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Yield Analysis for the Long-finned Squid, *Loligo pealei* (LeSeuer), from the Northwest Atlantic

by

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Summary

The long-finned squid, *Loligo pealei*, has become increasingly important to the domestic fishery off the northeastern United States (US). US landings in 1982 were the highest on record totalling about 4,900 metric tons, while landings through July of 1983 exceeded 9,500 metric tons. If the trend continues from a predominantly offshore foreign winter fishery to one prosecuted primarily inshore in the spring and summer, it may result in a significant increase in potential yield from this stock.

A modified version of the Ricker yield-per-recruit model was used to estimate potential yields in the *Loligo pealei* fishery. The model applies monthly values of growth and fishing, spawning and natural mortality rates and accounts for variations in year-class structure as defined by peaks in time of spawning. Two patterns of exploitation were examined by simulating dominance of the offshore fishery versus the inshore fishery through variation of the monthly pattern of fishing mortality.

Simulated yield-per-recruit of *L. pealei* was significantly higher with an inshore fishery compared to an offshore/inshore fishery under most assumptions of mortality which were examined. Potential yield estimates, based on estimates of fishing, natural and spawning mortality rates derived from survey mean catch per tow data and commercial catch in numbers, per cohort, were within 6-8% of the observed average catch during 1968-81 (22,000 MT). Maximum potential yield estimates assuming 2.0 billion recruits ranged from 53,500 MT (F=3.0) for an offshore/inshore fishery to 66,800 MT (F=4.0) for an inshore fishery. However, fishing mortalities associated with these yields are significantly higher than calculated for the recent fishery and would result in substantial reductions in spawning stock size.

INTRODUCTION

The long-finned squid, *Loligo pealei*, is becoming increasingly important to the domestic fishery off the northeastern United States (US). If this trend continues it will result in a significant change in the pattern of fishing and on subsequent yields from the stock. The historic directed fishery has been centered on the offshore overwintering grounds of *L. pealei* by foreign fleets since the fishery intensified in the early 1970's. The majority of the US catch has traditionally been taken in the late spring and summer while the stock is inshore on its spawning grounds. This document examines the potential effects of changing the exploitation pattern on the stock and presents updated information on the *Loligo* fishery including US catch and catch-per-unit-effort and joint venture and foreign catch data.

Management of the stock has been based, in part, on yield-per-recruit analyses which assumed the exploitation pattern existing in 1974-75 (Sissenwine and Tibbetts 1977). Estimates of growth and natural and fishing mortality rates have been revised and understanding of the life cycle has improved since that earlier work. A modified Ricker type yield-per-recruit model (Lange 1981) was used in this

paper to simulate the effects of changing the exploitation pattern on the *L. pealei* stock. The model was designed to accept monthly inputs of fishing, spawning, and natural mortality and growth rates and to account for variations in year-class structure as defined by peaks in time of spawning.

Natural and fishing mortality rates were estimated from mean catch-per-tow data obtained from bottom trawl surveys conducted by the Northeast Fisheries Center (NEFC) during 1968-81 and mean catch per cohort estimates based on commercial catch and length frequency data (1978-81). Yield estimates based on revised mortality estimates were compared for exploitation patterns reflecting (1) a dominant offshore winter fishery coupled with a relatively small inshore summer fishery as has existed since the early 1970's (hereafter referred to as the offshore/inshore fishery) and (2) a dominant inshore summer fishery similar to that traditionally prosecuted by the US, with no offshore winter fishery (hereafter referred to as the inshore fishery).

COMMERCIAL FISHERY

Catch

The directed US fishery for *Loligo* since about 1976 has been conducted primarily in late spring in the southern

New England area, although significant catches have been made in Mid-Atlantic and southern New England areas throughout the year. Joint ventures since 1981 involving US fishing and foreign processing vessels have resulted in increased directed effort in the Mid-Atlantic area. US landings of Loligo in 1982 were the highest on record totalling about 3,800 metric tons (mt) (Table 1), with an additional 1,100 mt taken in joint ventures. US landings from January through July 1983 were 8,000 mt with joint ventures accounting for an additional 1,500 mt. The total for 1983 will likely be far above the previous US high.

The distant water fleet catch of Loligo during 1982 totalled 15,805 tons (Table 1), representing a 17% increase from 1981 but an 18% decrease from the 1968-81 mean. Catches by Japan, Spain, and Italy totalled 2,732 mt, 8,668 mt, and 4,405 mt, respectively. The total international catch in 1982 was 20,500 mt, approximately equal to the 1968-81 mean.

Catch-per-unit-effort

Catch-per-unit-effort (CPUE) data from the US directed otter trawl fishery during 1976-82 were examined as a possible index of stock abundance or availability of this stock to the inshore area. US fishing trips which landed Loligo were examined according to the percentage (in 5%

intervals) which Loligo comprised of the total catch for each trip to determine which trips constituted directed effort. A large number of vessel trips landed Loligo in quantities amounting to 25% or less of the total trip catch, these were assumed to constitute non-directed effort. The number of trips with 26-75% Loligo in the catch was low. However, there was an increase in the number of trips reporting 76-100% Loligo. Directed effort was, therefore, defined as that from trips (otter trawl vessels) in which 76% or more of the catch was Loligo.

CPUE fluctuated widely during 1976-82 (Table 2), ranging from 7.63 mt per day in 1976 (all vessels, all areas) to 2.50 in 1978. Similar trends were observed for each vessel class indicating that fluctuations were due to availability or abundance of Loligo rather than changes in vessel fishing power. The 1982 value (5.27) was the second highest of the series. Preliminary indications suggest that CPUE in 1983 may exceed all previous levels observed, especially in the southern New England area (Statistical Areas 538 and 539, Figure 1).

YIELD-PER-RECRUIT-ANALYSIS

The Model

A modified Ricker yield-per-recruit model (Lange 1981) was used to simulate the effects of various fishing patterns on the *L. pealei* stock. This stock spawns during April-September with peaks generally occurring in late spring and early autumn resulting in two cohorts each year. The model was designed to accept monthly rates of natural and fishing mortality and growth for each of these two cohorts throughout their life span beginning at 6 months of age. Relative size of the two cohorts, expressed in proportion (in number) to the year-class total at 6 months, and mean weights of each cohort at that age were also input. Spawning mortality was considered to be significant during April-September (the spawning season) since all individuals are assumed to die after spawning, as reported for other squid species. This component of natural mortality affects only that portion of the stock which has reached maturity and was, therefore, considered separately in the simulations. A constant natural mortality rate (M) was used throughout the period of the life cycle used in the model (over 6 months of age, or about 6 cm and greater) since the data were not adequate to estimate M with finer temporal

resolution. Annual fishing mortality (F) was apportioned throughout the year according to the monthly pattern of exploitation.

Data

Data used in this analysis included mean numbers at length per tow from the NEFC spring and autumn bottom trawl surveys (1968-81) and commercial US and distant-water-fleet length frequencies and total catch (mt) by month (1978-81). Stratified mean numbers at length per tow, pooled separately over the southern New England and Mid-Atlantic areas, were subjected to modal length analysis (Tomlinson 1971) to determine percent composition and mean number per cohort by area. Modal analysis, using the program NORMSEP, provides a method of separating length frequencies into representitive normal distributions approximating age classes. This is a subjective technique which relies on determination by the user of the number of age groups and their respective cutoff points represented in the length distribution. It also assumes that lengths are normally distributed within an age class.

Only day tows (0800-1600 hours) were used in this analysis since vulnerability of *Loligo* to the survey trawl is considerably less during dawn (0400-0800), dusk (1600-2000) (Lange 1980), and night (2000-0400, Sissenwine

and Bowman 1978), and size compositions from night tows were obviously different from those observed during the day.

Loligo caught during surveys in the Mid-Atlantic area were consistently smaller than those from the southern New England area. These slight differences in estimated mean length per cohort by area were assumed to be due to the timing of the seasonal surveys in each area. Mid-Atlantic stations generally occurred 2-3 weeks prior to those in southern New England waters (Figure 2). Observed length frequencies from spring and autumn surveys (pooled over 1968-81) in the southern New England area and corresponding estimated numbers at length per cohort from modal analysis are presented in Figure 3, as an example of this aging method. Percent composition and mean numbers per cohort per tow from the two areas were, therefore, calculated separately (differences in length frequencies would have prevented separation of cohorts by modal analysis) and averaged (weighted by area) to produce a single estimate of mean number (and percent) per cohort.

Total abundance of recruits was estimated by areal expansion of stratified mean numbers per tow (day tows only) from the autumn (for the spring cohort) and spring (for the autumn cohort) surveys. Several assumptions of trawl catchability, were applied to these estimates, resulting in four different estimates of abundance.

Parameter Estimation

Monthly estimates of population parameters are presented in Table 3. The autumn cohort entered the simulation at 6 months of age based on abundance estimated from the spring survey. Mortality and growth rates prior to that time are, therefore, not included. Age selectivity (by month) to the fishery based on mesh selectivity information for *Loligo* sp. in the eastern Central Atlantic (Ikeda, Far Seas Fisheries Laboratory, Shimizu, Japan, personal communication, 1973) was assumed to be 25%, 50%, 75%, and 100% at 6, 7, 8, and 9 months and older, respectively, for the spring cohort and 75% and 100% at 6 and 7 months and older, respectively, for the autumn cohort based on mean length at age estimates (Lange 1981). Initial individual weights were calculated from mean lengths at the time of the autumn and spring surveys for the spring and autumn cohorts, respectively, using:

$$W = 0.25662L^{2.15182} \quad \text{(Lange and Johnson 1981)} \quad (1)$$

where W = weight (g) and L = dorsal mantle lengtn (cm).

Growth rates were based on weight-at-age estimates calculated from growth functions developed previously (Lange 1980). Total mortality (Z) per cohort was estimated

assuming that each cohort would be fully recruited to the first NEFC survey conducted about 6 months following hatching. The spring cohort would, therefore, recruit to the autumn survey in its first year and the autumn cohort to the following spring survey. Mean number per tow from the 1968-81 pooled survey data from the appropriate cohort was compared to mean number per tow from the same cohort one year later using:

$$Z_k = -\ln(C_{i+1}/C_i) \quad (2)$$

where Z_k = total mortality for cohort k and C_i = mean catch per tow in year i.

Fishing mortality (F) was estimated for each cohort based on solution of the catch equation:

$$C = (NF/Z)(1-e^{-Z}) \quad (3)$$

where C = catch in numbers per cohort over the same 12 months used in calculating Z and estimated from expanded length frequencies from the 1978-81 international catch separated to cohort using modal analysis, Z = the estimate of annual total mortality for each cohort, and N = the average annual abundance (1968-81) of the cohort at 6 months of age calculated by areal expansion of the mean number per

tow of the spring cohort in the autumn survey or the autumn cohort in the spring survey. Differences in trawl efficiency between spring and autumn surveys, due partly to differences in seasonal distribution of this species, prevent comparisons of catch-per-tow data between seasons and therefore annual differences were used.

Abundance estimates based on areal expansion of survey catch-per-tow data assume that all Loligo in the path of the survey trawl are caught (which is probably not true) and, therefore, represent minimum estimates of actual abundance. Catchability coefficients, if known, can be used to adjust abundance estimates to account for individuals which escape capture. Since estimates of survey catchablilty are not available for Loligo, catchability coefficients calculated for haddock were applied to the minimum abundance estimate for Loligo to provide an estimate of abundance presumably closer to actual abundance.

Catchability of haddock, considered to be highly vulnerable to survey gear, was estimated based on the average (1963-74) of annual ratios of mean catch per tow (numbers) of age 1 and older individuals in the autumn survey (expanded to encompass the area of the stock) to estimated stock size of age 2 and older individuals at the beginning of the following year (Clark et al. 1982). The average catchability coefficient was 0.45 indicating that

45% of the haddock, on average, in the path of the trawl were caught.

Natural mortality (M) was considered to be the difference between the total and fishing mortality estimates for each cohort. However, individuals from the spring cohort begin spawning during the summer of their second year prior to the autumn survey, while the autumn cohort is considered to spawn in its second spring after the spring survey. The difference in natural mortality estimates between the two cohorts was assumed, therefore, to be associated with spawning by the spring cohort. The spring cohort is assumed to spawn during August-September of its second summer at 16-17 months of age, so the annual estimate of spawning mortality was divided by 2 to obtain a monthly estimate. This mortality rate was applied to the spring cohort during the 2 months that it was assumed to spawn in its first spawning season (Table 3). The spring cohort also survives to spawn during April-July of the following year and the annual rate was apportioned equally to those four months as well.

The autumn cohort does not begin spawning until its second spring at about 18 months of age. Total mortality (Z) for the autumn cohort between 18 and 30 months of age was calculated from the mean numbers per tow for that cohort from spring surveys conducted during its second and third

spring. Annual fishing and natural mortality were assumed to be the same as during 6-18 months, and spawning mortality for the autumn cohort was estimated as the difference between Z (during 18-30 months) and the sum of F plus M. Since the autumn cohort spawns over a 6-month period (April-September) the annual estimate of spawning mortality was divided by 6 to obtain a monthly estimate. This mortality was applied to the autumn cohort during each month that it was assumed to spawn (Table 3). Natural mortality was assumed to be the same for each cohort and equivalent to that calculated for the autumn cohort.

Annual fishing mortality was initially apportioned to months according to observed monthly exploitation patterns (1978-81) assuming that catch in numbers was directly proportional to fishing mortality. The use of proportional F values implies a constant population size, which is not true, but was necessary to initiate the estimation procedure. Simulations were run, therefore, varying the proportional F values until the simulated monthly yield in number for all cohorts approximated the observed monthly catches in number (1978-81 average). The resulting monthly F vector was used for all simulations of the offshore/inshore exploitation pattern. A second fishing mortality vector was calculated for the inshore fishery concentrated primarily during the spring and summer and based on the

1978-81 US fishery. Monthly F values were calculated as the ratio of monthly US to monthly total international catch in number. These monthly ratios were then converted to proportions of their total so they would sum to 1, accounting for all of the annual fishing mortality.

The autumn cohort is generally not available to the inshore fishery during its first spring. The average percent composition of the autumn cohort in the 1978-81 US fishery in April-May was 89% below the average foreign composition in March of the same years. This difference was accounted for in the model by reducing relative fishing mortality on the autumn cohort by 89% in April and May of its first spring.

The proportion of the year class belonging to each of the two cohorts at 6 months of age was calculated from mean number-per-tow data for each cohort from the autumn or spring surveys (spring and autumn cohorts, respectively), pooled over 1968-81.

Simulations

Simulations were run for each exploitation pattern using estimated numbers of recruits apportioned into spring and autumn cohorts and natural (M), spawning (S), and fishing (F) mortality rates based on 1968-81 pooled survey data. Four sets of M and F were calculated, as described above, under different assumptions of the catchability of

the survey trawl. These resulted in varying levels of estimated abundance and subsequent rates of fishing and natural mortality producing a range of potential yields. One additional M value and five other F values were included to examine the sensitivity of the model to estimates of M and F.

Sensitivity of the model to differences in spawning mortality (S) was also tested by simulating yields with monthly spawning mortality rates of approximately 0.5 and 2 times the average calculated level. Output from all simulations included estimates of yield in number and weight per 1,000 individuals recruited at 6 months of age, and mean weight of the Loligo taken in the fishery. Total weight and number of spawners was also estimated to provide an indication of the impact of the various levels of fishing and natural mortality rates on spawning.

RESULTS AND DISCUSSION

Total mean numbers of Loligo per tow averaged 679.8 in the autumn surveys and 130.4 in the spring surveys (1968-81). Breakdown of those catches to cohort and age was as follows:

Survey	Cohort			
	Autumn		Spring	
	No./tow	Approx. age (months)	No./tow	Approx. age (months)
Autumn	228.64	0+	287.98	6
Spring	59.70	6	38.37	12
Autumn	151.21	12	11.22	18
Spring	14.06	18	18.06	24
Autumn	0.74	24	-	-
Spring	0.17	30	-	-

A relatively high average number of individuals from the spring cohort was observed in its second spring survey (18.06) compared to the number in the previous autumn (11.22). This apparent discrepancy may be the result of increased availability of the spring cohort at that age in some years as it moves inshore to spawn. The greater number per tow of the autumn cohort in its second autumn (151.21) compared to its first spring (59.70) survey may be accounted for by the greater availability of that cohort in the survey area during autumn. The spring survey is conducted prior to

onshore movement of immature Loligo, and the autumn cohort does not mature until after its second spring survey.

Total mortality between 6 and 18 months of age was estimated from equation (2) to be 3.245 for the spring cohort and 1.446 for the autumn cohort. Total mortality between 18 and 30 months was estimated to be 4.415 for the autumn cohort. However, relatively small errors in determining composition by cohort using modal analysis, especially in the older age groups, could dramatically alter the calculated Z values. Alternative techniques for determining age structure of a population from length frequencies (modal analysis) are being investigated. The estimated average minimum abundance of each cohort based on survey catches at 6 months of age was 0.729 billion individuals for the spring cohort and 0.151 billion for the autumn cohort for a total of 0.880 billion for the entire year class. The spring cohort accounted for 82.8% of this total, although this may be partly an artifact of the differences in catchability between spring and autumn surveys. Applying a trawl catchability coefficient of 0.45, as applicable to haddock, to this minimum estimate resulted in an estimated abundance of about 2 billion individuals at 6 months of age. Estimates of fishing, natural, and spawning mortality rates were made assuming that level of average abundance. Mean weights at 6 months of age were

calculated as 13.3 g for spring and 12.6 g for autumn-spawned cohorts.

The average annual (1978-81) international catch in numbers between 6 and 18 months of age was 0.201 billion for the spring cohort and 0.066 billion for the autumn cohort, based on expanded length frequencies and modal analysis. Estimates of annual fishing mortality determined from equation (3) based on the average catch and abundance of 2 billion individuals (1.656 billion - spring cohort and 0.344 billion - autumn cohort) were 0.410 for the spring and 0.363 for the autumn cohorts. Natural mortality was estimated as 1.083 per year (1.446 minus 0.363) or 0.090 per month based on the autumn cohort. This estimate of M was used for both cohorts. Spawning mortality was estimated to be 1.752 per year for the spring cohort (3.245 minus 0.410 minus 1.083) or 0.876 per month in its first spawning season (2 months) and 0.438 per month when partitioned over the 4 months of its second spawning season. Spawning mortality for the autumn cohort was estimated to be 2.969 per year (4.415 minus 0.363 minus 1.083) or 0.495 per month, for each of the months that it spawns.

Three additional levels of year-class abundance were determined, assuming catchability coefficients for Loligo of 100% (0.88 billion individuals), 60% (1.5 billion), and 30% (3.0 billion). Fishing, natural, and spawning mortality

rates were recalculated for each assumption of year-class abundance. Annual estimates of mortality rates for each level of abundance were as follows:

	F			S	
Abundance	Spring	Autumn	M	Spring	Autumn
0.88	0.931	0.827	0.619	1.695	2.969
1.50	0.546	0.487	0.962	1.738	2.969
2.00	0.410	0.363	1.083	1.752	2.969
3.00	0.273	0.242	1.204	1.768	2.969

The international fishery for Loligo (offshore/inshore) has been predominantly an offshore fishery, with a minor inshore component primarily in the spring and summer, over the time period considered in this analysis (1968-81). Simulations assuming this exploitation pattern revealed that maximum yield (kg) per 1000 recruits (about 26.7 kg) would be expected at an annual F of about 3.0 assuming a monthly M of 0.09 (based on an abundance at 2 billion individuals) and would result in harvesting about 66% of the initial recruits (Table 4). Yield would be greatest at a higher F if M was higher (at an F of 4.0-5.0 for M = 0.15).

Under all simulated levels of F and M, greater yields in terms of weight would be expected from an inshore fishery than an offshore/inshore fishery (Table 4). The offshore/inshore fishery relies on the capture of great numbers of immature squid, taken during the time when growth

is significantly greater than natural mortality. By delaying harvest, as in an inshore fishery, the squid are larger and fewer need be taken for the same yield. Maximum yield per 1000 recruits of 33.4 kg from an inshore fishery with M = 0.09 would result from an annual F of 4.0, which would harvest 60% of the initial recruits at an average size of 56.0 g, compared with a harvest of 66% of the recruits at an average size of 40.7 g in the offshore/inshore fishery.

Sensitivity analysis indicates that the effect of an error in the estimation of spawning mortality is much less critical than the effect of errors in estimating natural mortality (Table 5). Simulated yield per recruit for each exploitation pattern assuming the calculated levels of monthly spawning mortality (0.876 and 0.495) were, for the simulated range in F values, on average 12-14% less than when spawning mortality was reduced to 0.43 for the spring cohort and 0.25 for the autumn cohort, and 7-8% greater than when spawning mortality was increased to 1.74 for the spring and 1.0 for the autumn cohort (for M = 0.09). Similar variations in natural mortality (0.5 - 2.0 times) resulted in an average 25% increase in yield (kg) when M was reduced from 0.09 to 0.052 (43% decrease) and an average 26% decrease in simulated yield when M was increased from 0.09 to 0.15 (67% increase). This is primarily because the spring cohort, which comprises 83% of an average year class,

has been reduced during simulation by 10 months of natural and fishing mortality prior to the occurrence of spawning mortality. Spawning does not occur until after growth has substantially slowed, whereas natural mortality is continually reducing abundance of the year class throughout its life, including during the peak growth period, thus producing a greater impact on the available biomass.

Estimates of potential spawning biomass (and abundance) per 1,000 recruits (at 6 months of age) are presented in Table 6 for each set of mortality (F, M, and S) estimates and for each exploitation pattern. These are estimates of total biomass suffering spawning mortality per 1,000 recruits and since all individuals are assumed to die after spawning, represent the number and weight of all spawners (not the spawning product). Spawning was greater under an inshore compared to an offshore/inshore fishery for all levels of F, M, and S which were simulated. Spawning decreased with increases in natural or fishing mortality. Assuming natural mortality was 0.09, as estimated for an abundance of 2.0 billion individuals, spawning biomass would increase 16% (14% for an inshore fishery) if fishing mortality were lowered from 0.41 (as calculated) to 0.27, and would decrease 92% (90% for an inshore fishery) if F were increased to the level needed to produce maximum yield (F=3.0). The relationships of yield and spawning biomass to

changes in fishing mortality are presented in Figure 4 for the offshore/inshore and the inshore fisheries, assuming an abundance of 2.0 billion recruits.

Potential yield estimates were obtained by multiplying simulated yield per recruit (kg) values by four different abundance levels of recruits at 6 months of age (Table 7). Assuming an abundance of 2.0 billion recruits and a monthly natural mortality rate of 0.09, as estimated in this paper, the simulated maximum yield from an offshore/inshore fishery would be 53,500 mt at an F of 3.0. In comparison, maximum yield from an inshore fishery would be 66,800 mt at an F of 4.0. However, these F values are significantly higher than those estimated in this paper and would result in significant reductions in spawning stock size. It should also be noted that these represent average potential yields based on a 14-year average abundance and catchability in the survey of 45%. Annual abundance and potential yield will vary from year to year, and 45% catchability is uncertain for Loligo.

Yield was also simulated for the three other levels of year-class abundance (Table 7). Simulated yields using each set of mortality estimates for the offshore/inshore fishery were within 3-8% of the observed average catch during 1968-81 (22,000 mt). Simulated mean weights per individual were within 6-8% of the observed mean weight (59 g) from the

fishery. These results verify the consistency of the methods used to estimate input parameters for the model.

Maximum yield estimates for the offshore/inshore fishery ranged from 28,400 mt (assuming recruitment of 0.88 billion individuals and monthly M=0.052) to 76,500 mt (assuming 3.0 billion recruits and M=0.100). Corresponding estimates for the inshore fishery ranged from 38,100 to 94,100 mt (Table 7, Figure 5). Again, it should be noted that these yields correspond to extremely high levels of fishing mortality which could result in declines in spawning stock.

The Fisheries Management Plan (FMP) for Loligo specifies MSY as 44,000 mt based on an analysis published in 1977 (Sissenwine and Tibbetts 1977). Major differences between that analysis and the present one are as follows:

1. Separate spring and autumn cohorts recruiting to the fishery at 6 months of age (about 6-7 cm) but 6 months apart were assumed in the present analysis, whereas the earlier work assumed a single cohort with all individuals recruiting to a winter fishery in December at an average length of 8.5 cm. Initial individual size was, therefore, significantly smaller in the current analysis.

2. A minimum abundance estimate of 1.5 billion recruits from the autumn survey was assumed in the previous assessment compared to a range of 0.88 to 3.0 billion

individuals at 6 months of age (divided into two cohorts) in the present analysis resulting in maximum yield estimates of 43,400 mt compared to 28,400 - 76,500 mt (for the offshore/ inshore fishery).

3. The apportionment of annual fishing mortality to months in the previous assessment was based on the 1974-75 monthly catches (mt), but in the present assessment this was based on 1978-81 catch-in-numbers data for the international fishery and the US fishery, each adjusted to simulate average observed monthly catches.

4. Estimates of natural and spawning mortality in the present analysis were based on survey catch-per-tow data, whereas in the previous assessment they were derived intuitively from assumptions about the life cycle. Monthly natural mortality estimates in the present analysis ranged from 0.052 to 0.100 for abundance estimates of 0.88-3.0 billion, monthly spawning mortality ranged from 0.848 to 0.884 for the spring cohort in its first spawning season, and from 0.424 to 0.442 in its second spawning season, and spawning mortality was 0.495 in each month that spawning occurred for the autumn cohort. In the previous analysis, monthly natural mortality was assumed to be 0.05 and spawning mortality was considered to increase from 0.13 to 0.29 in the first spawning season and from 0.22 to 0.69 in the second spawning season.

CONCLUSIONS

US landings of Loligo have been well above historic levels since 1979, with 1983 landings through mid-July already exceeding past records. Catch-per-unit-effort in the US directed fishery (1976-82) has fluctuated widely, but was at the second highest level of the time series in 1982. The 1983 CPUE level is expected to exceed the previous high.

Simulations based on an offshore/inshore fishery, as has existed since the early 1970's, and applying natural and spawning mortality rates as calculated from NEFC bottom trawl survey data, indicate that maximum yield per recruit of Loligo would occur at an annual F of about 3.0. This level of fishing mortality would produce an average annual yield of 53,500 mt if annual abundance at 6 months of age is 2.0 billion individuals. This level of abundance assumes that Loligo have a catchability coefficient of 45% in the survey trawl, the same as determined for haddock. Long-term maximum yields will be higher or lower than the above estimate depending on the extent to which actual average abundance is higher or lower than 2.0 billion individuals per year. As the US catch of Loligo increases and if that fishery continues to be prosecuted inshore primarily during the summer, a greater potential yield from the stock should

occur compared to that from an offshore (primarily winter) fishery. Simulated maximum yield estimates for an inshore fishery (66,700 mt at F = 3.0) were 25% greater than when a combined offshore/inshore fishery is assumed. These results indicate that, to maximize the yield of Loligo, unless natural mortality is significantly higher than calculated here, the directed fishery should take place primarily inshore in the spring and summer during the spawning season. However, further analysis is required to explore the possibility of defining the relationship between the number of spawners and subsequent recruitment. Increasing fishing mortality to 3.0 would result in reduced spawning biomass and, if a strong relationship exists, could significantly reduce yield unless those individuals which are captured have already spawned.

LITERATURE CITED

Clark, S.H., W. J. Overholtz, and R.C. Hennemuth. 1982. Review and assessment of the Georges Bank and Gulf of Maine haddock fishery. J. Northw. Atl. Fish. Sci. 3(1):1-27.

Lange, A.M.T. 1980. The biology and population dynamics of the squids, Loligo pealei (LeSueur) and Illex illecebrosus (LeSueur), from the Northwest Atlantic. M.S. thesis, Univ. of Washington, Seattle, WA. 178 p.

Lange, A.M.T. 1981. Yield-per-recruit analyses for squid, Loligo pealei and Illex illecebrosus, from the Northwest Atlantic. J. Shellfish Res. 1(2):197-207.

Lange, A.M.T. 1982. Status of the squid (Loligo pealei and Illex illecebrosus) populations off the Northeastern USA. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 82-27. 20 p.

Lange, A.M.T. and K.L. Johnson. 1981. Dorsal mantle length-total weight relationships of squids, Loligo pealei and Illex illecebrosus from the Atlantic coast of the United States. NOAA Tech. Rep. NMFS SSRF-745. 17 p.

Sissenwine, M.P. and E. Bowman. 1978. An analysis of some factors affecting the catchability of fish by bottom trawls. Int. Comm. Northw. Atl. Fish., Res. Bull. 13:81-87.

Sissenwine, M.P. and A.M.Tibbetts. 1977. Simulating the effect of fishing on squid (Loligo and Illex) populations off the Northeastern United States, Int. Comm. Northw. Atl. Fish., Sel. Pap. 2: 71-84.

Tomlinson, P.K. 1971. Program name - NORMSEP. Programmed by Victor Hasselblad. In: N.J. Abramson (compiler), Computer programs for fish stock assessment. FAO (Food Agric. Organ., U.N.) Fish. Tech. Pap. 101, 10 p.

Table 1. Annual *Loligo pealei* catches (in metric tons) from the Northwest Atlantic (Cape Hatteras to Gulf of Maine), by the US and the distant water fleet (DWF), 1963-1982.

Year	USA	DWF	Total
1963	1,294	0	1,294
1964	576	2	578
1965	709	99	808
1966	722	226	948
1967	547	1,130	1,677
1968	1,084	2,327	3,411
1969	899	8,643	9,542
1970	653	16,732	17,385
1971	727	17,442	18,169
1972	725	29,009	29,734
1973	1,105	36,508	37,613
1974	2,274	32,576	34,850
1975	1,621	32,180	33,801
1976	3,602	21,682	25,284
1977	1,088	15,586	16,674
1978	1,291	9,355	10,646
1979	3,991	13,421	17,413
1980	3,996	19,750	23,746
1981	2,316	13,566	15,882
1982	4,900	15,805	20,705

Table 2. US catch-per-unit-effort from otter trawls (metric tons per day) from trips where Loligo was 75% or more of the catch 1976-82.

Area	Ton class[1]	Year 1976	1977	1978	1979	1980	1981	1982
				Annual				
All	All	7.63	4.91	2.50	5.18	5.18	3.76	5.27
538 + 539	All	7.20	5.01	2.54	5.21	5.24	3.67	4.96
	2	7.94	5.28	2.55	4.37	4.91	3.11	3.65
	3	6.61	4.82	2.38	5.99	5.69	4.55	6.22
	4	-	-	-	-	4.07	6.23	5.51
538	All	7.32	5.10	2.54	5.22	5.28	3.57	4.94
539	All	4.84	0.90	2.64	-	1.92	9.76	8.00
				May - June				
All	All	7.69	5.06	2.63	5.19	5.22	3.67	5.23
538 + 539	All	7.28	5.13	2.54	5.22	5.27	3.64	4.95
	2	8.14	5.50	2.55	4.34	4.93	3.10	3.62
	3	6.61	4.85	2.47	6.04	5.73	4.48	6.22
	4	-	-	-	-	4.18	6.05	5.51
538	All	7.32	5.13	2.54	5.22	5.27	3.57	-
539	All	6.14	-	-	-	4.54	9.98	-

[1] Ton class
2- 5-50 tons
3- 51-150 tons
4- 151-500 tons

Table 3. Monthly estimates of: fishing mortality (F), selectivity (Sel), natural (M) and spawning (S) mortality, and growth (G) rates for two cohorts of *L. pealei* under two exploitation patterns, assuming abundance of 2.0 billion individuals at 6 months of age. (Each cohort enters simulations at 6 months of age)

	Relative F		Spring Cohort				Autumn Cohort			
Month	Fa	Fb	Sel	M	S	G	Sel	M	S	G
Oct	.013	.066	0.25	.09	0.000	0.360	-	-	-	-
Nov	.038	.028	0.50	.09	0.000	0.309	-	-	-	-
Dec	.130	.019	0.75	.09	0.000	0.270	-	-	-	-
Jan	.350	.009	1.00	.09	0.000	0.216	-	-	-	-
Feb	.210	.019	1.00	.09	0.000	0.196	-	-	-	-
Mar	.180	.019	1.00	.09	0.000	0.180	-	-	-	-
Apr	.010	.085	1.00	.09	0.000	0.166	0.75	.09	0.000	0.278
May	.050	.575	1.00	.09	0.000	0.154	1.00	.09	0.000	0.246
Jun	.010	.094	1.00	.09	0.000	0.144	1.00	.09	0.000	0.221
Jul	.003	.028	1.00	.09	0.000	0.135	1.00	.09	0.000	0.200
Aug	.002	.019	1.00	.09	0.876	0.127	1.00	.09	0.000	0.183
Sep	.004	.038	1.00	.09	0.876	0.120	1.00	.09	0.000	0.169
Oct	.013	.066	1.00	.09	0.000	0.113	1.00	.09	0.000	0.157
Nov	.038	.028	1.00	.09	0.000	0.108	1.00	.09	0.000	0.146
Dec	.130	.019	1.00	.09	0.000	0.103	1.00	.09	0.000	0.137
Jan	.350	.009	1.00	.09	0.000	0.098	1.00	.09	0.000	0.128
Feb	.210	.019	1.00	.09	0.000	0.094	1.00	.09	0.000	0.121
Mar	.180	.019	1.00	.09	0.000	0.090	1.00	.09	0.000	0.115
Apr	.010	.085	1.00	.09	0.438	0.086	1.00	.09	0.495	0.109
May	.050	.575	1.00	.09	0.438	0.083	1.00	.09	0.495	0.104
Jun	.010	.094	1.00	.09	0.438	0.080	1.00	.09	0.495	0.099
Jul	.003	.028	1.00	.09	0.438	0.077	1.00	.09	0.495	0.095
Aug	.002	.019	1.00	.09	(3)	0.074	1.00	.09	0.495	0.091
Sep	.004	.035	-	-	-	-	1.00	.09	0.495	0.087
Oct	.013	.066	-	-	-	-	1.00	.09	0.000	0.084
Nov	.038	.028	-	-	-	-	1.00	.09	0.000	0.080
Dec	.130	.019	-	-	-	-	1.00	.09	0.000	0.078
Jan	.350	.009	-	-	-	-	1.00	.09	0.000	0.075
Feb	.210	.019	-	-	-	-	1.00	.09	0.000	0.072
Mar	.180	.019	-	-	-	-	1.00	.09	0.000	0.070
Apr	.010	.085	-	-	-	-	1.00	.09	0.495	0.068
May	.050	.575	-	-	-	-	1.00	.09	(3)	0.066

1 Fa - Monthly fishing mortality ratio assuming the traditional offshore/inshore fishery (1978-81 pattern).
2 Fb - Monthly fishing mortality ratio assuming a dominant inshore fishery (1978-81 US pattern).
3 - infinity, no individuals remain.

Table 4. Simulated yield per recruit of *Loligo pealei* for two exploitation patterns (offshore/inshore and inshore fisheries) assuming ranges of annual fishing (F) and monthly natural (M) and spawning (S) mortality rates based on NEFC surveys, pooled over 1968-81, and four levels of average annual abundance.

			Offshore/Inshore Fishery			Inshore Fishery		
M	S[1]	F	Yield/1000 No.	Yield/1000 Wt(kg)	Mean wt(g)	Yield/1000 No.	Yield/1000 Wt(kg)	Mean wt(g)
N = 0.88 billion								
0.052	0.848	0.27	185.7	11.7	62.9	151.6	13.2	87.2
	0.495	0.41	263.5	16.0	60.8	216.6	18.5	85.2
		0.55	331.0	19.5	58.8	273.9	22.9	83.4
		0.93	473.5	25.8	54.4	398.2	31.5	79.1
		1.50	610.6	30.3	49.5	523.7	38.6	73.7
		2.00	684.5	31.8	46.4	595.5	41.6	69.9
		3.00	764.0	32.3	42.2	680.4	43.3	63.7
		4.00	800.4	31.6	39.5	725.9	42.7	58.9
		5.00	818.8	30.8	37.6	753.5	41.4	55.0
N = 1.50 billion								
0.080	0.869	0.27	159.3	9.2	58.0	123.2	10.2	82.5
	0.495	0.41	226.8	12.8	56.3	176.6	14.3	80.8
		0.55	285.9	15.7	54.8	224.1	17.8	79.3
		0.93	412.5	21.1	51.3	328.6	24.8	75.6
		1.50	537.3	25.4	47.3	437.0	31.0	70.9
		2.00	606.3	27.1	44.7	501.2	33.7	67.2
		3.00	683.6	28.1	41.0	581.1	35.7	61.4
		4.00	721.3	27.8	38.6	627.5	35.6	56.8
		5.00	741.9	27.3	36.9	658.2	34.9	53.0
N = 2.00 billion								
0.09	0.876	0.27	151.2	8.5	56.5	114.7	9.3	81.0
	0.495	0.41	215.5	11.8	55.0	164.6	13.1	79.5
		0.55	272.0	14.6	53.5	209.1	16.3	78.0
		0.93	393.4	19.8	50.3	307.4	22.9	74.4
		1.50	514.0	23.9	46.6	410.4	28.6	69.8
		2.00	581.3	25.7	44.2	472.0	31.3	66.4
		3.00	657.7	26.7	40.7	550.1	33.3	60.6
		4.00	695.6	26.6	38.3	596.5	33.4	56.0
		5.00	716.8	26.2	36.6	628.0	32.8	52.3
N = 3.00 billion								
0.100	0.884	0.27	143.6	7.9	55.1	106.8	8.5	79.6
	0.495	0.41	205.0	11.0	53.7	153.5	12.0	78.1
		0.55	259.0	13.6	52.4	195.2	15.0	76.7
		0.93	375.5	18.6	49.4	287.8	21.1	73.3
		1.50	492.1	22.6	45.9	385.7	26.5	68.8
		2.00	557.7	24.3	43.6	444.9	29.1	65.5
		3.00	633.0	25.5	40.3	521.1	31.2	59.8
		4.00	671.0	25.5	38.0	567.5	31.4	55.3
		5.00	692.8	25.2	36.3	599.6	30.9	51.5

1 - Upper values are monthly spawning mortalities for the spring cohort in its first spawning season (applied to two months, S would be one half this value during each of the four months in the second spawning season), lower values are monthly S for the autumn cohort.

Table 5. Sensitivity analysis of simulated *Loligo* yield per recruit assuming two levels of monthly spawning (S) mortality and a range of monthly natural mortality (M) and annual fishing mortality (F) rates.

			Offshore/inshore Fishery			Inshore Fishery		
S[1]	M	F	Yield/1000 No.	Yield/1000 Wt(kg)	Mean wt(g)	Yield/1000 No.	Yield/1000 Wt(kg)	Mean wt(g)
0.43	0.05	0.27	205.8	16.3	79.2	171.1	18.0	105.3
0.25		0.41	288.9	21.7	75.4	241.8	24.5	101.5
		0.55	359.5	25.9	76.9	302.9	29.7	98.0
		0.93	503.7	32.2	64.0	430.9	38.7	89.9
		2.00	704.3	35.3	50.1	621.2	46.2	74.4
		4.00	808.9	32.5	40.1	739.0	44.2	59.9
	0.09	0.27	160.9	10.9	67.9	123.7	11.6	93.6
		0.41	227.8	14.8	65.1	176.3	16.0	90.7
		0.55	285.6	17.9	62.5	222.4	19.6	88.0
		0.93	407.4	23.1	56.7	322.1	26.3	81.7
		2.00	589.0	27.4	46.5	482.2	33.4	69.3
		4.00	697.0	26.9	38.7	599.7	39.4	56.6
	0.15	0.27	116.8	6.6	56.4	79.8	6.4	80.8
		0.41	166.7	9.1	54.7	114.7	9.0	78.8
		0.55	210.8	11.2	53.1	146.0	11.2	76.9
		0.93	306.5	15.2	49.4	216.0	15.6	72.4
		2.00	459.9	19.7	42.8	339.4	21.3	62.8
		4.00	564.5	20.8	36.9	448.7	23.3	51.9
1.74	0.05	0.27	176.7	9.2	51.9	143.1	11.0	77.2
1.00		0.41	252.5	12.9	51.1	205.7	15.7	76.3
		0.55	319.1	16.1	50.4	261.5	19.7	75.4
		0.93	462.6	22.4	48.5	385.0	28.2	73.2
		2.00	681.9	30.2	44.3	588.7	39.6	67.3
		4.00	804.8	31.6	39.3	728.2	42.5	58.4
	0.09	0.27	145.6	7.2	49.5	109.1	8.1	74.4
		0.41	208.6	10.2	48.8	157.3	11.6	73.6
		0.55	264.3	12.7	48.2	200.5	14.6	72.7
		0.93	385.5	17.9	46.5	297.5	21.0	70.4
		2.00	576.9	24.7	42.8	464.2	30.0	64.6
		4.00	694.7	26.5	38.1	593.4	33.0	55.6
	0.15	0.27	110.8	5.2	46.7	74.0	5.2	70.2
		0.41	159.3	7.3	46.1	107.2	7.4	69.3
		0.55	202.5	9.2	45.6	137.3	9.4	68.4
		0.93	297.9	13.2	44.2	206.1	13.6	66.1
		2.00	455.1	18.6	40.9	331.8	20.0	60.1
		4.00	563.6	20.6	36.6	446.0	22.9	51.2

1 - Upper values are monthly spawning mortalities for the spring cohort in its first spawning season (applied to two months, S would be one half this value during each of the four months in the second spawning season), lower values are monthly S for the autumn cohort.

Table 6. Simulated spawning biomass (and number) per 1,000 recruits at 6 months of age, for an offshore/inshore and inshore fishery, and assuming a range of monthly natural (M), spawning (S), and annual fishing (F) mortality rates.

			Offshore/inshore		Inshore	
			Spawning /1,000		Spawning /1,000	
M	S[1]	F	No.	Wt(kg)	No.	Wt(kg)
N = 0.88 billion						
0.052	0.848	0.27	390.1	58.4	402.2	60.6
	0.495	0.41	338.7	50.1	354.7	53.0
		0.55	294.7	43.1	313.1	46.4
		0.93	202.5	28.9	224.2	32.5
		3.00	27.8	3.8	40.2	5.4
N = 1.50 billion						
0.080	0.869	0.27	282.7	41.3	290.9	42.7
	0.495	0.41	246.0	35.6	256.9	37.5
		0.55	214.3	30.8	227.0	32.9
		0.93	148.0	20.8	163.0	23.2
		3.00	20.6	2.8	29.3	3.9
N = 2.00 billion						
0.090	0.876	0.27	252.3	36.6	259.4	37.8
	0.495	0.41	219.8	31.6	229.2	33.2
		0.55	191.5	27.3	202.6	29.2
		0.93	132.4	18.6	145.6	20.6
		3.00	18.9	2.5	26.2	3.5
N = 3.00 billion						
0.100	0.884	0.27	225.5	32.4	231.6	33.5
	0.495	0.41	196.5	28.1	204.7	29.4
		0.55	171.2	24.3	181.0	25.9
		0.93	118.5	16.5	130.1	18.3
		3.00	16.6	2.2	23.4	3.1

1 - Upper values are monthly spawning mortalities for the spring cohort in its first spawning season (applied to two months, S would be one half this value during each of the four months in the second spawning season), lower values are monthly S for the autumn cohort.

Table 7. Simulated yield (mt) of Loligo pealei for two exploitation patterns (offshore/inshore and inshore fisheries) and four estimates of abundance (N) at 6 months of age, (with corresponding monthly natural (M) and spawning (S) mortalities and a range of annual fishing (F) mortality rates.

N	M	S[1]	F	Offshore/Inshore	Inshore
0.88	0.052	0.848	0.27	10,275	11,628
		0.495	0.41	14,086	16,246
			0.55	17,134	20,110
			0.93	22,678	27,711
			1.50	26,620	33,980
			2.00	27,966	36,615
			3.00	28,384	38,136
			4.00	27,834	37,608
			5.00	27,123	36,450
1.50	0.080	0.869	0.27	13,846	15,240
		0.495	0.41	19,149	21,421
			0.55	23,489	26,663
			0.93	31,713	37,238
			1.50	38,103	46,471
			2.00	40,641	50,555
			3.00	42,085	53,547
			4.00	41,768	53,438
			5.00	41,016	52,292
2.00	0.090	0.876	0.27	17,075	18,575
		0.495	0.41	23,684	26,157
			0.55	29,125	32,614
			0.93	39,573	45,737
			1.50	47,893	57,282
			2.00	51,327	62,652
			3.00	53,482	66,684
			4.00	53,284	66,838
			5.00	52,464	65,625
3.00	0.100	0.884	0.27	23,751	25,510
		0.495	0.41	33,031	35,983
			0.55	40,722	44,939
			0.93	55,653	63,273
			1.50	67,817	79,623
			2.00	72,999	87,355
			3.00	76,527	93,501
			4.00	76,527	94,098
			5.00	75,535	92,700

1 - Upper values are monthly spawning mortalities for the spring cohort in its first spawning season (applied to two months, S would be one half this value during each of the four months in the second spawning season), lower values are monthly S for the autumn cohort.

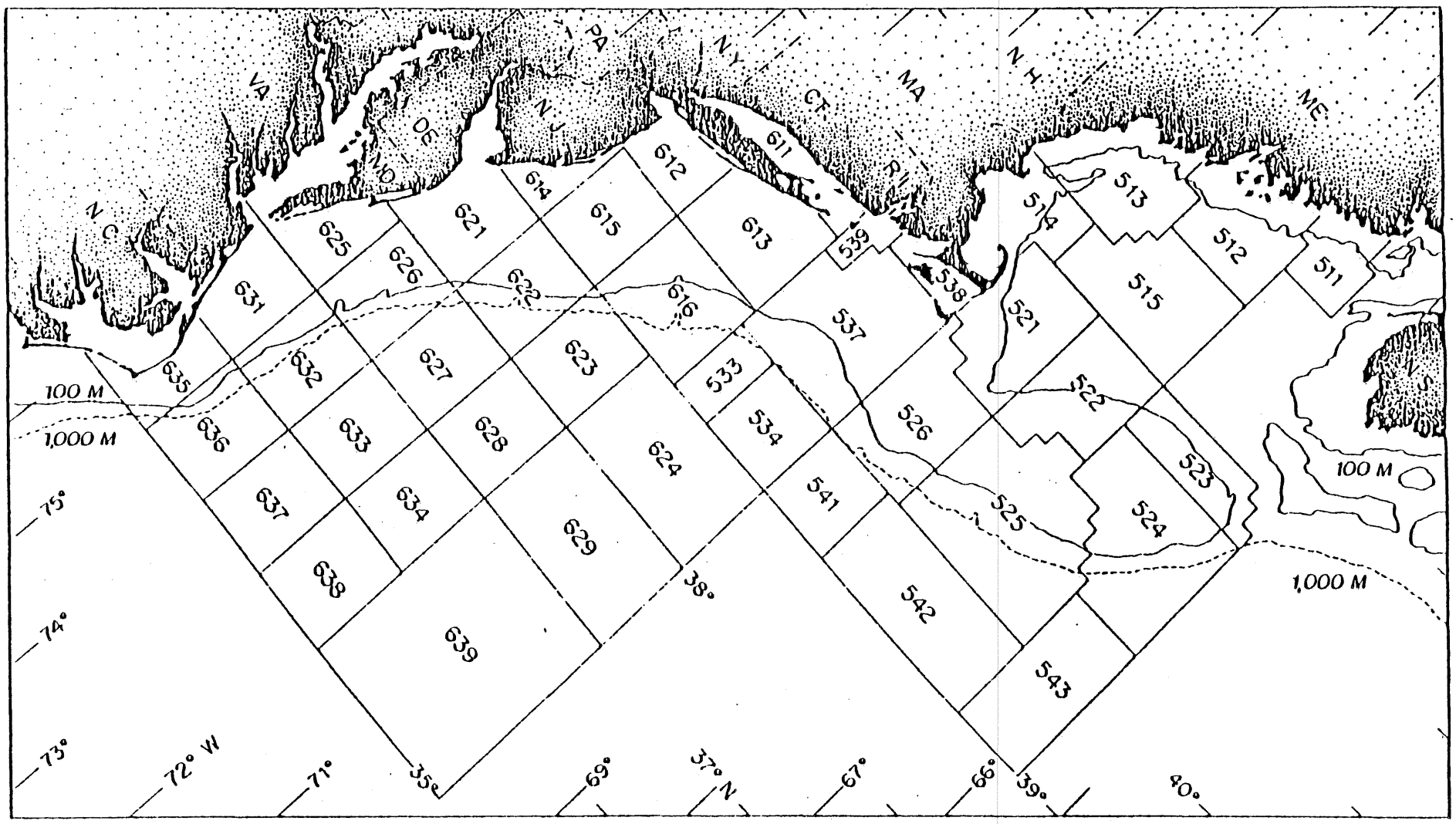


Figure 1. US Statistical Areas used in reporting location of catch and effort data.

A

B

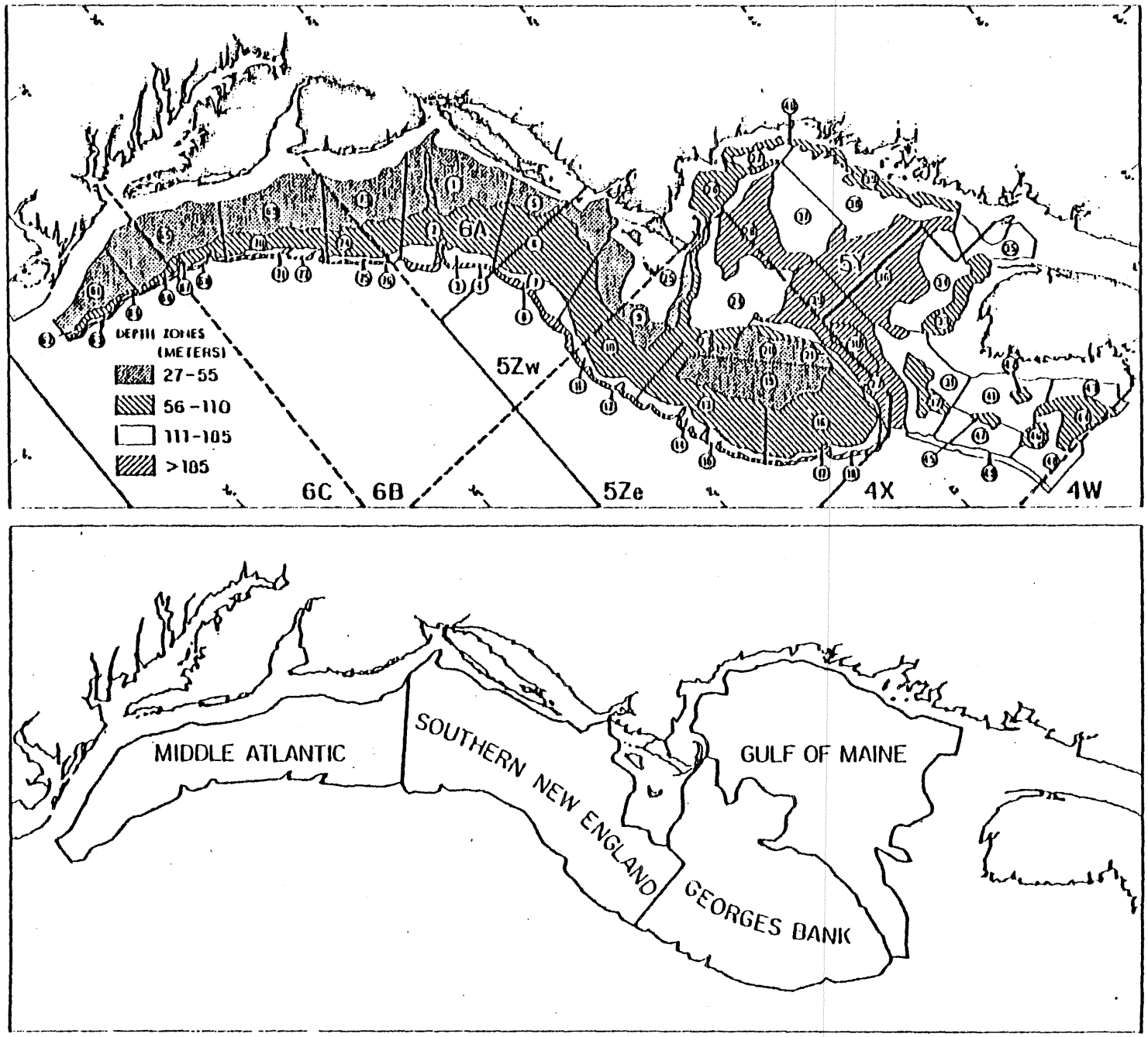
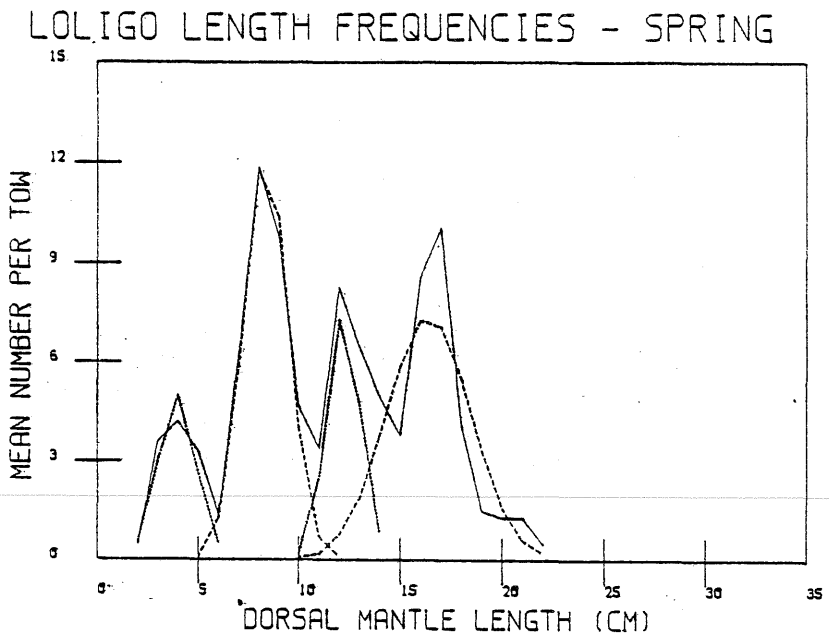


Figure 2. A. USA bottom trawl survey strata and NAFO Subareas 4-6.
B. Geographical areas off the Northeast coast of the United States.



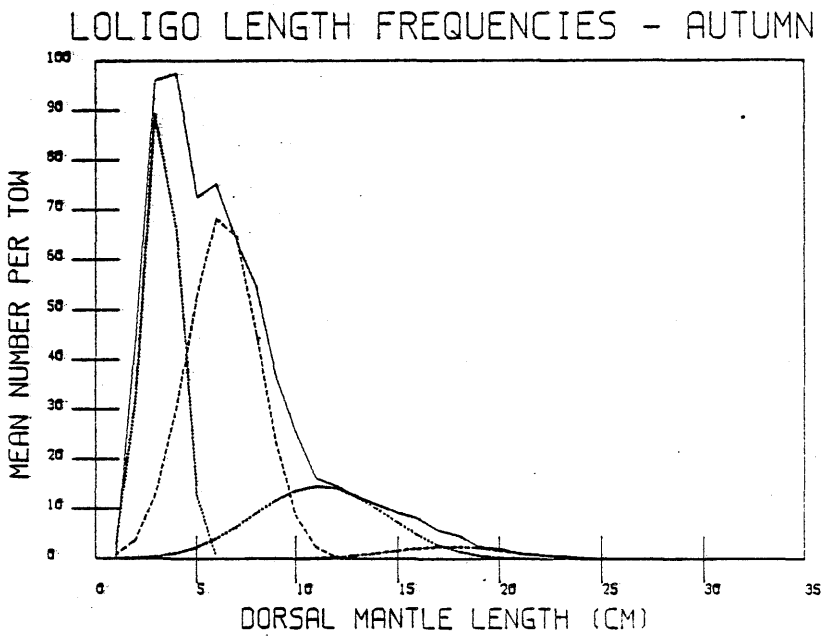


Figure 3. Length frequency distributions from the southern New England area and corresponding composition by cohort from modal analysis from spring and autumn surveys (1968-81 pooled data).

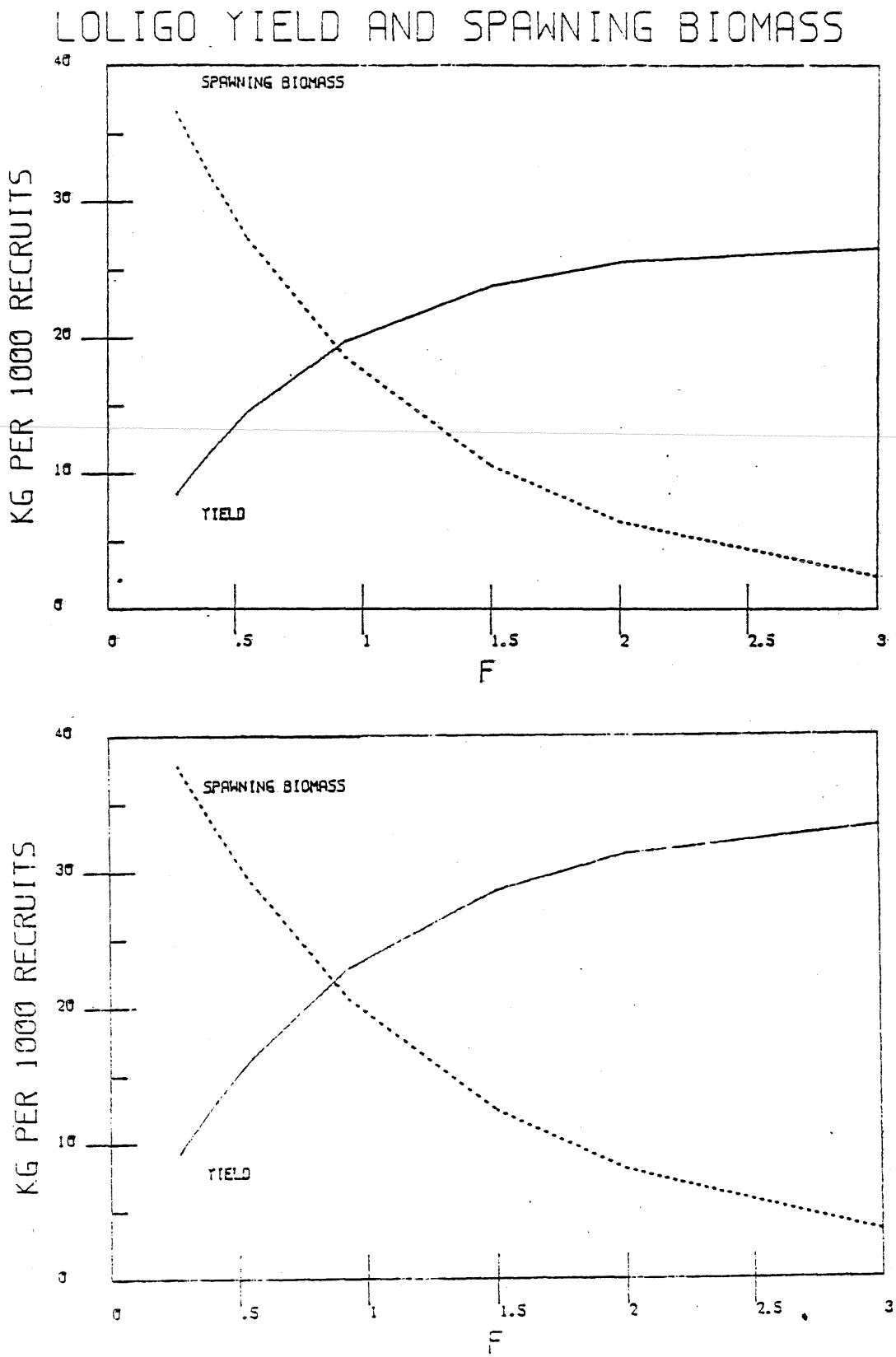


Figure 4. Yield (kg) and spawning biomass (kg) per 1000 Loligo recruits at 6 months of age, assuming natural and spawning mortality rates as calculated for an abundance of 2.0 billion recruits (monthly M=0.09, annual S=1.752 for the spring and 2.969 for the autumn cohorts), for the offshore/inshore (A) and the inshore (B) fisheries.

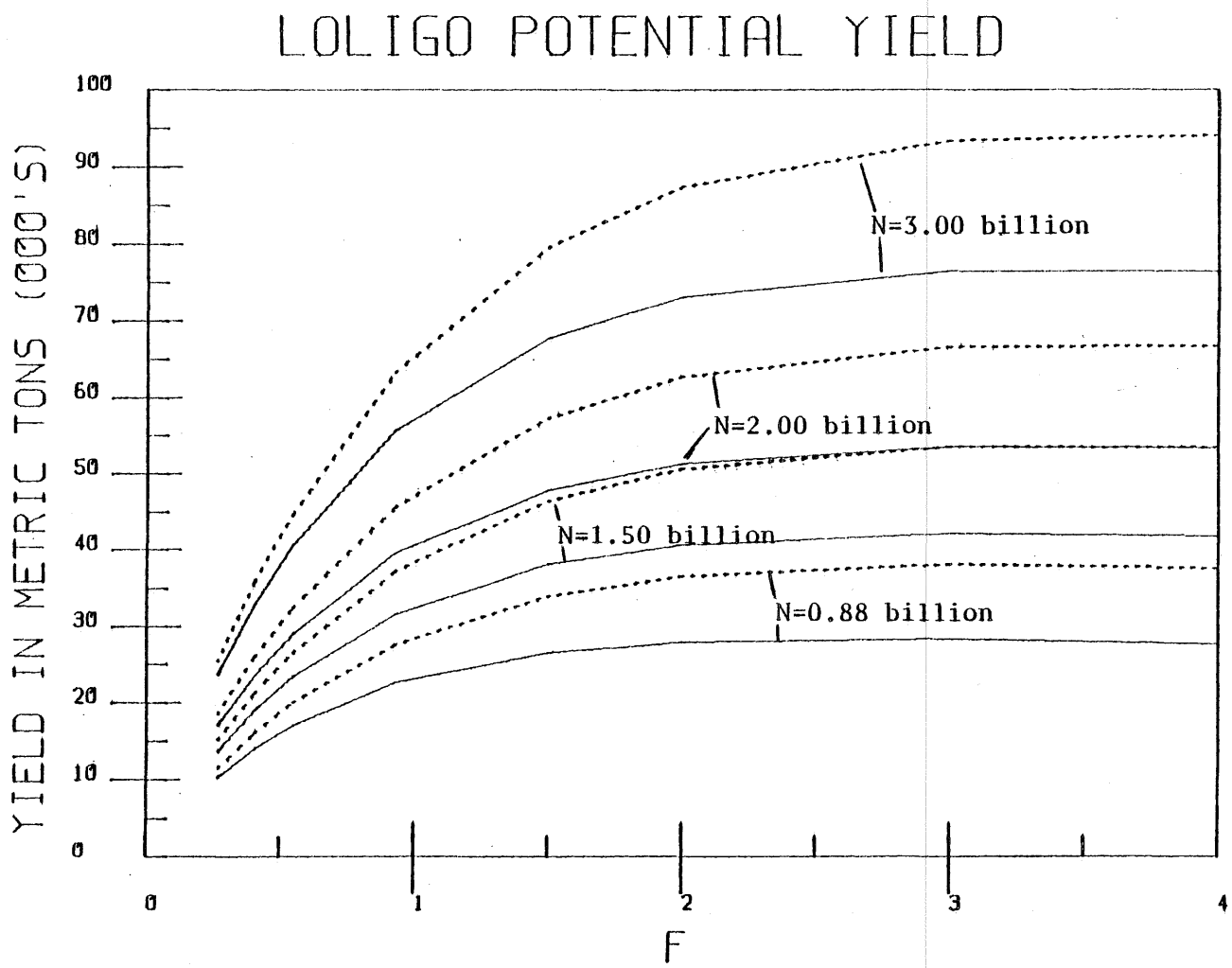


Figure 5. Potential yield of *Loligo*, in thousands of metric tons, for the offshore/inshore fishery (solid lines) and the inshore fishery (dashed lines), associated with four assumptions of annual abundance (N= 0.88, 1.50, 2.00, and 3.00 billion individuals), at 6 months of age.