## B. *Loligo pealeii* STOCK ASSESSMENT FOR 2010

### Executive Summary

**Term of Reference 1:** Landings data are presented for 1963-2010 but the 2010 landings are preliminary and incomplete. Landings of squid (*Loligo pealeii* and *Illex illecebrosus*) during 1928-196 were taken inshore and ranged from 500 to 2,000 mt. Total landings were dominated by offshore distant water fleets during 1967-1984, averaging 20,130 mt with a peak of 37,613 mt in 1973. After 1986, fishing by distant water fleets was prohibited and landings from the U.S. fleets, dominated by those from the winter offshore fishery, averaged 16,610 mt during 1987-2009 with a peak of 23,738 mt in 1989. There is substantial uncertainty in the landings data prior to 1987, due to a lack of observer coverage of distant water fleets prior to 1978 and reporting of unspecified squid catches.

Overall, annual discards were low, averaging 3.4% of the landings during 1989-2009. However, precision of the estimates was also low. Annual CVs averaged 0.53 during this same period. During 1988-1995, catches were generally at or above the 1987-2008 median (17,328 mt), but have generally been below the median since in-season quotas were implemented, in 2000. After 2005, catches declined and reached the lowest level since 1968 in 2009 (9,560 mt).

Annual trends in nominal LPUE (mt/day fished) were correlated for the January-June and July-December fisheries during 1996-2009. However, the trends are difficult to interpret because of one or more fishery closures during each year since 2000 and the lack of a clear understanding of what the LPUE values actually represent given the complex population dynamics of the species.

**Term of Reference 2:** *Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, age-length data, etc.). Describe the uncertainty in these sources of data.*

NEFSC fall and spring bottom trawl survey data are used in this assessment to compute q-adjusted biomass estimates for two of the primary seasonal cohorts. The average lifespan of a seasonal *Loligo* cohort is about six months and the spring and fall surveys occur about six months apart. *Loligo* caught in the spring surveys (March) were hatched about six months prior, during the previous fall, and *Loligo* caught in the fall (September) surveys were hatched during the previous spring.

Swept-area biomass estimates from inshore fall NEAMAP surveys were used to account for biomass in inshore areas (≤ 18 m) which are no longer able to be sampled by the new research survey vessel starting in 2009. Only daytime survey tows are used in the assessment because *Loligo* are most available to bottom trawls during the daytime. The higher catch rates resulting from daytime tows were used in the swept-area biomass calculations and reduced the variance of the stratified mean survey indices during most years. CVs were on the order of 10-25%, indicating reasonable levels of precision.

As is typical for most squid species, abundance and biomass indices for *Loligo* were highly variable, particularly for NEFSC fall surveys, making it difficult to discern trends. The large differences in the biomass estimates for the seasonal cohorts caught in the spring and fall surveys are a major source of uncertainty. The spring biomass levels are only about one fifth of the fall biomass levels. Fall and spring survey indices from the same, but not adjacent, years are correlated. However, it is not known whether these "year" effects reflect true seasonal cohort dynamics for *Loligo*, which have a cohort lifespan of about 6 months, or if they are due to environmental effects on availability to the survey gear.

**Term of Reference 3:** *Estimate annual fishing mortality, recruitment and stock biomass for the time series, and characterize the uncertainty of those estimates (consider Loligo TOR-4). Include a historical retrospective analysis to allow a comparison with previous assessment results.*

A simple survey-based approach, similar to one of the methods used in the previous assessment, was used to estimate biomass and exploitation indices. The method is based on a composite q-prior for survey catchability which incorporates uncertainty and bounds on all of the key factors that affect *Loligo* catchability. Uncertainties in *q*-priors have been substantially reduced since the last assessment by an in-depth review of existing and new information and the results of paired-tow catchability experiments using the survey vessels, SRV *Albatross IV* and SRV *H. B. Bigelow*. For "best estimates", we used the median *q*-prior catchability value because the chance of being either too low or too high is 50% (the median is risk-neutral). One of the most important aspects of the *q*-prior is the upper bound for survey catchability, which corresponds to the upper bound for fishery exploitation and the minimum bound for biomass.

Annual measures of biomass were derived by averaging the annual biomass estimates for the NEFSC fall and spring surveys after adjustment using the median *q*-prior for catchability. Annual biomass fluctuated widely about the median of 76,329 mt during 1976-2009 and ranged between 25,806 mt and 175,894 mt. Annual exploitation indices were computed as the annual catch divided by the annual biomass. However, the rapid growth rates, high cohort turnover rates and short lifespan of *Loligo* make the exploitation indices difficult to interpret. During 1993-1998, annual exploitation indices were generally at or above the 1987-2008 median (0.237), averaging 0.273, and generally at or below the median during 1999-2008, averaging 0.18.

Seasonal *Loligo* cohorts have different growth rates and the assessment results suggest that cohorts caught in the spring and fall surveys appear to have very different levels of productivity and biomass. Exploitation indices for the January-June fishery (median = 0.315) are much higher on the lesser productive, spring survey cohort than the exploitation indices for the July-December fishery (median = 0.064) on the more productive fall survey cohort.

Comparison of results from the current assessment with results from historical assessments is difficult because of the lack of temporal overlap between assessments and changes to the data and methods used to estimate stock status. The majority of assessments relied on relative trends in survey data. The stock is now considered lightly exploited but overfishing was determined to be occurring in 2 out of 4 historical assessments. The stock has never been considered overfished, although it was close to its biomass threshold at the time in two cases. In contrast, the current assessment concludes that the stock was not overfished and that overfishing was probably not occurring in 2009.

**Term of Reference 4:** *Summarize what is known about consumptive removals of Loligo by predators and explore how this could influence estimates of natural mortality (M).*

On an annual basis, *Loligo* catches appears minor relative to preliminary minimum consumption estimates for a subset of fish predators (i.e. without adjusting abundance for some predators to account for survey catchability and excluding consumption by birds, large pelagic fish and marine mammals). Thus, the consumption data for *Loligo* provide a frame of reference for judging the potential importance of fishery removals.

Minimum consumption is generally higher on the fall survey cohort than on the spring survey cohort. Seasonal estimates of minimum consumption are a substantial fraction of the estimated biomass, particularly during the spring.

This assessment did not require any assumptions about M. However, natural mortality rates for non-spawning *Loligo* are known to be high based on their short 6-8 month lifespan, and because the species is semelparous, natural mortality rates after spawning are even higher. Based on the results from two models that have been used to estimate M for other squid species, preliminary estimates of non-spawning and spawning mortality are 0.11 and 0.19-0.48 per week, respectively. It is doubtful that consumption data would substantially change or improve these estimates of *M*.

**Term of Reference 5:** *State the existing stock status definitions for the terms "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; estimates or proxies for $B_{MSY}$, $B_{THRESHOLD}$, and $F_{MSY}$; and estimates of their uncertainty). Comment on the scientific adequacy of existing BRPs and for the "new" (i.e., updated, redefined, or alternative) BRPs.*

The current overfishing definition states that overfishing is occurring when the exploitation index falls below the 75th percentile of the quarterly exploitation indices during 1987-2000. However, there is no sound scientific basis for using this $F_{MSY}$ proxy because the *Loligo* stock is lightly exploited. Under these conditions, any percentile of the exploitation time series is unsuitable as an estimate of or proxy for $F_{MSY}$.

Conventional approaches for deriving BRPs are based on finfish population dynamics and are inappropriate for *Loligo*. In particular, there is no theory linking *M* and $F_{MSY}$ for short lived squid species like *Loligo* and per-recruit reference points can only be approximated (a). In addition, there is no theory linking $F_{SPR}$ per-recruit reference points to $F_{MSY}$ for species like *Loligo*. Finally, there is too little contrast in the catch or survey data to provide information that could be used to estimate $F_{MSY}$ in a modern dynamical model.

There are no existing biomass-based reference points. The current assessment recommends a new threshold $B_{MSY}$ proxy of 21, 203 mt and a biomass target of 42, 405 mt. $B_{MSY}$ is estimated as $B_{MSY} \approx 0.5\frac{\breve{b}}{0.9}$ where $\breve{b}$ is the 1976-2008 median annual biomass (76,329 mt). Annual biomass is defined as the average the annual biomass estimates for the NEFSC fall and spring surveys after adjustment using the median $q$-prior for catchability. The median biomass is assumed to represent 90% of carrying capacity because the stock is lightly fished. If the underlying surplus production curve is symmetrical, $B_{MSY}$ occurs at 50% of the carrying capacity. Annual biomass estimates exceed annual carrying capacity in multiple years, which is to be expected for a species with highly variable seasonal population dynamics which are linked to variability in environmental conditions. It is not necessary for *b* to be in biomass units because unscaled survey data would give the same results.

**Term of Reference 6:** *Evaluate stock status with respect to the existing BRPs, as well as with respect to the "new" BRPs (from Loligo TOR 5).*

There are no existing biomass reference points for the stock, and as a result, overfished status cannot be determined. Based on the current fishing mortality reference point threshold, overfishing was not occurring because the 2009 exploitation index (estimated using the method from SARC 34, Oct-Dec. catch over *q*-adjusted fall survey swept-area biomass) was 0.063 compared to the Fthreshold (i.e., 75$^{th}$ percentile of the exploitation indices during 1987-2009) which is 0.277). However, the current F reference point is inappropriate for the lightly exploited *Loligo* stock. In addition, the new exploitation indices used in the current assessment are not comparable to the existing fishing mortality reference points because of differences in computation methods and input data.

Based on the new recommended biomass reference point threshold from SAW/SARC-51, the stock was not overfished during 2009. The two-year average of catchability-adjusted spring and fall survey biomass levels during 2008-2009 was 54,442 mt (80% CI = 38,452-71,783 mt) and is higher than the proposed threshold Bmsy proxy of 21,203 mt. The overfishing status during 2009 is unknown because new fishing mortality reference points could not be recommended in the current assessment due to the lack of evidence that fishing impacted annual biomass levels during 1975-2009. The 2009 exploitation index of 0.176 (catch in 2009 divided by the average of the spring and fall survey biomass during 2008-2009; 80% CI = 0.124-0.232) was slightly below the 1987-2008 median of 0.237.

**Term of Reference 7:** *Develop approaches for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs), and comment on the ability to perform projections for this stock.*

<u>Possible approaches</u>

*Use the omnibus amendment approach*. The Council is developing an omnibus amendment that provides the SSC with a general procedure for setting ABC levels. The omnibus approach ranks stocks into four tiers, depending on the information about the stock and reference points provided in the assessment. The omnibus approach is flexible and may well be a sufficient basis for specifying ABC levels for the *Loligo* fishery.

*Consider the differences in seasonal cohort productivity and biomass*. *Loligo* biomass and productivity appear to be substantially lower for the cohort caught in the spring survey than for the cohort caught in the fall survey. Lower spring biomass may be due to a variety of factors, including differences in available habitat, migration patterns, seasonal reproduction, differences in growth rates, and/or consumption removals. Within-year relative abundance indices from the spring and fall surveys are correlated and exploitation indices for the January-June fishery (median = 0.315) are much higher on the less-productive, spring survey cohort than those for the

July-December fishery (median = 0.064) on the more-productive fall survey cohort.

*ABC by analogy to consumption estimates for key predators*. *Loligo* are prey for a wide range of marine fish, diving birds, and marine mammals. Natural mortality rates for non-spawning *Loligo* range from 0.058 to 0.110 per week (3.0 to 5.7 per year) due, presumably, to predation. The ecological importance of *Loligo* as prey for a wide range of species could be considered in specifying ABC levels.

Consumption estimates for six (cod, bluefish, goosefish, pollock, summer flounder and weakfish) of the 15 *Loligo* finfish predators included in this assessment are based on predator stock biomass estimates from peer-reviewed assessment reports that include estimates of survey catchability. The consumption estimates for these six species may be plausible estimates of consumption. Considering consumption by humans and fish predators, specifying ABC levels for *Loligo* based on consumption estimates for important predators may be a practical approach to ecosystem-based management. Consumption is generally higher during the fall than spring and seasonal differences could be considered as well.

**Term of Reference 8:** *Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.*

Substantial progress was achieved for many of the research recommendations in the last assessment and a number of additional topics were identified. Please see the relevant portions of the text.

**Terms of Reference**

1. Characterize the commercial catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.

2. Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, age-length data, etc.). Describe the uncertainty in these sources of data.

3. Estimate annual fishing mortality, recruitment and stock biomass for the time series, and characterize the uncertainty of those estimates (consider *Loligo* TOR 4). Include a historical retrospective analysis to allow a comparison with previous assessment results.

4. Summarize what is known about consumptive removals of *Loligo* by predators and explore how this could influence estimates of natural mortality (M).

5. State the existing stock status definitions for the terms "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; estimates or proxies for $B_{MSY}$, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). Comment on the scientific adequacy of existing BRPs and for the "new" (i.e., updated, redefined, or alternative) BRPs.

6. Evaluate stock status with respect to the existing BRPs, as well as with respect to the "new" BRPs (from *Loligo* TOR 5).

7. Develop approaches for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs), and comment on the ability to perform projections for this stock.

8. Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.

**Introduction**

**Range, distribution and life history**

Longfin inshore squid (*Loligo pealeii*) are distributed primarily in continental shelf waters located between Newfoundland and the Gulf of Venezuela (Cohen 1976; Dawe *et al.* 1990). In the northwest Atlantic Ocean, longfin squid are most abundant in the waters between Georges Bank and Cape Hatteras, NC where the species is commercially exploited. The stock area extends from the Gulf of Maine to southern Florida. However, the southern limit of the species' distribution in US waters is unknown due to an overlap in geographic distribution with the congener, *Loligo pleii*, which cannot be visually distinguished from *L. pealeii* using gross morphology (Cohen 1976). Three genetics studies indicate that the population between Cape Cod Bay, MA and Cape Hatteras, NC is a single stock (Garthwaite *et al.*1989; Herke & Foltz, 2002; Shaw *et al.* 2010), but Buresch *et. al.* (2006) concluded there are multiple stocks. Distribution varies seasonally. North of Cape Hatteras, squid migrate offshore during late autumn to overwinter in warmer waters along the shelf edge and slope, and then return inshore during the spring where they remain until late autumn (Jacobson 2005).

The life history characteristics of short-lived, semelparous cephalopod species, like *Loligo pealeii*, present some unique challenges to stock assessment and most of the traditional approaches that have been used for finfish species have not been successfully applied to squid stocks (Boyle and Rodhouse 2005). *Loligo pealeii* serves as a key prey species for a variety of marine mammals, diving birds, and finfish species (Clarke 1996; Overholtz *et al*. 2000; Jacobson 2005). Consequently, natural mortality rates are very high, especially after spawning. The species is migrates long distances during its short lifespan; inshore during spring and offshore during late fall. Recruitment occurs throughout the year with seasonal peaks in overlapping "microcohorts" which have rapid and different growth rates (Brodziak and Macy 1996; Macy and Brodziak 2001). As a result, seasonally stable biomass estimates may mask substantial population turnover (Guerra *et al*. 2010). Recruitment of *L. pealeii* is largely driven by environmental factors (Dawe *et al.* 2007). For most squid species, temperature plays a large role in migrations and distribution, growth, and spawning (Boyle and Rodhouse 2005). For *Loligo pealeii*, individuals hatched in warmer waters during the summer grow more rapidly than those hatched in winter and males grow faster and attain larger sizes than females (Brodziak and Macy 1996).

A schematic of the life history of *Loligo pealeii*, in relation to the timing of the directed fisheries and NEFSC surveys is shown in Figure B1. Recruitment occurs year-round with seasonal peaks in cohorts. The average lifespan of a *Loligo pealeii* cohort is about six months. Individuals hatched inshore during the summer are taken in the winter offshore fishery and those hatched in the winter are taken in the inshore summer fishery (Macy and Brodziak 2001). Age data indicate that NEFSC spring surveys (March-April) capture *Loligo* that were hatched during the previous six months, in the fall, and *Loligo* caught in the NEFSC fall surveys (September-October) were hatched during the previous spring. *Loligo peaeleii* attaches its egg masses to the substrate and fixed objects (MAFMC 2009). Fishing and spawning mortality occur concurrently during late spring through fall, when spawning *Loligo* and an unknown proportion of their egg masses are taken inshore, in bottom trawl fisheries (Hatfield and Cadrin 2002) and in weirs (MAFMC 2009). The locations of spawning sites at other times of the year are unknown.

**Management background**

During 1974-1977, the *Loligo pealeii* stock was managed by the Northwest Atlantic Fisheries Organization (formerly ICNAF) and was subject to annual TACs (Lange and Sissenwine 1980). Historically, the distant water fleets fishing for *Loligo* were subject to a minimum codend mesh size (60 mm inside stretched mesh), fishing in defined offshore fishing areas during the fall and winter (Kolator and Long 1980). Since 1978, the stock has been managed by the Mid-Atlantic Fishery Management Council (MAFMC) under the Atlantic Mackerel, Squid, and Butterfish Fishery Management Plan (MSB FMP). Distant water fleets have been prohibited from fishing for *Loligo pealeii* in US waters since 1987. Since 1996, the primary stock management measures have included: a total allowable catch (TAC); mandatory reporting of *Loligo* landings purchased by federally-permitted dealers; and mandatory submittal of Vessel Trip Reports (VTRs) by fishermen who possess federal *Loligo*/butterfish moratorium and incidental catch permits (Table B1). A minimum codend mesh size requirement of 48 mm (1 7/8 in., inside stretched mesh) and a strengthener minimum mesh size of 114 mm (4.5 in.) were also implemented in 1996.

Since 2000, the *Loligo* fishery has been subject to in-season quotas which were trimester-based during 2000 and 2007-2010 and quarterly-based during 2001-2006. When the in-season quotas are attained, trip limits of < 2,500 lbs go into effect. Since 2000, *Loligo* fishery closures have occurred when 90% of each trimester or quarterly quota was landed or when 95% of the annual quota was landed. Closures have occurred at least once per year under this management system (Table B2). The annual quota has only been exceeded once, during 2000, when the quota of 15,000 mt was exceeded by 16.5%. Currently, the annual quota is allocated as: 43% in Trimester 1, 17% in Trimester 2, and 40% in Trimester 3. Currently, there are also roll-overs of quota underages (Trimester 1 toTrimesters 2 and 3; Trimester 2 to Trimester 3) and overages (Trimesters 1 and 2 to Trimester 3).

**Term of Reference 1:** *Characterize the commercial catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.*

The stock boundary includes all Statistical Areas located within the Northeast Region of the Northwest Atlantic Ocean (Figure B2). Commercial landings data are available for 1963-2009 (Table B3, Figure B3). The 2010 landings data are presented as well, but are preliminary and incomplete (i.e, retrieved from the landings database on October 27, 2010).

Several caveats are important in interpreting landings data. The two major species of squid landed in US east coast waters (i.e., *Illex illecebrosus* and *Loligo pealeii*) were not recorded by species until 1979. Landings during 1963-1978 for each species were estimated by proration (Lange and Sissenwine 1980). Since 1979, a portion of the U.S. squid landings have been reported as unspecified squid species (i.e., *Illex illecebrosus* and *Loligo pealeii*). Unspecified squid landings for 1982-1995 were prorated by month and two-digit Statistical Area by Cadrin and Hatfield (1999) and these landings are included in the current assessment. Unspecified squid landings reported from 1996 onward have been much lower (0- 161 mt per year), and since a majority of the prorated landings of unspecified squid are *L. pealeii* landings, all unspecified squid landings were combined with the *L. pealeii* landings for 1996-2009.

Several different methods have been used to collect the landings, fishing location and effort data. During 1963 through April of 1994, U.S. commercial landings, effort, fishing area, and other fishery-related data were collected and entered into Northeast Region Commercial Fisheries Database (CFDBS) by NMFS port agents, who entered landings data from all dealer purchase receipts and interviewed a subset of captains to obtain information about fishing location and effort (Burns *et al*. 1983). Since then, landings data have been self-reported electronically by dealers who have a federal permit to purchase *Loligo*, but such reporting was not mandatory until 1996. Beginning in May of 1994, fishing location (Statistical Area) and effort data, plus estimated catch, were self-reported by fishermen on logbooks (i.e., Vessel Trip Reports or VTRs) and are entered into the Vessel Trip Report Database. However, submittal of VTRs was not mandatory for fishermen who hold *Loligo* fishing permits until 1996. In order to integrate data from the VTR Database with data from the CFDBS, an "allocation" database was created using a trip-based allocation scheme (Wigley *et al*. 2008). Landings data are assumed known and originate from the CFDBS. The allocation determines the area fished and effort information reported on the VTR data and joins this information with the landings data from each trip as reported in the CFDBS. Two levels (A and B) represent vessel-oriented data and two levels (C and D) represent fleet-oriented data. Level A comprises audited VTR trips that have not been grouped and for which a one-to-one match exists between the VTR and CFDBS fields which define a trip (i.e., year, month, day and permit). Level B comprises VTR trips from Level A that have been pooled by vessel permit, gear group, main species group, and month. Level C comprises VTR trips from Level A that have been pooled by ton class, port group, gear group, main species group, and calendar quarter. Level D comprises VTR trips from Level A that have been grouped by port group. If a CFDBS trip has a corresponding one-to-one match with a VTR trip, then the area fished and the effort information, if present, is transferred directly onto the CFDBS trip record. "A" level trips correspond to pre-1994 trips for which similar information was obtained from a vessel captain via a port agent interview.

## Landings

The U.S. squid fishery began in the late 1800s as a source of bait, and from 1928 to 1967, annual squid landings (including *Illex illecebrosus* landings) from Maine to North Carolina ranged from 500 to 2,000 mt (Lange 1980). During 1964 through the mid-1980s, landings of *L. pealeii* by distant water fleets occurred in offshore waters and landings by the U.S. fishery occurred when *Loligo* were available inshore during spring and summer (Lange *et al*. 1984). Total landings increased rapidly during 1967-1973 with the development of a directed fishery by distant water fleets in offshore waters, from 1,677 mt in 1967 to a peak of 37,613 mt in 1973, but then declined to 10,646 mt in 1978 (Figure B3, Table B3). Total landings were dominated by landings from the foreign fleets during 1967-1984, ranging between 76% and 98% of the total landings during most years and averaging 20,130 mt.

During 1978-1982, bottom trawlers engaged in directed fisheries for *Illex* and *Loligo* in U.S. waters were required to fish with a minimum codend mesh size of 60 mm (with specific chafing gear requirements) and were restricted to fishing seaward of the 183 m isobath and during late fall through winter (ICNAF 1978). Fishing by distant water fleets was phased out by 1987 due to the development of an offshore U.S. fishery for *L. pealeii*. There is substantial uncertainty in the landings data prior to 1987, due to the lack of observer coverage of distant water fleets prior to 1978 and low coverage thereafter, and because unspecified squid landings were as high as 20% during some years (Cadrin and Hatfield 1999).

The domestic fishery currently occurs primarily in Southern New England and Mid-Atlantic waters, but some fishing also occurs along the southern edge of Georges Bank. Spatial patterns in fishing effort reflect seasonal *Loligo* migration patterns whereby effort is generally directed offshore during October-March and inshore during April-September (Figure B4). The fishery is dominated by small-mesh otter trawlers, modal codend mesh size = 50 mm inside stretched mesh (Hendrickson 2011), but near-shore pound net and weir fisheries also occur during spring and summer. During 1963-1982, the domestic fishery occurred primarily in inshore waters during spring and summer. Offshore fishing by U.S. vessels began in 1983. During 1987-1999, total landings averaged 18,453 mt with a peak of 23,738 mt in 1989 (Table B3).

Since the implementation of in-season quotas, in 2000, landings have been lower (averaging 14,214 mt) and have declined from 16,720 mt in 2005 to 9,307 mt in 2009. Although preliminary and incomplete, the 2010 landings through mid-October are very low (5,256 mt). Despite a general decline in landings during 1994-2009, the annual ex-vessel price (average dollars per lb in 1990 dollars) of *L. pealeii* increased during 1990-1998 (from $0.43/lb to $0.83/lb), then decreased to $0.60/lb in 2000, but remained remained fairly stable thereafter (Figure B5). Since 1996, annual TACs have ranged between 15,000 mt and 25,000 mt and were only exceeded in 2000, when the annual TAC of 15,000 mt was exceeded by 16.9% (Table B3).

Changes in the monthly distribution of landings occurred during 1987-2009, particularly during the first half of the year. Since 1989, most of the landings have been taken in the offshore winter fishery, during Quarters 1 and 4 (Cadrin and Hatfield 1999). Between 1987-1995 and 1996-1999 (mandatory reporting of squid landings began in 1996), landings increased by 9% during Quarter 1 and decreased by 9% during Quarter 2, but remained similar during Quarters 3 and 4 (Figure B6).

Since 2000, the seasonal distribution of landings has been affected by in-season quotas (i.e., quotas were trimester-based in 2000 and during 2007-2009 and quarterly-based during 2001-2006) which have led to one or more fishery closures per year. Landings increased during January from 10% during 1996-1999 to 13% during 2000-2009. Landings during Quarter 2 increased from 16% during 1996-1999- to 18% during 2000-2009 (Figure B6). During 2007-2009, landings during Trimesters 1-3 represented 43%, 26% and 32% of the total landings, respectively.

During 1994-2009, most of the *Loligo* landings were from Rhode Island ports which accounted for 40-50% of the total during 1994-2002 and 55-60% of the total during 2003-2009 (Figure B7). The second and third highest percentages of the annual landings since 1994 were from New York (15-34%) and New Jersey ports. The proportion of total landings in New Jersey ports declined from 31% in 1994, to 9% in 2004 then increased to 17% in 2009. Massachusetts and Connecticut ports accounted for < 10% of landings since 1994.

**Landings size composition**

The size composition of the landings was estimated from samples collected at the principal ports where *Loligo* are landed. The numbers of samples and landings length composition for 1987-1995 was taken from Cadrin and Hatfield (1999) and the landings length composition for 1996-2009 was updated for the current assessment. Annual sampling intensity was low during 1987-1996, ranging between 48 and 94 trips per year, with no sampling of trips during some months (Table B4). After 1996, sampling intensity increased and ranged between 131 and 214 trips per year with sampling during every month.

Most *L. pealeii* landings during 1987-1996 were landed as "Unclassified" rather than by market category (i.e., Large, Medium, Small and Super Small). After 1996, sampling occurred by market category and the numbers of length samples also increased (Table B5). During 1996-2009, there was a large amount of size overlap between the different market categories (Figure B8). Most samples were from the Unclassified size category, which includes all sizes except for a portion of squid in the Large size category.

Landings at length were estimated using monthly, quarterly and half-year time bins, depending on sample availability by month and market category. Numbers of *Loligo* length samples, by month and market category, are presented in Table B6. Unclassified sizes were prorated. Sampled length compositions were expanded to the landings using predicted sample weights (Lange and Johnson 1981). A small proportion (< 0.05) of squid between 5 and 8 cm dorsal mantle length (DML) are partially recruited to the fishery, but most pre-recruits are > 8 cm DML. Squid were fully recruited to the fishery at 12 cm DML during 1987-2009 (Figure B9). Length compositions of the landings were similar for 1996-1999, a period of annual quota management, and 2000-2009, a period of in-season quota management, but a greater proportion of squid larger than 18 cm DML were landed during 1987-1995 (Figure B9).

**Discards**

Kept and discarded portions of the catches, along with length composition data for both portions, have been collected onboard fishing vessels by the Northeast Fishery Observer Program (NEFOP) since 1989. Discards for the most recent *Loligo* assessment (NEFSC 2002a) were assumed to be 6% of the landings, based on an analysis conducted by (Cadrin and Hatfield (1999). Cadrin and Hatfield (1999) computed an average ratio of discarded to kept *Loligo* of 6% based on observed tows from all otter trawl trips (N=915 trips) which landed *L. pealeii* during 1989-1998 . Quarterly discard to kept ratios for these trips were scaled up to the quarterly landings then summed across quarters to obtain annual discard estimates. The total amount of discards from trips with no *Loligo* landings (i.e., trips where all *Loligo* catches were discarded) was minor (10 mt for 207 trips).

For the subject assessment, the combined ratio method (Wigley *et al.* 2007), which has become the standard discard estimation methodology for the Northeast Fisheries Science Center stock assessments, was used to estimate *Loligo* discards (mt) and their precision (CV) during 1989-2009. The combined ratio method is based on a ratio estimate pooled over all strata and trips within a fleet. For each trip, a combined discard to catch (d/k) ratio estimator (Cochran 1977) was computed using NEFOP data, where d = discard weight of *Loligo* and k = kept weight of all species. These discard ratios were then expanded by the total weight of all species landed during a trip (using landings from the dealer database) to estimate total discard weight.

Strata included in the discard analysis included: gear type, bottom trawl codend mesh size, and fishing region. The majority of *Loligo* discards occur in trawl fisheries Cadrin and Hatfield 1999). Therefore, bottom trawls, midwater trawls and scallop trawls/dredges were included in the current discard analysis. Fishing trips that occurred within in Statistical Areas ≥ 600 and < 600 were defined as the Mid-Atlantic and New England regions, respectively. Bottom trawl codend mesh sizes categories included: large mesh (codend mesh sizes ≥ 5.5 in.), medium mesh (codend mesh sizes of 2.5-5.49 in.), and small mesh (codend mesh sizes < 2.5 in.). Discards were estimated by quarter and cells with fewer than two trips were imputed using the respective annual estimate for each stratum. Discards that occurred during years where no trips were sampled for a particular fleet were estimated by interpolation and are noted as such in the discard summary tables.

The largest source of *Loligo* discards during 1989-2009 was from bottom trawl fisheries (≥ 95% during most years), primarily the small-mesh bottom trawl fisheries, which accounted for 60-98% of the total annual discards during 2001-2009 (Table B7). Most of the small-mesh discards occurred in the Mid-Atlantic region (Table B8). During 2000-2003, when seasonal *Loligo* quotas were frequently attained and a trip limit of 2,500 lbs was in place, regulatory discarding of *Loligo* occurred in the directed fishery (MAFMC 2009).

*Loligo* discard estimates were highly variable inter-annually, ranging between 54 mt and 2,140 mt and averaging 534 mt during 1989-2009 (Table B7). However, the 95% confidence intervals of the annual estimates were very wide (Figure B10). Overall, annual discards were low in relation to landings, averaging 3.4% of the landings during 1989-2009. Annual CVs averaged 0.53 during this same period (Table B7). Annual CVs for the small-mesh fleets were lower during 2004-2009 (0.26-0.77), concurrent with increased sampling of small-mesh bottom trawl trips in the Mid-Atlantic region. However, the annual numbers of Mid-Atlantic small-mesh trips that were sampled during 2004-2009 (57-145 trips per year) were very low compared to the numbers of trips for medium and large-mesh fleets (Table B8, Figure B11). In addition to low sampling coverage, the high variability in discard ratios for this schooling species also probably affected the precision of the discard estimates.

**Size composition of the discards**

During 1989-2009, the numbers of NEFOP observer trips sampled for length compositions of the catches for directed *Loligo* trips (i.e., tows where the captain specified *Loligo peaelii* as the target species) was fairly high for the kept portion of the catch, particularly from 2004 onward, but the numbers of trips sampled for discards was quite low during most years (Table B9). The low sampling intensity of the discards may have been attributable to a low incidence of discarding, but this possibility was not examined.

Since 2000, *Loligo* trip limits have been in effect for the directed fishery during portions of each year. Therefore, discard size compositions were compared for 1994-1999, 2001-2006 and 2000 and 2007-2009. The discard reason indicated by the captain for most tows was lack of a market for small individuals and this is evident in the discard size composition data. The modal size of the discards was 5 cm DML during 1994-1999, and was 8 cm DML from 2000 onward (Figure B12). Discards were generally small squid (≤ 10 cm DML), but a greater percentage of squid larger than 10 cm were discarded during 2001-2006, a period when the fishery was closed multiple times per year during 2002, 2005 and 2006 (Table B2). The size compositions of the kept portions of the catches during 2000-2009 were similar to the size composition of the landings during the same time period (Figure B9), with a modal size of about 12 cm DML (Figure B12).

## Catches

Total catches during the period of dominance by the distant water fleets (1967-1984) averaged 20,814 mt with a peak of 38,892 mt in 1973 (Figure B13; Table B10). During the period of dominance by the domestic fishery, (1987-2009), catches averaged 17,181 mt with a peak of 24,566 mt in 1994. Catches for 1989-2009 include quantitative estimates of discards. However, since most of the catch consists of landings, and landings are substantially uncertain prior to 1987 (Cadrin and Hatfield 1999), this assessment focuses on catches during 1987-2009. During 1988-1995, catches were generally at or above the 1987-2008 median (17,328 mt), but have generally been below the median since in-season quotas were implemented in 2000. After 2005, catches declined to the lowest level since 1968 in 2009 (9,560 mt).

## Nominal LPUE

As described above in paragraph two of this Term of Reference, reporting of *Loligo* landings purchased by federally permitted dealers and *Loligo* catches by federally permitted fishermen did not become mandatory until 1996. Therefore, a nominal LPUE time series was derived from *Loligo* fishery data for 1996-2009. Since 2000, when in-season quotas were implemented, the regulatory definition of a directed *Loligo* trip has been a trip for which ≥ 2,500 lbs of *Loligo* was landed. Trips with ≥ 2,500 lbs of *Loligo* comprised 90% of the cumulative *Loligo* landings during 1996-1999 and 2000-2009 (Figure B14A), which equates to trips where *Loligo* comprised > 30% of the landed trip weight (i.e., the 40% bin in Figure B14B). During 1996-2009, most of the annual *Loligo* landings were taken in trips lasting 2-7 days (Figure B15). During 1996-2009, a fairly high percentage of the annual *Loligo* landings in the CFDBS, 60-75%, matched on a one-to-one basis with VTR trips (i.e., "A" level trips) and could be used to compute nominal LPUE (Figure B16). Nominal LPUE was calculated for the January-June fishery and the July-December fishery based on the regulatory definition of a directed *Loligo* trip.

During the period of quarterly landings quotas, 2001-2006, nominal effort (days fished) was higher during January and February, than when either annual or trimester quotas were in place (Figure B17). Since implementation of trimester-based quotas, in 2007, nominal effort during January-May has been greatly reduced, but annual effort has remained highest during January-March. Nominal effort in both the January-June and July-December fisheries were much lower during 2000-2009, than during 1996-1999, primarily due to fishery closures when the in-season quotas were attained (Table B11, Figure B18A).

In summary, the July-December fishery shows an increasing trend in nominal LPUE during 1996-2004, followed by a decrease through 2009 (Figure B18A). The nominal LPUE trend is similar for the January-June fishery, but the trend is delayed by one year. LPUE trends for the two fisheries are correlated ($r = 0.48$). However, these trends are difficult to interpret because of one or more fishery closures during each year since 2000 and the lack of a clear understanding of what the LPUE values actually represent given the complex population dynamics of the species and the fact that effort has not been standardized.

**Term of Reference 2:** *Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, age-length data, etc.). Describe the uncertainty in these sources of data.*

**Seasonal distribution patterns**

The NEFSC conducts annual bottom trawl surveys, using a stratified random design (Azarovitz 1981), during the fall (generally during September-October) and spring (generally during March-April) between the Gulf of Maine and Cape Hatteras, North Carolina (Figure B19). Inshore strata (8-27 m) and offshore strata (27-366 m) have been most consistently sampled by the SRVs *Albatross IV* and *Delaware II* since 1975.

The distribution of *Loligo* during the spring and fall surveys depends on the timing of the survey in relation to the annual offshore and southerly migration of *Loligo* in the fall and the inshore and northerly migration of the species in the spring. In general, the species is distributed offshore during October-March and inshore during April-September. During fall surveys, *Loligo* are widely distributed across most of the shelf (Figure B20). Squid ≤ 8 cm DML (fishery pre-recruits) prefer shallow depths of < 55 m (catches were highest at bottom temperatures > 16°C) and squid larger than 8 cm DML (recruits) prefer deeper waters of 111-366 m where bottom temperatures are 11-16°C (Brodziak and Hendrickson 1999). During spring surveys, *Loligo* are distributed primarily in warmer offshore waters near the edge of the shelf (Figure B20) where bottom temperatures are ≥ 8°C (Summers 1969). A portion of the stock is also distributed south of Cape Hatteras, North Carolina during both survey periods. However, the amount is unknown because the strata south of Cape Hatteras are not consistently sampled during every survey and the species' range overlaps with the congener, *Loligo pleii*, which cannot be readily distinguished from *L. pealeii* at sea on the basis of gross morphology (Cohen 1976). Thus, it is unknown which of the two *Loligo* species is represented in the catches shown south of Cape Hatteras (Figure B20).

**Survey relative abundance and biomass indices**

Indices of relative abundance (stratified mean number per tow) and biomass (stratified mean kg per tow) were derived for fishery pre-recruits (≤ 8 cm DML) and recruits (> 8 cm DML), as well as all sizes combined, for NEFSC spring and fall bottom trawl surveys. Important improvements to the indices used in this assessment include:

1) Expanding the set of survey strata to include most of the surveyed area where *Loligo* occur. The previous assessment included only offshore habitat (strata 1-23, 25 and 61-76) and this assessment includes important inshore and offshore habitat (inshore strata 2-46, 58-61, and 65-66 plus offshore strata 1-23, 25-26, and 61-76).
2) Derivation of relative abundance and biomass estimates for both of the primary *Loligo* cohorts caught in the NEFSC fall (1975-2009) and spring surveys (1976-2010). An average of the annual spring and fall survey biomass is used as the main survey time series instead of using only the fall survey.
3) Use of an adjustment factor to account for the survey door change that occurred in 1985 (i.e., pre-1985 kg per tow x 1.24 ; no adjustment for number per tow (Byrne and Forrester (1991a)).
4) Use of SRV *Delaware II* catchability adjustment factors for both surveys to obtain *Albatross IV* equivalents (i.e., *DE II* number per tow x 0.83 and weight per tow x 0.85 (Byrne and Forrester 1991b)).
5) Use of "daytime" tows instead of using all tows with night and dawn/dusk converted to daytime equivalents using diel catchability factors estimated using a GLM
6) Addition of swept-area biomass estimates from the fall NEAMAP surveys to account for biomass in inshore areas (≤ 18 m) which are no longer able to be sampled by the new research vessel (SRV *H. B. Bigelow*) beginning in 2009.
7) Use of "daytime" calibration coefficients, as of 2009, to convert SRV *H. B. Bigelow* catches (for numbers of recruits, pre-recruits, and all sizes combined) to *AL IV* equivalents

## Definition of *Loligo* habitat

The strata set used to derive relative abundance and biomass indices from the NEFSC spring and fall surveys has been expanded to include important inshore habitat (inshore strata 2-46, 58-61, and 65-66, shown in pink) as well as the offshore habitat included in the previous assessment (offshore strata 1-23, 25-26, and 61-76, shown in blue, Figure B21). Since 2009, when the SRV *H. B. Bigelow* replaced the SRV *Albatross IV*, the two shallowest series of inshore strata (8-18 m depths) are no longer sampled due to the deeper draft of the Bigelow. Since these inshore strata constitute important *Loligo* habitat during the fall, the swept-area biomass estimate from the 2009 NEAMAP survey was added to the 2009 biomass estimate from the NEFSC fall survey to compute total stock biomass. The estimation method and results are described below in the section for Term of Reference 3.

## Diel effects on bottom trawl catches of *Loligo*

Catches of *Loligo* in bottom trawls tend to be higher during the daytime because of diel migration patterns. *Loligo* are on or near the bottom during the day and feeding higher in the water column at night (Sissenwine and Bowman 1978). Diel effects on survey catches of *Loligo* are size-dependent (Brodziak and Hendrickson 1999). The swept-area based methods used in this assessment are most accurate when the survey data are for daytime tows only because they provide estimates as close as possible to actual stock biomass.

In the most recent stock assessment (NEFSC 2002a), tows during dawn/dusk and nighttime were adjusted to daytime equivalents based on adjustment factors, for pre-recruit and recruit squid, from GLM models fit to log transformed catches for positive tows. The primary disadvantages of the approach used in the last assessment are: 1) diel effects on the probability of a positive tow are ignored; 2) bias in adjustment factors due to log transforming survey catches is ignored; 3) additional model and estimation uncertainty is generated; and 4) model and estimation uncertainty are not included in the variance estimates for survey mean numbers and weight per tow.

In this assessment, only survey data from daytime tows are used. The major benefits are that stratified mean numbers and weight per tow provide more accurate measures of stock biomass (in effect, the capture efficiency of the survey gear is increased) and estimates have similar or lower CVs (equivalent or increased precision). Other benefits of using only daytime tows are: 1) zero tows are included in calculations so that diel effects on the probability of a positive tow are handled automatically; 2) additional and complex modeling to estimate adjustment factors and their variance is not required; 3) standard variance formulas for stratified means are unbiased estimates of sampling variability in mean numbers and weight per tow; 4) differences in diel adjustments for individual sizes are accommodated automatically; and 5) the approach is very simple and easy to implement in standard software used to calculate stratified random mean number and weight per tow indices.

The major potential disadvantages are that sample size (i.e., number of tows) is reduced and strata sampled exclusively during the night are omitted. Both of these disadvantages are exacerbated if the number of tows per stratum is often small. Another disadvantage is that criteria for defining the daytime period are required in deciding which tows to use and which tows to omit from calculations. In this assessment, GAM models and a grid-search procedure were used to find objective criteria for defining daytime tows based on the solar zenith (see Appendix B2). Solar zenith is the angle of the sun at the time of a survey tow relative to a line drawn normal to the earth at the geographic location of a tow and is the primary factor controlling irradiance at the ocean surface and at depth. Solar zenith is more useful than time of day in modeling because illumination depends on latitude, longitude, Julian date and year (which are all used in calculation of the solar zenith). Although there is a clear general relationship between solar zenith and time of day (Figure B22), tows carried out at the same time but at different geographic locations may have substantially different solar zenith and illumination levels that might affect survey catchability.

The results of the grid-search procedure (Appendix B2) show that a wide range of criteria work for defining cut points for daytime tows and that it is only important to avoid using tows conducted at night. An objective method was used to select the solar zenith cut points, performance scores based on an approximate mean squared error (MSE) approach. Based on this method, daytime fall survey data used in this assessment include tows with solar zenith values of 43-80$^o$ and daytime spring survey data include tows with solar zenith values of 29-84$^o$. In general, daytime tows for these fall and spring survey solar zenith angles were conducted during approximately 6:30 AM-4:30 PM and 6:30 AM-5:30 PM, respectively (Figure B22). The relationships between *Loligo* catch rates (number per tow) and solar zenith angle for the spring and fall survey time series included in the assessment are shown in Figure B23.

Some strata, particularly small strata with few tows, may be lost using daytime tows only. The practical significance of this loss is modest because the lost strata tend to be small. Maps of station locations indicate that daytime tows cover the entire survey area and that large portions of the survey area are not ignored using daytime tows (Figure B24). There is a general pattern with respect to cruise timing and cruise track from year to year, but sampling stations are randomly selected within strata and delays occur due to special sampling and weather conditions so that the locations of day- and nighttime tows vary from survey to survey. As mentioned above, trends based solely on daytime data are similar to trends based on both day and night data. The trends are robust because catch rates are very low for *Loligo* during the nighttime. In effect, nighttime tows contribute little additional information about trends in relative abundance of *Loligo*. The major effect of nighttime tows is to reduce mean numbers and weight per tow by approximately $n_d/n_{24}$, where $n_d$ is the number of daytime tows and $n_{24}$ is the total number of tows.

Another explanation for the robustness of survey trends to the use of daytime only catches is theoretical. NEFSC bottom trawl surveys are based on numerous small strata and the survey may be over-stratified for a species like *Loligo*. In the context of an over-stratified survey area, the use of daytime only tows approximates an unbiased two-stage sampling design. The first stage is a random determination (with probability of sampling = $n_d/n_{24}$) of whether or not a stratum is sampled. The second stage is random selection of tow locations within a sampled stratum. A stratum may be missed entirely if daytime only data are used. However, the effect of the missed stratum is minimized because strata with similar densities of *Loligo* were likely sampled during the daytime and used to estimate mean numbers and weight per tow.

For *Loligo*, the potential loss of precision due to reduced sample size is more than counterbalanced by reducing the variability in survey catches. Differences in catch rates between day and night are substantial (e.g., 11.5 times higher during the day than at night, for catches of squid ≤ 8 cm DML in NEFSC fall surveys, Table B12) and diel sources of variance are removed when only daytime tows are used. Relative abundance indices computed for the daytime tows used in the assessment versus all tows were compared for pre-recruits and recruits during the 1975-2008 fall surveys and the 1976-2008 spring surveys. The results indicate similar annual trends between the sets of indices computed using all tows versus daytime tows for both size categories and time series (Figures B25-B28). In addition, the CVs of indices computed from daytime tows were reduced for pre-recruits and recruits during 65% and 50% of the years, respectively, in the fall survey time series (Table B13) and during 70% and 67%, respectively, of the years in the spring survey time series (Table B14).

The magnitude of the effect of solar zenith on *Loligo* relative abundance indices (i.e., the percent difference computed using daytime tows versus all tows) was greater during the fall surveys than during the spring surveys and and affected pre-recruits and recruits differently by season. The average increase in daytime relative abundance indices for pre-recruits and recruits from the fall surveys was 87% and 172%, respectively (Table B13), and was 56% and 25% for the spring surveys, respectively (Table B14).

Similar to trends in relative abundance indices, trends in the percentage of tows with *Loligo* catch were also similar between daytime tows and all tows during spring and fall surveys (Figure B29). The magnitude of the effect of solar zenith on the percentage of tows with *Loligo* catch was also greater for fall survey tows (i.e., averages of 77% for all tows versus 84% for day tows) than for spring survey tows (i.e., averages of 31% for all tows versus 33% for day tows; Figure B29).

**Survey length composition**

*Loligo* length compositions computed using all tows were similar to those computed using “daytime” tows for the fall surveys conducted during 1975-2008 and the spring surveys conducted during 1976-2008 (Figure B30). Squid were fully-recruited to the gear used in the fall and spring surveys at 3 and 4 cm DML, respectively.

The 2009 length compositions of the *Bigelow* catches were slightly different depending on whether they were computed using all tows or “daytime” tows (Figure B30). For the 2009 fall survey, the “daytime” tows included a smaller proportion of squid larger than 7 cm DML than the length composition of all tows, but the opposite was true for the “daytime” tows in the spring survey. Squid were fully recruited to the Bigelow’s net at 5 cm DML. However, more years of data are needed to confirm the 2009 trends.

**Conversion factors for the new SRV *H. B. Bigelow***

The vessels and gear types used to conduct the fall and spring bottom trawl surveys are shown in Tables B15 and B16, respectively. In addition to the gear and vessel conversion factors described earlier in this section, gear/vessel calibration coefficients were also applied to *Loligo* catches by the SRV *H. B. Bigelow,* beginning in 2009, when the SRV *Albatross IV* was decommissioned and the SRV *H.BH. Bigelow* was used to conduct the spring and fall bottom trawl surveys. Calibration coefficients were computed from paired tow studies using daytime tows conducted during the spring and fall of 2008. The paired tow studies are described in Miller *et al*. (2007) and Miller *et al*. (2010). and the methods used to compute the *Bigelow* calibration coefficients for *Loligo* catches are described in Appendix B3. The calibration coefficients (ρ) that were applied to catch numbers of pre-recruits, recruits and all sizes combined, and their CVs, are included in Table B17.

**Trends**

As is typical for squid species (Boyle and Rodhouse 2005), indices for both surveys show a high degree of inter-annual variability, particularly for the fall survey, which makes any trends difficult to discern. Although the spring survey indices are much lower than the fall survey indices, trends are more evident in the spring time series (Figure B31). Relative biomass indices were generally above the median level during 1979-1992, 1999-2002 and 2005-2008, but were generally at or slightly below the median during 1993-1998, 2003-2004 and 2009-2010. During 1976-2009, correlations between spring and fall relative abundance indices were fairly high (*r* =

0.53, $p < 0.01$), but correlations between relative biomass indices were much lower ($r = 0.32$, $p < 0.05$).

Fall relative abundance and biomass indices were more precisely estimated (median CVs were 13% and 12%, respectively, Table B18) than the spring indices (median CVs were 18% and 15%, respectively, Table B19). Overall, both surveys were dominated by pre-recruits (≤ 8 cm DML) and relative abundance of recruits was higher prior to 1987 than after (Figure B31). Trends in pre-recruit and recruit relative abundance indices were significantly correlated for the spring surveys ($r = 0.58$, $p < 0.01$) but not for the fall surveys ($r = 0.20$, $p = 0.19$; Figure B32).

**Term of Reference 3:** *Estimate annual fishing mortality, recruitment and stock biomass for the time series, and characterize the uncertainty of those estimates (consider Loligo TOR-4). Include a historical retrospective analysis to allow a comparison with previous assessment results.*

**Data and methodological differences between current and prior assessment**

**Previous assessment**

This section explains the data and methodological differences between the current and prior assessment and documents the effects of each change on key assessment results. The previous assessment (NEFSC 2002a) included a variety of stock assessmentmethods including length-based VPA (LVPA), *q*-adjusted fall survey swept-area biomass (i.e., based on a composite prior distribution for survey catchability), exploitation indices (i.e., Oct-Dec. catch over *q*-adjusted fall survey swept-area biomass), a complicated surplus production model ("PDQ") tailored to *Loligo*, and traditional age-based per-recruit calculations.

The previous assessment's conclusion that the stock was "unlikely to be overfished" during 2000 was based on a comparison of a fall survey biomass estimate in 2000 (= 34,000 mt, assuming $q$ = 0.45 from the PDQ model) with the Bmsy threshold which existed at thae time (1/2 Bmsy = 40,000 mt) and a variety of other information. The conclusion that "it is unlikely that overfishing was occurring", was based on a comparison of fishing mortality estimates from the PDQ model with a new quarterly estimate for Fmax.

However, the SARC reviewers concluded that the existing biomass reference points were inappropriate and that new biomass reference points could not be estimated (NEFSC 2002b). The SARC reviewers also concluded that "overfishing was not occurring" based on a comparison of the 2000 exploitation index (Oct-Dec landings plus 6% assumed discards/fall survey biomass) with a new quarterly Fmsy proxy (= 0.31 per quarter or 1.24 per year). The new Fmsy proxy represents the 75$^{th}$ percentile of the 1987-2000 exploitation indices. The mean exploitation index during 1987-2000 was selected as the Ftarget (= 0.24 per quarter or 0.96 per year). These fishing mortality references points were implemented in 2009 (MAFMC 2009).
The existing threshold reference point calculations involved an assumed value of *Loligo* catchability ($q$) in the fall survey that was estimated in the PDQ production model (even though assumptions about $q$ would have no effect on status determination results which are based on

trends in catch and survey data). The key source of information about survey catchability in the PDQ model was the *q*-prior used in fitting it because the survey and catch data were not informative for *Loligo*. Thus, the most important and useful parts of the previous assessment were the catch and fall survey data, with the *q*-prior providing bounds on possible biomass and exploitation levels and information about scale.

In view of this history, the current assessment is based on the most promising of the approaches from the previous assessment and includes a number of improvements. In particular, the current assessment uses updated and improved *q*-priors, additional and improved survey data, landings, and improved discard estimates to bound biomass and exploitation estimates. The *q*–prior provides bounds and a set of plausible estimates of biomass and exploitation rates but does not affect status determination measures, which are based on relative trends.

A number of changes were made in the current assessment to *q*-prior calculations, survey data, and catch data. The changes in *q*-prior calculations include:

- Updated estimates for bounds on mean tow distance and effective net width and use of the expanded survey strata area as the stock area, in place of bounds on stock area.
- Updated estimates for bounds on capture efficiency.
- Use of the median *q*-prior value in place of an estimate from the PDQ model.

Changes to survey and catch data included:

- Expanding the set of survey strata used to derive stratified mean number and weight per tow indices. The previous assessment included only offshore habitat (strata 1-23, 25 and 61-76) and this assessment includes important inshore and offshore habitat (inshore strata 2-46, 58-61, and 65-66 plus offshore strata 1-23, 25-26, and 61-76).
- Derivation of biomass estimates for both of the two primary *Loligo* cohorts caught in the NEFSC fall (1975-2009) and spring surveys (1976-2010)
- Use of standard door conversion factors for both survey time series (i.e., pre-1985 kg per tow x 1.24, no adjustment for number per tow), where appropriate.
- Use of standard SRV *Delaware II* catchability adjustment factors for both survey time series (i.e., *DE II* number per tow x 0.83 and weight per tow x 0.85), where appropriate.
- Addition of the fall 2009 biomass estimate from the NEAMAP survey to account for *Loligo* biomass at depths <= 18 m because these inshore strata can no longer be sampled by the SRV *H.B. Bigelow*
- Use of only daytime survey tows instead of using all survey tows with diel correction factors for night and dawn/dusk.
- Use of average annual survey mean weight per tow as the main survey time series instead of fall survey data only (i.e. average of spring and fall biomass estimates in year *t*).

- Use of annual catches in place of fall (October-December) catches and with improved estimates of discards.

A historical retrospective analysis was conducted to allow a comparison of the current assessment results with those from the previous assessment (NEFSC 2002a; NEFSS 2002b). The effects of the changes noted above on *q*-prior calculations and mean catch, biomass indices and biomass estimates during 1987-2000 (the time period of overlap between assessments), along with an exploitation measure (mean annual catch/mean annual q-adjusted survey biomass), indicate that the most important assessment differences were the new bounds for capture efficiency and the calculation of survey biomass as the annual mean of the spring and fall survey biomass estimates (Table B20).

**Biomass estimation**

A comparison of biomass estimates from a surplus production model used in a previous assessment to minimum swept-area biomass estimates (assuming 100% efficiency or the capture of 100% of the squid in the water column above the ground swept by the net) resulted in implausibly high estimates of q, or survey bottom trawl catchability and implausibly low biomass estimates (Cadrin and Hatfield 1999). Biomass is estimated as B=I/q where I is the survey biomass index, in kg per tow, and tends to be too low when q is too large. This problem seems to pervade all previous modeling approaches.

In the current assessment, upper and lower bounds on factors which affect the daytime survey bottom trawl catchability of *Loligo* by the SRV *Albatross*, in both the spring and fall surveys, were used to compute upper and lower bounds on *q*. Based on non-informative uniform prior distributions for uncertainty in each underlying factor, we characterized uncertainty about survey catchability by means of a composite prior distribution, which includes uncertainty in all of the underlying factors.

The hypothetical relationship between survey biomass indices ($I_y$ = stratified mean biomass per tow computed from all survey tows in year *y*) and the true *Loligo* biomass in year *y* is:

$$I_y = qB_y$$

where *q* is a survey-specific catchability coefficient. The catchability coefficient is:

$$q = \frac{aeu}{A}$$

where $u$=$10^6$ converts from kg to thousands of mt, *a* is the area swept during one standard tow ((in $km^2$), *e* is the capture efficiency of the survey bottom trawl (the trawl captures the proportion *e* of *Loligo* in the water column above the ground swept by the trawl) and *A* is the area of the stock. Capture efficiency must be larger than zero if the survey takes at least one individual and, by definition, must be smaller than or equal to one ($0 < e \leq 1$). Area swept (*a*) is equal to the product of average effective tow distance for the survey (*d*, assumed constant over time) and average effective width (*w*) of the area swept by the survey gear such that:

$$q = \frac{dweu}{A}$$

Upper and lower bounds for each of the key factors (*d, w*, *e*, and *A*) affecting the daytime catchability of *Loligo* in the NEFSC fall and spring bottom trawl surveys, during 1975-2010, are shown in Table B21. The bounds included in the previous assessment, for NEFSC fall surveys, are also shown. For 2009 onward, differences between the *Albatross* and *Bigelow* with respect to *d*, *w*, and *e* are accounted for in the *Bigelow* to *Albatross* conversion coefficients (Table B17) that were applied to the relative biomass indices from the *Bigelow*.

*Bounds for effective tow distance (d)*

Variance in the length of individual tows probably contributes little uncertainty to estimates of average tow distance because the tow distance used in the calculations is based on a relatively large sample size (see the following paragraph). However, the mean value is uncertain due to questions about when the survey trawl starts and stops fishing for *Loligo* during daytime tows. Actual tow distance is not likely the same as the nominal tow distance because of lags between winch lock and net touchdown and between winch re-engage and net lift-off (which may vary with station depth) and changes in sea state and tides. All of these factors may affect when the net starts and stops fishing.

The nominal tow distance in the 1975-2008 surveys is 3.42 km based on a target tow duration and speed of 30 minutes at 3.5 knots. However, one study where actual measurements of mean tow distance were measured using Doppler distance indicated that the modal tow distance was 2.96 km during the 1975 and 1976 surveys (Overholtz and Lewis 1978). We also computed the GPS tow distance for the 2007 fall and the 2008 spring surveys. We examined plots of speed over ground, tow duration, temperature, wingspread, and doorspread to determine the times when net touchdown and liftoff occurred for a range of survey station depths (N= 445 tows). GPS tow distance was then computed for the time period between net touchdown and lift-off. We found that tow distance was not dependent on station depth (Figure B33) because depth-related changes in the delay between winch lock and net touchdown was offset by changes in the delay between winch re-engage and net lift-off. Although individual tow distances were variable, the mean for both surveys combined (3.57 km, 95% CI = ±0.01 km) was not. Based on these two estimation methods, we used 2.96 km and 3.57 km as the lower and upper bounds on effective tow distance, respectively.

*Bounds for effective width swept by the survey gear (w)*

The mean of the SRV *Albatross* wingspread measurements for the Yankee 36 bottom trawl, during the 2006-2008 spring and fall surveys (N = 1,985 tows) was used as the lower bound for effective width of the area swept by the survey gear (0.01069 km, 95% CI = ±0.000201). The mean of the *Albatross* doorspread measurements (N = 1,992 tows), during the same time period, was used as the upper bound for effective width of the area swept by the survey gear (0.02192 km, 95% CI = ±0.000743). The lower bound accommodates the hypothesis that no horizontal herding of *Loligo* occurs during daytime fishing and the upper bound accommodates the alternate hypothesis that such herding does occur (i.e., 100% of the squid between the wings and doors are herded into the mouth of the trawl are captured and don't escape). Uncertainty about squid which avoid capture by swimming out beyond the area swept by the doors and wings are included in the bounds for effective width of the survey gear.

*Bounds for survey bottom trawl capture efficiency (e)*

Uncertainty due to squid avoiding capture because they are initially located above the headrope ("school slicing") or because they eventually move up and over the headrope is included in uncertainty about capture efficiency *e*. Escapement beneath the footrope and through the trawl meshes following capture is also included in the uncertainty about capture efficiency. The average headrope height of the Yankee 36 trawl (1.95 m, 95% CI = ±0.17) is low in relation to commercial *Loligo* bottom trawls. This mean is based on 21 tows conducted by the *Albatross* with 1-3 three sensor measurements per tow. Headrope height ranged between 1.7 and 2.1 m. However, given that the survey bottom trawl is towed at a similar or faster speed (3.2-3.8 knots) than that used in the *Loligo* fishery,3.0-3.2 knots, (Hendrickson 2005) and because survey data include only daytime tows (when *Loligo* are closest to the bottom), escapement over the net may be minimized.

If the bottom trawl used on the SRV *Albatross* failed to catch one individual, then the efficiency (*e*) of the trawl would be zero. However, *Loligo* are caught at relatively high rates and within the survey strata used in the assessment. In addition, the use of only the survey catches of *Loligo* from daytime tows effectively increase efficiency because both the percentages of tows with *Loligo* catch and the amounts of *Loligo* catch per tow are greater for daytime tows (Figures B25-B29). The lower bound for *e* accommodates the hypothesis that the gear has low efficiency due, for example, to squid initially distributed above the trawl and/or squid that escape capture by moving up and over the headrope. Escapement through the trawl meshes following capture is another possibility. The upper bound for *e* accommodates the alternate hypothesis that the Yankee 36 bottom trawl is very efficient for *Loligo* during the daytime.

In order to estimate a lower bound for *e* during the daytime, we used behavioral information gleaned from daytime video footage of *Loligo* in front of the sweep and within various types of bottom trawls. In general, squid behaved similarly to the capture behavior reported by Glass *et al*. (1999) for *Loligo* in bottom trawls used in the directed fishery. Video camera recordings of bottom trawl capture behavior indicate that *L. pealeii* tires shortly after encountering the net. Individuals swim for approximately three minutes at a towing speed of 3 knots then rise upward in the net, turn toward the codend, cease swimming and allow the net to overtake them (Glass *et*. al. 1999). We observed schools of squid located on and near the seabed, in front of the sweep, to use alternating jet population and finning to swim forward in the direction of the tow and upward within the net mouth. This same behavior appeared to result in capture, even for raised footrope trawls (footrope at 1-1.5 m above the seabed and rigged with tickler chains), whereby schools of squid tended to use burst speed to quickly jet off the bottom and above the sweep where they were quickly overtaken by the net. Given this rising behavior, it is highly unlikely that escapement occurs beneath the footrope. In addition, squid schools were never observed turning perpendicular to the meshes in the mouth and attempting to escape. Although these behaviors suggest little likelihood of escapement once captured, there is no video footage to determine whether escapement over the headrope occurs. The rapid towing speed of the NEFSC survey trawl and the presence of a square in the Yankee 36 net (webbing that overhangs the area in front of the sweep) probably minimize escapement over the headrope. However, the rapid rising behavior of *Loligo* near the net mouth combined with the lack of information about the height of schools suggests that these low-opening survey nets may only be slicing off the lower portion of schools. Taking all of this information into consideration, we set the lower bound on *e* at 0.20.

The upper bound on capture efficiency for *Loligo* taken in surveys conducted by the *Albatross* was based on calibration factors ($\rho$) derived experimentally and used to convert *Loligo* catches by the *Bigelow* to *Albatross* catch equivalents. Capture efficiency for *Loligo* is higher for the *Bigelow* than for the *Albatross* due to differences in net design and other factors. For these calculations, the maximum possible capture efficiency of the *Bigelow* was assumed to be 0.95. Although this assumed efficiency of the *Bigelow* is somewhat arbitrary, it is intended to be an upper bound and a number of factors indicate that the bottom trawl towed by the *Bigelow* is likely to have high efficiency, particularly during the daytime. The wingspread and doorspread of the *Bigelow* are wider, and the headrope height is higher than for the Yankee 36 and Yankee 41 trawls. The Polyice net used on the Bigelow is a modified version of one type of commercial *Loligo* trawl. Based on sensor measurements from 357 tows conducted during the 2009 fall survey, the mean wingspread of the Bigelow Polyice net (12.76 m, 95% CI = ±0.21 m) is 19.4% wider than the mean wingspread of the Yankee 36 net (10.69 m, 95% CI = ±0.20) and the mean doorspread of the Polyice net (33.02 m, 95% CI = ±0.49, N=361 tows) is 50.6% wider than the mean doorpsread of the Yankee 36 (21.92 m, 95% CI = ±0.74). The mean headrope height of the Polyice net (= 3.69 m, 95% CI = ±0.09, N=360 tows) is 89.2% higher than the mean headrope height of the Yankee 36 net (1.95 m, 95% CI = ±0.17).

Assuming the maximum capture efficiency of the *Bigelow* is 0.95, maximum capture efficiency of the *Albatross* ($e_{max}$) could be no larger than 0.95/$\rho$, where $\rho$ is the calibration factor for converting *Bigelow* catches to *Albatross* equivalents adjusted for wingspread swept-area differences. Thus, the upper bound on *e* was computed as:

$$e_{max} = \frac{0.95\ a_{Bigelow}}{\rho\ a_{Albatross}} = 0.393$$

Where $\rho$ is the calibration factor for the fall survey (= 1.51 for all sizes combined using daytime tows), 0.95 is an upper bound for capture efficiency on the *Bigelow*, and $a_{Bigelow}$ = 0.0382 km$^2$ and $a_{Albatross}$ = 0.0239 km$^2$ are the areas swept by the bottom trawls used by the two vessels. The upper bound for the NEFSC spring survey was nearly identical so, for the sake of simplicity, only $e_{max}$ for fall was used in the assessment.

*Definition of the* stock *area (A)*

Instead of setting upper and lower bounds on the stock area, *A*, we assumed that the *Loligo* strata set used in the assessment (total area = 166,007 km$^2$) represents the stock area. The expanded strat set is much larger than the strata set used in the previous assessment and includes the primary *Loligo* habitat within the surveyed area. As noted in Term of Reference 2, the expanded strata includes the offshore strata used in the previous assessment (1-23, 24-26, and 61-76) plus a set of inshore strata (2-46, 58-61 and 65-66) because GIS maps (see Figures B20 and B21) indicate that these strata constitute important *Loligo* habitat, primarily during the fall.

In order to determine the importance of the inshore habitat which can no longer be sampled by the *Bigelow* (strata ≤ 18 m deep), we conducted several analyses. The annual percentages of *Loligo* relative abundance and biomass originating from these strata were determined for daytime tows conducted during NEFSC spring (1976-2008) and fall surveys (1975-2008). The results indicate that this habitat is more important during the fall surveys than during the spring surveys. During the fall, 0.1-3% of the relative biomass and 0.1-4% of the relative abundance occurred in strata ≤ 18 m deep (Figure B34). However these percentages are probably underestimated because only 50% or less of the total area of these inshore strata was sampled in the daytime during the fall surveys in most years (Figure B35). During the spring surveys, strata ≤ 18 m deep only accounted for a substantial percentage of the relative abundance (4.3%) and biomass (7.2%) during 1985 and 2002, respectively (Figure B34).

In order to account for *Loligo* biomass in the survey strata ≤ 18 m deep, we computed swept area estimates of biomass from the 2009 fall NEAMAP (Northeast Area Assessment and Monitoring Program) survey, which now surveys these inshore strata, and added this amount to the 2009 *q*-adjusted biomass estimate from the NEFSC fall survey. The NEAMAP survey has been conducted during the fall (late Sept.-mid-Oct., which is similar to the timing of the fall NEFSC survey) and during spring (late April-mid-May, which is later than the NEFSC spring survey) since the fall of 2007 (Bonzek *et al*. 2009). Approximately 150 stations are sampled at depths ranging between 6.1 and 18.3 m in waters located between Cape Hatteras, NC and the eastern end of Montauk, NY. Fourteen of the stations are located in Block Island Sound and Rhode Island Sound at depths ranging between 18.3 m and 36.6 m (Figure B36). The total area of all strata is 15,191 km$^2$, but a slightly smaller area was sampled during the fall of 2007 and spring of 2008 (Table B22).

There have been no calibration studies conducted between the *Bigelow* and the NEAMAP survey vessel (the F/V *Darana R*) but the towing protocols are the same (20 minutes at 3 knots) and the nets are similar barring some minor differences.Other differences include a 3-inch cookie sweep on the *Darana R* (versus a rockhopper sweep on the *Bigelow*) and different types of doors.

Biomass estimates were computed for *Loligo* by multiplying the geometric mean weight per tow (C. Bonzek, pers. comm.), for all NEAMAP strata, by the area swept by the trawl (0.025 km$^2$); the latter which is based on mean wingspread and tow distance (Bonzek *et al*. 2009). For the short time series available, the *Loligo* minimum biomass estimates from the fall NEAMAP surveys were fairly low, and ranged between 1,720 mt and 3,482 mt (CV range of 3.5-4.5%) during 2007-2009 (Table B22). However, the estimates were not adjusted for catchability of the NEAMAP survey gear and are probably biased low. The CVs for these biomass estimates were low, ranging between 3.5% and 4.5%. Biomass estimates from the spring NEAMAP surveys were more variable and lower than the fall estimates, ranging between 389 mt and 1,420 mt during 2008-2010 and the estimates were less precise (.CV range of 5.4-9.3%). The spring estimates were likely lower and more variable because the NEAMAP survey occurs at a time when the species is migrating into the survey area. An attempt was also made to compare the fall biomass estimates from the NEAMAP surveys, during 2007-2008, with biomass estimates for a set of overlapping strata sampled during NEFSC surveys, by the *Albatross*, during a similar time period.. However, the resulting estimates were not reliable because the numbers of “daytime” tows conducted by the *Albatross* in these inshore strata were too few (Table B22).

Several additional analyses were conducted in order to address the question of whether substantial amounts of *Loligo* exist outside the NEFSC survey strata, in particular at depths greater than the limit of the surveys (> 366 m), during the time periods in which the NEFSC spring and fall surveys are conducted. The methods utilized and the results of these analyses are included in Appendix B4. One set of analyses used catch-per-tow data from the *Loligo* fishery and NEFSC spring and fall surveys to characterize daytime catch rates of *Loligo* as a function of depth. Results for spring indicated declining fishery catch rates at depths beyond 175 m, although data for deep water tows were limited. Results for all *Loligo* size groups caught in NEFSC spring and fall surveys indicated that the predicted daytime catches declined to low values with increasing depth.

A third analysis involved an examination of *Loligo* catch rates in seasonal depth transect surveys that were conducted at depths greater than the limit of NEFSC surveys, by Rutgers University, during 2003-2007. The surveys utilized a standardized towing protocol (tow distance of 2 nautical miles at a speed of 3 knots) and a commercial *Loligo* bottom trawl. Catch rates of *Loligo pealeii* (kg per tow) in these surveys also show declines with increasing depth, similar to the analysis of catch rates with depth for daytime tows from NEFSC surveys. During some years, daytime catch rates declined to very low levels at stations with depths shallower than 366 m (e.g., < 274 m). Catch rates of *Loligo* were also very low at depths greater than 366 m during January, March and November. However, this result may be an artifact of nighttime sampling at depths > 274 m. In conclusion, the results from all three analyses suggest that high densities of *Loligo* at depths greater than those included in this assessment are unlikely.

*Bounds for q*

The lower bounds or $q_{min}$ values were 0.038 for 1975-2008 and 0.041 for 2009-2010 (Table B21) for catchability in the NEFSC fall and spring bottom trawl surveys and were calculated from the minimum values for *d, w* and *e* in the numerator, and the value for stock area, *A*, in the denominator:

$$q_{\min} = \frac{u\, d_{\min} w_{\min} e_{\min}}{A}$$

Similarly, the upper bounds or $q_{max}$ values were 0.185 for 1975-2008 and 0.197 for 2009-2010 (Table B21) were calculated using the maximum values for *d, w* and *e* in the numerator and the value for stock area, *A*, in the denominator:

$$q_{\max} = \frac{u\, d_{\max} w_{\max} e_{\max}}{A}$$

*Statistical distributions to characterize uncertainty*

We characterized uncertainty in effective tow distance, effective trawl width *w*, and trawl efficiency *e* with uniform distributions that had upper and lower bounds described above. This means, for example, that any value of *w* between the upper and lower bound seemed equally probable, *a priori*. Uniform distributions for these parameters are “non-informative” prior distributions that don’t require knowing or guessing the most likely single value or most probable values (Gelman *et al*. 1995).

Uncertainties about *d, w* and *e* were independent in our analysis because of the definitions for each term. Therefore, the bounds for each term were statistically independent (uncertainty and bounds for efficiency *e* did not depend, for example, on bounds and uncertainty about effective width *w* of the net). Moreover, we tried to choose bounds for each factor in an independent manner so that, for example, the lower bound on effective net width was independent of the upper bound on effective net width.

Given independence, the statistical distribution for uncertainty in *q* can be evaluated by simulation. The first step is to draw random numbers *d'*, *w'*, and *e'* from uniform probability distributions (where, for example, *d'* is drawn from the uniform distribution with upper and lower bounds for effective tow distance, *d*). The second step is to calculate simulated catchability values as $q'=(d'w'e'u)/A$. Recall that *A*, the stock area, is a constant.

We characterized the distribution of the uncertainty in *q* using five million simulated *q'* values (Figure B37). Minimum, maximum and quantiles (Q25, Q50 and Q75) of the two simulated distributions, for 1975-2009 and 2009-2010, are presented in Table B23. Both distributions were similar in shape and were slightly skewed to the left. The distribution ranges were narrow, 0.038-0.185 for 1975-2008 and 0.041-0.197 for 2009-2010, with modes at 0.082 and 0.087 for the two time periods, respectively. The median *q*-priors (Q50 = 0.092 for 1975-2009 and 0.098 for 2009-2010) were located slightly to the right of the distribution modes. In comparison, the q-prior in the previous assessment had bounds between 0.20 and 0.56, was strongly skewed to the right, and had a broad mode between 0.05 and 0.22 (Figure A25 from NEFSC 2002a).

*Biomass trends*

Biomass estimates derived using the minimum, maximum, Q25, Q50, and Q75 values from the *q*-prior distributions are shown in Figure B38. The lowest feasible biomass estimates are more important than the highest feasible biomass estimates when determining stock status because they amount to "worst-case scenarios". The lowest feasible biomass estimates (derived using the minimum *q*-priors) ranged between 15,070 mt and 164,182 mt (median = 62,028 mt) for the fall surveys and ranged between 4,036 mt and 40,646 mt for the spring surveys (median = 13,386 mt; Figure B38). The biomass estimates used in the assessment were derived using the median *q*-priors because they have an equal probability of either under- or overestimating biomass.

The spring and fall NEFSC surveys track different seasonal cohorts which appear to have very different levels of productivity. The spring biomass levels are only about one fifth of the fall biomass levels (Table B24, Figure B39). During 1976-2008, biomass estimates (derived using the median q-priors) ranged between 30,304 and 330,148 mt (median = 124,730 mt) during the fall and between 8,116 mt and 81,734 mt during the spring (median = 27,578 mt).

Federal fishery regulations require that stock status be reported for the terminal "year" of the assessment data series. Therefore, in order to annualize the biomass estimates for this sub-annual species, annual averages of the fall and spring survey biomass estimates were computed for 1976-2009. As is characteristic for squid species (Boyle and Rodhouse 2005), annual biomass fluctuated widely about the median of 76,329 mt during 1976-2009 and ranged between 25,806 mt and 175,894 mt (Figure B40, Table B25). Consequently, trends were difficult to discern, with the exception of an increase in biomass from 25,806 mt in 1996 to the time series high of 175,894 mt in 2000. Biomass generally declined thereafter to about 50% of the median in 2009 (39,792 mt). However, given the high inter-annual variability in biomass estimates, a two-year moving average of stock biomass (i.e., mean biomass during 2008-2009) is recommended for the 2009 stock status determination.

**Exploitation indices**

Exploitation indices, which are considered to be correlated with fishing mortality on a relative basis, were used in the previous assessment and are also used in this assessment. The spring and fall biomass estimates represent mean biomass estimates for the seasonal cohorts that are available to the January-June and July-December fisheries, respectively. Exploitation indices for the two fisheries were computed for 1987-2009 as January-June catch/March biomass and July-December catch/September biomass. Annual exploitation indices were also computed as the annual catch divided by the annual average of NEFSC spring and fall survey biomass estimates.

Exploitation indices were calculated as catch/ biomass of all size groups of squid, including pre-recruit sizes (≤ 8 cm DML) which are not immediately selected by the fishery. Pre-recruit sizes were included in the calculations to partially account for the high turnover rates and the fact that these squid will be large enough to be selected by the fishery shortly after the survey. Likewise, given the semelparous life history of the species, most of the recruits that enter each six-month fishery period will have died by the end of each period.

The maximum feasible exploitation indices are more important than the minimum exploitation indices when determining stock status, because they amount to worst-case scenarios. During 1987-2009, the maximum feasible exploitation indices, computed using the biomass estimates derived with the maximum *q*-prior, ranged between 0.32 and 0.05 (median = 0.132) for the July-December fisheries and ranged between 0.317 and 2.535 for the January-June fisheries (median = 0.634; Figure B41).

The exploitation indices used in the assessment were derived using the biomass estimates for the median *q*-priors. During 1987-2009, catches in the January-June fishery were 1.4 times higher than the July-December catches on average (Table B24). Exploitation indices for the January-June fishery (range = 0.158-1.261; median = 0.315) are much higher on the lesser productive, spring survey cohort than those for the July-December fishery (range = 0.02-0.16; median = 0.064) on the more productive fall survey cohort (Figure B42, Table B24).

During 1993-1998, annual exploitation indices were generally at or above the 1987-2008 median (0.237), averaging 0.273, and generally at or below the median during 1999-2008, averaging 0.18 (Figure B43, Table B25). The 2009 annual exploitation index was 0.176. This 2009 value was computed as the catch in 2009 / mean of the 2008-2009 fall and spring survey biomass estimates. Given the inter-annual variability in biomass estimates, a two-year moving average of stock biomass is recommended for the 2009 stock status determination.

**Historical retrospective analysis**

Comparison of results from this assessment with results from historical assessments (NEFSC

1994; 1996; 1999; 2002a) is difficult because of the lack of temporal overlap between assessments (particularly between NEFSC 2002a and the current assessment), and changes to the data and models used to estimate stock status. However, comparisons (Table B26) reflect the difficulties encountered using both index-based approaches (NEFSC 1994) and surplus production models (NEFSC 1996; 1999; 2002a) for *Loligo*. The majority of assessments relied on relative trends in survey data (NEFSC 1994, 2002a and the current assessment). The stock is now considered lightly exploited but overfishing was determined to be occurring in 2 out of 4 historical assessments. The stock has never been considered overfished, although it was close to its biomass threshold at the time in two cases (NEFSC 1996; 1999).

**Term of Reference 4:** *Summarize what is known about consumptive removals of Loligo by predators and explore how this could influence estimates of natural mortality (M).*

## Natural Mortality

Spawning (Msp) and non-spawning (Mns) natural mortality rates were estimated for *Loligo pealeii* using the methods of Hendrickson and Hart (2006) and Caddy (1996), respectively. The methods and results are presented in Appendix B5. Preliminary natural mortality estimates were very high, 0.11 per week for Mns and 0.19-0.48 per for Msp, similar to estimates for another northwest Atlantic squid species (Hendrickson and Hart 2006). Natural mortality estimates from the current assessment are compared with those used in previous assessments in Table B27. Previous *Loligo* assessments used traditional natural mortality estimation approaches which apply to iteroperous finfish species. Estimates from the current assessment are considered more realistic because the estimation method accounts for the semelparous life history of the species and the fact that natural mortality increases with age for spawners. However, additional maturity-at-age data are needed to determine the range of M estimates for the various seasonal cohorts.

## Preliminary minimum consumption estimates of *Loligo pealeii*

Natural mortality attributable solely to predation was not estimated for *Loligo*, but preliminary minimum consumption estimates during spring and fall were used for comparison with seasonal fishery removals. Size compositions of the *Loligo* prey consumed were also compared to the size compositions of the *Loligo* caught during NEFSC spring and fall surveys and in the fishery. Preliminary estimates of the seasonal consumption of each of the two primary *Loligo* cohorts were computed using food habits data collected during the 1977-2009 NEFSC spring and fall surveys. The spring and fall estimates were summed to derive an annual estimate. Details of the methodology used to compute the consumption estimates, effective sample sizes, and results from the analysis are presented in Appendix B6.

The consumption estimates are preliminary and represent minimums because they do not include consumption by all predators, such as: marine mammals, seals, large pelagic fish species, and birds. In addition, ecosystem and predator dynamics in relation to the complex life history and high turnover rates of squid populations are poorly understood. Minimum consumption estimates were highly variable inter-annually, but were 0.8 to 11 times higher than annual catches during 1977-2009 (Figure B44).

During 1977-1984 and 1999-2010, minimum consumption was much higher during the fall than during the spring (Figure B45). Minimum seasonal consumption estimates, particularly during the spring, are a substantial fraction of the stock biomass (Figure B39). This may imply that the stock is very productive or that the biomass estimates (computed using the median *q* values) are too low, particularly during the spring. Fortunately, the status of the stock with respect to biomass thresholds is trend-based and would not be affected by an underestimation of *Loligo* biomass. Furthermore, higher levels of consumption would reinforce the assessment conclusion that catch is low relative to consumption and that the *Loligo* stock is lightly exploited.

**Term of Reference 5:** *State the existing stock status definitions for the terms "overfished" and "overfishing". Then update or redefine biological reference points (BRPs; estimates or proxies for $B_{MSY}$, $B_{THRESHOLD}$, and $F_{MSY;}$ and estimates of their uncertainty). Comment on the scientific adequacy of existing BRPs and for the "new" (i.e., updated, redefined, or alternative) BRPs.*

**Existing Biological Reference Points**

There are no existing biomass reference points for the *Loligo* stock because the previous Bmsy proxy was deemed inappropriate at SARC 34 and a revised estimate was not provided (NEFSC 2002b). Proxies for Ftarget and Fthreshold were promulgated in Amendment 9 (MAFMC 2009) based on the recommendations from the SARC 34 reviewers that are reflected in the the SAW 34 Advisory Report (NEFSC 2002a). The existing Fmsy proxy is 1.24 per year and is based on the 75$^{th}$ percentile of the quarterly exploitation indices (0.31 per quarter) during 1987-2000. The annual $F_{target}$ is 0.96 and represents the quarterly mean of the exploitation indices during the same time period. The exploitation indices were computed in SARC 34 using a different methodology and different data that those used during the current assessment (refer to Term of Reference 3). In addition, the exploitation indices are ad-hoc because the fall survey data were scaled up by a catchability coefficient estimated in an independent model. The estimates from the independent model were based on survey data and, primarily, on a composite q-prior that is now obsolete because of improvements made in the current assessment.

Proposed **Biological Reference Points**

A new threshold Bmsy proxy of 21, 203 mt and a biomass target of 42, 405 mt are proposed (Table B28). The median of the average of the catchability-adjusted spring and fall survey biomass levels during 1976-2008 is 76,329 mt. The stock appears to be lightly exploited and assuming that biomass is at 90% of the stock's carrying capacity (*K*), a new Bmsy target of 50% of *K* (0.50*(76,329/0.90) = 42,405 mt) is recommended. Based on logistic production models, an appropriate biomass threshold for a short-lived species like *Loligo* is 50% of Bmsy (= 21,203 mt). Annual biomass estimates exceed annual carrying capacity in multiple years, which is to be expected for a species with highly variable seasonal population dynamics which are linked to variability in environmental conditions.

A new Fmsy proxy could not be recommended due to the lack of evidence that fishing has impacted stock biomass since 1975. Conventional approaches based on finfish population dynamics are inappropriate. In particular, there is no theory linking *M* and $F_{MSY}$ for short lived organisms like *Loligo* and per-recruit reference points can be calculated only approximately

(NEFSC 2002a). There is also no theory linking $F_{SPR}$ per recruit reference points to $F_{MSY}$ for species like *Loligo*. Finally, there is too little contrast in either the fishery catch or survey data to provide information that could be used to estimate $F_{MSY}$ in a modern dynamical model.

**Term of Reference 6:** *Evaluate stock status with respect to the existing BRPs, as well as with respect to the "new" BRPs (from Loligo TOR 5).*

**Stock status**

There are no existing biomass-based reference points for the stock, and as a result, overfished status cannot be determined. Based on the current fishing mortality reference points, overfishing was not occurring because the 2009 exploitation index (estimated using the method from SARC 34, Oct-Dec. catch over *q*-adjusted fall survey swept-area biomass) was 0.063 compared to the Fthreshold (i.e., 75$^{th}$ percentile of the exploitation indices during 1987-2009) which is 0.277). However, the current fishing mortality reference points are inappropriate for the lightly exploited *Loligo* stock. The stock appears to be lightly exploited because annual catches were low relative to annual estimates of minimum consumption by a subset of fish predators and there was no evidence of fishing effects on annual survey biomass estimates (i.e., annual averages of the spring and fall biomass estimates) during 1975-2009.

The new exploitation indices used in the current assessment are not comparable to the existing fishing mortality reference points because of differences in computation methods and input data. In the previous assessment, exploitation indices were computed for Quarter 1 as the landings during October-December, plus 6% discards, divided by a *q*-adjusted fall survey biomass estimate. The existing F reference points assume that exploitation is constant during the other three quarters the year. The fall survey catchability *q* (= 0.45) for *Loligo* in the NEFSC fall surveys was estimated from a production model based largely on the obsolete composite prior for fall survey catchability in the previous assessment. The relative biomass indices were computed using all survey tows adjusted to daytime equivalents (i.e., diel conversion factors for night and dawn/dusk). In addition, the fall survey biomass estimates did not include important inshore *Loligo* habitat and biomass estimates for the other primary seasonal cohort (i.e., spring survey biomass estimates) were not used in the assessment. In the current assessment, exploitation indices were computed as the annual catch divided by the mean of the annual spring and fall survey biomass estimates, the latter which were derived using a different survey strata set, only daytime tows, vessel and door correction factors, and the median values of the updated composite *q*-priors.

Based on the proposed biomass reference point threshold from the current assessment, the stock was not overfished during 2009. The two-year average of catchability-adjusted spring and fall survey biomass levels during 2008-2009 was 54,442 mt (80% CI = 38,452-71,783 mt) and is higher than the proposed threshold Bmsy proxy of 21,203 mt (Figure B46, Table B28). The overfishing status during 2009 is unknown because new fishing mortality reference points could not be recommended in the current assessment due to the lack of evidence that fishing impacted annual biomass levels during 1975-2009. The 2009 exploitation index of 0.176 (catch in 2009 divided by the average of the spring and fall survey biomass during 2008-2009; 80% CI = 0.124-0.232) was slightly below the 1987-2008 median of 0.237 (Figure B47, Table B28).

**Term of Reference 7:** *Develop approaches for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs), and comment on the ability to perform projections for this stock.*

**Stock size projections**

Stock size projections were not possible for this semelparous, sub-annual species due to the lack of an assessment model and because like most squid stocks, the short sub-annual lifespan and semelparous life history of this species result in rapid changes in stock size in response to environmental conditions (Hendrickson and Showell 2010; Dawe *et al.* 2007; Boyle and Rodhouse 2005).

**Potential approaches for computing ABCs**

TOR 7 does not include the specification of ABC levels for *Loligo* nor characterization of the various risks involved in fishery management, but rather involves recommending approaches for computing candidate ABCs. ABC refers to a level of "catch" that is "acceptable" given the "biological" characteristics of the stock. Adequate escapement of spawners is needed for this semelparous squid stock to ensure sufficient recruitment in the subsequent year. The magnitude of escapement could be affected by increased exploitation.

The following "Omnibus" approach to setting ABC levels is currently under consideration. It is described as follows. "Allowable biological catch is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of [overfishing limit] OFL and any other scientific uncertainty…" (Federal Register, vol. 74, no. 11, January 16, 2009). The MAFMC's Scientific and Statistical Committee (SSC) is responsible for adjusting OFL levels of catch downward, based on available information about the stock, fishery and uncertainty. The Council is already developing an omnibus amendment that provides the SSC with a general procedure for setting ABC levels. The omnibus approach ranks stocks into four tiers, depending on the information about the stock and reference points provided in the assessment. The omnibus approach is flexible and may well be a sufficient basis for specifying ABC levels for the *Loligo* fishery. The alternative ideas provided in this assessment should not be construed as an indication that the omnibus approach is inadequate.

The ecological importance of *Loligo* as prey for a wide range of species could be considered in specifying ABC levels. *Loligo* are prey for a wide range of non-demersal fish, birds, and marine mammals. Ignoring additional mortality at spawning, mortality rates (mostly natural mortality) for non-spawning *Loligo* range from 0.058 to 0.11 per week (3.0 to 5.7 per year) due, presumably, to predation.

Potential approaches to computing ABCs include:

1) *Seasonal ABC levels*. When setting the annual ABC, consideration of the differences in seasonal cohort productivity and biomass may be prudent. *Loligo* biomass and productivity appear to be substantially lower for the cohort caught in the spring survey than for the cohort caught in the fall survey. Lower spring biomass may be due to a variety of factors, including differences in available habitat, migration patterns, reproduction, growth rates, and/or consumption removals. Relative abundance indices from the spring and fall surveys are correlated and exploitation indices for the January-June fishery (median = 0.315) are much higher on the less-productive, spring survey cohort than those for the July-December fishery (median = 0.064) on the more-productive fall survey cohort.

2) *ABC by analogy to consumption estimates for key predators*. Consumption estimates for six (cod, bluefish, goosefish, pollock, summer flounder and weakfish) of the 15 *Loligo* finfish predators included in this assessment are based on predator stock biomass estimates from peer-reviewed assessment reports that include estimates of survey catchability. The consumption estimates for these six species are plausible estimates of consumption for the six species. Considering consumption by humans and fish predators, specifying ABC levels for *Loligo* based on consumption estimates, based on stock assessment abundance data, for important predators may be a practical approach to ecosystem-based management. Consumption is generally higher during the fall and seasonal differences could be considered as well.

3)

**Term of Reference 8: *Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports. Identify new research recommendations.***

**Prior research recommendations from SARC34**

1) Based on results from the SARC 34 assessment, it appears that traditional per-recruit reference points like $F_{MAX}$ may be poor proxies for $F_{MSY}$ in longfin squid because they do not permit a sufficient level of spawning escapement. There appears to be no satisfactory biomass based reference points for longfin squid at this time. Fishing mortality and biomass reference points for use as targets and thresholds are an important area for research.

   *A new Bmsy reference point was estimated in the current assessment, but an Fmsy BRP or a proxy thereof requires further research due to the complex life history of this species and the lack of theory linking $F_{SPR}$ per-recruit reference points to $F_{MSY}$ for species like Loligo .*

2) It is important to carry out further research on standardizing and modeling survey data for longfin squid. A preliminary GAM (general additive model) analysis of survey data should serve as a good starting point in developing standardization approaches that adjust for diel and other factors affecting catchability. PDQ model results show that survey

catchability processes errors follow similar trends in different surveys and are autocorrelated within surveys. Survey catchabilities probably vary in response to water temperatures. These circumstances suggest that survey catchability processes errors might be modeled robustly and parsimoniously as a simple function of water temperatures in the PDQ model.

*A new GAM was developed and used in the current assessment to define cut points for defining daytime survey tows, based on solar zenith angle, depth, temperature, and other factors, which were used to derive biomass estimates.*

3) Growth information, particularly for older longfin squid, is still uncertain. Additional age and growth studies are required to better estimate average growth patterns and to discern seasonal patterns. The latter are potentially important in more realistic, seasonally explicit population and reference point models like the preliminary, multi-cohort reference point model.

   *More statolith-based age data are needed, by season, for the fishery and NEFSC surveys to accomplish this task. Variable selectivities of the existing age data sets make this task difficult to accomplish.*

4) The potential for fuller use of catch data prior to 1987 from foreign fishing should be investigated for longfin squid. Current assessment approaches use seasonal time steps but historical catch data are currently available only by calendar year. The working group should consult historical NAFO reports and determine if monthly or quarterly catches can be estimated. Alternatively, the PDQ model could be modified to use annual time steps prior to 1987 and quarterly time steps later. Another approach would be to use an annual surplus production model including years before and after 1987.

   *The use of production models to assess squid stocks is not recommended by the ICES Working Group on Cephalopod Fisheries and Life History given their unique life history characteristics, which include the lack of a strong relationship between current and future stock size estimates and the fact that natural mortality is difficult to estimate and varies with age (Anonymous 2001).*

5) Results from this assessment demonstrate that retrospective analyses are a useful part of an assessment involving surplus production models because they provide an estimate of the stability of model estimates. However, retrospective patterns for estimates in production models may have a different meaning and origin than in traditional age structured models. This is a topic for analysis by the Methods Working Group.

   *This research recommendation is now moot because a production model is no longer used in the assessment.*

6) Available logbook data are not adequate to measure fishing effort after 1993, or to prorate landings and effort data by area. It is not currently possible to measure commercial catch rates after 1993, to track trends in fishing effort, or to investigate

relationships between catches and abundance in near shore, offshore, northern and southern areas. The spatial resolution, coverage and accuracy of commercial catch data for longfin squid should be improved.

*Logbook data for 1996-2009 were used in the current assessment to compute nominal fishing effort and LPUE indices.*

7) Information about the population biology of longfin squid has improved in recent years but relationships between seasonal migrations, environmental conditions and temporal and spatial variability in sex ratios, maturity and growth rates are still not clear. It may be useful to carryout additional studies that collect sex and maturity data from longfin squid taken during NEFSC surveys.

   *This task was not completed.*

**New research recommendations for SARC51**

1) Use a mass balance approach to determine if the large apparent differences between the spring and fall biomass estimates are plausible, and what they imply about seasonal patterns in growth, recruitment and mortality.
2) Investigate the use of assessment models with short time steps (i.e., weekly) that incorporate data which allow for cohort-based estimates of biomass and exploitation (e.g., depletion models). Especially consider methods that track changes in fishing mortality.
3) Biomass estimates from NEAMAP inshore survey strata that were previously sampled by NEFSC survey vessels (depths ≤ 18 m between Cape Hatteras and Long Island) were computed for this assessment. Develop additional approaches to estimating *Loligo* biomass in unsampled areas, in particular regions south of Cape Hatteras.
4) Refine consumption estimates for *Loligo*. Where possible, use stock assessment biomass estimates for predator biomass. If a stock assessment-based biomass estimate is not available, it may be advisable to assume a range of survey catchability values in calculating predator swept-area biomass. Estimate consumption by predators (including birds and marine mammals) not well sampled by bottom trawls. Consider smoothing consumption rate estimates to eliminate sampling errors.
5) Develop methods for describing trends in relative fishing mortality for *Loligo*. Conventional approaches developed for fish do not account for recruitment to fishable sizes during fishing or to very high mortality and somatic growth rates.
6) Develop new $F_{MSY}$ proxy or threshold reference point approaches for *Loligo* because conventional approaches developed for finfish with relatively low mortality and slow growth rates are not applicable. Refine $B_{MSY}$ proxies for *Loligo* as well.
7) Maturation-mortality results were encouraging but the data sets used in modeling were not ideal. Collect more age, sex and maturity data for each seasonal cohort and use it in

the model. Also, estimate age-reader error for *Loligo* because this information is important in estimating maturity-mortality model parameters.

8) Refine, carry out sensitivity analyses and document gnomonic natural mortality estimates for *Loligo*.
9) Refine the upper and lower bounds for factors (efficiency, tow distance, tow width, and stock area) that affect survey catchability, particularly for the new survey vessel, and evaluate whether uniform distributions are the best choice for representing uncertainty in these factors.
10) Analyze the costs and benefits of specifying ABC levels based on predator consumption estimates.
11) Develop approaches to smoothing survey biomass estimates that take into account the short lifespan of *Loligo* and differences between spring and fall surveys.

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## **B.** *Loligo*-Tables

Table B1. History summary of the Atlantic Mackerel, Squid and Butterfish Fishery Management Plan.

| Year | Document | Management Action |
|---|---|---|
| 1978-1980 | Original FMPs (3) and individual amendments | Established and continued management of Atlantic mackerel, squid, and butterfish fisheries |
| 1983 | Merged FMP | Consolidated management of Atlantic mackerel, squid, and butterfish fisheries under a single FMP |
| 1984 | Amendment 1 | Implemented squid OY adjustment mechanism |
| | | Revised Atlantic mackerel mortality rate |
| 1986 | Amendment 2 | Equated fishing year with calendar year |
| | | Revised squid bycatch TALFF allowances |
| | | Implemented framework adjustment process |
| | | Converted expiration of fishing permits from indefinite to annual |
| 1991 | Amendment 3 | Established overfishing definitions for all four species |
| 1991 | Amendment 4 | Limited the activity of directed foreign fishing and joint venture transfers to foreign vessels |
| | | Allowed for specification of OY for Atlantic mackerel for up to three years |
| 1996 | Amendment 5 | Adjusted *Loligo* MSY; established 1 7/8" minimum mesh size |
| | | Eliminated directed foreign fisheries for *Loligo*, *Illex*, and butterfish |
| | | Instituted a dealer and vessel reporting system; Instituted operator permitting |
| | | Implemented a limited access system for *Loligo*, *Illex* and butterfish |
| | | Expanded management unit to include all Atlantic mackerel, *Loligo*, *Illex*, and butterfish under U.S. jurisdiction. |
| 1997 | Amendment 6 | Established directed fishery closure at 95% of DAH for *Loligo*, *Illex* and butterfish with post-closure trip limits for each species |
| | | Established a mechanism for seasonal management of the *Illex* fishery to improve the yield-per recruit |
| | | Revised the overfishing definitions for *Loligo*, *Illex* and butterfish |
| 1997 | Amendment 7 | Established consistency among FMPs in the NE region of the U.S. relative to vessel permitting, replacement and upgrade criteria |
| 1998 | Amendment 8 | Brought the FMP into compliance with new and revised National Standards and other required provisions of the Sustainable Fisheries Act. |
| | | Added a framework adjustment procedure. |
| 2001 | Framework 1 | Established research set-asides (RSAs). |

| Table B1 (cont.) | | |
|---|---|---|
| **Year** | **Document** | **Management Action** |
| 2002 | Framework 2 | Established that previous year specifications apply when specifications for the management unit are not published prior to the start of the fishing year (excluding TALFF specifications) |
| | | Extended the *Illex* moratorium for one year; Established *Illex* seasonal exemption from *Loligo* minimum mesh; |
| | | Specified the *Loligo* control rule; Allowed *Loligo* specs to be set for up to 3 years |
| 2003 | Framework 3 | Extended the moratorium on entry to the *Illex* fishery for an additional year |
| 2004 | Framework 4 | Extended the moratorium on entry to the *Illex* fishery for an additional 5 years |
| 2009 | Amendment 9 | Extended the moratorium on entry into the *Illex* fishery, without a sunset provision |
| | | Adopted biological reference points for *Loligo* recommended by the stock assessment review committee (SARC). |
| | | Designated EFH for *Loligo* eggs based on available information |
| | | Prohibited bottom trawling by MSB-permitted vessels in Lydonia and Oceanographer Canyons |
| | | Authorized specifications to be set for all four MSB species for up to 3 years |
| 2010 | Amendment 10 | Implemented a butterfish rebuilding program. (cap to begin in 2011) |
| | | Increased the *Loligo* minimum mesh in Trimesters 1 and 3. |
| | | Implemented a 72-hour trip notification requirement for the *Loligo* fishery (2011). |

[1]In 2000, a 2,500-pound trip limit was implemented during fishery closures.
[2]During 2000 and 2007-2009, the *Loligo* DAH was divided up into trimesters. Quarterly quotas were implemented during 2001-2006. The fishery closes during each seasonal time period when the threshold of the seasonal quota allocation is reached.

Table B2. *Loligo* fishery closure dates (prohibition on *Loligo* landings ≥ 2,500 lbs per trip), during 2000-2009, when in-season quotas were in effect. Quotas were trimester-based during 2000 and 2007-2009 and quarterly during 2001-2006.

| **Year** | **Quota period I** | **Quota period II** | **Quota period III** | **Quota period IV** |
|---|---|---|---|---|
| 2000 | Mar 25 – Apr 30 | Jul 1- Aug 31 | Sep 7 – Oct 6, | |
| | | | Oct 26 - Dec 31 | |
| 2001 | | May 29 – Jun 30 | | |
| 2002 | | May 28 – Jun 30 | Aug 16 – Sep 30 | Nov 2 - Dec 11 |
| | | | | Dec 24 – Dec 31 |
| 2003 | Mar 25 - Mar 31 | | | |
| 2004 | Mar 5 - Mar 31 | | | |
| 2005 | Feb 20 - Mar 31 | Apr 25 - Jun 30 | | Dec 18 - Dec 31 |
| 2006 | Feb 13 - Mar 31 | Apr 21 - Apr 27 | Sep 2 - Sep 30 | |
| | | May 23 - Jun 30 | | |
| 2007 | Apr 13 - Apr 30 | | | |
| 2008 | | July 17 - Aug 31 | | |
| 2009 | | Aug 6 - Aug 31 | | |

Table B3. *Loligo pealeii* landings during 1963-2010 and Total Allowable Catches (TACs) during 1974-2010. The 2010 landings are preliminary and incomplete.

| Year | U.S. | Foreign | Total | Annual TAC | % Foreign |
|---|---|---|---|---|---|
| 1963 | 1,294 | 0 | 1,294 | | 0.0% |
| 1964 | 576 | 2 | 578 | | 0.3% |
| 1965 | 709 | 99 | 808 | | 12.3% |
| 1966 | 722 | 226 | 948 | | 22.6% |
| 1967 | 547 | 1,130 | 1,677 | | 67.4% |
| 1968 | 1,084 | 2,327 | 3,411 | | 68.2% |
| 1969 | 899 | 8,643 | 9,542 | | 90.6% |
| 1970 | 653 | 16,732 | 17,385 | | 96.2% |
| 1971 | 727 | 17,442 | 18,169 | | 96.0% |
| 1972 | 725 | 29,009 | 29,734 | | 97.6% |
| 1973 | 1,105 | 36,508 | 37,613 | | 97.1% |
| 1974 | 2,274 | 32,576 | 34,850 | 71,000 | 93.5% |
| 1975 | 1,621 | 32,180 | 33,801 | 71,000 | 95.2% |
| 1976 | 3,602 | 21,682 | 25,284 | 44,000 | 85.8% |
| 1977 | 1,088 | 15,586 | 16,674 | 44,000 | 93.5% |
| 1978 | 1,476 | 9,355 | 10,831 | 44,000 | 87.9% |
| 1979 | 4,252 | 13,068 | 17,320 | 44,000 | 75.5% |
| 1980 | 3,996 | 19,750 | 23,746 | 44,000 | 83.2% |
| 1981 | 2,316 | 20,212 | 22,528 | 44,000 | 89.7% |
| 1982 | 2,848 | 15,805 | 18,653 | 44,000 | 84.7% |
| 1983 | 10,867 | 11,720 | 22,587 | 44,000 | 51.9% |
| 1984 | 7,689 | 11,031 | 18,720 | 44,000 | 58.9% |
| 1985 | 6,899 | 6,549 | 13,448 | 44,000 | 48.7% |
| 1986 | 11,525 | 4,598 | 16,123 | 44,000 | 28.5% |
| 1987 | 10,367 | 2 | 10,369 | 44,000 | <0.1% |
| 1988 | 18,593 | 3 | 18,596 | 44,000 | <0.1% |
| 1989 | 23,733 | 5 | 23,738 | 44,000 | <0.1% |
| 1990 | 15,399 | 0 | 15,399 | 44,000 | |
| 1991 | 20,299 | 0 | 20,299 | 44,000 | |
| 1992 | 19,018 | 0 | 19,018 | 44,000 | |
| 1993 | 23,020 | 0 | 23,020 | 44,000 | |
| 1994 | 23,480 | 0 | 23,480 | 44,000 | |
| 1995 | 18,880 | 0 | 18,880 | 36,000 | |
| 1996 | 12,503 | 0 | 12,503 | 25,000 | |
| 1997 | 16,270 | 0 | 16,270 | 21,000 | |

Table B3. (cont.)

| Year | U.S. | Foreign | Total | Annual TAC | % Foreign |
|---|---|---|---|---|---|
| 1998 | 19,145 | 0 | 19,145 | 21,000 | |
| 1999 | 19,173 | 0 | 19,173 | 21,000 | |
| 2000 | 17,540 | 0 | 17,540 | 15,000 | |
| 2001 | 14,345 | 0 | 14,345 | 17,000 | |
| 2002 | 16,868 | 0 | 16,868 | 17,000 | |
| 2003 | 11,941 | 0 | 11,941 | 17,000 | |
| 2004 | 15,629 | 0 | 15,629 | 17,000 | |
| 2005 | 16,978 | 0 | 16,978 | 17,000 | |
| 2006 | 15,920 | 0 | 15,920 | 17,000 | |
| 2007 | 12,342 | 0 | 12,342 | 17,000 | |
| 2008 | 11,418 | 0 | 11,418 | 17,000 | |
| 2009 | 9,306 | 0 | 9,306 | 19,000 | |
| 2010 | 5,256 | 0 | 5,256 | 19,000 | |

[1] Landings during 1963-1978 were not reported by species, but are proration-based estimates by Lange and Sissenwine (1980)
[2] Landings during 1979-2010 are from the NEFSC Commercial Fisheries Database
[3] Domestic landings during 1982-1991 include Joint-Venture landings
[4] Domestic landings include unclassified squid which were pro-rated by month and 2-digit Statistical Area (1982-1995) or additive (since 1996)
[5] The source of the landings data for 1963-1995 is NEFSC CRD 02-06.
[6] Since May of 2004, landings have been reported electronically by dealers
[7] Landings during 2010 are preliminary and incomplete
[8] TACs for 1974 and 1975 are for *Illex* and *Loligo* combined

Table B4. Numbers of trips sampled, by month, for landings length composition during 1987-2009.

| | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
| 1987 | 1 | 3 | 7 | 4 | 5 | 11 | 1 | 2 | 3 | 1 | 5 | 5 | 48 |
| 1988 | 1 | 3 | 5 | 5 | 15 | 7 | 6 | 3 | 1 | 3 | 3 | 2 | 54 |
| 1989 | 4 | 2 | 11 | 2 | 17 | 10 | 5 | 2 | 8 | 10 | 7 | 4 | 82 |
| 1990 | 6 | 7 | 11 | 5 | 16 | 11 | 3 | 5 | 6 | 13 | 8 | 3 | 94 |
| 1991 | 3 | 5 | 9 | 8 | 11 | 4 | 1 | 5 | 6 | 5 | 7 | 9 | 73 |
| 1992 | 8 | 3 | 8 | 8 | 7 | 3 | 6 | 6 | 3 | 6 | 10 | 3 | 71 |
| 1993 | 4 | 4 | 10 | 4 | 3 | 5 | 2 | 4 | 1 | 9 | 5 | 2 | 53 |
| 1994 | 4 | 2 | 7 | 0 | 1 | 6 | 3 | 3 | 7 | 7 | 4 | 2 | 46 |
| 1995 | 4 | 5 | 6 | 3 | 5 | 0 | 3 | 3 | 0 | 3 | 0 | 2 | 34 |
| 1996 | 1 | 2 | 16 | 1 | 3 | 3 | 5 | 4 | 0 | 11 | 13 | 13 | 72 |
| 1997 | 10 | 12 | 16 | 12 | 12 | 8 | 7 | 9 | 4 | 15 | 6 | 1 | 112 |
| 1998 | 7 | 18 | 24 | 15 | 2 | 3 | 3 | 9 | 3 | 13 | 18 | 16 | 131 |
| 1999 | 18 | 14 | 13 | 31 | 11 | 15 | 36 | 25 | 12 | 12 | 14 | 13 | 214 |
| 2000 | 18 | 17 | 15 | 1 | 10 | 28 | 10 | 7 | 2 | 6 | 5 | 7 | 126 |
| 2001 | 7 | 16 | 17 | 21 | 10 | 9 | 16 | 9 | 6 | 22 | 24 | 6 | 163 |
| 2002 | 25 | 13 | 18 | 21 | 6 | 5 | 20 | 16 | 1 | 22 | 3 | 5 | 155 |
| 2003 | 9 | 20 | 16 | 10 | 9 | 2 | 6 | 14 | 7 | 14 | 20 | 4 | 131 |
| 2004 | 7 | 21 | 13 | 10 | 15 | 10 | 14 | 8 | 1 | 17 | 10 | 19 | 145 |
| 2005 | 20 | 25 | 15 | 21 | 21 | 4 | 4 | 7 | 4 | 21 | 36 | 14 | 192 |
| 2006 | 38 | 9 | 22 | 34 | 14 | 6 | 14 | 18 | 3 | 27 | 32 | 10 | 227 |
| 2007 | 16 | 10 | 25 | 20 | 4 | 6 | 30 | 25 | 4 | 38 | 9 | 6 | 193 |
| 2008 | 23 | 24 | 3 | 19 | 13 | 7 | 32 | 2 | 4 | 37 | 6 | 4 | 174 |
| 2009 | 12 | 16 | 18 | 18 | 16 | 4 | 29 | 7 | 4 | 21 | 9 | 10 | 164 |

Table B5. Numbers of *Loligo* sampled for landings length composition, by market category, during 1987-2009.

| Year | Unclassified | Lg | Sm | Med | SS | Total |
|---|---|---|---|---|---|---|
| 1987 | 2,449 | 49 | | | | 2,498 |
| 1988 | 3,153 | | | | | 3,153 |
| 1989 | 4,455 | | | | | 4,455 |
| 1990 | 4,903 | 152 | | | | 5,055 |
| 1991 | 3,626 | 252 | | | | 3,878 |
| 1992 | 3,852 | 50 | | | | 3,902 |
| 1993 | 2,718 | 151 | | | | 2,869 |
| 1994 | 3,462 | 316 | | | | 3,778 |
| 1995 | 2,370 | 1,100 | | | | 3,470 |
| 1996 | 5,071 | 1,183 | | | | 6,254 |
| 1997 | 8,850 | 1,765 | 1,136 | 100 | 200 | 12,051 |
| 1998 | 9,650 | 2,944 | 451 | 195 | 888 | 14,128 |
| 1999 | 12,659 | 7,210 | 1,258 | 956 | 1,701 | 23,784 |
| 2000 | 8,381 | 3,904 | 118 | 161 | 430 | 12,994 |
| 2001 | 9,884 | 4,538 | 8,080 | 2,033 | 1,807 | 26,342 |
| 2002 | 6,638 | 5,632 | 18,598 | 7,373 | 8,680 | 46,921 |
| 2003 | 7,457 | 1,740 | 8,210 | 2,381 | 12,638 | 32,426 |
| 2004 | 11,090 | 3,322 | 699 | | 1,983 | 17,094 |
| 2005 | 12,966 | 4,867 | 3,738 | 1,051 | 10,392 | 33,014 |
| 2006 | 14,123 | 8,664 | 1,614 | 109 | 2,138 | 26,648 |
| 2007 | 14,145 | 5,282 | 603 | 269 | 548 | 20,847 |
| 2008 | 12,020 | 5,649 | 200 | 100 | | 17,969 |
| 2009 | 9,605 | 6,197 | 305 | 400 | | 16,507 |

Table B6. Number of *Loligo* length samples from the landings, by market category and month, during 1996-2009.

| | | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Market category | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
| 1996 | 8010 | 1 | 2 | 12 | 1 | 3 | 2 | 5 | 3 | | 8 | 12 | 8 | 57 |
| | 8011 | | | 4 | | | 1 | | 1 | | 3 | 1 | 5 | 15 |
| Total | | 1 | 2 | 16 | 1 | 3 | 3 | 5 | 4 | | 11 | 13 | 13 | 72 |
| 1997 | 8010 | 10 | 9 | 10 | 7 | 12 | 8 | 5 | 7 | 1 | 12 | 5 | 1 | 87 |
| | 8011 | | 3 | 5 | 2 | | | 2 | 2 | 2 | 1 | 1 | | 18 |
| | 8012 | | | 1 | 1 | | | | | 1 | 1 | | | 4 |
| | 8013 | | | | 1 | | | | | | | | | 1 |
| | 8014 | | | | 1 | | | | | | 1 | | | 2 |
| Total | | 10 | 12 | 16 | 12 | 12 | 8 | 7 | 9 | 4 | 15 | 6 | 1 | 112 |
| 1998 | 8010 | 4 | 12 | 19 | 10 | 2 | 3 | 2 | 7 | 3 | 7 | 14 | 11 | 94 |
| | 8011 | 3 | 5 | 5 | 5 | | | 1 | 2 | | 3 | 2 | 3 | 29 |
| | 8012 | | 1 | | | | | | | | 1 | | 1 | 3 |
| | 8013 | | | | | | | | | | 1 | 1 | | 2 |
| | 8014 | | | | | | | | | | 1 | 1 | 1 | 3 |
| Total | | 7 | 18 | 24 | 15 | 2 | 3 | 3 | 9 | 3 | 13 | 18 | 16 | 131 |
| 1999 | 8010 | 12 | 8 | 4 | 17 | 7 | 12 | 14 | 17 | 7 | 9 | 10 | 3 | 120 |
| | 8011 | 4 | 2 | 5 | 12 | 4 | 3 | 19 | 7 | 5 | 3 | 4 | 4 | 72 |
| | 8012 | 1 | 2 | 1 | 1 | | | 1 | | | | | 2 | 8 |
| | 8013 | 1 | | 2 | | | | 2 | 1 | | | | 2 | 8 |
| | 8014 | | 2 | 1 | 1 | | | | | | | | 2 | 6 |
| Total | | 18 | 14 | 13 | 31 | 11 | 15 | 36 | 25 | 12 | 12 | 14 | 13 | 214 |
| 2000 | 8010 | 9 | 15 | 12 | 1 | 9 | 12 | 8 | 3 | 1 | 4 | 3 | 5 | 82 |
| | 8011 | 6 | 2 | 3 | | 1 | 14 | 2 | 4 | 1 | 2 | 2 | 2 | 39 |
| | 8012 | 1 | | | | | | | | | | | | 1 |
| | 8013 | 1 | | | | | | | | | | | | 1 |
| | 8014 | 1 | | | | | 2 | | | | | | | 3 |
| Total | | 18 | 17 | 15 | 1 | 10 | 28 | 10 | 7 | 2 | 6 | 5 | 7 | 126 |
| 2001 | 8010 | 6 | 9 | 11 | 11 | 8 | 5 | 13 | 6 | 5 | 14 | 5 | 2 | 95 |
| | 8011 | 1 | 6 | 6 | 9 | 2 | 4 | 3 | 3 | 1 | 5 | 5 | | 45 |
| | 8012 | | | | | | | | | | 1 | 7 | 2 | 10 |
| | 8013 | | 1 | | 1 | | | | | | 1 | 6 | 2 | 11 |
| | 8014 | | | | | | | | | | 1 | 1 | | 2 |
| Total | | 7 | 16 | 17 | 21 | 10 | 9 | 16 | 9 | 6 | 22 | 24 | 6 | 163 |
| 2002 | 8010 | 8 | 7 | 5 | 11 | 2 | 1 | 5 | 5 | | 10 | 2 | 5 | 61 |
| | 8011 | 7 | 2 | 6 | 4 | 1 | 2 | 6 | 7 | | 5 | | | 40 |
| | 8012 | 4 | 2 | 3 | 2 | 1 | 1 | 3 | 3 | 1 | 3 | 1 | | 24 |
| | 8013 | 4 | 2 | 3 | 2 | 1 | 1 | 3 | | | 3 | | | 19 |
| | 8014 | 2 | | 1 | 2 | 1 | | 3 | 1 | | 1 | | | 11 |
| Total | | 25 | 13 | 18 | 21 | 6 | 5 | 20 | 16 | 1 | 22 | 3 | 5 | 155 |
| 2003 | 8010 | 3 | 10 | 9 | 4 | 5 | 2 | 6 | 13 | 4 | 4 | 11 | 4 | 75 |
| | 8011 | 1 | 4 | 2 | 1 | 1 | | | 1 | | 5 | 3 | | 18 |
| | 8012 | 2 | 2 | 2 | 2 | 1 | | | | 1 | 1 | 2 | | 13 |
| | 8013 | 1 | 2 | 1 | 1 | 1 | | | | 1 | 2 | 2 | | 11 |
| | 8014 | 2 | 2 | 2 | 2 | 1 | | | | 1 | 2 | 2 | | 14 |
| Total | | 9 | 20 | 16 | 10 | 9 | 2 | 6 | 14 | 7 | 14 | 20 | 4 | 131 |

| Table B6 (cont.) | | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Market category | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
| 2004 | 8010 | 6 | 14 | 9 | 3 | 11 | 8 | 12 | 7 | 1 | 15 | 10 | 13 | 109 |
| | 8011 | 1 | 7 | 4 | 7 | 4 | 2 | 2 | 1 | | 2 | | 2 | 32 |
| | 8012 | | | | | | | | | | | | 2 | 2 |
| | 8014 | | | | | | | | | | | | 2 | 2 |
| Total | | 7 | 21 | 13 | 10 | 15 | 10 | 14 | 8 | 1 | 17 | 10 | 19 | 145 |
| 2005 | 8010 | 10 | 14 | 11 | 11 | 16 | 3 | 3 | 6 | 4 | 8 | 21 | 10 | 117 |
| | 8011 | 3 | 5 | 4 | 10 | 4 | 1 | 1 | 1 | | 5 | 9 | 4 | 47 |
| | 8012 | 2 | 2 | | | | | | | | 3 | 1 | | 8 |
| | 8013 | 2 | 1 | | | 1 | | | | | 2 | 2 | | 8 |
| | 8014 | 3 | 3 | | | | | | | | 3 | 3 | | 12 |
| Total | | 20 | 25 | 15 | 21 | 21 | 4 | 4 | 7 | 4 | 21 | 36 | 14 | 192 |
| 2006 | 8010 | 22 | 7 | 15 | 19 | 9 | 5 | 13 | 12 | | 14 | 15 | 6 | 137 |
| | 8011 | 11 | 2 | 7 | 15 | 5 | 1 | 1 | 6 | 3 | 13 | 17 | 4 | 85 |
| | 8012 | 2 | | | | | | | | | | | | 2 |
| | 8013 | 1 | | | | | | | | | | | | 1 |
| | 8014 | 2 | | | | | | | | | | | | 2 |
| Total | | 38 | 9 | 22 | 34 | 14 | 6 | 14 | 18 | 3 | 27 | 32 | 10 | 227 |
| 2007 | 8010 | 12 | 7 | 14 | 12 | 3 | 5 | 18 | 18 | 4 | 32 | 7 | 5 | 137 |
| | 8011 | 4 | 3 | 8 | 8 | 1 | 1 | 12 | 7 | | 6 | 2 | | 52 |
| | 8012 | | | 1 | | | | | | | | | | 1 |
| | 8013 | | | 1 | | | | | | | | | 1 | 2 |
| | 8014 | | | 1 | | | | | | | | | | 1 |
| Total | | 16 | 10 | 25 | 20 | 4 | 6 | 30 | 25 | 4 | 38 | 9 | 6 | 193 |
| 2008 | 8010 | 19 | 22 | 3 | 11 | 10 | 5 | 16 | 1 | 1 | 21 | 5 | 2 | 116 |
| | 8011 | 4 | 2 | | 7 | 3 | 2 | 16 | 1 | 3 | 14 | 1 | 2 | 55 |
| | 8012 | | | | 1 | | | | | | 1 | | | 2 |
| | 8013 | | | | | | | | | | 1 | | | 1 |
| Total | | 23 | 24 | 3 | 19 | 13 | 7 | 32 | 2 | 4 | 37 | 6 | 4 | 174 |
| 2009 | 8010 | 6 | 11 | 14 | 8 | 11 | 4 | 12 | 5 | 2 | 10 | 5 | 7 | 95 |
| | 8011 | 5 | 5 | 4 | 9 | 5 | | 17 | 2 | 2 | 9 | 3 | 1 | 62 |
| | 8012 | 1 | | | 1 | | | | | | | | 1 | 3 |
| | 8013 | | | | | | | | | | 2 | 1 | 1 | 4 |
| Total | | 12 | 16 | 18 | 18 | 16 | 4 | 29 | 7 | 4 | 21 | 9 | 10 | 164 |

Table B7. *Loligo* discard estimates (mt) and CVs, by fleet, and number of observer trips per year during 1989-2009.

| | ***Loligo* Discards (mt)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Bottom trawls by codend mesh size** | | | | | | | | |
| | **>= 5.5 in.** | **2.5-5.49 in.** | **<= 2.49 in.** | **Total** | **MW trawls** | **Scallop dredges/trawls** | **Grand Total** | **CV** | **Total N obs. trips** |
| 1989 | 134 | 479 | 183 | 796 | 2.11 | 8.79 | 806 | 0.22 | 178 |
| 1990 | 285 | 164 | 698 | 1,147 | 2.11 | 8.79 | 1,158 | 0.59 | 139 |
| 1991 | 98 | 155 | 254 | 506 | 28.94 | 8.79 | 544 | 0.78 | 269 |
| 1992 | 113 | 353 | 303 | 770 | 0.01 | 10.26 | 780 | 0.64 | 213 |
| 1993 | 8 | 149 | 195 | 352 | 0.02 | 15.02 | 367 | 0.02 | 110 |
| 1994 | 284 | 703 | 85 | 1,072 | 0.29 | 14.19 | 1,086 | 0.49 | 119 |
| 1995 | 28 | 39 | 1,121 | 1,187 | 2.11 | 19.46 | 1,209 | 0.29 | 288 |
| 1996 | 6 | 264 | 19 | 288 | 2.11 | 2.67 | 293 | 0.90 | 224 |
| 1997 | 3 | 89 | 99 | 191 | 2.11 | 10.34 | 204 | 1.14 | 130 |
| 1998 | 5 | 45 | 161 | 211 | 2.11 | 18.15 | 232 | 0.87 | 82 |
| 1999 | 12 | 27 | 2,099 | 2,139 | 0.06 | 1.24 | 2,140 | 0.64 | 124 |
| 2000 | 113 | 6 | 12 | 131 | 2.11 | 3.51 | 137 | 0.28 | 452 |
| 2001 | 4 | 3 | 40 | 47 | 2.11 | 5.04 | 54 | 0.43 | 380 |
| 2002 | 3 | 3 | 348 | 354 | 2.11 | 16.61 | 373 | 0.64 | 450 |
| 2003 | 18 | 3 | 134 | 156 | 2.11 | 10.94 | 169 | 0.79 | 690 |
| 2004 | 7 | 3 | 266 | 277 | 0.04 | 6.58 | 283 | 0.30 | 1,431 |
| 2005 | 4 | 7 | 682 | 692 | 0.02 | 3.62 | 696 | 0.25 | 2,343 |
| 2006 | 20 | 50 | 119 | 189 | 0.00 | 10.47 | 199 | 0.52 | 1,180 |
| 2007 | 10 | 3 | 112 | 125 | 0.08 | 5.23 | 130 | 0.42 | 1,463 |
| 2008 | 17 | 5 | 81 | 103 | 0.05 | 2.63 | 106 | 0.59 | 1,799 |
| 2009 | 73 | 3 | 175 | 251 | 0.07 | 2.25 | 254 | 0.40 | 2,075 |
| Average 1989-2009 | 59 | 122 | 342 | 523 | 2 | 9 | 534 | 0.53 | 673 |

Table B8. Number of NEFOP observer trips, *Loligo* discard estimates (mt) and CVs, by fleet and region, during 1989-2009.

**Bottom trawls with codend mesh size ≥ 5.5 in.**

| YEAR | MA N Obs trips | MA Discards (mt) | MA CV | NE N Obs trips | NE Discards (mt) | NE CV | Total N Obs trips | Total Discards (mt) | Total CV |
|---|---|---|---|---|---|---|---|---|---|
| 1989 | 1 | 66.9 | 0.72 | 56 | 66.9 | 0.72 | 57 | 133.8 | 0.72 |
| 1990 | 0 | 142.7 | 0.43 | 54 | 142.7 | 0.43 | 54 | 285.4 | 0.43 |
| 1991 | 4 | 64.0 | 2.41 | 78 | 34.0 | 0.38 | 82 | 98.0 | 1.58 |
| 1992 | 14 | 8.8 | 1.36 | 68 | 104.6 | 1.09 | 82 | 113.4 | 1.01 |
| 1993 | 7 | 3.8 | 1.98 | 31 | 4.1 | 1.50 | 38 | 7.8 | 1.23 |
| 1994 | 13 | 13.8 | 0.86 | 27 | 269.7 | 0.57 | 40 | 283.5 | 0.54 |
| 1995 | 52 | 9.1 | 0.75 | 67 | 18.7 | 0.53 | 119 | 27.8 | 0.43 |
| 1996 | 16 | 1.4 | 3.68 | 39 | 4.5 | 4.75 | 55 | 5.8 | 3.75 |
| 1997 | 5 | **2.7** | 0.63 | 24 | 0.2 | 0.63 | 29 | 2.9 | 0.63 |
| 1998 | 13 | 4.1 | 0.90 | 11 | 1.2 | 0.44 | 24 | 5.3 | 0.69 |
| 1999 | 5 | 3.1 | 1.09 | 32 | 9.3 | 0.25 | 37 | 12.4 | 0.33 |
| 2000 | 27 | 105.0 | 0.33 | 99 | 8.3 | 0.37 | 126 | 113.3 | 0.31 |
| 2001 | 44 | 0.1 | 0.97 | 156 | 3.7 | 0.40 | 200 | 3.7 | 0.40 |
| 2002 | 37 | 0.1 | 0.45 | 214 | 2.8 | 0.30 | 251 | 2.8 | 0.30 |
| 2003 | 11 | 16.1 | 0.89 | 386 | 2.4 | 0.57 | 397 | 18.5 | 0.78 |
| 2004 | 91 | 5.6 | 0.40 | 527 | 1.7 | 0.37 | 618 | 7.3 | 0.32 |
| 2005 | 87 | 1.1 | 0.62 | 1346 | 2.4 | 0.26 | 1,433 | 3.5 | 0.27 |
| 2006 | 62 | 4.5 | 0.88 | 613 | 15.1 | 0.16 | 675 | 19.6 | 0.68 |
| 2007 | 160 | 4.8 | 0.41 | 619 | 4.9 | 0.30 | 779 | 9.7 | 0.25 |
| 2008 | 127 | 7.6 | 0.89 | 750 | 9.1 | 0.26 | 877 | 16.6 | 0.43 |
| 2009 | 164 | 68.7 | 0.40 | 868 | 4.1 | 0.31 | 1,032 | 72.7 | 0.38 |

Table B8 (cont.)

| | Bottom trawls with codend mesh size 2.5-5.49 in. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MA | | | NE | | | Total | | |
| YEAR | N Obs trips | Discards (mt) | CV | N Obs trips | Discards (mt) | CV | N Obs trips | Discards (mt) | CV |
| 1989 | 23 | 282.49 | 0.41 | 68 | 196.12 | 0.32 | 91 | 479 | 0.28 |
| 1990 | 36 | 120.91 | 0.51 | 30 | 42.71 | 1.30 | 66 | 164 | 0.51 |
| 1991 | 47 | 95.44 | 0.50 | 67 | 59.30 | 0.33 | 114 | 155 | 0.33 |
| 1992 | 26 | 215.61 | 0.48 | 33 | 137.85 | 0.60 | 59 | 353 | 0.38 |
| 1993 | 7 | 123.03 | 0.67 | 17 | 26.20 | 0.64 | 24 | 149 | 0.56 |
| 1994 | 8 | 23.63 | 0.80 | 9 | 679.64 | 0.69 | 17 | 703 | 0.67 |
| 1995 | 21 | 31.33 | 1.37 | 4 | 7.27 | 0.75 | 25 | 39 | 1.12 |
| 1996 | 28 | 24.86 | 0.61 | 8 | 239.27 | 1.08 | 36 | 264 | 0.98 |
| 1997 | 15 | 5.43 | 1.26 | 9 | 83.97 | 1.01 | 24 | 89 | 0.95 |
| 1998 | 5 | 0.46 | 1.10 | 1 | **44.78** | 1.10 | 6 | 45 | 1.10 |
| 1999 | 10 | 1.87 | 0.93 | 9 | **25.19** | 0.93 | 19 | 27 | 0.93 |
| 2000 | 16 | 0.45 | 1.58 | 12 | 5.60 | 1.39 | 28 | 6 | 1.29 |
| 2001 | 19 | 0.03 | 6.68 | 14 | 3.46 | 0.76 | 33 | 3 | 0.75 |
| 2002 | 19 | 2.84 | 0.35 | 44 | 0.45 | 0.57 | 63 | 3 | 0.31 |
| 2003 | 54 | 0.67 | 0.65 | 45 | 2.27 | 0.56 | 99 | 3 | 0.46 |
| 2004 | 158 | 2.75 | 0.34 | 120 | 0.72 | 0.87 | 278 | 3 | 0.32 |
| 2005 | 111 | 5.42 | 0.37 | 199 | 1.39 | 0.49 | 310 | 7 | 0.31 |
| 2006 | 59 | 49.40 | 0.71 | 46 | 0.38 | 2.04 | 105 | 50 | 0.70 |
| 2007 | 157 | 2.28 | 0.43 | 42 | 0.90 | 0.81 | 199 | 3 | 0.39 |
| 2008 | 95 | 5.03 | 0.48 | 25 | 0.09 | 1.57 | 120 | 5 | 0.47 |
| 2009 | 142 | 1.93 | 0.37 | 75 | 1.16 | 0.52 | 217 | 3 | 0.30 |

Table B8 (cont.)

| | Bottom trawls with codend mesh size ≤ 2.49 in. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MA | | | NE | | | Total | |
| YEAR | N Obs trips | Discards (mt) | CV | N Obs trips | Discards (mt) | CV | N Obs trips | Discards (mt) | CV |
| 1989 | 11 | 125 | 0.56 | 19 | 58 | 0.62 | 30 | 183 | 0.43 |
| 1990 | 12 | 581 | 0.98 | 7 | 117 | 0.95 | 19 | 698 | 0.83 |
| 1991 | 33 | 171 | 2.24 | 31 | 82 | 0.46 | 64 | 254 | 1.52 |
| 1992 | 21 | 295 | 1.57 | 24 | 8 | 2.02 | 45 | 303 | 1.53 |
| 1993 | 1 | **182** | | 4 | **12** | | 5 | 195 | 0.00 |
| 1994 | 3 | 70 | 2.47 | 1 | **15** | | 4 | 85 | 2.47 |
| 1995 | 42 | 1104 | 0.32 | 36 | 17 | 0.89 | 78 | 1,121 | 0.31 |
| 1996 | 51 | 15 | 0.56 | 42 | 4 | 1.32 | 93 | 19 | 0.52 |
| 1997 | 36 | 92 | 2.25 | 12 | 7 | 5.53 | 48 | 99 | 2.13 |
| 1998 | 22 | 54 | 1.27 | 4 | 106 | 1.37 | 26 | 161 | 1.00 |
| 1999 | 24 | 124 | 0.65 | 10 | 1975 | 0.69 | 34 | 2,099 | 0.65 |
| 2000 | 20 | 7 | 0.68 | 5 | 5 | 2.65 | 25 | 12 | 1.14 |
| 2001 | 36 | 23 | 0.52 | 4 | 17 | 1.08 | 40 | 40 | 0.55 |
| 2002 | 14 | 328 | 0.73 | 21 | 20 | 0.56 | 35 | 348 | 0.68 |
| 2003 | 18 | 50 | 0.93 | 27 | 84 | 1.45 | 45 | 134 | 0.97 |
| 2004 | 96 | 207 | 0.40 | 49 | 59 | 0.26 | 145 | 266 | 0.32 |
| 2005 | 63 | 559 | 0.29 | 54 | 123 | 0.55 | 117 | 682 | 0.26 |
| 2006 | 89 | 88 | 1.11 | 38 | 32 | 0.29 | 127 | 119 | 0.51 |
| 2007 | 64 | 45 | 0.98 | 36 | 66 | 0.45 | 100 | 112 | 0.48 |
| 2008 | 57 | 27 | 1.37 | 37 | 54 | 0.92 | 94 | 81 | 0.77 |
| 2009 | 145 | 160 | 0.62 | 146 | 16 | 0.53 | 291 | 175 | 0.56 |

[1] Values shown in bold were interpolated either because there were fewer than 2 trips per year or all trips occurred in one quarter

Table B9. Numbers of *Loligo* length measurements used to characterize the kept and discarded portions of the catches and
numbers of trips sampled by NEFOP observers during 1994-2009.

| | N *Loligo* sampled | | N trips sampled | |
|---|---|---|---|---|
| Year | Kept | Discarded | Kept | Discarded |
| 1994 | 3,162 | 224 | 3 | 2 |
| 1995 | 5,398 | 2,958 | 36 | 14 |
| 1996 | 5,310 | 1,138 | 22 | 7 |
| 1997 | 10,803 | 884 | 29 | 5 |
| 1998 | 8,030 | 0 | 18 | 0 |
| 1999 | 18,463 | 2,442 | 34 | 9 |
| 2000 | 8,898 | 1,163 | 25 | 5 |
| 2001 | 15,126 | 1,579 | 31 | 10 |
| 2002 | 9,278 | 1,075 | 31 | 4 |
| 2003 | 3,060 | 108 | 18 | 1 |
| 2004 | 20,653 | 1,082 | 81 | 9 |
| 2005 | 17,082 | 1,127 | 71 | 9 |
| 2006 | 9,715 | 637 | 51 | 9 |
| 2007 | 3,407 | 628 | 28 | 7 |
| 2008 | 5,875 | 309 | 36 | 5 |
| 2009 | 12,810 | 1,432 | 88 | 17 |

Table B10. *Loligo pealeii* landings (mt), during 1963-2010, and discards (mt) and catches (mt) during 1963-2009.

| | Landings (mt) | | | Discards (mt) | Catch (mt) |
|---|---|---|---|---|---|
| Year | U.S. | Foreign | Total | | |
| 1963 | 1,294 | 0 | 1,294 | 44 | 1,338 |
| 1964 | 576 | 2 | 578 | 20 | 598 |
| 1965 | 709 | 99 | 808 | 27 | 835 |
| 1966 | 722 | 226 | 948 | 32 | 980 |
| 1967 | 547 | 1,130 | 1,677 | 57 | 1,734 |
| 1968 | 1,084 | 2,327 | 3,411 | 116 | 3,527 |
| 1969 | 899 | 8,643 | 9,542 | 324 | 9,866 |
| 1970 | 653 | 16,732 | 17,385 | 591 | 17,976 |
| 1971 | 727 | 17,442 | 18,169 | 618 | 18,787 |
| 1972 | 725 | 29,009 | 29,734 | 1,011 | 30,745 |
| 1973 | 1,105 | 36,508 | 37,613 | 1,279 | 38,892 |
| 1974 | 2,274 | 32,576 | 34,850 | 1,185 | 36,035 |
| 1975 | 1,621 | 32,180 | 33,801 | 1,149 | 34,950 |
| 1976 | 3,602 | 21,682 | 25,284 | 860 | 26,144 |
| 1977 | 1,088 | 15,586 | 16,674 | 567 | 17,241 |
| 1978 | 1,476 | 9,355 | 10,831 | 368 | 11,199 |
| 1979 | 4,252 | 13,068 | 17,320 | 589 | 17,909 |
| 1980 | 3,996 | 19,750 | 23,746 | 807 | 24,553 |
| 1981 | 2,316 | 20,212 | 22,528 | 766 | 23,294 |
| 1982 | 2,848 | 15,805 | 18,653 | 634 | 19,287 |
| 1983 | 10,867 | 11,720 | 22,587 | 768 | 23,355 |
| 1984 | 7,689 | 11,031 | 18,720 | 636 | 19,356 |
| 1985 | 6,899 | 6,549 | 13,448 | 457 | 13,905 |
| 1986 | 11,525 | 4,598 | 16,123 | 548 | 16,671 |
| 1987 | 10,367 | 2 | 10,369 | 353 | 10,722 |
| 1988 | 18,593 | 3 | 18,596 | 632 | 19,228 |
| 1989 | 23,733 | 5 | 23,738 | 806 | 24,544 |
| 1990 | 15,399 | 0 | 15,399 | 1,158 | 16,557 |
| 1991 | 20,299 | 0 | 20,299 | 544 | 20,843 |
| 1992 | 19,018 | 0 | 19,018 | 780 | 19,798 |
| 1993 | 23,020 | 0 | 23,020 | 367 | 23,387 |
| 1994 | 23,480 | 0 | 23,480 | 1,086 | 24,566 |
| 1995 | 18,880 | 0 | 18,880 | 1,207 | 20,087 |
| 1996 | 12,503 | 0 | 12,503 | 293 | 12,796 |
| 1997 | 16,270 | 0 | 16,270 | 204 | 16,474 |
| 1998 | 19,145 | 0 | 19,145 | 232 | 19,377 |
| 1999 | 19,173 | 0 | 19,173 | 2,140 | 21,313 |
| 2000 | 17,540 | 0 | 17,540 | 135 | 17,674 |
| 2001 | 14,345 | 0 | 14,345 | 54 | 14,399 |
| 2002 | 16,868 | 0 | 16,868 | 373 | 17,241 |
| 2003 | 11,941 | 0 | 11,941 | 167 | 12,107 |
| 2004 | 15,738 | 0 | 15,738 | 283 | 16,022 |
| 2005 | 16,720 | 0 | 16,720 | 696 | 17,416 |
| 2006 | 15,920 | 0 | 15,920 | 1,138 | 17,058 |
| 2007 | 12,342 | 0 | 12,342 | 130 | 12,472 |
| 2008 | 11,418 | 0 | 11,418 | 106 | 11,524 |
| 2009 | 9,307 | 0 | 9,307 | 254 | 9,560 |
| 2010 | 5,256 | 0 | 5,256 | | |

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

[2] Landings during 1979-2010 are from the NEFSC Commercial Fisheries Database

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

[4] Domestic landings include unclassified squid which were pro-rated by month and 2-digit Statistical Area (1982-1995) or additive (1996-2008)

[5] Since May of 2004, landings have been reported electronically by dealers

[6] Landings during 2010 are preliminary and incomplete

Table B11. Nominal effort (days fished), landings (mt), and nominal LPUE (mt/day fished) for bottom trawl trips with *Loligo* landings ≥ 2,500 lbs during January-June and July-December, 1996-2009.

| | Jan-June fishery | | | July-Dec fishery | | |
|---|---|---|---|---|---|---|
| Year | Days fished | Landings (mt) | Nominal LPUE (mt/day fished) | Days fished | Landings (mt) | Nominal LPUE (mt/day fished) |
| 1996 | 1064 | 5162 | 4.85 | 373 | 866 | 2.32 |
| 1997 | 800 | 2936 | 3.67 | 1322 | 6016 | 4.55 |
| 1998 | 1277 | 7466 | 5.85 | 999 | 3364 | 3.37 |
| 1999 | 1141 | 4265 | 3.74 | 1350 | 5729 | 4.24 |
| 2000 | 1045 | 5516 | 5.28 | 521 | 4117 | 7.91 |
| 2001 | 642 | 3620 | 5.64 | 775 | 4394 | 5.67 |
| 2002 | 872 | 4433 | 5.08 | 796 | 4890 | 6.14 |
| 2003 | 727 | 3892 | 5.35 | 585 | 3848 | 6.57 |
| 2004 | 828 | 5889 | 7.11 | 458 | 3719 | 8.12 |
| 2005 | 715 | 6320 | 8.84 | 430 | 2761 | 6.43 |
| 2006 | 832 | 5459 | 6.56 | 870 | 4717 | 5.42 |
| 2007 | 690 | 4633 | 6.71 | 427 | 3018 | 7.06 |
| 2008 | 692 | 3971 | 5.74 | 777 | 3715 | 4.78 |
| 2009 | 582 | 2647 | 4.55 | 626 | 2712 | 4.33 |

Table B12. Relative catch rates during the day, versus night and dawn/dusk, for *Loligo* pre-recruits (≤ 8 cm DML) and recruits (> 8 cm DML), during NEFSC fall and spring surveys. For example, the relative catch rate of fall nighttime catches of pre-recruits, on average, is 11.5 times higher than for daytime tows. These diel conversion factors, estimated from a GLM, were used in the previous assessment.

| NEFSC survey | Time period | ≤ 8 cm DML | > 8 cm DML |
|---|---|---|---|
| Fall[1] | Night (8PM-4AM) | 11.5 | 2.9 |
| | Dawn/Dusk (4-7:59AM and 4-7:59PM) | 2.2 | 1.2 |
| | Day (8AM-3:59PM) | 1.0 | 1.0 |
| Spring[2] | Night (8PM-4AM) | 2.0 | 0.8 |
| | Dawn/Dusk (4-7:59AM and 4-7:59PM) | 1.2 | 0.9 |
| | Day (8AM-3:59PM) | 1.0 | 1.0 |

[1] Source: Brodziak and Hendrickson (1999)

[2] Source: Hatfield and Cadrin (2002)

Table B13. Comparison of *Loligo* relative abundance indices, pre-recruits (≤ 8 cm DML) and recruits (> 8 cm DML), for all times of day versus daytime only (solar zenith = 43-80°) during 1975-2008 NEFSC fall surveys.

| | Pre-recruits (≤ 8 cm DML) | | | | | Recruits (> 8 cm DML) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean number per tow | | CV | | CV difference | Mean number per tow | | CV | | CV difference |
| Year | All | Day | All | Day | All-Day | All | Day | All | Day | All-Day |
| 1975 | 415 | 902 | 22 | 15 | 6 | 85 | 103 | 16 | 14 | 2 |
| 1976 | 304 | 562 | 15 | 13 | 2 | 102 | 144 | 22 | 19 | 3 |
| 1977 | 259 | 404 | 13 | 17 | -4 | 71 | 101 | 19 | 23 | -4 |
| 1978 | 101 | 193 | 15 | 21 | -6 | 41 | 72 | 16 | 12 | 4 |
| 1979 | 149 | 297 | 14 | 13 | 1 | 30 | 69 | 13 | 14 | -1 |
| 1980 | 297 | 432 | 14 | 16 | -1 | 67 | 115 | 13 | 10 | 3 |
| 1981 | 137 | 269 | 16 | 14 | 1 | 51 | 119 | 14 | 8 | 6 |
| 1982 | 226 | 427 | 22 | 14 | 7 | 49 | 91 | 17 | 21 | -4 |
| 1983 | 281 | 595 | 15 | 19 | -4 | 112 | 192 | 15 | 24 | -9 |
| 1984 | 154 | 407 | 22 | 7 | 15 | 135 | 196 | 17 | 21 | -4 |
| 1985 | 240 | 482 | 18 | 20 | -1 | 105 | 201 | 14 | 12 | 2 |
| 1986 | 295 | 554 | 17 | 16 | 1 | 77 | 146 | 14 | 8 | 6 |
| 1987 | 38 | 72 | 14 | 10 | 4 | 25 | 30 | 16 | 7 | 9 |
| 1988 | 397 | 565 | 13 | 16 | -3 | 82 | 105 | 13 | 19 | -6 |
| 1989 | 230 | 490 | 14 | 21 | -7 | 116 | 312 | 22 | 40 | -19 |
| 1990 | 216 | 364 | 16 | 14 | 2 | 74 | 109 | 11 | 16 | -5 |
| 1991 | 177 | 245 | 11 | 16 | -5 | 95 | 126 | 14 | 11 | 3 |
| 1992 | 698 | 1919 | 28 | 27 | 1 | 36 | 56 | 13 | 18 | -4 |
| 1993 | 102 | 117 | 31 | 39 | -8 | 52 | 62 | 8 | 11 | -3 |
| 1994 | 308 | 564 | 12 | 11 | 1 | 155 | 314 | 15 | 15 | -1 |
| 1995 | 142 | 269 | 21 | 18 | 2 | 45 | 53 | 15 | 13 | 1 |
| 1996 | 155 | 253 | 22 | 19 | 3 | 30 | 42 | 20 | 32 | -12 |
| 1997 | 259 | 436 | 16 | 22 | -7 | 67 | 105 | 21 | 20 | 1 |
| 1998 | 153 | 310 | 16 | 15 | 1 | 43 | 62 | 14 | 12 | 2 |
| 1999 | 572 | 1139 | 14 | 11 | 2 | 96 | 150 | 10 | 11 | -1 |
| 2000 | 529 | 643 | 15 | 17 | -2 | 128 | 372 | 19 | 6 | 12 |
| 2001 | 268 | 318 | 20 | 13 | 7 | 69 | 102 | 13 | 10 | 3 |
| 2002 | 642 | 1659 | 26 | 4 | 22 | 129 | 236 | 13 | 5 | 9 |
| 2003 | 332 | 730 | 27 | 11 | 16 | 56 | 175 | 24 | 13 | 11 |
| 2004 | 468 | 968 | 24 | 15 | 9 | 43 | 66 | 15 | 12 | 3 |
| 2005 | 185 | 389 | 19 | 13 | 5 | 74 | 127 | 16 | 27 | -11 |
| 2006 | 820 | 1572 | 27 | 11 | 16 | 92 | 155 | 11 | 14 | -3 |
| 2007 | 562 | 988 | 17 | 18 | -1 | 71 | 110 | 19 | 24 | -5 |
| 2008 | 308 | 530 | 18 | 17 | 1 | 57 | 112 | 17 | 23 | -6 |
| % years with reduction in CV | | | | | 65 | | | | | 50 |

[1] Pre-1985 data multiplied by door conversion factors (nos.= 0, wt.= 1.24) and data from R/V *DE II* tows multiplied by vessel conversion factors (nos.= 0.83, wt. = 0.85) during 1975-2008.

Table B14. Comparison of *Loligo* relative abundance indices, pre-recruits (≤ 8 cm DML) and recruits (> 8 cm DML), for all times of day versus daytime only (solar zenith = 29-84$^{0}$) during 1976-2008 NEFSC spring surveys.

| | Pre-recruits (≤ 8 cm DML) | | | | | Recruits (> 8 cm DML) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean number per tow | | CV | | CV difference | Mean number per tow | | CV | | CV difference |
| Year | All | Day | All | Day | All-Day | All | Day | All | Day | All-Day |
| 1976 | 116 | 185 | 19 | 18 | 1 | 34 | 54 | 14 | 12 | 2 |
| 1977 | 7 | 11 | 24 | 20 | 4 | 7 | 9 | 46 | 51 | -4 |
| 1978 | 31 | 27 | 44 | 22 | 22 | 11 | 18 | 34 | 6 | 29 |
| 1979 | 68 | 128 | 38 | 17 | 22 | 13 | 19 | 18 | 8 | 10 |
| 1980 | 28 | 71 | 44 | 27 | 18 | 11 | 20 | 20 | 9 | 11 |
| 1981 | 20 | 25 | 30 | 32 | -3 | 14 | 16 | 31 | 32 | -1 |
| 1982 | 34 | 70 | 37 | 5 | 32 | 16 | 25 | 19 | 12 | 7 |
| 1983 | 15 | 20 | 24 | 9 | 15 | 25 | 24 | 31 | 50 | -20 |
| 1984 | 45 | 71 | 34 | 37 | -3 | 20 | 37 | 37 | 11 | 26 |
| 1985 | 54 | 65 | 25 | 16 | 9 | 19 | 29 | 27 | 7 | 19 |
| 1986 | 59 | 70 | 31 | 39 | -8 | 24 | 23 | 15 | 11 | 4 |
| 1987 | 11 | 13 | 14 | 16 | -2 | 16 | 19 | 23 | 32 | -9 |
| 1988 | 81 | 164 | 37 | 26 | 11 | 30 | 31 | 13 | 14 | -1 |
| 1989 | 66 | 112 | 43 | 39 | 4 | 44 | 53 | 20 | 9 | 11 |
| 1990 | 75 | 124 | 27 | 22 | 6 | 24 | 19 | 25 | 23 | 3 |
| 1991 | 93 | 179 | 30 | 23 | 8 | 36 | 45 | 16 | 12 | 4 |
| 1992 | 59 | 118 | 36 | 6 | 30 | 17 | 25 | 23 | 4 | 20 |
| 1993 | 26 | 36 | 40 | 47 | -7 | 17 | 16 | 23 | 18 | 5 |
| 1994 | 15 | 18 | 19 | 18 | 2 | 7 | 7 | 15 | 12 | 3 |
| 1995 | 38 | 70 | 18 | 28 | -10 | 17 | 21 | 12 | 17 | -5 |
| 1996 | 17 | 33 | 30 | 18 | 12 | 5 | 9 | 32 | 33 | -1 |
| 1997 | 57 | 85 | 42 | 40 | 2 | 22 | 38 | 35 | 12 | 23 |
| 1998 | 38 | 38 | 17 | 13 | 4 | 13 | 10 | 25 | 36 | -12 |
| 1999 | 160 | 282 | 25 | 26 | -1 | 25 | 36 | 15 | 18 | -3 |
| 2000 | 81 | 68 | 30 | 13 | 17 | 26 | 24 | 19 | 9 | 10 |
| 2001 | 80 | 127 | 28 | 27 | 1 | 14 | 19 | 13 | 16 | -3 |
| 2002 | 251 | 336 | 10 | 10 | -1 | 34 | 41 | 13 | 12 | 1 |
| 2003 | 25 | 33 | 50 | 60 | -10 | 9 | 9 | 18 | 16 | 2 |
| 2004 | 31 | 46 | 25 | 9 | 16 | 9 | 9 | 25 | 7 | 18 |
| 2005 | 63 | 152 | 45 | 11 | 34 | 17 | 18 | 21 | 26 | -5 |
| 2006 | 115 | 134 | 15 | 16 | -1 | 44 | 39 | 20 | 19 | 1 |
| 2007 | 112 | 181 | 19 | 17 | 2 | 30 | 45 | 24 | 18 | 6 |
| 2008 | 121 | 191 | 30 | 16 | 14 | 8 | 8 | 14 | 12 | 2 |
| % years with reduction in CV | | | | | 70 | | | | | 67 |

[1] Pre-1985 data multiplied by door conversion factors (nos.= 0, wt.= 1.24) and data from R/V *DE II* tows multiplied by vessel conversion factors (nos.= 0.83, wt. = 0.85) during 1976-2008.

Table B15. Summary of NEFSC fall bottom trawl surveys during 1975-2009. Mean Julian date and N stations pertain to stations sampled in the *Loligo* strata set during the daytime (solar zenith 43-80°) and area sampled also pertains to the *Loligo* strata set. The 1975-2008 strata set includes offshore strata 1-23, 25-26, and 61-76 plus inshore strata 2-46, 58-61, and 65-66. The 2009 strata set is the same but without strata ≤ 18 m.

| Year | Mean Julian Date | Trawl Type | Research Vessels | Trawl Doors | N stations sampled during "day" | Area Sampled ($km^2$) |
|---|---|---|---|---|---|---|
| 1975 | 294 | Yankee 36 | Albatross IV, Delaware II | BMV | 103 | 129,866 |
| 1976 | 290 | Yankee 36 | Albatross IV | BMV | 104 | 149,547 |
| 1977 | 287 | Yankee 36 | Delaware II | BMV | 100 | 135,989 |
| 1978 | 280 | Yankee 36 | Delaware II | BMV | 114 | 147,102 |
| 1979 | 286 | Yankee 36 | Albatross IV, Delaware II | BMV | 113 | 133,578 |
| 1980 | 284 | Yankee 36 | Delaware II | BMV | 90 | 112,233 |
| 1981 | 283 | Yankee 36 | Albatross IV, Delaware II | BMV | 95 | 137,539 |
| 1982 | 279 | Yankee 36 | Albatross IV | BMV | 85 | 130,312 |
| 1983 | 279 | Yankee 36 | Albatross IV | BMV | 95 | 140,527 |
| 1984 | 273 | Yankee 36 | Albatross IV | BMV | 78 | 124,255 |
| 1985 | 284 | Yankee 36 | Albatross IV, Delaware II | Polyvalent | 97 | 144,498 |
| 1986 | 277 | Yankee 36 | Albatross IV, Delaware II | Polyvalent | 89 | 134,459 |
| 1987 | 272 | Yankee 36 | Albatross IV | Polyvalent | 77 | 131,479 |
| 1988 | 275 | Yankee 36 | Albatross IV, Delaware II | Polyvalent | 77 | 130,412 |
| 1989 | 274 | Yankee 36 | Delaware II | Polyvalent | 84 | 126,526 |
| 1990 | 270 | Yankee 36 | Delaware II | Polyvalent | 86 | 133,821 |
| 1991 | 267 | Yankee 36 | Delaware II | Polyvalent | 85 | 135,999 |
| 1992 | 273 | Yankee 36 | Albatross IV | Polyvalent | 87 | 135,323 |
| 1993 | 266 | Yankee 36 | Delaware II | Polyvalent | 89 | 140,040 |
| 1994 | 271 | Yankee 36 | Albatross IV | Polyvalent | 82 | 129,541 |
| 1995 | 265 | Yankee 36 | Albatross IV | Polyvalent | 84 | 130,998 |
| 1996 | 270 | Yankee 36 | Albatross IV | Polyvalent | 87 | 120,678 |
| 1997 | 270 | Yankee 36 | Albatross IV | Polyvalent | 89 | 143,730 |
| 1998 | 279 | Yankee 36 | Albatross IV | Polyvalent | 80 | 126,066 |
| 1999 | 280 | Yankee 36 | Albatross IV | Polyvalent | 84 | 128,374 |
| 2000 | 266 | Yankee 36 | Albatross IV | Polyvalent | 89 | 123,360 |
| 2001 | 265 | Yankee 36 | Albatross IV | Polyvalent | 81 | 127,421 |
| 2002 | 269 | Yankee 36 | Albatross IV | Polyvalent | 82 | 136,020 |
| 2003 | 271 | Yankee 36 | Albatross IV | Polyvalent | 79 | 119,981 |
| 2004 | 273 | Yankee 36 | Albatross IV | Polyvalent | 83 | 139,319 |
| 2005 | 274 | Yankee 36 | Albatross IV | Polyvalent | 82 | 135,258 |
| 2006 | 267 | Yankee 36 | Albatross IV | Polyvalent | 87 | 130,690 |
| 2007 | 274 | Yankee 36 | Albatross IV | Polyvalent | 87 | 129,174 |
| 2008 | 270 | Yankee 36 | Albatross IV | Polyvalent | 88 | 134,559 |
| 2009 | 281 | 400x12 cm 4-seam | Henry H. Bigelow | Polyice Oval | 84 | 132,271 |

Table B16. Summary of NEFSC spring bottom trawl surveys during 1976-2010. Mean Julian date and N stations pertain to stations sampled in the *Loligo* strata set during the daytime (solar zenith 29-84°) and area sampled also pertains to the *Loligo* strata set. The 1976-2008 strata set includes offshore strata 1-23, 25-26, and 61-76 plus inshore strata 2-46, 58-61, and 65-66. The 2009-2010 strata set is the same but without strata ≤ 18 m.

| Year | Mean Julian Date | Trawl Type | Research Vessels | Type Trawl Doors | N stations sampled during "day" | Area Sampled ($km^2$) |
|---|---|---|---|---|---|---|
| 1976 | 82 | Yankee No. 41 | Albatross IV, Delaware II | BMV | 127 | 152,785 |
| 1977 | 98 | Yankee No. 41 | Albatross IV, Delaware II | BMV | 133 | 155,008 |
| 1978 | 97 | Yankee No. 41 | Albatross IV | BMV | 118 | 150,652 |
| 1979 | 102 | Yankee No. 41 | Albatross IV, Delaware II | BMV | 152 | 154,099 |
| 1980 | 101 | Yankee No. 41 | Albatross IV, Delaware II | BMV | 155 | 132,610 |
| 1981 | 102 | Yankee No. 41 | Delaware II | BMV | 119 | 145,476 |
| 1982 | 97 | Yankee No. 36 | Delaware II | BMV | 125 | 151,022 |
| 1983 | 90 | Yankee No. 36 | Albatross IV | BMV | 118 | 152,223 |
| 1984 | 82 | Yankee No. 36 | Albatross IV | BMV | 125 | 152,123 |
| 1985 | 76 | Yankee No. 36 | Albatross IV | Polyvalent | 111 | 138,500 |
| 1986 | 85 | Yankee No. 36 | Albatross IV | Polyvalent | 115 | 131,513 |
| 1987 | 98 | Yankee No. 36 | Albatross IV, Delaware II | Polyvalent | 113 | 147,277 |
| 1988 | 79 | Yankee No. 36 | Albatross IV | Polyvalent | 110 | 136,887 |
| 1989 | 72 | Yankee No. 36 | Delaware II | Polyvalent | 92 | 145,984 |
| 1990 | 81 | Yankee No. 36 | Delaware II | Polyvalent | 102 | 145,510 |
| 1991 | 81 | Yankee No. 36 | Delaware II | Polyvalent | 102 | 145,994 |
| 1992 | 80 | Yankee No. 36 | Albatross IV | Polyvalent | 104 | 145,123 |
| 1993 | 88 | Yankee No. 36 | Albatross IV | Polyvalent | 115 | 133,560 |
| 1994 | 82 | Yankee No. 36 | Delaware II | Polyvalent | 104 | 143,466 |
| 1995 | 89 | Yankee No. 36 | Albatross IV | Polyvalent | 107 | 136,256 |
| 1996 | 89 | Yankee No. 36 | Albatross IV | Polyvalent | 121 | 146,477 |
| 1997 | 80 | Yankee No. 36 | Albatross IV | Polyvalent | 111 | 144,649 |
| 1998 | 78 | Yankee No. 36 | Albatross IV | Polyvalent | 107 | 136,706 |
| 1999 | 85 | Yankee No. 36 | Albatross IV | Polyvalent | 113 | 133,807 |
| 2000 | 91 | Yankee No. 36 | Albatross IV | Polyvalent | 112 | 151,396 |
| 2001 | 83 | Yankee No. 36 | Albatross IV | Polyvalent | 117 | 141,676 |
| 2002 | 85 | Yankee No. 36 | Albatross IV | Polyvalent | 109 | 128,964 |
| 2003 | 85 | Yankee No. 36 | Delaware II | Polyvalent | 113 | 151,132 |
| 2004 | 82 | Yankee No. 36 | Albatross IV | Polyvalent | 108 | 148,371 |
| 2005 | 81 | Yankee No. 36 | Albatross IV | Polyvalent | 110 | 132,370 |
| 2006 | 81 | Yankee No. 36 | Albatross IV | Polyvalent | 109 | 150,912 |
| 2007 | 82 | Yankee No. 36 | Albatross IV | Polyvalent | 125 | 142,564 |
| 2008 | 87 | Yankee No. 36 | Albatross IV | Polyvalent | 125 | 146,772 |
| 2009 | 88 | 400x12 cm 4-seam | Henry H. Bigelow | Polyice Oval | 140 | 149,016 |
| 2010 | 82 | 400x12 cm 4-seam | Henry H. Bigelow | Polyice Oval | 123 | 147,431 |

Table B17. Coefficients (rho) used to convert SRV *H. B. Bigelow* catches of *Loligo pealeii* to SRV *Albatross IV* equivalents for the fall 2009 and spring 2009-2010 NEFSC bottom trawl surveys.

| | Spring Surveys | | | Fall Surveys | | |
|---|---|---|---|---|---|---|
| Size range (DML) | rho | SE | CV | rho | SE | CV |
| ≤ 8 cm | 1.29 | 0.204 | 16 | 1.26 | 0.088 | 7 |
| > 8 cm | 2.11 | 0.325 | 15 | 1.70 | 0.090 | 5 |
| All sizes combined | 1.53 | 0.171 | 11 | 1.51 | 0.064 | 4 |

Table B18. Stratified mean numbers and weight (kg) per tow for *Loligo pealeii* pre-recruits (≤ 8 cm DML) and recruits (> 8 cm) caught in NEFSC fall surveys during 1975-2009. The 1975-2008 survey strata set includes offshore strata 1-23, 25-26, and 61-76 plus inshore strata 2-46, 58-61, and 65-66. The 2009 strata set is the same except strata ≤ 18 m were not included because they are too shallow to be sampled by the new survey vessel, the FRV *Henry B. Bigelow.*

| | Number per tow | | | | | | Kg per tow | |
|---|---|---|---|---|---|---|---|---|
| Year | Pre-recruits | CV | Recruits | CV | All sizes | CV | All sizes | CV |
| 1975 | 902 | 15 | 103 | 14 | 1,004 | 14 | 14.4 | 11 |
| 1976 | 562 | 13 | 144 | 19 | 707 | 12 | 18.8 | 15 |
| 1977 | 404 | 17 | 101 | 23 | 505 | 14 | 11.5 | 18 |
| 1978 | 193 | 21 | 72 | 12 | 265 | 16 | 7.6 | 11 |
| 1979 | 297 | 13 | 69 | 14 | 366 | 12 | 8.2 | 12 |
| 1980 | 432 | 16 | 115 | 10 | 547 | 13 | 14.2 | 8 |
| 1981 | 269 | 14 | 119 | 8 | 388 | 10 | 12.5 | 6 |
| 1982 | 427 | 14 | 91 | 21 | 518 | 13 | 12.4 | 15 |
| 1983 | 595 | 19 | 192 | 24 | 787 | 14 | 23.7 | 20 |
| 1984 | 407 | 7 | 196 | 21 | 603 | 9 | 20.8 | 17 |
| 1985 | 482 | 20 | 201 | 12 | 683 | 15 | 19.6 | 11 |
| 1986 | 554 | 16 | 146 | 8 | 700 | 13 | 14.8 | 4 |
| 1987 | 72 | 10 | 30 | 7 | 101 | 8 | 2.8 | 9 |
| 1988 | 565 | 16 | 105 | 19 | 670 | 14 | 9.3 | 13 |
| 1989 | 490 | 21 | 312 | 40 | 803 | 25 | 21.5 | 34 |
| 1990 | 364 | 14 | 109 | 16 | 474 | 12 | 10.4 | 14 |
| 1991 | 245 | 16 | 126 | 11 | 371 | 12 | 11.5 | 10 |
| 1992 | 1,919 | 27 | 56 | 18 | 1,975 | 27 | 10.4 | 20 |
| 1993 | 117 | 39 | 62 | 11 | 179 | 26 | 4.9 | 10 |
| 1994 | 564 | 11 | 314 | 15 | 878 | 11 | 27.5 | 15 |
| 1995 | 269 | 18 | 53 | 13 | 322 | 15 | 5.8 | 8 |
| 1996 | 253 | 19 | 42 | 32 | 295 | 18 | 3.8 | 20 |
| 1997 | 436 | 22 | 105 | 20 | 541 | 21 | 10.3 | 22 |
| 1998 | 310 | 15 | 62 | 12 | 372 | 14 | 5.3 | 14 |
| 1999 | 1,139 | 11 | 150 | 11 | 1,289 | 10 | 15.4 | 10 |
| 2000 | 643 | 17 | 372 | 6 | 1,014 | 12 | 30.4 | 7 |
| 2001 | 318 | 13 | 102 | 10 | 421 | 11 | 8.5 | 8 |
| 2002 | 1,659 | 4 | 236 | 5 | 1,895 | 4 | 23.4 | 5 |
| 2003 | 730 | 11 | 175 | 13 | 904 | 8 | 14.0 | 11 |
| 2004 | 968 | 15 | 66 | 12 | 1,034 | 14 | 8.6 | 10 |
| 2005 | 389 | 13 | 127 | 27 | 515 | 14 | 9.9 | 20 |
| 2006 | 1,572 | 11 | 155 | 14 | 1,727 | 10 | 22.9 | 6 |
| 2007 | 988 | 18 | 110 | 24 | 1,097 | 17 | 10.1 | 18 |
| 2008 | 530 | 17 | 112 | 23 | 642 | 18 | 11.3 | 25 |
| 2009 | 437 | 8 | 49 | 18 | 419 | 8 | 6.4 | 12 |
| Median 1976-2008 | 436 | 16 | 112 | 14 | 603 | 13 | 11 | 12 |

[1] Pre-1985 indices were multiplied by door conversion factors (nos.= 0, wt.= 1.24) and data from R/V *DE II* tows multiplied by vessel conversion factors (nos.= 0.83, wt. = 0.85) during 1975-2008.
[2] Only daytime tows (solar zenith of 43-80 degrees) were used to compute the above indices
[3] Bigelow conversion factors of 1.26 for pre-recruits, 1.70 for recruits, and 1.51 for all sizes were applied to the 2009 number and weight indices

Table B19. Stratified mean numbers and weight (kg) per tow for *Loligo pealeii* pre-recruits (≤ 8 cm DML) and recruits (> 8 cm) caught in NEFSC spring surveys during 1976-2010. The 1976-2008 survey strata set includes offshore strata 1-23, 25-26, and 61-76 plus inshore strata 2-46, 58-61, and 65-66. The 2009-2010 strata set is the same except strata ≤ 18 m were not included because they are too shallow to be sampled by the new survey vessel, the FRV *Henry B. Bigelow*.

| | Number per tow | | | | | | Kg per tow | |
|---|---|---|---|---|---|---|---|---|
| Year | Pre-recruits | CV | Recruits | CV | All sizes | CV | All sizes | CV |
| 1976 | 185 | 18 | 54 | 12 | 239 | 15 | 7.5 | 11 |
| 1977 | 11 | 20 | 9 | 51 | 20 | 30 | 1.0 | 41 |
| 1978 | 27 | 22 | 18 | 6 | 45 | 15 | 2.2 | 9 |
| 1979 | 128 | 17 | 19 | 8 | 147 | 15 | 3.2 | 8 |
| 1980 | 71 | 27 | 20 | 9 | 91 | 22 | 3.2 | 12 |
| 1981 | 25 | 32 | 16 | 32 | 40 | 29 | 2.0 | 26 |
| 1982 | 70 | 5 | 25 | 12 | 95 | 6 | 2.9 | 12 |
| 1983 | 20 | 9 | 24 | 50 | 44 | 29 | 2.2 | 46 |
| 1984 | 71 | 37 | 37 | 11 | 107 | 28 | 4.5 | 15 |
| 1985 | 65 | 16 | 29 | 7 | 94 | 12 | 2.9 | 6 |
| 1986 | 70 | 39 | 23 | 11 | 93 | 31 | 2.5 | 17 |
| 1987 | 13 | 16 | 19 | 32 | 32 | 21 | 2.1 | 27 |
| 1988 | 164 | 26 | 31 | 14 | 195 | 23 | 4.0 | 16 |
| 1989 | 112 | 39 | 53 | 9 | 165 | 28 | 4.8 | 12 |
| 1990 | 124 | 22 | 19 | 23 | 143 | 19 | 2.8 | 15 |
| 1991 | 179 | 23 | 45 | 12 | 223 | 18 | 4.3 | 9 |
| 1992 | 118 | 6 | 25 | 4 | 143 | 5 | 3.6 | 4 |
| 1993 | 36 | 47 | 16 | 18 | 52 | 35 | 1.6 | 25 |
| 1994 | 18 | 18 | 7 | 12 | 25 | 15 | 0.7 | 13 |
| 1995 | 70 | 28 | 21 | 17 | 91 | 25 | 2.2 | 22 |
| 1996 | 33 | 18 | 9 | 33 | 42 | 17 | 0.9 | 28 |
| 1997 | 85 | 40 | 38 | 12 | 122 | 28 | 2.7 | 13 |
| 1998 | 38 | 13 | 10 | 36 | 48 | 16 | 0.9 | 30 |
| 1999 | 282 | 26 | 36 | 18 | 318 | 24 | 4.1 | 16 |
| 2000 | 68 | 13 | 24 | 9 | 92 | 10 | 2.0 | 10 |
| 2001 | 127 | 27 | 19 | 16 | 145 | 25 | 2.5 | 17 |
| 2002 | 336 | 10 | 41 | 12 | 376 | 10 | 5.0 | 12 |
| 2003 | 33 | 60 | 9 | 16 | 42 | 47 | 0.9 | 21 |
| 2004 | 46 | 9 | 9 | 7 | 55 | 8 | 0.8 | 5 |
| 2005 | 152 | 11 | 18 | 26 | 170 | 12 | 1.8 | 21 |
| 2006 | 134 | 16 | 39 | 19 | 173 | 13 | 3.2 | 14 |
| 2007 | 181 | 17 | 45 | 18 | 226 | 14 | 3.7 | 15 |
| 2008 | 191 | 16 | 8 | 12 | 199 | 15 | 1.4 | 8 |
| 2009 | 38 | 22 | 10 | 26 | 46 | 22 | 1.1 | 22 |
| 2010 | 38 | 25 | 7 | 19 | 42 | 22 | 0.8 | 17 |
| Median 1976-2008 | 71 | 18 | 21 | 12 | 95 | 18 | 3 | 15 |

[1] Pre-1985 indices were multiplied by door conversion factors (nos.= 0, wt.= 1.24) and data from R/V *DE II* tows multiplied by vessel conversion factors (nos.= 0.83, wt. = 0.85) during 1976-2008.
[2] Only daytime tows (solar zenith of 29-84 degrees) were used to compute the above indices
[3] Bigelow conversion factors of 1.29 for pre-recruits, 2.11 for recruits, and 1.53 for all sizes were applied to the 2009-2010 number and weight indices

Table B20. Comparison of the previous and current assessments for *Loligo*, with a stepwise demonstration of effects on mean catch and mean survey kg/tow and mean survey biomass, in NEFSC surveys, during 1987-2000 (the time period of overlap). Effects on a simple average exploitation index (mean catch/mean survey biomass) are also shown. Note that the mean catch/mean survey biomass is a ratio of averages, not the average of annual exploitation indices. Values in the table are meant to show effects of changes in data, methodology and assumptions and should not be used for management purposes. Boxes indicating parameter changes are shaded.

| Step | Notes and explanation | *q*-prior | | | *q* used | Estimates for 1987-2000 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Lower bound | Median | Upper bound | | Mean catch (000s mt/year) | Mean survey kg/tow | Mean survey biomass (*q* x kg/tow, 000s mt) | Mean catch / mean survey biomass |
| Previous assessment | Note: a *q*-prior was calculated in the last assessment and used in the PDQ model but not used directly for status determination. | 0.022 | 0.187 | 0.556 | 0.450 | 19.436 | 11.1 | 24.59 | 0.790 |
| 1 | Update all factors in *q*-prior except capture efficiency | **0.019** | **0.154** | **0.423** | 0.450 | 19.436 | 11.1 | 24.59 | 0.790 |
| 2 | Update capture efficiency in *q*-prior | **0.038** | **0.092** | **0.185** | 0.450 | 19.436 | 11.1 | 24.59 | 0.790 |
| 3 | Use median *q* from *q*-prior distribution | 0.038 | 0.092 | 0.185 | **0.092** | 19.436 | 11.1 | **120.17** | **0.162** |
| 4 | Fall survey data for expanded strata set; vessel correction factors for SRVs *Albatross IV* and *Delaware II*; daytime tows only | 0.038 | 0.092 | 0.185 | 0.092 | 19.436 | **12.1** | **131.31** | **0.148** |
| 5 | Average fall and spring survey data | 0.038 | 0.092 | 0.185 | 0.092 | 19.436 | 7.4 | **79.96** | **0.243** |
| Current assessment | Improved discard information | 0.038 | 0.092 | 0.185 | 0.092 | **19.098** | 7.4 | 79.96 | **0.239** |

Table B21. Bounds for factors affecting catchability of *Loligo* in NEFSC fall and spring bottom trawl surveys, during 1975-2010, for the current assessment and the previous assessment. Survey biomass indices for the previous assessment were adjusted to daytime equivalents based on diel correction factors from a GLM. Indices for the current assessment were computed using "daytime" tows (solar zenith angle = 43-80° for fall surveys and 29-84° for spring surveys) to account for diel catchability effects.

| | **Previous assessment (SARC 34)** | | | **Current assessment (SARC 51)** | | |
|---|---|---|---|---|---|---|
| **Factor** | **Lower Bound** | **Upper Bound** | **Basis** | **Lower Bound** | **Upper Bound** | **Basis** |
| Tow distance ($d$) | 5% < nominal $d$ = 3.34 km | 10% > nominal $d$ = 3.87 km | Based on information from clam and scallop studies; Nominal $d$ = 3.52 km | Mean of SRV*Albatross IV* (*AL*) doppler tow distance for 30 min. at 3.2 kts = 2.96 km | Mean of *AL* GPS tow distance for 30 min. at 3.8 kts = 3.57 km | Lower bound is mode of AL doppler distance (LRD 78-08) Upper bound is mean of *AL* GPS distances between net touchdown and liftoff based on plots of speed over ground, tow duration, and wingspread and doorspread for 2007 fall and 2008 spring surveys |
| Effective survey trawl width ($w$) | Mean wing spread = 0.01164 km | Mean door spread = 0.02380 km | Based on *AL* wingspread and doorspread sensor measurements | Yankee 36 mean wingspread = 0.01069 km | Yankee 36 mean doorspread = 0.02192 km | *AL* mean wingspread and doorspread measurements for the Yankee 36 trawl during 2006-2008 fall and spring surveys |
| Survey bottom trawl efficiency ($e$) | 0.1 | 0.9 | $0< e \le 1$ based on arbitrary guestimates | 0.20 | 0.39 (CV=4%) | Lower bound based on videos of daytime *Loligo* behavior in front of sweep and in trawl; upper bound based on wingspread area swept ratio of *Bigelow* to *AL* (= 0.625) x 1/rho x *Bigelow* max $e$ rho = 1.51 and *Bigelow* max $e$ = 0.95 |
| Effective stock area ($A$) | 5% > *Loligo* strata set = 146,324 km$^2$ | 30% > *Loligo* strata set = 181,163 km$^2$ | Fall surveys (offshore strata 1-25, 61-76) | Expanded *Loligo* strata set 1975-2008 = 166,007 km$^2$ 2009-2010 *Bigelow* strata set = 155,896 km$^2$ | | 1975-2008 fall and spring surveys (inshore strata 2-46, 58-61, 65-66 and offshore strata 1-23,25-26, 61-76 ) 2009-2010 *Bigelow* strata set is same, but without strata ≤ 18 m |
| Weight units ($u$) | 100,000 | 100,000 | Survey data in kg/tow, biomass in 1000 MT | 100,000 | 100,000 | Survey data in kg/tow, biomass in 1000 MT |
| Survey daytime catchability ($q$) | $q_{min}$ = 0.02149 | $q_{max}$ = 0.5569 | $q_{min}=[d_{min}\, w_{min}\, e_{min}]/A_{max}$ $q_{max}=[d_{max}\, w_{max}\, e_{max}]/A_{min}$ | $q_{min}$ 1975-2009 = 0.038 $q_{min}$ 2009-2010 = 0.041 | $q_{max}$ 1975-2008 = 0.185 $q_{max}$ 2009-2010 = 0.197 | $q_{min}=[d_{min}\, w_{min}\, e_{min}]/A$ $q_{max}=[d_{max}\, w_{max}\, e_{max}]/A$ |

Table B22. Minimum biomass estimates of *Loligo* for inshore strata (≤ 18 m) no longer sampled during NEFSC surveys as of 2009, but sampled during the NEAMAP spring and fall surveys (2007-2010). NEFSC fall survey biomass estimates were based on day tows which occurred during 6:30 AM-4:30 PM (2007-2008). Area swept by the trawl during NEAMAP surveys is 0.025 $km^2$ and is 0.038 $km^2$ during NEFSC surveys based on mean wingspread and tow distance measurements for the *Albatross IV*. Inestimable CVs were a result of too few daytime *Albatross IV* tows in strata ≤ 18 m deep. Therefore, the 2007 and 2008 minimum biomass estimates for the NEFSC fall surveys are not reliable.

| | | NEAMAP | | | | NEFSC | | | |
|---|---|---|---|---|---|---|---|---|---|
| Season | Year | Area sampled ($km^2$) | N tows | Min. biomass (mt) | CV | Area sampled ($km^2$) | N tows | Min. biomass (mt) | CV |
| fall | 2007 | 14,666 | 150 | 2,951 | 3.9 | 2,909 | 12 | 7,071 | inestimable |
| fall | 2008 | 15,191 | 150 | 1,720 | 4.5 | 5,388 | 16 | 1,076 | inestimable |
| fall | 2009 | 15,191 | 160 | 3,482 | 3.5 | | | | |
| spring | 2008 | 14,666 | 150 | 1,420 | 5.4 | | | | |
| spring | 2009 | 15,191 | 160 | 966 | 5.6 | | | | |
| spring | 2010 | 15,191 | 160 | 389 | 9.3 | | | | |

[1] NEAMAP standardized tows are 20 min. tow at 3.0 kts with sampling between sunrise and sunset

[2] NEFSC standardized tows for *AL IV* are 30 min. at 3.8 kts with sampling round-the-clock, but include only daytime tows (6:30-4:30 PM)

Table B23. Minimum, maximum and quantiles (Q25, Q50 and Q75) for the composite *q*-priors for *Loligo* catches in NEFSC spring and fall surveys, 1975-2010. The median values were used in the assessment.

| Survey years | Minimum | Q25 | Q50 | Q75 | Maximum |
|---|---|---|---|---|---|
| 1975-2008 | 0.038 | 0.075 | 0.092 | 0.113 | 0.185 |
| 2009-2010 | 0.041 | 0.080 | 0.098 | 0.121 | 0.197 |

Table B24. Biomass estimates (000s mt) for the spring survey *Loligo* cohort (1976-2009) in relation to exploitation indices for the Jan-June fishery (1987-2009) and biomass estimates for the fall survey cohort in relation to exploitation indices for the July-Dec fishery. Spring and fall biomass estimates are for March-April and September-October, respectively.

| Year | Spring biomass (000s mt) | Jan-June catch (000s mt) | Exploitation Indices Jan-June fishery (Jan-June catch/Spring biomass) | Fall biomass (000s mt) | July-Dec catch (000s mt) | Exploitation Indices July-Dec fishery (July-Dec catch/Fall biomass) |
|---|---|---|---|---|---|---|
| 1976 | 81.734 | | | 204.483 | | |
| 1977 | 10.842 | | | 124.730 | | |
| 1978 | 23.709 | | | 82.372 | | |
| 1979 | 34.657 | | | 89.006 | | |
| 1980 | 34.948 | | | 154.830 | | |
| 1981 | 21.293 | | | 135.505 | | |
| 1982 | 31.449 | | | 135.185 | | |
| 1983 | 23.719 | | | 257.470 | | |
| 1984 | 48.822 | | | 226.068 | | |
| 1985 | 31.270 | | | 212.810 | | |
| 1986 | 27.578 | | | 160.412 | | |
| 1987 | 22.304 | 6.990 | 0.313 | 30.304 | 3.716 | 0.123 |
| 1988 | 43.315 | 11.352 | 0.262 | 101.390 | 7.841 | 0.077 |
| 1989 | 52.510 | 16.629 | 0.317 | 233.315 | 7.106 | 0.030 |
| 1990 | 29.904 | 8.529 | 0.285 | 112.536 | 7.406 | 0.066 |
| 1991 | 46.615 | 9.044 | 0.194 | 125.268 | 10.881 | 0.087 |
| 1992 | 39.402 | 10.692 | 0.271 | 113.255 | 8.260 | 0.073 |
| 1993 | 17.875 | 17.582 | 0.984 | 52.983 | 8.379 | 0.158 |
| 1994 | 8.116 | 7.224 | 0.890 | 298.443 | 16.411 | 0.055 |
| 1995 | 23.652 | 9.780 | 0.414 | 62.885 | 9.774 | 0.155 |
| 1996 | 10.133 | 10.196 | 1.006 | 41.480 | 2.508 | 0.060 |
| 1997 | 29.379 | 6.247 | 0.213 | 112.203 | 10.064 | 0.090 |
| 1998 | 10.229 | 12.897 | 1.261 | 57.658 | 6.411 | 0.111 |
| 1999 | 44.192 | 8.927 | 0.202 | 167.873 | 12.296 | 0.073 |
| 2000 | 21.639 | 10.010 | 0.463 | 330.148 | 7.600 | 0.023 |
| 2001 | 26.917 | 6.468 | 0.240 | 92.460 | 7.821 | 0.085 |
| 2002 | 54.622 | 8.619 | 0.158 | 253.946 | 8.458 | 0.033 |
| 2003 | 9.393 | 5.926 | 0.631 | 151.733 | 6.175 | 0.041 |
| 2004 | 8.976 | 9.300 | 1.036 | 93.264 | 5.779 | 0.062 |
| 2005 | 19.843 | 12.272 | 0.618 | 107.945 | 5.405 | 0.050 |
| 2006 | 34.397 | 9.820 | 0.285 | 249.422 | 7.225 | 0.029 |
| 2007 | 40.325 | 7.731 | 0.192 | 109.552 | 4.741 | 0.043 |
| 2008 | 15.486 | 5.814 | 0.375 | 122.699 | 5.691 | 0.046 |
| 2009 | 10.795 | 4.648 | 0.431 | 68.788 | 4.912 | 0.071 |
| Median | | | | | | |
| 1976-2008 | 27.578 | | | 124.730 | | |
| 1987-2008 | | 9.172 | 0.315 | | 7.503 | 0.064 |

Table B25. Annualized biomass estimates (000s mt), during 1976-2009, and annualized exploitation indices, during 1987-2009, for *Loligo pleaeii*. Annualized biomass estimates are the means of the annual estimates from the NEFSC spring and fall surveys. The two-year moving averages were only used for the 2009 stock status determination.

| Year | Annual biomass (000s mt) | Two-year moving average of biomass (000s mt) | Annual catch (000s mt) | Annual exploitation index: Catch/biomass (000s mt) | Annual exploitation index: Catch/2yr moving avg. of biomass (000s mt) |
|---|---|---|---|---|---|
| 1976 | 143.108 | | | | |
| 1977 | 67.786 | 105.447 | | | |
| 1978 | 53.041 | 60.413 | | | |
| 1979 | 61.832 | 57.436 | | | |
| 1980 | 94.889 | 78.360 | | | |
| 1981 | 78.399 | 86.644 | | | |
| 1982 | 83.317 | 80.858 | | | |
| 1983 | 140.594 | 111.956 | | | |
| 1984 | 137.445 | 139.020 | | | |
| 1985 | 122.040 | 129.743 | | | |
| 1986 | 93.995 | 108.018 | | | |
| 1987 | 26.304 | 60.150 | 10.722 | 0.408 | 0.178 |
| 1988 | 72.353 | 49.328 | 19.228 | 0.266 | 0.390 |
| 1989 | 142.912 | 107.633 | 24.544 | 0.172 | 0.228 |
| 1990 | 71.220 | 107.066 | 16.557 | 0.232 | 0.155 |
| 1991 | 85.942 | 78.581 | 20.843 | 0.243 | 0.265 |
| 1992 | 76.329 | 81.135 | 19.798 | 0.259 | 0.244 |
| 1993 | 35.429 | 55.879 | 23.387 | 0.660 | 0.419 |
| 1994 | 153.280 | 94.354 | 24.566 | 0.160 | 0.260 |
| 1995 | 43.269 | 98.274 | 20.087 | 0.464 | 0.204 |
| 1996 | 25.806 | 34.538 | 12.796 | 0.496 | 0.370 |
| 1997 | 70.791 | 48.299 | 16.474 | 0.233 | 0.341 |
| 1998 | 33.944 | 52.367 | 19.377 | 0.571 | 0.370 |
| 1999 | 106.032 | 69.988 | 21.313 | 0.201 | 0.305 |
| 2000 | 175.894 | 140.963 | 17.674 | 0.100 | 0.125 |
| 2001 | 59.688 | 117.791 | 14.399 | 0.241 | 0.122 |
| 2002 | 154.284 | 106.986 | 17.241 | 0.112 | 0.161 |
| 2003 | 80.563 | 117.423 | 12.107 | 0.150 | 0.103 |
| 2004 | 51.120 | 65.841 | 16.022 | 0.313 | 0.243 |
| 2005 | 63.894 | 57.507 | 17.416 | 0.273 | 0.303 |
| 2006 | 141.909 | 102.902 | 17.058 | 0.120 | 0.166 |
| 2007 | 74.939 | 108.424 | 12.472 | 0.166 | 0.115 |
| 2008 | 69.092 | 72.015 | 11.524 | 0.167 | 0.160 |
| 2009 | 39.792 | 54.442 | 9.560 | 0.240 | 0.176 |
| Median | | | | | |
| 1976-2008 | 76.329 | 83.890 | | | |
| 1987-2008 | | | 17.328 | 0.237 | 0.236 |

Table B26. Historical retrospective analysis covering the current and previous four assessments. Start year and end year are for the survey data used in making status determinations. The primary approach or model for status determination is identified for each assessment but a variety of auxiliary data or calculations were usually considered as well.

| SARC/ SAW | Citation | Start year | End year | Primary approach for status determination | Type of F threshold | Fishing mortality status | Over-fishing? | Type biomass reference points | Biomass status | Over-fished? |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 | NEFSC (1994) | 1967 | 1994 | Relative fall suurvey trends for prerecruits | Three-year average of prerecruits from the NEFSC fall survey falls below the first quartile of the time series | 3-year moving average for 1992 (mean for 1991-1993)/first quartile of same = 412 / 123=3.3 | No | Overfishing and overfished stock conditions not distinguished. Only overfishing status was evaluated. | | |
| 21 | NEFSC (1996) | 1987 | 1999 for biomass, 1998 for F | Shaeffer surplus production model (semester time steps but *K* and *r* are constant) using spring and fall survey data | F / Fmsy (threshold value is 1) | F / Fmsy=1.7 (average of estimates for 4 qtrs in 1998) | Yes | January biomass / Bmsy in January 1999 (threshold is 0.5) | 0.57 | No |
| 29 | NEFSC (1999) | 1987 | 1999 for biomass, 1998 for F | Shaeffer surplus production model (quarterly time steps but *K* and *r* are constant) using spring and fall survey data, and two season CPUE indices | F / Fmsy (threshold value is 1) | F/Fmsy=1.7 on January 1, 1999 | Yes | B/Bmsy during spring 2009 (threshold value is 0.5) | 0.57 | No |
| 34 | NEFSC (2002) | 1967 | 2001 | Fall survey and exploitation index trends. Survey data were scaled by a catchability parameter estimated from the PDQ model, but status determination would be the same without scaling. | F proxy/ Fmsy (threshold value is 1) | F proxy / Fmsy proxy=0.2 / 0.31 (F proxy is the mean of quarterly estimates in 2000 | No | No satisfactory reference point available | NA | NA |
| 51 | In prep. | 1976 | 2009 | Average spring & fall survey biomass and exploitation index. Survey data were scaled by the median catchability of a prior, but status determination would be the same without scaling. | No satisfactory reference point available | Not model based, uses a wide range of data and judgement | Probably not | Mean biomass during 2008-2009 / Bmsy | 1.28 | No |

Table B27. Summary of weekly natural mortality rate estimates for *Loligo* spp. (published and new estimates for *Loligo pealeii* from this assessment). The estimate M=0.069 for lifetime natural mortality (juvenile through spawner) used for the SARC 21 assessment (NEFSC 1996) and Cadrin and Hatfield (1999) is the average of the three estimates from Brodziak (1998) which are shown in the table below. Non-spawning estimates (Mns) are for juvenile through pre-spawning stages. Spawning estimates (Msp) are for actively spawning squid. Estimates in the first row (labeled NEFSC 2002) are from the last assessment.

| Source | Lifestages/cohort assumptions | Winter-hatched cohort (per week) | | Summer-hatched cohort (per week) | | Details |
|---|---|---|---|---|---|---|
| | | Non-spawning ($M_{ns}$) | Spawning ($M_{sp}$) | Non-spawning ($M_{ns}$) | Spawning ($M_{sp}$) | |
| NEFSC (2002) Previous assessment | Juvenile through spawner, by cohort | 0.076 | | 0.058 | | Observed maximum size; 3/M rule; assumed to double at maturity |
| Brodziak (1998) | Juvenile through spawner, both cohorts | 0.078 | | | | Hoenig's (1983) method assuming maximum age 296 days |
| | | 0.060 | | | | Rosenberg's (1990) estimate for *Illex argentinus* |
| | | 0.069 | | | | Peterson and Wroblewski (1984) , bioenergetics |
| Macewicz (2004) for California market squid (*Loligo opalescens*) | Spawners, cohort not specified | | 3.15 * | | | Reproductive biology assuming maximum life of spawners = 8 days; implies an average spawning lifespan of 1.67 days |
| Gnomonic method for Mns ; Maturation-natural mortality model for Msp (this assessment) | Separate estimates for non-spawning and spawning stages, winter-hatched cohort only | 0.110 | 0.19-0.48 * | | | The gnomonic estimate $M_{ns}$ = 0.11 is for lifestages up to maturity; estimates for $M_{sp}$ from maturity-mortaltity model assume gnomonic estimate of $M_{ns}$=0.11 |
| Min ** | Non-spawning | 0.058 | | | | Excludes $M_{sp}$ estimates |
| Average ** | | 0.075 | | | | |
| Max ** | | 0.110 | | | | |

* Includes some fishing mortality

** Non-spawning natural mortality estimated from all sources listed in the above table

Table B28. Current and proposed biological reference points for the *Loligo pealeii* stock and the 2009 exploitation index and biomass estimate used to determine stock status.

| Biomass Reference Points | | | | Fishing Mortality Reference Points | | |
|---|---|---|---|---|---|---|
| | Current | Proposed | **Mean 2008-2009 Biomass (mt)[3]** | Current | Proposed | **2009 Exploitation Index[4]** |
| Target | Bmsy[1] | Bmsy proxy = 42,405 mt (50% of carrying capacity)[2] | | Mean quarterly exploitation rate during 1987-2000 = 0.96/yr | None | |
| Threshold | 50% of Bmsy | 50% of Bmsy proxy = 21,203 mt | 54,442 mt 80% CI (38,452-71,783) | FMSY proxy = 75th percentile of exploitation rates during 1987-2000 = 1.24/yr | None | 0.176 |

[1] Amendment 9 to the SMB FMP states that the previous biomass reference points were rejected at SARC34 and new ones were not proposed
[2] Based on averages of the annual NEFSC spring and fall swept-area biomass estimates, at the median *q*-prior level, and assumes that the stock is lightly exploited and that the median biomass during 1976-2008 (76,329 mt) represents 90% of carrying capacity (*K*), so *K* = 84,810 mt
[3] Based on annual mean of the NEFSC 2008-2009 spring and fall survey swept area biomass estimates

[4] Computed as the 2009 catch / mean of 2008-2009 spring and fall survey swept area biomass estimates

## B. *Loligo*-Figures

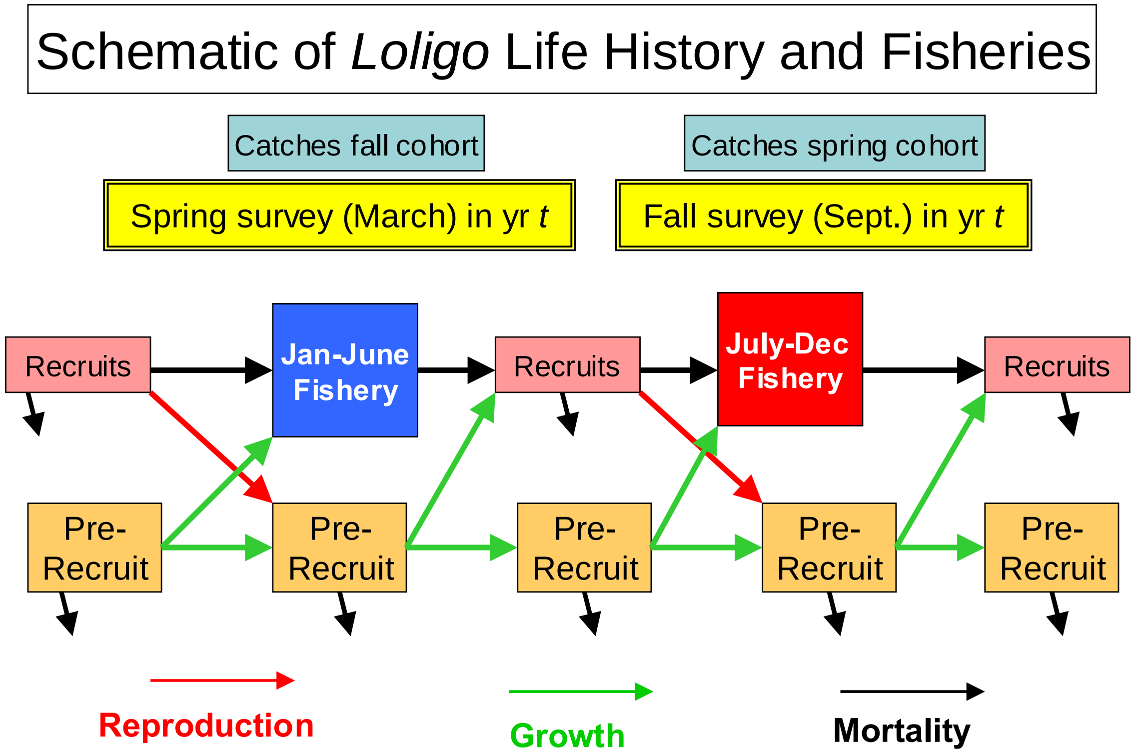



Figure B1. Schematic of *Loligo pealeii* life history in relation to NEFSC spring and fall surveys and the January-June and July-December *Loligo* fisheries. Fishery pre-recruits are ≤ 8 cm DML and recruits are > 8 cm DML.

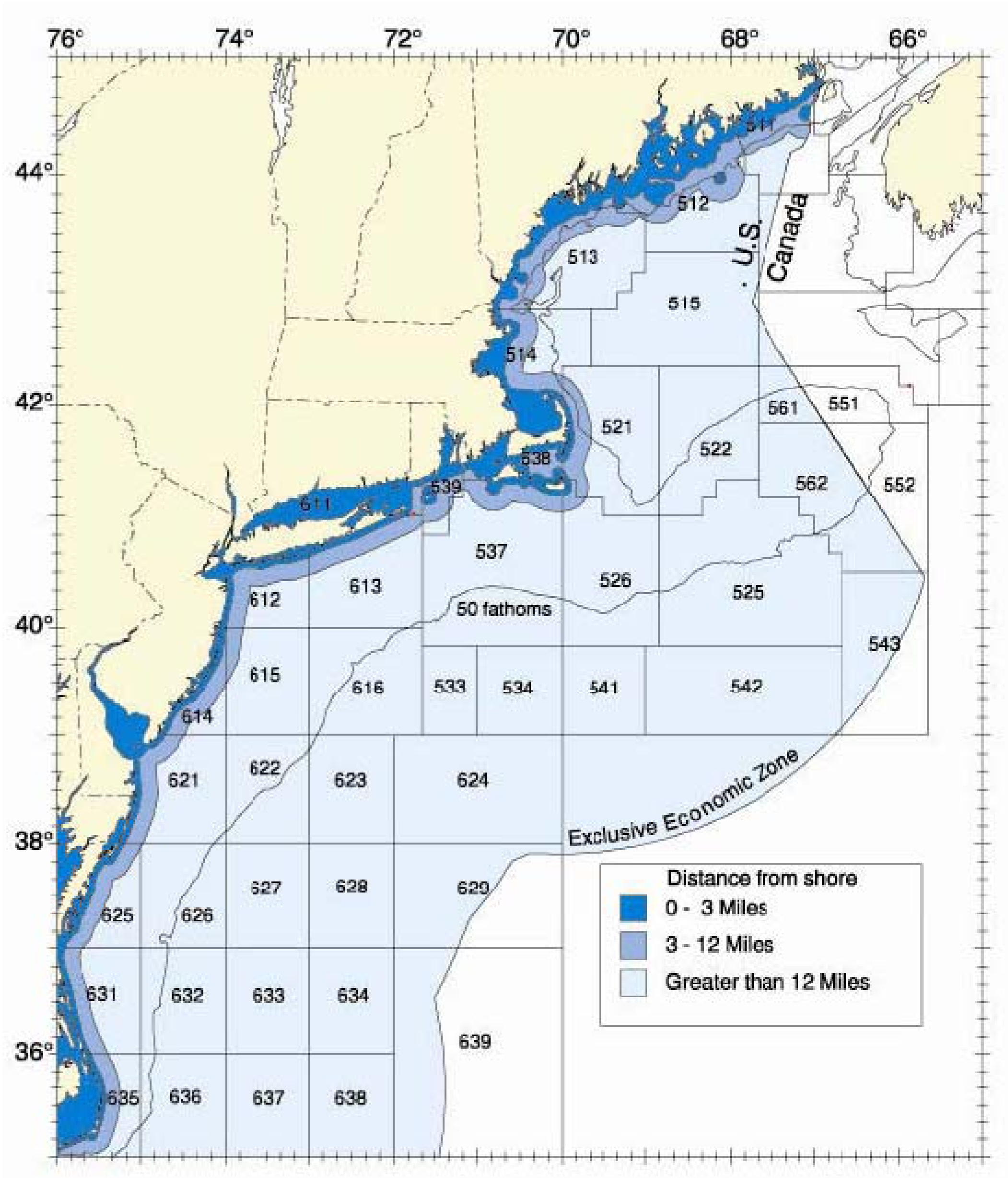



Figure B2. Statistical Areas used for reporting fishery data in the Northeast region of the U.S. and Federal (Exclusive Economic Zone) and state (0-3 miles) jurisdictional limits.

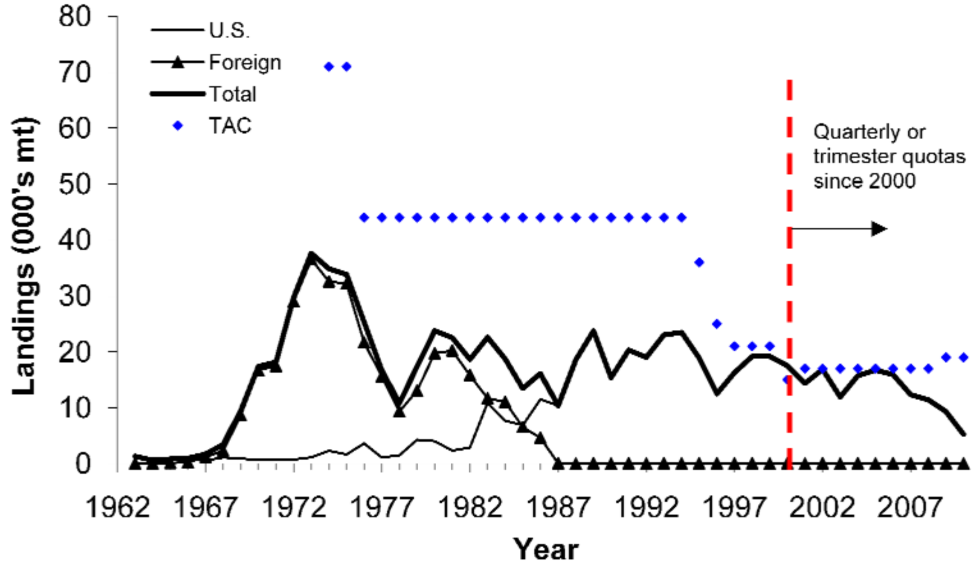
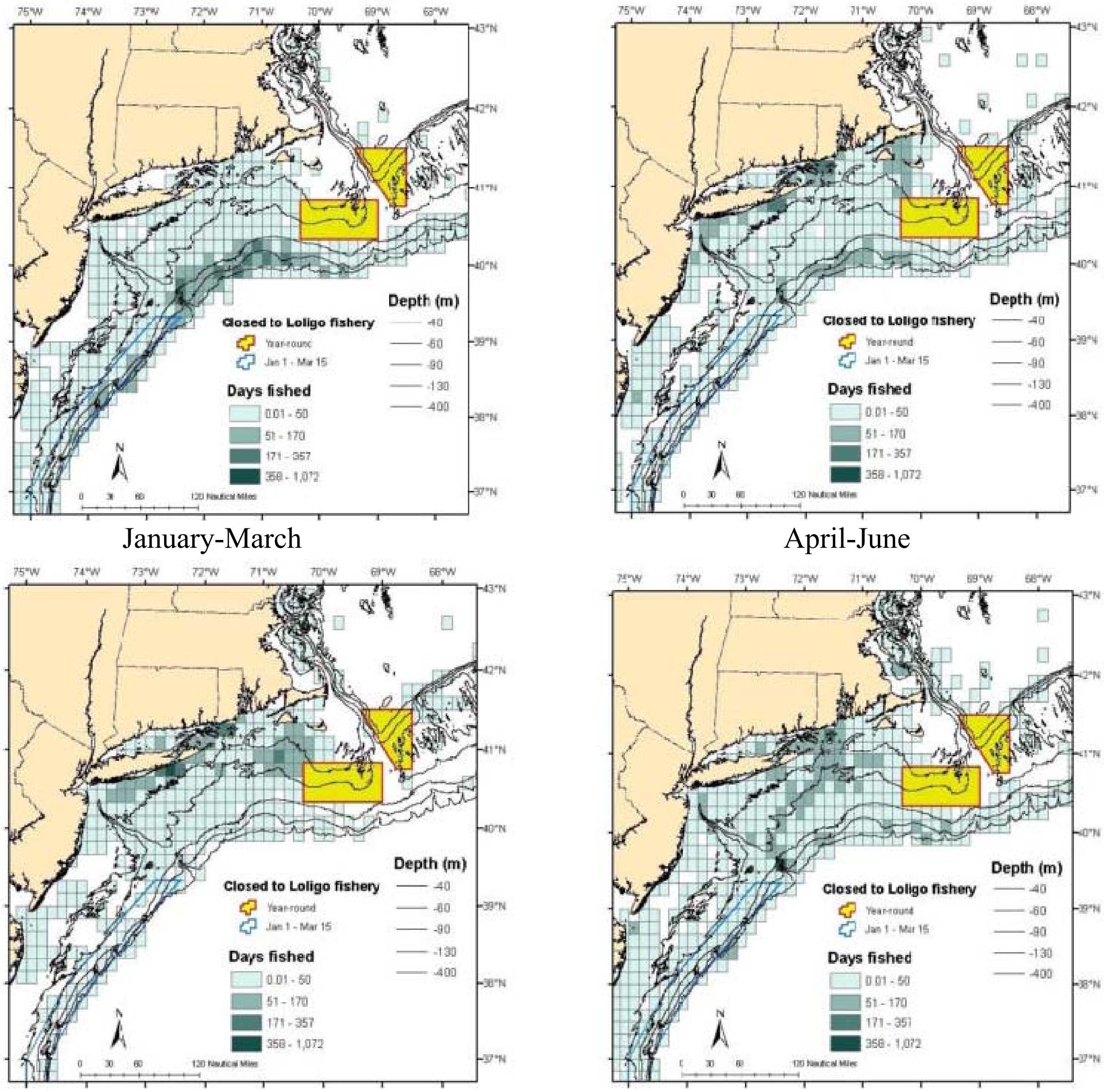



Figure B3. U.S. foreign, and total *Loligo pealeii* landings during 1963-2010 and TACs during1974-2010. The 2010 landings are preliminary and incomplete.




January-March April-June

July-September October-December

Figure B4. Spatial distribution of *Loligo* fishing effort (days fished) during the winter (Jan.-March and Oct.-Dec.) offshore fishery and the summer (April-Sept.) inshore fishery during 1997-2004.

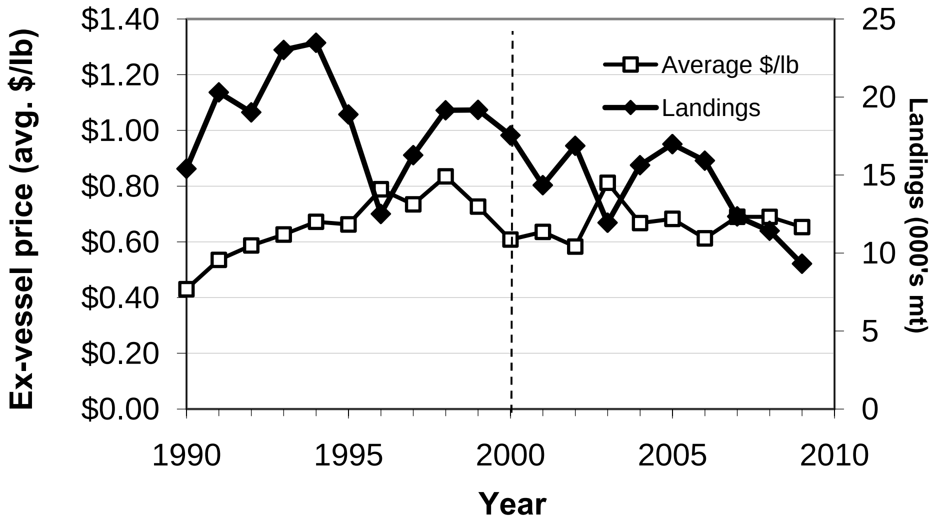



Figure B5. Annual ex-vessel price (avg. $ per lb in 1990 dollars) of *L. pealeii*, in relation to landings, during 1990-2009.

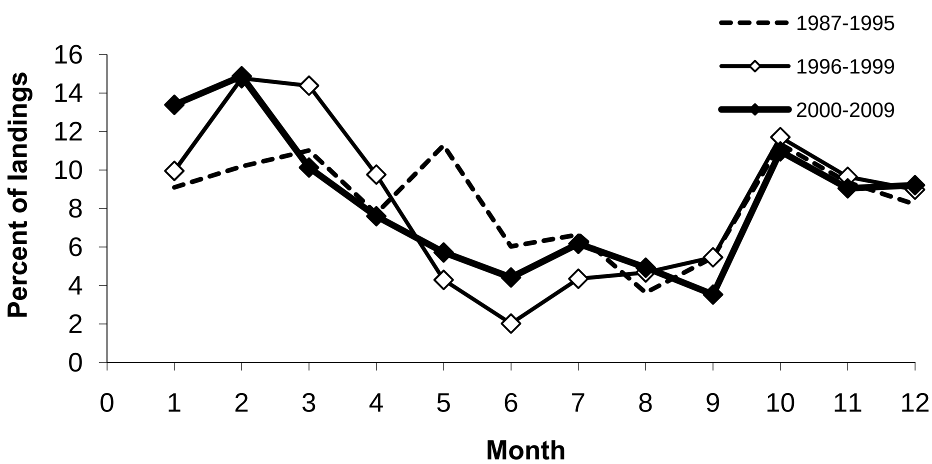



Figure B6. Trends in *Loligo* landings, percent by month, during 1987-1995, 1996-1999, and 2000-2009.

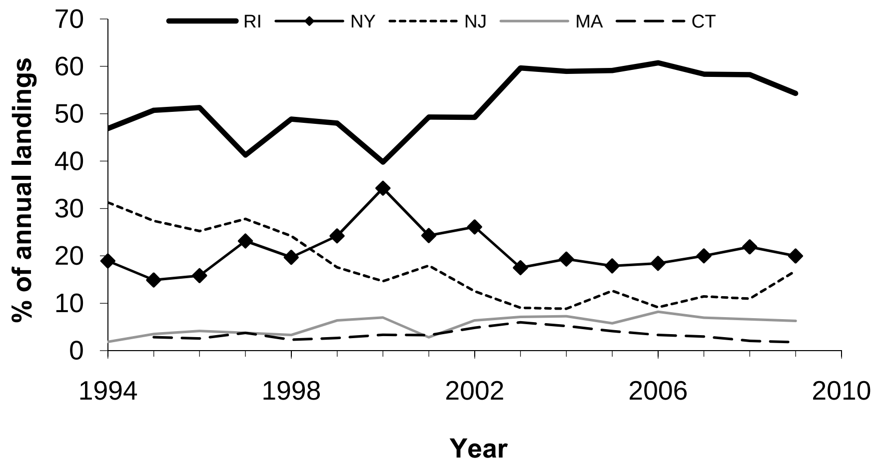



Figure B7. *Loligo* landings by state during 1994-2009.

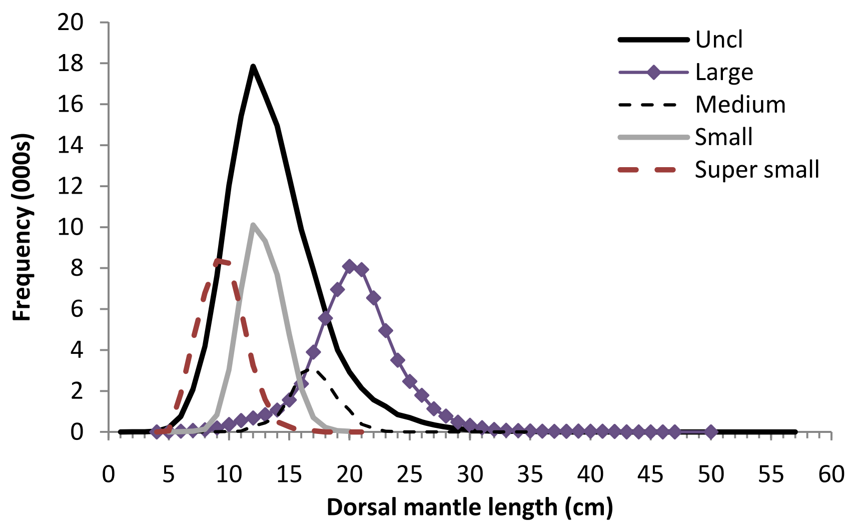



Figure B8. Length composition of the landings samples, during 1996-2009, by market category.

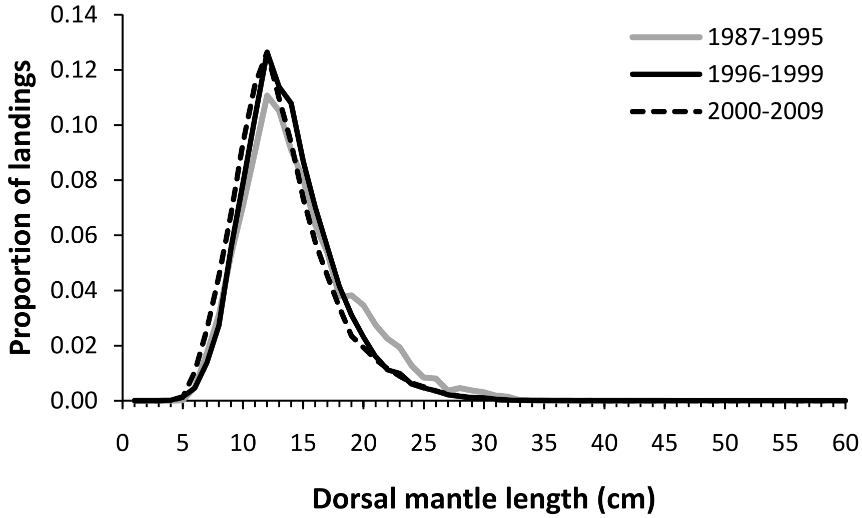



Figure B9. Length compositions of the *Loligo* landings during 1987-1995, 1996-1999, and 2000-2009.

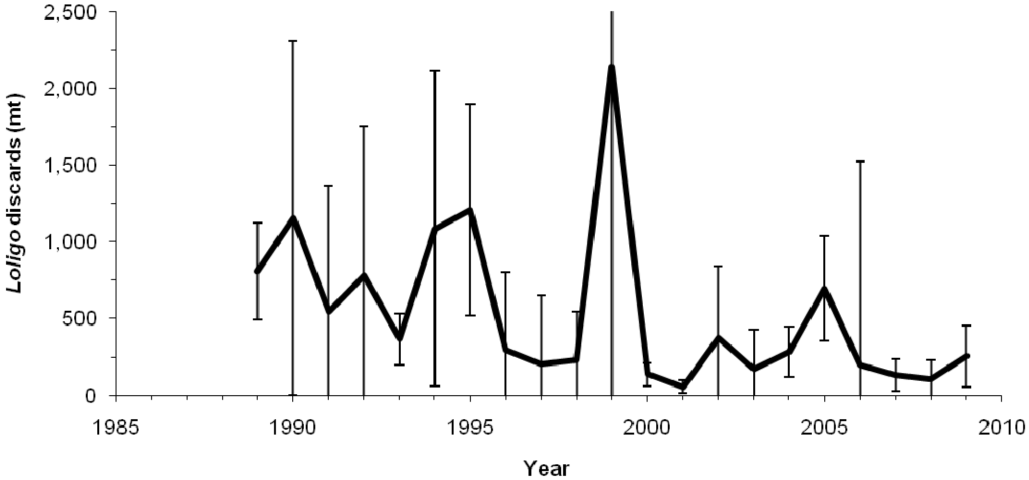



Figure B10. Discards of *Loligo pealeii* during 1989-2009 and 95% confidence intervals.

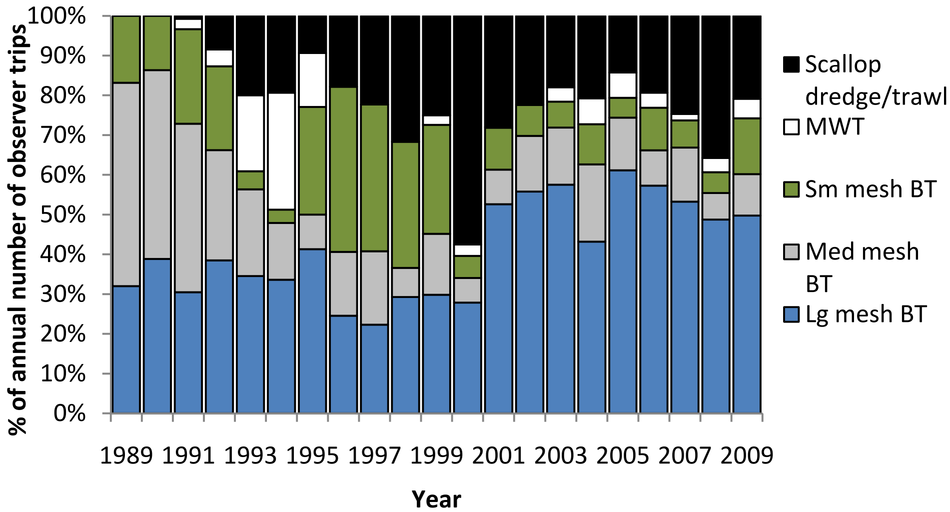



Figure B11. Percentage of annual numbers of fishery observer trips, by fleet, that were used to compute *Loligo* discards.

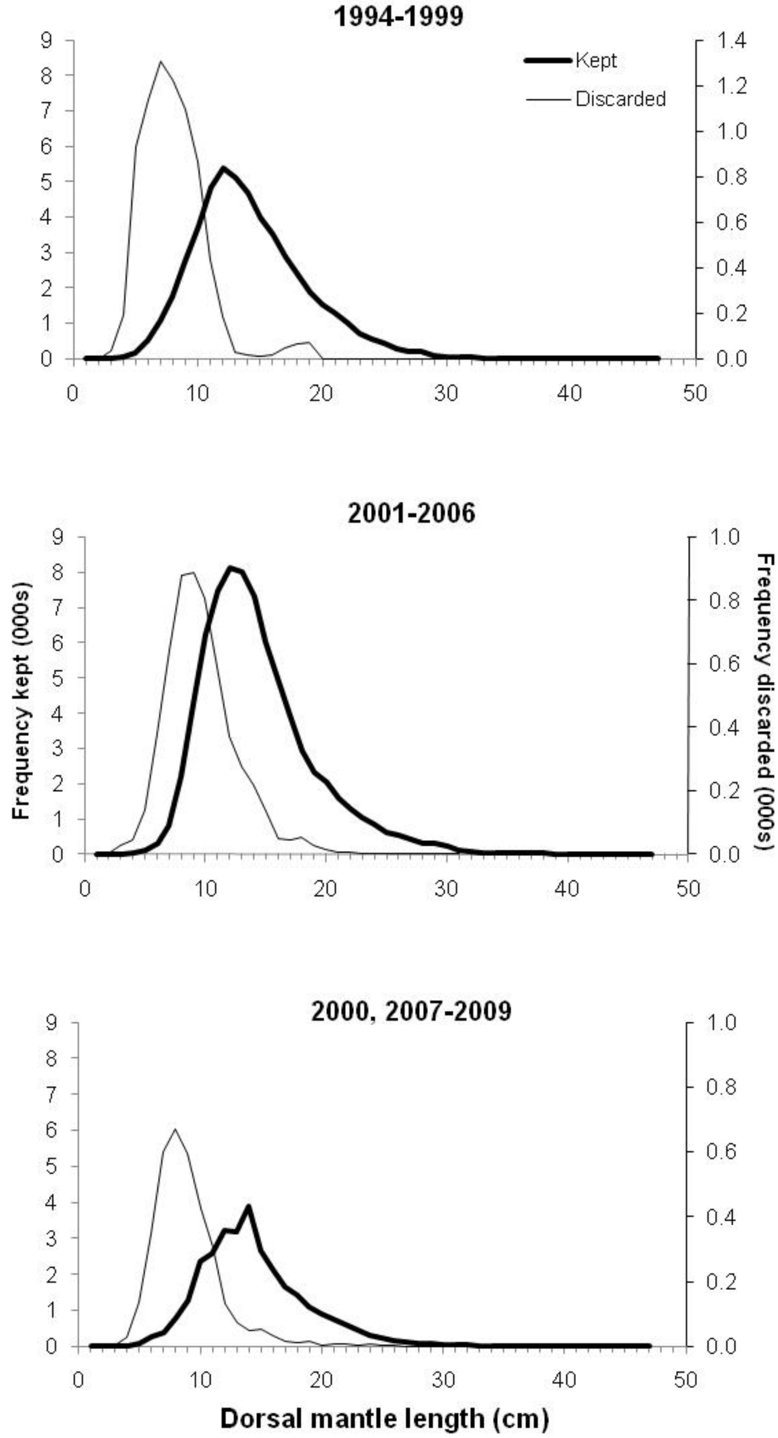



Figure B12. Length compositions of the kept and discarded portions of catches on trips where *Loligo* were discarded during 1994-1999, 2001-2006 and 2000 and 2007-2009. Since 2000, trip limits have been in effect during portions of each year.

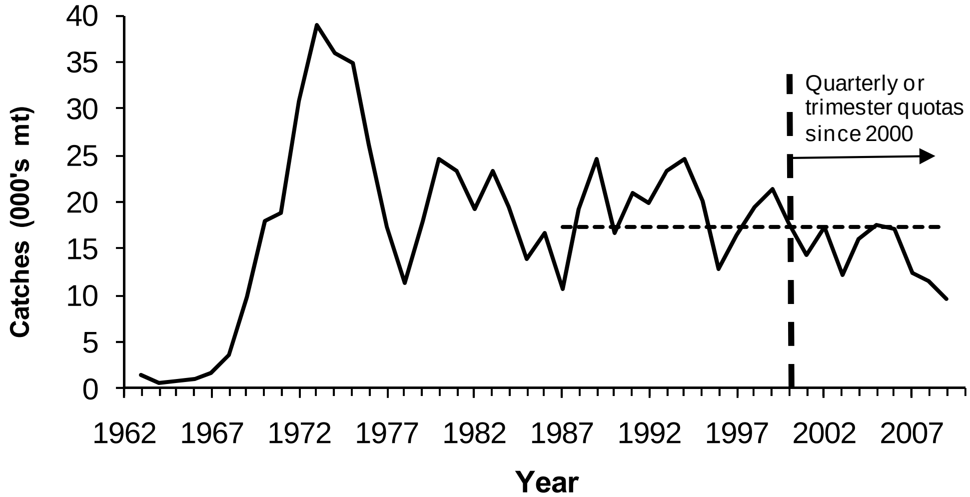



Figure B13. Catches (000s mt) of *Loligo pealeii* during 1963-2009 and the 1987-2008 median.

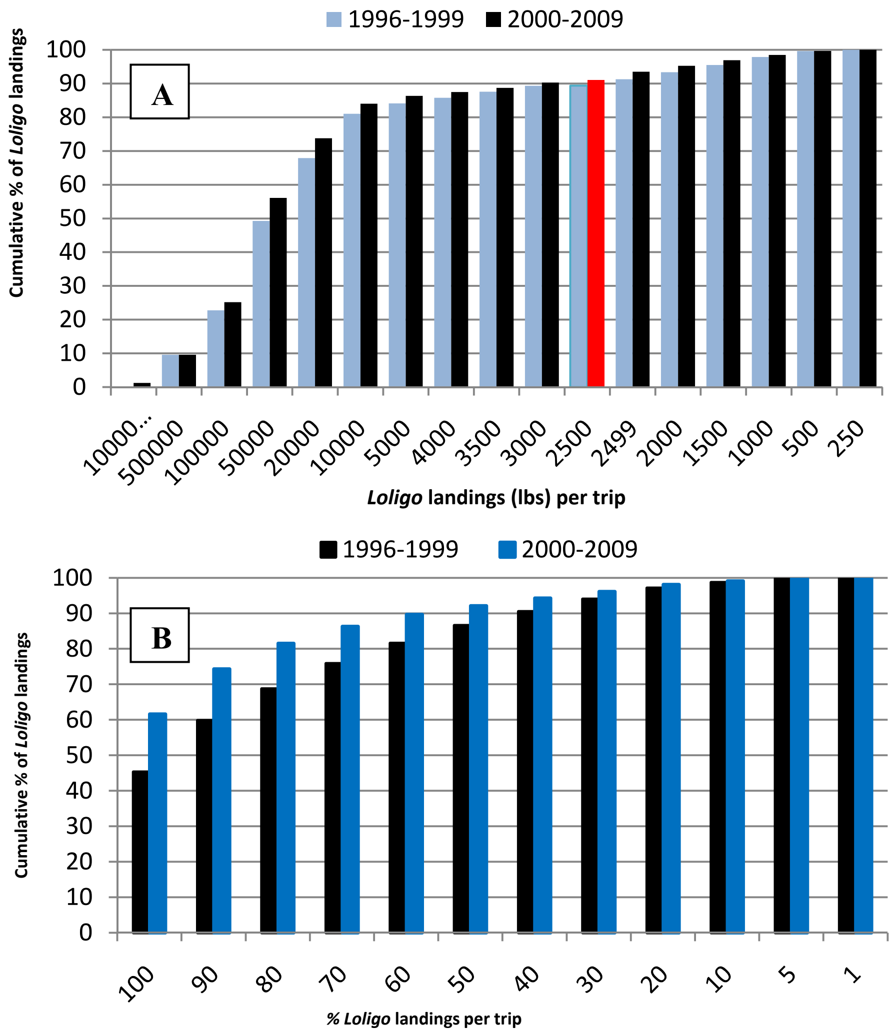



Figure B14. *Loligo* landings (lbs) per trip (A) and *Loligo* landings as a percentage of the total trip weight (B) as cumulative percentages of the *Loligo* landings during a period of annual quotas (1996-1999) versus a period of in-season quotas (2000-2009).

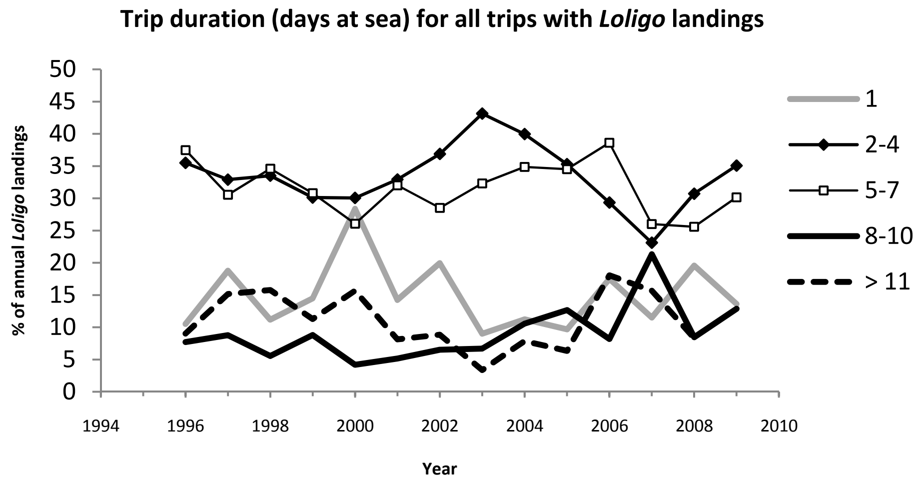



Figure B15. Percent of annual *Loligo* landings, during 1996-2009, by trip duration (days at sea).

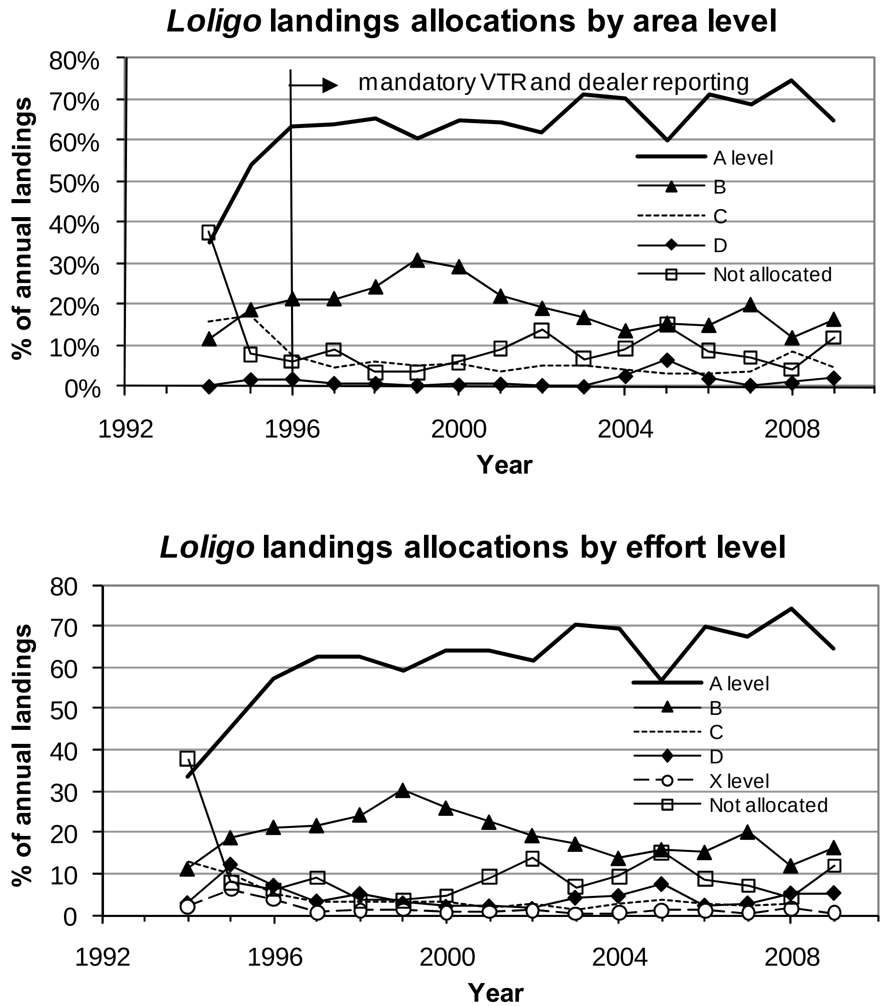



Figure B16. Percentage of annual *Loligo* landings allocated by fishing area level (A) and effort allocation level (B) during 1994-2009. The "A level" trips, which represent a one-to-one match between a trip in the Dealer Database and the Vessel Trip Report Database, were used to computed nominal LPUE for the directed fishery.

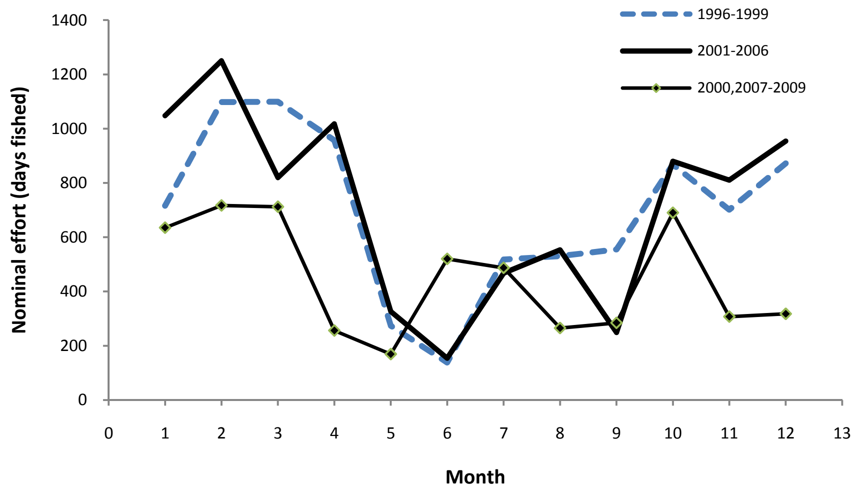



Figure B17. Monthly nominal effort (days fished) in the *Loligo* fishery during 1996-2009.

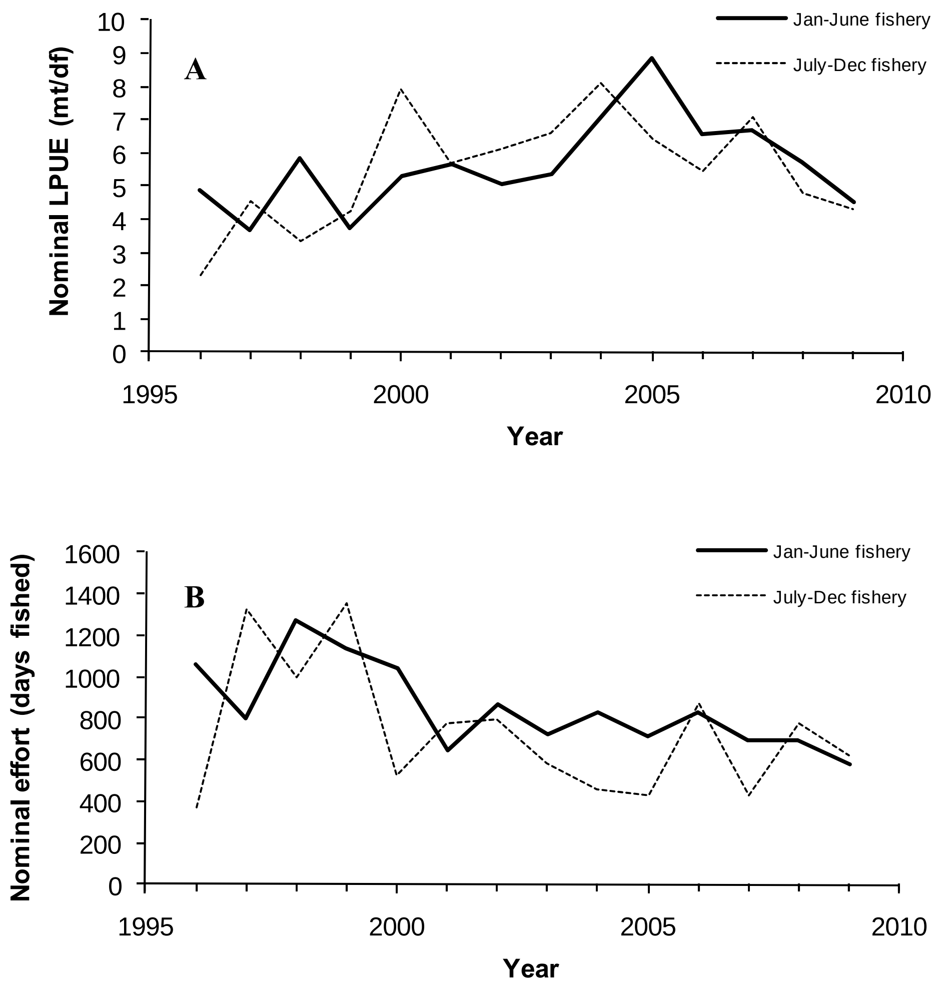



Figure B18. Nominal landings per unit of effort (mt/day fished) (A) and nominal effort (B) in the January-June fishery versus the July-December fishery.

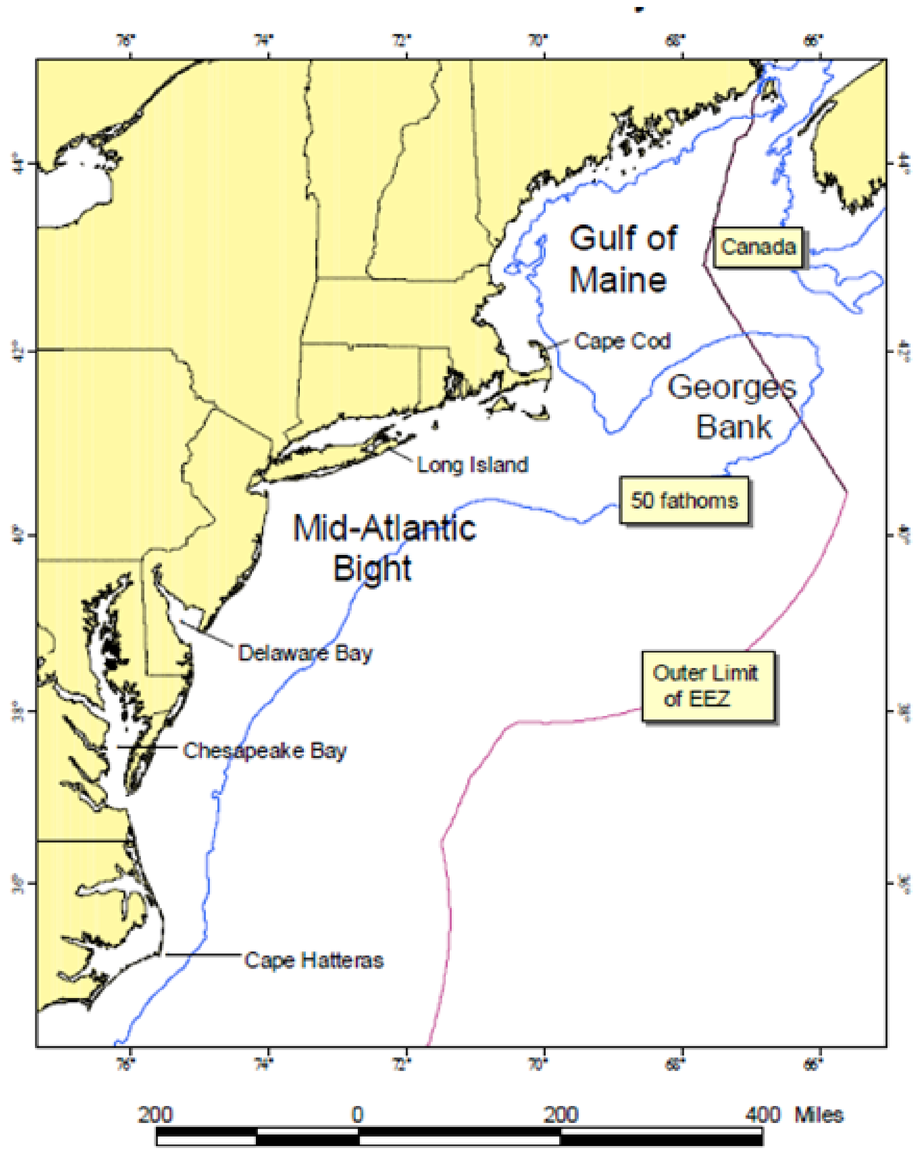



Figure B19. Map of the region covered by the Northeast Fisheries Science Center bottom trawl surveys; the Gulf of Maine to Cape Hatteras, North Carolina.

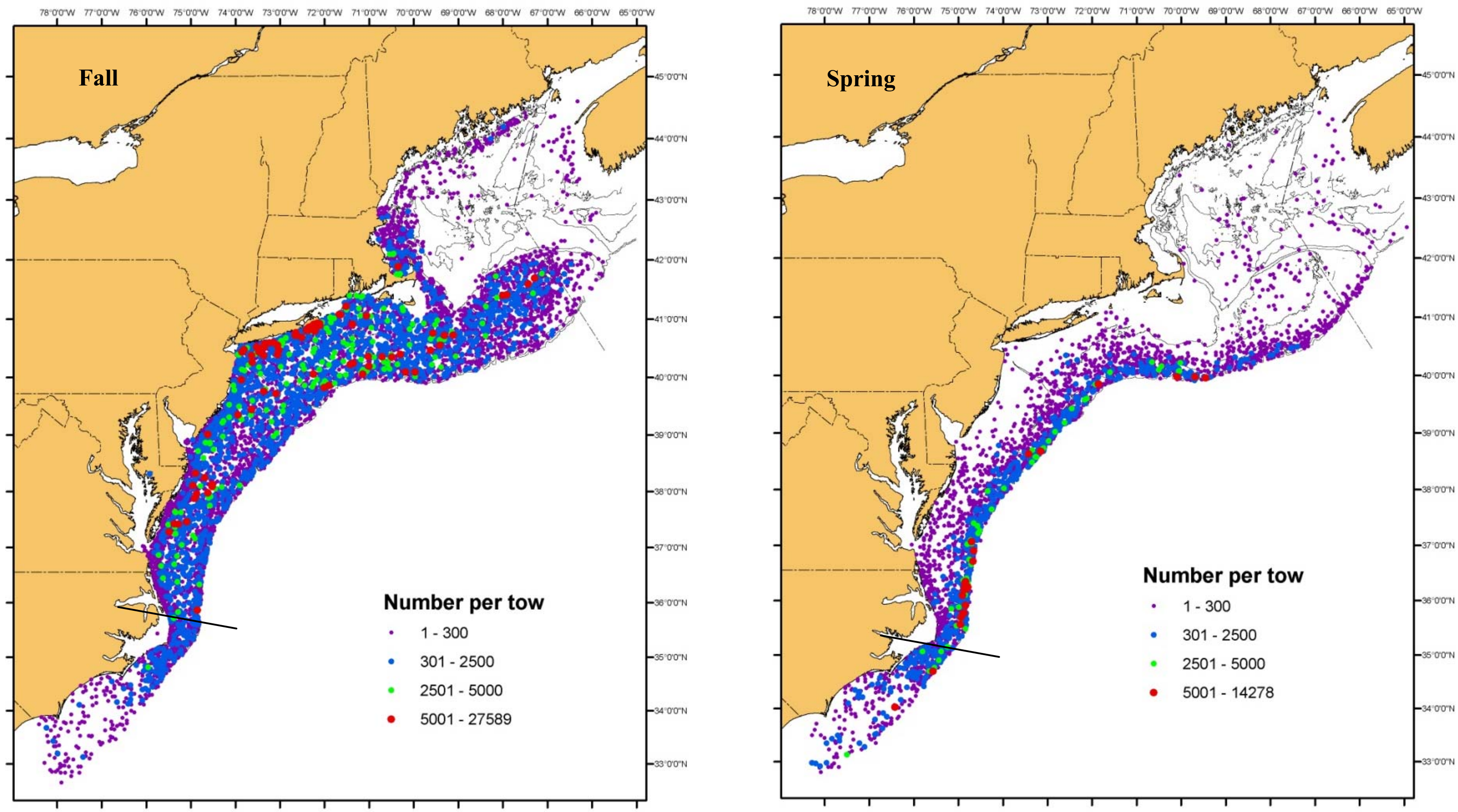



Figure B20. Distribution of *Loligo pealeii* during NEFSC fall (1975-2008) and spring (1976-2008) bottom trawl surveys. Survey strata located south of the solid black line (Cape Hatteras, NC) were not regularly sampled and these squid represent an unknown mix of *Loligo pealeii* and *Loligo pleii.* The 60, 100,200 and 400 m isobaths are also shown.

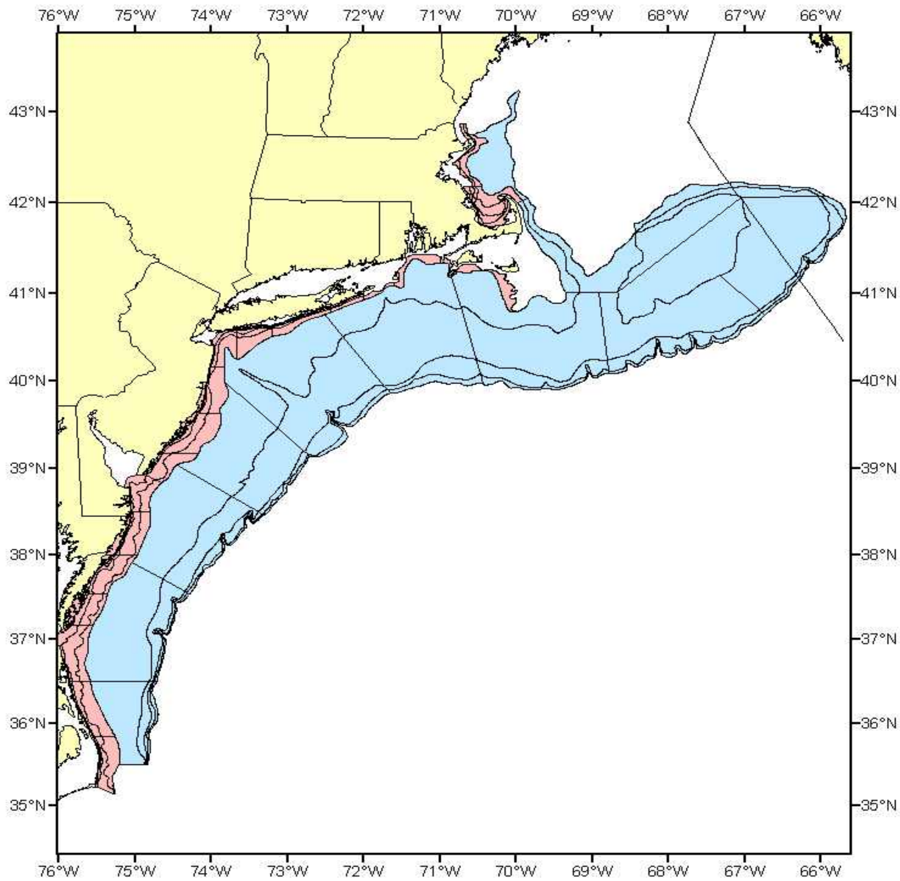



Figure B21. NEFSC survey depth strata used to derive relative abundance and biomass estimates. Inshore strata, including depths 8-27 m, are shaded pink and offshore strata, including depths 27-366 m, are shaded blue.

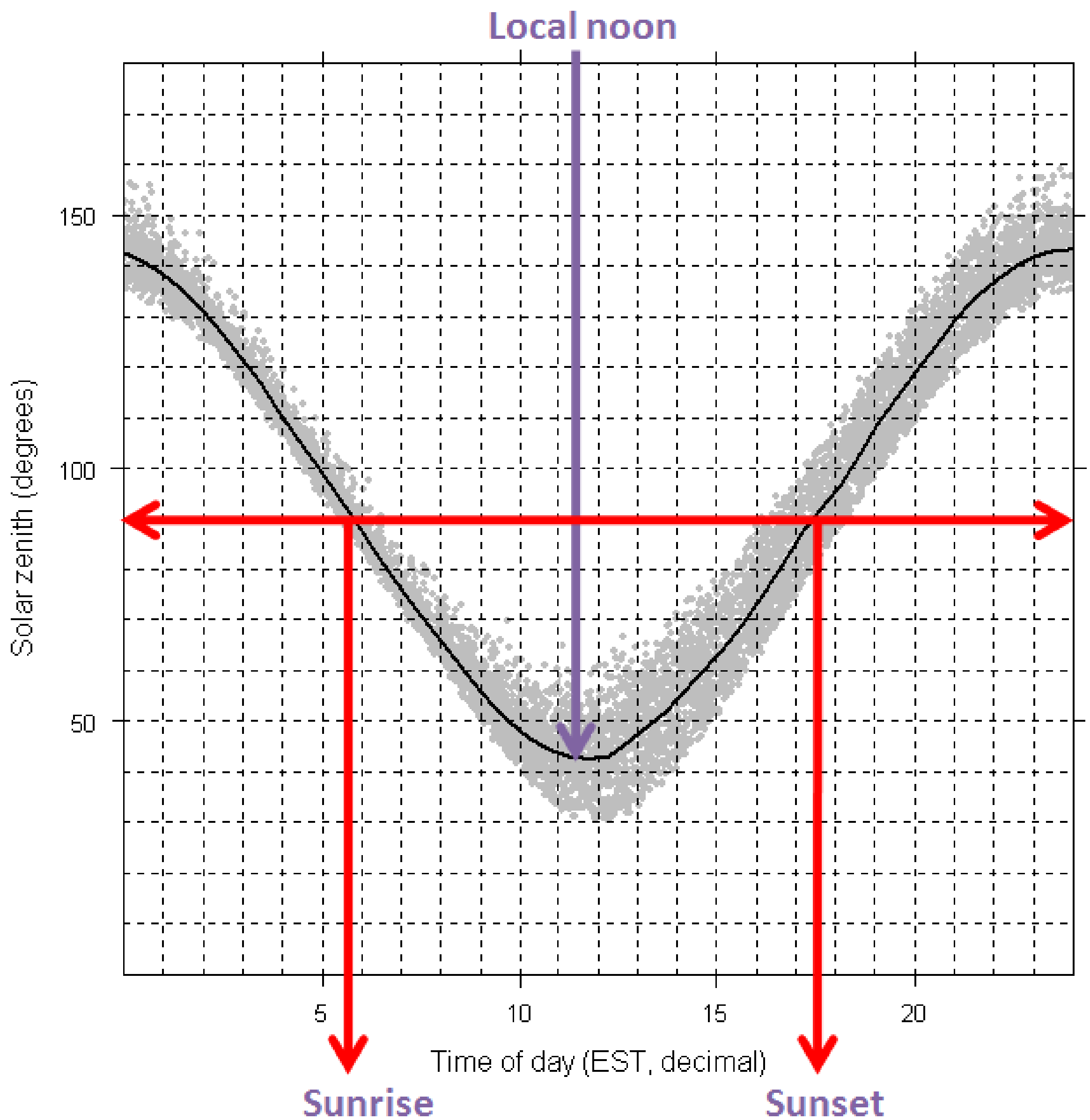
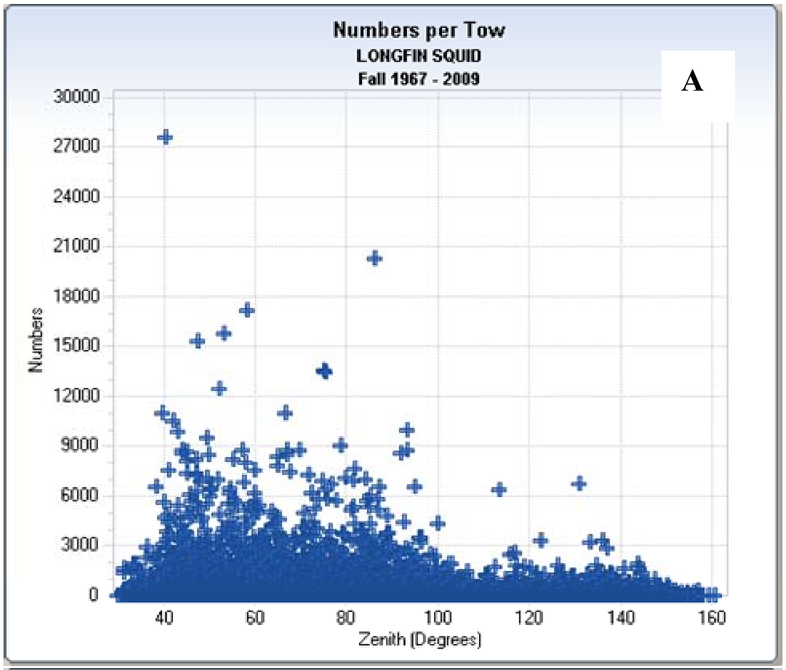



Figure B22. The relationship between solar zenith and time of day in NEFSC fall surveys, 1975-2008. The sun rises and sets at a solar zenith of 90.83° when the disk of the sun first appears or disappears along the horizon. At local noon, the sun is at its apogee and the solar zenith is at its minimum value.



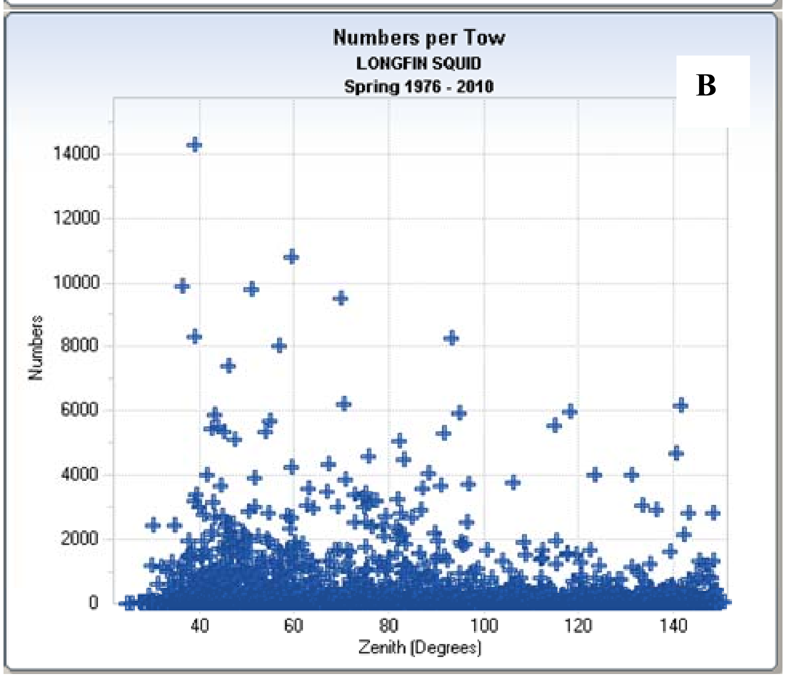




Figure B23. *Loligo* catch rates, number per tow, in relation to solar zenith angle (degrees) during NEFC bottom trawl surveys conducted during fall, 1975-2009 (A), and spring, 1976-2010 (B).

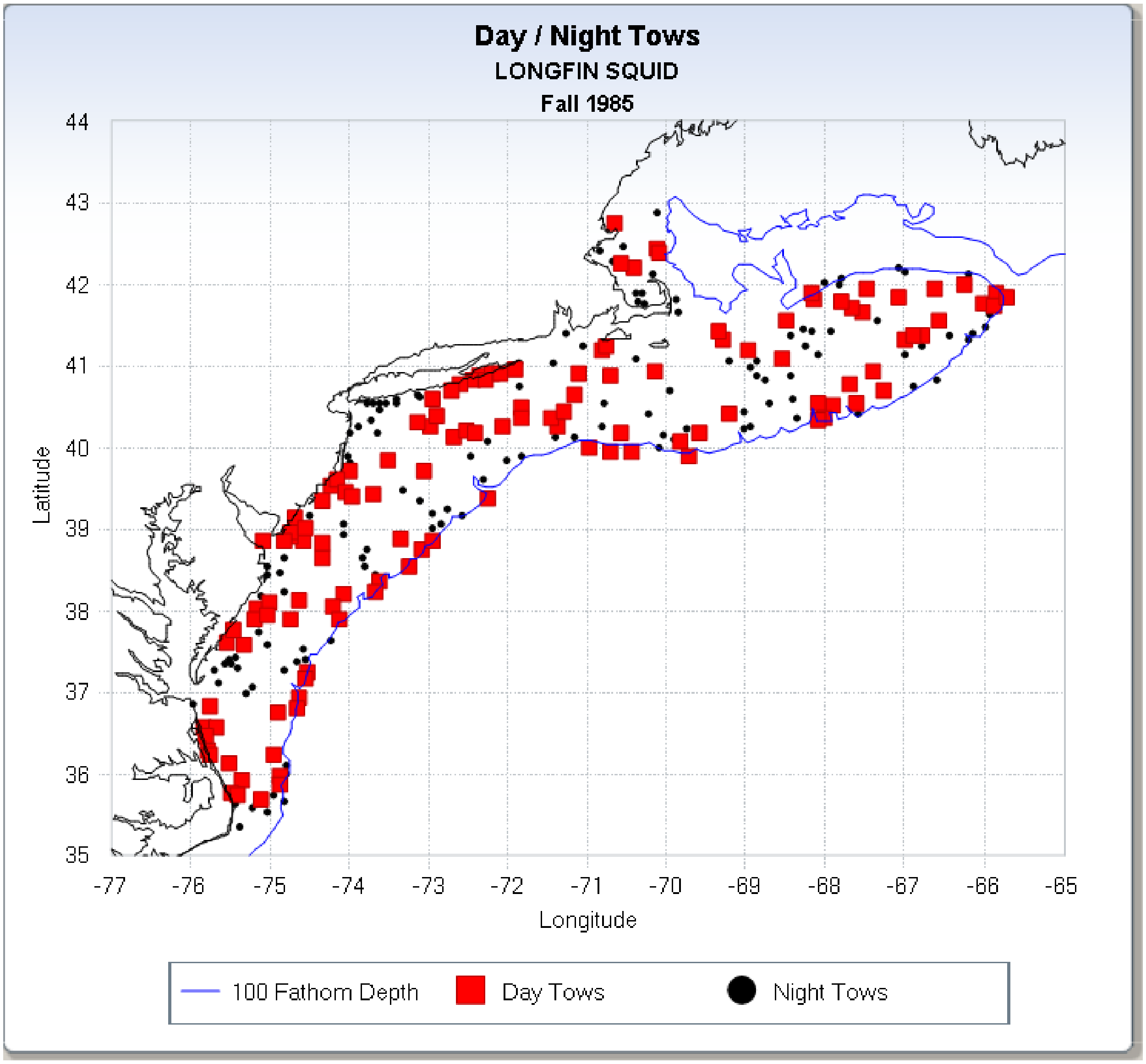
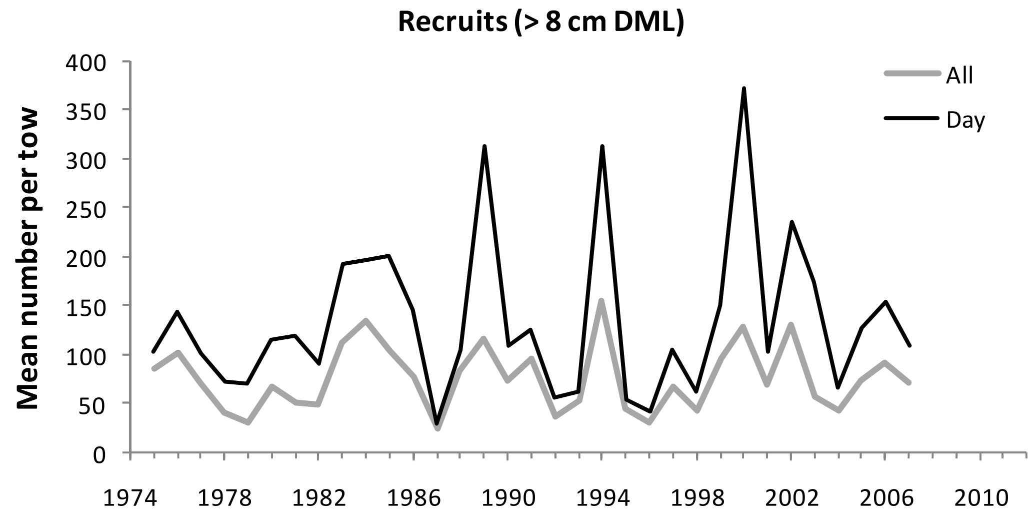



Figure B24. Location of day- and nighttime tows, for the *Loligo pealeii* strata set, during the fall 1985 survey. The year shown was chosen at random.



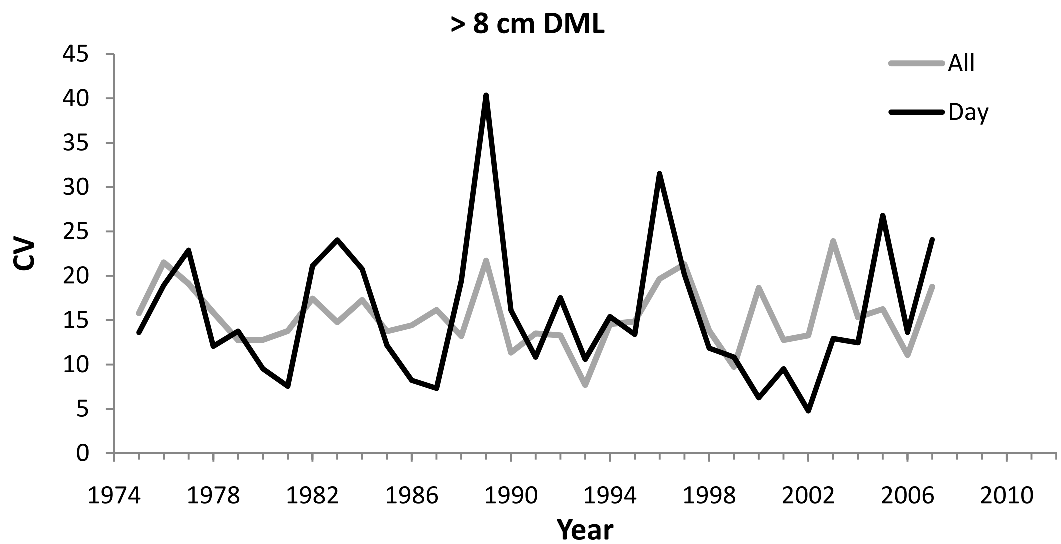
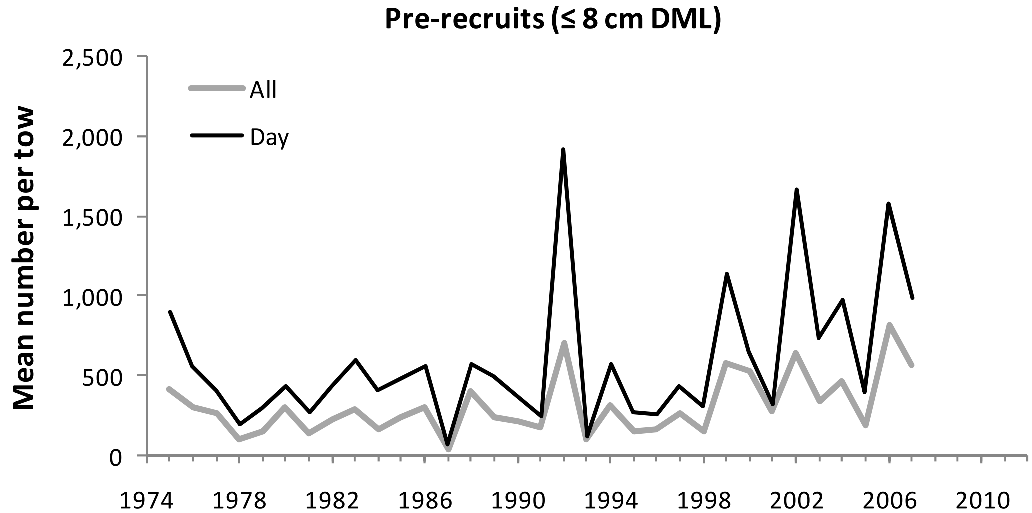




Figure B25. Comparison of *Loligo pealeii* relative abundance indices and CVs for recruits (> 8 cm DML) based on day tows (solar zenith 43-80□) versus all tows from NEFSC fall bottom trawl surveys, 1975-2008.



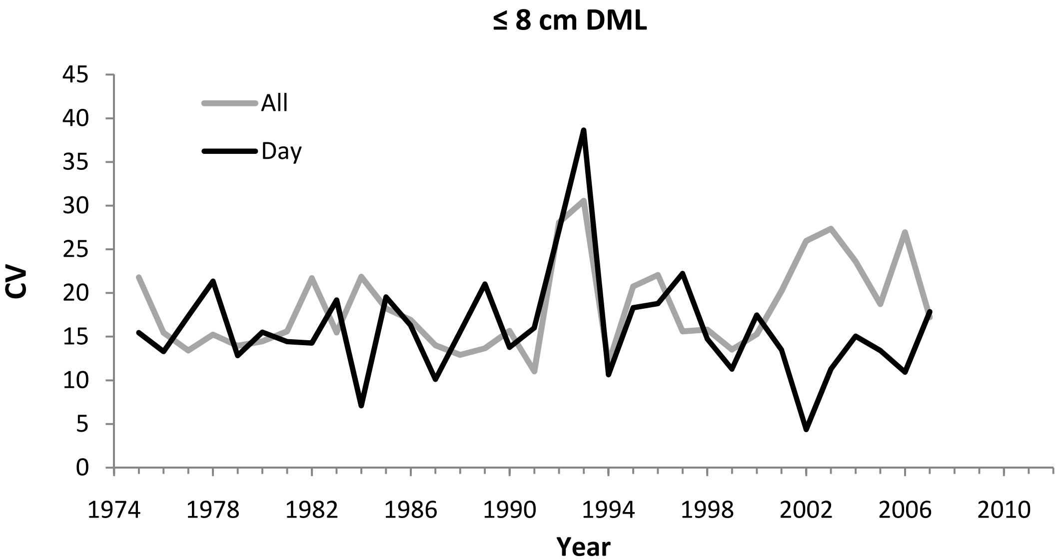
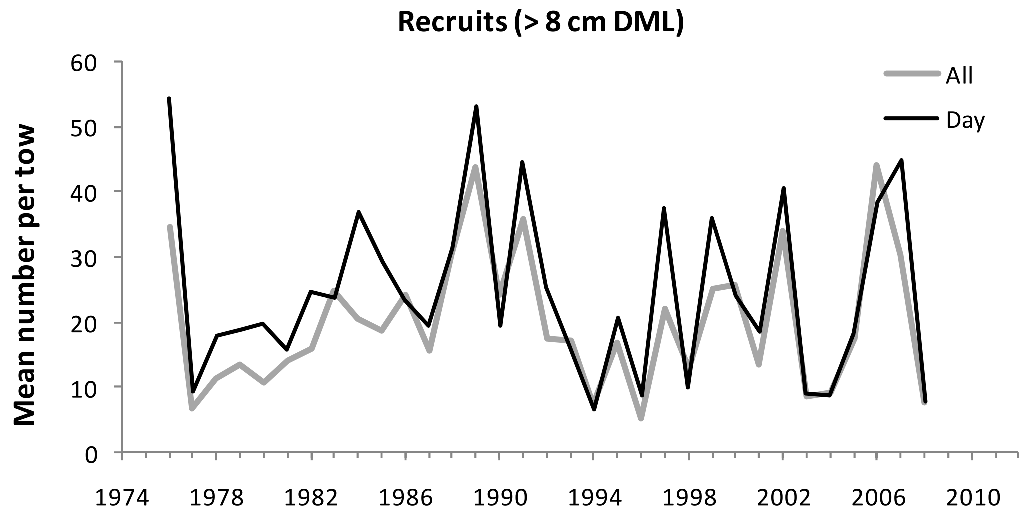




Figure B26. Comparison of *Loligo pealeii* relative abundance indices and CVs for pre-recruits (≤ 8 cm DML) based on day tows (solar zenith 43-80) versus all tows from NEFSC fall bottom trawl surveys, 1975-2008.



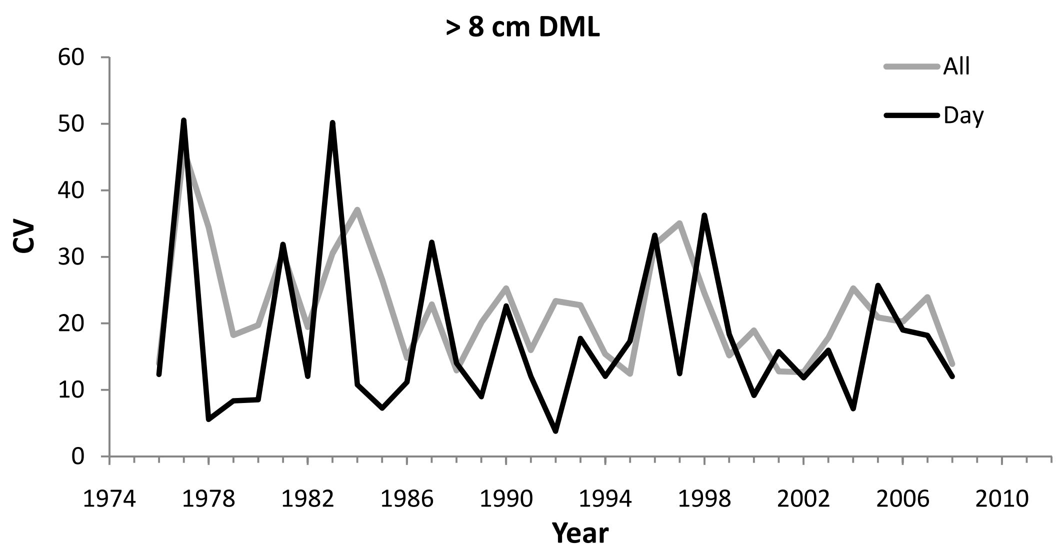
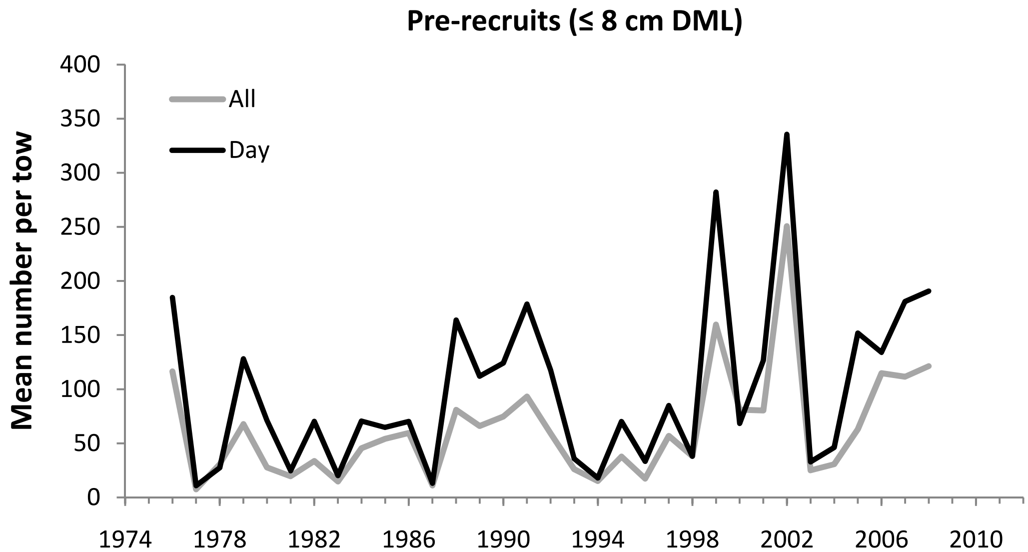




Figure B27. Comparison of *Loligo pealeii* relative abundance indices and CVs for recruits (> 8 cm DML) based on day tows (solar zenith 29-84□) versus all tows from NEFSC spring bottom trawl surveys, 1976-2008.



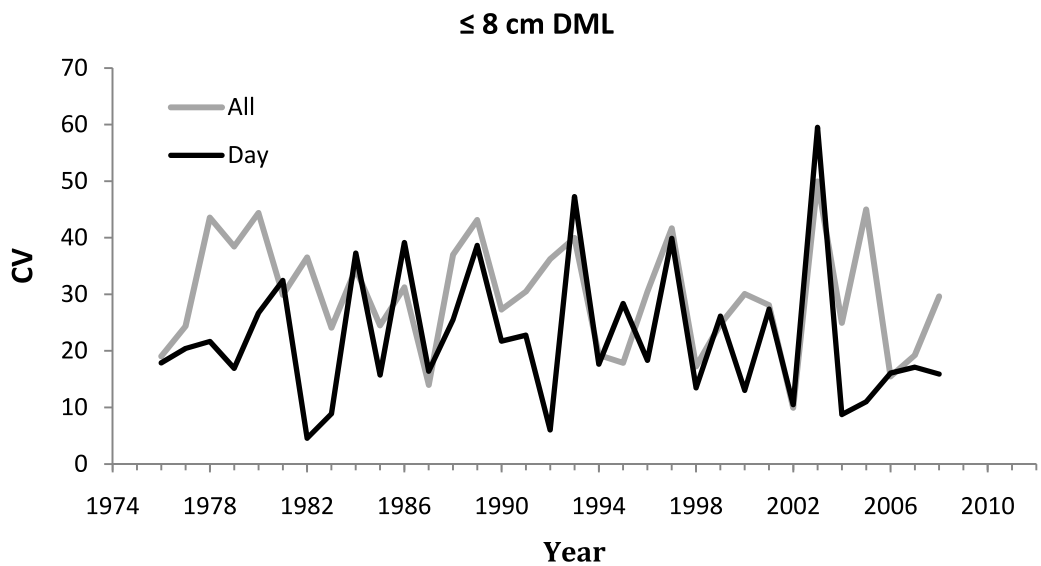




Figure B28. Comparison of *Loligo pealeii* relative abundance indices and CVs for pre-recruits (≤ 8 cm DML) based on day tows (solar zenith 29-84□) versus all tows from NEFSC spring bottom trawl surveys, 1976-2008.

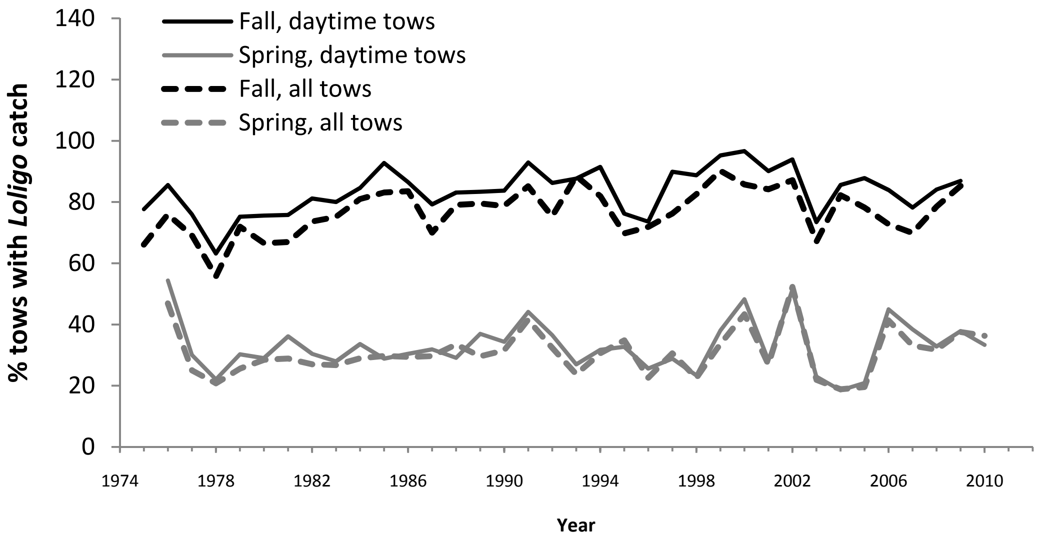


Figure B29. Percentages of “daytime” tows versus all tows with *Loligo pealeii* catch in NEFSC spring (1976-2010) and fall (1975-2009) bottom trawl surveys. Solar zenith angles of 29-84□ and 43-80□ were used to define daytime tows for the spring and fall surveys, respectively.

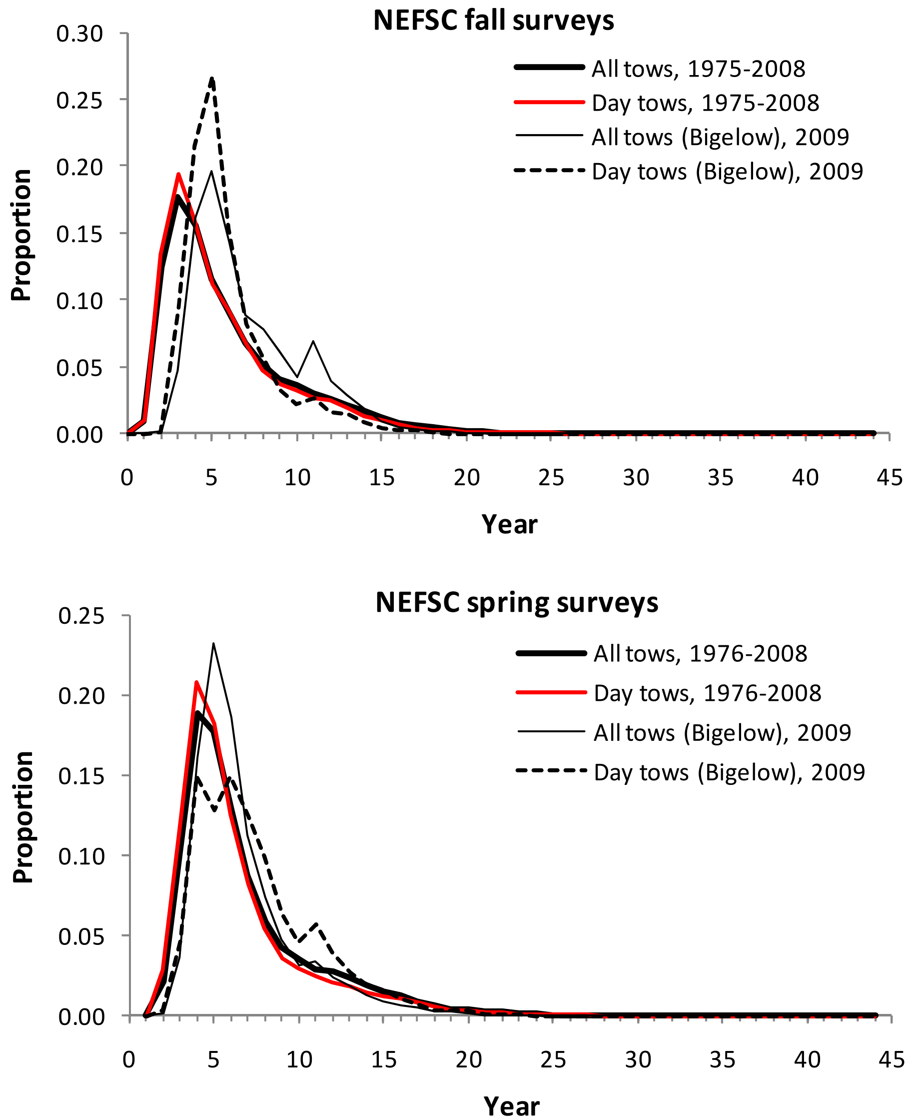



Figure B30. *Loligo* length compositions for NEFSC fall and spring surveys, based on all tows versus "daytime" tows (fall and spring "daytime" tows are for solar zenith angles of 43-80° and 29-84°, respectively).

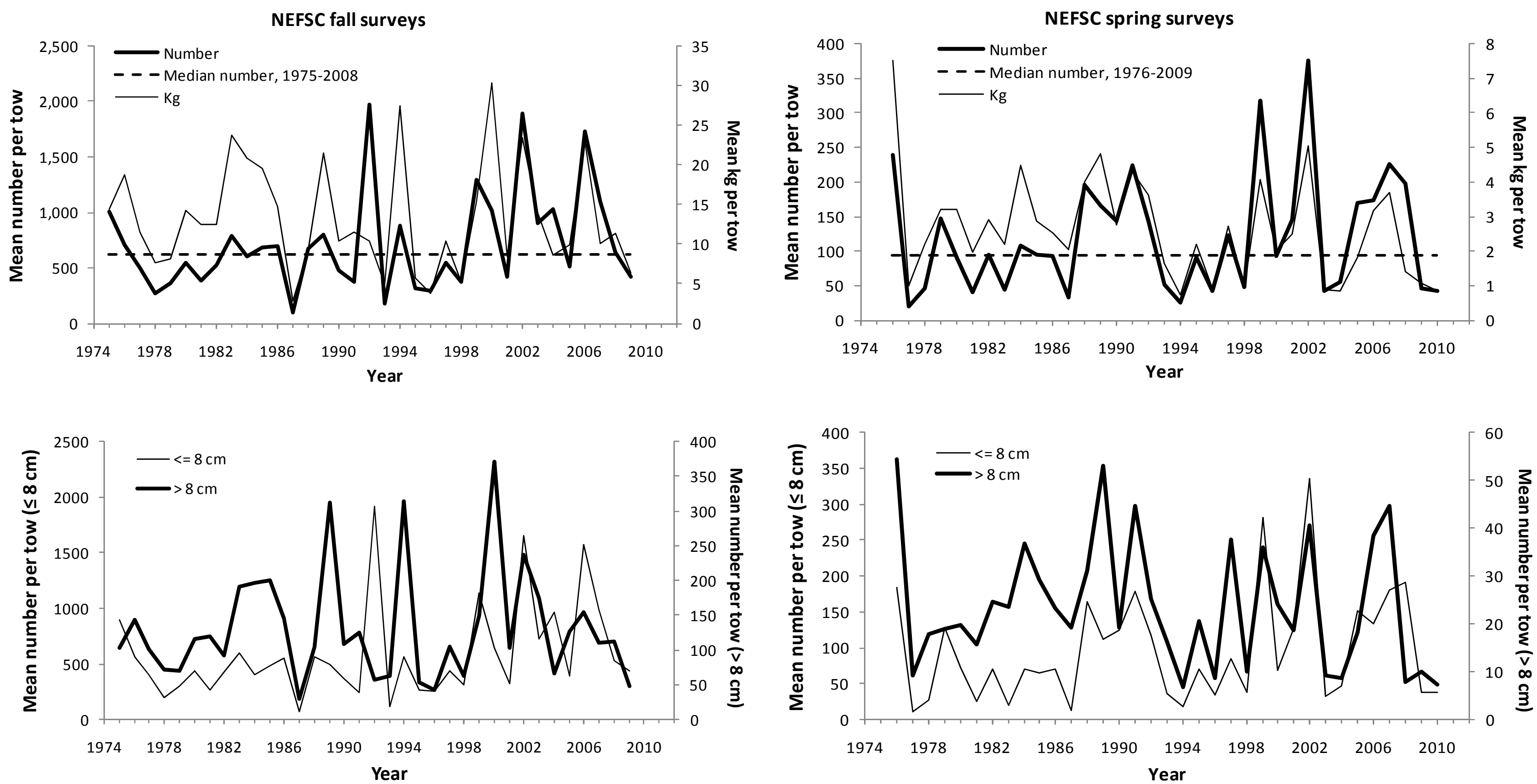
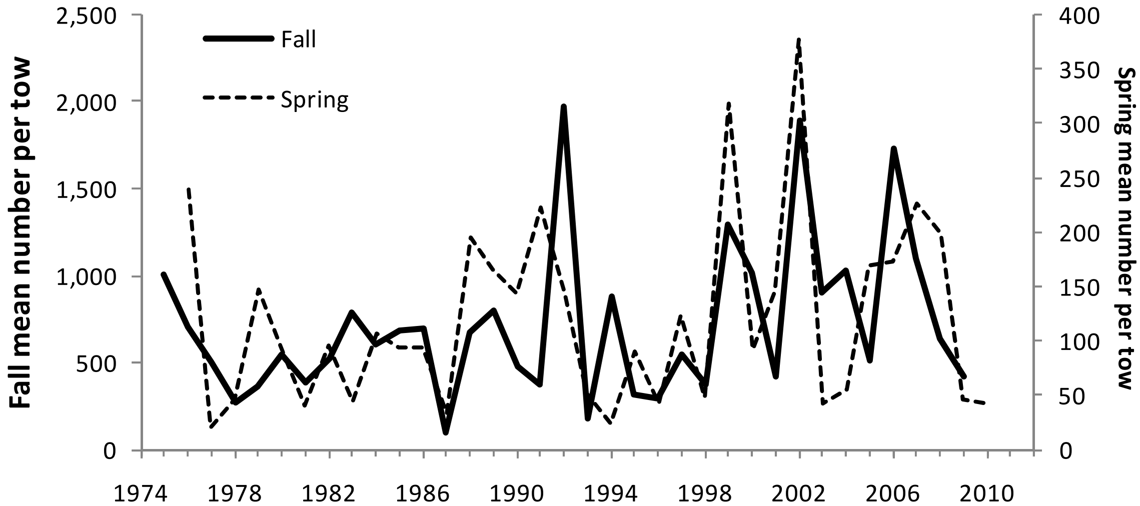



Figure B31. *Loligo pealeii* relative abundance and biomass indices (stratified mean number and kg per tow) and relative abundance indices for pre-recruits (≤ 8 cm DML) and recruits (> 8 cm DML) from NEFSC fall (1975-2009) and spring (1976-2010) bottom trawl surveys.



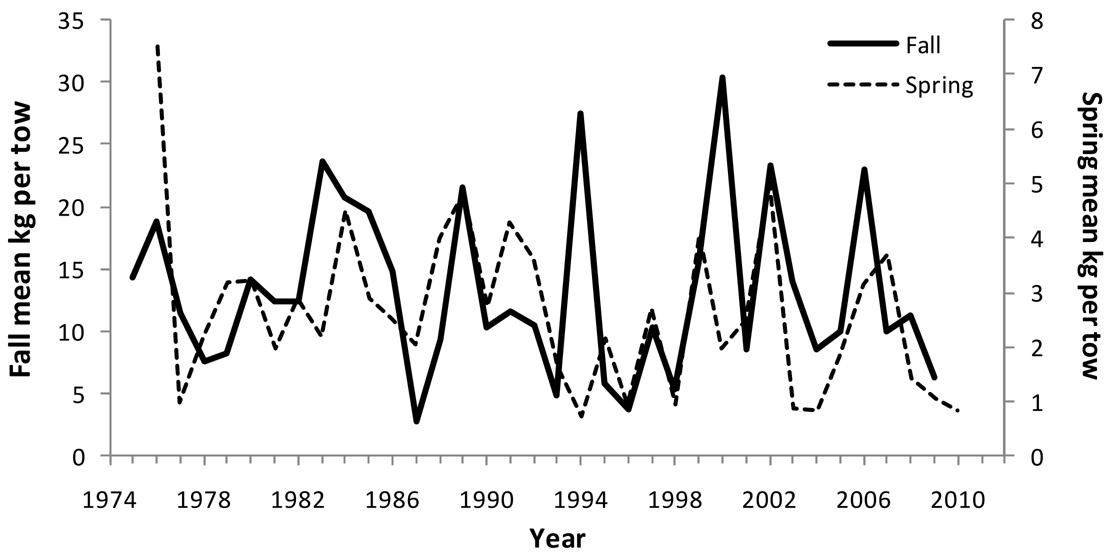




Figure B32. Trends in *Loligo* relative abundance and biomass indices for NEFSC spring (1976-2010) and fall (1975-2009) bottom trawl surveys.

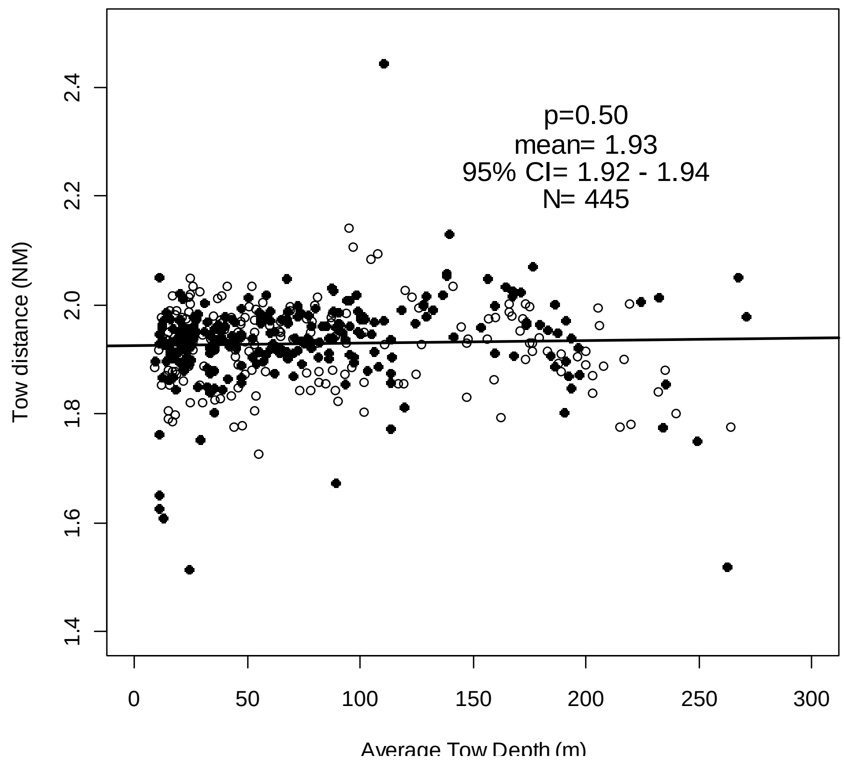



Figure B33. Tow distance (nautical miles) in relation to average station depth based on data from the 2008 spring (open circles) and 2007 fall bottom trawl surveys (solid circles).

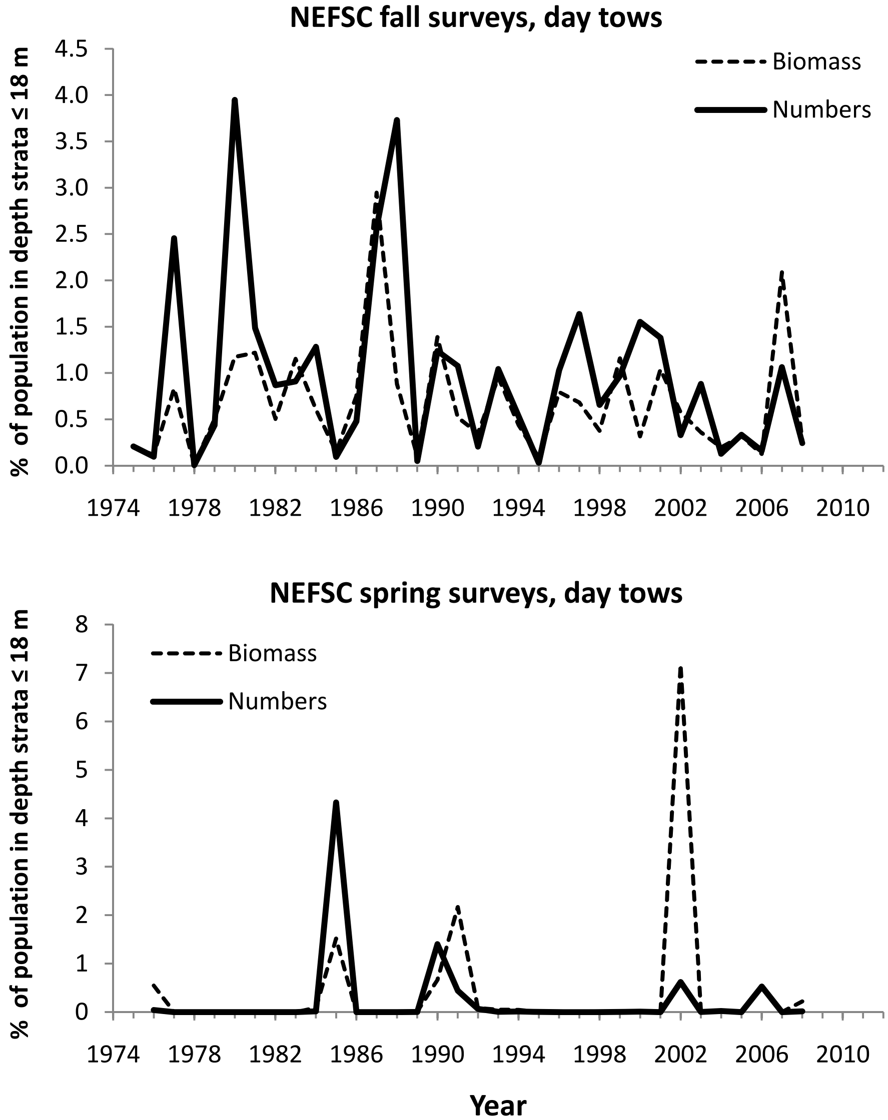



Figure B34. Percentages of the *Loligo pealeii* stratified mean number and kg per tow indices, based on “day” tows conducted during NEFSC spring and fall bottom trawl surveys, in NEFSC survey strata that can no longer be sampled as of 2009.

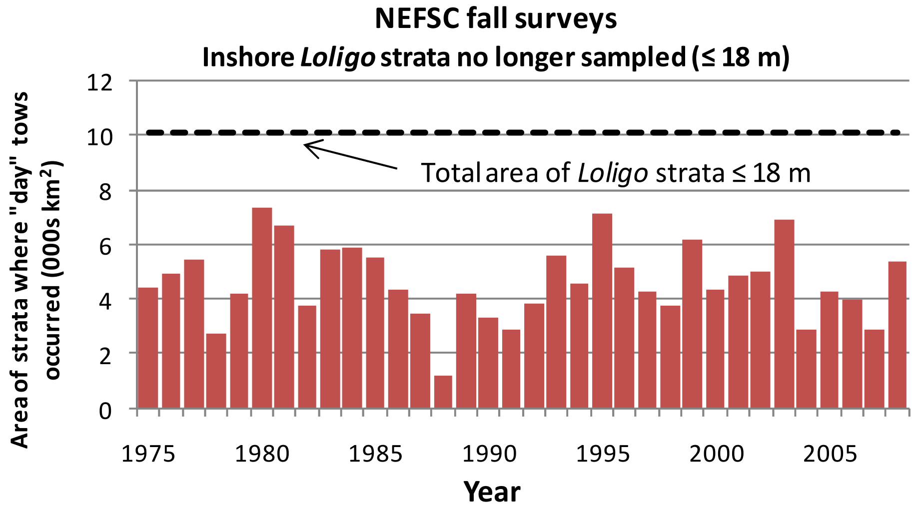



Figure B35. Areas (000s km$^2$) where daytime tows occurred during NEFSC fall surveys (1975-2008), in the inshore *Loligo* strata (≤ 18 m) which are no longer sampled. The dashed line indicates the total area (10,111 km$^2$) of these inshore strata.

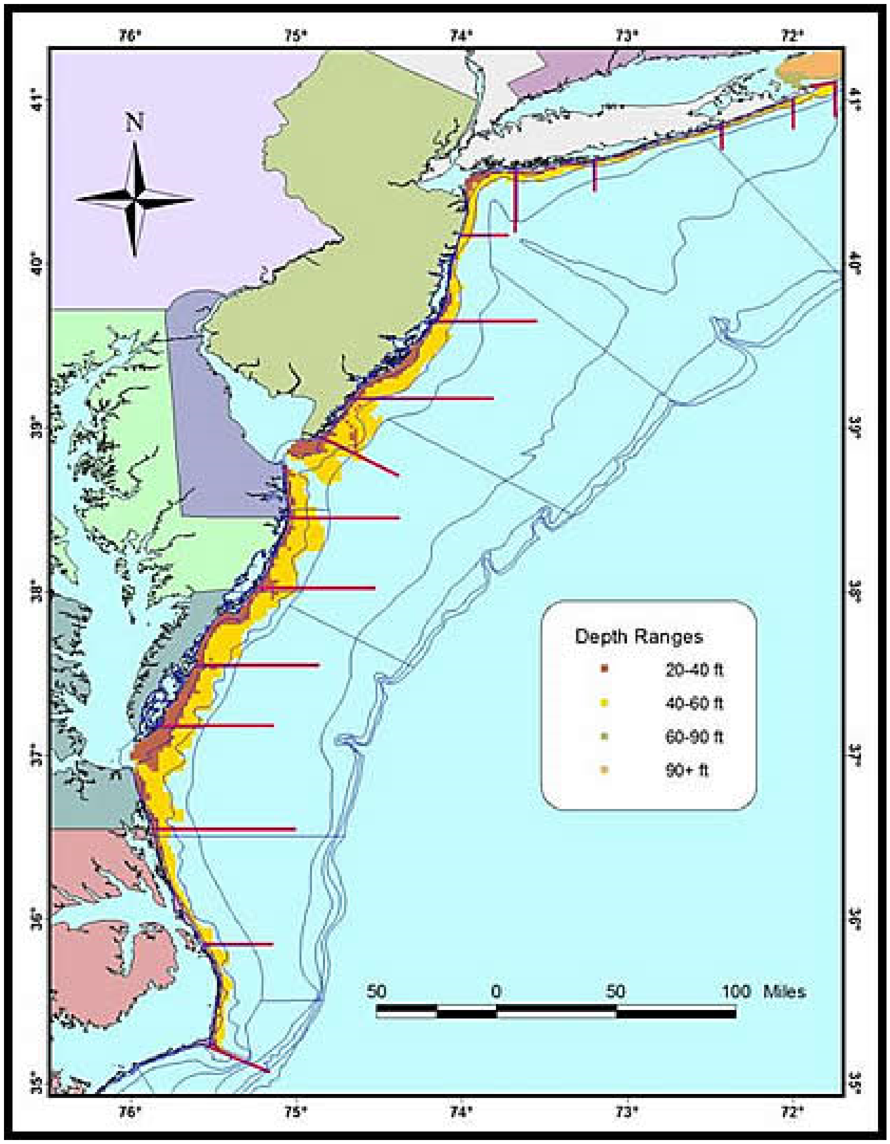



Figure B36. Locations of the NEAMAP bottom trawl survey strata (the two shallowest strata sets shaded red and yellow and ranging in depth from 6.1-18.3 m), between Long Island, NY and Cape Hatteras, NC, in relation to the NEFSC bottom trawl survey strata (polygons outlined in blue).

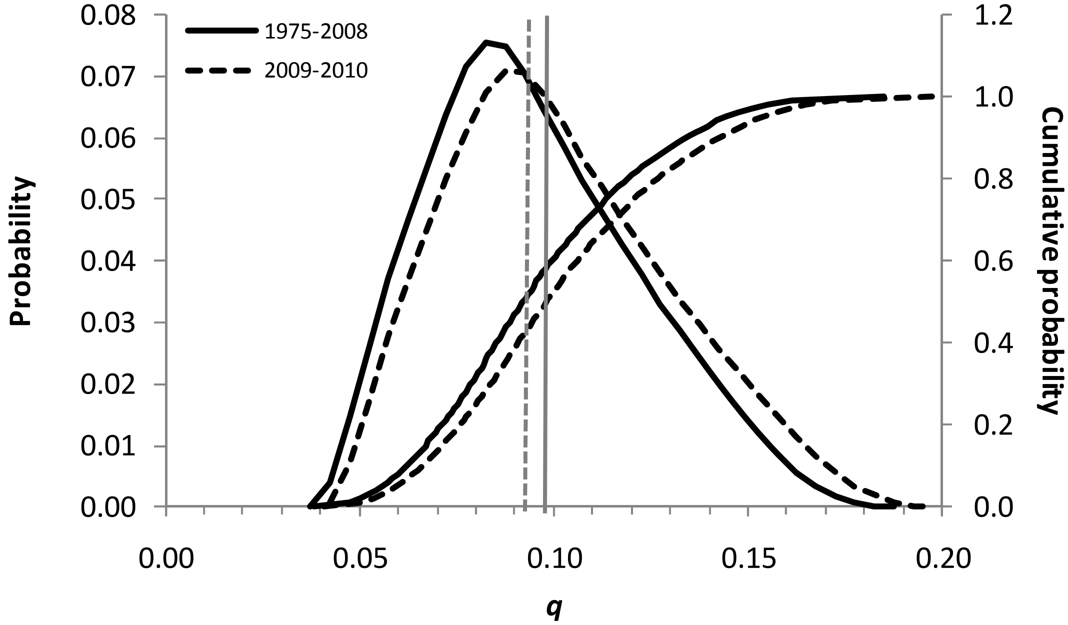



Figure B37. Uncertainty in catchability (*q*) priors for *Loligo pealeii* in NEFSC spring and fall surveys and median *q*-priors (0.092 for 1975-2009 and 0.098 for 2009-2010) used to compute biomass estimates.

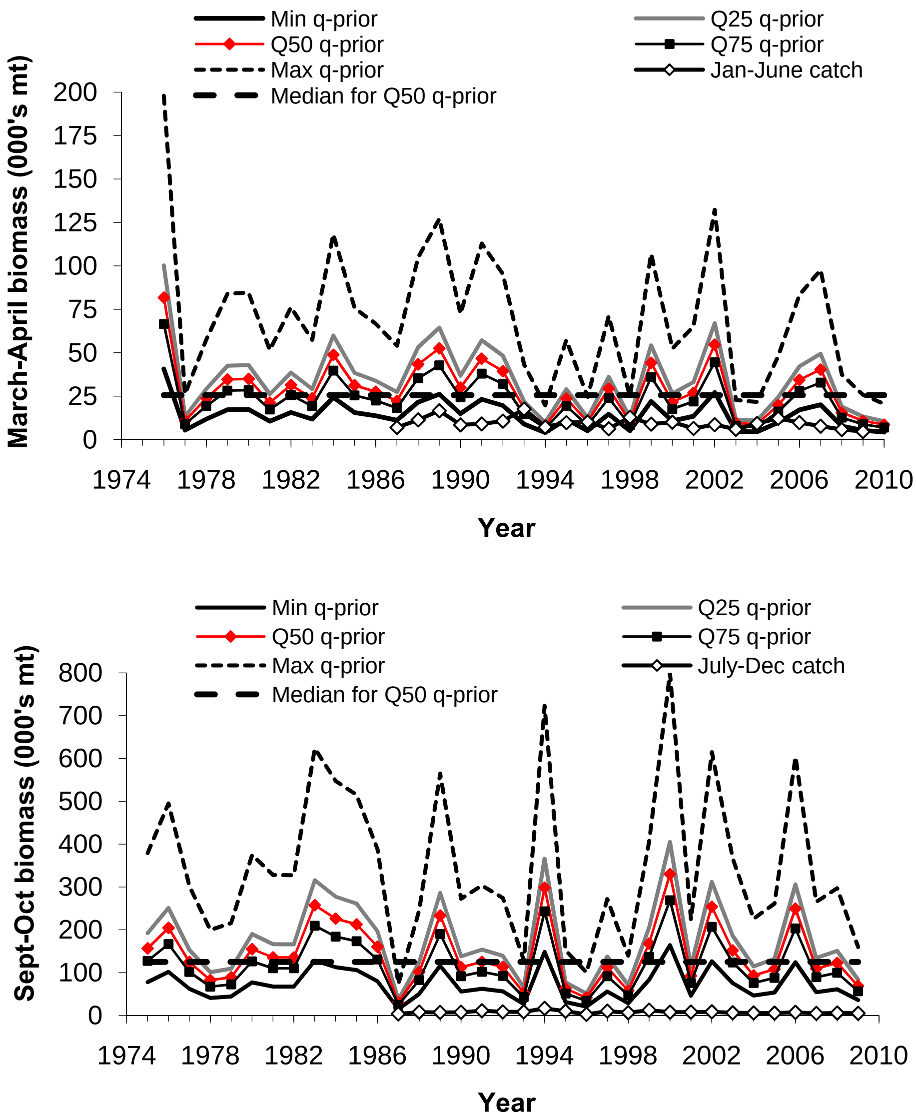
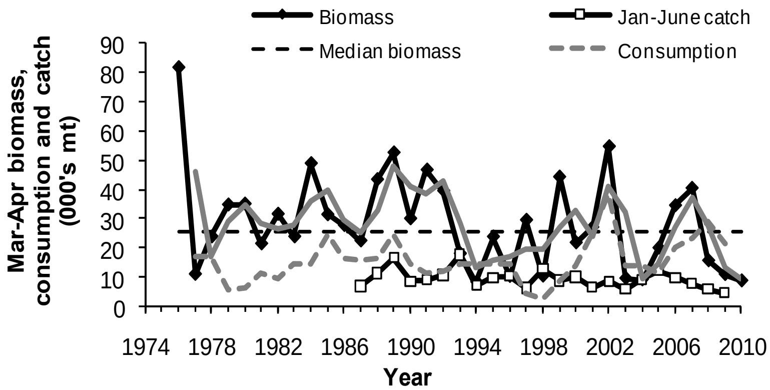



Figure B38. *Loligo* biomass estimates, derived using the minimum, maximum, 25th, 50th and 75th percentiles of the *q*-prior distributions (Q25,50 and 75), for cohorts caught in the NEFSC spring (1976-2010, top) and fall (1975-2009, bottom) bottom trawl surveys.



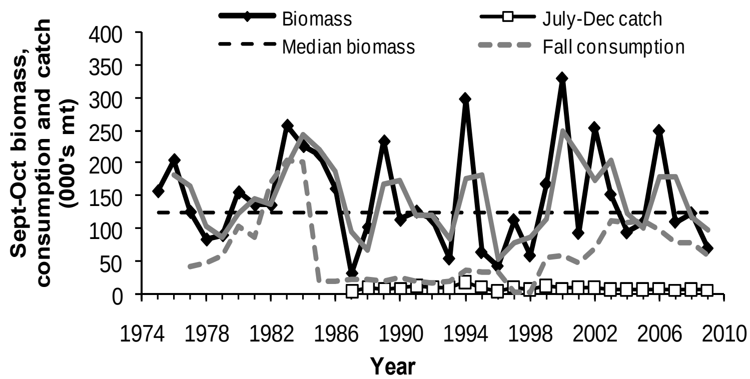




Figure B39. Estimates of *Loligo pealeii* biomass (derived using the median q-priors) for seasonal cohorts caught in the NEFSC spring (top) and fall surveys (bottom) in relation to their respective seasonal consumption estimates and fishery catches. The grey lines represent the two-year moving averages of the biomass estimates.

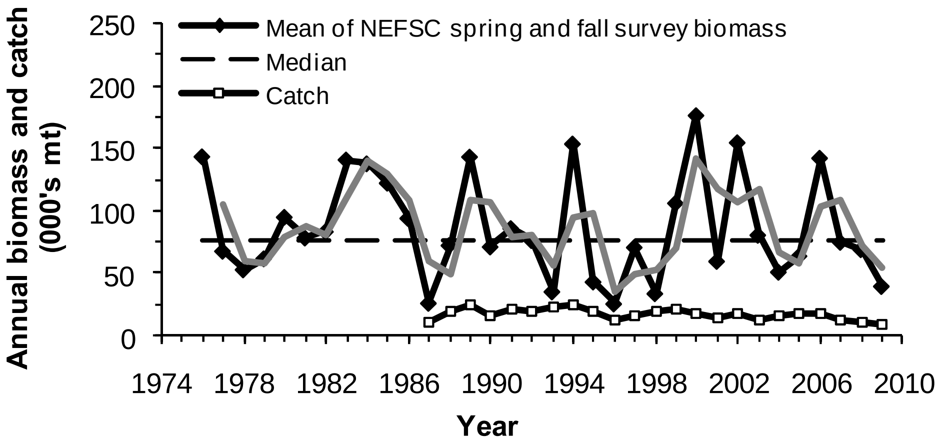
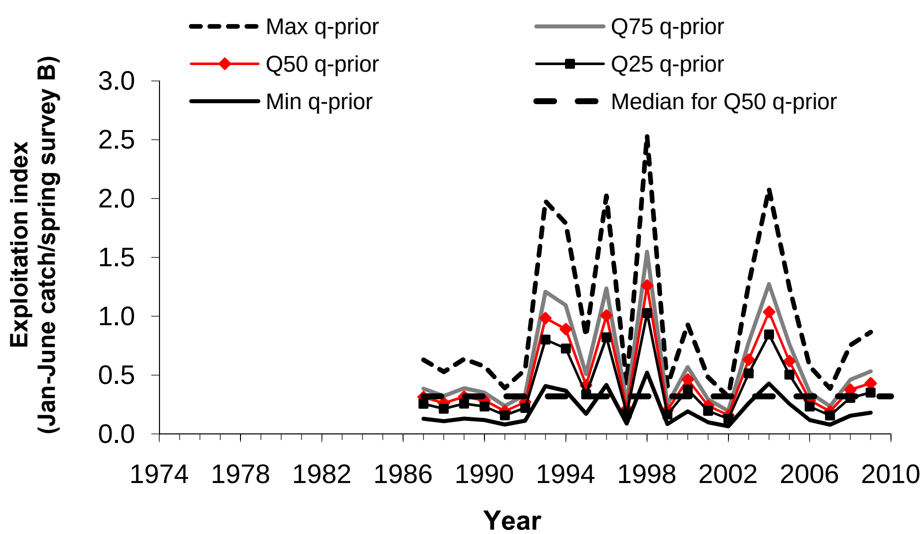



Figure B40. Annualized estimates (annual averages of NEFSC spring and fall survey biomass) of *Loligo* biomass in relation to annual catches. The grey line is the two-year moving average of the biomass estimates.



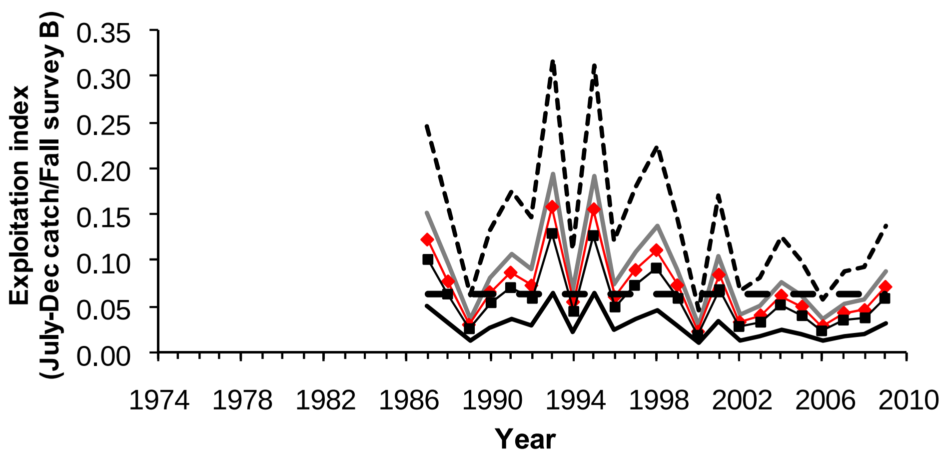
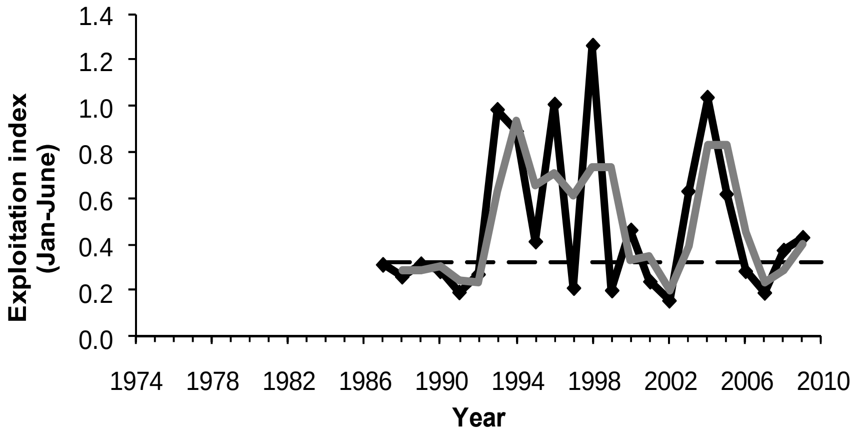




Figure B41. *Loligo* exploitation indices, derived using the minimum, maximum, 25th, 50th and 75th percentiles of the *q*-prior distributions (Q25,50 and 75), for the January-June fishery (January-June catch/March survey biomass, top) and the July-December fishery (July-December catch/September survey biomass, bottom), 1987-2009.



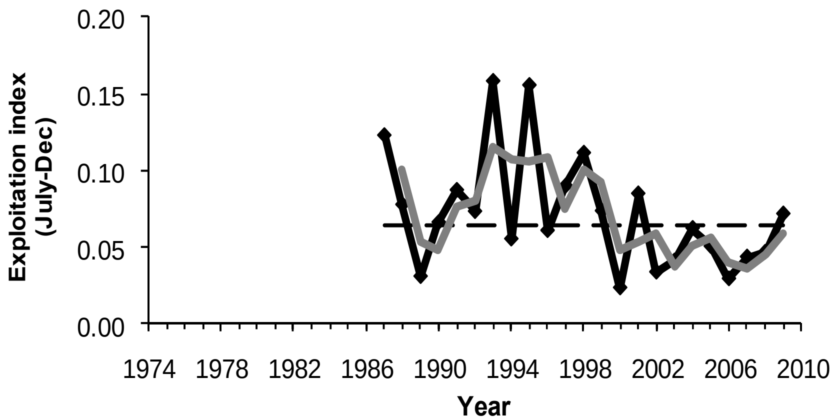




Figure B42. Exploitation indices for the January-June fishery (top) and the July-December fishery (bottom) in relation their medians during 1987-2008. The grey lines represent the two-year moving averages.

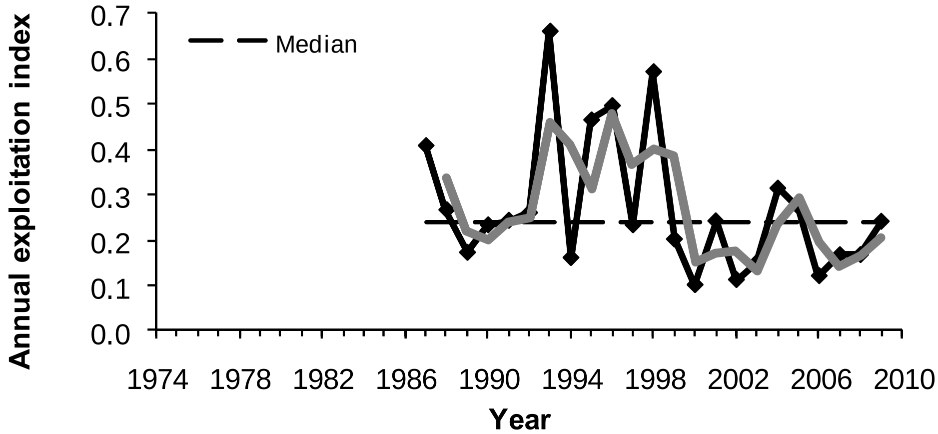



Figure B43. Annual exploitation indices for *Loligo* (annual catch/ annual mean of NEFSC spring and fall survey biomass). The grey lines represent the two-year moving averages.

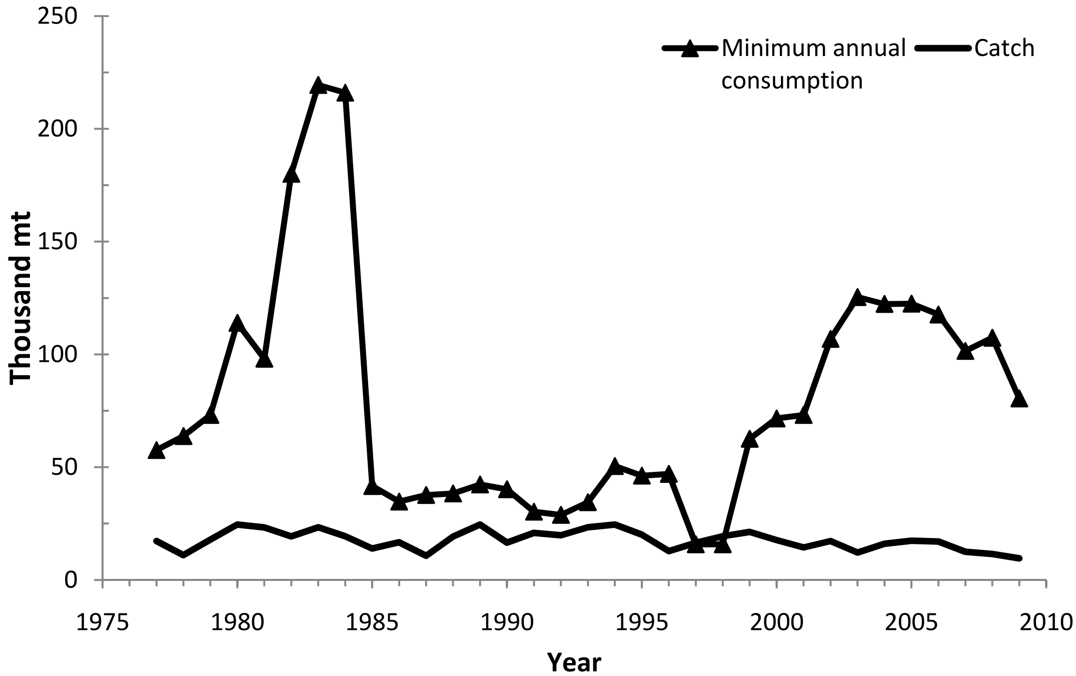



Figure B44. Annual estimates of minimum consumption and catches of Loligo pealeii during 1977-2009.

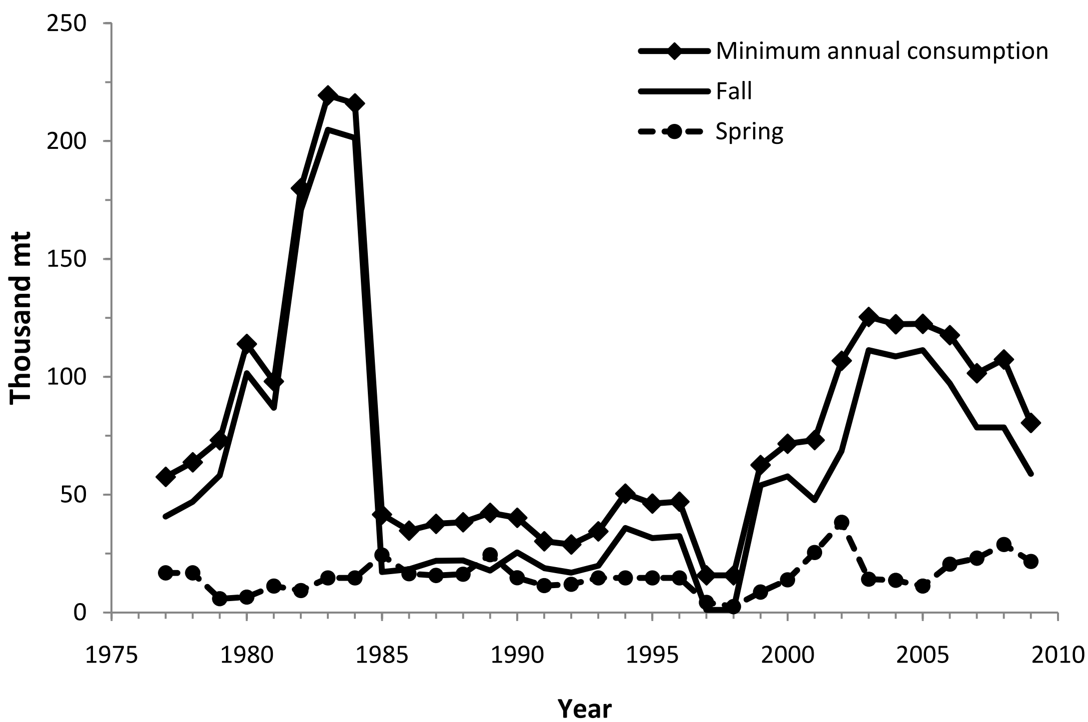



Figure B45. Minimum seasonal and annual estimates of *Loligo* consumption.

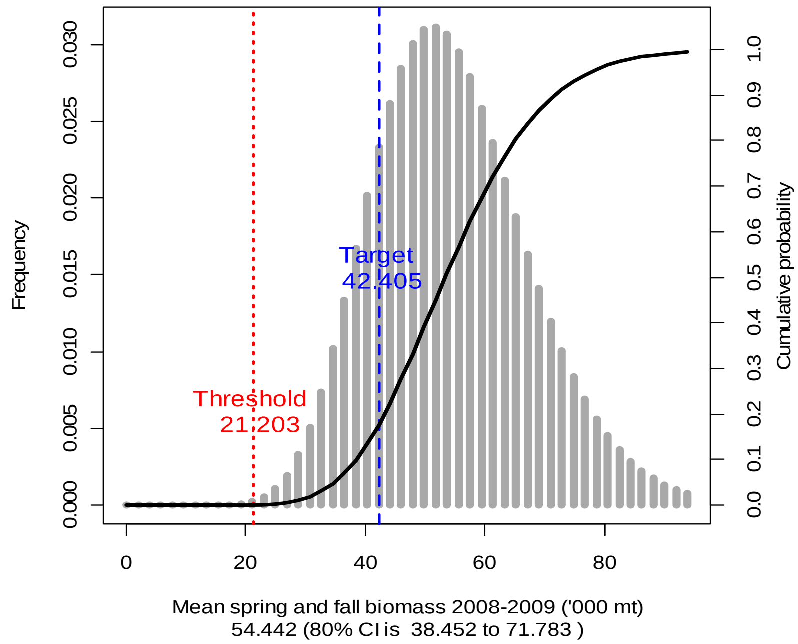



Figure B46. *Loligo* biomass estimate (000s mt), spring and fall survey average for 2008-2009, shown as a probability distribution. Also shown are proposed biomass reference points.

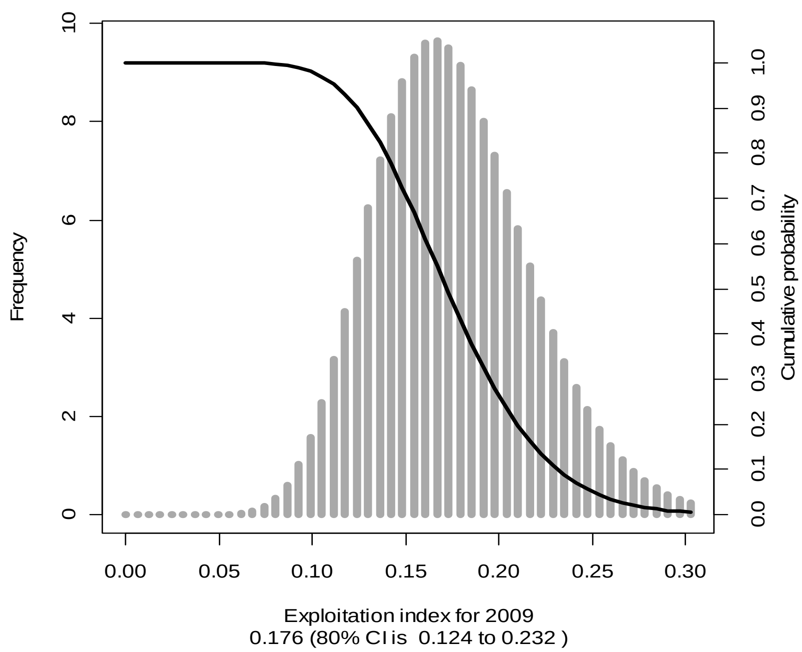



Figure B47. *Loligo* exploitation index for 2009 (2009 catch / mean of 2008-2009 spring and fall survey biomass) shown as a probability distribution.

**Appendix B1:** Invertebrate Subcommittee meetings for the SAW/SARC-51 assessment of *Loligo.*

The Invertebrate Subcommittee met on September 28-29 and on October 18-20 at the Northeast Fisheries Science Center in Woods Hole, MA to work on the SAW/SARC-51 stock assessment for *Loligo pealeii*. Members attended in person and by Webex/conference call. The Subcommittee met again briefly by WebEx/conference call on the morning of October 25 to complete its work. The following persons attended one or more of the meetings.

- Lisa Hendrickson, Northeast Fisheries Science Center (NEFSC), Assessment Lead
- Larry Jacobson, NEFSC, Subcommittee Chair
- Toni Chute, NEFSC, Rapporteur
- Dan Hennen, NEFSC, Rapporteur
- Aja Peters-Mason, NERO (SMB Plan Manager)
- Chris Legault, NEFSC
- DJ Kowalske, NEFSC, Cooperative Research
- Fred Serchuk, NEFSC
- Greg DiDomenico (Industry Advisor)
- Jason Didden (MAFMC,SMB staff person)
- Jason Link, NEFSC
- Jeff Kaelin (Lunds Fisheries, Cape May, NJ)
- Jeff Reichle (Lunds Fisheries, Cape May, NJ)
- Jon Knight (Superior Trawl, Pt. Judith, RI)
- Lars Axelsson (F/V Flicka, Cape May, NJ)
- Mark Terciero, NEFSC
- Paul Rago, NEFSC
- Sam Martin (Atlantic Cape Fisheries, Cape May, NJ)
- Tim Miller, NEFSC
- Vidar Westpestad (Industry consultant)

**Appendix B2**: Assessment of the effects of solar zenith angle and other environmental factors on the diel catchability of *Loligo* in bottom trawls

Solar zenith at the time and geographic location of each tow was used in place of the more conventional time of day in estimating diel effects on *Loligo* catchability in bottom trawls. Solar zenith is the angle between a line drawn between the center of the sun and the observer and a line drawn directly overhead at the location of the observer (Meeus, 1998). Solar zenith is the primary determinant of the amount of irradiance (watts $m^{-2}$) at the surface of the ocean where the observer is located (Frouin *et al.*, 1989). Solar zenith is more useful than time of day in modeling because irradiance varies by latitude, longitude, Julian date and year (which are all used in calculation of the solar zenith). Although there is a clear general relationship between solar zenith and time of day (Figure 1), tows carried out at the same time but at different geographic locations may have substantially different irradiance levels that might affect survey catchability to different extents.

GAM models were fit to fall and spring survey data from the same strata and years used elsewhere in the assessment, and used to confirm diel catchability patterns as functions of squid size, season and other variable. Based on preliminary analyses, the maximum likelihood GAM models fit using the *R* statistical language were:

$$Y = f[s(L,Z) + s(L,D) + s(T) + region + year] + \varepsilon$$

where $Y$ is the dependent variable for one size group in one tow, *f()* is the link function (see below), and ε is a statistical error. The continuous variables are $L$ (DML in 1 cm increments), $Z$ (solar zenith at the time and location of tow, degrees), $D$ (tow depth, m), and $T$ (bottom temperature, $^{o}$C). The categorical predictor variables are region (Gulf of Maine, Georges Bank, Southern New England, Mid-Atlantic Bight, and Chesapeake Bay to Cape Hatteras) and year. One *s(x)* and two dimensional *s(x,y)* nonlinear spline functions were used to model the continuous predictor variables. The two dimensional splines allow interaction between size and soar zenith or between size and depth. The degree of nonlinearity in the spline functions were chosen using by minimizing of an AIC-type statistic (Wood, 2006).

Modeling mimicked delta-distribution methods in which the probability of a positive survey tow (catch > 1 squid) was estimated in presence-absence models and the catch in positive tows was estimated separately in catch number models. In presence absence modeling, the dependent variable was $Y$=0 or 1 (if at least one squid was taken in the tow), *f( )* was the logit link function, likelihood was calculated assuming errors were from a binomial distribution, and data for all size groups in each tow were included. In catch numbers models, the dependent variable was the survey catch, *f( )* was the log link function was used, likelihood was calculated assuming that the errors were from a negative binomial distribution with estimated shape and scale parameters, and only data for positive tows and size groups were used. Spring and fall survey data were modeled separately. The linear and nonlinear terms in all of the models were statistically significant.

Predicted values from the models showed clear diel effects on the probability of a positive tow and catches in positive tows. Diel effects were size and season dependent (Figures 2-5).

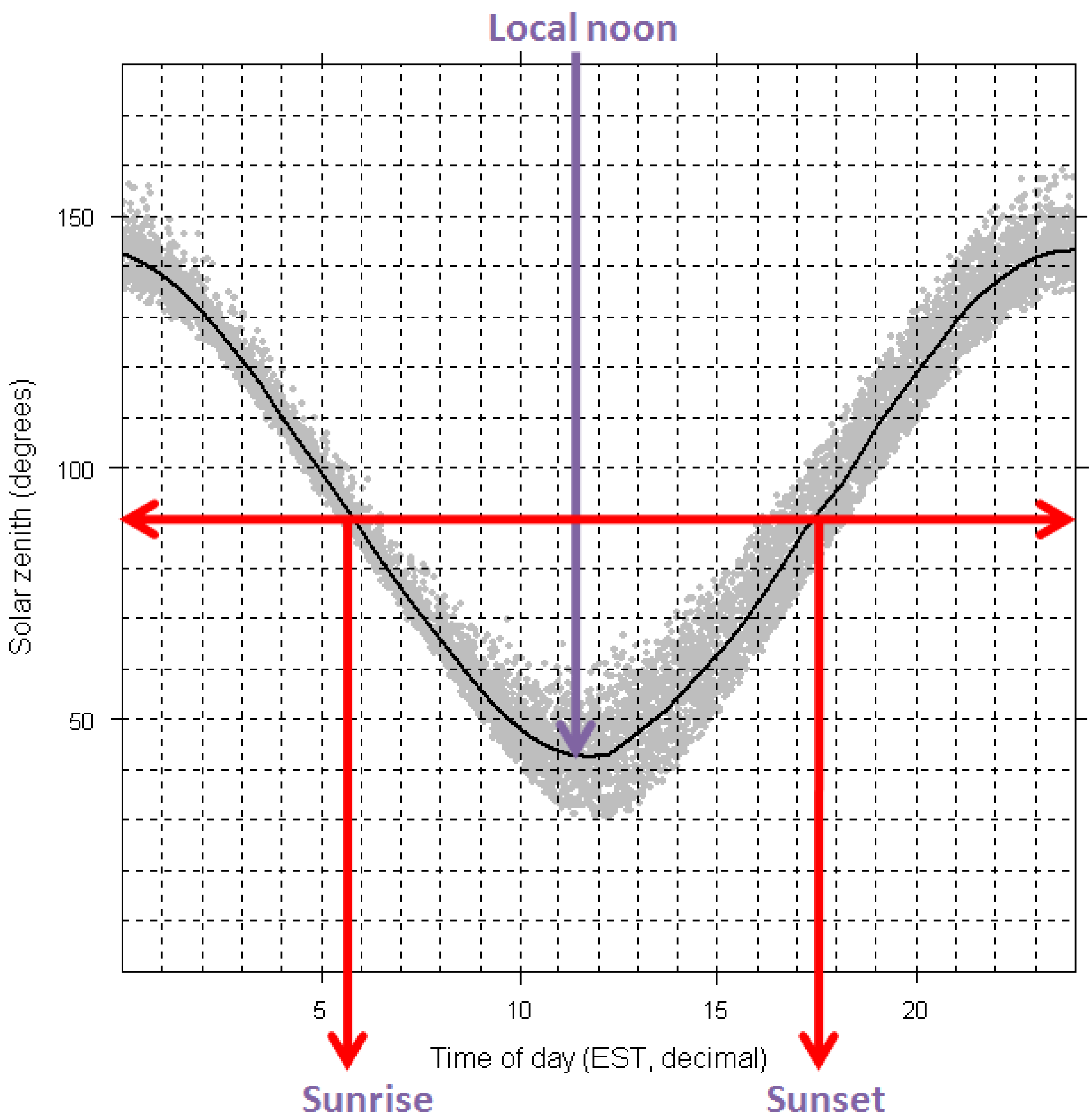
**Objective criteria for defining daytime tows**

All preliminary choices of solar zenith cutoffs to define daytime tows resulted in higher mean survey abundance and biomass levels and similar or smaller CVs. However, there was uncertainty about whether to include data collected around noon and data collected around dawn/dusk. Criteria for defining daytime tows were therefore defined objectively using performance scores based on an approximate mean squared error (MSE) approach. In particular, if the bias in a measurement is $b$ and the variance of the measurements is $\sigma^2$, then $MSE=b^2+\sigma^2$. We chose criteria with minimum values of the MSE in order to reduce bias (due to night time tows) and variance of mean numbers and weight per tow. This analysis was not based on GAM or any other model results. Rather, annual mean numbers and weight per tow were calculated from survey data for a wide range of possible criteria. Spring and fall surveys were analyzed separately.

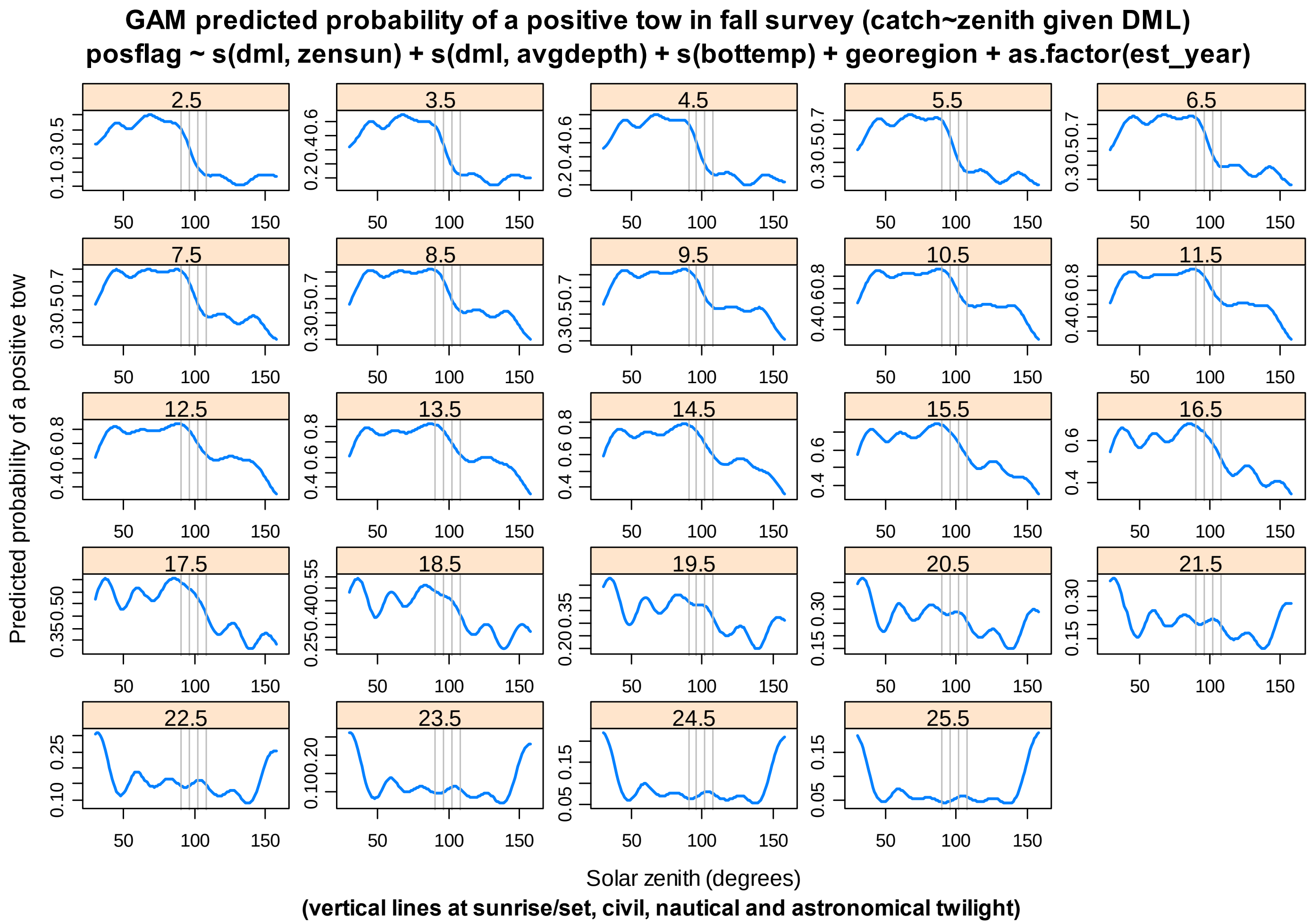
The score used to choose solar zenith criteria was:

$$\mathrm{X}_{\mathrm{test}}^{\mathrm{n}} = [\bar{\mathrm{cv}}_{\mathrm{test}} - (\bar{\mathrm{n}}_{\mathrm{test}} - \bar{\mathrm{n}}_{24})^2] + \left[\frac{\bar{\mathrm{cv}}_{\mathrm{test}}}{\bar{\mathrm{cv}}_{24}} - \frac{\bar{\mathrm{n}}_{\mathrm{test}}}{\bar{\mathrm{n}}_{24}}\right]$$

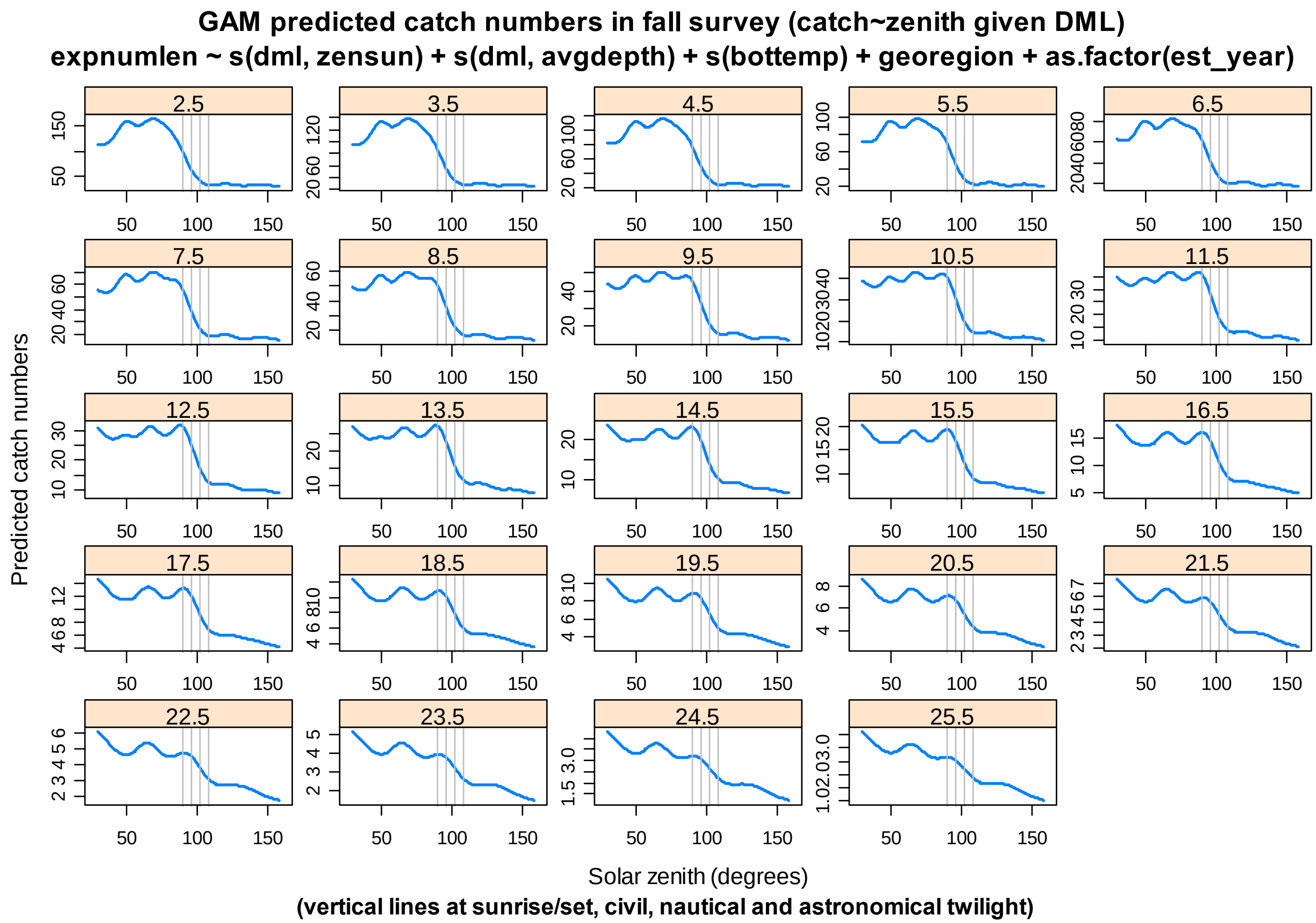
where $\mathrm{X}_{\mathrm{test}}^{\mathrm{n}}$ was the score for mean numbers per tow and a particular set of minimum and maximum values for solar zenith ($Z_1$ and $Z_2$, one possible set of criteria for defining daytime tows), $\bar{\mathrm{n}}_{\mathrm{test}}$ and $\bar{\mathrm{n}}_{24}$ were the average (over all years) of the annual stratified random mean numbers per tow for the test criteria and using all tows (day and night), $\bar{\mathrm{cv}}_{\mathrm{test}}$ and $\bar{\mathrm{cv}}_{24}$ were the average (over all years) CVs of the annual stratified mean numbers per tow. The terms $(\bar{\mathrm{n}}_{\mathrm{test}} -$ n24 and ntestn24 are approximate absolute and relative measures of the reduction in bias using the test criteria relative to using all tows. The terms $\bar{\mathrm{cv}}_{\mathrm{test}}$ and $\frac{\bar{\mathrm{cv}}_{\mathrm{test}}}{\bar{\mathrm{cv}}_{24}}$ are approximate absolute and relative measures of variance. A similar score $\mathrm{X}_{\mathrm{test}}^{\mathrm{b}}$ was calculated for mean weight per tow. The combined score $\mathrm{X}_{\mathrm{test}} = \mathrm{X}_{\mathrm{test}}^{\mathrm{n}} + \mathrm{X}_{\mathrm{test}}^{\mathrm{b}}$ was calculated $Z_1$= 30 to 45$^{\circ}$ and $Z_2$ = 75 to 90$^{\circ}$ in steps of one degree. The combined score surfaces were very bumpy with a wide range of criteria giving similar performance but inclusion of nighttime tows resulted in poor performance. The resulting grid of calculated values was smoothed using a two dimensional loess regression surface and contoured for graphical analysis. The "best" choice for the criteria $Z_1$ and $Z_2$ was the combination with the lowest combined score. The criteria chosen for the fall survey was $Z_1$ =43$^{\circ}$ and $Z_2$ =80$^{\circ}$ (Figure 6). The criteria chosen for the spring survey was $Z_1$ =29$^{\circ}$ and $Z_2$ =84$^{\circ}$ (Figure 7). Thus, daytime fall survey data used in this assessment are for tows with solar zenith values of 43-80$^{\circ}$ and daytime spring survey data are for tows with solar zenith values of 29-84$^{\circ}$.



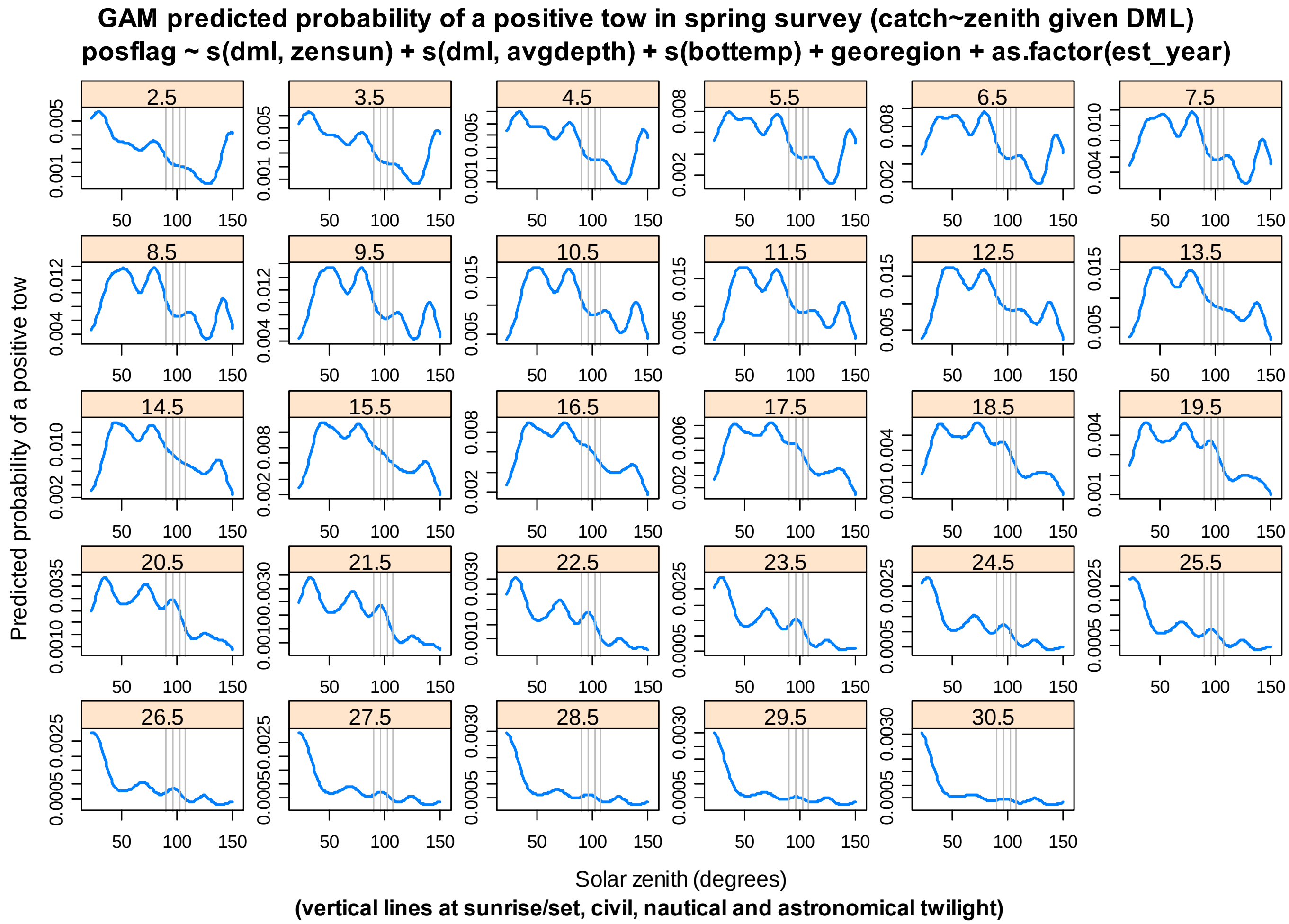

Appendix B2 Figure B1. The relationship between solar zenith and time of day (EST) in fall surveys, 1975-2008. Relationships during the spring survey are similar. The sun rises and sets at a solar zenith of 90.83° when the sun first appears or disappears along the horizon. At local noon, the sun is at its apogee and the solar zenith is at its minimum value.



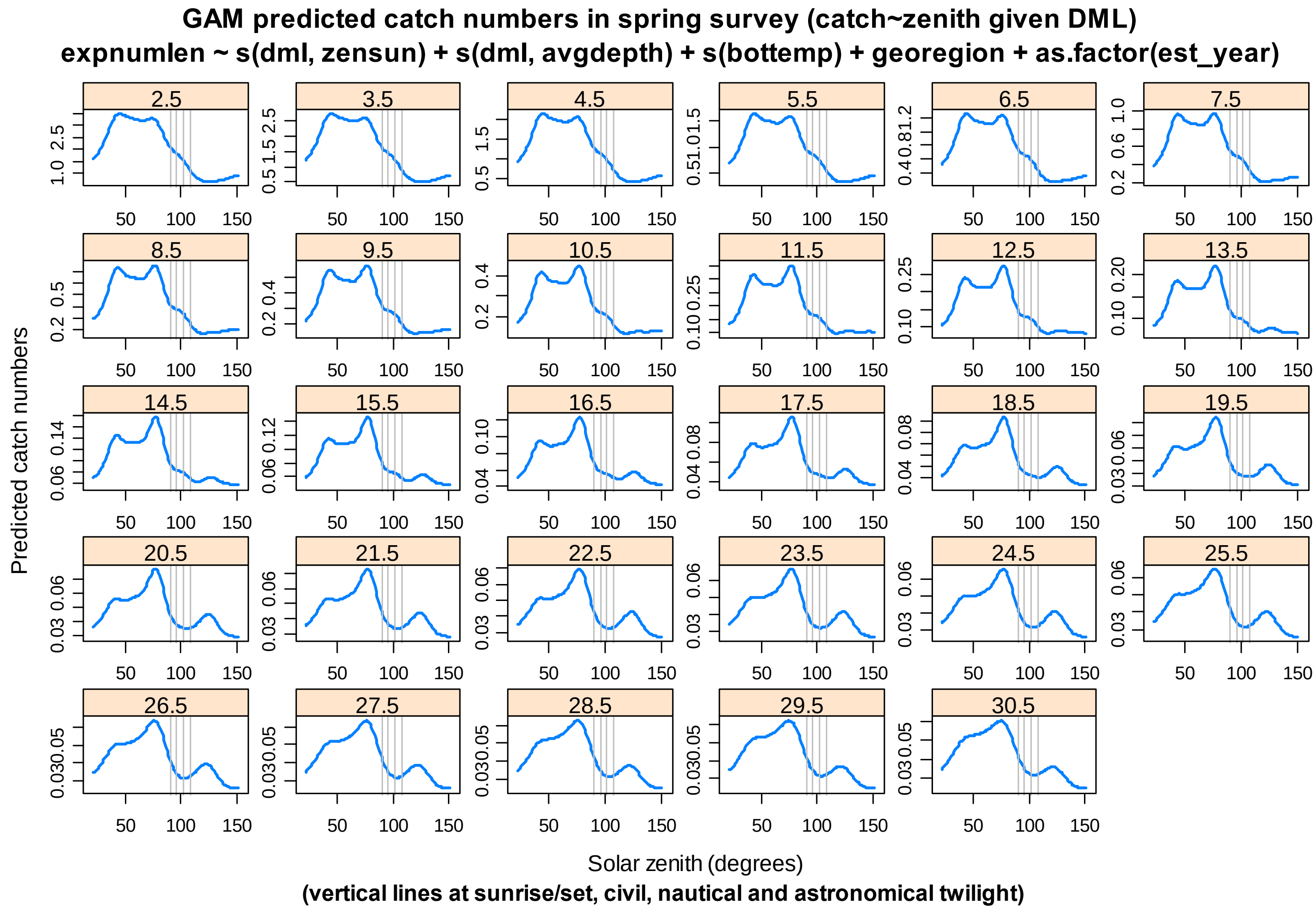

Appendix B2 Figure2. Predicted probability of a positive tow from a GAM model fit to fall survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).



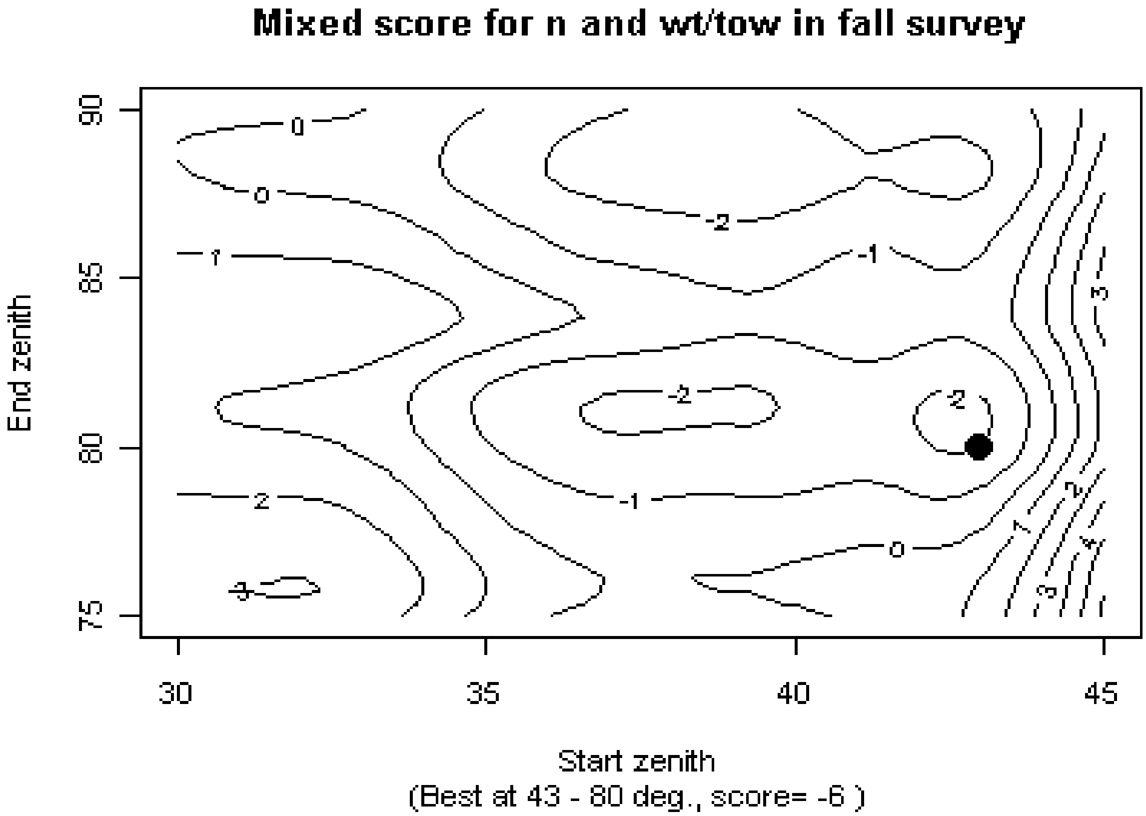

Appendix B2 Figure 3. Predicted catch in positive tows from a GAM model fit to fall survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).



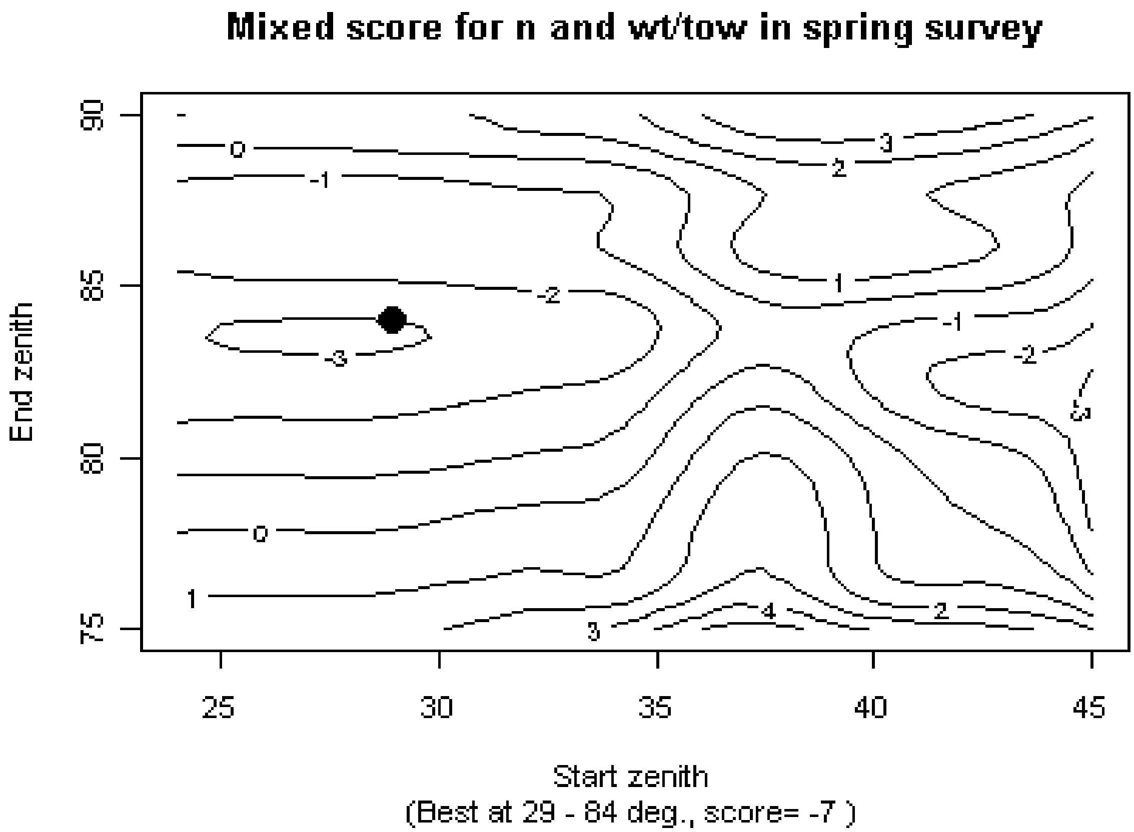

Appendix B2 Figure 4. Predicted probability of a positive tow from a GAM model fit to spring survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).




Appendix B2 Figure 5. Predicted catch in positive tows from a GAM model fit to spring survey data for an arbitrary location and date. The labels at the top of each frame are dorsal mantle length groups in cm (e.g. 19.5 means 19-19.9 cm DML).




Appendix B2 Figure 6. Contours showing lowess smoothed overall scores for solar zenith criteria used to choose daytime cutoff points for fall survey tows.




Appendix B2 Figure 7. Contours showing loess smoothed overall scores for solar zenith criteria used to choose daytime cutoff points for spring survey tows.

**Appendix B3:** Calculation of SRV *H. B. Bigelow* calibration coefficients for *Loligo pealeii*

In 2009 the *FRV Henry B. Bigelow* replaced the *R/V Albatross IV* as the primary vessel for conducting spring and fall annual bottom trawl surveys for the Northeast Fisheries Science Center (NEFSC). There are many differences in the vessel operation, gear, and towing procedures between the new and old research platforms (NEFSC Vessel Calibration Working Group 2007). To merge information collected in 2009 onward with that collected previously, we need to be able to transform indices (perhaps at size and age) of abundance from the *FRV Henry B. Bigelow* into those that would have been observed had the *R/V Albatross IV* still been in service. The general method for merging information from these two time series is to calibrate the new information to that of the old. Specifically we need to predict the relative abundance that would have been observed by the *Albatross IV* ( $\hat{R}_A$ ) using the relative abundance from the *Henry B. Bigelow* ( $R_B$ ) and a "calibration factor" ( $\rho$ ),

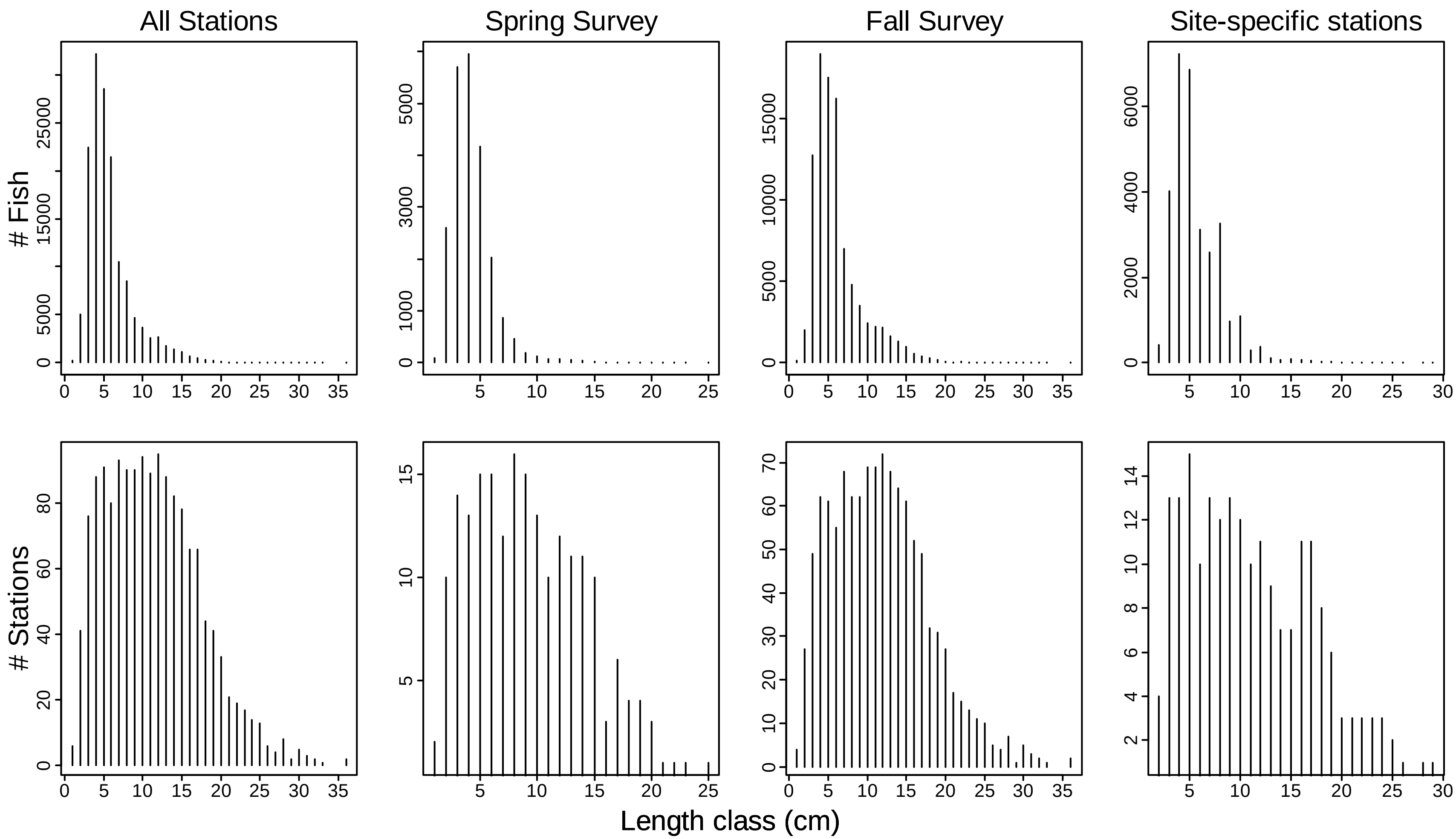
$$\hat{R}_A = \rho R_B . \qquad (2)$$

To provide information from which to estimate calibration factors for a broad range of species, 636 paired tows were conducted with the two vessels during 2008. Paired tows occurred at many stations in both the spring and fall surveys. Paired tows were also conducted during the summer and fall at non-random stations to improve the number of non-zero observations for some species. Protocols for the paired tows are described in NEFSC Vessel Calibration Working Group (2007).

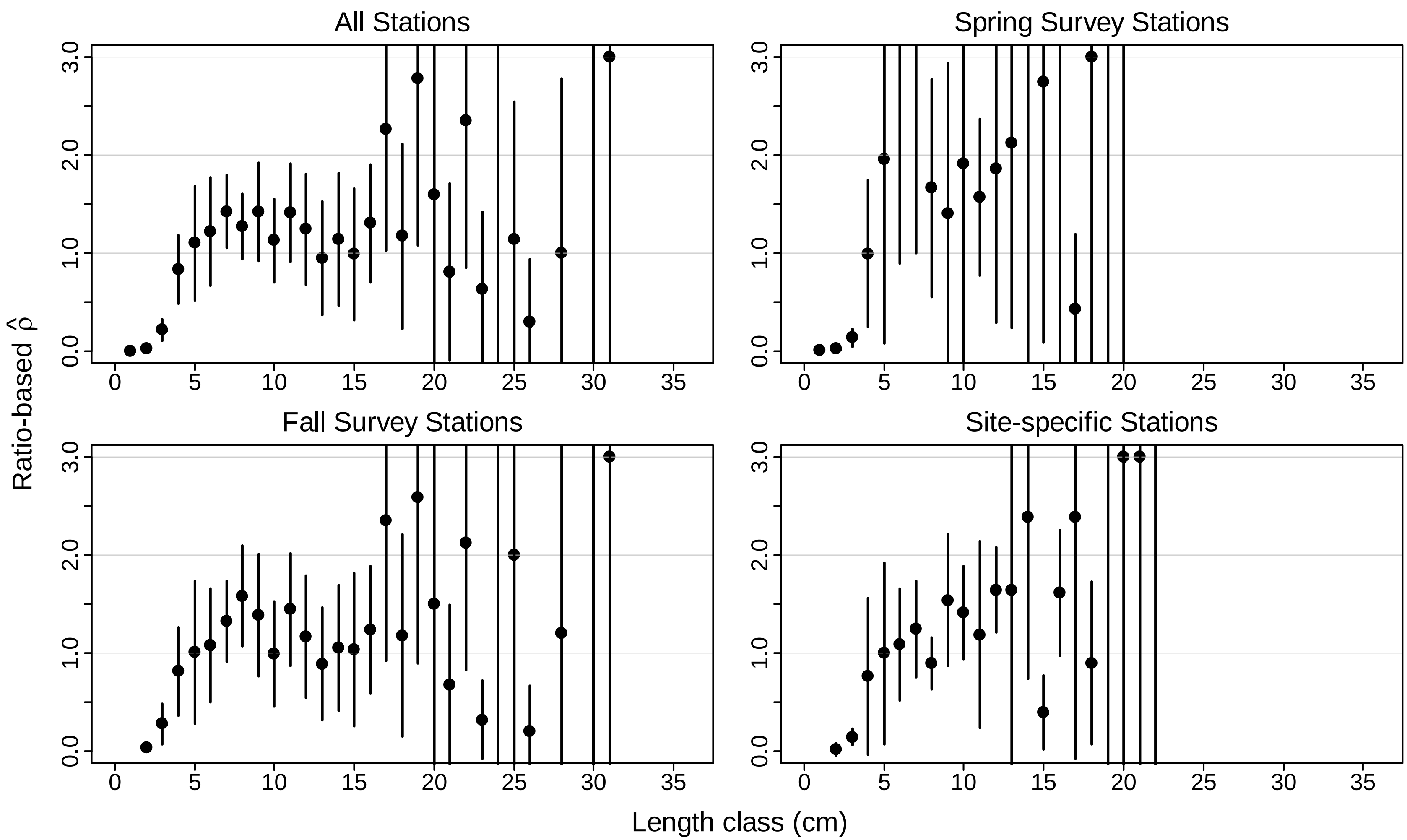
The methodology for estimating the calibration factors was proposed by the NEFSC and reviewed by a panel of independent scientists in 2009. The reviewers considered calibration factors that could potentially be specific to either the spring or fall survey (Miller *et al.* 2010). They recommended using a calibration factor estimator based on a beta-binomial model for the data collected at each station for most species, but also recommended using a ratio-type estimator under certain circumstances and not attempting to estimate calibration factors for species that were not well sampled.

Since the review, it has become apparent that accounting for size of individuals can be necessary for many species. When there are different selectivity patterns for the two vessels, the fraction of available fish of a given size taken by the two gears is different. Therefore, the ratio of the mean catches by the two vessels will change with size. Under these circumstances, the estimated calibration factor that ignores size reflects an average ratio weighted across sizes where the weights of each size class are at least in part related to the number of individuals at that size and the number of stations where individuals at that size were caught. Applying calibration factors that ignore size effects to surveys conducted in subsequent years when the size composition is unchanged should not produce biased predictions (eq. 1). However, when the size composition changes, the frequency of individuals and number of stations where individuals are observed at each size changes and the implicit weighting across size classes used to obtain the estimated calibration factor will not apply to the new data. Consequently, the predicted numbers per tow that would have been caught by the *Albatross IV* will be biased.

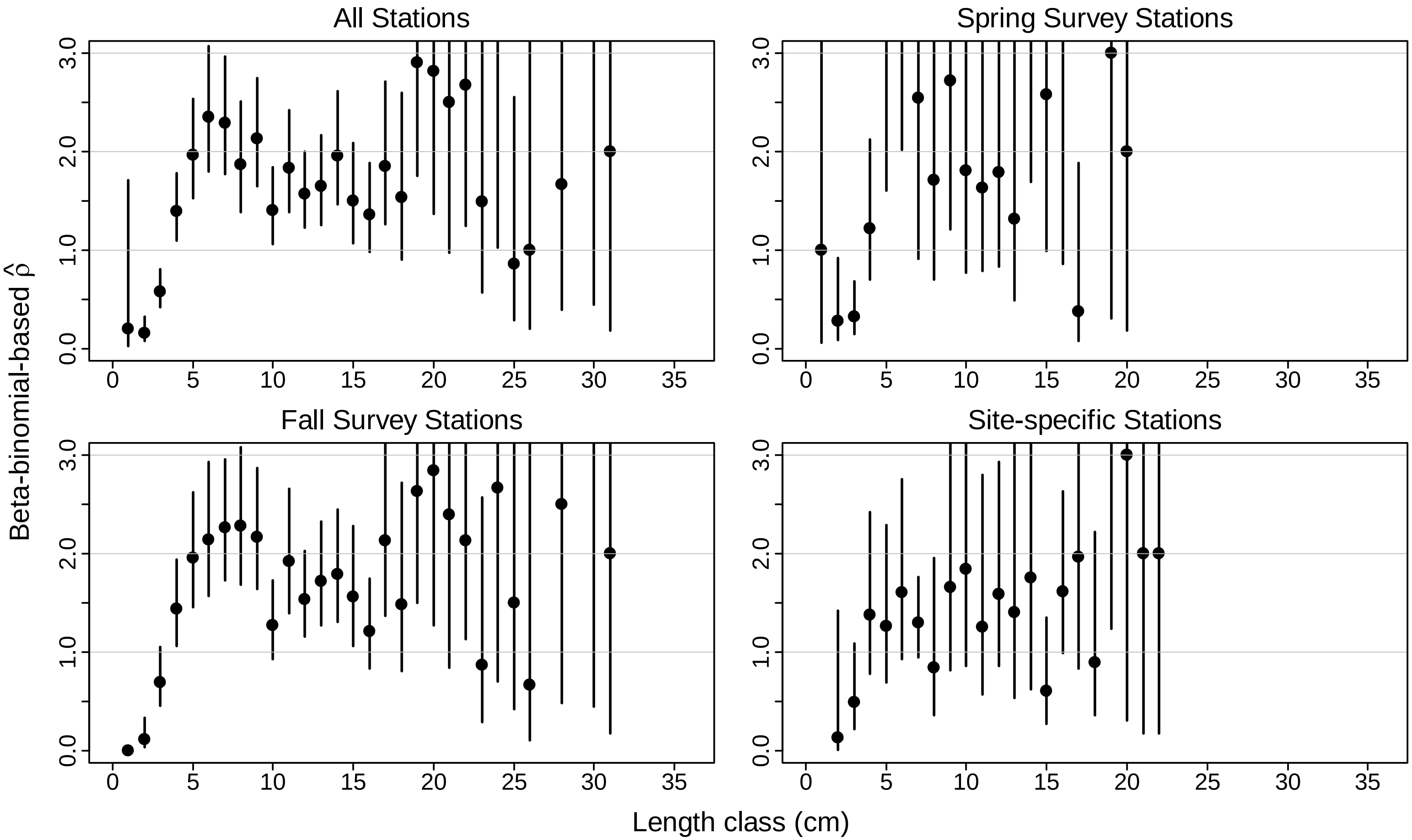
For *Loligo*, there are two primary seasonal cohorts observed each year in the NEFSC bottom trawl surveys and their abundances fluctuate substantially from year to year. Also, the assessment defines two size classes: pre-recruits (≤ 8 cm DML) and recruits (> 8 cm DML). The effects of inter-annual changes in size composition are negligible within each of the pre-recruit and recruit size classes. Therefore, we used a simple size-based calibration model that provided estimates of calibration factors that differ seasonally and are constant within each of the two size classes. Because only tows conducted during the daylight hours (between 0630 and 1630 during the fall and between 0630 and 1730 in the spring) were used in calculating abundance indices, we used the subset of paired tows from the calibration experiment that occurred during the same periods to fit models and estimate the *Loligo* calibration factors.



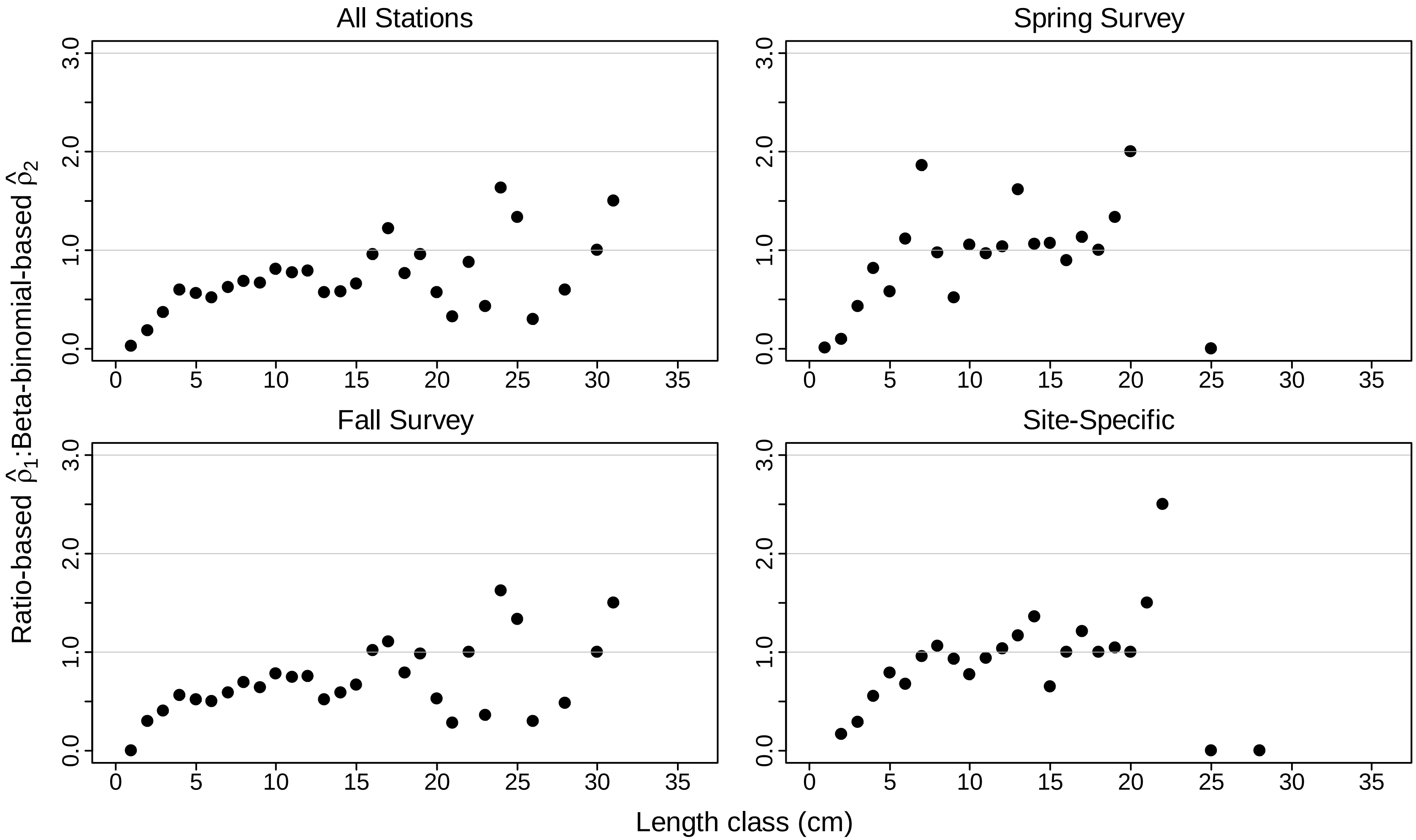

Appendix B3 Figure 1. Numbers of fish and number of stations where some fish were caught by length class for *Loligo* data from Spring and Fall survey stations, site-specific stations and all stations combined.



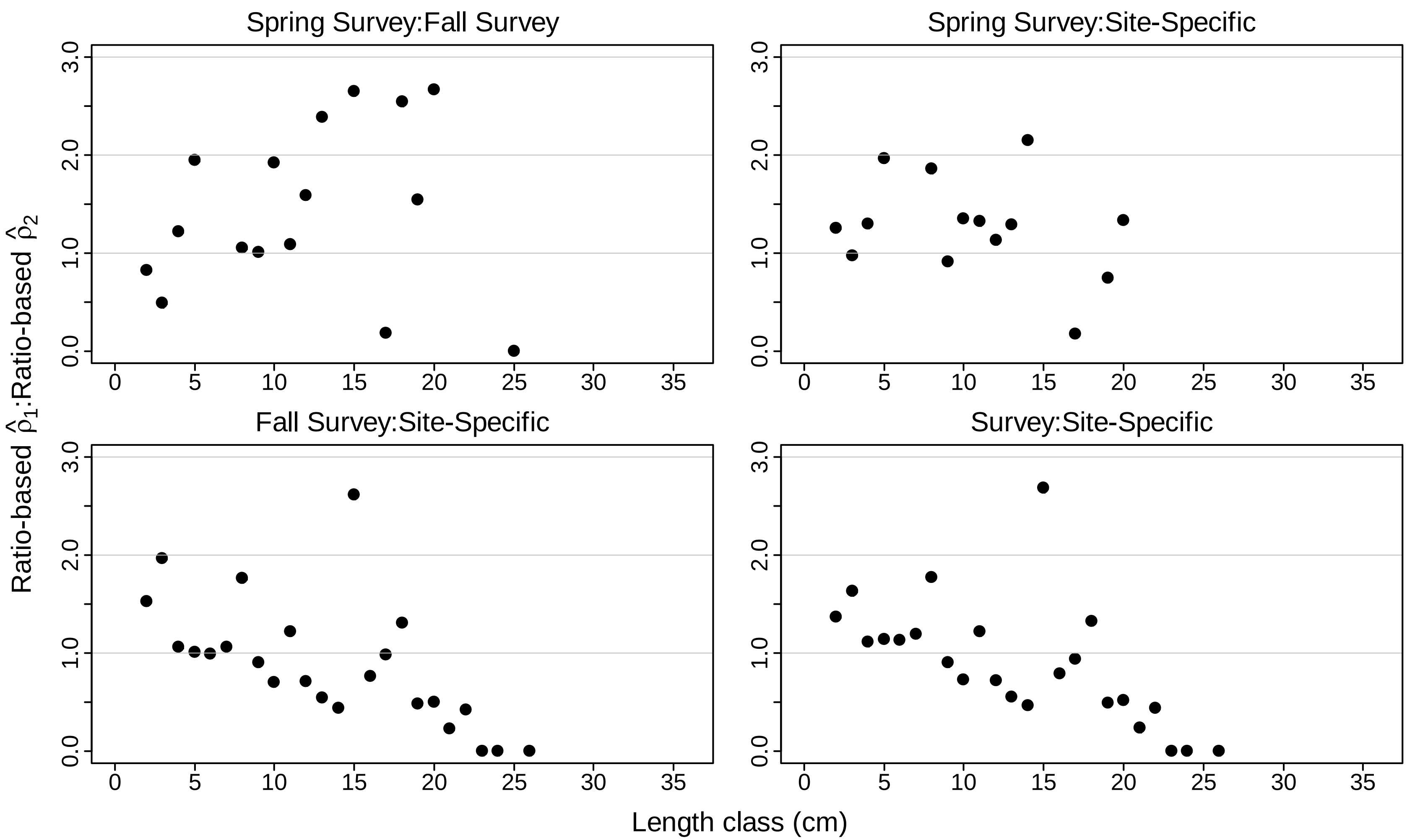

Appendix B3 Figure 2. Calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of stations based on ratios of mean catches. Lengths are binned in 1 cm intervals.



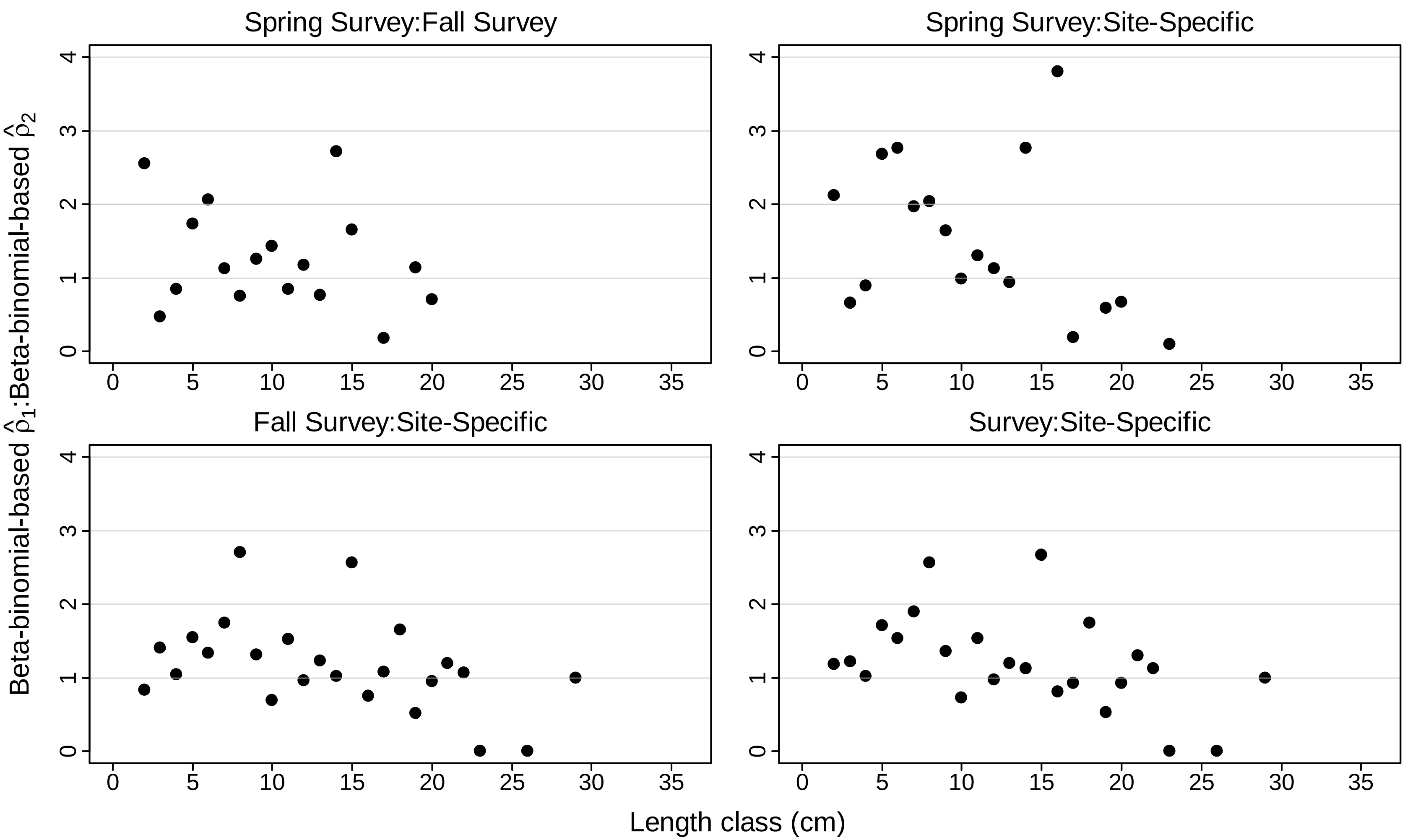

Appendix B3 Figure 3. Calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of stations based on a beta-binomial model. Lengths are binned in 1 cm intervals.



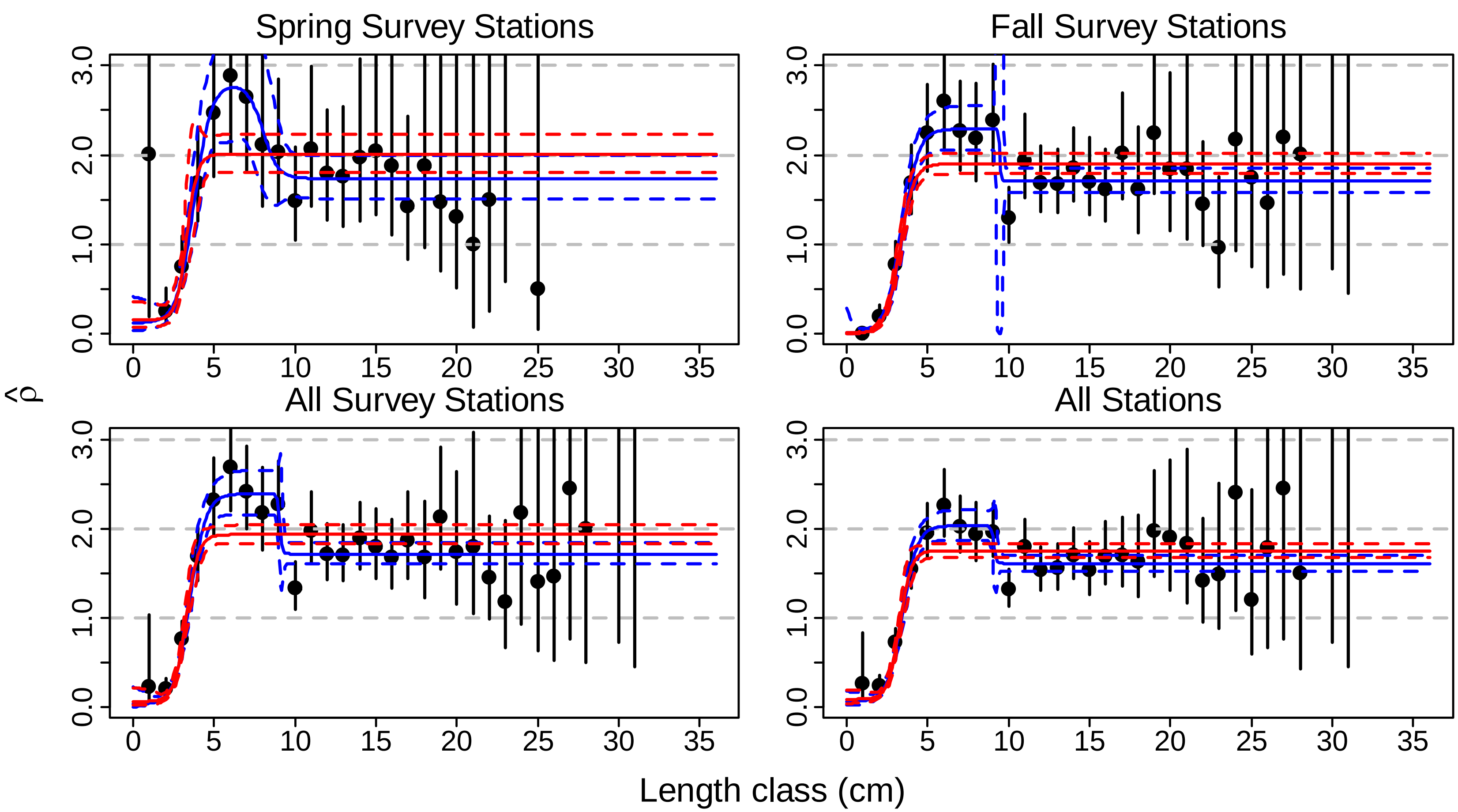

Appendix B3 Figure 4. Ratios of ratio-based to beta-binomial based calibration factors, by length bin, for *Loligo* catches from the Bigelow and Albatross IV in different sets of data. Lengths are binned in 1 cm intervals.



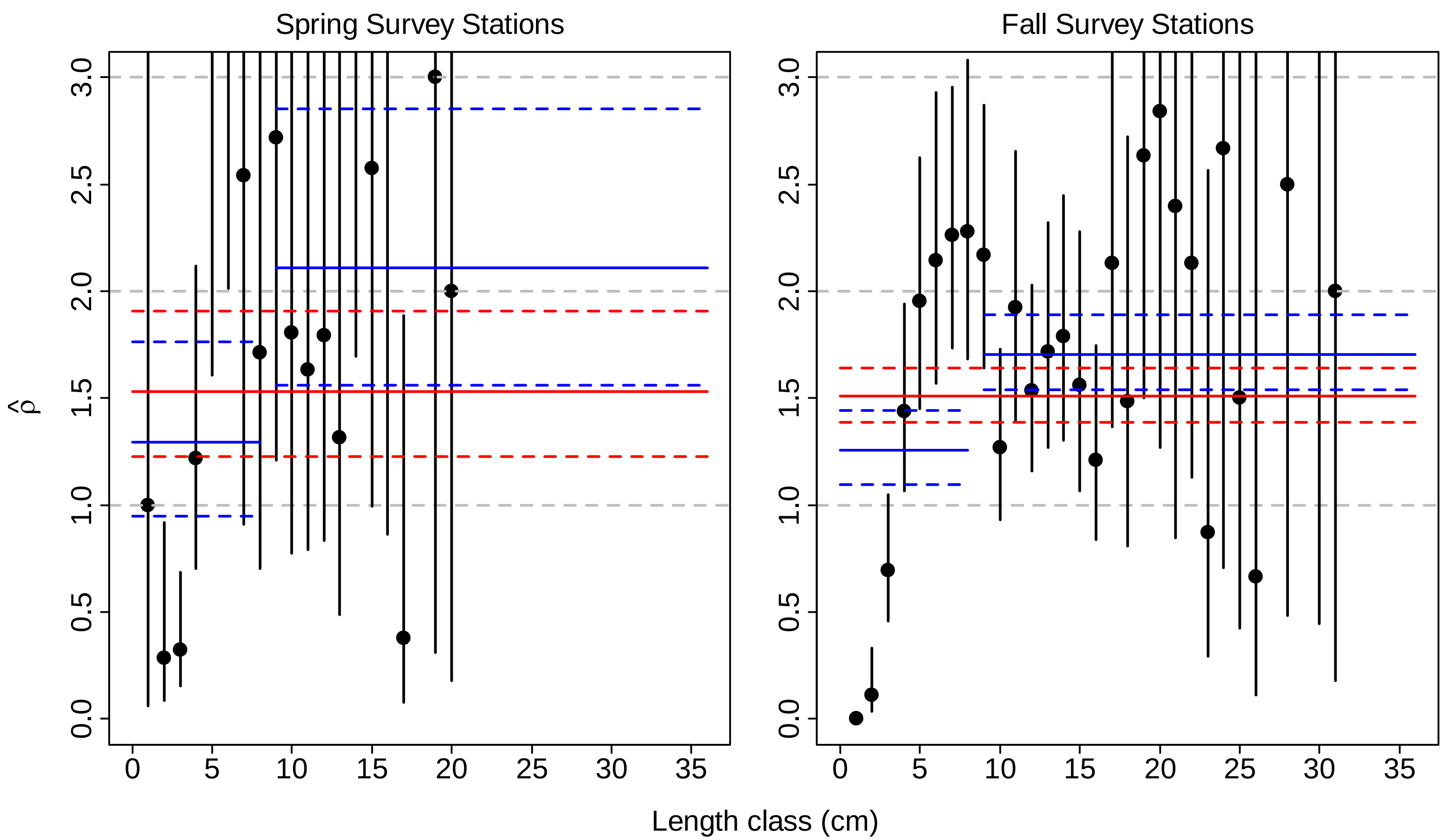

Appendix B3 Figure 5. Ratios of calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of data based on ratios of mean catches. Lengths are binned in 1 cm intervals.




Appendix B3 Figure 6. Ratios of calibration factor estimates for *Loligo* catches from the Bigelow and Albatross IV by length bin in different sets of data based on a beta-binomial model. Lengths are binned in 1 cm intervals.




Appendix B3 Figure 7. Calibration factors for *Loligo* at length based on a logistic (red) or double-logistic (blue) functional form fit to data from spring, fall, and all survey stations, and all stations combined.




Appendix B3 Figure 8. Calibration factors for pre-recruit (≤ 8 cm DML) and recruit (> 8cm DML) *Loligo* for stations sampled during daytime hours.

Appendix B3 Table 1. AIC values for models fit to *Loligo* length data.

| Model | # parameters | -LL | $AIC_c$ | $\Delta (AIC_c)$ | $AIC_c$ Weights |
|---|---|---|---|---|---|
| | | | | | |
| Constant | 2 | 10804.69 | 21613.37 | 539.7736 | 0.0000 |
| Survey, S-S, constant | 4 | 10790.77 | 21589.55 | 515.9484 | 0.0000 |
| S,F,S-S, constant model | 6 | 10787.28 | 21586.58 | 512.9762 | 0.0000 |
| | | | | | |
| Logistic model | 5 | 10562.58 | 21135.17 | 61.5728 | 0.0000 |
| Survey, S-S logistic | 10 | 10538.09 | 21096.22 | 22.6256 | 0.0000 |
| S, F, S-S, logistic | 15 | 10529.00 | 21088.10 | 14.5053 | 0.0006 |
| | | | | | |
| Double logistic model | 8 | 10551.54 | 21119.11 | 45.5072 | 0.0000 |
| Survey, S-S, double-logistic model | 16 | 10522.42 | 21076.96 | 3.3617 | 0.1569 |
| S,F,S-S, double-logistic model | 24 | 10512.67 | 21073.60 | 0.0000 | 0.8425 |
| | | | | | |

The constant model that ignores length is

$$\rho(l) = e^{\gamma}$$

and the logistic model is

$$\rho(l) = e^{\gamma} + \frac{e^{\alpha}}{1 + e^{-(\beta_0 + \beta_1 l)}}$$

which allows the lowest calibration factors to asymptote at a value greater than zero and the difference between the lowest and greatest values to be different than 1.
The double-logistic model is

$$\rho(l) = e^{\alpha}\left(e^{\gamma_1} + \frac{1 - e^{\gamma_1}}{1 + e^{-(\beta_0 + e^{\beta_1} l)}}\right)\left(e^{\gamma_2} + \frac{1 - e^{\gamma_2}}{1 + e^{(\beta_2 + e^{\beta_3} l)}}\right)$$

which allows the lowest calibration factors to asymptote at a value greater than zero at both small and large size classes and the difference between the lowest and greatest values to be greater than 1. In all models, the exponentiation of various parameters avoids boundary conditions during estimation. The parameters may differ for data obtained at spring or fall survey stations or the site-specific stations.

Letting the full set of calibration factor parameters be $\theta$ (which depends on the above models used), the beta-binomial likelihood we maximized is

$$L(\theta, \phi) = \prod_{i=1}^{S} \prod_{j=1}^{M} \frac{\text{Beta}\left(a_j + N_{Bij}, b_j + N_{Aij}\right)}{\text{Beta}\left(a_j, b_j\right)} \binom{N_{Aij} + N_{Bij}}{N_{Bij}}$$

where $\text{Beta}()$ is the beta function, and $N_{Aij}$ and $N_{Bij}$ are the numbers caught at station $i$ in length class $j$ by the Albatross IV and Bigelow, respectively. The likelihood is parameterized with parameters $a$ and $b$ which are functions of the calibration factor and dispersion parameter $\phi$,

$$a_j = \rho\left(l_j \mid \theta\right)\phi$$

and

$$b_j = \phi / (1 + \rho(l_j \mid \theta)).$$

**Appendix B4.** *Loligo* habitat outside the range of the survey strata set used in the assessment

The following analyses were conducted to determine the likelihood that substantial amounts of *Loligo pealeii* exist outside the range of the NEFSC bottom trawl survey strata used in the assessment during the survey time periods.

**Density-depth relationships for *Loligo***

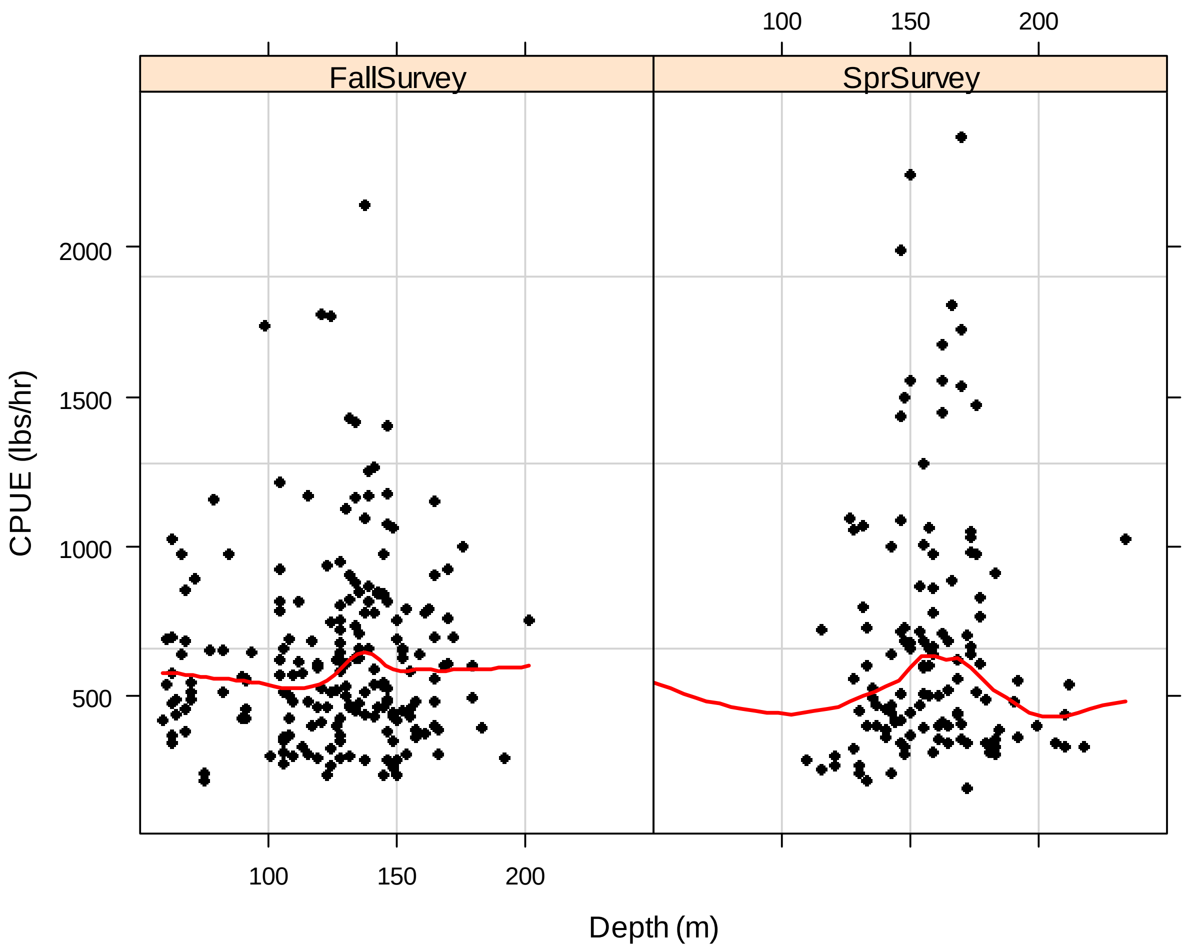
One set of analyses used catch-per tow data from the *Loligo* fishery and NEFSC spring and fall surveys to characterize daytime catch rates of *Loligo* as a function of depth. The analyses included only daytime tows based on the solar zenith criteria described in Appendix B2.

Commercial data were subset for spring (March-April, the time period of the spring survey) and fall (September-October-November, the time period of the fall survey). The data set included bottom trawl tows conducted during 1996-2009, with *Loligo* catches ≥ 2500 lbs, and with *Loligo* identified as the target species. The data for each tow included the time and location at the beginning and end of each haul, in addition to *Loligo* catch. The following variables were computed for each tow: tow duration (hours), CPUE (lbs $hour^{-1}$), and time, location and solar zenith for the middle of the tow. Tows were excluded if the solar zenith at the middle of the tow failed to meet the criteria for daytime tows. Categorization of daytime commercial tows was more difficult than for survey tows because commercial tows ranged from 1.2 to 6.8 hours in duration, often beginning in the day and ending at night or vice-versa. The commercial data used in the analysis were from 200 daytime tows in the fall and 129 daytime tows in the spring. CPUE was plotted against depth and smoothed with a loess regression line to identify trends. Results for fall were equivocal because there were no tows at depths beyond about 200 m. Results for spring indicated declining CPUE at depths beyond 175 meters (Figure 1), although data for deep water tows were limited.

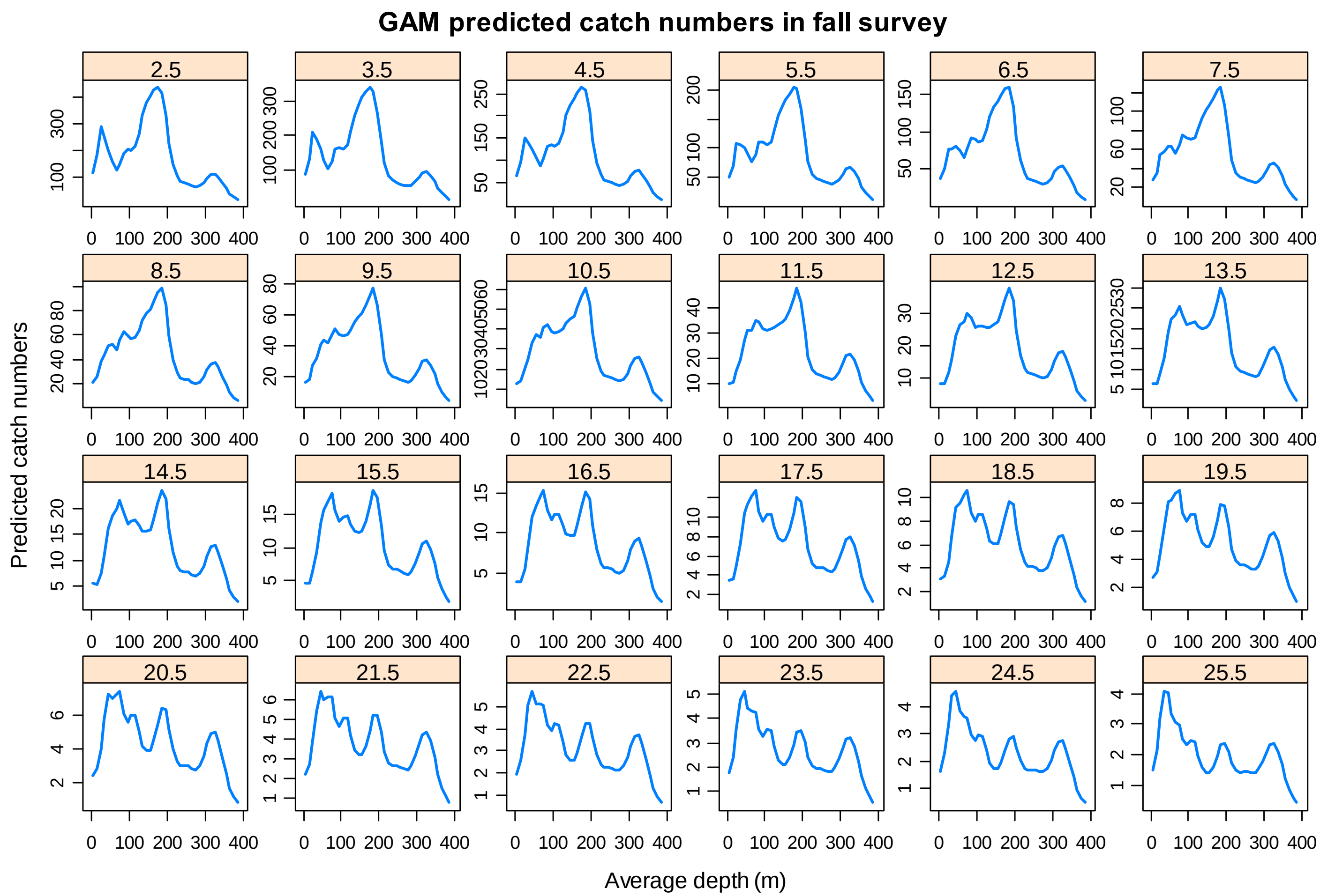
Survey catches at depth were predicted for *Loligo* of different sizes using the GAM models that were also used to characterize diel patterns in survey catches. As described in Appendix B2, the GAM models predicted survey catches in positive tows (tows catching at least one individual). The predictor variables included *Loligo* length (DML, in 1 cm increments), solar zenith, depth, temperature, region and year as well as interactions between size and solar zenith and size and depth. Spring and fall survey data were modeled separately.

Results for all size groups indicated that the predicted daytime catches declined to low values with increasing depth during fall and spring surveys (Figures 2-3). These trends suggest that high densities of *Loligo* at depths greater than those included in this assessment are unlikely.

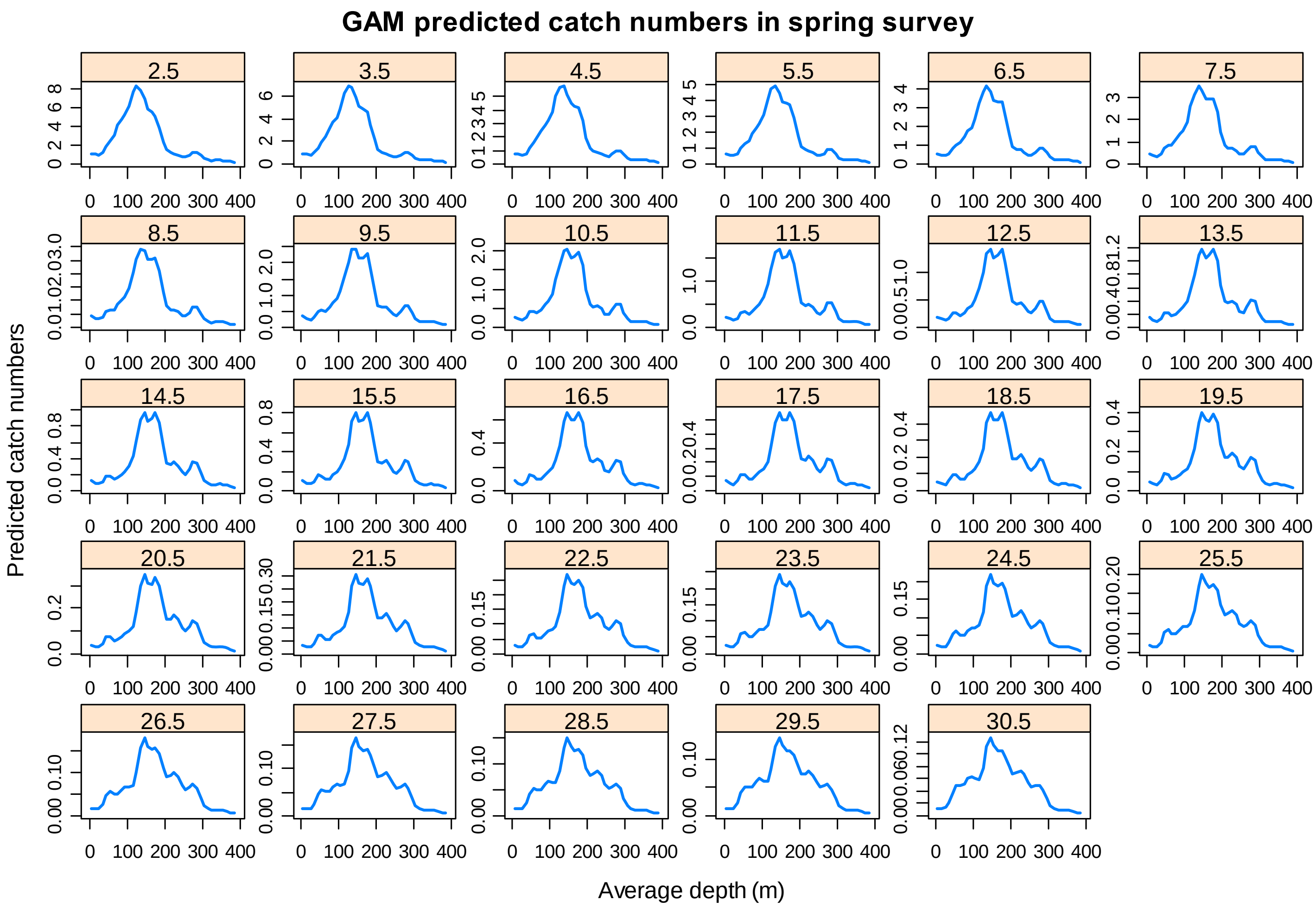
A third analysis used information from seasonal bottom trawl surveys that were conducted at depths greater than the limit of NEFSC surveys (366 m), by Rutgers University, during 2003-2007. Stations along transects located parallel to Baltimore and Hudson Canyons were sampled using a commercial *Loligo* bottom trawl. However, stations located at depths greater than 274 m were sampled at night. Catch rates of *Loligo pealeii* (kg per tow) in these surveys also show declines with increasing depth, similar to the analysis of catch rates with depth for daytime tows from NEFSC surveys. During some years, catch rates decline to very low levels at depths < 274 m which were sampled during the day (i.e., Hudson Canyon March 2003 and Nov. 2004 and 2007, Figure 4). Catch rates of *Loligo* were very low at depths greater than 366 m during January, March and November, but this result may be an artifact of nighttime sampling.



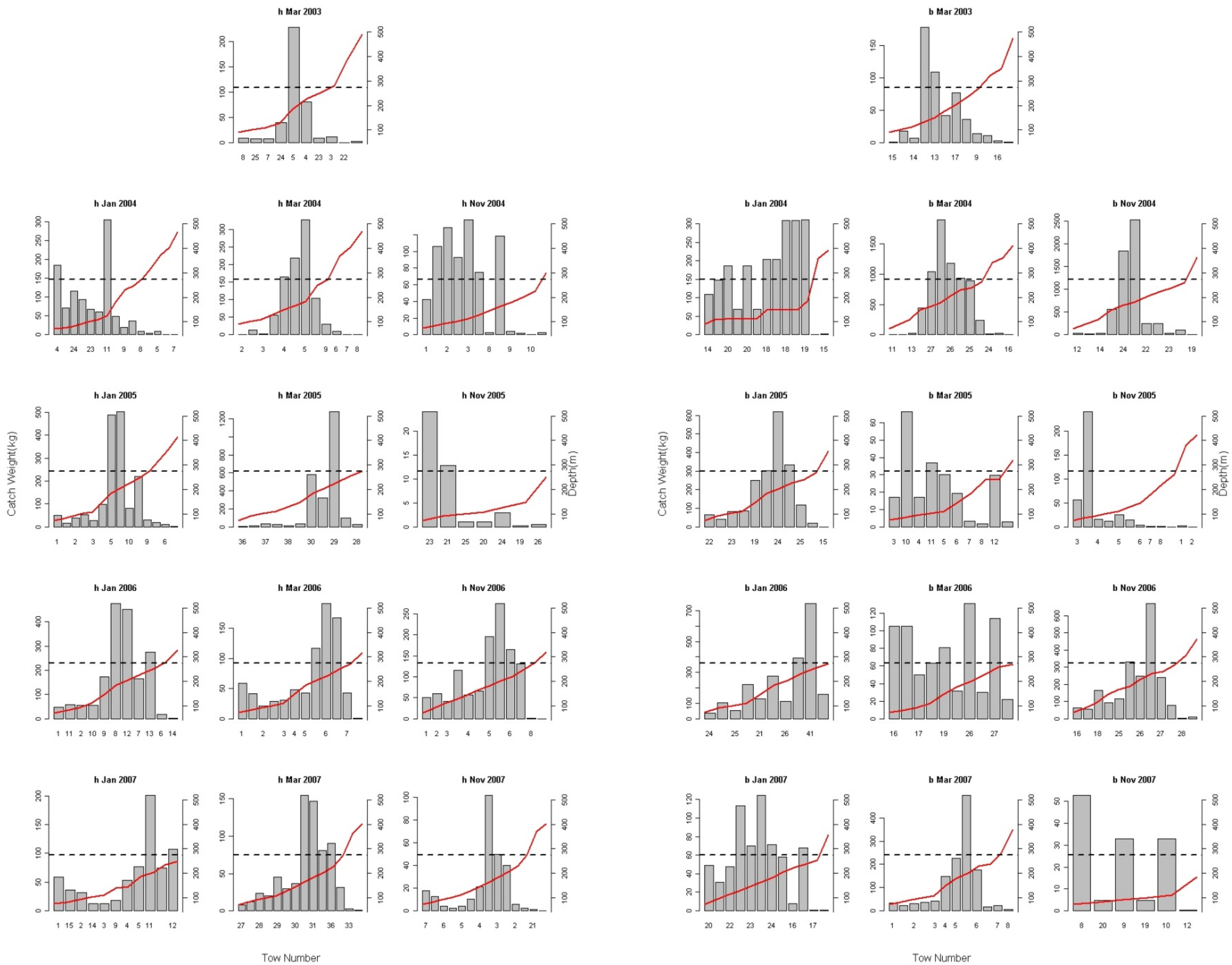

Appendix B4 Figure 1. CPUE for commercial tows targeting *Loligo* during the daytime vs. depth of tow, based on NEFOP observer data. The red line was fit by loess regression and is meant to show underlying trends.




Appendix B4 Figure 2. Predicted catch numbers in positive tows for NEFSC fall bottom trawl surveys as a function of depth from, GAM modeling. The label at the top of each panel is squid size (DML, in 1 cm intervals).




Appendix B4 Figure 3. Predicted catch numbers in positive tows for NEFSC spring bottom trawl surveys as a function of depth, from GAM modeling. The label at the top of each panel is squid size (DML, in 1 cm intervals).




Appendix B4 Figure 4. Relationship between *Loligo pealeii* catch rates (kg per tow) and depth based on seasonal bottom trawl transect surveys conducted by Rutgers University during 2003-2007. The red lines indicate station depths (m) and the black dashed line indicates the depth (274 m) beyond which stations were sampled at night. The titles indicate the transect identifier (b = Baltimore Canyon and h =Hudson Canyon.

**Appendix B5.** Estimation of natural mortality

Hendrickson and Hart (2006) developed an age-based cohort model for estimating the spawning mortality of semelparous cephalopods (a "maturation-natural mortality model"). The model was designed to estimate spawning and non-spawning natural mortality rates and maturity parameters based on maturity and age samples for another semelparous squid species, *Illex illecebrosus*. The model was used for *Loligo* for the first time in this assessment. The approach appears promising for estimation of maturity and mortality parameters but model estimates in this assessment should be regarded as preliminary due to data limitations and other uncertainties. Mortality and maturity rates in this analysis are weekly rates, unless stated otherwise.

Natural mortality rates for semelparous, short-lived squid species like *Loligo* tend to be very high (Hendrickson and Hart 2006). However, this is not unusual since *Loligo* serve as prey for many marine species and natural mortality rates increase at the time of spawning. The traditional approach to estimating maturity-at-age is misleading for squid species like *Loligo* because mature individuals are underrepresented in samples due to increased mortality rates after spawning. Similarly, age composition data are difficult to interpret because maturation rates (and total mortality) increase with age. Thus, in principle, a simple catch curve (log-transformed abundance vs. age) should be nonlinear (concave) and it is necessary to account for maturity and mortality rates in the same model.

## Materials and methods

The data for the model are assumed to consist of a random sample from the cohort or population over a range of ages, including spawning ages and ages completely recruited to the sampling gear. Age and maturity were recorded for each individual in the sample.

Two data sets were available and only results for females are reported here. The first (N=128 with 37 mature females) was collected during NEFSC and Connecticut (Long Island Sound) spring bottom trawl surveys in March (mostly) and May, respectively, during 1996-1998. The second set (N=68 with 51 mature females) was collected in March and May (mostly), during 1991-1993, in the offshore *Loligo* fishery and the Massachusetts weir fishery, respectively.. It was necessary to combine sampling locations and years because data were limited.

Ignoring gender, the maturity-mortality model assumes that maturation rates $R_a$ are a quadratic function of age $a$:

$$R_a = r_0 + r_1 a + r_2 a^2$$

where $r_0$, $r_1$ and $r_2$ are potentially estimable maturation parameters. In this assessment, the statistical significance of each of the maturation parameters is evaluated with the goal of omitting imprecise parameters and simplifying the model.Population dynamics are based on the differential equations:

$$\frac{dN}{dt} = -(M_{ns} + R)N$$

and

$$\frac{dS}{dt} = RN - (M_{ns} + M_{sp})S$$

where $N$ is the number of immature individuals, $S$ is the number of spawners, $M_{ns}$ is the non-spawning (immature) mortality rate, $M_{sp}$ is the spawning (mature) mortality rate, and the mortality parameters ($M_{ns}$ and $M_{sp}$) are potentially estimable. Hendrickson and Hart (2006) give exact solutions for these differential equations.

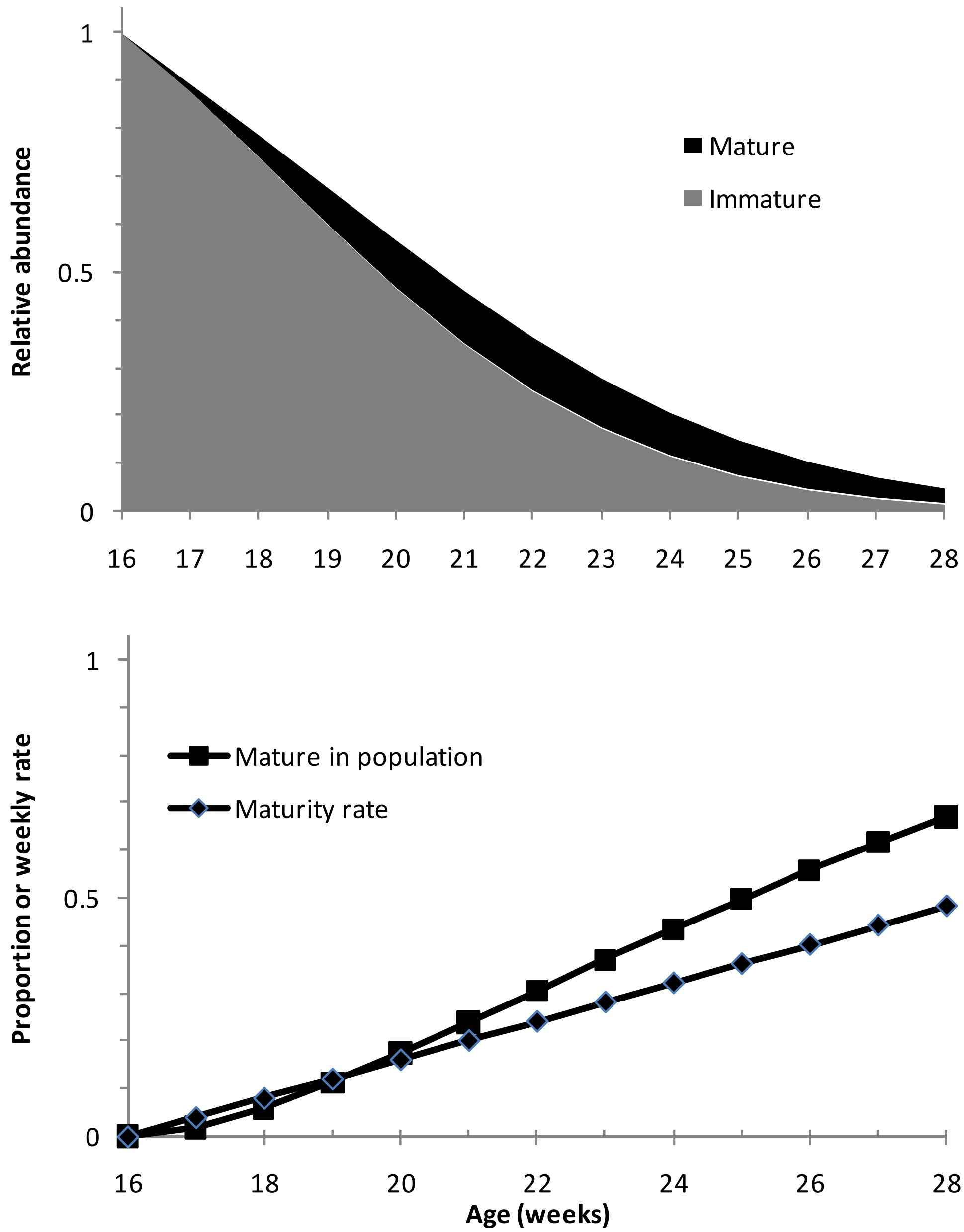
The maximum likelihood objective function used in fitting the model assumes that the age composition data (for fully recruited ages only) are multinomial with predicted age composition for mature and immature *Loligo* from the model (i.e., predicted age composition proportional to $N_a+S_a$), conditioned on the sample size. The objective function assumes that the observed proportions of mature individuals in each age group are independent binomials with sample size equal to the number of maturity samples in each age group, and predicted values from the model [i.e. predicted values = $S_a / (N_a+S_a)$]. There are five potentially estimable parameters ($r_0$, $r_1$, $r_2$, $M_{ns}$, $M_{sp}$). The parameters $r_0$, $M_{ns}$ and $M_{sp}$ were estimated as log transformed parameters and therefore constrained to be positive. The remaining maturity parameters were estimated directly so that estimates might be either positive or negative.

Hendrickson and Hart (2006) used data from a special age reader experiment to quantify aging precision. The predicted values from the model were smeared to account for ageing imprecision, before comparison to the data. Maturity parameter estimates for *Illex illecebrosus* were sensitive to assumptions about ageing imprecision, but natural mortality parameters were not. Ageing precision was not included for *Loligo* due to lack of experimental data.

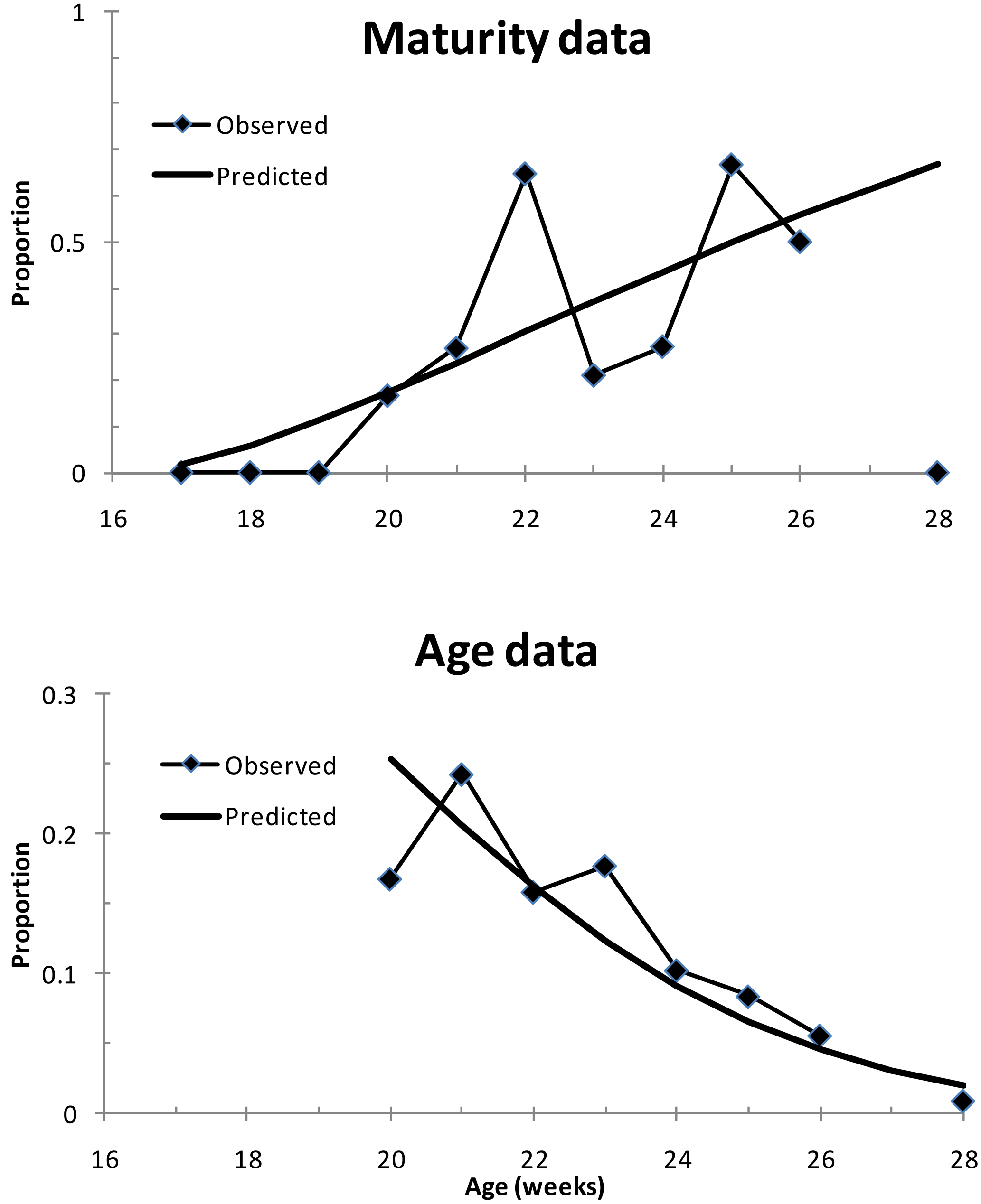
**Results**

As in Hendrickson and Hart (2006), preliminary model runs indicated that it was not possible to estimate both $M_{ns}$ and $M_{sp}$ simultaneously. Following Hendrickson and Hart, $M_{ns}$ was estimated using Caddy's (1996) gnomonic approach (= 0.11) and assumed in the model while fitting other parameters. As suggested by Hendrickson and Hart's (2006) results, only one ($r_1$ for data set 1) or two ($r_0$ and $r_1$ for data set 1) maturity parameters were statistically significant. Other maturity parameters were "turned off" and did not affect model estimates.

The best models for each data set (after fixing $M_{ns}$ = 0.11 and omitting unnecessary maturity parameters), gave estimated maturation rates ≤ 0.8 at all ages (Appendix B5 Figure 1). However, the shapes of the estimated relationships between age and maturity rates were different for the two data sets. $M_{sp}$ estimates ranged 0.19 (CV 0.40) to 0.48 (CV 0.11). There were no trends in the residual plots (Appendix B5 Figure 2).




Appendix B5 Figure 1. Biological estimates for *Loligo* from the best maturation-natural mortality model fit to data set 1. Estimates for data set 2 were generally similar although the maturity rate for data set 2 declined with age.




Appendix B5 Figure 2. Example residual plots for *Loligo* from the best maturation-mortality model fit to data set 1. Goodness of fit to data set 2 was generally similar.

**Appendix B6:** Estimates of minimum consumption of *Loligo pealeii*

Food habits were evaluated for 15 fish predators that consume *Loligo pealeii* consistently and commonly occur in NEFSC spring and fall bottom trawl surveys. The amount of food eaten, the type of food eaten and estimates of predator abundance were used to compute per capita consumption (*Loligo* consumed per predator) and total consumption of *Loligo*.

*Loligo* consumption estimates in this paper are minimum estimates and may represent a small fraction of total consumption because predation by other *Loligo*, birds, marine mammals and large pelagic fish area was not included. Predation by predators outside the survey area was not included either. Moreover, swept-area biomass estimates for many of predators were based on bottom trawl survey data without adjustments for survey bottom trawl catchability, resulting in underestimates of predator abundance and consumption. Finally, formulas used to compute per capita consumption probably produce conservative (biased low) estimates.

Results suggest that minimum consumption estimates for 15 fish predators in the survey area is relatively large in comparison to catches in most years (Figure 1). Consumption appears highest during fall when *Loligo* are most abundant and are widely distributed across the continental shelf and when predators which migrate south of the survey area during the spring surveys (e.g., bluefish and weakfish) are within the survey area.

## Methods

Every predator that contained *Loligo* was identified in the NEFSC Food Habits Database. From that original list, a subset of key predators (Table 1) was according to several "rules of thumb". In particular, the selected predators had *Loligo*: 1) amounting to more than 1% of prey composition during at least one five year block; as prey in more than 10 tows for each two year block; and in at least 10 stomachs for each three year block (Tables 2 and 3).

Food habits data collection is a routine part of NEFSC spring and fall bottom trawl surveys (Azarovitz 1981; NEFC 1988). Annual consumption for each predator species was estimated on a seasonal basis (January-June ="spring" and July-December = "fall") using data from spring and fall bottom trawl surveys during 1977-2009. Although food habits sampling was quantitative beginning in 1973, not all *Loligo* predators were sampled prior to 1977 (Link and Almeida (2000)). Consumption was calculated separately based on two size groups (≤ 20 cm and > 20 cm) for large predators. Total consumption for a predator was estimated as the sum of the estimates for each size group. Annual consumption was computed as the sum of estimates for spring and fall.

Methods were similar to previously described methods for estimating consumption using an evacuation rate model (Durbin *et al.* 1983; Ursin *et al.* 1985; Pennington 1985; Overholtz *et al.* 1991, 1999, 2000, 2008; Tsou & Collie 2001a, 2001b; Link & Garrison 2002; Link *et al.* 2006, 2008, 2009; Methratta & Link 2006; Link & Soseebe 2008; Overholtz & Link 2007, 2009; Tyrrell *et al.* 2007, 2008; Link and Idoine 2009, Moustahfid *et al.* 2009; NEFSC 2006, 2007a, 2007b, 2008, 2010a, 2010b). The main input data are: mean stomach contents ($S_i$) for each *Loligo* predator *i*; diet composition ($D_i$, proportion of total stomach contents consisting of *Loligo*), and bottom temperature records *T* from the bottom trawl surveys (Taylor *et al.* 2005). Units for stomach estimates are in grams.

As noted above, the gastric evacuation rate method was used to calculate per capita consumption (Eggers 1977, Elliott and Persson 1978). The two main parameters were fixed at α =0.004 and β =0.115, based on previous studies and sensitivity analyses (NEFSC 2007a, 2007b). However, α was set at 0.002 for elasmobranch predators to reflect relatively high metabolic costs in sharks and rays. As in most other studies, an additional parameter γ was set to one and had no effect on consumption estimates (Gerking 1994).

Per capita consumption rates $C_{it}$ were calculated:

$$C_{it} = 24 \cdot E_{it} \cdot \overline{S_{it}}^{\gamma}$$

where 24 is the number of hours in a day and the evacuation rate $E_{it}$ is:

$$E_{it} = \alpha e^{\beta T}$$

where *t* is a subscript for time period (season and year). Due to lack of data and to limit variability in the results, stomach contents data for some predators were averaged in blocks of two or three years (Table 1).

Estimated daily per capita consumption rates were scaled up to seasonal per capita consumption estimates for each *Loligo* predator. This was done by multiplying per capita consumption by the diet composition $D_{ij}$ for *Loligo,* and then by the number of days in each half year. The seasonal per capita estimates were summed to estimate annual per capita consumption. Annual per capita consumption was multiplied by the abundance of each predator to estimate the minimum amount of *Loligo* consumed on an annual basis.

Abundance estimates from stock assessments were available for six of the fifteen predators (Table 1). A crude estimate of the survey catchability parameter was derived by comparison of simple swept-area and stock assessment abundance estimates. The catchability parameter was used to scale minimum swept area estimates for the six predators to estimates of total abundance. Predator species without stock assessments used minimum swept area abundances without adjustment for catchability.

We used a simple and crude approach to approximate variance in *Loligo* consumption estimates (Link and Almeida 2000). Previous studies indicate that the largest source of variance is associated with the estimates of abundance. We therefore took the largest CV (with slight modifications) for abundance of each predator as a variance measure for total consumption These CVs ranged from 0.1 to 1.0 and were mostly in the range 0.35-0.50.

Length compositions of *Loligo* prey present in predator stomachs were plotted for each predator and season and compared to *Loligo* size composition data from the surveys and fishery data. These comparisons show the extent to which surveys, the fishery and predators sample the same size groups.

**Results**

The consumption estimates from this analysis are considered preliminary because further research is needed regarding the multiple sources of uncertainty noted below and because ecosystem and predator dynamics in relation to the complex life history and high turnover rates of squid populations are poorly understood. Minimum estimates of consumption for *Loligo* were 16,000-219,000 mt per year during 1977-2009 (Figure 1 and Table 4). During most years, consumption was higher during the fall than during the spring (Figure 2).

Most of the *Loligo* consumed were <10 cm DML (Figures 3 and 4) although some predators (summer flounder and goosefish) consumed larger individuals. In general, *Loligo* size compositions from stomachs samples were similar to survey size compositions indicating that predators may "sample" the *Loligo* stock in a representative manner. The fishery targets *Loligo* > 8 cm DML (annual modal size = 12 cm), which are larger than the bulk of *Loligo* prey found in predator stomachs.

Ignoring the differences in length composition that reduce the comparability of fishery and consumption data, minimum estimates of annual consumption removals were larger (often substantially) than annual catches (Figures 1 and 5). The exception was 1997 to 1998, when minimum consumption and catch were about equal.

**Sources of Uncertainty**

1. Stock assessment estimates of abundance were not available for all predators resulting in underestimation of *Loligo* consumption.
2. The assumed value $\alpha$ =0.004 is in the range used in other studies, but may be too low resulting in underestimation of consumption.
3. The distribution of *Loligo pleii* overlaps with *L. pealeii* near Cape Hatteras and the two species cannot be distinguished between using gross morphology. Therefore, the amount of *Loligo pealeii* consumption may be overestimated in geographic range where the two species overlap.
4. Some fish predators that did not consistently consume *Loligo* (e.g. some of the skates) were not included in the analysis resulting in underestimation of consumption.
5. Consumption of *Loligo* by seabirds, squids and marine mammals and cannibalism by other *Loligo* was not included resulting in underestimation of consumption.
6. Squid beaks are not enumerated in food habits sampling and *Loligo* probably digest rapidly. Thus per-capita consumption estimates may be biased low.
7. The analysis assumed complete spatial-temporal overlap of predators and *Loligo*.

Appendix B6 Table 1. *Loligo* predators included in minimum consumption estimates. Abundance information was from either from minimum swept area calculations (SWA) or from stock assessments (SA). The temporal resolution of the data (annual, 2 yr, or 3 yr) indicates the number of years used to average stomach contents and diet composition data.

| Common name | Scientific name | Source of abundance estimates | Time blocks |
|---|---|---|---|
| Pollock | *Pollachius virens* | SA | 2 yr |
| Bluefish | *Pomatomus saltatrix* | SA | 2 yr |
| Weakfish | *Cynoscion regalis* | SA | 2 yr |
| Summer Flounder | *Paralichthys dentatus* | SA | 3 yr |
| Goosefish | *Lophius americanus* | SA | 3 yr |
| Atlantic cod | *Gadus morhua* | SA | Annual |
| Red hake | *Urophycis chuss* | SWA | 2 yr |
| Spotted hake | *Urophycis regia* | SWA | 2 yr |
| Smooth dogfish | *Mustelus canis* | SWA | 3 yr |
| Fourspot flounder | *Paralichthys oblongus* | SWA | 3 yr |
| Spiny dogfish | *Squalus acanthias* | SWA | Annual |
| Little skate | *Raja ocellata* | SWA | Annual |
| Winter skate | *Raja erinacea* | SWA | Annual |
| Silver Hake | *Merluccius bilinearis* | SWA | Annual |
| White hake | *Urophycis tenuis* | SWA | Annual |

Appendix B6 Table 2. Numbers of tows in which *Loligo* was detected during spring survey food habits sampling. Figures are given starting in 1975, instead of 1977 when consumption estimates begin, because data were averaged in three year blocks for some species.

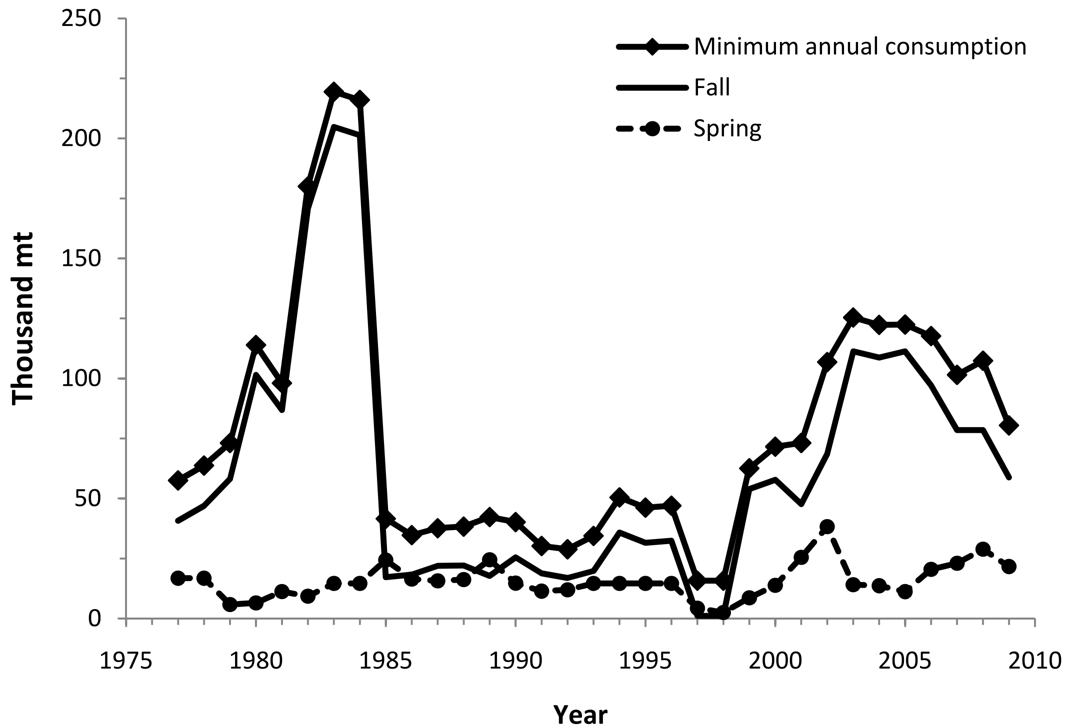
| Year | COD | BLUEFISH | FOURSPOT FLOUNDER | GOOSEFISH | LITTLE SKATE | POLLOCK | RED HAKE | SILVER HAKE | SMOOTH DOGFISH | SPINY DOGFISH | SPOTTED HAKE | SUMMER FLOUNDER | WEAKFISH | WHITE HAKE | WINDOWPANE | WINTER SKATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1975 | 2 | 0 | 1 | 0 | 7 | 1 | 2 | 14 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1976 | 40 | 0 | 7 | 0 | 26 | 33 | 18 | 37 | 0 | 0 | 11 | 0 | 0 | 11 | 0 | 0 |
| 1977 | 22 | 0 | 5 | 31 | 15 | 8 | 39 | 36 | 3 | 50 | 0 | 9 | 0 | 3 | 16 | 11 |
| 1978 | 15 | 0 | 3 | 26 | 18 | 6 | 35 | 42 | 7 | 44 | 0 | 6 | 1 | 5 | 21 | 11 |
| 1979 | 17 | 2 | 4 | 21 | 7 | 2 | 30 | 27 | 7 | 50 | 0 | 23 | 3 | 5 | 28 | 22 |
| 1980 | 22 | 3 | 5 | 29 | 3 | 11 | 18 | 25 | 9 | 37 | 0 | 14 | 3 | 3 | 20 | 14 |
| 1981 | 47 | 0 | 1 | 13 | 2 | 7 | 5 | 45 | 20 | 111 | 0 | 2 | 0 | 13 | 11 | 0 |
| 1982 | 70 | 2 | 3 | 40 | 10 | 24 | 23 | 65 | 12 | 102 | 5 | 21 | 3 | 35 | 10 | 16 |
| 1983 | 24 | 2 | 6 | 31 | 10 | 22 | 59 | 35 | 6 | 115 | 3 | 16 | 0 | 47 | 6 | 5 |
| 1984 | 3 | 0 | 1 | 11 | 6 | 36 | 60 | 0 | 7 | 114 | 0 | 1 | 0 | 28 | 2 | 5 |
| 1985 | 115 | 3 | 12 | 17 | 27 | 38 | 50 | 150 | 8 | 115 | 1 | 18 | 6 | 33 | 23 | 29 |
| 1986 | 82 | 7 | 31 | 30 | 52 | 28 | 51 | 148 | 6 | 137 | 15 | 48 | 3 | 57 | 36 | 40 |
| 1987 | 85 | 0 | 30 | 23 | 77 | 17 | 51 | 115 | 2 | 134 | 6 | 24 | 0 | 44 | 35 | 57 |
| 1988 | 83 | 1 | 20 | 17 | 50 | 15 | 43 | 90 | 1 | 109 | 1 | 21 | 0 | 44 | 1 | 57 |
| 1989 | 106 | 0 | 37 | 24 | 120 | 27 | 67 | 138 | 3 | 139 | 29 | 19 | 3 | 43 | 87 | 92 |
| 1990 | 91 | 1 | 1 | 16 | 97 | 24 | 48 | 103 | 5 | 147 | 9 | 12 | 4 | 36 | 37 | 79 |
| 1991 | 100 | 1 | 41 | 55 | 149 | 52 | 61 | 146 | 8 | 167 | 30 | 43 | 7 | 53 | 42 | 100 |
| 1992 | 72 | 4 | 55 | 38 | 130 | 29 | 70 | 133 | 7 | 149 | 23 | 50 | 10 | 53 | 79 | 94 |
| 1993 | 89 | 6 | 70 | 43 | 160 | 37 | 92 | 149 | 10 | 150 | 37 | 49 | 12 | 52 | 84 | 103 |
| 1994 | 81 | 1 | 56 | 45 | 141 | 29 | 85 | 144 | 8 | 145 | 45 | 58 | 9 | 62 | 90 | 98 |
| 1995 | 70 | 0 | 75 | 60 | 143 | 33 | 105 | 158 | 8 | 177 | 50 | 45 | 13 | 57 | 75 | 82 |
| 1996 | 72 | 6 | 62 | 40 | 153 | 20 | 90 | 121 | 13 | 165 | 41 | 61 | 1 | 50 | 87 | 114 |
| 1997 | 82 | 4 | 73 | 26 | 127 | 40 | 85 | 142 | 7 | 178 | 60 | 61 | 2 | 35 | 59 | 68 |
| 1998 | 74 | 3 | 71 | 76 | 184 | 50 | 134 | 185 | 12 | 195 | 73 | 72 | 7 | 62 | 114 | 97 |
| 1999 | 68 | 5 | 83 | 80 | 155 | 40 | 117 | 181 | 14 | 185 | 83 | 78 | 4 | 53 | 96 | 88 |
| 2000 | 82 | 7 | 73 | 71 | 170 | 43 | 101 | 156 | 12 | 171 | 67 | 80 | 17 | 56 | 97 | 101 |
| 2001 | 66 | 3 | 80 | 81 | 146 | 32 | 103 | 162 | 11 | 150 | 63 | 71 | 6 | 51 | 64 | 68 |
| 2002 | 90 | 8 | 85 | 75 | 146 | 39 | 109 | 184 | 27 | 210 | 87 | 85 | 22 | 56 | 79 | 71 |
| 2003 | 69 | 5 | 67 | 56 | 163 | 31 | 111 | 134 | 12 | 160 | 70 | 73 | 3 | 47 | 81 | 101 |
| 2004 | 81 | 2 | 59 | 50 | 138 | 33 | 98 | 151 | 9 | 143 | 60 | 72 | 1 | 49 | 70 | 104 |
| 2005 | 73 | 5 | 63 | 58 | 129 | 31 | 88 | 130 | 13 | 141 | 59 | 64 | 6 | 49 | 69 | 71 |
| 2006 | 69 | 10 | 79 | 44 | 132 | 37 | 130 | 177 | 15 | 200 | 82 | 78 | 9 | 56 | 76 | 90 |
| 2007 | 79 | 5 | 84 | 49 | 148 | 34 | 122 | 153 | 12 | 183 | 89 | 75 | 7 | 50 | 77 | 101 |
| 2008 | 67 | 5 | 63 | 40 | 120 | 42 | 114 | 164 | 15 | 180 | 85 | 75 | 12 | 54 | 74 | 89 |
| 2009 | 91 | 3 | 117 | 131 | 209 | 30 | 200 | 272 | 19 | 198 | 113 | 118 | 1 | 103 | 120 | 187 |
| Total | 2299 | 104 | 1523 | 1447 | 3370 | 981 | 2614 | 4112 | 328 | 4651 | 1298 | 1542 | 175 | 1455 | 1866 | 2265 |

Appendix B6 Table 3. Numbers of tows in which *Loligo* was detected during fall survey food habits sampling. Figures are given starting in 1975, instead of 1977 when consumption estimates begin, because data were averaged in three year blocks for some species.

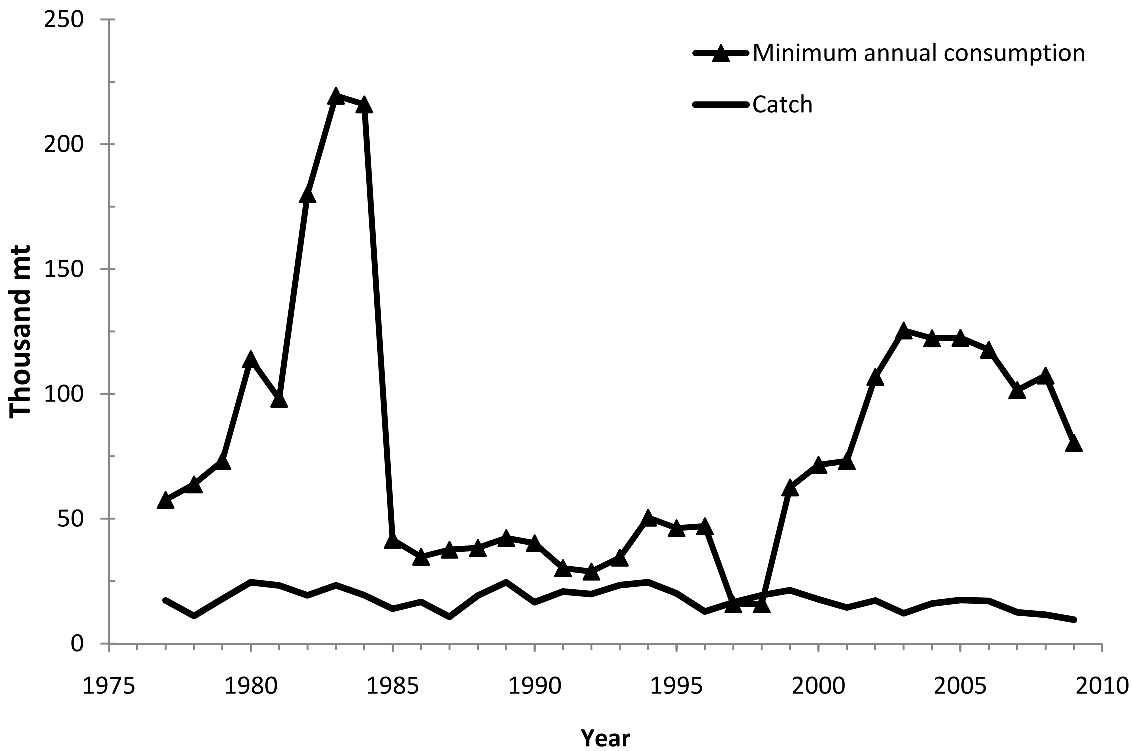
| Year | COD | BLUEFISH | FOURSPOT FLOUNDER | GOOSEFISH | LITTLE SKATE | POLLOCK | RED HAKE | SILVER HAKE | SMOOTH DOGFISH | SPINY DOGFISH | SPOTTED HAKE | SUMMER FLOUNDER | WEAKFISH | WHITE HAKE | WINDOWPANE | WINTER SKATE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1975 | 34 | 0 | 3 | 0 | 17 | 18 | 7 | 41 | 0 | 0 | 6 | 0 | 0 | 14 | 0 | 0 |
| 1976 | 30 | 0 | 9 | 0 | 17 | 13 | 16 | 43 | 0 | 0 | 12 | 0 | 0 | 11 | 0 | 0 |
| 1977 | 0 | 1 | 0 | 32 | 11 | 1 | 31 | 34 | 10 | 34 | 0 | 9 | 0 | 3 | 12 | 11 |
| 1978 | 4 | 19 | 4 | 50 | 14 | 0 | 28 | 26 | 21 | 35 | 0 | 17 | 11 | 2 | 8 | 11 |
| 1979 | 2 | 40 | 7 | 44 | 3 | 1 | 31 | 19 | 32 | 36 | 2 | 49 | 13 | 1 | 33 | 9 |
| 1980 | 1 | 15 | 0 | 29 | 1 | 0 | 18 | 7 | 4 | 17 | 0 | 14 | 4 | 0 | 9 | 13 |
| 1981 | 26 | 27 | 4 | 14 | 2 | 5 | 6 | 24 | 11 | 38 | 3 | 19 | 2 | 12 | 3 | 1 |
| 1982 | 0 | 20 | 5 | 32 | 1 | 21 | 54 | 10 | 15 | 64 | 7 | 10 | 9 | 45 | 6 | 5 |
| 1983 | 0 | 7 | 0 | 24 | 0 | 24 | 47 | 2 | 12 | 97 | 0 | 1 | 0 | 60 | 0 | 3 |
| 1984 | 23 | 24 | 11 | 17 | 9 | 19 | 61 | 26 | 16 | 72 | 1 | 4 | 5 | 58 | 6 | 25 |
| 1985 | 45 | 42 | 18 | 24 | 16 | 26 | 55 | 115 | 25 | 78 | 17 | 40 | 25 | 50 | 11 | 6 |
| 1986 | 63 | 32 | 18 | 13 | 30 | 12 | 39 | 112 | 25 | 65 | 8 | 15 | 15 | 73 | 15 | 21 |
| 1987 | 43 | 47 | 30 | 24 | 24 | 14 | 36 | 99 | 25 | 46 | 43 | 31 | 8 | 53 | 28 | 20 |
| 1988 | 55 | 23 | 40 | 17 | 14 | 23 | 52 | 115 | 26 | 63 | 47 | 29 | 4 | 52 | 0 | 26 |
| 1989 | 60 | 60 | 51 | 24 | 60 | 19 | 73 | 132 | 40 | 63 | 55 | 40 | 38 | 68 | 38 | 41 |
| 1990 | 55 | 46 | 76 | 21 | 74 | 22 | 76 | 160 | 43 | 94 | 53 | 53 | 23 | 96 | 50 | 45 |
| 1991 | 55 | 43 | 63 | 65 | 95 | 30 | 75 | 153 | 42 | 87 | 63 | 63 | 21 | 121 | 62 | 62 |
| 1992 | 54 | 54 | 96 | 47 | 106 | 25 | 70 | 177 | 45 | 97 | 85 | 72 | 36 | 86 | 75 | 59 |
| 1993 | 49 | 48 | 93 | 66 | 111 | 24 | 98 | 186 | 45 | 82 | 72 | 65 | 24 | 88 | 78 | 62 |
| 1994 | 0 | 3 | 90 | 10 | 122 | 18 | 101 | 173 | 39 | 89 | 75 | 6 | 34 | 80 | 79 | 65 |
| 1995 | 51 | 4 | 82 | 65 | 116 | 23 | 102 | 147 | 52 | 90 | 77 | 77 | 60 | 69 | 80 | 84 |
| 1996 | 66 | 54 | 95 | 60 | 108 | 26 | 99 | 146 | 51 | 123 | 89 | 70 | 44 | 59 | 82 | 67 |
| 1997 | 55 | 53 | 68 | 52 | 85 | 30 | 92 | 138 | 45 | 124 | 58 | 81 | 25 | 71 | 65 | 56 |
| 1998 | 81 | 54 | 99 | 55 | 125 | 34 | 132 | 182 | 56 | 156 | 95 | 94 | 37 | 88 | 86 | 86 |
| 1999 | 64 | 69 | 92 | 69 | 126 | 36 | 104 | 147 | 57 | 137 | 81 | 107 | 62 | 80 | 79 | 73 |
| 2000 | 49 | 59 | 91 | 72 | 114 | 42 | 101 | 134 | 47 | 105 | 72 | 96 | 51 | 66 | 72 | 60 |
| 2001 | 56 | 61 | 85 | 81 | 110 | 54 | 101 | 163 | 61 | 116 | 103 | 94 | 41 | 60 | 70 | 70 |
| 2002 | 42 | 64 | 91 | 84 | 120 | 27 | 90 | 129 | 62 | 119 | 84 | 94 | 50 | 54 | 64 | 60 |
| 2003 | 52 | 65 | 99 | 75 | 120 | 39 | 118 | 166 | 82 | 111 | 131 | 92 | 66 | 60 | 97 | 57 |
| 2004 | 49 | 57 | 66 | 59 | 76 | 38 | 83 | 156 | 60 | 96 | 69 | 97 | 38 | 75 | 56 | 47 |
| 2005 | 51 | 58 | 99 | 64 | 105 | 41 | 115 | 136 | 63 | 126 | 97 | 79 | 44 | 60 | 79 | 68 |
| 2006 | 62 | 86 | 95 | 63 | 114 | 25 | 108 | 180 | 80 | 166 | 104 | 93 | 65 | 72 | 84 | 71 |
| 2007 | 54 | 61 | 99 | 46 | 103 | 23 | 111 | 155 | 61 | 119 | 70 | 96 | 43 | 79 | 71 | 67 |
| 2008 | 55 | 69 | 95 | 45 | 106 | 27 | 112 | 178 | 60 | 131 | 97 | 96 | 59 | 81 | 77 | 64 |
| 2009 | 45 | 50 | 152 | 136 | 134 | 14 | 150 | 206 | 49 | 129 | 141 | 97 | 21 | 96 | 71 | 58 |
| Total | 1431 | 1415 | 2026 | 1579 | 2389 | 794 | 2592 | 4017 | 1362 | 3005 | 1917 | 1900 | 978 | 2043 | 2905 | 1473 |

Appendix B6 Table 4. Minimum annual consumption estimates (000s mt) and CVs for *Loligo*.

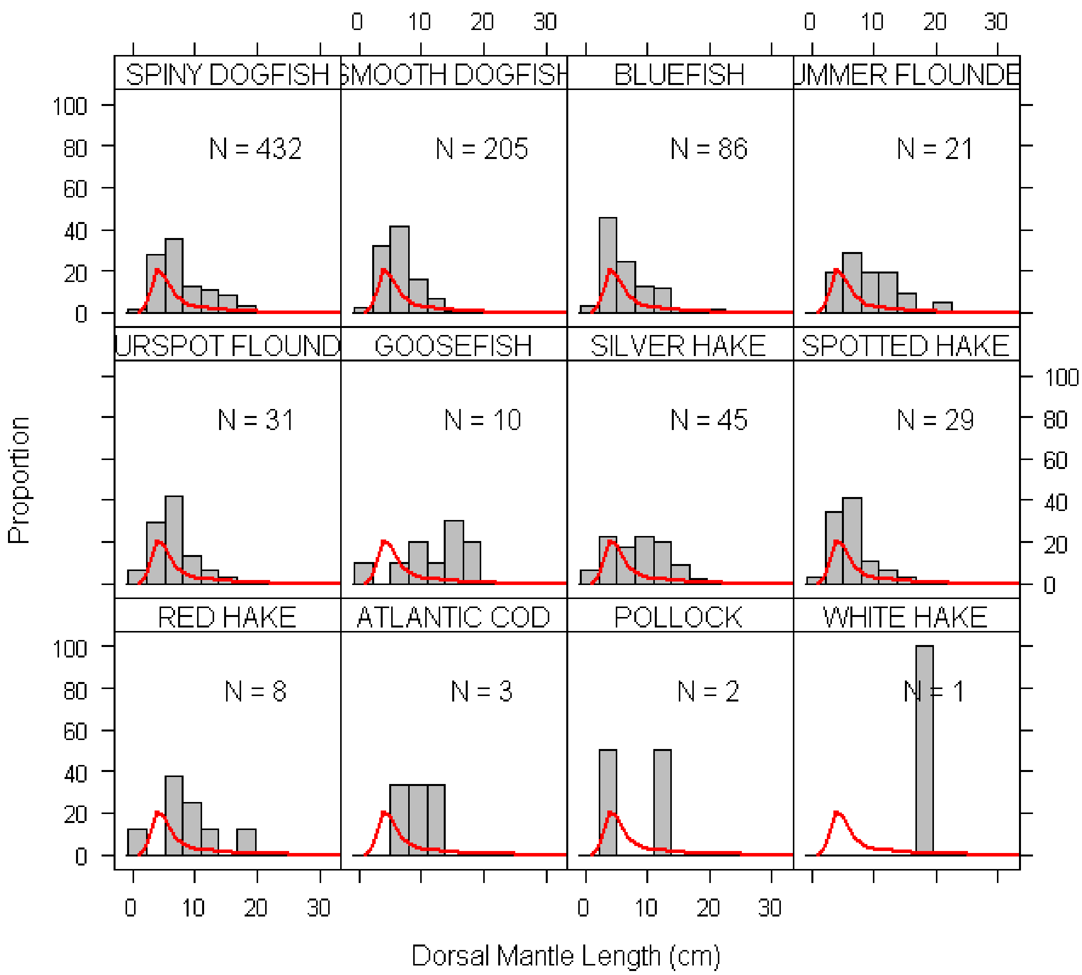
| Year | Mimimum consumption (1000 mt) | CV |
|---|---|---|
| 1977 | 57.5 | 0.35 |
| 1978 | 63.7 | 0.35 |
| 1979 | 73.1 | 0.35 |
| 1980 | 113.9 | 0.35 |
| 1981 | 98.1 | 0.35 |
| 1982 | 180.0 | 0.68 |
| 1983 | 219.4 | 0.63 |
| 1984 | 216.0 | 0.60 |
| 1985 | 41.6 | 0.75 |
| 1986 | 34.7 | 0.81 |
| 1987 | 37.6 | 0.42 |
| 1988 | 38.3 | 0.47 |
| 1989 | 42.3 | 0.58 |
| 1990 | 40.2 | 0.47 |
| 1991 | 30.2 | 0.48 |
| 1992 | 28.9 | 0.37 |
| 1993 | 34.4 | 0.38 |
| 1994 | 50.4 | 0.61 |
| 1995 | 46.2 | 0.37 |
| 1996 | 47.0 | 0.58 |
| 1997 | 15.8 | 0.50 |
| 1998 | 15.8 | 0.45 |
| 1999 | 62.6 | 0.69 |
| 2000 | 71.6 | 0.39 |
| 2001 | 73.1 | 0.63 |
| 2002 | 106.8 | 0.35 |
| 2003 | 125.4 | 0.35 |
| 2004 | 122.3 | 0.66 |
| 2005 | 122.5 | 0.46 |
| 2006 | 117.7 | 0.43 |
| 2007 | 101.5 | 0.43 |
| 2008 | 107.4 | 0.45 |
| 2009 | 80.5 | 0.45 |



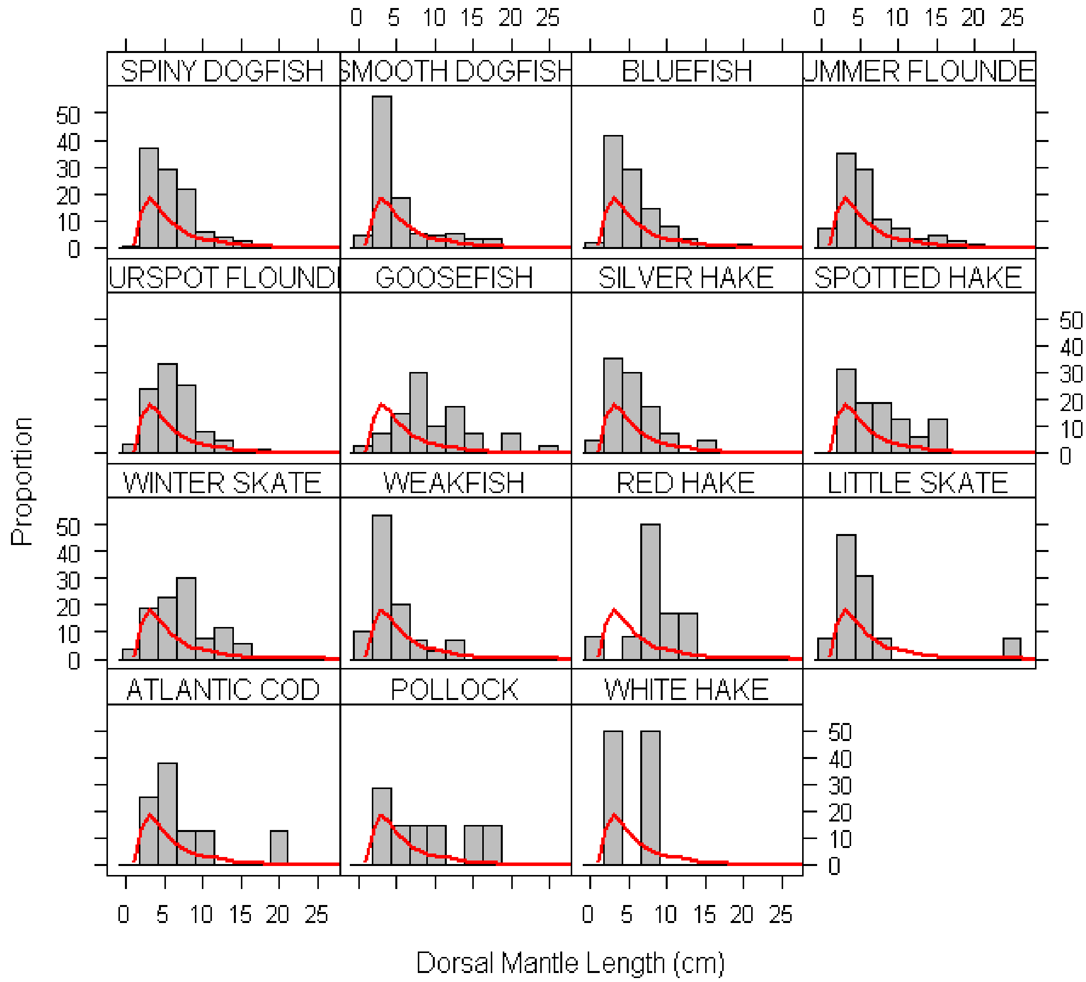

Appendix B6 Figure 1. Minimum seasonal and annual estimates of consumption for *Loligo*.



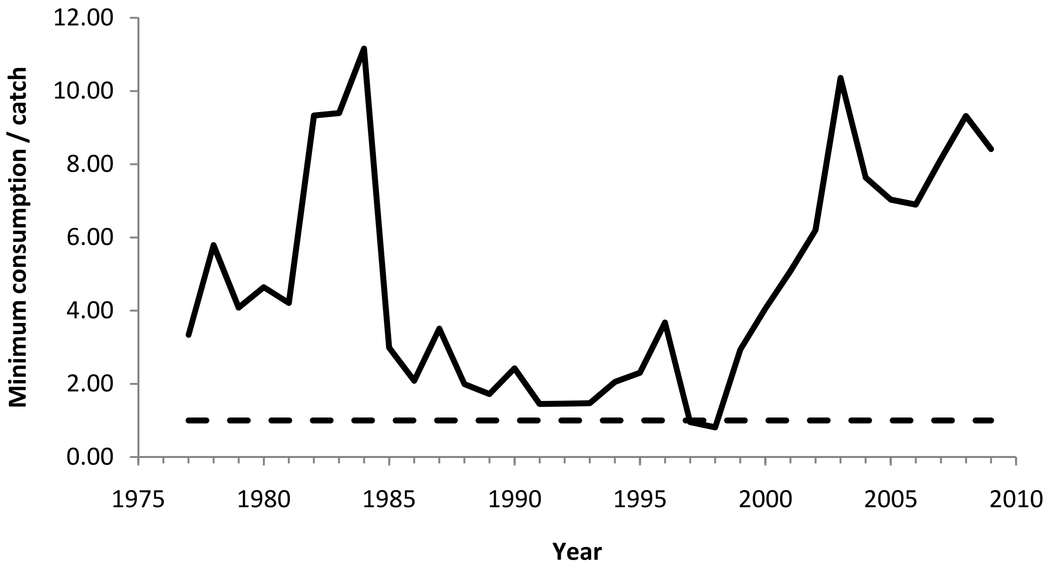

Appendix B6 Figure 2. Annual estimates of minimum consumption and catch for *Loligo*.




Appendix B6 Figure 3. Size frequency of *Loligo* eaten by the predators sampled during spring surveys. The red line shows the average survey length composition during 1975-2009. Numbers in each panel are the number of *Loligo* measured.




Appendix B6 Figure 4. Size frequency of *Loligo* eaten by the predators sampled during fall surveys. The red line shows the average survey length composition during 1975-2009. Numbers in each panel are the number of *Loligo* measured.




Appendix B6 Figure 5. Minimum annual consumption estimates divided by annual catch for *Loligo*. The horizontal line is drawn at one (minimum consumption / catch =1).