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An Analysis of Some Factors Affecting Survey Catches of Squids, *Loligo pealei* and *Illex illecebrosus*, in the Northwest Atlantic

by

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Contents

Tables

Figures

INTRODUCTION

In this paper, we examine how research survey catches of two commercially important squid[1] species, *Loligo pealei* and *Illex illecebrosus*, are affected by environmental factors. In particular, the univariate habitat association test of Perry and Smith (1994) is applied to evaluate whether squid catch rates during the NEFSC autumn bottom trawl surveys are associated with depth, time of day, bottom temperature, and surface temperature. Consistent associations of squid catches with environmental factors indicate some characteristics of preferred habitat. Previous research has suggested that diurnal effects on bottom trawl catch rates of *Loligo* and *Illex* are important (Sissenwine and Bowman 1978; Shepherd and Forrester 1987) with greater catch rates occurring during the day. In this study, we also investigate size-specific differences in squid catches, by time of day, and compute adjustment factors to standardize catch numbers by time of day. Adjustment factors for catch weight per tow by time of day are also evaluated. Potential effects of depth and temperature on squid catch rates are also explored.

MATERIALS AND METHODS

During 1967-1994, data from the NEFSC autumn bottom trawl surveys were collected at stations located between Cape Hatteras and the Gulf of Maine. Survey procedures and the stratified random sampling design are described in Azarovitz (1981). Data from stations with representative tows consisting of 20-30 minute duration and with no substantial tearup of gear were analyzed for offshore survey strata 1-30, 33-40, and 61-76 (Figure 1). Sampling was conducted round the clock. For each station, measurements of the total number and weight (to the nearest 0.1 kg) of *Loligo* and *Illex* captured, depth of the tow (m), time of the tow (HH:MM, military time based on Eastern Standard Time), bottom water temperature (°C), and surface water temperature (°C) were obtained.

Habitat Association Test

Perry and Smith (1994) developed a nonparametric univariate test of association between an environmental factor and fish catch during a stratified random survey. Their method uses the maximum absolute difference between the cumulative distribution function of the environmental factor and the cumulative distribution function of catch with respect to the environmental factor as a test statistic in a randomization procedure to evaluate whether a significant association exists. In particular, the test algorithm is as follows. First, the empirical cumulative distribution function (f) of the environmental factor is computed as

[1] We abbreviate *Loligo pealei* as *Loligo* and *Illex illecebrosus* as *Illex*.

$$f(t) = \sum_h \sum_i \frac{W_h}{n_h} I(x_{ih}) \tag{1}$$

where t is the value of the environmental factor, h is an index for the survey strata, i is an index for the tow in stratum h, x_{ih} is the observed value of the environmental factor from the ith tow in stratum h, W_h is the proportion of the survey area in stratum h, n_h is the number of tows in stratum h, and I(x) is an indicator function with I(x)=1 when $x \leq t$ and I(x)=0 when $x > t$. Second, the empirical cumulative distribution of catch as a function of the environmental factor (g) is computed as

$$g(t) = \sum_h \sum_i \frac{W_h}{n_h} \frac{y_{hi}}{E(y)} I(x_{ih}) \tag{2}$$

where y_{hi} is the squid catch from the ith tow in stratum h and E(y) is the stratified mean squid catch. Note that if the quotient $y_{hi}/E(y)$ is less than 1, the squid catch from the ith tow in stratum h was below average while if $y_{hi}/E(y)$ is greater than 1, the catch was above average. The maximum absolute value of the difference between f(t) and g(t) over all values of the environmental factor is the test statistic (S) where

$$S = \underset{\forall t}{MAX} \left| \sum_h \sum_i \frac{W_h}{n_h} \left(\frac{y_{hi} - E(y)}{E(y)} \right) I(x_{ih}) \right| \tag{3}$$

To evaluate whether the test statistic is significant, the observed environmental measurements (x_{ih}) are randomly sampled with replacement and assigned to observed catches with probability W_h/n_h under the hypothesis that the association between catch and environmental factor is random. The value of the test statistic (S_R) is then computed for this random assignment. The randomization procedure of assigning environmental measurements to catches and computing S_R is repeated a large number of times to generate a distribution of test statistics for the null hypothesis of random association between catch and environmental factor. Last, the observed test statistic is compared to the distribution of test statistics from the randomization procedure to evaluate whether the null hypothesis of random association can be rejected.

We applied the univariate randomization test to *Loligo* and *Illex* numbers per tow, collected during the 1967-1994 NEFSC autumn bottom trawl surveys, based on four environmental factors: average depth of tow (m), time of tow (HH:MM), bottom water temperature (°C), and surface water temperature (°C). Stations where an environmental factor was not measured were excluded from the test for that particular factor. A total of 2,000 randomizations were performed to give an empirical distribution based on 2,001 test statistics where the original test statistic was included.

Diurnal Effects on Survey Catches

Size-specific differences in the catch rates of *Loligo* by time of day have been suggested (Sissenwine and Bowman 1978). We investigated the effects of time of day on the catches of pre-recruits for *Loligo* (≤8 cm) and *Illex* (≤10 cm) and catches of recruits for *Loligo* (≥9 cm) and *Illex* (≥11 cm). Number per tow and weight per tow values from the 1967-1994 NEFSC autumn bottom trawl surveys were used in this analysis. For each species, the total number of pre-recruits and recruits per tow and the time of tow were obtained for tows where both pre-recruits and recruits were captured. The time of tow was categorized into three periods: night (20:00-23:59 and 00:00 to 3:59), dawn/dusk (4:00-7:59 and 16:00-19:59), and day (8:00-15:59). Mean catch per tow of pre-recruits and recruits were tested for significant differences by time period using the GT-2 test which is appropriate for unplanned comparisons with unequal sample sizes (Sokal and Rohlf 1981) A natural logarithmic transformation was applied to stabilize the variance of the number per tow. Mean catch weights were also compared by time period using the GT-2 test on log-transformed weight-per-tow data. Tows where the catch weight was reported as less than 0.1 kg were excluded from the analyses. For both number- and weight-per-tow analyses, time periods that did not have significantly different mean catch rates were grouped. Sample estimates of the ratio (R) of mean catch per tow by time period were computed using the mean catch in the time period of highest catch rate (μ_{std}) as the numerator. This ratio was computed for all time periods that had a significantly different mean catch rate (μ_t) from the standard. That is, $R=\mu_{std}/\mu_t$. The ratio R is an estimate of the multiplicative adjustment factor to rescale catch rates for time periods that have significantly lower catch rates to be comparable to catch rates during the standard time period. In particular, catch per tow in a time period (C_t) is adjusted by multiplying by R so that RC_t is the catch per tow in standard units.

Mean Catch by Depth and Temperature Zone

Size-specific effects of depth, bottom temperature, and surface temperature on the mean catch rates of each species were also examined. For this analysis, tow depth was categorized according to the depth zones used to define NEFSC bottom trawl offshore survey strata. The depth zones were: < 56 m, 56-100 m, 111-185 m, and > 185 m. Bottom and surface temperatures were grouped into three zones, based on the 25th (P_{25}) and 75th (P_{75}) percentiles of the species-specific empirical temperature distributions, for tows that captured both pre-recruits and recruits. The zones were: P_0 to P_{25}, P_{25} to P_{75}, and P_{75} to P_{100}. For each depth zone, we computed bottom temperature, surface temperature, mean catch per tow of pre-recruits and recruits, and mean weight per tow.

RESULTS

Habitat Association Test

Results of the univariate randomization test of association between total number of *Loligo* captured and depth, time of day, bottom temperature, and surface temperature (Table 1) indicated that the associations between these factors and *Loligo* catches were consistently significant. In particular, associations were significant ($P<0.05$) in all years for depth, bottom temperature, and surface temperature. For time of day, associations were significant in all years except 1980 (96%).

Results of the univariate randomization test of association between total number of *Illex* captured and depth, time of day, bottom temperature, and surface temperature (Table 2) indicated that *Illex* catches were significantly associated with these factors in some years. For depth, a total of 15 associations were significant (54%): 1968, 1971, 1973, 1976-1977, 1979-1980, 1982-1986, 1990-1991, and 1994. For time of day, a total of 13 associations were significant (46%): 1967, 1969, 1971, 1974-1975, 1978, 1980-1983, 1985, 1990, and 1992. For bottom temperature, a total of 7 associations were significant (25%): 1967-1968, 1970-1971, 1974, 1983, and 1992. For surface temperature, a total of 12 associations were significant (43%): 1967-1968, 1970, 1972, 1975, 1977-1978, 1983-1984, 1987, 1992-1993.

For both species, the interquartile range of the cumulative and catch-weighted cumulative distribution functions for depth were computed for years where a significant depth association was detected (Table 3). This range indicates where 50% of the squid catch occurred in relation to depth when a significant association was detected. The interquartile range of depth for *Loligo* catches was consistently shallower than the interquartile range of tow depth. On average, 50% of the *Loligo* catch in numbers occurred at depths of 37-75 m. In contrast, the interquartile range of *Illex* catches was slightly deeper than the interquartile range of tow depth when a significant association was detected. On average, 50% of the *Illex* catch occurred at depths of 79-149 m.

Interquartile ranges of the cumulative and catch-weighted cumulative distribution functions for time of day were computed in years where a significant time association was detected (Table 4). The interquartile range of time of day for *Loligo* catches spanned the daylight hours and was consistently different from the interquartile range of time of day. On average, 50% of the *Loligo* catches occurred between 10 AM and 5 PM Eastern Standard Time. The interquartile range of time of day for *Illex* catches was also concentrated in daylight hours. On average, 50% of the *Illex* catches occurred between 10 AM and 6 PM Eastern Standard Time when there was a significant time association.

Interquartile ranges of the cumulative and catch-weighted cumulative distribution functions for bottom temperature were computed in years where a significant bottom temperature association was detected (Table 5). The interquartile range of *Loligo* catches was consistently higher than the interquartile range of bottom temperature. On average, 50% of the *Loligo* catches occurred at bottom temperatures of 11-15 °C. The interquartile range of *Illex* catches was slightly higher than the interquartile range for bottom temperature. On average, 50% of the *Illex* catch occurred at bottom temperatures of 9-13 °C when a significant association was detected.

Interquartile ranges of the cumulative and catch-weighted cumulative distribution functions for surface temperature were computed in years where a significant surface temperature association was detected (Table 6). The interquartile range of *Loligo* catches was consistently higher than the interquartile range of surface temperature. On average, 50% of the *Loligo* catches occurred at surface temperatures of 16.5-20 °C. The interquartile range of surface temperature for *Illex* catches was also higher than the interquartile range of surface temperature. On average, 50% of the *Illex* catch occurred at surface temperatures of 13-20 °C when a significant association was detected.

Diurnal Effects on Survey Catches

As expected, the highest catch per tow of *Loligo* pre-recruits, recruits, and weight were found to occur during day while the lowest catch rates occurred at night (Table 7). The comparison of log-transformed mean catch per tow of *Loligo* pre-recruits by time period indicated that means for day, dawn/dusk, and night tows were all significantly different ($P<0.05$). The comparison for *Loligo* recruits indicated that means were significantly different between day and night tows and between dawn/dusk and night tows. As a result, day and dawn/dusk tows for *Loligo* recruits were grouped. For log-transformed weight per tow by time of day, means for day, dawn/dusk, and night tows were all significantly different. The sample ratio of means were computed for catches of *Loligo* pre-recruits, recruits, and weight per tow so that catches during night and dawn/dusk tows could be adjusted to be comparable to a standard day or day and dawn/dusk tow (Table 7). For *Loligo* pre-recruits, the adjustment factors were 4.53 for night tows and 1.36 for dawn/dusk tows. For *Loligo* recruits, the adjustment factor for night tows was 2.69. For *Loligo* weight, the adjustment factors were 3.49 for night tows and 1.21 for dawn/dusk tows.

For *Illex*, the highest catch per tow of pre-recruits and weight occurred during day tows while the highest catch per tow of recruits occurred during dawn/dusk (Table 8). The lowest catch of pre-recruits occurred during dawn/dusk while the lowest catch per tow of recruits and weight occurred during night tows. The comparison of log-transformed mean catch per tow of pre-recruits by time period indicated that means for dawn/dusk and night tows were not significantly different while the mean for day tows was significantly different from the means for dawn/dusk and night tows. As a result, dawn/dusk and night tows were grouped. The comparison for *Illex* recruits indicated that means were significantly different between day and night tows and between dawn/dusk and night tows. As a result, day and dawn/dusk tows for *Illex* recruits were grouped. For log-transformed weight per tow by time of day, means were significantly different between day and night tows and between dawn/dusk and night tows. As a result, day and dawn/dusk tows for *Illex* weight were grouped. The sample ratio of means were computed for catches of *Illex* pre-recruits, recruits, and weight per tow so that catches during night and dawn/dusk tows could be adjusted to be comparable to a standard day or day and dawn/dusk tow (Table 8). For *Illex* pre-recruits, the adjustment factors were 2.55 for night and dawn/dusk tows. For *Illex* recruits, the adjustment factor was 2.05 for night tows. For *Illex* weight, the adjustment factor was 1.80 for night tows.

Mean Catch by Depth and Temperature Zone

The mean catch per tow of *Loligo* pre-recruits, recruits, and weight by depth zone indicated that catch rates were dependent upon depth (Table 9). The highest catch rate of pre-recruits (432/tow) occurred at depths of less than 56 m, while the highest catch rates of recruits (216/tow) and weight (13 kg/tow) occurred at depths of 111-185 m. The lowest catch rates of *Loligo* pre-recruits (149/tow) and weight (6 kg/tow) occurred at depths greater than 185 m, while the lowest catch rates of *Loligo* recruits occurred at depths less than 56 m.

For *Illex*, the mean catch per tow of pre-recruits, recruits, and weight by depth zone also indicated that catch rates were dependent upon depth (Table 9). The highest catch rates of pre-recruits (19/tow), recruits (37/tow), and weight (8 kg/tow) occurred at depths greater than 185 m. The lowest catch rate of pre-recruits (10/tow) occurred at depths of 56-110 m, while the lowest catch rates of recruits (20/tow) and weight (2 kg/tow) occurred at depths of less than 56 m.

For bottom temperature, the mean catch per tow of *Loligo* pre-recruits, recruits, and weight indicated that catch rates were influenced by bottom temperature (Table 10). The highest catch rate of pre-recruits (519/tow) occurred at temperatures greater than 16.1 °C, while the highest catch rates of recruits (139/tow) and weight (11 kg/tow) occurred at temperatures of 10.9-16.1 °C. The lowest catch rate of pre-recruits (199/tow) occurred at temperatures of less than 10.9 °C, while the lowest catch rates of recruits (70/tow) and weight (6 kg/tow) occurred at temperatures of greater than 16.1 °C.

The mean catch of *Illex* pre-recruits, recruits, and weight by bottom temperature zone also indicated that catch rates were dependent upon bottom temperature (Table 10). For *Illex* pre-recruits, the highest catch rate (15/tow) occurred at temperatures of less than 10.2 °C, while the highest catch rates of recruits (28/tow) and weight (7 kg/tow) occurred at temperatures of 10.2-12.9 °C. The lowest catch rates of *Illex* pre-recruits (7/tow), recruits (18/tow), and weight (4 kg/tow) occurred at temperatures greater than 12.9 °C.

For surface temperature, the mean catch per tow of *Loligo* pre-recruits, recruits, and weight indicated that catch rates were affected by surface temperature (Table 11). The highest catch rates of pre-recruits (487/tow), recruits (145/tow), and weight (13 kg/tow) occurred at temperatures of 14.8-20.9 °C. The lowest catch rates of pre-recruits (122/tow), recruits (59/tow), and weight (5 kg/tow) occurred at temperatures of less than 14.8 °C.

For *Illex*, the mean catch per tow of pre-recruits, recruits, and weight by surface temperature zone indicated that catch rates were affected by surface temperature (Table 11). The highest catch rates of pre-recruits (17/tow) occurred at temperatures of 14.4-20.6 °C, while the highest catch rates of recruits (31/tow), and weight (7 kg/tow) occurred at temperatures greater than 20.6 °C. The lowest catch rates of pre-recruits (6/tow), recruits (19/tow), and weight (6 kg/tow) occurred at temperatures of less than 14.4 °C.

DISCUSSION

In this study, we found that *Loligo* catch rates were consistently associated with all of the environmental factors examined. *Loligo* is primarily a neritic species found within continental shelf waters and substantial overlap exists between *Loligo* habitat and the area sampled during the NEFSC bottom trawl survey in the autumn (NEFSC 1994). In comparison with *Loligo*, autumn survey catches of *Illex* were much lower and associations between *Illex* catch rates and the environmental factors examined were not consistently significant for half or more of the years examined. *Illex* is primarily an oceanic species which undergoes lengthy offshore migrations between areas south of Cape Hatteras and Newfoundland and opportunistically feeds within continental shelf waters during the summer and autumn (O'Dor and Dawe *In Press*). In part, the lack of consistent habitat associations may be due to incomplete survey coverage of *Illex* habitat during the autumn. For example, the timing of the offshore and southward migration of *Illex* may preceed the timing of the autumn survey during some years.

The significant associations of *Loligo* catches with depth, bottom temperature, and surface temperature suggested that these factors may be useful in characterizing preferred habitat for this species. In contrast, the significant association with time of day appeared to be a consequence of the behavioral ecology of the species as it migrates vertically in the water column to avoid predation and to acquire prey.

The fact that *Loligo* catches were significantly associated with depth was consistent with previous studies. Serchuk and Rathjen (1974) examined the distribution and relative abundance of *Loligo* using NEFSC bottom trawl survey data and found that the highest catch rates were at depths less than 100 m during autumn. In this study, we found that roughly 50% of the *Loligo* catch in total numbers occurred at depths of 37-75 m. However, most of the shallow water catches (< 56 m) were comprised of pre-recruits and this suggested that relatively shallow waters of the continental shelf were preferred habitat of *Loligo* pre-recruits during autumn. In contrast, the highest catches of *Loligo* recruits and population biomass were at depths of 111-185 m. This suggested that the preferred habitat of *Loligo* recruits was at greater depths than pre-recruits during autumn.

The result that *Loligo* catches were significantly associated with bottom and surface temperature was also consistent previous studies. Summers (1969) reported that large catches of *Loligo* during winter were restricted to bottom temperatures of 8 °C or higher. This temperature limitation was supported by Serchuk and Rathjen (1974) who also reported that the majority of *Loligo* catches during autumn occurred when bottom temperatures were 10-14 °C. Similarly, in this study we found that roughly 50% of the *Loligo* catch occurred when bottom temperatures were 11-15°C. However, catch rates for *Loligo* pre-recruits were higher for bottom temperatures above 16.1 °C, while catch rates for recruits and weight were highest for bottom temperatures of 10.9-16.1 °C. This suggested that *Loligo* pre-recruits preferred waters with warmer bottom temperatures in comparison to recruits. For surface temperature, Murawski (1993) found that there was a significant relationship between the mean latitudinal occurrence of *Loligo* and surface temperature during autumn and calculated the mean surface temperature weighted by *Loligo* catch to be roughly 17 °C. This value was consistent with the fact that roughly 50% of the *Loligo* catch occurred for surface temperatures of 16-20 °C. In contrast to bottom temperature, changes in catch rates by size class were similar with respect to surface temperature. The highest catch rates for both *Loligo* pre-recruits and recruits were at temperatures of 15-21 °C, while the catch rates of pre-recruits and recruits were lowest for temperatures less than 15 °C. Although *Loligo* catches can be expected to be associated with relatively warm water temperatures, catch rates for *Loligo* recruits declined in the zones of highest bottom and surface temperature. This suggested that the highest temperatures were not the preferred habitat of *Loligo* recruits. Regardless, the strong association of *Loligo* with temperature suggested that annual variation in patterns of bottom and surface temperature may affect the range of preferred *Loligo* habitat and potentially influence growth and survival in the population.

The dependence of *Loligo* catch rate on time of day was also consistent with previous studies. Summers (1968) noted that *Loligo* migrate vertically and that adults could be observed near the surface at night. Summers (1969) observed that survey catches of *Loligo* during the day (6 AM-6 PM) were consistently higher than night catches (6 PM-6 AM). Serchuk and Rathjen (1974) observed that 90% of *Loligo* survey catches occurred during daylight. Sissenwine and Bowman (1978) also found that *Loligo* catch was significantly higher during daylight but noted that the mean weight of squid captured during the night was 7 times higher than for squid captured during the day. We computed the mean weight of *Loligo* captured during the 1967-1991 NEFSC autumn bottom trawl surveys as 25 g during the day versus 41 g at night. In addition, we detected significant diurnal catch rate differences between pre-recruit and recruit size classes. In particular, night and dawn/dusk catch rates of pre-recruits were 22% and 73%, respectively, below the mean daytime catch rate, while night catch rates of recruits were 37% below the combined day and dawn/dusk catch rate. The size-specific adjustment factors reported here can be used to rescale *Loligo* catch rates at night and dawn/dusk to the standard day catch rate units.

Approximately 50% of the time, *Illex* catch rates were associated with depth, time of day, and surface temperature, and to a lesser extent (25% of the time), with bottom temperature. The significant associations of *Illex* catch with depth and surface temperature suggested that these factors may be useful to characterize preferred habitat for this species. The significant association of *Illex* catch with time of day suggested that the species made vertical migrations similar to those of *Loligo*.

The significant associations between *Illex* catch and depth were consistent with previous studies. Whitaker (1980) reported that *Illex* catches were relatively low for depths less than 56 m and were highest for depths of 184-367 m in a study of trawl survey data collected south of Cape Hatteras. During a research survey of the Scotian Shelf, Grinkov and Rikhter (1981) reported that *Illex* catches were highest for depths of 100-150 m. In this study, 50% of the *Illex* catch occurred at depths of roughly 80-150 m. During autumn, there did not seem to be depth preference differences between pre-recruits and recruits since the highest catch rates of

Illex pre-recruits, recruits, and weight were at depths greater than 185 m. The higher catch rates at greater depth were consistent with the location of the convergence zone between continental shelf and slope waters which intersects the shelf edge at roughly 150-200 m (Bowman 1973). Lange *et al.* (1984) found that, during autumn, the highest catch rates recorded by domestic observers of the distant-water *Illex* fishery were generally located within several miles of the shelf-slope front at the shoreward edge of the convergence zone. These observations suggested that the shelf-slope convergence zone may be an important habitat for *Illex* within the U.S. EEZ. Regardless of this point, these data clearly indicated that *Illex* generally occurs at greater depths than *Loligo* during autumn.

The significant associations of *Illex* catches with surface temperature in roughly half of the years examined suggested that surface temperature had a potential influence on *Illex* distribution, while the significant associations of *Illex* catches with bottom temperature suggested that bottom temperature had a lesser influence on *Illex* distribution. Whitaker (1980) reported that *Illex* catches occurred in bottom temperatures of 7-27 °C, but that roughly 80% of the catch was taken in 8-10 °C water. Murawksi (1993) examined the potential for a linear relationship between the mean latitudinal occurrence of *Illex* and bottom temperature and surface temperature during the autumn NEFSC bottom trawl survey and did not detect a significant relationship. Rowell *et al.* (1985) found that *Illex* appeared to prefer bottom temperatures in excess of 6 °C during summer in waters of the Scotian Shelf, but that temperature did not appear to be a limiting factor. In this study, 50% of the *Illex* catch occurred when bottom temperatures were 9-13 °C and surface temperatures were 13-20 °C. There did not appear to be preference differences between pre-recruits and recruits, with respect to fall bottom temperatures, since catches for both categories were highest in waters cooler than 10.2 °C. However, catch rates for recruits were highest for surface water temperatures greater than 20.6 °C, while catch rates for pre-recruits were highest for surface water temperatures of 14.4-20.6 °C. This suggested that *Illex* recruits preferred warmer surface waters than pre-recruits during autumn. In general, *Illex* catches were associated with cooler water temperatures than *Loligo*.

The fact that *Illex* catches were dependent on time of day in roughly 50% of the years examined was consistent with Sissenwine and Bowman (1978) and Shepherd and Forrester (1987) who found that time of day had a significant effect on survey catches of *Illex*. In this study, 50% of the *Illex* catches occurred during the day from 10 AM to 6 PM and the highest mean catch rates occurred during day and dawn/dusk. The fact that catch rates were highest during the day supported the review of *Illex* by O'Dor and Dawe (In press) who reported that *Illex* had a tendency to migrate to the surface at night and to descend to depths of over 100 m during the day on the continental shelf. The highest catch rate of *Illex* recruits occurred during dawn/dusk, which coincided with the lowest catch rate of pre-recruits. This difference between catch rates of pre-recruits and recruits might result from the segregation of schools of *Illex* by size class. Arkhipkin and Fedulov (1986) reported that differences in diel vertical movements of juvenile (2-10 cm ML) *Illex illecebrosus* were size-related and attributable to feeding behaviour. Regardless, the adjustment factors presented here can be used to standardize *Illex* catch rates during night and dawn/dusk to standard day catch rate units.

Since the bottom trawl gear used on the NEFSC autumn survey collects samples from the bottom to several meters above it, diurnal differences in squid catch rates should be expected if squid migrate vertically in response to predation risk and food availability. The fact that significant differences were detected between catch rates by time period, for pre-recruits and recruits of both species, indicated that adjustments were appropriate for both juveniles and adults. The differences between *Loligo* and *Illex* catch rates for each depth zone suggested that the depth stratification of the NEFSC bottom trawl survey design was appropriate for both species. The differences in *Loligo* and *Illex* catch rates for each temperature zone suggested that preferred temperature ranges likely exist for both species. However further evaluation is needed to determine whether temperature is an appropriate stratification variable for either species.

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Table 1. Results of univariate randomization test of association between catches of *Loligo pealei* (number of squid) and average depth, time of day, bottom temperature, and surface temperature, during the NEFSC autumn bottom trawl surveys, 1967-1994. Shown are the probabilities of random association[1] (of having a test statistic greater than or equal to the observed value by chance alone) between *Loligo* catches and the environmental factor.

	ENVIRONMENTAL FACTOR			
YEAR	AVERAGE DEPTH	TIME OF DAY	BOTTOM TEMPERATURE	SURFACE TEMPERATURE
1967	0.00*	0.00*	0.00*	0.00*
1968	0.00*	0.00*	0.00*	0.00*
1969	0.00*	0.00*	0.00*	0.00*
1970	0.00*	0.00*	0.00*	0.00*
1971	0.03*	0.00*	0.00*	0.00*
1972	0.00*	0.00*	0.00*	0.00*
1973	0.04*	0.00*	0.00*	0.00*
1974	0.00*	0.00*	0.00*	0.00*
1975	0.00*	0.00*	0.00*	0.00*
1976	0.00*	0.00*	0.00*	0.00*
1977	0.00*	0.00*	0.00*	0.00*
1978	0.00*	0.00*	0.00*	0.00*
1979	0.00*	0.00*	0.00*	0.00*
1980	0.00*	0.07	0.00*	0.00*
1981	0.00*	0.00*	0.00*	0.00*
1982	0.01*	0.00*	0.03*	0.00*
1983	0.01*	0.00*	0.00*	0.00*
1984	0.00*	0.00*	0.00*	0.00*
1985	0.00*	0.00*	0.00*	0.00*
1986	0.01*	0.00*	0.00*	0.00*
1987	0.00*	0.00*	0.00*	0.00*
1988	0.00*	0.02*	0.00*	0.00*
1989	0.00*	0.00*	0.02*	0.00*
1990[2]	0.00*	0.00*	0.00*	0.00*
1991	0.00*	0.00*	0.00*	0.00*
1992	0.00*	0.00*	0.00*	0.00*
1993	0.02*	0.01*	0.00*	0.00*
1994	0.00*	0.00*	0.00*	0.00*

[1] Associations significant at the α=0.05 level are indicated with an asterisk.
[2] No bottom temperature data were collected on Georges Bank during 1990.

Table 2. Results of univariate randomization test of association between catches of *Illex illecebrosus* (number of squid) and average depth, time of day, bottom temperature, surface temperature during the NEFSC autumn bottom trawl surveys, 1967-1994. Shown are the probabilities of random association[1] (of having a test statistic greater than or equal to the observed value by chance alone) between *Illex* catches and the environmental factor.

	ENVIRONMENTAL FACTOR			
YEAR	AVERAGE DEPTH	TIME OF DAY	BOTTOM TEMPERATURE	SURFACE TEMPERATURE
1967	0.13	0.01*	0.01*	0.00*
1968	0.03*	0.24	0.05*	0.01*
1969	0.08	0.03*	0.26	0.33
1970	0.16	0.15	0.02*	0.02*
1971	0.01*	0.01*	0.00*	0.08
1972	0.24	0.30	0.12	0.03*
1973	0.04*	0.13	0.71	0.12
1974	0.52	0.03*	0.03*	0.23
1975	0.34	0.00*	0.77	0.00*
1976	0.02*	0.20	0.54	0.30
1977	0.04*	0.44	0.26	0.01*
1978	0.12	0.00*	0.87	0.03*
1979	0.00*	0.15	0.07	0.07
1980	0.01*	0.01*	0.24	0.25
1981	0.61	0.01*	0.51	0.25
1982	0.03*	0.00*	0.09	0.18
1983	0.03*	0.00*	0.01*	0.00*
1984	0.03*	0.47	0.42	0.00*
1985	0.00*	0.00*	0.24	0.12
1986	0.03*	0.51	0.60	0.31
1987	0.39	0.34	0.53	0.04*
1988	0.98	0.12	0.06	0.34
1989	0.69	0.10	0.32	0.58
1990	0.00*	0.00*	0.27	0.09
1991	0.04*	0.36	0.11	0.48
1992	0.13	0.01*	0.00*	0.00*
1993	0.33	0.24	0.53	0.03*
1994	0.04*	0.18	0.09	0.39

[1] Associations significant at the $\alpha=0.05$ level are indicated with an asterisk.

[2] No bottom temperature data were collected on Georges Bank during 1990.

Table 3. Interquartile ranges of the cumulative distribution function of depth and the catch-weighted cumulative distribution function of depth for years where *Loligo* or *Illex* catches were signficantly associated with depth.

	INTERQUARTILE RANGE		
YEAR	DEPTH	LOLIGO CATCH	ILLEX CATCH
1967	51-172	31-70	
1968	49-165	29-70	82-137
1969	52-165	37-75	
1970	52-172	33-67	
1971	53-168	41-116	72-135
1972	51-159	35-60	
1973	50-167	81-132	81-132
1974	51-170	30-55	
1975	50-157	27-49	
1976	51-153	33-74	79-134
1977	51-157	30-60	71-155
1978	53-167	37-70	
1979	50-165	34-93	71-135
1980	52-170	28-53	87-180
1981	54-169	41-76	
1982	49-168	32-70	64-134
1983	51-165	39-88	81-134
1984	52-169	29-72	75-151
1985	52-169	47-81	93-154
1986	51-166	41-79	75-150
1987	49-166	34-90	
1988	51-160	43-82	
1989	50-163	36-78	
1990	52-172	37-69	76-176
1991	54-160	33-59	79-187
1992	47-168	27-66	
1993	54-173	39-91	
1994	53-166	40-68	97-143

Table 4. Interquartile ranges of the cumulative distribution function of time of day and the catch-weighted cumulative distribution function of time of day for years where *Loligo* or *Illex* catches were signficantly associated with time. Time of day (hours) is reported as standard military time based on Eastern Standard Time.

	INTERQUARTILE RANGE		
YEAR	TIME	LOLIGO CATCH	ILLEX CATCH
1967	1300-0000	0800-1400	1100-1700
1968	1300-0000	1100-1600	
1969	1300-0100	1100-1600	1000-1700
1970	1300-0100	1100-1800	
1971	1200-2300	0900-1600	0900-1900
1972	1200-0000	1400-1700	
1973	1200-0100	1000-1700	
1974	1300-0100	1100-1700	1000-1400
1975	1200-0000	0900-1400	1000-1400
1976	1300-0100	1200-1800	
1977	1200-2300	1000-1600	
1978	1300-0100	1000-2100	0900-2000
1979	1300-0000	1400-1700	
1980	1300-0100		1100-2000
1981	1100-2300	0800-1400	1000-1300
1982	1200-0000	0900-1900	0900-2000
1983	1300-0200	1000-0000	0900-2100
1984	1100-0000	0900-1700	
1985	1300-0100	0900-1700	1100-1900
1986	1200-2300	1000-1700	
1987	1200-0100	1000-1800	
1988	1100-2300	1400-1800	
1989	1100-0000	0800-1500	
1990	1200-2300	1000-1800	0900-1700
1991	1100-0000	0900-1700	
1992	1200-0000	1300-1600	1000-1900
1993	1200-2300	1200-1700	
1994	1200-0100	1000-1600	

Table 5. Interquartile ranges of the cumulative distribution function of bottom temperature (°C) and the catch-weighted cumulative distribution function of bottom temperature for years where *Loligo* or *Illex* catches were signficantly associated with bottom temperature.

	INTERQUARTILE RANGE		
YEAR	BOTTOM TEMPERATURE	LOLIGO CATCH	ILLEX CATCH
1967	6-10	10-16	9-11
1968	8-12	11-19	9-12
1969	7-13	10-16	
1970	7-11	10-13	9-12
1971	8-12	11-15	9-12
1972	8-13	13-19	
1973	8-14	13-17	
1974	9-14	13-17	10-20
1975	8-13	12-17	
1976	9-13	11-16	
1977	9-13	12-16	
1978	7-12	10-13	
1979	8-13	11-15	
1980	8-13	11-17	
1981	7-12	10-13	
1982	8-12	12-16	
1983	8-12	11-14	9-13
1984	8-13	11-16	
1985	9-14	13-15	
1986	9-13	11-14	
1987	8-12	11-14	
1988	8-12	10-12	
1989	7-12	9-13	
1990	7-12	12-16	
1991	8-13	10-15	
1992	8-13	10-16	9-13
1993	8-12	12-16	
1994	9-13	13-15	

Table 6. Interquartile ranges of the cumulative distribution function of surface temperature (°C) and the catch-weighted cumulative distribution function of surface temperature for years where *Loligo* or *Illex* catches were signficantly associated with surface temperature.

	INTERQUARTILE RANGE		
YEAR	SURFACE TEMPERATURE	LOLIGO CATCH	ILLEX CATCH
1967	8-15	15-16	10-17
1968	9-17	15-20	13-18
1969	10-17	16-18	
1970	10-17	14-25	13-23
1971	12-20	18-21	
1972	10-18	17-19	13-21
1973	10-19	17-20	
1974	12-19	16-21	
1975	12-16	16-17	14-19
1976	10-18	18-19	
1977	9-17	16-21	11-18
1978	11-19	15-20	13-17
1979	11-18	15-19	
1980	10-18	16-21	
1981	11-15	13-17	
1982	11-19	16-20	
1983	11-19	18-20	18-21
1984	12-20	16-21	14-22
1985	11-18	17-19	
1986	11-20	17-21	
1987	11-19	17-21	14-22
1988	11-20	18-20	
1989	12-20	19-22	
1990	13-20	18-21	
1991	13-20	19-23	
1992	12-20	18-20	15-21
1993	12-21	17-21	15-21
1994	13-19	16-21	

Table 7. Mean catch per tow of *Loligo* pre-recruits (≤ 8 cm) and recruits (≥ 9 cm) and of *Loligo* weight per tow (kg) by time of day and sample ratio (R) of means to standardize catches to the time period of highest catch rate.

Mean catch per tow by time period

	TIME OF DAY		
	NIGHT	DAWN/DUSK	DAY
Pre-recruits	108.137	360.157	490.069
Recruits[1]	49.706	124.494	142.029
Weight	3.502	10.099	12.222
Sample size	798	1,309	1,429

[1] Mean catch of recruits for day and dawn/dusk combined was 133.646

Ratio of mean catch per tow by time period

	STANDARD TIME PERIOD	ADJUSTMENT FACTOR (R)	
		NIGHT	DAWN/DUSK
Pre-recruits	DAY	4.53	1.36
Recruits	DAY & DAWN/DUSK	2.69	-
Weight	DAY	3.49	1.21

Table 8. Mean catch per tow of *Illex* pre-recruits (≤ 10 cm) and recruits (≥ 11 cm) and of *Illex* weight per tow (kg) by time of day and sample ratio of means (R) to standardize catches to the time period of highest catch rate.

Mean catch per tow by time period

	TIME OF DAY		
	NIGHT	DAWN/DUSK	DAY
Pre-recruits[1]	9.828	5.270	16.803
Recruits[2]	15.149	32.530	29.981
Weight[3]	3.814	5.895	7.770
Sample size	87	215	315

[1] Mean catch of pre-recruits for night and dawn/dusk combined was 6.583
[2] Mean catch of recruits for day and dawn/dusk combined was 31.015
[3] Mean catch in weight for day and dawn/dusk combined was 6.879

Ratio of mean catch per tow by time period

	STANDARD TIME PERIOD	ADJUSTMENT FACTOR	
		NIGHT	NIGHT & DAWN/DUSK
Pre-recruits	DAY	-	2.55
Recruits	DAY & DAWN/DUSK	2.05	-
Weight	DAY & DAWN/DUSK	1.80	-

Table 9. Mean catch per tow of *Loligo* and *Illex* pre-recruits, recruits, and weight by depth zone.

	DEPTH ZONE			
LOLIGO	< 56 m	56-110 m	111-185 m	> 185 m
Pre-recruits (≤ 8 cm)	432.200	252.737	321.212	148.658
Recruits (≥ 9 cm)	84.071	150.228	216.192	89.468
Weight (kg)	7.507	10.807	12.996	5.925
Sample Size	2,088	1,045	292	111

	DEPTH ZONE			
ILLEX	< 56 m	56-110 m	111-185 m	> 185 m
Pre-recruits (≤ 10 cm)	10.558	9.770	12.110	19.310
Recruits (≥ 11 cm)	19.558	28.880	29.470	36.524
Weight (kg)	2.227	5.844	6.283	8.306
Sample Size	86	283	164	84

Table 10. Mean catch per tow of *Loligo* and *Illex* pre-recruits, recruits, and weight per tow by bottom temperature zone.

LOLIGO	BOTTOM TEMPERATURE ZONE < 10.9 °C	10.9-16.1 °C	> 16.1 °C
Pre-recruits (≤ 8 cm)	198.926	330.365	519.495
Recruits (≥ 9 cm)	112.708	138.564	69.564
Weight (kg)	7.884	11.074	6.247
Sample size	638	1455	732

ILLEX	BOTTOM TEMPERATURE ZONE < 10.2 °C	10.2-12.9 °C	> 12.9 °C
Pre-recruits (≤ 10 cm)	14.672	13.238	7.488
Recruits (≥ 11 cm)	27.098	28.115	17.919
Weight (kg)	6.469	6.834	3.836
Sample size	122	244	123

Table 11. Mean catch per tow of *Loligo* and *Illex* pre-recruits, recruits, and weight per tow by surface temperature zone.

	SURFACE TEMPERATURE ZONE		
LOLIGO	< 14.8 °C	14.8-20.9 °C	> 20.9 °C
Pre-recruits (≤ 8 cm)	121.762	487.320	269.572
Recruits (≥ 9 cm)	59.330	145.024	106.097
Weight (kg)	4.708	12.538	7.150
Sample size	681	1,448	725

	SURFACE TEMPERATURE ZONE		
ILLEX	< 14.4 °C	14.4-20.6 °C	> 20.6 °C
Pre-recruits (≤ 10 cm)	6.268	16.674	8.548
Recruits (≥ 11 cm)	18.829	25.496	31.496
Weight (kg)	5.970	6.195	7.012
Sample size	123	242	135

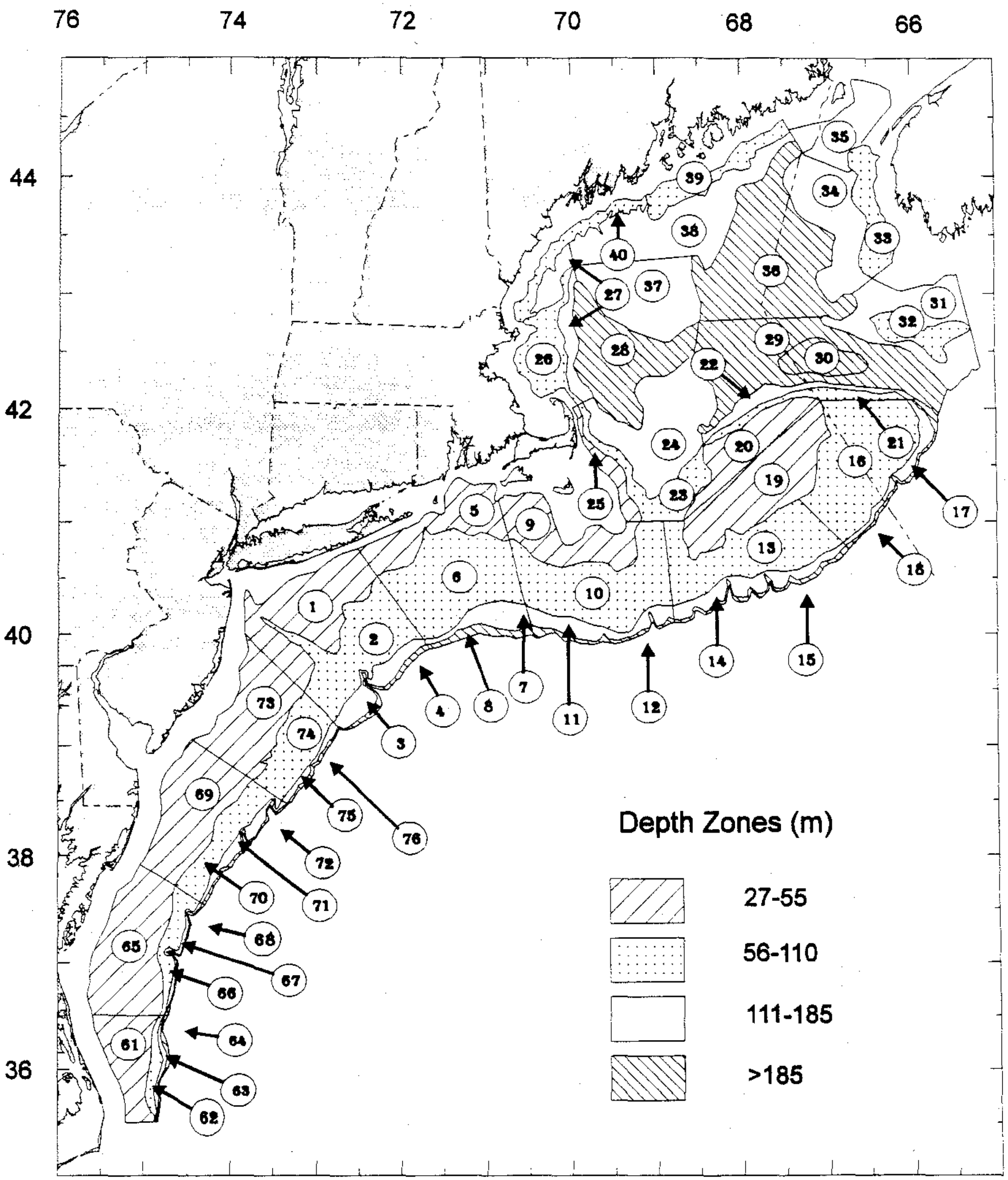

Figure 1. Area of the Northwest Atlantic showing offshore strata sampled during NEFSC bottom trawl surveys.