Biological Considerations Relevant to the Management of Squid (*Loligo pealei* and *Illex illecebrosus*) of the Northwest Atlantic

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Introduction

Loligo pealei (common or long-finned squid) and *Illex illecebrosus* (short-finned squid) are found in commercially exploited quantities along the northwest Atlantic continental shelf of the United States and Canada. This paper reviews aspects of the biology and population dynamics of these species relevant to the management of squid in this region. Catch statistics, research cruise results, and stock size estimates previously reported by Tibbetts (1977) are updated. For a more general discussion of the biology of *L. pealei* and *I. illecebrosus* see Summers (1969, 1971) and Squires (1957, 1967).

Until the mid-1960's squid supported only small domestic coastal fisheries along the coasts of the United States (1,000-2,000 t/year) and Canada (insignificant amounts to 11,000 t/year). Distant water fleet catches of squid along the U.S. coast have been reported since 1964. With the initiation of directed squid fisheries by Japan in 1967 and Spain in 1970 the catch increased rapidly to 57,000 t in 1973, but has declined since then to about 28,500 t in 1978 (Table 1). The catch of squid along the coast of Canada continued to increase through 1978 when it reached about 98,700 t.

The International Commission for the Northwest Atlantic Fisheries (ICNAF) set the total allowable catch (TAC) for both species of squid combined along the U.S. coast (ICNAF Subarea 5 and Statistical Area 6) at 71,000 t/year for 1974 and 1975, based primarily on a Japanese estimate of stock size of *L. pealei* (Ikeda et al., 1973). In 1976, ICNAF established a 44,000-t TAC for *L. pealei* and a 30,000-t TAC for *I. illecebrosus* after consideration of assessment documents by U.S. scientists (Au[1]; Tibbetts, 1977; Sissenwine and Tibbetts, 1977). In 1977 the ICNAF TAC's were set at 44,000 and 35,000 t for *L. pealei* and *I. illecebrosus*, respectively. These TAC's were included in the preliminary management plan for squid by the U.S. Department of Commerce, and adopted by the United States when extended jurisdiction began on 1 March 1977. The TAC's established in the U.S. 1978 and 1979 squid preliminary management plans were 44,000 t and 30,000 t for *L. pealei* and *I. illecebrosus*, respectively. These are also the levels set forth in the Fishery Management Plan of the Mid-Atlantic Fishery Management Council, which was put into effect in June 1979.

Biology

The loliginid squid, *Loligo pealei*, has been reported as far north as New Brunswick (Summers, 1969) but is primarily distributed from Cape Hatteras to Georges Bank (Tibbetts, 1977). *Loligo pealei* probably forms one stock which migrates on and offshore as much as 200 km seasonally, generally remaining in waters where the temperature is >8° C. *Loligo pealei* overwinter offshore along the upper continental slope (about 200 m deep) from western

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[1]Au, D. 1975. Considerations on squid (*Loligo* and *Illex*) population dynamics and recommendations for rational exploitation. Int. Comm. Northwest Atl. Fish. Res. Doc. 75/61, Serial No. 3543, 13 p.

*ABSTRACT–The general biology and distribution of squid (*Loligo pealei *and* Illex illecebrosus*) in the northwest Atlantic are reviewed based on previous literature and observations from research and commercial catches. Commercial catch and effort data from the Middle Atlantic area to Gulf of Maine inshore and offshore squid fisheries are presented as background for management. Research vessel catch per tow data provide indices for abundance, prerecruit indices, and stock size and biomass estimates.*

A dynamic pool model designed to simulate the effect of fishing on squid is presented. The instantaneous growth, fishing, and natural mortality rates were varied on a monthly basis, and spawning was simulated over an extended period. Recruitment was described by the Beverton and Holt stock-recruitment function.

Based on these models, the exploitation rates that will result in maximum sustainable yield (E_{msy}) are 0.40 and 0.37 for L. pealei *and* I. illecebrosus, *respectively, assuming moderate dependence of recruitment on spawning stock size. These models indicate a catch of 44,000 t of* L. pealei, *if annual recruitment of 1.5 billion individuals is maintained. Appropriate catch levels of* I. illecebrosus *varied from 21 to 95 thousand tons based on biomass estimates in recent years.*

Table 1.—Annual squid catches[1] (*L. pealei* and *I. illecebrosus*) in metric tons, 1963-78, by country, from the northwest Atlantic, Cape Hatteras, N.C., to the Gulf of Maine.

Year	Country[2]															Total
	Bulg.	Can.	Cuba	Fra.	FRG	GDR	Ire.	Italy	Japan	Pol.	Rom.	Spain	U.S.A.	U.S.S.R.	Mex.[3]	
1963													2,104			2,104
1964													934	4		938
1965													1,153	177		1,330
1966													1,174	344		1,518
1967									7				1,251	1,411		2,669
1968			10						1.734				1,762	3,176		6,682
1969			1						7,711			566	1,461	1,340		11,079
1970						20			13,639			4,426	1,061	1,065		20,211
1971	90	1							10,602			6,770	1,182	6,138		24,783
1972	499		14	296	463			3,200	18,691	5,428	66	10,545	1,197	6,976		47,375
1973	410			820	1,641	313		3,165	15,526	9,199	150	14,932	1,635	8,977		56,768
1974	592	27						4,260	16,820	6.709	9	16,144	2,422	8,495		55,478
1975	205		151		27	898	4,745	4,274	13,985	6,836	48	9,902	1,728	8,928		51,727
1976	23	54	265		1,023	1,313	3,283	4,421	8,285	6,756	22	13,200	3,831	7,644		50,120
1977	60	20	34			9	23	4,185	12,690	888		13,438	2,112	8,010		41,469
1978								3,497	6,053		67	13,186	1,861	40	3,822	28,526

[1] 1963-1976 ICNAF (International Commission of the Northwest Atlantic Fisheries) Statistical Bulletins No. 13-26. 1977—ICNAF Summary Document No. 78/VI/28. Provisional Nominal Catches in the Northwest Atlantic, 1977. 1978—Preliminary, as reported to NMFS, by foreign fisheries officials.
[2] Countries are: Bulgaria, Canada, Cuba, France, Federal Republic of Germany, German Democratic Republic, Ireland, Italy, Japan, Poland, Romania, Spain, United States of America, Union of Soviet Socialist Republics, and Mexico.
[3] Mexico did not fish in this area prior to U.S. extended jurisdiction.

Georges Bank to Cape Hatteras (Summers, 1969). About April, larger mature *L. pealei* move inshore as far north as Long Island. United States commercial catches from southern New England (1973-77) indicate that large (>28 cm, dorsal mantle length) individuals arrive in the Massachusetts area by late April and early May. Smaller (<20 cm) individuals arrive by summer in much greater numbers.

The greatest number of eggs are spawned during May and hatch in July (Summers, 1971). Size differences in young-of-the-year and observations of ripe adults from samples of U.S. commercial catches in southern New England in July and from autumn groundfish survey cruises (Grosslein, 1969) in September, indicate an extended breeding season of about 6 months (April to September).

The life span of *L. pealei* was estimated by Summers (1971) to be 14-24 months with a maximum length of 18-28 cm (dorsal mantle length). However, he did find that some males survive to about 36 months and grow to > 40 cm. There may be a significant number that survive two spawning seasons, as seen in April 1973-74 where over 20 percent of the U.S. commercial samples were 30 cm or over and presumably about 1½ years old. It is not known whether these individuals spawned in their first season.

Mesnil (1977) has suggested a complicated crossover life cycle that is related to this extended spawning season. He hypothesizes two overlapping reproductive cycles for *L. pealei*, with maturation occurring over the winter and spawning occurring in April-May or in August-September. Those squid spawned in spring hatch in June, mature during their first winter, and spawn during late summer of the following year (at about 14 months). Their progeny, those spawned in late summer, hatch in September, are too young to mature over the first winter, and spend the next spring and summer feeding and growing. This group matures during their second winter to spawn, as large individuals, early in the spring. Mesnil based this proposed cycle on analysis of length frequencies and growth and maturation patterns observed in samples of *L. pealei* from four research cruises conducted in 1973, 1974, and 1975, as well as from known behavioral patterns of European squids.

Our observations of mature *L. pealei* and egg clusters in May support the occurrence of spring spawning. Young-of-the-year from the May spawned group, according to Mesnil, were represented by 7-9 cm individuals taken in September, indicating monthly growth of 1.7 to 2.0 cm. A subsequent mode, observed 2 months later at 11 cm implies growth at 1.0-1.5 cm/month after September, while an associated mode at 13-15 cm in May of the following year, indicates a 0.4-0.6 cm monthly growth increment during the winter months. Mature individuals of both sexes, which would probably spawn late in the summer initiating the second cycle of the proposed scheme, were present in this last mode. United States commercial length frequencies (Fig. 1) exhibited modes similar to those described by Mesnil, but the smallest mode was only 5-7 cm in U.S. autumn bottom trawl survey samples (Fig. 2).

Individuals from the second cycle first appeared in the May samples at about 10 cm in length. In October this group is represented by a 12-14 cm mode for an average monthly growth of 1 cm through the first year. Mesnil attributed the lower growth rate of late summer spawned individuals to the colder, winter temperatures during their first several months. During their second winter this group matures and is represented as mature individuals with a mode at 20-28 cm in the May samples.

Many of Mesnil's findings seem to be supported by U.S. research survey and commercial length frequency and maturity data, and further investigation is underway at the Northeast Fisheries Center of the National Marine Fisheries Service to study this proposed life and reproductive cycle. At present an average growth of 1.0-1.5 cm/month is assumed for *L. pealei*, with males growing faster and larger than females (Summers, 1971). The growth function (for males) estimated by Ikeda and Nagasaki[2] is:

$$L = 38.3\,(1 - e^{-0.59t}) \qquad (1)$$

where L = mean mantle length at age t (in years).

Length-weight equations (Lange and Johnson, in press), derived for males and females separately and combined from least squares regression of the $\log_e$ of weight (grams) on $\log_e$ of dorsal mantle length (centimeters) for 1975-77 data are:

Males (n=915)
$$W = 0.41917\,L \cdot \exp 1.97528$$
Females (n=697)
$$W = 0.16762\,L \cdot \exp 2.32364 \qquad (2)$$
Total (n=1,709)
$$W = 0.25662\,L \cdot \exp 2.15182$$

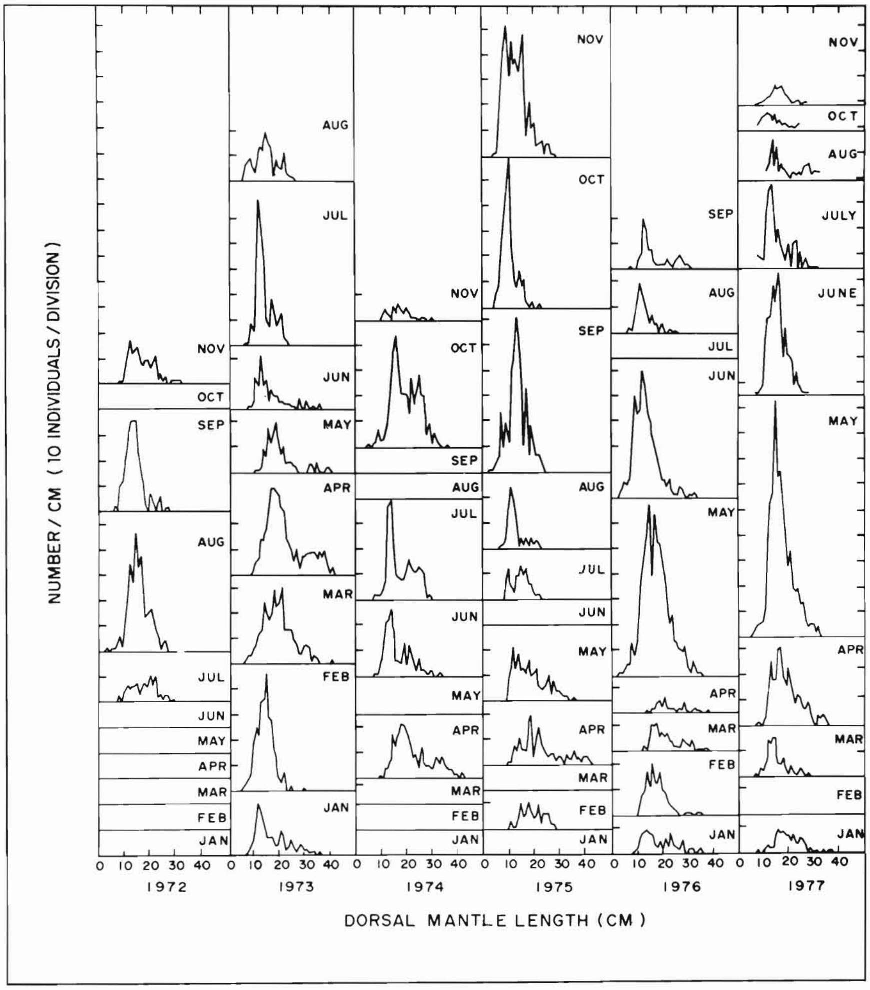


Figure 1.—United States commercial length frequencies for *Loligo pealei* by month, southern New England-Middle Atlantic, 1972-77.

Illex illecebrosus belongs to the oceanic family Ommastrephidae, and little is known of its biology or life history. It is a more northern species than *L. pealei*, ranging to Greenland, but with autumn concentrations as far south as Cape Hatteras (Squires, 1957). Seasonal migrations to coastal Newfoundland, Nova Scotia, and New England, into shallow water (10-50 m) during the warmer months allow for an inshore fishery (Squires, 1957). In late autumn (October-December) movement is to the southeast and open ocean from Newfoundland, and offshore in the area from the Gulf of Maine to Cape Hatteras. Mercer[3] found *I. illecebrosus* in concentrations along the edge of the continental shelf in the summers of 1971 and 1972, in waters with temperatures >5°C. Spawning is believed to occur offshore at great depths from December to June (primarily December to March), with most *I. illecebrosus* dying after spawning (Squires, 1957). However, mature males, which develop sooner than the females, were collected on Georges Bank in August 1963[4] and along the shelf edge in >100 m depths from southern Georges Bank to the waters off Delaware, during a joint United States-Japanese research cruise in July 1977.

Mesnil (1977) has proposed a crossover life cycle for *I. illecebrosus*, as he has with *L. pealei*. Again, he suggests two overlapping reproductive cycles, with spawning occurring for this

[2]Ikeda, I., and F. Nagasaki. 1975. Stock assessment of *Loligo* in ICNAF Subarea 5 and Statistical Area 6. Int. Comm. Northwest Atl. Fish. Res. Doc. 44, Serial No. 3523, 5 p.

[3]Mercer, M. C. 1973. Distribution and biological characteristics of the ommastrephid squid, *Illex illecebrosus* (LeSueur) on the Grand Banks, St. Pierre Bank, and Nova Scotia Shelf (Subareas 3 and 4) as determined by otter trawl surveys 1970 to 1972. Int. Comm. Northwest Atl. Fish. Res. Doc. 73/79, Serial No. 3031.

[4]R. Wigley, National Marine Fisheries Service, NEFC, Woods Hole, MA 02543, pers. commun. 1975.

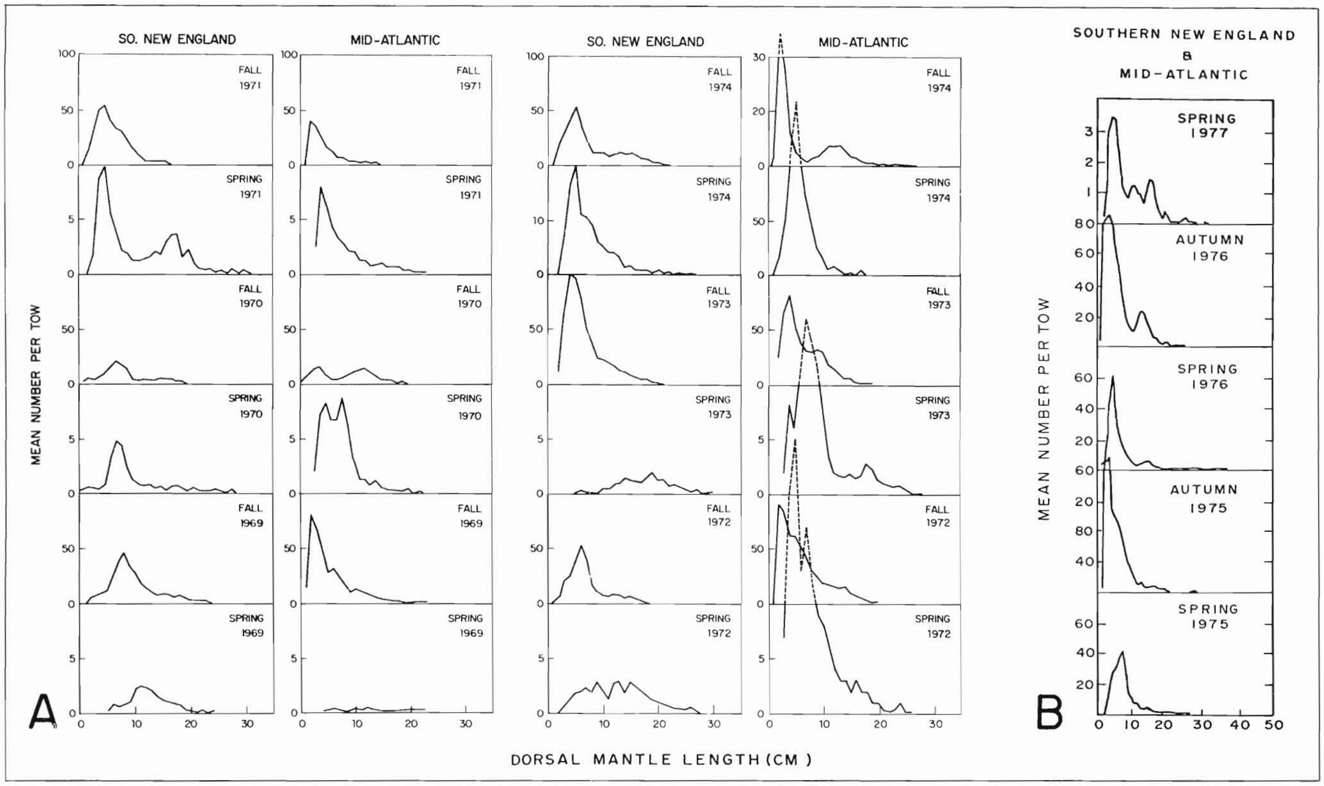


Figure 2.—Mean numbers at length per tow of *Loligo pealei* from U.S. bottom trawl surveys, southern New England and Middle Atlantic. A. Spring 1969 to fall 1974 (Tibbetts, 1977). B. Spring 1975 to spring 1977.

species in January and July, and each generation living about 18 months. So, those individuals which hatched in January-February, would spawn in July of the following year and those hatched in August would spawn in January of their second year. The basis of this proposed cycle is also length-frequency analysis and observations on maturity and growth. Data from six research cruises (from 1973 to 1975) were used in this analysis, and Mesnil found single modes for both sexes in his May and July samples and three modes in each of his September through December samples. He begins by relating a May mode of 14-15 cm to an 18-19 cm July mode, a 21-22 cm September-October mode and a 24-25 cm November to December mode. From this sequence he estimated a 1.6-1.9 cm average monthly growth to calculate that the squid taken in May were 8-9 months old and, therefore, hatched in the previous summer. He then associated this with an 8 cm September mode, and the 11-12 cm November mode, for one complete cycle. Mesnil's second cycle originates with spawning in January by the large individuals of the previous cycle. These first appear in September-October as an 18-19 cm mode, and are represented again in November-December by a 16-17 cm group (sampled from different years) containing many maturing or mature males. Mesnil feels these individuals will spawn during the following July (even though they are not represented in the samples) completing the second cycle. United States commercial length frequencies for *I. illecebrosus* (Fig. 3) generally showed a single mode, progressing from about 17 to 28 cm in length between May and November, though minor modes were also present in some months. These modes generally agreed with Mesnil's observations, but were 1 to 3 cm larger than what he found during each month. United States survey samples revealed large modes of individuals 4-7 cm in length during the spring and autumn of different years (Fig. 4). Though, in general, available data do not refute Mesnil's conclusions, further study of the life cycle of this species is necessary.

It is generally felt that *I. illecebrosus* is fast growing and shorter lived than *L. pealei*, surviving 14-18 months, with monthly growth increments of about 2 cm for both sexes. Squires (1967) stated they attain sizes of up to 33 cm. A growth function for *I. illecebrosus* has been calculated by Au (footnote 1) as follows:

$$L_t = 32.0\,(1 - e^{-0.21t}), \qquad (3)$$

with age t in months (note Equation (3) has been changed to express age in months). This function implies a curve

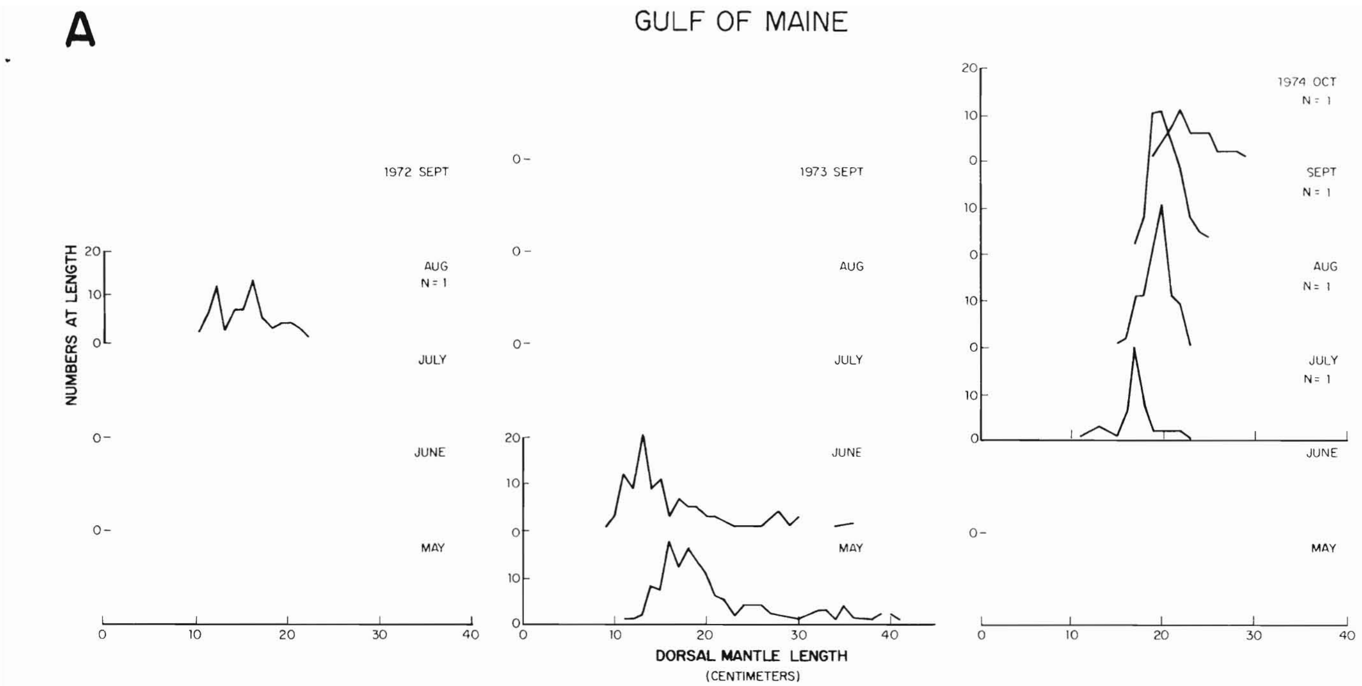
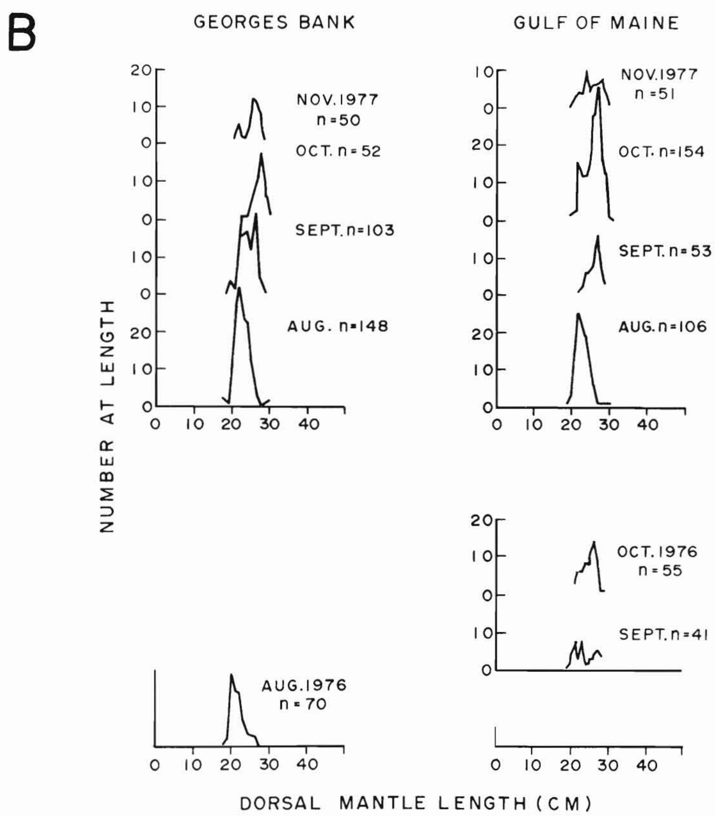


Figure 3.—United States commercial length frequencies for *Illex illecebrosus*, by month, Georges Bank-Gulf of Maine. A. 1972-74, Gulf of Maine. B. 1976-77, Georges Bank and Gulf of Maine.



with length at age $t=0$ at 0 cm, and at age $t=1$ at 6 cm, then growth increments decreasing to 0.6 cm by 15 months. This function does not adequately represent growth in the first few months for this species, since data for that early time period is not available.

The linear least squares fit of $\log_e$ weight (grams) on $\log_e$ dorsal mantle length (centimeters) for *I. illecebrosus*, from 2,605 individuals taken during research vessel cruises in 1975-77 (Lange and Johnson, in press), is:

$$W = 0.04810\,L \cdot \exp 2.71990$$
(n=2,605 including unsexed *I. illecebrosus*) (4)

for males and females, these equations are:

Males: $W = 0.05483\,L \cdot \exp 2.68514$ (n = 1,074) (5)

Females: $W = 0.04397\,L \cdot \exp 2.74348$ (n = 1,511). (6)

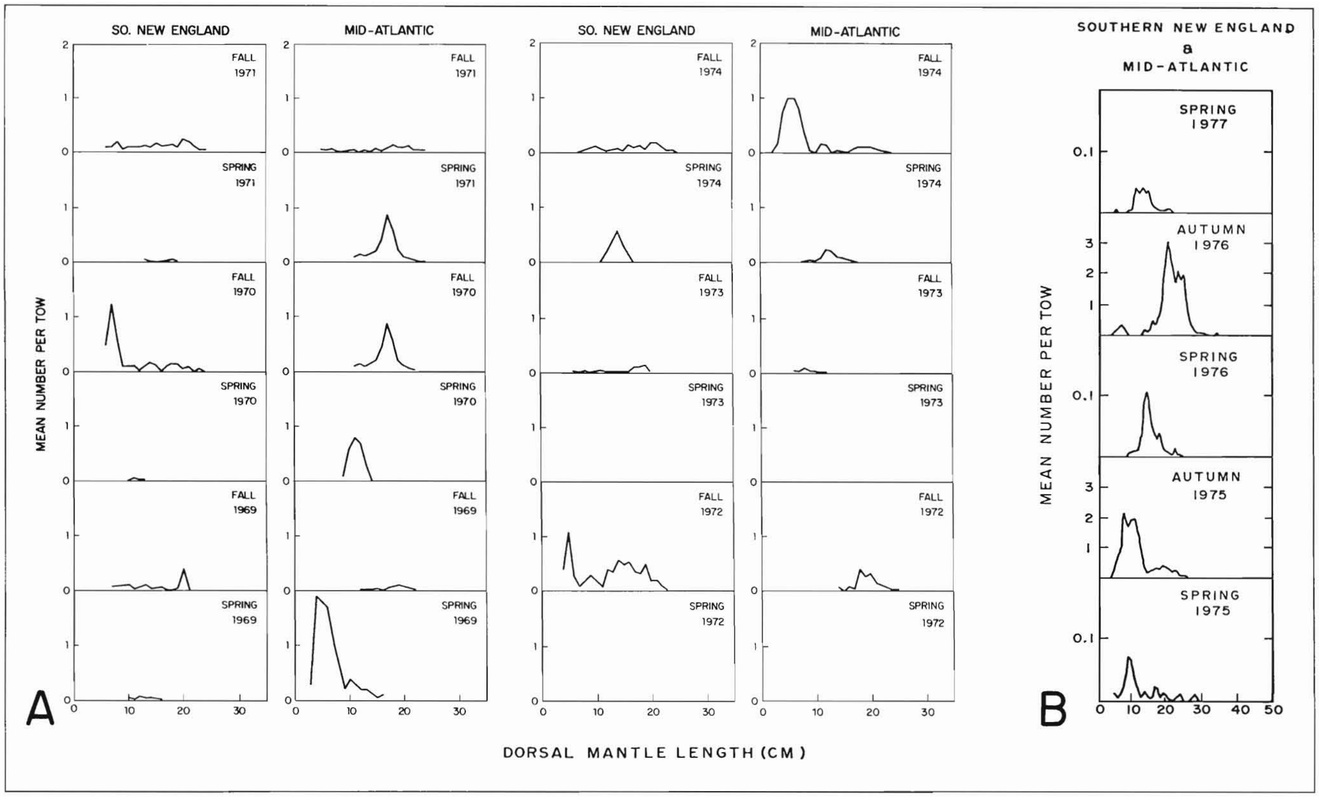


Figure 4.—Mean numbers at length per tow of *Illex illecebrosus* from U.S. bottom trawl surveys, southern New England and Middle Atlantic. A. Spring 1969 to fall 1974. B. Spring 1975 to spring 1977.

Squid play a key role as prey and predator in the flow of energy through the coastal northwest Atlantic ecosystem. They are rapid growing (high production to biomass ratio), abundant, and widely distributed during the warmer months of the year when the ecosystem is more productive. Heavy exploitation of squid could impact other fisheries resources which compete with man for squid as food, while substantial increases in squid abundance might impact on abundance of species of fish that are consumed during early life stages by squid.

Both *L. pealei* and *I. illecebrosus* feed on small fish, crustaceans, and squid (Tibbetts, 1977). Young squid feed heavily on euphausiids and other small crustaceans, but as they grow, their diet gradually changes to small (often young) fish. For example, Squires (1957) reported that as the mantle length of *I. illecebrosus* increased from 10-12 to 25-30 cm, the percentage of individuals with fish in their stomachs increased from 11.8 percent to 62.5 percent. Major prey of *I. illecebrosus* include cod, *Gadus morhua*; haddock, *Melanogrammus aeglefinus*; redfish, *Sebastes marinus*; capelin, *Mallotus villosus*; mailed sculpin, *Triglops nybellini*; Atlantic mackerel, *Scomber scombrus*; Atlantic herring, *Clupea harengus*; and flounders (Squires, 1957; Bigelow and Schroeder, 1953).

Vovk (1972) reported that squid, euphausiids, fish, pandalid shrimp, copepods, crabs, and the above items were found in >25 percent of the *L. pealei* stomachs which he examined. Vovk found a higher occurrence of fish in the stomachs as the squid increased in size. Representatives of various fish groups were found: *Diaphus* (Myctophidae), *Anchova* (Engraulidae), *Stenotomus* (Sparidae), *Clupea* (Clupeidae), and *Alosa* (Clupeidae), with most individual fish between 5 and 19 cm in length.

Squid are the prey of numerous species of fish (Table 2), sea birds, and marine mammals. Mercer[5] discussed the importance of *I. illecebrosus* as a food source of pilot whales, *Globicephala melaena*. Vovk (1972) also reported that squid are an important prey of northern sea birds such as streaked shearwaters and jackass penguins.

[5]Mercer, M. C. 1974. Modified Leslie-DeLury assessments of the Northern Pilot Whale (*Globicephala melaena*) and annual production of the short-finned squid (*Illex illecebrosus*) based upon their interaction at Newfoundland. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/49, Serial No. 3259 (mimeo).

Table 2.—Fish predators of squid (*Loligo pealei* and/or *Illex illecebrosus*) from the northwest Atlantic, Cape Hatteras to Newfoundland.

Pelagic	
bonito	*Sarda sarda*
bluefin tuna	*Thunnus thynnus*
skipjack tuna	*Euthynnus pelamis*
mackerel	*Scomber scombrus*
swordfish	*Xiphias gladius*
Semi-pelagic	
alewife	*Alosa pseudoharengus*
butterfish	*Peprilus triacanthus*
scup	*Stenotomus chrysops*
bluefish	*Pomatomus saltatrix*
striped bass	*Morone saxatilis*
redfish	*Sebastes marinus*
Inshore	
silverside	*Menidia menidia*
smelt	*Osmerus mordax*
three-spine stickleback	*Gasterosteus aculeatus*
weakfish	*Cynoscion regalis*
Other	
spiny dogfish	*Squalus acanthias*
smooth dogfish	*Mustelus canis*
mackerel shark	*Lamna nasus*
thresher shark	*Alopias vulpinus*
barrelfish	*Hyperoglyphe perciformis*
angel shark	*Squatina dumerili*
roughtail stingray	*Pasyatis centroura*
Benthic	
haddock	*Melanogrammus aeglefinus*
cod	*Gadus morhua*
pollock	*Pollachius virens*
red hake	*Urophysis chuss*
silver hake	*Merluccius bilinearis*
spotted hake	*Urophycis regius*
white hake	*Urophycis tenuis*
tom cod	*Microgadus tomcod*
searobin	*Prionotus carolinus*
four-spot flounder	*Paralichthys oblongus*
summer flounder	*Paralichthys dentatus*
windowpane flounder	*Lophopsetta maculata*
witch flounder	*Glyptocephalus cynoglossies*
barndoor skate	*Raja laevis*
little skate	*Raja erinacea*
big skate	*Raja binoculata*
clearnose skate	*Raja eglanteria*
tilefish	*Lopholatilus chamaeleonticeps*
longhorn sculpin	*Myoxocephalus octodecemspinosus*
white perch	*Morone americana*
toadfish	*Opsanus tau*
black seabass	*Centropristis striata*
goosefish	*Lophius americanus*
tautog	*Tautoga onitis*

Maurer[6] found that squid composed over 10 percent of the stomach contents of the bluefish, sea raven, fourspot flounder, spiny dogfish, and goosefish that he examined.

[6]Maurer, R. 1975. A preliminary description of some important feeding relationships. Int. Comm. Northwest Atl. Fish. Res. Doc. 75/IX/130, Serial No. 3681.

Table 3.—U.S. catch (for major New England ports) of *L. pealei*, *I. illecebrosus*, and all squid by month, expressed as percent of the total (1970-76).

Month	Percentage monthly catch		
	Loligo	*Illex*	Squid
January	0.7	0.0	2.4
February	1.6	0.0	2.9
March	2.4	0.0	3.4
April	2.4	0.0	4.1
May	57.8	0.0	29.7
June	25.2	5.5	15.2
July	1.8	6.8	5.8
August	0.8	18.3	7.7
September	1.3	27.3	8.0
October	2.9	32.8	10.4
November	2.5	9.0	7.2
December	0.6	0.3	3.3

Commercial Fishery

United States squid catches off New England have been reported since the late 1800's (ranging from 500 to 2,000 t/year), but until recently, there had been no separation of species in reported catches. Interest in squid in the northwest Atlantic by other countries has increased since the U.S.S.R. first reported by-catches in 1964. In 1974 there were nine countries reporting squid catches totaling about 56,000 t (Table 1). Aside from a U.S. trap fishery for *I. illecebrosus* (as bait), squid off the northeast United States are fished with otter trawls. Monthly percentages of U.S. squid catches by species for 1970 to 1976 are given in Table 3.

Japan, Spain, and Italy are the primary participants in the offshore directed squid fishery. Japan began her fishery in 1967, with Spain entering the fishery in 1970 and Italy in 1972 (Table 1). Until 1977, Japan and Italy fished for *L. pealei* from October to March along the edge of the continental shelf. Japan had a butterfish, *Peprilus triacanthus*, fishery associated with its *L. pealei* fishery, occasionally taking more butterfish in a given month, than squid (ICNAF, 1975b, 1976b). Spain, in addition to its winter fishery for long-finned squid, steadily increased its effort in the summer months, exploiting short-finned squid in the same offshore waters. Spain's squid fishery produced substantial by-catch of species such as butterfish and mackerel (up to 65 percent in March and April)[7], most of which was discarded. However, under extended jurisdiction (Fishery Conservation and Management Act (FCMA) of 1976) squid fishing has been restricted in time and locations in an attempt to avoid by-catch, as well as conflicts with domestic offshore lobster gear. A directed fishery for butterfish has not been permitted.

Prior to 1973, when Japan, Spain, Romania, and Bulgaria began reporting squid catches by species, only total squid landings were available; even now not all U.S. landings are reported by species. Recently, however, most nations have supplied ICNAF with estimates of squid catch by species (Table 4), for the years 1965-75. Total squid landings, by species, are presented in Figure 5. Catch composition for 1976 and 1977 is as reported, by species. Those catches which are still reported as squid (nonspecified) have been apportioned to species according to the species composition of the catch of those countries reporting by species.

The catch per day fished with squid (both species) as the main species sought (i.e., either reported as main species or composing >50 percent of the total monthly catches of gear type in an area) for Japan and Spain is given in Table 5. The overall catch per effort (C/E) in the directed offshore squid fisheries of Japan and Spain decreased between 1972 and 1976 in all areas from Georges Bank through the Mid-Atlantic, though C/E of a given vessel class in a given area, may increase in an individual year. Table 6 shows the inshore catch per effort for squid from the U.S. fishery from 1976 through 1978.

United States overall C/E in the inshore fishery had increased from 1973 to 1976 from 1.3 to 5.9 t/day, as a small directed fishery (based on trips where squid composed >50 percent of the catch) developed and consequently

[7]Lopez-Veiga, E. C., and E. Labarta. 1974. Some observations on the Spanish squid (*Illex* and *Loligo*) fishery in Subarea 5 and Statistical Area 6 of the ICNAF. 11 p. ICNAF Working Paper, ICNAF Secretariat, Halifax, N.S.

Table 4.—Squid catches (in tons), by species,[1] year, and country, from the northwest Atlantic, Cape Hatteras to the Gulf of Maine, 1963-78.

Year	Country[2]															Total
	Bulg.	Can.	Cuba	Fra.	FRG	GDR	Ire.	Italy	Japan	Pol.	Rom.	Spain	U.S.A.	U.S.S.R.	Mex.[3]	
								Long-finned squid								
1963													1,294			1,294
1964													576	2		578
1965													709	99		808
1966													722	226		948
1967									5				547	1,125		1,677
1968									177				1,084	2,150		3,411
1969									7,125			438	899	1,080		9,542
1970									13,250			2,790	653	692		17,385
1971	10								10,426			3,446	727	3,560		18,169
1972	20			288	463			2,000	16,293	164	66	5,667	725	4,048		29,734
1973	46			793	1,641			2,360	14,459	911	150	11,148	1,105	5,000		37,613
1974	172	27						3,280	13,493	1,706	3	9,375	2,274	4,520		34,850
1975	34		30		27	16	1,660	3,390	10,748	3,785		7,698	1,621	4,792		33,801
1976	23		257		22	317	1,042	3,304	5,029	1,706	13	9,137	3,602	832		25,284
1977	8	15	28			9		2,237	7,814	232		5,236	1,088	7		16,674
1978								1,366	2,309		17	4,603	1,476	7	1,053	10,831
								Short-finned squid								
1963													810			810
1964													358	2		360
1965													444	78		522
1966													452	118		570
1967									2				707	286		995
1968			10						1,557				678	1,026		3,271
1969			1						586			128	562	260		1,537
1970						20			389			1,636	408	373		2,826
1971	80	1							176			3,324	455	2,578		6,614
1972	479		14	8				1,200	2,398	5,264		4,878	472	2,928		17,641
1973	364			27		313		805	1,067	8,288		3,784	530	3,977		19,155
1974	420							980	3,327	5,003	6	6,769	148	3,975		20,628
1975	171		121			882	3,085	884	3,237	3,051	48	2,204	107	4,136		17,926
1976		54	8		1,101	996	2,241	1,117	3,256	5,050	9	4,063	229	6,812		24,936
1977	52	5	6				23	1,948	4,876	656		8,202	1,024	8,003		24,795
1978								2,131	3,744		50	8,583	385	33	2,769	17,695

[1] 1963-66 estimated breakdown of total squid catch, prorated by ratio of reported *L. pealei* to *I. illecebrosus*, from ICNAF Statistical Bulletins No. 13-16. 1967-76 from ICNAF Sum. Doc. 78/VI/6. 1977 ICNAF Sum. Doc. 78/VI/28. 1978—Preliminary—As reported to NMFS by foreign nations.
[2] Countries are: Bulgaria, Canada, Cuba, France, Federal Republic of Germany, German Democratic Republic, Ireland, Italy, Japan, Poland, Romania, Spain, United States of America, Union of Soviet Socialist Republics, and Mexico.
[3] Mexico did not fish in this area prior to U.S. extended jurisdiction.

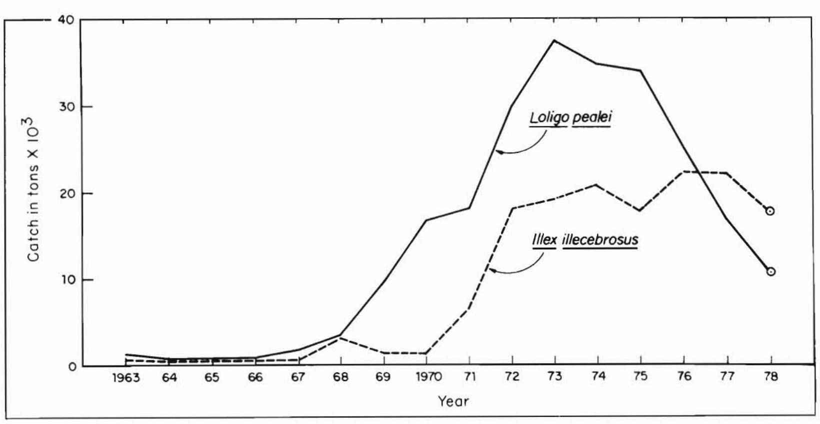


Figure 5.—Total catches of squid, *Loligo pealei* and *Illex illecebrosus*, in metric tons, by species, Cape Hatteras to Gulf of Maine, 1963-78.

more of the squid was landed. However, since 1976, mean C/E of each species has declined, for each vessel size class and in each area. This U.S. directed squid fishery has occurred primarily during a 2-5 week period in the early summer (May-June) when *L. pealei* are inshore in great concentrations to spawn. The vessels involved fish for other species during the remainder of the year and a significant portion of the U.S. squid landings are still as by-catch in other fisheries, although in May 1979 the directed fishery produced about 2,000 t of *L. pealei*. *Illex illecebrosus* is caught by U.S. vessels primarily as by-catch, although during a period of great abundance

Table 5.—Offshore squid landings per day in metric tons by area and gear (for Japan and Spain), 1970-75.

Area	Country	Gear[1] and tonnage class[2]	Year 1970	1971	1972	1973	1974	1975
Georges Bank	Spain	OTSN 4						4.0
	Spain	OTSN 5			14.8	9.2	6.9	3.4
	Spain	OTSN 6						4.4
	Japan[3]	OTSN 5					28.7	21.4
	Japan	OTSN 6	22.6	6.3		16.3	15.0	18.7
	Japan	OTSN 7	37.3	26.3	24.4	33.6	17.9	20.31
South New England	Spain	OTSN 4						3.5
	Spain	OTSN 5		4.0	8.5	7.6	5.5	0
	Japan	OTSN 6	19.7	14.9		14.1		
	Japan	OTSN 7	28.4	11.3	19.9	18.6		
North Mid-Atlantic	Spain	OTSN 4						3.3
	Spain	OTSN 5		7.8	7.9	7.1	7.0	3.8
	Spain	OTSN 6						5.2
	Japan	OTSN 4						25.3
	Japan	OTSN 6	24.3	13.8	18.7	14.4		16.6
	Japan	OTSN 7	32.5	13.4	17.3	13.2		21.25
Central Mid-Atlantic	Spain	OTSN 4						3.4
	Spain	OTSN 5		11.9	12.3		6.9	4.0
	Spain	OTSN 6						5.0
	Japan	OTSN 5						20.2
	Japan	OTSN 6	24.88	12.9		10.0	10.3	10.1
	Japan	OTSN 7	25.3	16.2	17.2	14.4	11.9	14.8
South Mid-Atlantic	Spain	OTSN 4						2.8
	Spain	OTSN 5		8.6	12.9		7.0	4.0
	Spain	OTSN 6						9.0
	Japan	OTSN 5					12.5	17.9
	Japan	OTSN 6				16.4	15.3	15.1
	Japan	OTSN 7			15.4	14.6	16.1	11.7
Total	Spain	OTSN 4						3.5
	Spain	OTSN 5		9.0	11.3	7.4	6.8	3.9
	Spain	OTSN 6						5.3
	Japan	OTSN 5					17.8	20.5
	Japan	OTSN 6	22.8	12.2	18.7	13.4	12.9	14.3
	Japan	OTSN 7	29.9	16.9	18.8	19.7	14.8	16.4

[1]Gear OTSN: Otter trawl stern.
[2]Tonnage class: 4 = 150.00 to 499.9 tons; 5 = 500 to 999 tons; 6 = 1,000 to 1,999 tons; 7 = >2,000 tons.
[3]All Japanese catch/effort based on 24 hours/day.

Table 6.—Inshore catch per effort for squid from U.S. landings per day fished (metric tons) in southern New England and northern Mid-Atlantic, 1967-76.

Year	Metric tons/day	No. of trips
1967	5.6	33
1968	3.4	37
1969	5.4	120
1970	2.2	110
1971	2.6	43
1972	1.8	24
1973	1.3	46
1974	2.2	84
1975	3.2	65
1976	5.9	30

[1]Based on ton class 2 (0-50 tons) vessel trips, with squid composing >50 percent of the catch.

in summer-fall 1976, in the Gulf of Maine, a modest directed fishery developed.

Length Frequency Samples

United States commercial and research survey length samples taken for each species of squid between July 1972 and November 1977 are presented in Figures 1-4.

Modal values for *L. pealei* based on U.S. commercial (inshore) length frequencies (Fig. 1) and U.S. bottom trawl surveys (1969-77; Fig. 2a, b) are generally as would be expected according to the growth and spawning schedules described by Summers (1971), with two or three modes present throughout the year. In the January commercial samples the first mode (11-12 cm) probably represents 7-8 month old individuals, hatched in the previous spring, which will spawn late in the summer. The second and third modes of larger individuals probably hatched late in the summer of 2 years prior (16-18 months). In spring, the larger groups (>18 cm) are mature, and spawning begins with most individuals > 28 cm disappearing from the fishery by summer. *Loligo pealei* of 20-28 cm are present through September, at which time they presumably spawn.

Length samples of *L. pealei* from spring surveys (1969-77; Fig. 3a, b) ranged from 2 to 30 cm, with a major mode generally at 5-8 cm (composing about 70-89 percent of the individuals) and one of lesser importance at 15-30 cm (5-30 percent). From 1974 through 1976 increases in abundance were evident in the first mode, while in 1977 catches of all sizes decreased to the levels of prior years. Autumn frequencies contain fewer large individuals but the overall numbers are increased with recruitment of the 0-group *L. pealei* (3-10 cm). A second mode (13-18 cm) probably represents those individuals hatched late in the previous summer, which did not mature in time for spawning in the current year.

Length frequencies of *L. pealei* from Japanese, U.S.S.R., and Polish commercial catches as reported to ICNAF from 1970 to 1974, are consistent with U.S. samples, demonstrating the presence of larger individuals (30-40 cm) in the fishery in March and April, with the upper limit decreasing to about 19 cm in May. U.S.S.R. 1975 *L. pealei* length frequencies from January through May samples from the southern New England area ranged from 4 to 29 cm. The mean length increased from 12.0 cm in January to 17.3 cm in April and then decreased to 10.2 cm in May. Length samples from the March and April 1975 Polish fishery ranged from 3 to 39 cm with monthly means of 10.5 and 11.9

cm. United States and U.S.S.R. length frequencies from autumn bottom trawl surveys, all strata combined, also exhibit consistent length modes for *L. pealei*.

Monthly length samples of *I. illecebrosus* from the U.S. commercial fishery on Georges Bank (1975-77) and in the Gulf of Maine for 1972-77 (Fig. 4) indicate a single mode through most of the year. In May and June of 1973, however, the distribution was skewed to the right due to the presence of large individuals (23-40 cm) which disappear from the fishery in late summer. As *I. illecebrosus* is believed to spawn from December to June, the great range in length could be due to difference in time of hatching of a single age class. However, as Mesnil (1977) suggested, this could also be the result of two separate spawning groups.

Length compositions from U.S. bottom trawl survey catches of *I. illecebrosus* were also reviewed (Fig. 4). Availability of *I. illecebrosus* in the area during the spring survey is always low, and in 1972 and 1973 there were too few in the samples to obtain length frequency distributions for southern New England and Middle Atlantic strata. For spring samples, there is a single mode (Fig. 5a, b) ranging from 5 cm (in 1969) to 17 cm (in 1971). Autumn samples generally have broader size ranges (4-33 cm) with one or two modes. Combined samples for the southern New England and Middle Atlantic areas give a single mode in 1969 at 20 cm; in 1970-73 there were two modes at 5-7 and 17-18 cm. These modes may represent the two groups of *I. illecebrosus* as described by Mesnil, one spawned early (December-January) and the other late (August-September). The relative strengths of these two modes (when present) varies from year to year. In autumn 1974 and 1975 the first mode (5-10 cm) composed about 70 percent of the total, while in 1976, the second mode (22-26 cm, possibly the same age group) represented about 80 percent of those taken, and in 1977 this second mode (21-28 cm) accounted for 70 percent of the total. However, except when *I. illecebrosus* were in high abundance as in 1976 and 1977, larger individuals were rare in the survey catches. Spring cruises are conducted in late March through April, prior to onshore feeding movements and after many of the larger *I. illecebrosus* have spawned and died. In autumn (late September to mid-November) it is generally assumed that large individuals have begun to move offshore to spawn.

In some cases, modal length increases through time following the growth of a single cohort (note autumn 1975-autumn 1976). The great abundance of large (>20 cm) *I. illecebrosus* in the autumn of 1976 might have been predicted by the strong mode at 5-10 cm in autumn 1975, apparently indicating successful spawning in the summer of that year. Unfortunately, an abundance of larger *I. illecebrosus* did not materialize in the autumn of 1975 following a strong autumn mode at 5-10 cm in the autumn of the previous year.

Length frequencies of *I. illecebrosus*, obtained by the U.S.S.R. surveys, were generally similar to those of the U.S. surveys, with consistent autumn modes at 19-21 cm (from 1969 to 1974). Length samples of *I. illecebrosus* from the U.S.S.R. and Polish fisheries reported to ICNAF[8] (1974-76) show large individuals (26-36 cm) present in the fishery in March, but not in later months. Beginning in May there is a single mode (with an average length of 15 cm); this mean length increases to 23 cm by August, but in September with recruitment of the new age class (5-12 cm) apparently resulting from summer spawning, the overall mean length drops to 17 cm. In October the large *I. illecebrosus* move offshore and the average length in commercial samples drops to 11.5 cm in November.

In general the commercial and research survey length frequencies of both species show the progression of the main group of individuals hatched the previous year. However, in *L. pealei* there may be second and third modes also appearing in the spring, that are variable in importance from year to year. These modes possibly correspond to age-groups two and three. With *I. illecebrosus*, a second mode of small individuals may appear in the autumn, probably as a result of summer hatching.

Length samples from commercial catches generally support Mesnil's hypothesis, with peak spawning periods of spring and late summer for *L. pealei* and winter and summer for *I. illecebrosus*. The relative importance of these spawning periods may vary from year to year and it is not clear that individuals of each species originating from a particular spawning period will, necessarily, spawn during the alternate period, as hypothesized from the cross-over life cycle.

[8]ICNAF Secretariat 1978 Length composition data for squid-*Illex*, 1973-1976. Int. Comm. Northwest Atl. Fish., Special STACRES (Stand. Comm. Res. Stat.) Meeting Working Paper 78/II/3, 23 p.

Research Cruise Abundance

Estimates of relative abundance of squid, based on data from U.S. bottom trawl surveys were made for the southern New England-Middle Atlantic (strata 1-12, 61-76), Georges Bank (strata 13-25), and the Gulf of Maine (strata 26-30, 36-40) regions. The location of each strata set is given in Figure 6.

Plots of locations of squid catches made during U.S. bottom trawl survey cruises (Tibbetts, 1977), indicate that both species are distributed across the width of the shelf during autumn surveys, although the extent of onshore distribution of *I. illecebrosus* is variable between years. During spring, *L. pealei* is concentrated along the continental slope (110-200 m) from Cape Hatteras to Georges Bank, and *I. illecebrosus* is found in the survey area only in small numbers (generally from southern Georges Bank, and south). Autumn surveys were consequently chosen as the best measure of relative abundance of these two species in this area (Gulf of Maine to Cape Hatteras). Autumn cruises from 1968 to 1978 were considered as prior to the 1968 cruise. Complete records of the catch of squid, by species, were not kept though it may be noted that fewer squid were taken. The stratified mean catch per

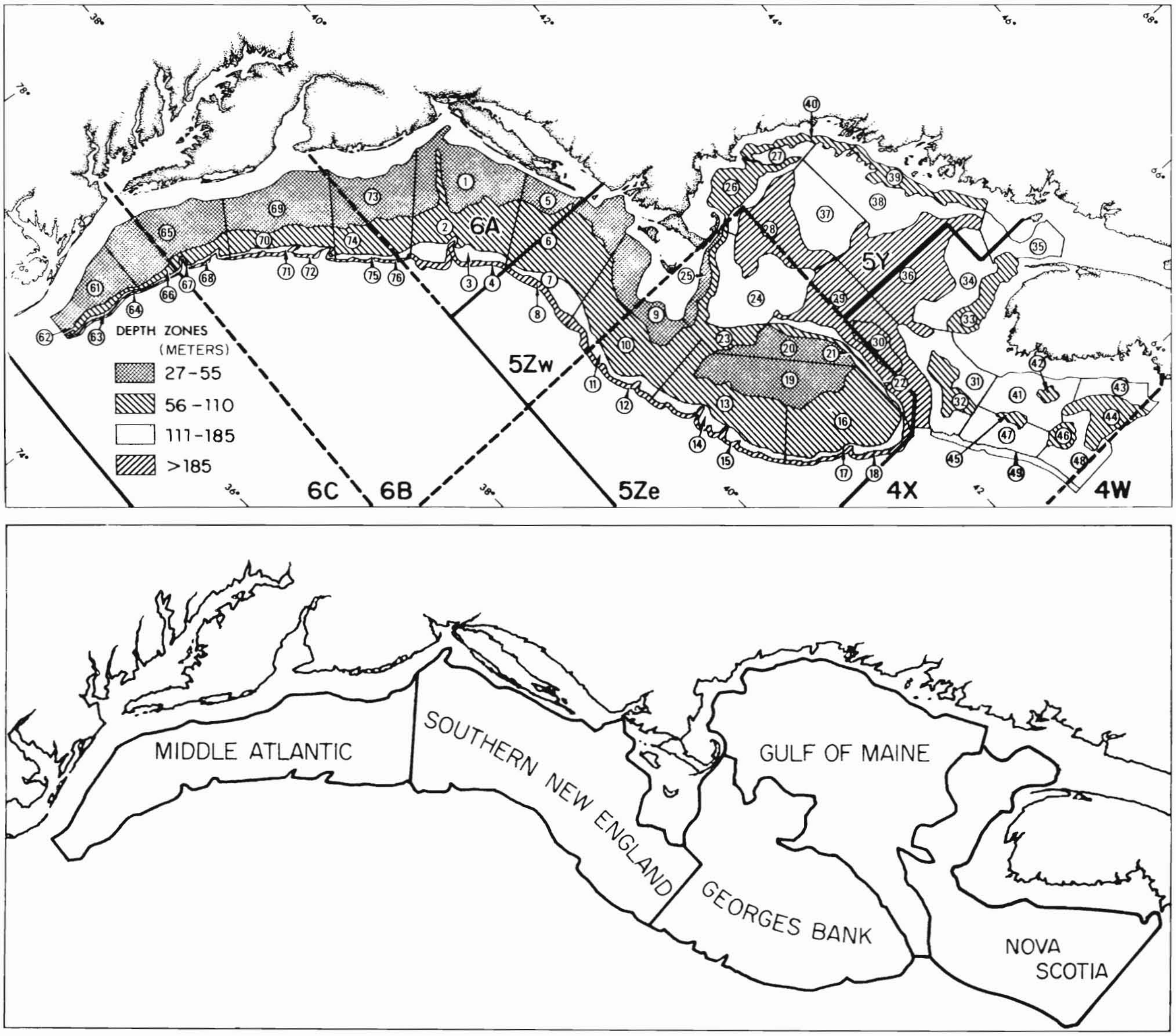


Figure 6.—Strata areas used for relative abundance indices of squid given in Table 5.

tow, in kilograms for both species, was calculated as reported in Table 7 (a and b). *Loligo pealei* is abundant primarily in the southern New England-Middle Atlantic area, and is also consistently found on Georges Bank. In 1975 and 1976, *L. pealei* abundance was significantly higher on Georges Bank than in any year since 1968, while abundance in 1976 and 1977 was slightly less than in 1975 in the southern New England-Middle Atlantic area. The 1978 index from this area was the second lowest since 1968, but may be related as much to late spawning in the summer of 1978 as to a significant reduction in the stock. Spring 1977 and 1978 indices in the southern New England-Middle Atlantic region were also much lower than in recent years (though there is usually great variability in catches during this time of the year). *Illex illecebrosus* catch per tow indices were generally low in all areas, until 1975, when catches in numbers from the southern New England-Middle Atlantic area increased about fivefold over the previous average. Since 1976, *I. illecebrosus* concentrations have been significantly greater than in prior years, especially on Georges Bank and in the southern New England-Middle Atlantic area.

The mean natural logarithm catch per tow (+1) from autumn survey cruises for all areas combined, was used as an

Table 7a.—*Loligo pealei* indices of abundance (stratified mean weight in kg and number per tow by strata set), minimum (B_1) and diel adjusted, minimum (B_2) biomass (in tons) and abundance (in numbers) estimates, 1968-78.

Year	Area	Total			Day			Night			B_1 Wt.	B_1 No.	B_2 Wt.	B_2 No.
		No. tows	Wt./tow	No./tow	No. tows	Wt./tow	No./tow	No. tows	Wt./tow	No./tow	t	$\times 10^6$	t	$\times 10^6$
1968	SNE/Mid-Atl.	124	10.86	267.57	40	16.23	362.60	43	2.51	30.58	28,073	692.6	29,114	1,211.9
	Geo. Bank	69	0.40	10.73	22	0.77	17.13	25	0.02	0.12				
	Gulf Maine	50	0.01	0.09	18	0.01	0.10	15	0.00	0.11				
1969	SNE/Mid-Atl.	119	13.99	347.50	39	27.32	777.30	39	3.29	51.29	37,643	931.6	48,053	2,393.1
	Geo. Bank	73	1.56	36.70	25	2.49	60.37	32	0.54	9.70				
	Gulf Maine	51	0.03	0.40	17	0.06	0.90	16	0.00	0.00				
1970	SNE/Mid-Atl.	122	4.13	105.40	38	5.55	168.10	40	2.98	63.70	12,095	337.9	19,640	1,946.2
	Geo. Bank	70	1.12	49.40	23	2.99	133.73	24	0.22	6.40				
	Gulf Maine	53	0.05	1.46	18	0.06	1.55	16	0.00	0.00				
1971	SNE/Mid-Atl.	125	4.04	234.20	43	8.55	515.70	41	0.27	11.29	11,752	641.4	14,050	1,106.1
	Geo. Bank	73	1.06	34.10	27	1.51	63.75	24	0.51	9.69				
	Gulf Maine	55	0.03	0.57	16	0.08	1.08	20	0.01	0.42				
1972	SNE/Mid-Atl.	114	9.41	398.90	31	13.14	524.90	40	1.24	31.25	25,400	1,065.1	21,039	1,533.3
	Geo. Bank	73	1.13	39.30	29	1.70	68.71	21	0.28	5.08				
	Gulf Maine	55	0.00	0.20	18	0.00	0.00	18	0.00	0.02				
1973	SNE/Mid.-Atl.	111	14.20	542.90	38	17.47	817.10	35	3.68	66.94	42,338	1,460.9	44,252	3,092.0
	Geo. Bank	73	4.53	60.90	27	7.16	96.15	28	2.31	30.44				
	Gulf Maine	54	0.05	0.91	16	0.08	1.56	21	0.02	0.48				
1974	SNE/Mid.-Atl.	108	11.41	355.90	33	16.33	886.10	38	5.38	130.00	32,014	989.0	46,442	4,757.0
	Geo. Bank	74	2.21	62.07	20	2.67	96.20	26	2.93	22.10				
	Gulf Maine	57	0.03	0.78	19	0.03	0.63	21	0.03	0.23				
1975	SNE/Mid-Atl.	115	15.55	895.50	41	20.27	1,548.40	36	6.11	115.20	41,912	2,412.0	48,636	7,789.0
	Geo. Bank	73	1.80	102.56	23	1.64	142.70	25	0.47	1.82				
	Gulf Maine	65	0.81	0.81	19	0.03	1.56	23	0.02	0.40				
1976	SNE/Mid-Atl.	123	15.79	579.79	37	22.05	979.90	40	3.65	90.74	44,935	1,632.0	51,436	4,372.0
	Geo. Bank	67	3.14	103.52	27	5.82	207.53	19	2.18	54.94				
	Gulf Maine	55	0.36	12.67	14	0.51	16.00	21	1.37	8.58				
1977	SNE/Mid-Atl.	119	11.92	577.89	46	14.20	729.54	35	1.89	94.67	31,600	1,526.0	27,421	3,157.0
	Geo. Bank	101	0.95	43.76	38	1.34	84.06	33	0.23	7.31				
	Gulf Maine	71	0.06	0.81	23	0.04	0.48	22	0.02	0.11				
1978	SNE/Mid-Atl.	134	5.68	198.36	41	8.93	362.00	52	1.37	23.26	16,583	566.0	18,800	1,251.0
	Geo. Bank	156	1.57	45.63	53	4.04	116.10	50	0.41	11.01				
	Gulf Maine	120	0.01	0.18	39	0.06	2.08	45	0.00	0.01				

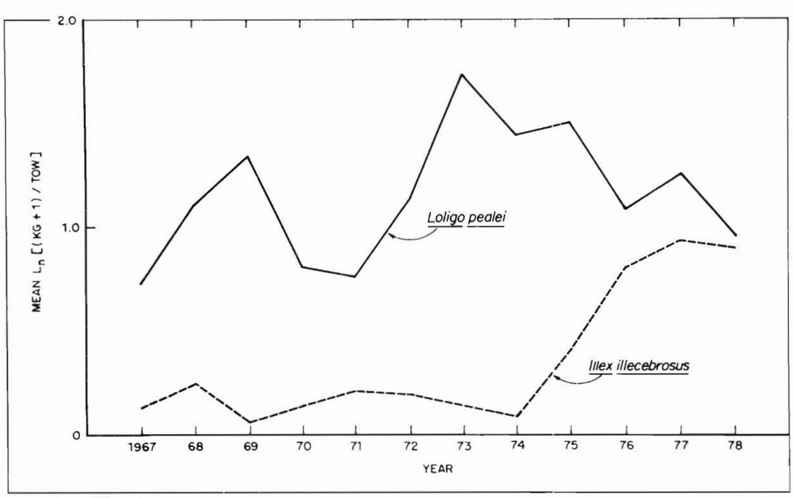


Figure 7.—Squid (*Loligo pealei* and *Illex illecebrosus*) abundance indices for the Middle Atlantic through Georges Bank areas, from U.S. bottom trawl surveys, 1967-78.

index of abundance for each species (Fig. 7) to illustrate the overall trend of squid abundance (1967-78). Log_e mean catch values are used in evaluating squid abundance trends since this transformation tends to adjust the highly skewed distribution of the raw mean catch per tow data. The *L. pealei* index of abundance shows a general increase during the period, 1967-73, while it has been decreasing since then (1974-78). The *I. illecebrosus* index remained at a relatively low, but stable level through 1974, after which it steadily increased from about 20 percent or less of the *L. pealei* index, to a level comparable to that of *L. pealei* in 1978.

Minimum stock size estimates (Table 7) based on U.S. autumn bottom trawl surveys can be obtained from

Table 7b.—*Illex illecebrosus* indices of abundance (stratified mean weight in kg and number, per tow, by strata set), and minimum biomass (in tons) and abundance (in numbers) estimates, 1968-78.

		Total			Day			Night			B_1	B_1
Year	Area	No. tows	Wt./tow	No./tow	No. tows	Wt./tow	No./tow	No. tows	Wt./tow	No./tow	Wt. t	No. $\times 10^6$
1968	SNE/Mid-Atl.	124	0.48	2.62	40	0.28	1.69	43	0.13	0.60	1,845.4	9.70
	Geo. Bank	69	0.34	1.68	22	0.72	2.35	25	0.04	0.26		
	Gulf Maine	50	0.10	0.46	18	0.18	1.49	15	0.04	0.25		
1969	SNE/Mid-Atl.	119	0.10	0.98	38	0.17	1.64	39	0.06	0.50	418.8	3.60
	Geo. Bank	73	0.04	0.48	25	0.04	0.57	32	0.06	0.43		
	Gulf Maine	51	0.07	0.27	17	0.14	0.51	16	0.00	0.07		
1970	SNE/Mid-Atl.	122	0.29	3.83	38	0.21	4.53	40	0.14	1.54	1,523.6	14.60
	Geo. Bank	70	0.24	2.62	23	0.60	4.89	24	0.05	0.56		
	Gulf Maine	53	0.29	0.82	18	0.50	1.36	16	0.02	0.11		
1971	SNE/Mid-Atl.	125	0.28	1.95	43	0.24	1.94	41	0.13	0.71	2,024.1	10.10
	Geo. Bank	73	0.46	1.70	27	0.55	2.23	24	0.25	0.93		
	Gulf Maine	55	0.43	1.81	16	1.21	4.44	20	0.16	0.85		
1972	SNE/Mid-Atl.	114	0.45	4.86	31	0.42	8.12	40	0.27	1.57	1,716.1	15.00
	Geo-Bank	73	0.20	1.07	29	0.15	0.83	21	0.15	0.72		
	Gulf Maine	55	0.19	0.75	18	0.34	1.50	18	0.04	0.09		
1973	SNE/Mid-Atl.	111	0.07	0.62	38	0.08	0.66	35	0.03	0.30	1,862.0	8.20
	Geo. Bank	73	0.50	2.51	27	0.70	2.51	28	0.44	3.29		
	Gulf Maine	54	0.63	2.02	16	1.57	5.19	21	0.09	0.26		
1974	SNE/Mid-Atl.	108	0.18	4.07	33	0.11	7.98	38	0.20	1.23	2,500.0	18.02
	Geo. Bank	74	0.16	1.12	20	0.22	1.19	26	0.09	0.58		
	Gulf Maine	57	1.16	3.92	19	1.76	5.88	21	0.46	1.41		
1975	SNE/Mid-Atl.	115	0.99	15.74	41	1.11	23.08	36	0.23	1.58	8,306.0	60.25
	Geo. Bank	73	1.11	6.41	23	1.85	13.01	25	0.76	2.03		
	Gulf Maine	65	2.71	7.31	19	3.34	9.17	23	0.29	0.60		
1976	SNE/Mid-Atl.	123	6.23	19.79	37	2.60	11.23	40	3.90	10.49	42,929.0	134.34
	Geo. Bank	67	14.78	45.03	27	8.06	23.83	19	3.54	9.82		
	Gulf Maine	55	4.20	13.75	14	5.25	16.83	21	1.35	3.47		
1977	SNE/Mid-Atl.	119	4.46	15.79	46	3.93	16.21	35	2.32	7.71	21,747.0	73.34
	Geo. Bank	101	5.02	15.81	38	4.09	15.23	33	5.31	16.23		
	Gulf Maine	71	2.21	7.24	23	4.26	14.82	22	0.40	1.29		
1978	SNE/Mid-Atl.	134	2.57	19.50	41	2.53	24.66	52	1.97	8.54	26,435.0	120.68
	Geo. Bank	156	12.17	44.67	53	34.25	109.75	50	2.68	12.56		
	Gulf Maine	120	1.91	5.84	39	3.75	11.25	45	0.41	1.41		

areal expansion of the stratified mean weight or number per tow for each species. A first approximation of this stock size, B_1, was made using the equation:

$$B_1 = \frac{WA}{a} \qquad (7)$$

where B_1 = estimate of biomass or abundance, W = stratified mean weight or number per tow, A = strata area sampled (in square miles), and a = area swept by each tow (0.011 miles^2).

Diel variations (caused by vertical migrations) in relative apparent abundance of *L. pealei* are significant, with daytime (0800 to 1600 hours) survey catches 2.66 and 18.77 times greater (in weight and number, respectively), than nighttime catches (2000-0400 hours) according to Sissenwine and Bowman (1978). Therefore, a second estimate (B_2) of *L. pealei* abundance was made by adjusting night catches upward when calculating stratified mean catch per tow, prior to areal expansion (Table 7a). As diel variations in *I. illecebrosus* were not found to be significant, no adjustment was made to the initial biomass estimate (B_1) for that species (Table 7b).

It should be noted that the spatial distribution of *I. illecebrosus* is broader than the area covered by the U.S. bottom trawl surveys. This species is also abundant north and east of the survey area (along the coast of Canada) and the abundance of *I. illecebrosus* further offshore is unknown. Consequently, the abundance indices observed in the survey areas may reflect yearly distributional differences in these areas for this species, and not overall population size. The biomass estimate for *I. illecebrosus* (B_1) from 1968 to 1975 averaged only 7.5 percent of the *L. pealei* estimates in weight, while since then (1976-78) they have increased to 97.8 percent of the *L. pealei* value. However, a much greater difference exists in population size in numbers. Estimated numbers of *L. pealei* in 1976 ($4,372 \times 10^6$) were 33 times that of *I. illecebrosus* (134.3×10^6), while biomass estimates differed only by a factor of 1.2 (51,436 vs. 41,929, respectively). In 1977 and 1978, *I. illecebrosus* biomass estimates remained high while *L. pealei* decreased; and the 1978 catch of *I. illecebrosus* was 40 percent greater (26,435 vs. 18,800 t) than that of *L. pealei*, while in terms of numbers, it was 90 percent less.

Biomass estimates for *I. illecebrosus* have also been made by the U.S.S.R. for the area of Georges Bank and Nova Scotia. These estimates made from areal expansion of survey catches, were: 100,000 t in 1971; 58,000 t in 1972; 197,000 t in 1975, and 258,000 t in 1976 (Konstantinov and Noskov[9]).

Loligo pealei and *Illex illecebrosus* in commercial length samples are usually >8 and 10 cm in mantle length, respectively. Therefore, the abundance of individuals less than or equal to the appropriate length at recruitment, in autumn bottom trawl survey catches, may be a useful prerecruit index (Table 8).

For *L. pealei*, most of the catch in numbers during the autumn surveys are prerecruits, but these are much less important to survey catch in weight. Even though these *L. pealei* prerecruits are the mainstay of the winter offshore fishery there has been no significant correlation between these indices and subsequent catches or C/E in the commercial fishery, or in subsequent survey catches.

Illex illecebrosus prerecruits are rare in the survey catches, but when they are abundant, as a result of significant summer spawning, they may be a good predictor of the following summer's fishery (note 1975-76). This relationship, however, needs further verification. It should also be noted that when *I. illecebrosus* prerecruits are scarce, the abundance during the following summer may still be high as a result of successful winter spawning.

Table 8.—Pre-recruit indices of squid. (Stratified mean number per tow of *L. pealei* and *I. illecebrosus* of all sizes and of *L. pealei* ≤8 cm and *I. illecebrosus* ≤10 cm mantle length in autumn bottom trawl survey, Middle Atlantic to Georges Bank.)

	Loligo (#/tow)		*Illex* (#/tow)	
Year	All sizes	≤ 8 cm	All sizes	≤ 10 cm
1967	134.5	126.9	2.1	0.7
1968	176.5	159.9	2.3	0.6
1969	237.3	217.4	0.8	0.3
1970	85.6	79.3	3.4	0.2
1971	163.3	161.5	1.9	0.6
1972	271.4	258.5	3.5	1.8
1973	372.0	353.9	1.3	0.3
1974	251.7	233.3	3.0	2.1
1975	614.4	593.3	12.4	9.6
1976	410.9	302.5	28.7	0.6
1977	388.5	297.7	15.8	1.1
1978	144.2	93.4	28.4	5.1

Simulation Model of Squid Populations

The traditional stock assessment methods which are usually applied to finfish species are not readily applicable to squid populations. Surplus-production or stock-production models (such as the Schaefer model) are not applicable because of the short time series of catch and effort data. Virtual population analysis as presented by Ikeda and Nagasaki (footnote 2), requires estimates of the age-class structure of the catch which are presently unavailable. Au (footnote 1) applied the Beverton and Holt yield per recruit equation (dynamic pool model) to both species of squid, but this model has several shortcomings in this case. The Beverton and Holt model assumes that fishing and natural mortality ratios are constant during the exploited phase of the life cycle and these assumptions are too restrictive for squid.

Therefore, a dynamic pool model designed specifically to simulate the effect of fishing on squid was developed (Sissenwine and Tibbetts, 1977). The model allows monthly values of instantaneous growth, fishing, and natural mortality rates. A 1-year life cycle with winter (January-March) spawning and a 2-year life cycle with summer (May-September) spawning were assumed for *I. illecebrosus* and *L. pealei*, respectively. The model also simulated postspawning mortality.

A major shortcoming of fisheries management based on yield per recruit (YPR) considerations is that fishing at F_{max} (which maximizes YPR) usually results in a severe reduction in spawning stock biomass and increases the probability of recruitment failure. The fishing mortality rate where the increased yield of an additional unit of effort is 10 percent of the yield from the first unit of effort ($F_{0.1}$) is often selected as a target fishing mortality in order to lessen the reduction in spawning stock biomass and thus guard against recruitment failure. An alternative approach was applied in the simulation model described here. The relationship between spawning stock size and recruitment to the exploited phase of the next generation was assumed as follows:

$$R = \frac{P}{1 + A(P-1)} \tag{8}$$

(Beverton and Holt, 1957) where R and P are the number of recruits and weight of spawners, respectively, related to the unexploited stock, i.e., R and P both equal 1.0 for the unexploited stock. A is a parameter ranging from 0 to 1.0. The function is graphed in Figure 8 for the three values of A (0.4, 0.8, and 1.0) applied to squid. In order to calculate the maximum sustainable yield per recruit and corresponding exploitation rate (E_{MSY}), the model was run for successive generations until recruitment converged to an equilibrium value. Because of uncertainty in the life cycle and parameter estimates used in the models for *L. pealei*, and particularly *I. illecebrosus*, simulation results should be applied with caution. Nevertheless, in the absence of more definitive results, the simulations do offer some guidance in selecting a target exploitation rate. As expected, the simulation results were most sensitive to the input value of A. Typical results for the equilibrium YPR and the mean weight of individuals in the catch corresponding to an exploitation rate of E_{MSY} for A equal 0.4, 0.8, and 1.0 are given in Table 9. E_{MSY}, corresponding to a moderate stock-recruitment relationship (A = 0.8), was selected as a target exploitation rate in order to determine the annual catch limit (TAC under ICNAF, optimum yield under FCMA) for *L. pealei* in 1977. The same catch limit has been maintained to date. The choice of A = 0.8 is arbitrary, but this value is

[9]Konstantinov, K. G., and A. S. Noskov. 1977. Report of the USSR investigations in the ICNAF area, 1976. Annu. Rep. Int. Comm. Northwest Atl. Fish. 1976, Summ. Doc. 77/VI/15.

Table 9.—Yield per recruit (YPR) and mean weight of individuals in the catch (*W*) of squid by species, corresponding to the exploitation rate that maximizes sustainable yield (E_{MSY}) for a strong (A = 0.4), moderate (A = 0.8), and no stock recruitment relationship (A = 1.0).

Species	Stock-recruitment relationship	*Y* (g)	*W* (g)	E_{MSY}
L. pealei	None	39	52	0.75
	Moderate	29	72	0.40
	Strong	13	85	0.15
I. illecebrosus	None	45	72	0.63
	Moderate	33	90	0.37
	Strong	15	100	0.15

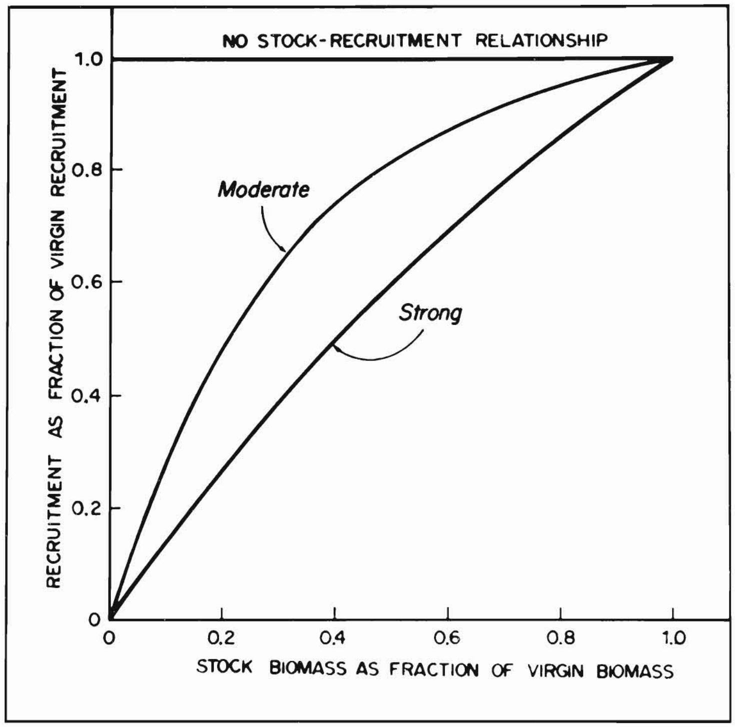


Figure 8.—Relationship of recruitment (R) to spawner biomass (P) of the form $R = P/[1 + A(P-1)]$ for values of A applied to squid.

more reasonable than the other examples of A considered in the analysis. If $A = 1.0$, then E_{MSY} corresponds to fishing at F_{max} and past experience with finfish indicates that fishing at this level of mortality results in recruitment overfishing. Unless stock size has been grossly underestimated, if $A = 0.4$, the stock should have already shown signs of overfishing, but this is not the case.

Population size estimates of *L. pealei* range from about 1 to 7 billion individuals between 1968 and 1977. These are probably underestimates since they are based on the areal expansion of bottom trawl survey data (see Sissenwine[10]). Most of the squid taken in autumn bottom trawl surveys were small recruiting squid. Therefore, an annual recruitment of >1.5 billion *L. pealei* seems likely. If a moderately strong stock recruitment relationship (A = 0.8) is assumed, then a catch of about 44,000 t ($1.5 \times 10^9 \cdot 0.40 \cdot 72 \times 10^{-6}$ t) is indicated by the model.

The biomass of *I. illecebrosus* on Georges Bank and the southern Scotian Shelf was estimated by areal expansion as 100, 58, 197, and 258 thousand tons during the summers of 1971, 1972, 1975, and 1976, respectively (Konstantinov and Noskov footnote 9). The high abundance of *I. illecebrosus* in 1976 was confirmed by Canadian, French, Polish, and United States research vessels. Applying $E_{MSY} = 0.37$ (for a moderate stock-recruitment relationship), these estimates indicate a catch of 37, 21, 73, and 95 thousand tons during the appropriate years according to the model. This stock supports fisheries in both Canadian and United States fishery zones. A total northwest Atlantic catch of *I. illecebrosus* of 55,000 t was recommended for 1976 and again for 1977 by the Standing Committee on Research and Statistics (STACRES) of ICNAF with 25,000 t and 30,000 t to be allocated to Canadian and United States waters, respectively. The regulations that were established were more liberal than STACRES' recommendations (particularly in Canadian waters) with a resulting total catch of 69,500 t in 1976, about 105,000 t in 1977, and about 117,000 t in 1978. If the U.S.S.R. biomass estimates are realistic, then even a catch of 55,000 t would result in an exploitation higher than E_{MSY} in some years according to the model (for $A = 0.8$).

Discussion and Conclusions

Management of squid stocks (*L. pealei* and *I. illecebrosus*) in the northwest Atlantic began in 1974 with establishment, by ICNAF, of a preemptive quota of 71,000 t, based on early estimates of *L. pealei* stock size. As more information relative to the biology of the populations of *I. illecebrosus* and *L. pealei* became available, a model simulating the effect of fishing on these stocks was developed (Sissenwine and Tibbetts, 1977). This model incorporates relevant biological information and assumptions on growth, spawning, recruitment, and mortality, with knowledge of the fishery based on historical monthly catch statistics, and estimates of population size from research vessel surveys, to determine the maximum sustainable yield per recruit

[10]Sissenwine, M. P. 1976. A review of stock size estimates of squid (*Loligo* and *Illex*) in Subarea 5 and Statistical Area 6. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/VI/31, Serial No. 3811, 4 p.

and corresponding exploitation rate for each species of squid.

For *L. pealei*, assuming a moderately strong stock recruitment relationship ($A = 0.8$), models indicate an exploitation rate of 0.40, with an average weight of individuals in the catch of 72.4 g. Annual recruitment is probably >1.5 billion individuals, indicating that a yearly catch of 44,000 t ($1.5 \times 10^9 \cdot 0.40 \cdot 72 \times 10^{-6}$ t), may be reasonable.

Stock size estimates for *I. illecebrosus* are more variable than for *L. pealei*, and since this species ranges to areas beyond the scope of research surveys and commercial fisheries, these estimates may not reflect the abundance of the entire population. However, these do provide information for preliminary estimates of appropriate catch levels. Assuming a moderate stock-recruitment relationship, with an exploitation rate of 0.37, these estimates indicate catches between 21,000 and 95,000 t may have been appropriate during recent years. Unless available stock size estimates are below actual values, however, recent levels of catch may produce exploitation rates in some years which are greater than E_{MSY}, according to the model.

Recent decreases in catch and catch per effort in the directed squid fishery, especially for *L. pealei*, may indicate lower abundance of these stocks due to declines in recruitment. As suggested by the model, when $A = 0.8$, at E_{MSY} recruitment should decrease by 28 percent for *L. pealei* and by 25.5 percent for *I. illecebrosus*. However, the apparent declines in recruitment may be due to natural fluctuations and not related to fishing.

Further understanding of the biological relationships, especially stock recruitment, of *L. pealei* and *I. illecebrosus* is needed for more rational management of their stocks.

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