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RECRUITMENT OF LONG-FINNED SQUID IN NEW ENGLAND (USA) WATERS

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ABSTRACT

Age and growth rates of the New England long-finned squid (*Loligo pealei*) were determined from statolith microstructure and provide insights into the timing of reproduction and recruitment. The ages of 457 squid from size-stratified samples collected inshore and offshore were determined. Hatching dates indicate that squid spawn throughout the year, mainly from March-November. About 36% of squid hatched during March-May, 27% during June-August, 28% during September-November, but only 7% from December through February. This squid lives less than one year, and seasonal differences in growth rates have been demonstrated. Two major hatching periods have been identified, and it now appears that there are actually 4 micro-cohorts with respect to age, which spawn at different sizes dependent upon the season in which they hatched.

The New England *Loligo* fishery has become fully exploited with landings worth $US 20-30M ex-vessel. Two recent changes in the fishery may be adversely affecting recruitment. The rapidly developing winter offshore fishery, concentrating on pre-spawning adults, now produces 90% of the total landings. A new export market has developed for juvenile pre-recruits (≤ 5 cm mantle length). Current management policy based on total annual allowable catch is inadequate to properly manage the long-finned squid fishery, given recent biological findings. Management plan improvements currently being discussed include limiting entry, setting quarterly quotas, and increasing the minimum mesh size. Additional provisions which take into account details of recruitment and growth, such as seasonal area closures to insure sufficient spawning and survival of pre-recruits, will also be needed to optimize and balance inshore and offshore fisheries.

Introduction

Research begun in 1991 (Sea Grant # NOAA NA89AA-D-SG082) has provided the first direct estimates of age and growth rates for the long-finned squid, *Loligo pealei*, based on statolith micro-structure (Brodziak and Macy, 1994). Previous age and growth rate estimates were deduced from analyses of polymodal length-frequency distributions (Summers 1983) and appear to have generally over-estimated maximum life spans and under-estimated growth rates. Hard-part ageing suggests that this squid lives a maximum of 12 months, with typical sexually mature adults being only 6-9 months old (this study; Brodziak and Macy 1994). These new lifespan estimates are consistent with recent data for a variety of other loliginid squids (Jackson, 1994; Arkhipkin, 1993; Jackson, et al., 1993; Natsukari and Komine, 1992; Jackson, 1990a; Jackson, 1990b; Kinoshita, 1989; Natsukari, et al., 1988). We have previously indicated that spawning occurs throughout the year (Macy 1995;)Brodziak and Macy 1994), and that growth rates vary depending upon the time of year of hatching. For the first 5-6 months growth is a relatively slow, only 0.9 cm mo^{-1} on average. Thereafter mean growth rates accelerate and may exceed 3.5 cm mo^{-1} for mature males. Males grow faster and attain larger sizes than females (Brodziak and Macy 1994). Disregarding sex and season hatched, growth in length and weight was best described by an exponential model. In the following paper recruitment will be examined using an enlarged ageing database of 457 squid.

Materials and Methods

A combined collection of 2191 long-finned squid, *Loligo pealei*, was obtained from a variety of locations and seasons from 1991 through 1994. Offshore samples were obtained from a commercial fishery vessel (F/V Huntress, Pt. Judith, RI, USA). Inshore samples were obtained from research surveys conducted by the Rhode Island Department of Environmental Management, the Graduate School of Oceanography, University of Rhode Island, and the Massachusetts Department of Marine Resources (Fig. 1). Since the initial goals of the research were to develop a statolith-based ageing method for *L. pealei*, to ascertain its maximum lifespan, and to examine general growth patterns, the largest and presumably oldest squid were first obtained from the winter offshore season. Large male squid were thus over-represented in winter samples (Fig. 2). Because of the large mesh size used in the commercial fishery (63.5 -79.4 mm) small juveniles were particularly under-represented in the offshore samples. Not all seasons were equally represented for each year of sampling, but rather an attempt was made to obtain a general sense of the population structure and dynamics. Representative sub-samples totaling over 450 squid were selected for ageing (Macy, 1995; Brodziak and Macy, 1994), based on the observed size distributions of each collection. Details of the statolith preparation and increment counting procedures have been presented elsewhere and will not be further discussed here (Macy, 1995; Brodziak and Macy, 1994).

Results

Several characteristics of some of the data sets used in this study should be mentioned before continuing. The 50% retention size of *Loligo* has not been estimated for any of the sampling nets used (but see Summers, 1971). The commercial offshore fishery employed the largest mesh size, varying from 63.5 to 79.4 mm stretched mesh, while the Massachusetts inshore survey employed only 6.5 mm mesh. Thus sampling gear bias of unknown magnitude exists. Random samples representing the actual range of sizes and maturity stages present at any time likely were not obtained from the commercial fishery samples. More generally, one must also anticipate that any observed length-frequency distributions of *Loligo* already reflect size-selective effects due to ongoing fishing activity (Lange 1980) to some extent. One would expect this bias to be largest for the largest squid which have been traditionally the most commercially desirable.

Throughout the annual cycle the squid population size structure varies considerably. Winter and spring samples are characterized by their broad size range and contain the largest squid (Fig. 2) (see also Macy, 1980), while summer and fall length distributions are significantly narrower and are dominated by juvenile, sexually indeterminate squid ≤ 5 cm mantle length (ML) (Figs. 3a & b). During summer and fall few squid larger than ca. 20 cm ML were captured. Males reached greater sizes in winter and spring (ML and weight) than females (Fig. 3a). No females larger than 30 cm ML were captured, but a few males exceeded 40 cm ML. While no juveniles ≤ 5 cm ML were captured during the winter, about 5% of the spring collection were in this size category. Sex ratios remained approximately 1:1 throughout the year (Fig. 3b).

On a seasonal basis, the oldest and the highest proportion of sexually mature or nearly mature squid (Macy 1982) were captured during spring (Fig. 3b). The majority of spring squid hatched during the previous fall and summer (Fig. 4a), but a few small winter-hatched squid were also present. Spent, actively spawning, and ready-to-spawn adults were not distinguished (Macy 1982). Virtually all the larger squid examined were fully mature, and most all of these females had mated as indicated by the presence of spermatophores in the buccal spermatheca. Immature members of both sexes (stages 1 & 2) were absent from spring samples (Fig. 4a, lower), but some immature females from fall hatchings were present. The few unsexable squid caught hatched during the previous winter.

Summer samples consisted mainly of sexually indeterminate young of the year (Figs. 3b, 4b). A few squid caught during summer (≈8%) hatched earlier the same summer, but the majority hatched the previous spring and winter. The few maturing or mature individuals observed during summer hatched the previous winter.

Fall samples (Fig. 4 c) hatched mainly during the previous summer and spring. A significant proportion of maturing squid hatched in winter (Fig. 4c, lower). Nearly 40% of the entire fall sub-sample was composed of unsexable juveniles, and with the exception of a single mature male hatched the previous winter, no mature (stage 3 or 4) squid were present. Stage 2 squid of both sexes, however, were the most abundant stage of sexual maturity during the fall sampling period.

Winter samples were dominated by summer-hatched squid (Fig. 4 d). About 20% of the sample was spawned the previous spring. No fully mature females were collected, but all the males were fully mature . A single mature male was captured that hatched the previous winter and was thus nearly 12 months old. No unsexable juveniles were present. Only 16.4% of all aged squid were collected during the winter, but spring, summer, and fall seasons were roughly equally represented at 32.2, 26.7, and 24.7 % of the total (457), respectively.

Discussion-

Until statolith ageing was used to elucidate the age structure of the southern New England (SNE) *Loligo pealei* population, Summers' work (1983, 1971) provided the basis for the fisheries biology of the species. Simply stated, some individuals were believed to live as long as 30 months, but the average age at capture was believed to be only 12 to 18 months. Post-spawning mortality was inferred from the disappearance as the season progresses of the larger size classes present early in the protracted inshore spawning season. Using growth rates inferred from polymodal length-frequency analysis of samples collected inshore and offshore throughout the year, Summers suggested that spawning and recruitment occurred in 2 phases. The major spawning period was inshore and peaked in July. Squid of this cohort were thought to grow rapidly and form a "short generation" living about 1 year. A second, smaller cohort resulted from a November hatching in the southern part of the range. This cohort was believed to form a "long generation", with some individuals surviving into their third year (30 mo. ±). Another hypothesis involving "crossed generations" was proposed by Mesnil (1977) for *L. pealei*, based on aspects of the spawning and reproductive cycle of the European cuttlefish, *Sepia.*, to account for the observed changing length-frequency distributions.

Age determinations of 457 long-finned squid permit a new interpretation of the squid life cycle in SNE waters which has significant implications for management of the fishery. The revised life cycle hypothesis can be understood in the context of the annual cycle of inshore- offshore movements. By late April large mature squid have moved into SNE coastal waters and have begun to spawn (Macy 1980). As shown in Figure 5, there is a prolonged inshore hatching period lasting at least from April through September. As was shown previously (Figs.2, 3) the largest squid were captured during winter and spring, and it is this group which moves inshore first to spawn and then die. Throughout the summer subsequent waves of squid appear inshore and spawn in decreasing order of size (Macy, 1980; Summers, 1971). During the inshore season the mean size of mature males (M4) declined from 33 cm ML in April, to a low of 5.8 cm in August, increasing to 14 cm in September. Similarly, mature females (F4) decreased in size from 20 cm ML to a low of 7.4 cm in June, and then increased to 11.1 cm ML in September. Clear evidence for post-spawning mortality can be seen by the loss of squid larger than 20 cm in the summer and fall samples (Figs. 2 & 3; Macy,1980).

Offshore movements begin sometime in October, and while few or no mature squid were present in the fall samples, large numbers of maturing squid 10-20 cm ML were present inshore and on the continental shelf (Figs. 1-4). Typically, squid leave Rhode Island waters by early November (Macy, 1980) when water temperatures drop below 9°C. Unfortunately no fall samples from the winter distribution along the edge of the continental shelf (Fig. 1) were available for this study.

Assuming that mature or nearly mature squid (stages 3,4, Macy, 1982) are actively spawning or will begin to spawn during the month of capture, the calculated month of hatching can be used to estimate lifespan and predict when the offspring of each micro-cohort should mature and spawn. McMahon and Summers (1971) showed that *Loligo* eggs take from 27 to 10 days after deposition to hatch at temperatures from 12°- 23°C in the laboratory. Thus, eggs laid inshore during early April in 8-10°C water (Macy, 1980) should hatch by early May and recruit to the inshore population. Jon Brodziak and I (1994) have shown that summer hatched squid grow faster than those hatched during the winter months.

Offshore, some spring/summer hatched recruits mature early and spawn from January through March (Fig. 5); having grown to 20 cm and larger (Fig. 4d); at ages of about 9 months. The remainder of the spring/summer hatch mature later and move inshore to spawn during April and May. The oldest surviving squid from the previous spring hatching are thus 10-11 months old when they spawn in April and May, while the younger squid from the previous summer spawning are only 8-10 months old. A third group of rapidly growing squid, recruited in October through December, move inshore to spawn from April through July at only 6 to 8 months of age. Thus the mass of relatively large, mature squid (Fig.2) which arrive and spawn inshore first, from April into June are actually components of 3 different aged groups, spawned at different times the previous year. These 3 micro-cohorts support the May-June SNE inshore fixed gear fishery. Late spring hatched recruits (April-June) grow rapidly in the warm inshore waters, reaching sizes of 5-10 cm ML by fall offshore (Fig.2). Another group of increasingly smaller but mature squid recruited the previous fall arrive inshore later and spawn from July through August. The recruits from this micro-cohort move offshore by November at about 5 cm ML.

By the end of June the inshore population consists solely of the fall recruits (5<ML<10 cm) for which, until recently, there has been little commercial demand. Small numbers of fall-spawned squid continue to arrive and spawn inshore through July and are then joined by the younger components of the winter (Jan.-Mar.) offshore spawning, about 6-7 months old. Members of the winter spawnings continue to appear in samples as mature individuals through

September and into October at increasing mean sizes. These squid are thought to be 8-9 months old when they mature. Thus there is new evidence for the existence of 4 inshore-spawning micro-cohorts, as shown in the following tabulation.

SEASON	HATCH	SPAWN	AGE, mo.	LOCATION
SPRING	IV-VI	I-V	9 - 11	Off & In- shore
SUMMER	VII-IX	I-V	6 - 10	Off & In- shore
FALL	X-XII	IV-VII	6 - 9	Inshore
WINTER	I-III	VII-X	6 - 9	Inshore

Parts of the spring and summer spawned groups spawn both offshore and inshore, while the subsequent fall and winter hatched groups spawn inshore. Thus "knowing "the age composition of the samples it has been possible to discriminate 4 micro-cohorts. Since the variability in size at age increases with size and the micro-cohorts overlap considerably in size (ML) it had not been previously possible to reliably discriminate them on the basis of size or weight alone.

Rather than being restricted to 1 or more distinct, reproductive periods of relatively short duration, it has been shown that in SNE waters *L.pealei* has a more nearly continuous reproductive cycle, reminiscent of that of a number of coral reef fishes. The underlying mechanisms which allow gonad maturation to be induced throughout the year under differing environmental condition are not known. It seems likely that both growth rates and the rate of sexual maturation are influenced strongly by environmental factors such as temperature and food abundance. Latitudinal effects may also account for some of the observed variation in size at age and in the timing of reproduction, but there is insufficient information to evaluate these possibilities. For the sake of simplicity fishery managers have assumed that there is but a single stock of *Loligo pealei* from Cape Hatteras to Nova Scotia and Newfoundland, but this is not necessarily so.

The biology of the winter offshore phase of *Loligo* is considerably less well understood than that of the inshore phase. The relative contributions of the two reproductive seasons to overall population recruitment can not yet be determined. Squid egg masses have been reported by fishermen on the continental shelf during winter, but no attempts to systematically document the occurrence of egg masses have been undertaken. The overall size-age structure of the exploited offshore squid population is not well documented either. Some length-frequency information can be derived from commercial landing statistics (60-80 mm mesh cod ends), but winter fisheries survey data for finer mesh nets (11.3 mm), which would be expected to retain smaller squid, are available only since 1992. As shown in Figure 6 squid as small as 2 cm ML were captured, but did not appear in the commercial data shown in Figure 2. Figure 6 also provides evidence for interannual variation in the offshore size structure. In February 1994 (Fig. 6, lower panel) the 2 cm size class was an order of magnitude more abundant than either of 2 previous years. Squid 2-3 cm ML would be about 3 months old and therefore would have hatched November-December.

During the past 15 years, the southern New England *Loligo* fishery has changed from a short inshore summer fishery into a 12 month directed fishery. The inshore fishery, from May into June, is conducted with fixed gear such as weirs, while freezer trawlers are used for the November -March offshore season. Although total *Loligo* landings have remained relatively constant during the past 3-4 years, the winter offshore fishery (Fig. 7) currently harvests over 90% of the annual catch. This shift does not simply reflect a shift in effort, but rather an actual decline in the amount of squid landed inshore. In spite of the fact that reported landings have been significantly less than the 36,000 mt TAC (total allowable catch) the fishery is considered fully exploited (J. Brodziak, NEFSC, NMFS, personal communication). The major cause for the discrepancy seems to be under-reporting of by-catch, including discards of less commercially valuable sizes, not underestimation of the stock biomass as fishermen have argued. During 1995 a new market for very small *L. pealei*, ≤ 5.1 cm ML, has developed in Spain (personal communication Deep Sea Fish; Angel Gonzalez, Vigo, Spain), while foreign demand for *Loligo* larger than 20.3 cm ML has decreased. If demand for these small juveniles continues a new pressure will be put on squid stocks. Additional new pressure on squid stocks may result indirectly from the emergency moratorium declared for the vital Georges Bank groundfish fishery: vessels may now switch to fishing squid and butterfish, thereby increasing the overall effort directed towards squid stocks.

Development of a prudent squid fishery management is hindered by a number of major gaps in our understanding of *Loligo* biology. The nature of the stock /recruitment relationships is unknown. Aspects of the natural history and ecology, such as the vertical and geographic distributions of hatchling and small juvenile squid are also poorly known, largely due to the gear selectivity of standard fishery surveys. As previously mentioned, it is not currently possible to evaluate the relative contributions of the inshore and offshore spawning seasons to overall annual recruitment. For all the above reasons and more it is not yet practical to establish the minimum escapement rate from the fishery for any size group needed to insure a stable biomass. Thus it is unclear what sort of management strategies should be recommended. Should temporal and/or area closures be employed to protect adult spawners and/or juveniles? Empirically, it seems that thus far total catch limitations (TAC) have been successful, in that wild fluctuations in abundance have not occurred, but with the expected arrival of displaced ground fishery vessels the need to limit effort and catch becomes more urgent. Based on the extreme susceptibility of *Loligo pealei* to handling damage, minimum mesh-size restrictions would probably be futile. Any squid herded into the gear would not be likely to survive long after escaping through the twine mesh.
Thus while some major progress in squid biology has been made many vital aspects of *Loligo* biology remain uninvestigated.

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Figure Legends

Figure 1. Squid were sampled along the U.S. coast from Cape Hatteras to Cape Cod. From April through October samples were collected in the shallow (<60 m) inshore waters south of Cape Cod, indicated by the upper enclosed area. Winter and early spring samples were obtained from the commercial offshore fishery focused on canyons along the continental shelf (lower enclosed area), in depths of 100-200 m.

Figure 2. The population length-frequency composition varies considerably throughout the course of the year. The length-frequency distribution for the entire sample collection, n=2191, is shown here on by season collected. Squid were grouped to the nearest whole centimeter mantle length (ML).

Figure 3. The overall population structure of the aged squid can be described in terms of length and sexual maturity. In A. the size distribution is shown in length groupings which roughly correspond to the prevailing U.S. East coast commercial size categories for *Loligo*, by sex and season collected. U, F, and M indicate unsexable, female, and male. In B, below, the maturity composition is given on a 1-4 scale according to Macy (1982).

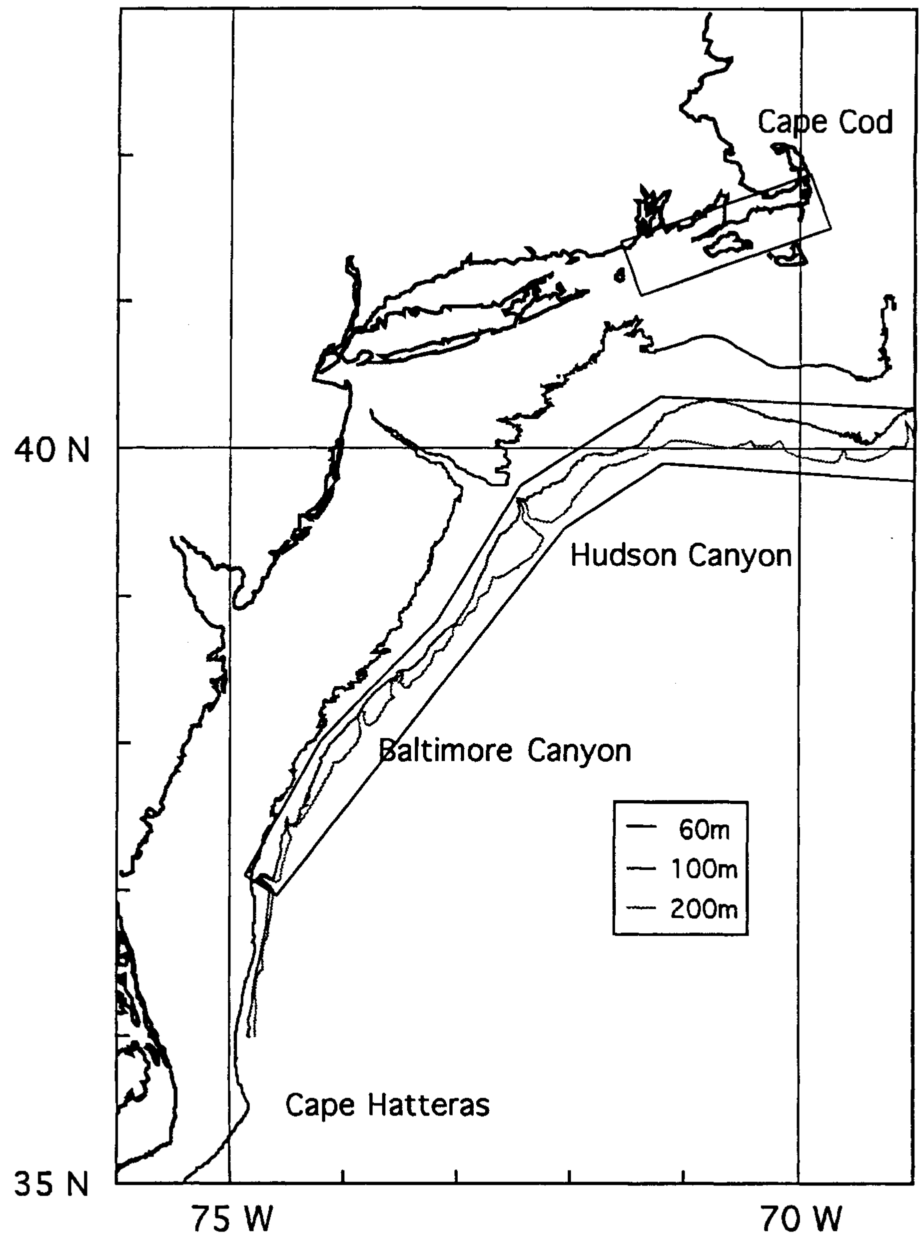
Figure 4, Size and maturity for each season of collection are shown by season hatched. Sample size, n, is given for each pair of panels. Sex and maturity nomenclature as in Figure 3..

Figure 5. The calculated hatching dates of all aged squid were pooled on a monthly basis. Although overall squid hatched in all months of the year, the timing of sampling was not sufficiently regular to determine if the same pattern is true every year.

Figure 6. Length-frequency distributions for 3 winter surveys conducted by NMFS during the month of February are shown here. Sampling extended from Cape Hatteras in the south to Georges Bank in the north. Detail of the 0-5 cm size range is shown on an expanded scale in the lower panel to show the presence of very small squid, less than 5 cm M L.

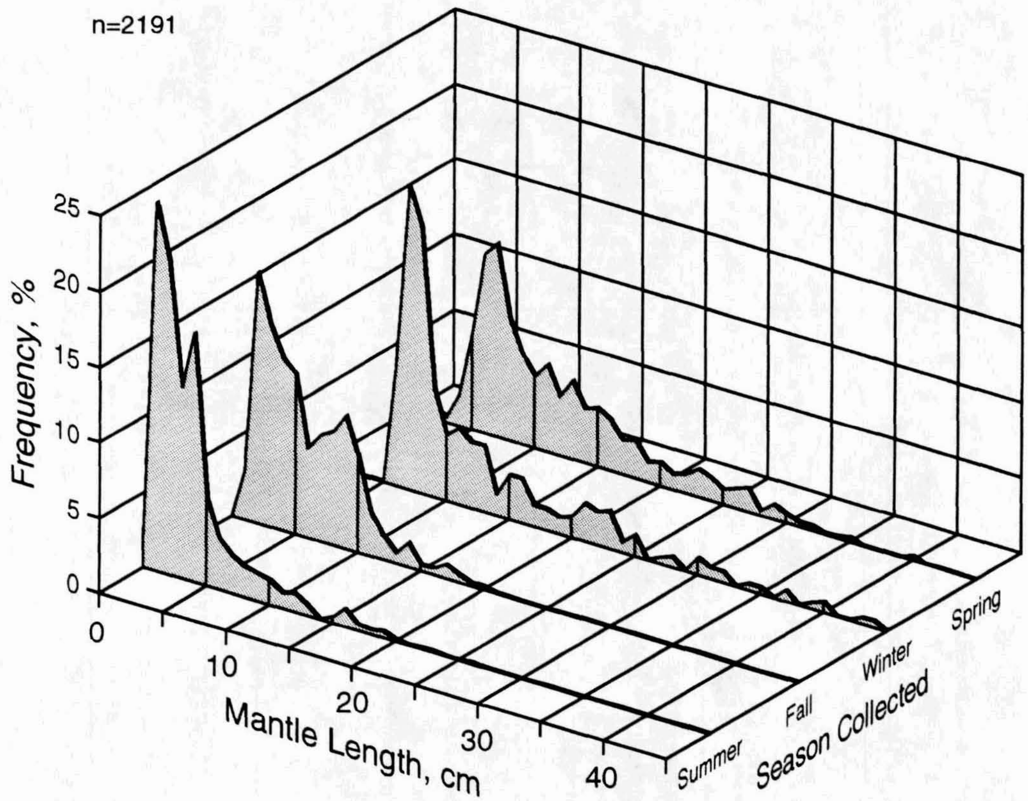
Figure 7. Total squid landings (*Loligo* and *Illex*) have varied considerably since 1978. Landings rose sharply in 1982 due to greatly expanded effort U.S. fleet which displaced foreign vessels from the fishery. Although offshore landings declined and then rose again in the late 1980's, the inshore fishery has continued its downward decline.

Figure 1



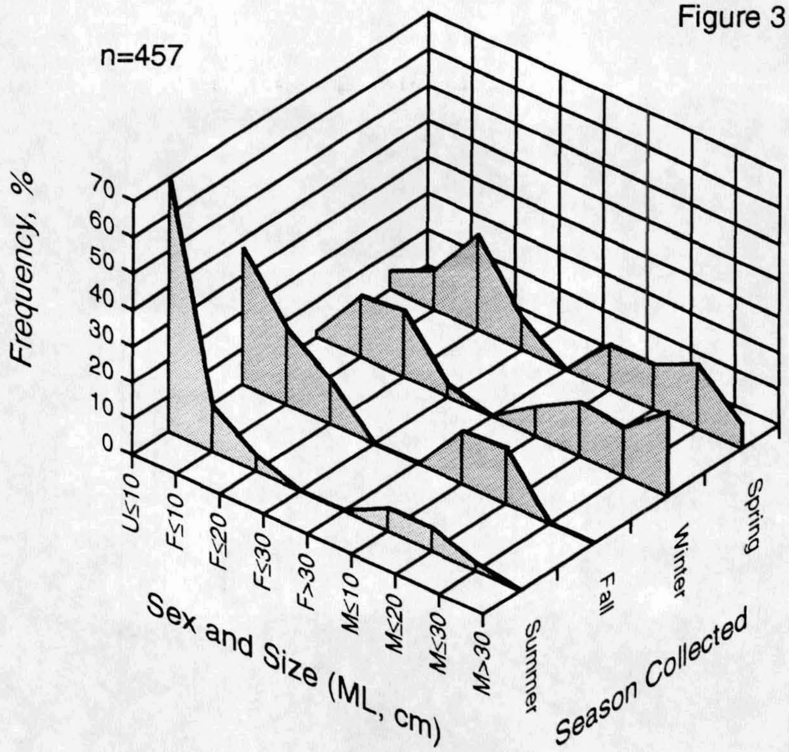
Cape Cod
40 N
Hudson Canyon
Baltimore Canyon
60m
100m
200m
Cape Hatteras
35 N
75 W
70 W

Figure 2



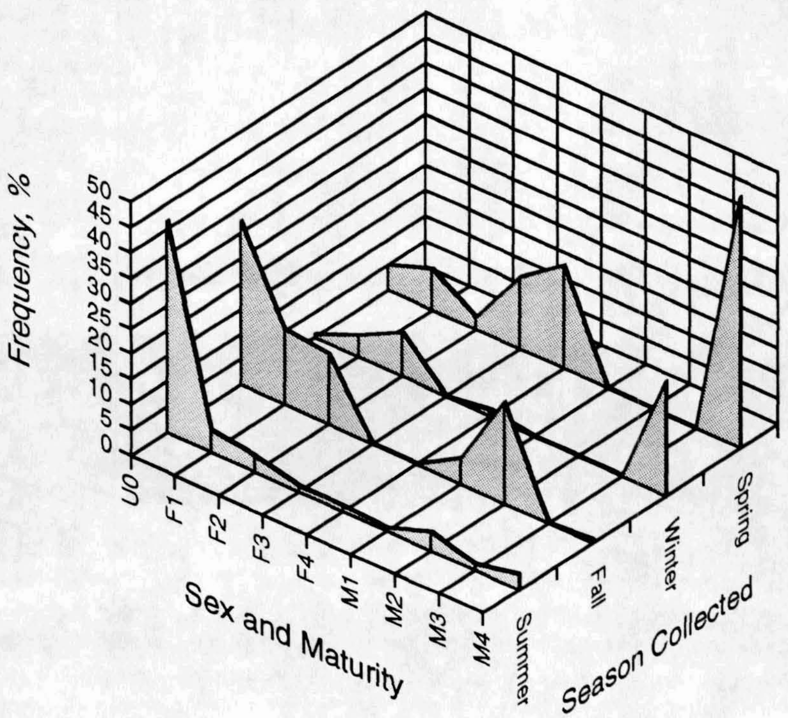
n=2191
Frequency, %
25
20
15
10
5
0
0
10
20
30
40
Mantle Length, cm
Summer
Fall
Winter
Spring
Season Collected

Figure 3



n=457
Frequency, %
70
60
50
40
30
20
10
0
U≤10
F≤10
F≤20
F≤30
F>30
M≤10
M≤20
M≤30
M>30
Sex and Size (ML, cm)
Summer
Fall
Winter
Spring
Season Collected

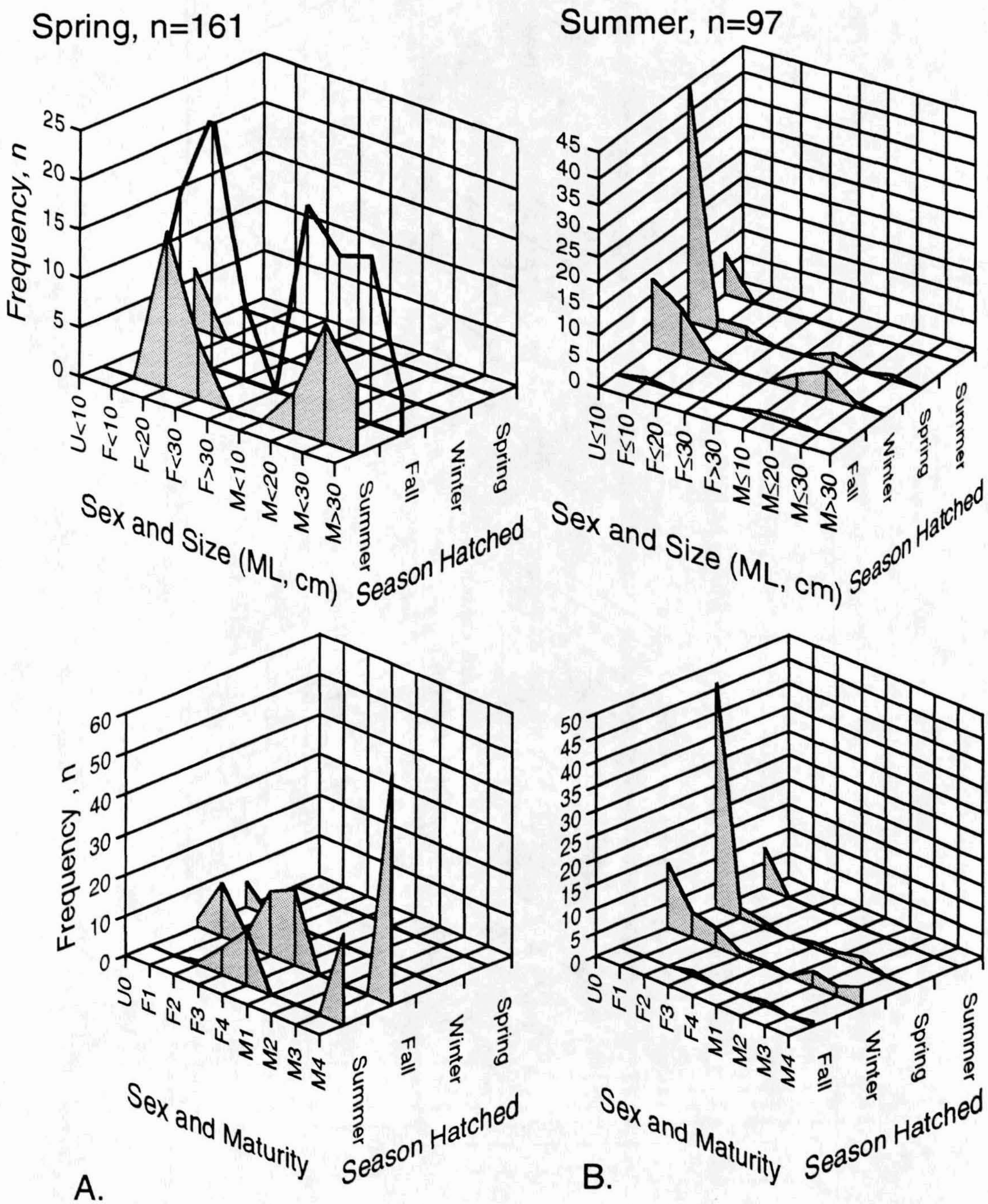
A.



Frequency, %
50
45
40
35
30
25
20
15
10
5
0
U0
F1
F2
F3
F4
M1
M2
M3
M4
Sex and Maturity
Summer
Fall
Winter
Spring
Season Collected

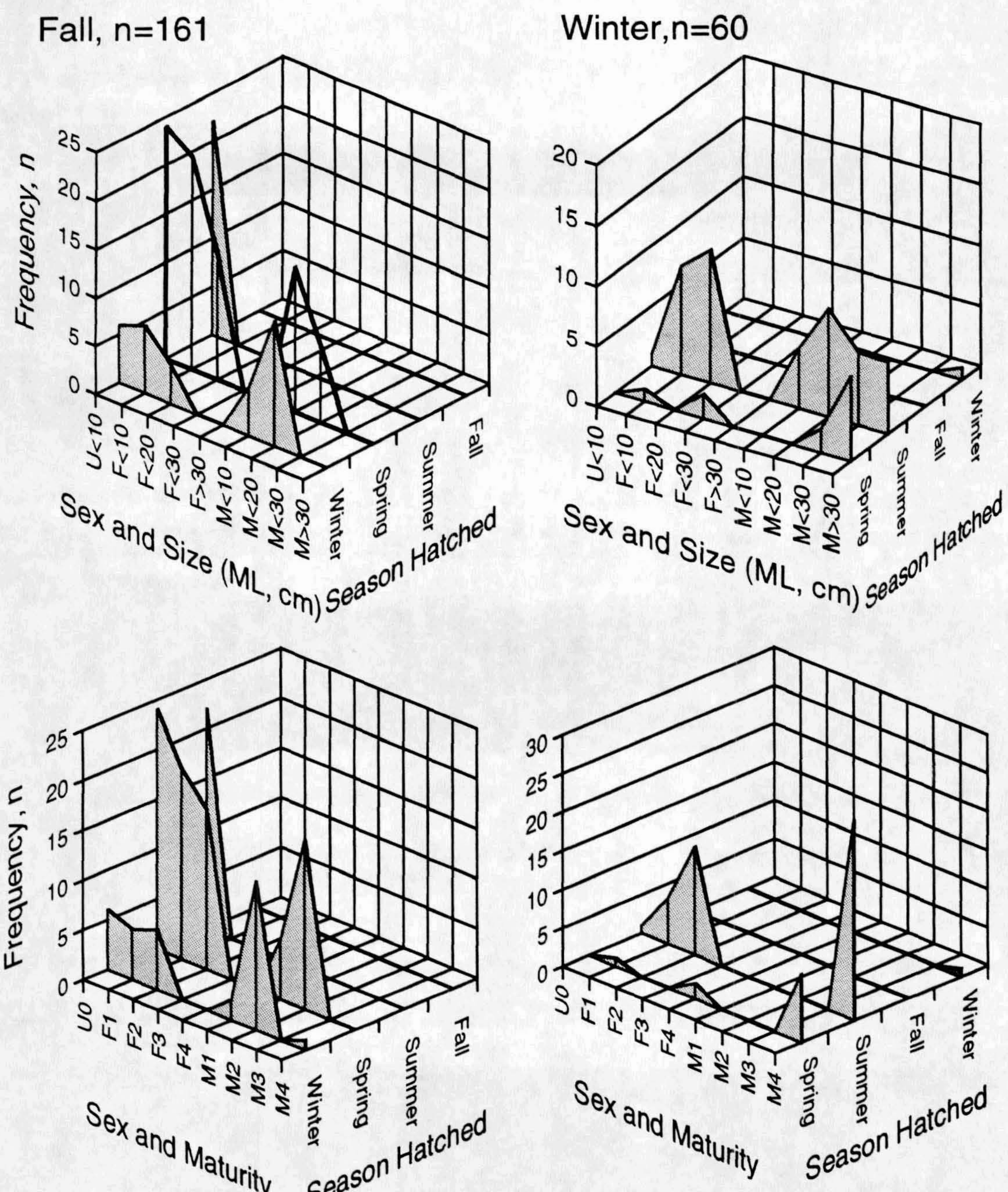
B.

Figure 4



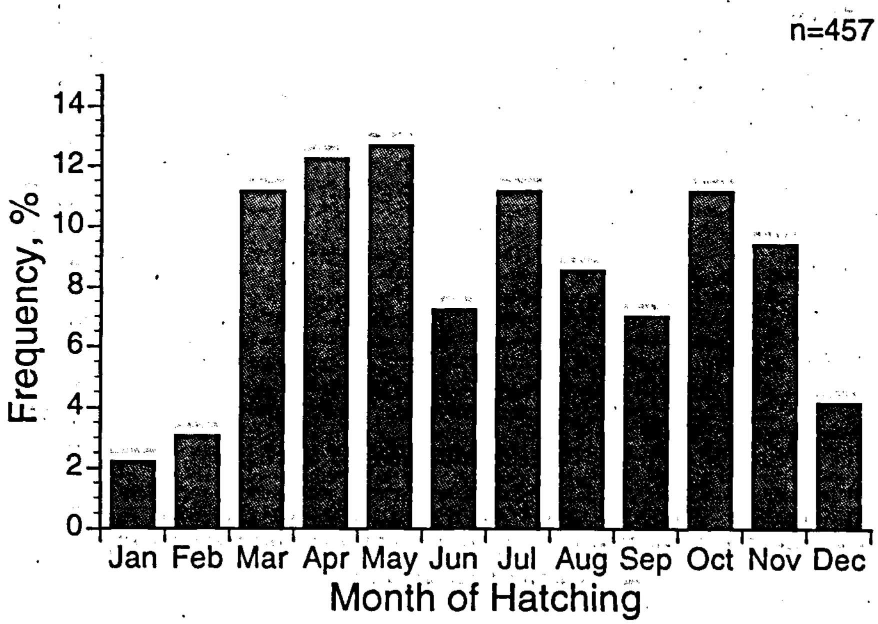
Spring, n=161
Summer, n=97
Frequency, n
Sex and Size (ML, cm)
Season Hatched
U<10
F<10
F<20
F<30
F>30
M<10
M<20
M<30
M>30
Summer
Fall
Winter
Spring
Frequency , n
Sex and Maturity
U0
F1
F2
F3
F4
M1
M2
M3
M4
A.
B.

Figure 4



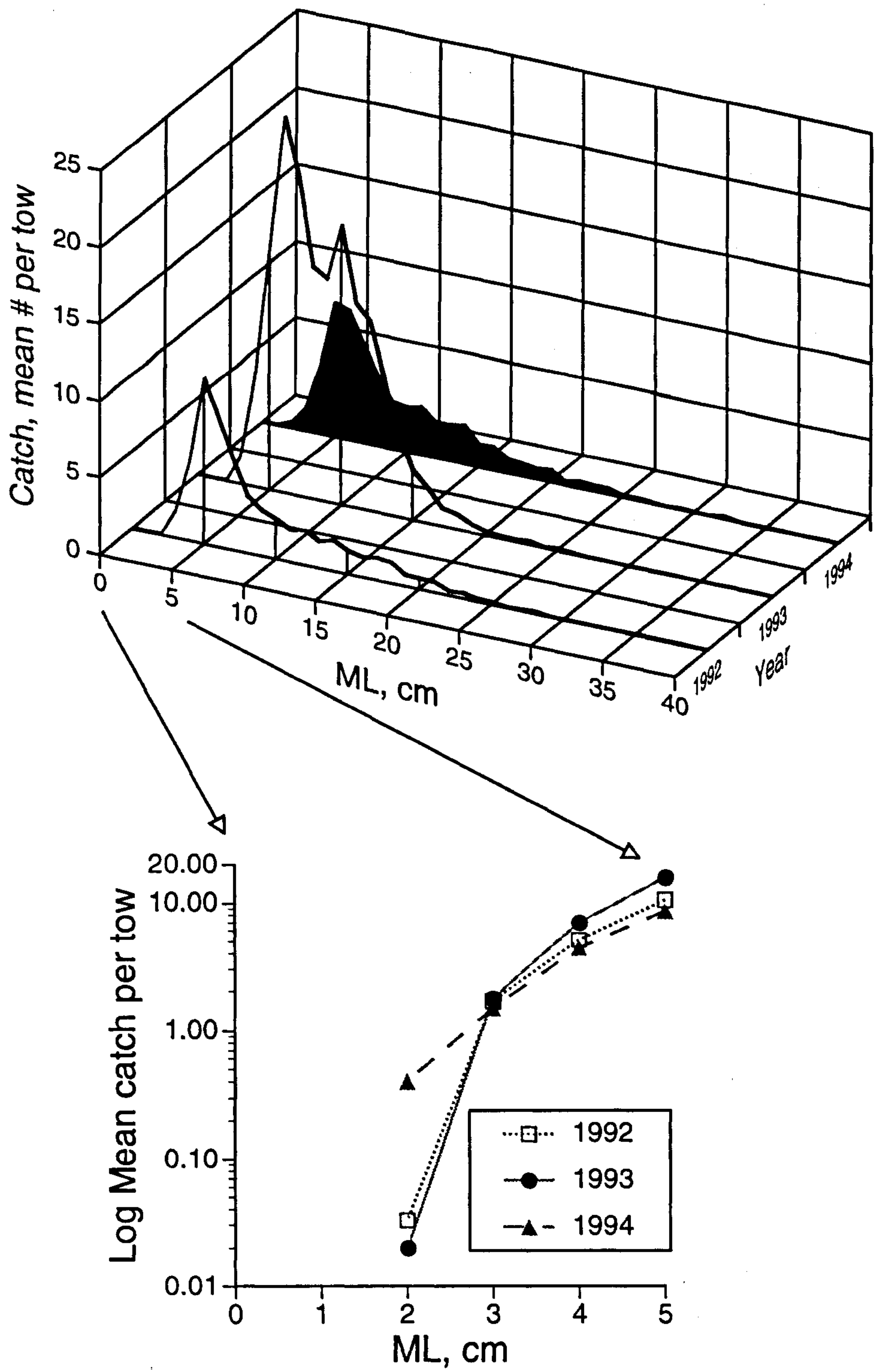
Fall, n=161
Frequency, n
0
5
10
15
20
25
U<10
F<10
F<20
F<30
F>30
M<10
M<20
M<30
M>30
Sex and Size (ML, cm)
Winter
Spring
Summer
Fall
Season Hatched
Winter,n=60
0
5
10
15
20
U<10
F<10
F<20
F<30
F>30
M<10
M<20
M<30
M>30
Sex and Size (ML, cm)
Spring
Summer
Fall
Winter
Season Hatched
Frequency, n
0
5
10
15
20
25
U0
F1
F2
F3
F4
M1
M2
M3
M4
Sex and Maturity
Winter
Spring
Summer
Fall
Season Hatched
C.
0
5
10
15
20
25
30
U0
F1
F2
F3
F4
M1
M2
M3
M4
Sex and Maturity
Spring
Summer
Fall
Winter
Season Hatched
D.

Figure 5



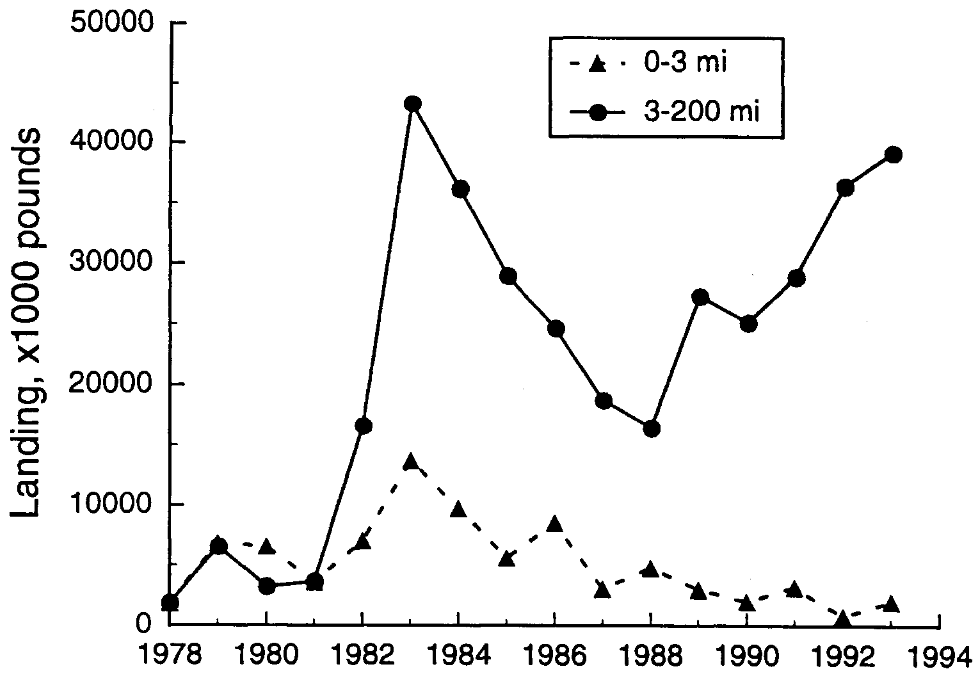
n=457
Frequency, %
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month of Hatching

Figure 6



Catch, mean # per tow
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
ML, cm
1992
1993
1994
Year
Log Mean catch per tow
20.00
10.00
1.00
0.10
0.01
0
1
2
3
4
5
ML, cm
1992
1993
1994

Figure 7



Loligo plus *Illex*