Atlantic Ocean and initial documentation of a spawning site in the Mid-Atlantic Bight (USA). ICES J. Mar. Sci.

Hendrickson, L.C., J. Brodziak, M. Basson, and P. Rago. 1996. Stock assessment of northern shortfin squid, *Illex illecebrosus*, in the Northwest Atlantic during 1993. Northeast Fish. Sci. Cent. Ref. Doc. 96-05g; 63 p.

Hendrickson, L.C., E.G. Dawe and M.A. Showell. 2003. Interim monitoring report for the assessment of northern shortfin squid (*Illex illecebrosus*) in Subareas 3+4 during 2002. NAFO SCR Doc. 03/48. Ser. No. N4866. 13 p.

Hendrickson, L.C., D.A. Hiltz, H.M. McBride, B.M. North and J.E. Palmer. 2003. Implementation of electronic logbook reporting in a squid bottom trawl study fleet during 2002. Northeast Fish. Sci. Cent. Ref. Doc. 03-07; 30 p.

Holzwarth, T.J. and D. Mountain. 1990. Surface and Bottom Temperature Distributions from the Northeast Fisheries Center Spring and Fall Bottom Trawl Survey Program, 1963-1987. Northeast Fish. Sci. Cent. Ref. Doc. 90-03.

Holzwarth-Davis, T.J. and M. Taylor. 1992. Description of the 1991 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc.92-08.

Holzwarth-Davis, T.J. and M. Taylor. 1993. Description of the 1992 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc.93-25.

Holzwarth-Davis, T.J. and M. Taylor. 1994. Description of the 1993 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 94-11.

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

ICES. 1999. Report of the working group on cephalopod fisheries and life history. ICES CM 1999/G:4.

Jossi, J.W. and R. L. Benway. 2003. Variability of temperature and salinity in the Middle Atlantic Bight and Gulf of Maine based on data collected as part of the MARMAP Ships of Opportunity Program, 1978-2001. NOAA Tech. Memo. NMFS-NE-172.

Laptikhovsky, V. V. and C. M. Nigmatullin. 1993. Egg size, fecundity and spawning in females of the genus *Illex* (Cephaloppoda: Ommastrephidae). ICES J. Mar Sci. 50:393-403.

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

Lange, A.M.T., and M.P. Sissenwine. 1980. Biological considerations relevant to the management of squid *Loligo pealei* and *Illex illecebrosus* of theNorthwest Atlantic. Mar. Fish. Rev. 42(7-8):23-38.

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

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

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

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

Mid-Atlantic Fishery Management Council. 1995b. Amendment 5 to the Fishery Management Plan and the Final Environmental Impact Statement for the Atlantic Mackerel, Squid and Butterfish Fisheries. 168 p.

Mid-Atlantic Fishery Management Council. 1996a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1997.

Mid-Atlantic Fishery Management Council. 1996b. Resubmitted portion of Amendment 5 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 38 p.

Mid-Atlantic Fishery Management Council. 1996c. Amendment 6 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 17 p. + Appendices.

Mid-Atlantic Fishery Management Council. 1997a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1998.

Mid-Atlantic Fishery Management Council. 1998a. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 1999.

Mid-Atlantic Fishery Management Council. 1998b. Amendment 7 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 33 p. + Appendices.

Mid-Atlantic Fishery Management Council. 1998c. Amendment 8 to the Fishery Management Plan for the Atlantic Mackerel, Squid and Butterfish Fisheries. 351 p. + Appendices.

Mid-Atlantic Fishery Management Council. 2000. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, *Loligo*, *Illex*, and Butterfish for 2001.

Mid-Atlantic Fishery Management Council. 2001. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, Squid and Butterfish for 2002.

Mid-Atlantic Fishery Management Council. 2002. Optimum yield, domestic annual harvest, domestic annual processing, joint venture processing, and total allowable level of foreign fishing for Atlantic Mackerel, Squid and Butterfish for 2003.

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

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

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

NAFO [Northwest Atlantic Fisheries Organization]. 1999. Scientific Council Reports, 1998. 257 p.

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

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

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

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

NEFSC. 1996. Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. Northeast Fisheries Science Center Ref. Doc. 96-05d.

NEFSC. 1999. Report of the 29th Northeast Regional Stock Assessment Workshop (29th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments. Northeast Fisheries Science Center Ref. Doc. 99-14; 347 p.

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

O'Dor, R.K. and E.G. Dawe. 1998. Chapter 4. *Illex illecebrosus. In:* P.G. Rodhouse, E.G. Dawe, and R.K. O'Dor (Eds.). Squid recruitment dynamics: the genus *Illex* as a model, the commercial *Illex* species and influences of variability. FAO Fish. Tech. Paper 376.

Pierce, G.J. & Guerra, A., 1994. Stock assessment methods used for cephalopod fisheries. Fish. Res. 21: 255-285.

Prager, M. 1994. A suite of extensions to a non-equilibrium surplus-production model. Fish. Bull. 92:374-389.

Rivard, D., L. C. Hendrickson and F. M. Serchuk. 1998. Yield estimates for short-finned squid (*Illex illecebrosus*) in SA 3-4 from research vessel survey relative biomass indices. NAFO SCR Doc. 98/75.

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

Showell, M. 1999. Personal communication. Department of Fisheries and Oceans. Bedford Institute of Oceanography. Halifax, NS.

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

Taylor, M.H. and D.W. Almgren. 1996a. Description of the 1994 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 96-07.

Taylor, M.H. and D.W. Almgren. 1996b. Description of the 1995 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 96-11.

Taylor, M.H. and M.E. Kiladis. 1997. Description of the 1996 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 97-16.

Taylor, M.H. and C. Bascunan. 1998. Description of the 1997 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 98-01.

Taylor, M.H. and C. Bascunan. 1999. Description of the 1998 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 99-01.

Taylor, M.H. and C. Bascunan. 2000. Description of the 1999 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 00-01.

Taylor, M.H and C. Bascunan. 2001. Description of the 2000 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 01-01.

Taylor, M.H., C. Bascunan and J.P. Manning. 2002. Description of the 2001 Oceanographic Conditions on the Northeast Continental Shelf. Northeast Fish. Sci. Cent. Ref. Doc. 02-08.

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