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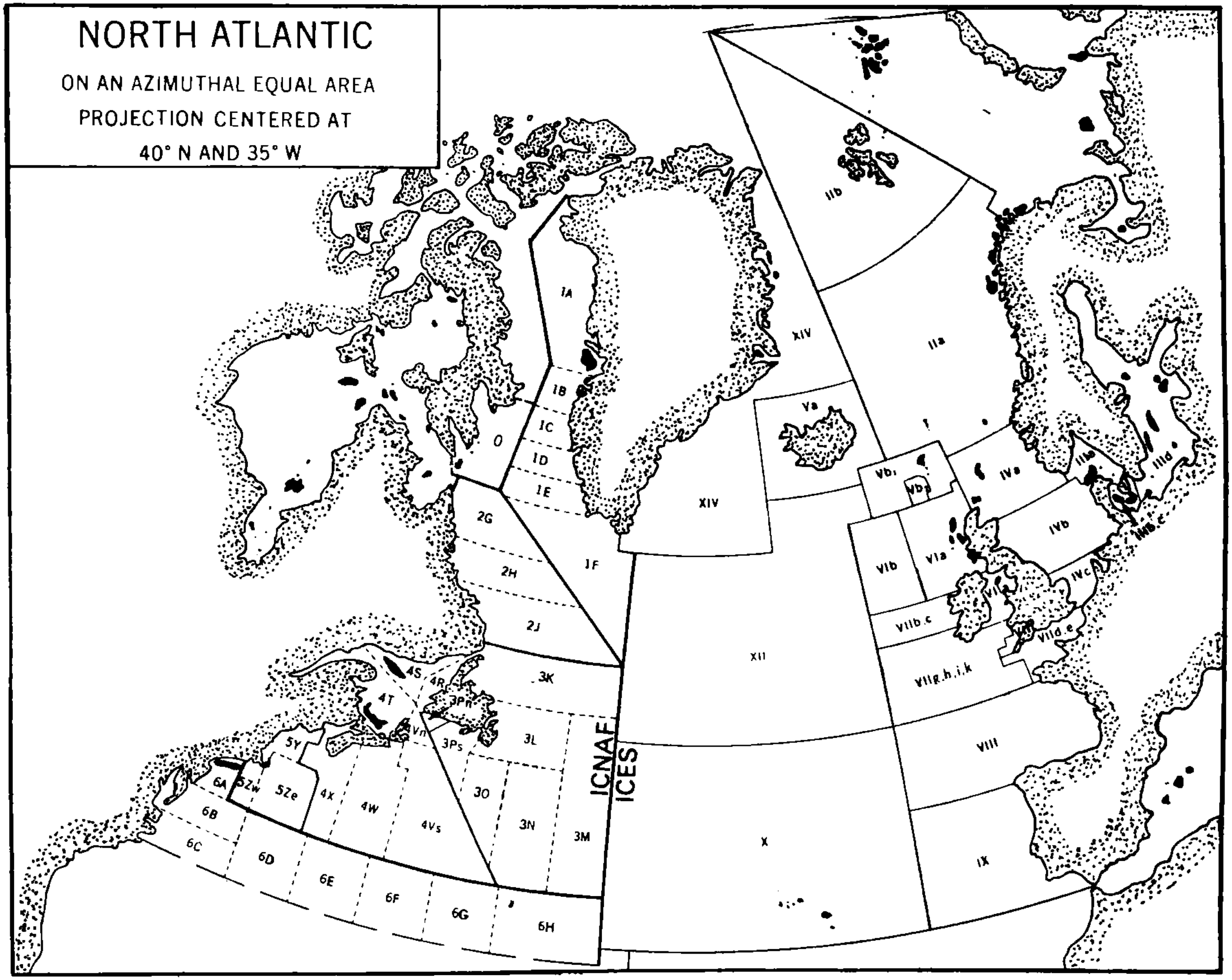
Foreword

This issue of Selected Papers is the second in the new series to be published annually or more frequently, depending on the number of contributions. During the period 1958 to 1973, selected papers from ICNAF Meetings were published in the Redbook series.

Papers for publication in this new series are selected, subject to the approval of the authors, by the Steering and Publications Subcommittee of STACRES (Standing Committee on Research and Statistics) from papers presented to scientific meetings of ICNAF. In general, the papers selected contain information which is considered worthy of wider circulation than is normal for meeting documents. Each author is supplied with 50 reprints of his or her contribution.

NORTH ATLANTIC

ON AN AZIMUTHAL EQUAL AREA
PROJECTION CENTERED AT
40° N AND 35° W



Contents

A Simple Iterative Method to Determine Fishing Mortality Rates Associated with Varying Catch Levels[1]

by

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ABSTRACT

A simple iterative procedure for determining the instantaneous fishing mortality rate (F) pertaining to a known exploitation rate and instantaneous natural mortality rate (M) is described. The solution is based on the near linear relationship between the square of the exploitation rate and F over a range of M from M = 0 to M = 1.

INTRODUCTION

Doubleday (1975) described a simple iterative method for estimating the instantaneous rate of fishing mortality and stock size at age at the beginning of the year from catch at age data and population size at age at the end of the year. This method has proved useful in applying computer programming techniques to the virtual population analysis method as it provides a quick and precise method for solving the catch equation when catch in numbers and stock size at age at the end of the year are known. When calculating future stock sizes from those presently known, it is useful to associate a fishing mortality rate and a resulting stock size with a particular catch level. This paper describes a quick iterative method for estimating fishing mortality rate from catch and stock size at age at the beginning of the year by an approximate linearizing of the exploitation rate in relation to fishing mortality. This can be done by squaring the catch to stock size ratio for a particular age group.

DEFINITIONS

C_n - catch of fish in numbers from a year-class at age n

F_n - instantaneous rate of fishing mortality on the year-class in year n

M - instantaneous rate of natural mortality

P_n - stock size in numbers of a year-class at the beginning of year n

exp - exponential function

ANALYSIS

The catch equation of Beverton and Holt (1957)

$$C_n = \frac{F_n}{F_n+M}\,[1-\exp(-F_n-M)]P_n$$

can be expressed as the exploitation rate

$$\frac{F_n}{F_n+M}\,[1-\exp(-F_n-M)] = \frac{C_n}{P_n} \qquad (1)$$

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[1] Submitted to 1976 Annual Meeting as ICNAF Res.Doc. 76/VI/96.

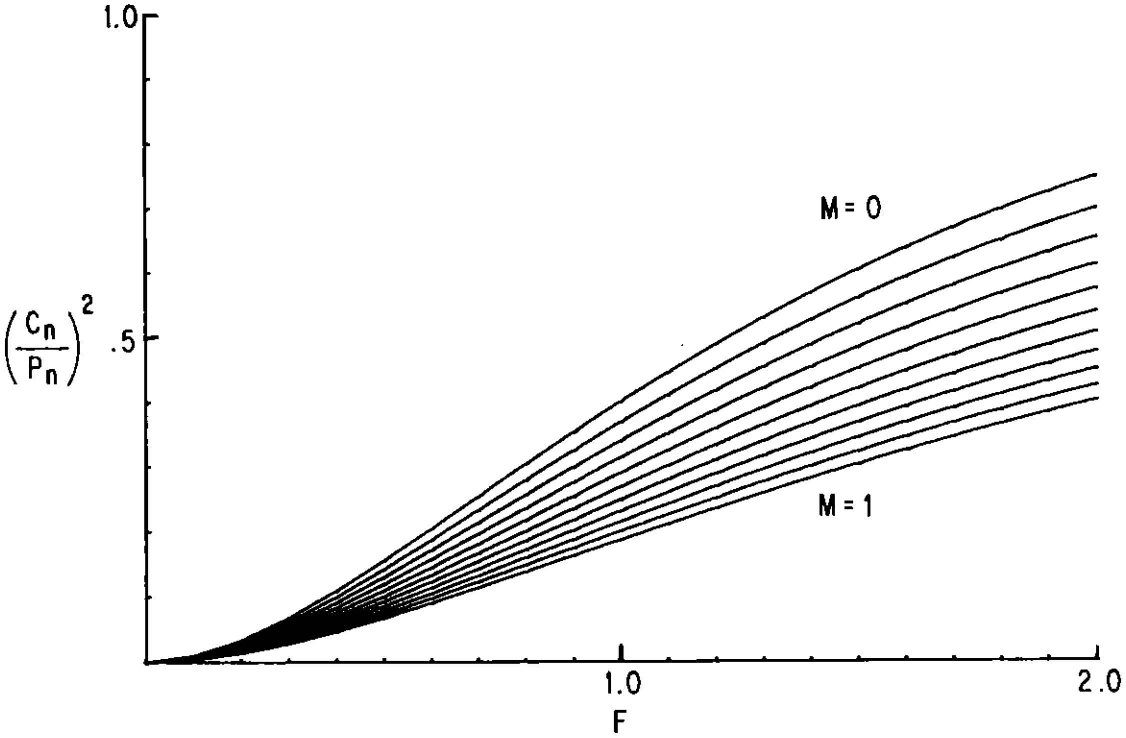

Fig. 1. Plot of $(C_n/P_n)^2$ as a function of F for M between 0 and 1.

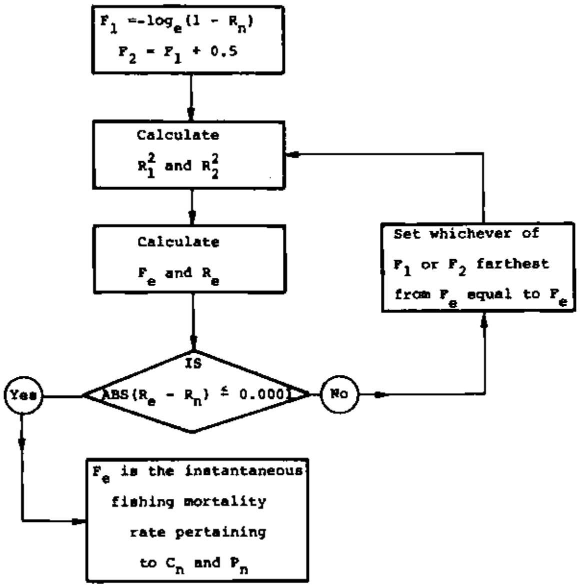

Fig. 2. Flow chart for estimating F_n if P_n, C_n, and M are known. F_1, F_2 - estimates of F used in each iteration;

$$R_1 = \frac{F_1}{F_1+M}\,[1-\exp(-F_1-M)]$$

$$R_2 = \frac{F_2}{F_1+M}\,[1-\exp(-F_2-M)]$$

F_e - estimated instantaneous fishing mortality rate

$$R_e = \frac{F_e}{F_e+M}\,[1-\exp(-F_e-M)]$$

$$R_n = \frac{C_n}{P_n}$$

Since the formula does not yield an analytical solution for F_n if C_n, P_n and M are known, it has to be solved numerically, either by an iterative procedure or by reference to tables.

Figure 1 shows $(C_n/P_n)^2$ as a function of F_n for values of M between 0 and 1. For $F_n > 0.1$, the curves are nearly linear. Since C_n, P_n and M are known, it is possible to solve Equation 1 for F_n by squaring both sides and applying successive linear interpolations or extrapolations until F_n is estimated with a predetermined accuracy. Once F_n is known, the resulting stock size after this fishing year (P_{n+1}) may be calculated by

$$P_{n+1} = P_n\ [\exp(-F_n-M)].$$

A program has been written for the Hewlitt Packard 9821A calculator to test this method. Initial estimates of $F_1 = \ell n(1-C_n/P_n)$ and $F_2 = F_1 + 0.5$ are used for the first iteration. In successive iterations, the latest estimate of F_n replaces either F_1 or F_2 depending which is farthest from the new estimate of F_n. The iterative procedure continues until the ratio of C_n/P_n associated with the estimated F_n is within 10^{-4} of the true value. Negative estimates of F_n are replaced by 0. Test runs indicate rapid convergence, with only 1 to 3 iterations usually required for M between 0 and 1.

Figure 2 shows a flow chart for a computer program employing this method.

CONCLUSION

The method described above provides a precise and quick iterative solution for F_n if P_n, C_n and M are known. This allows stock projection to be accomplished by specifying quota levels rather than fishing mortality rates.

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The Status of the Witch Flounder Fishery in ICNAF Subdivision 3Ps[1]

by

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ABSTRACT

The witch flounder stock in ICNAF Subdivision 3Ps was assessed using the Beverton and Holt yield-per-recruit model. The fishing mortality values were averaged over the 1970-75 period and represent removals from the stock during these years, averaging about 2,000 metric tons per year.

INTRODUCTION

The witch flounder (*Glyptocephalus cynoglossus*) stock in Subdiv. 3Ps is considered to be a single stock for management purposes. The main fishery in this area now occurs on the southwest slope of St. Pierre Bank with small quantities being taken in Fortune Bay by Newfoundland inshore fishermen. Although Pitt (MS 1973) reviewed the fishery trends for the various witch flounder stocks in Subarea 3, this paper presents the first analytical assessment of the Subdiv. 3Ps stock.

During the early 1950's, removals were primarily by Danish seine gear in Fortune Bay with annual catches of 500-700 tons. After 1955 the catch per unit effort was too low to support the commercial fishery in Fortune Bay, and practically the entire catch of witch flounder in Subdiv. 3Ps since then was taken on St. Pierre Bank. The largest catches occurred during 1967-69 with annual yields of 4,000-5,000 tons, most of which was taken by Canada and USSR (Table 1). Since then the fishery has been almost exlusively Canadian, with catches on a general downward trend. At the 1973 Annual Meeting of ICNAF, the Commission agreed to a total allowable catch (TAC) of 3,000 tons for 1974 (based on catch statistics) and this TAC continued in effect for 1975 and 1976.

Table 1. Nominal catches (metric tons) of witch flounder in ICNAF Subdiv. 3Ps, 1963-75.

Year	Canada	France	Portugal	USSR	UK	Total
1963	771	131	-	-	22	924
1964	963	-	-	-	48	1,011
1965	555	-	-	-	15	570
1966	1,344	-	-	79	21	1,444
1967	3,790	-	-	982	33	4,805
1968	2,561	106	-	1,464	-	4,131
1969	2,309	95	-	1,691	1	4,096
1970	2,591	111	-	-	-	2,702
1971	2,193	57	-	-	-	2,250
1972	1,517	69	-	8	-	1,594
1973	2,341	112	-	443	10	2,906
1974	1,699	2	40	-	-	1,741
1975	1,370	40	13	4	-	1,427

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[1] Submitted to the 1976 Annual Meeting as Res.Doc. 76/VI/39.

MATERIALS AND METHODS

Sampling data, used as the basis for this yield-per-recruit assessment, were collected from Canadian commercial trawler landings during 1975. Males and females were sufficiently different in age composition and growth to warrant separation of the sexes (Fig. 1 and 2). Since the fishery is almost exclusively Canadian, it was assumed that the length and age composition of the Canadian catches of witch flounder were representative of the catches by other countries for purposes of catch curve construction and mean selection length (ℓ_c) calculations. The ℓ_c for males and females are 34.55 cm and 34.77 cm respectively. The natural mortality (M) was assumed to be 0.20, based on data collected prior to the commencement of a significant commercial fishery (Bowering and Pitt, MS 1974).

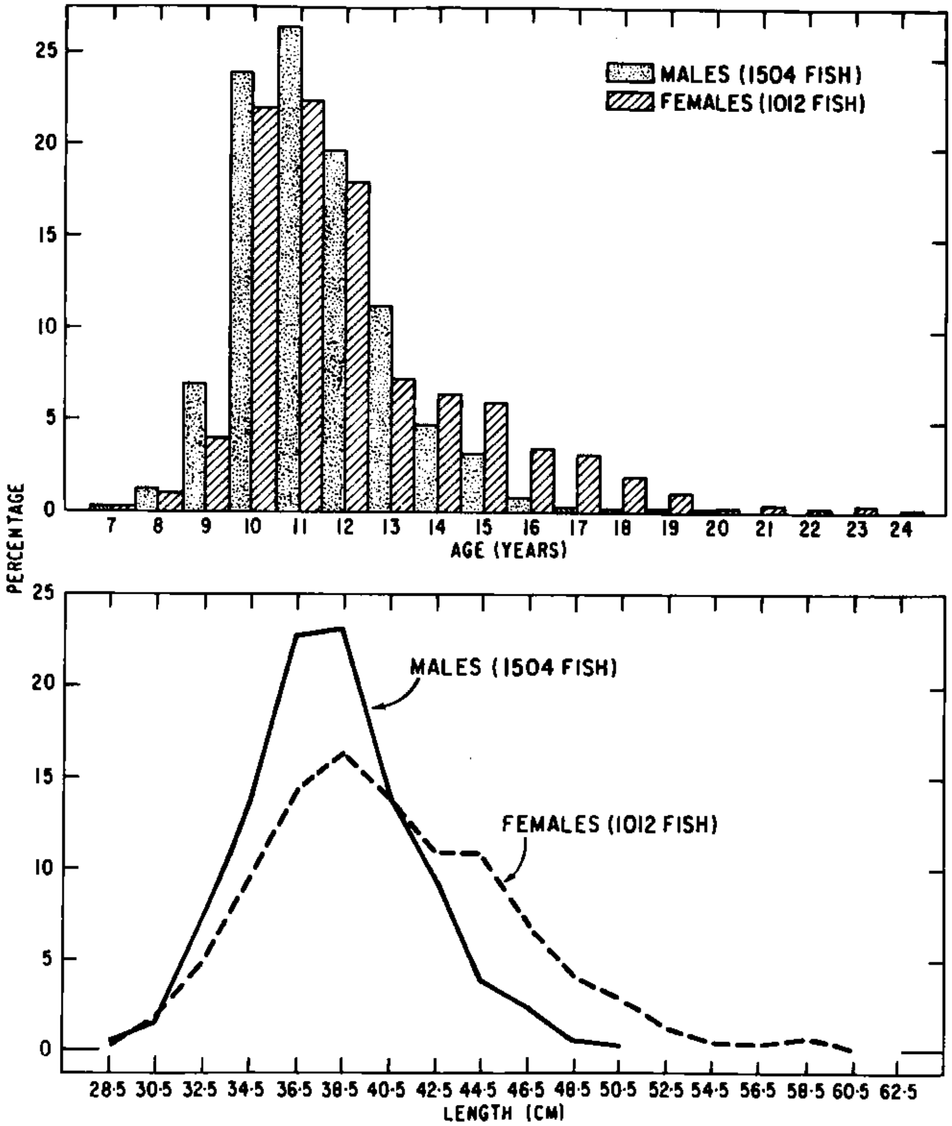

Fig. 1. Age and length composition of witch flounder in Canadian commercial trawl catches, Subdiv. 3Ps, 1975.

Von Bertalanffy (1938) growth curves were fitted to the age-length data, and the Beverton and Holt (1957) yield-per-recruit model was applied to males and females separately, using the following parameters:

		Male	Female
W_∞	- asymptotic weight (kg)	1.701	2.970
K	- growth coefficient	0.0973	0.0732
t_0	- arbitrary age (yr) for $\ell = 0$	0.41	0.25
t_ρ	- age at recruitment (yr)	7.0	7.0
t_ρ'	- age at mean selection (yr)	9.2	9.8
t_λ	- age at last significant contribution to fishery (yr)	20.0	24.0

Yield-per-recruit curves were plotted for M = 0.2 and for fishing mortality (F) values up to 2.5.

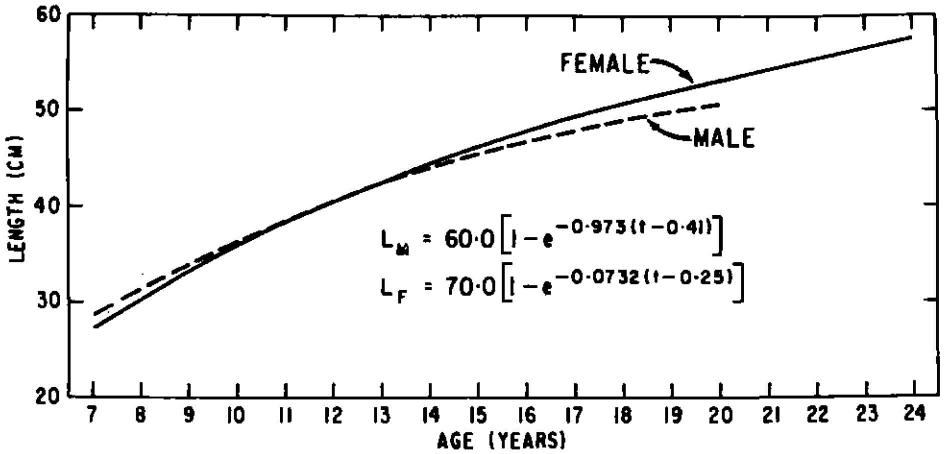

Fig. 2. Growth curves of male and female witch flounder in Subdiv. 3Ps (based on 1975 length-age data).

RESULTS

Catch curves (Fig. 3), plotted from the commercial age composition of Fig. 1, provide estimates of instantaneous total mortality (z) of 0.75 for males and 0.42 for females, with correlation coefficients (r) greater than 0.95. The yield-per-recruit curves (Fig. 4) are flat-topped and indicate no definitive F_{max} up to F = 2.5. In relation to the fishing mortality level of $F_{0.1}$[2], the present level of F is somewhat higher than $F_{0.1}$ (0.35) for males and about the same as $F_{0.1}$ (0.25) for females.

DISCUSSION

The removals from this stock are not so much dependent upon a directed fishery for this species but rather as by-catch in fisheries for other species, particularly cod and redfish. Since no information is available on the discarding of witch flounder at sea by countries with no interest in retaining this species, the total removals of witch flounder is not known and those represented by the nominal catches of Table 1 must therefore be considered minimal.

In view of the life-span of witch flounder, the value of M (0.20), assumed in the calculations, is probably maximal. In any case, the average value of F for approximately the 1970-74 period, indicated in Fig. 4, is close to the desired level of $F_{0.1}$ for females and somewhat higher for males. These values of F are considered to be representative of the fishing mortality during 1970-75, when the nominal catches averaged about 2,000 tons.

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[2] The level at which the change in yield per recruit with respect to change in mortality rate is one-tenth of that of the fishery on a very lightly-fished stock (ICNAF, 1972).

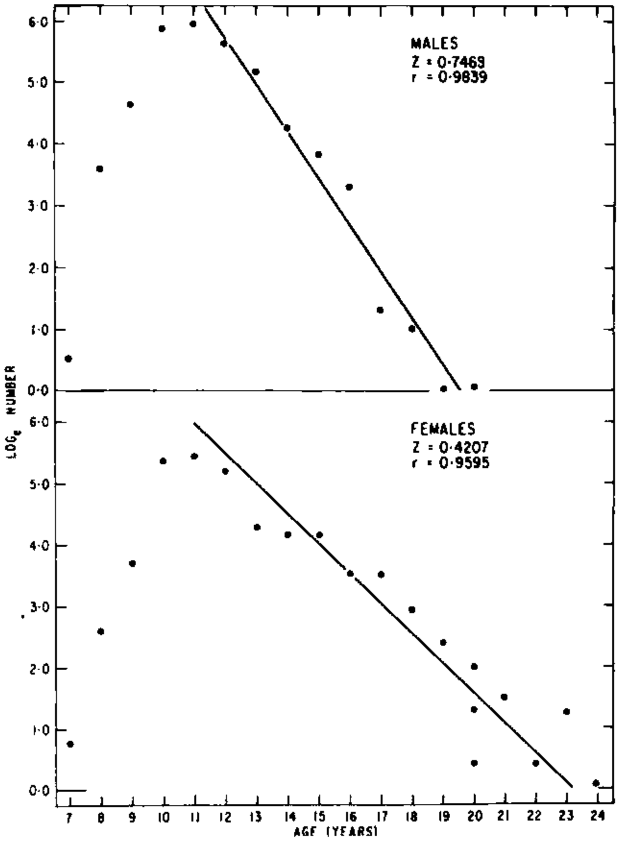

Fig. 3. Catch curves for male and female witch flounder in Canadian commercial trawl catches, Subdiv. 3Ps, 1975.

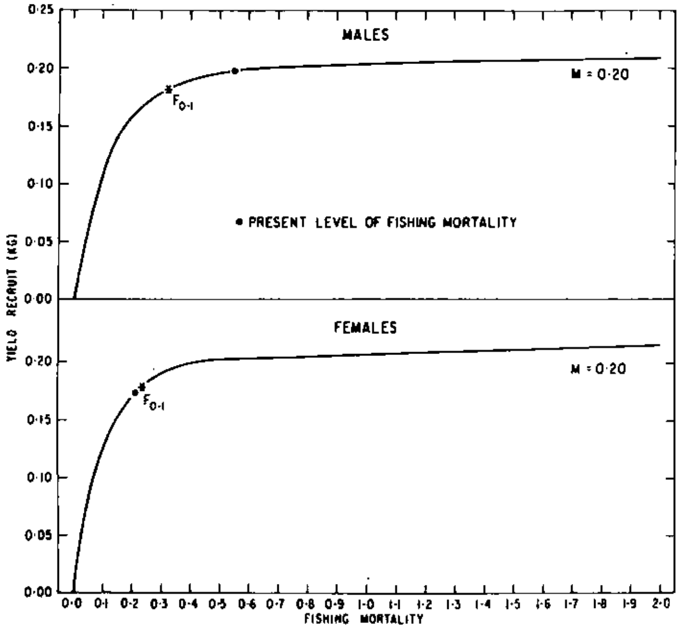

Fig. 4. Yield-per-recruit curves of male and female witch flounder in Subdiv. 3Ps (based largely on 1975 data).

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Assessment of the Pollock Fishery in ICNAF Divisions 4VWX and Subarea 5[1]

by

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ABSTRACT

Pollock catches in ICNAF Divisions 4VWX and Subarea 5 have fluctuated considerably since 1960, apparently in response to changes in abundance and to shifts in directed effort. Catches have increased substantially since 1970. Current evidence indicates that pollock in Div. 4VWX + Subarea 5 should be considered as a discrete stock for assessment purposes. Application of the von Bertalanffy growth equation to length-at-age data obtained on US spring and autumn bottom trawl surveys yielded the following parameter estimates: $L_\infty = 101.6$ cm; $K = 0.2159$, and $t_0 = 0.3782$. Commercial and research vessel survey abundance indices indicate declines in abundance since the mid-1960's, followed by an apparent increase; since 1973, abundance again appears to have declined. Research vessel survey data and cohort analysis also indicate substantial increases in F levels in recent years (to over 0.5 since 1973). Yield-per-recruit studies indicate F_{max} and $F_{0.1}$ values of 0.4 and 0.24 respectively, for a mean selection age of 3.5 years. Catches corresponding to F at the level of F_{max} and $F_{0.1}$ in 1977 would be 30,000 and 19,000 metric tons respectively.

INTRODUCTION

The pollock (*Pollachius virens*) is currently increasing in commercial importance in Subareas 4 and 5 of the ICNAF Convention Area. Historically, this has not been a prime species; amounts landed appear to have been determined chiefly by demand rather than supply although local variations have occurred. Until 1973, pollock catches were totally unregulated, but at the Special Commission Meeting in January of that year a TAC (total allowable catch) of 50,000 tons was approved for Div. 4X and Subarea 5 (ICNAF, 1973a) based on commercial and research vessel survey data. This TAC level was subsequently revised to 55,000 tons for 1974 for Div. 4VWX + Subarea 5 inclusive (ICNAF, 1973b). The 55,000-ton TAC has remained in effect for 1975 and 1976, as continued monitoring of commercial and research vessel survey data have shown no conclusive evidence for declining catch levels.

At the April 1975 Meeting of the Assessments Subcommittee, attention was drawn to the need for a more detailed assessment of this stock. In addition, the Commission's request that separate assessments be provided for pollock in Subareas 4 and 5 has also been noted (ICNAF, 1975). This paper represents an attempt to assess in greater detail the status of pollock in Div. 4VWX + Subarea 5 and also examines available evidence relative to stock boundaries.

The term "catch", when used in conjunction with quantities caught commercially, means "nominal catch" which is defined as the live weight equivalent of the quantities landed.

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[1] Submitted to the 1976 Annual Meeting as Res.Doc. 76/VI/47.

BIOLOGY

Distribution and Life History

Pollock occur on both sides of the North Atlantic in cool temperature and boreal waters. In the Northwest Atlantic, the species ranges from Cape Hatteras to Labrador and West Greenland (Bigelow and Schroeder, 1953); nominal catch data (Table 1) indicate the center of its distribution to lie in Div. 4X, although it is also common in Div. 5Y, Subdiv. 5Ze and Div. 4W. Pronounced declines in abundance occur to the west and east of these areas, and to the east of Div. 4W catches are of little significance commercially (Fleming, 1969). Templeman (1966) noted that stocks in the Newfoundland area were not adequate to sustain a large commercial operation and that in any event supply was subject to fluctuate due to temperature influences on year-class strength.

Table 1. Nominal catches (metric tons) of pollock by division for Div. 4VWX + Subarea 5 and Statistical Area 6, 1960-75.

Year	4Vn	4Vs	4W	4X	Total 4VWX	5Y	5Ze	5Zw	Total 5Z	5NK	Total SA 5	Total SA 6	Grand Total
1960[a]	692	811	8,354	20,132	29,989	6,545	-	-	3,834	18	10,397	-	40,386
1961	811	1,053	13,167	14,321	29,352	5,017	-	-	3,177	25	8,219	-	37,571
1962	554	738	12,045	19,624	32,961	2,560	-	-	3,576	15	6,151	-	39,112
1963	400	274	9,152	20,645	30,471	2,168	-	-	3,947	10	6,125	116	36,712
1964	337	137	12,488	19,283	32,245	1,754	-	-	7,250	-	9,004	4	41,253
1965	147	1,058	13,134	13,390	27,729	1,933	-	-	7,065	-	8,998	2	36,729
1966	226	562	11,040	12,648	24,476	953	-	-	8,846	-	9,799	48	34,323
1967	147	510	5,836	8,290	14,787	1,728	-	-	6,790	-	8,523	2	23,312
1968	256	757	5,954	10,656	17,623	1,416	3,724	82	3,806	-	5,222	4	22,849
1969	91	209	3,938	10,983	15,221	4,635	5,025	162	5,187	-	9,822	-	25,043
1970	130	519	2,952	8,194	11,795	6,281	5,157	123	5,280	-	11,561	-	23,356
1971	214	317	1,802	9,739	12,072	7,016	7,096	142	7,238	-	14,312	891	27,275
1972	102	495	3,419	16,190	20,206	6,419	6,519	51	6,570	-	12,989	24	33,219
1973	170	834	5,871	23,225	30,100	5,202	6,235	1,618	7,853	-	13,055	21	43,176
1974	68	239	4,740	20,362	25,409	6,106	6,233	5	6,238	-	12,370	44	37,802
1975[b]	-	431	3,690	20,203	24,324	5,568	7,718	-	13,286	-	13,286	-	37,610

[a] Catches for 1960-74 from ICNAF Statistical Bulletins, Vol. 10-24.
[b] From ICNAF provisional statistics for 1975.

Excellent reviews of pollock life history are given by Bigelow and Schroeder (1953) and Steele (1963) and the subject will be considered only briefly here. According to the latter author, ripe adults congregate in late autumn and winter in Div. 5Y in the area extending from Massachusetts Bay to the Isles of Shoals (Fig. 1). This is the only known spawning concentration in the Div. 4VWX + Subarea 5 area, although there is some evidence to suggest that spawning also occurs on the Scotian Shelf and off Cape Breton Island. Spawning occurs from November through February and reaches a climax before the winter minimum temperature is reached. Females produce an average of 225,000 pelagic eggs; incubation requires nine days at a temperature of 6°C (Bigelow and Schroeder, 1953).

Larvae are approximately 4 mm long at hatching. After absorption of the yolk sac, juveniles apparently live near the surface for a period of time, moving inshore into sublittoral areas in their first summer of life. After wintering offshore, 1-year-old "harbour pollock" return inshore in large numbers, where they remain until late summer or early autumn (Steele, 1963). Older pollock tend to frequent deeper waters and more definite localities. Steele (1963) has observed a tendency for segregation by size in the Bay of Fundy and in areas to the east and noted that segregation by size into schools is an important feature of pollock behavior. Sexual maturity occurs at 4-7 years of age (50-65 cm) in males; females mature at 5-7 years of age (55-70 cm).

Stock Structure

Primarily from tagging returns, Steele (1963) identified three separate groups of pollock in the Div. 4X + Subarea 5 area during summertime (a Bay of Fundy group, a western Nova Scotia group, and a southern Gulf of Maine group) but noted that the distinctness of

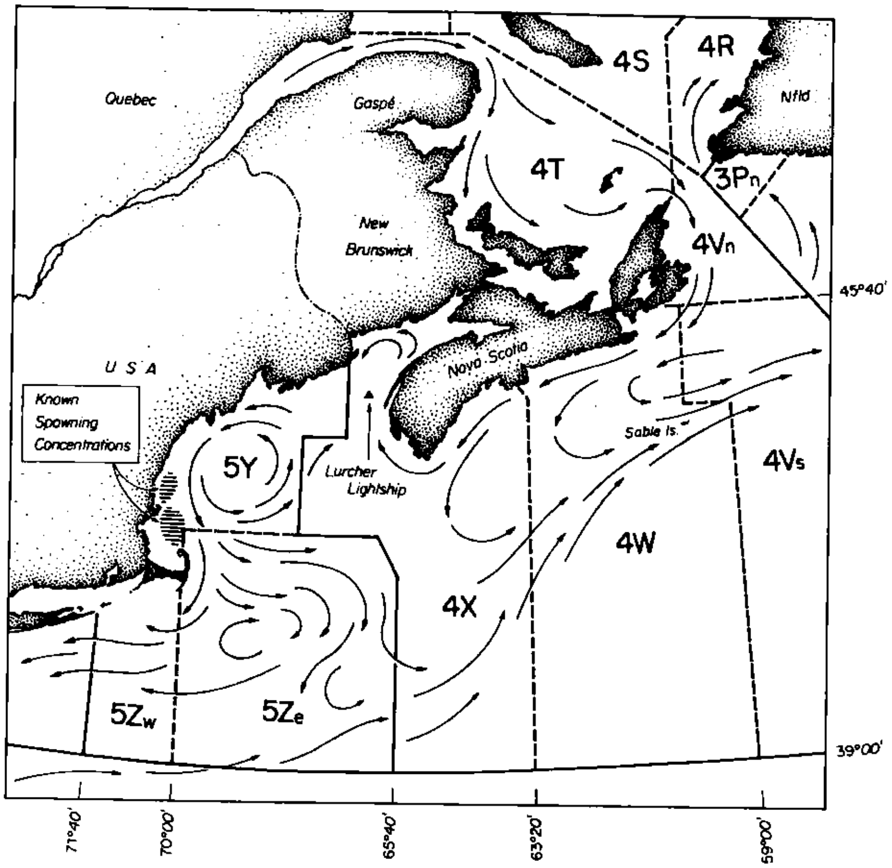

Fig. 1. Known pollock spawning concentration areas and non-tidal surface currents of western Atlantic coastal waters in summertime (after Colton and Temple, 1961; Steele, 1963).

these groups could not be determined. On the basis of distributional studies and tag returns, Kohler (1968) reported three groups of pollock in the region encompassing the Bay of Fundy and the western Nova Scotia banks and considered the Bay of Fundy group to be discrete from the remaining units. Lack of further definitive information prompted the Commission to establish Div. 4X and Subarea 5 as a stock area in January 1973 (ICNAF, 1973a); in June, this area was extended to include Div. 4V and 4W, as it was considered likely that pollock in these areas comprised part of the Div. 4X and Subarea 5 stock (Halliday, MS 1973; ICNAF, 1973b).

Seasonal Migrations

Distributions of catches by month in Div. 4X and 5Y provide information on seasonal movements. Monthly catches for the 1972-74 period for the Canadian fishery in Div. 4X (Fig. 2) increased to a peak during the summer months, followed by a precipitous decline during autumn and winter (Fig. 2A). At the same time, monthly catches for the US Div. 5Y fishery (Fig. 2B) show a reversal of this trend, with peak catches being taken in late autumn and winter. This pattern appears to reflect a southward spawning migration in autumn and winter, and certainly the data of Fig. 2 indicate that this movement may be quite substantial.

Bigelow and Schroeder (1953) mention tagging studies by the former US Bureau of Fisheries in the Gulf of Maine which were inconclusive; many recaptures were taken in the vicinity of the tagging area after relatively long periods of time, although some marked fish were recaptured at considerable distances to the eastward (one as far east as Sable Island, Fig. 1). Steele (1963) tagged 1,000 pollock (60-85 cm) in the Bay of Fundy in July 1960; during 1960-62, tags were recovered from the Bay of Fundy and off southwestern Nova Scotia in summer and early autumn, but in November, December and January, returns also came from the mouth of Massachusetts Bay in Div. 5Y. A limited number of recoveries were also made off southwestern Nova Scotia in spring.

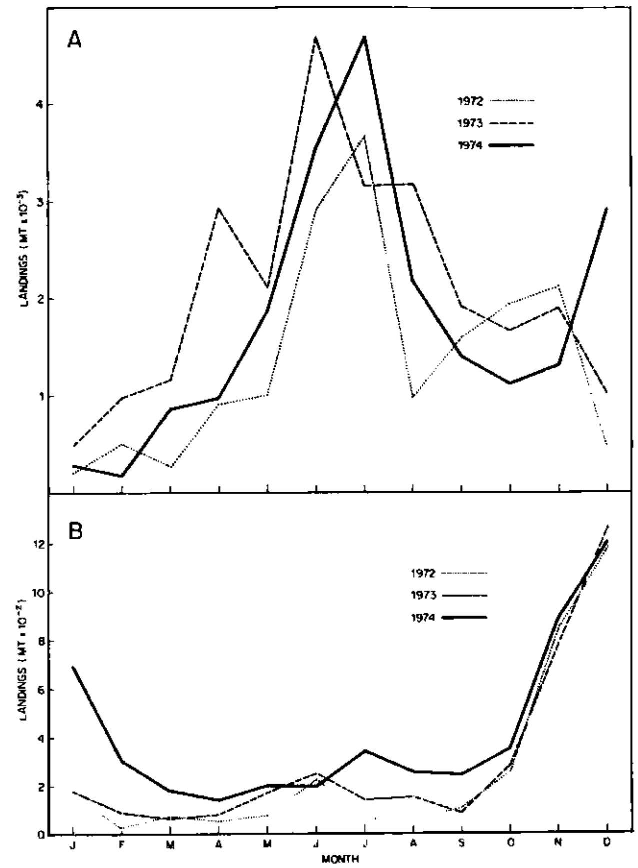

Fig. 2. (A) Canadian nominal catches by month in Div. 4VWX, and (B) US nominal catches in Div. 5Y, 1972-74. (ICNAF Statistical Bulletins, No. 22-24).

On the basis of the above information, Steele concluded that some of the Bay of Fundy population migrate south to spawn in Div. 5Y in autumn and winter and that a similar movement might well occur to the south of western Nova Scotia. There appeared to be little mixing between pollock in the Bay of Fundy, the southern Gulf of Maine, and the Scotian Shelf during summertime.

Distribution of Ripe Adults, Eggs and Larvae

In autumn and winter, ripe adults congregate in large numbers off the mouth of Massachusetts Bay and between Cape Ann and the Isles of Shoals (Bigelow and Schroeder, 1953, Fig. 1). Ripe fish have also been reported in limited numbers along the Maine coast and to the south of Massachusetts Bay, but no evidence was found to indicate that spawning occurs to the west of Cape Cod or within the Bay of Fundy, and accordingly Bigelow and Schroeder concluded that "no production of any importance takes place anywhere in the Gulf of Maine east of Cape Elizabeth". East of the Gulf of Maine, however, Steele (1963) noted the presence of large, mature pollock off Nova Scotia in winter, while nine ripe and ripening pollock were taken off Cape Breton Island in winter of 1961. These observations indicate that at least some spawning occurs east of the Gulf of Maine, although recent attempts to locate ripe fish on the Scotian Shelf by interviewing Canadian fishermen have been unsuccessful. Consequently, it does not appear that major spawning concentrations occur east of the Gulf of Maine.

Distributions of pollock eggs and larvae substantiate the importance of the western Gulf of Maine spawning concentrations and also give some indication of spawning on the Scotian Shelf. Bigelow and Schroeder (1953) found no pollock eggs anywhere north of the Isles of Shoals, nor have larvae been found in the Passamaquoddy region (Bigelow and Schroeder, 1953; Legaré and Maclellan, 1960, *In* Steele, 1963). In January and February, pollock larvae are concentrated in the southern Gulf of Maine and to the south of Cape

Cod; in March-May, larvae become more scattered throughout the Gulf of Maine, with some appearing on the Scotian Shelf (Colton, *In* Steele, 1963). However, Colton and St. Onge (1974) have reported larvae on the Scotian Shelf as early as January, while Steele (1963) reported larvae at the Lurcher Lightship in January 1960 (Fig. 1); thus, spawning on the Scotian Shelf would appear probable. Our knowledge of water circulation patterns in the Gulf of Maine in winter and early spring is incomplete at present, although a counter-clockwise eddy, supplemented by a strong movement southward along Cape Cod, exists for much of the year (Colton and Temple, 1961; Fig. 1). This configuration, and the presence of an opposing counter-current along the eastern Nova Scotia coast (Steele, 1963; Fig. 1) explain the observed winter and spring distribution of larvae within the Gulf of Maine nicely but do not provide a mechanism for transport of larvae to the eastern Nova Scotia area. As small "harbour" pollock are found along the length of the Nova Scotia coast northward to southern Newfoundland (Steele, 1963), it again would appear that at least some spawning occurs to the east of the Gulf of Maine.

Evidence currently suggests, therefore, that one major spawning location exists in the Div. 4VWX + Subarea 5 area, this being in the western Gulf of Maine (Fig. 1). There is evidence of additional spawning to the eastward, although information is scanty at present and in any event is not adequate to provide a basis for stock delineation. Accordingly, it is proposed to retain the present boundaries as suggested by Halliday (MS 1973), recognizing that this area may be further subdivided when more information becomes available.

Growth

Pollock growth is rapid in the first years of life, declining with the onset of sexual

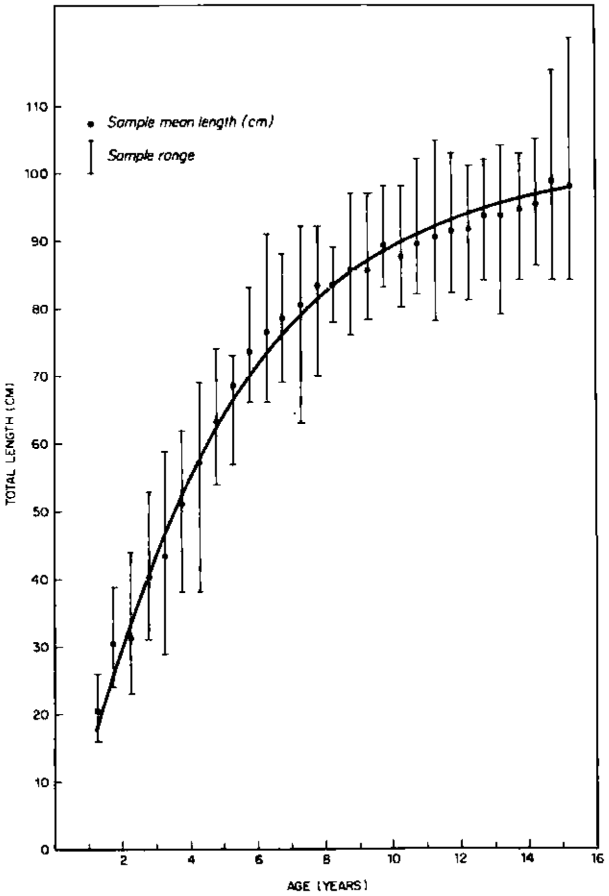

Fig. 3. Von Bertalanffy growth curve for Div. 4X and Subarea 5 pollock, fitted to length-at-age data collected on *Albatross IV* spring and autumn bottom trawl surveys, 1970-75.

maturity (Steele, 1963). Bigelow and Schroeder (1953) report the following length-at-age data: I, 13-18 cm; II, 30-33 cm; III, 43-46 cm; IV, 53-56 cm; V, 61 cm; and VI, 66 cm. These data indicate a slightly higher size at age than that reported by Hoberman and Jensen (1962) for the Gulf of Maine and by Steele (1963) for the Bay of Fundy and the Scotian Shelf.

A sample of 2,227 otoliths collected on *Albatross IV* spring and autumn bottom trawl survey cruises in the Div. 4X-Subarea 5 area from 1970 to 1975 was used to evaluate growth rates. The relation $y = -0.2909 + 1.0441x$ determined from *Albatross IV* survey data (where x = fork length in cm) was used to convert fork length to total length, and ages were coded at half-year intervals assuming a January birth date (e.g. a pollock hatched in January was assumed to be 0.75 years old in autumn of that year and 1.25 years old during the following spring). The von Bertalanffy growth equation was then fitted to the length-at-age data using the method of Tomlinson and Abramson (1961). The results (Table 2, Fig. 3) agree closely with data reported by Bigelow and Schroeder but again indicate a higher average size at age than observed by Hoberman and Jensen (1962) and Steele (1963).

Table 2. Length-at-age data for pollock caught in *Albatross IV* spring and autumn bottom trawl surveys in Div. 4VWX + Subarea 5, 1970-75, with fitted lengths and parameter estimates obtained by fitting the von Bertalanffy growth equation.

Age	Sample size	Sample mean length (cm)	Standard error of sample mean	Fitted length[a] (cm)
0.75	-	-	-	12.77
1.25	79	20.34	0.234	17.44
1.75	126	30.68	0.272	26.06
2.25	274	31.58	0.265	33.79
2.75	220	40.45	0.272	40.73
3.25	210	43.69	0.374	46.96
3.75	153	51.10	0.374	52.56
4.25	149	57.10	0.490	57.58
4.75	118	63.14	0.403	62.09
5.25	80	68.63	0.531	66.13
5.75	69	73.71	0.434	69.76
6.25	73	76.18	0.493	73.02
6.75	70	78.69	0.437	75.95
7.25	46	80.26	0.679	78.58
7.75	52	83.17	0.713	80.94
8.25	60	83.02	0.374	83.05
8.75	37	85.70	0.693	84.95
9.25	34	85.76	0.753	86.66
9.75	18	89.50	1.235	88.19
10.25	48	87.35	0.520	89.56
10.75	27	89.81	0.818	90.80
11.25	50	90.36	0.666	91.90
11.75	15	91.27	1.462	92.90
12.25	24	91.58	1.023	93.79
12.75	10	93.80	1.604	94.59
13.25	30	93.87	0.940	95.31
13.75	14	94.14	1.321	95.96
14.25	44	95.02	0.785	96.54
14.75	12	98.92	1.505	97.06
15.25+	85	97.68	0.870	97.52

	L_∞	K	t_0
Estimated parameters	101.62	0.2159	0.3782
Standard errors	0.49	0.0033	0.0262

[a] Total length.

COMMERCIAL LANDINGS

Coastal States

Historical catch data for the US and Canadian pollock fisheries in Div. 4VWX + Subarea

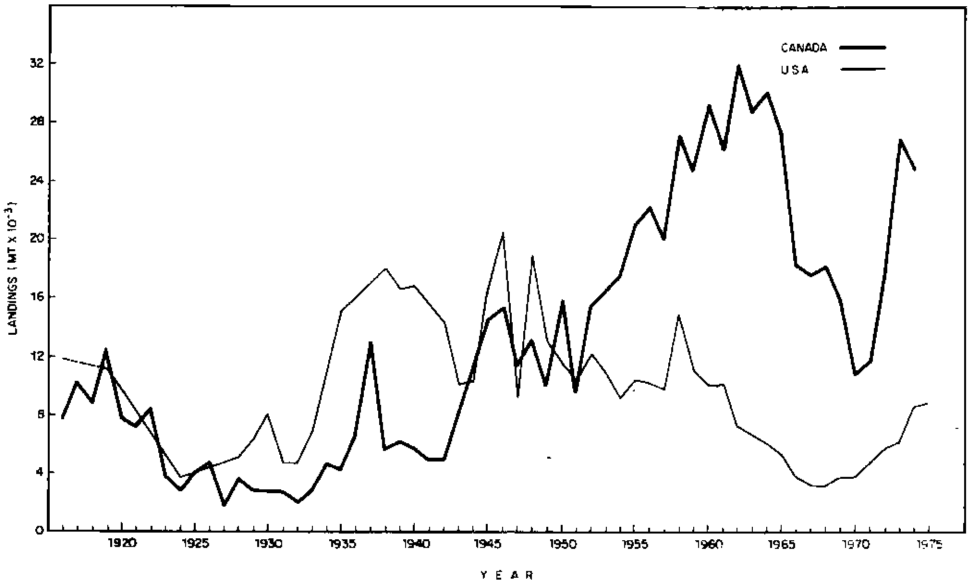

Fig. 4. Canadian and US landings from Div. 4VWX + Subarea 5, 1920-75. (Canadian landings prior to 1960 were approximated by using New Brunswick and Nova Scotia landings, converted to round fresh weight, as given in <u>Fisheries Statistics of Canada</u>; US figures prior to 1960 were obtained from the <u>Statistical Digest</u> for 1965).

5 are given in Fig. 4, and summaries by nation and area for 1960-1975 are given in Tables 1 and 3. These data reveal that until the present time the fishery has been dominated by Canada and USA, although other nations, notably German Democratic Republic (GDR) and USSR have on occasion made significant catches. With the exception of the Jeffreys Ledge winter fishery in Div. 5Y, the US fishery has been chiefly incidental in nature; in Canada, however, more effort appears to have been directed towards this species, particularly since 1950 (Fig. 4). The data of Fig. 4 reveal a sharp increase in US catches between 1930 and 1935, followed by a period of fluctuation between 10,000 and 30,000 tons from 1935 to 1960. This pattern probably reflects expansion and technological improvement in the US trawl fleet in the early 1930's, followed by relatively stabilized fishing (Hennemuth, MS 1969). In contrast, Canadian catches show a more gradual increase up until the mid-1940's and a brief period of relative stability between 1945 and 1952, followed by a continued increase until 1962. Declines and subsequent upswings which have occurred in both fisheries since the early 1960's (Fig. 4, Table 3) are thought to relate to changes in abundance (Halliday, MS 1973) although changing availability of primary species such as cod and haddock and consequent transfer of fishing effort may also have been involved. Historically, the bulk of the US catch has been taken in Subarea 5 and Statistical Area 6 (Table 3) and landed in Maine and Massachusetts ports; small quantities have also been landed in the remaining New England coastal states and in New York and New Jersey. Most of the Canadian catch, however, has been taken in Div. 4VWX (Table 3) and landed at Nova Scotia ports.

<u>Distant-Water Fleets</u>

Pollock catches by distant-water fleets appear to have been of relatively minor significance, although landings by other nations did range from 20 to 39% of the total from 1969 to 1971. The relative percentage of the total catch landed by foreign vessels increased continually from less than 1% in the early 1960's to approximately 39% in 1971, when the GDR catch reached a maximum level; since that time relative percentages have declined sharply (to 11% in 1974). Spain appears to have caught minor quantities of pollock from Div. 4VWX prior to 1960, although exact figures are not available. The Federal Republic of Germany (FRG), UK and USSR began fishing for pollock in this area in 1963, while GDR and Japan began taking pollock in 1967 and 1970 respectively (Table 3). With the possible exception of GDR and USSR, all of these fisheries appear to have been incidental in nature, and, in any event, GDR and USSR catches both dropped sharply following periods of relatively intense exploitation. Denmark, France, Italy, Iceland and Poland have also taken minor quantities on occasion. The data of Table 3 reveal that Spanish and Japanese effort was concentrated primarily in Div. 4VWX, while FRG and GDR effort was concentrated primarily in Subarea 5 and Statistical Area 6. USSR effort appears to have been divided rather equally between these areas.

Table 3. Nominal catches (metric tons) of pollock by country from Div. 4VWX, Subarea 5 + Statistical Area 6, and both areas combined, 1960-75.

Area	Year	Canada	FRG	GDR	Japan	Spain	USSR	UK	USA	Other[b]	Total
4VWX	1960[a]	27,259	-	-	-	783	-	-	1,946	1	29,989
	1961	25,965	-	-	-	982	-	-	2,404	1	29,352
	1962	31,120	-	-	-	-	-	-	1,841	-	32,961
	1963	28,046	126	-	-	-	291	28	1,980	-	30,471
	1964	28,065	208	-	-	-	2,631	48	1,238	55	32,245
	1965	25,272	71	-	-	1,361	627	11	387	-	27,729
	1966	14,259	-	-	-	2,339	7,254	4	620	-	24,476
	1967	12,280	-	4	-	1,675	299	1	528	-	14,787
	1968	16,322	-	-	-	770	231	-	295	5	17,623
	1969	13,525	16	-	-	1,175	62	-	436	7	15,221
	1970	9,900	77	393	39	526	476	-	384	-	11,795
	1971	10,121	-	-	10	728	1,053	-	158	2	12,072
	1972	16,656	8	14	4	536	2,452	4	486	46	20,206
	1973	25,263	39	-	1,556	2,314	340	-	572	16	30,100
	1974	21,436	118	-	40	836	2,301	1	676	1	25,409
	1975[c]	21,820	-	-	-	-	1,762	-	742	-	24,324
5+6	1960[a]	2,211	-	-	-	-	-	-	8,186	-	10,397
	1961	358	-	-	-	-	-	-	7,861	-	8,219
	1962	601	-	-	-	-	-	-	5,550	-	6,151
	1963	953	-	-	-	-	615	-	4,673	-	6,241
	1964	1,942	-	-	-	-	1,972	326	4,768	-	9,008
	1965	2,044	-	-	-	-	2,040	-	4,916	-	9,000
	1966	4,012	-	-	-	45	2,611	8	3,171	-	9,847
	1967	5,287	-	5	-	104	345	-	2,784	-	8,525
	1968	1,740	-	-	-	358	141	-	2,985	2	5,226
	1969	2,443	1,172	2,195	-	340	165	-	3,507	-	9,822
	1970	853	3,156	3,902	1	6	51	-	3,592	-	11,561
	1971	1,636	633	6,849	5	184	1,163	-	4,732	1	15,203
	1972	1,366	467	4,802	4	80	1,043	-	5,243	8	13,013
	1973	1,727	1,085	948	14	799	2,752	-	5,731	20	13,076
	1974	3,539	31	2	-	664	47	47	8,050	13	12,393
	1975[c]	4,692	-	96	1	-	288	-	8,192	17	13,286
Total	1960[a]	29,470	-	-	-	783	-	-	10,132	1	40,386
	1961	26,323	-	-	-	982	-	-	10,265	1	37,571
	1962	31,721	-	-	-	-	-	-	7,391	-	39,112
	1963	28,999	126	-	-	-	906	28	6,653	-	36,712
	1964	30,007	208	-	-	-	4,603	374	6,006	55	41,253
	1965	27,316	71	-	-	1,361	2,667	11	5,303	-	36,729
	1966	18,271	-	-	-	2,384	9,865	12	3,791	-	34,323
	1967	17,567	-	9	-	1,779	644	1	3,312	-	23,312
	1968	18,062	-	-	-	1,128	372	-	3,280	7	22,849
	1969	15,968	1,188	2,195	-	1,515	227	-	3,943	7	25,043
	1970	10,753	3,233	4,295	40	532	527	-	3,976	-	23,356
	1971	11,757	633	6,849	15	912	2,216	-	4,890	3	27,275
	1972	18,022	475	4,816	8	616	3,495	4	5,729	54	33,219
	1973	26,990	1,124	948	1,570	3,113	3,092	-	6,303	36	43,176
	1974	24,975	149	2	40	1,500	2,348	48	8,726	14	37,802
	1975[c]	26,512	-	96	1	-	2,050	-	8,934	17	37,610

[a] Catches for 1960-74 from ICNAF Statistical Bulletins, Vol. 10-24.

[b] Includes Cuba, Denmark, France, Italy, Iceland and Poland.

[c] From ICNAF provisional statistics for 1975.

Age Composition

Length-frequency sampling of the pollock catches in Div. 4VWX + Subarea 5 has been very limited. Samples have been collected since 1961, but from 1961 to 1973 seasonal coverage was incomplete. Canadian and US sampling during 1973-75 approximated one sample per 1,000 tons landed. There has been no sampling of pollock catches by other nations since 1972.

The age composition of the US commercial catch for 1973-75 was determined by applying Canadian age-length keys for the same period (obtained from commercial sampling of catches from the Div. 4X-Subarea 5 area) to US commercial length-frequency samples on a quarterly basis. Resulting sample numbers at age were divided by the total number sampled to provide percentage distributions at age. Mean length at age was calculated and converted to mean weight at age using the relation

$$W = 0.000010151L^{3.028}$$

where L = fork length (cm), as determined from sample data collected in *Albatross IV* groundfish surveys. The resulting values were multiplied by the corresponding sample percent-at-age distributions and divided by the cumulative sum over all ages to provide quarterly percentage distributions in weight by age, which were applied to commercial catches by quarter to provide the weight distribution at age of the total catch. These values were then divided by the corresponding mean weight at age figures to obtain actual numbers landed. Similar figures were computed for the Canadian fishery. Percentage age compositions of Canadian and US commercial catches (numbers) are given in Table 4.

Table 4. Percentage age composition of Canadian and US pollock landings for Div. 4VWX + Subarea 5 by quarter, 1973-75.

Year and quarter	Age (years)										
	2	3	4	5	6	7	8	9	10	11	12+
					Canada						
1973-1st	-	-	35.1	43.1	8.8	3.2	3.7	2.7	2.0	0.7	0.7
2nd	-	5.8	29.8	34.6	6.4	6.9	2.2	5.7	7.2	1.4	-
3rd	1.4	9.0	31.9	30.0	9.8	8.7	1.7	4.1	2.6	0.5	0.4
4th	3.5	15.4	47.6	23.3	4.7	2.2	1.7	1.0	0.6	-	-
1974-1st	-	-	4.8	56.1	22.6	4.9	6.4	-	3.1	1.1	1.1
2nd	-	10.7	20.3	36.7	19.7	5.8	3.0	1.5	1.6	0.7	0.1
3rd	4.1	48.5	22.9	16.8	4.3	1.5	1.0	0.4	0.1	0.3	0.1
4th	1.9	57.7	13.4	14.9	8.0	2.4	0.9	0.2	0.3	-	0.1
1975-1st	-	2.9	52.2	27.1	15.6	1.8	-	0.2	0.2	-	0.2
2nd	0.5	12.8	40.8	16.8	19.4	7.4	1.2	0.4	0.3	0.3	0.2
3rd	0.6	23.5	60.0	8.8	5.0	1.7	-	-	0.4	-	0.1
4th	4.5	22.5	42.5	11.9	12.0	3.4	1.5	0.5	0.4	0.5	0.4
					USA						
1973-1st	2.6	78.2	19.0	0.3	-	-	-	-	-	-	-
2nd	-	19.0	49.5	31.6	-	-	-	-	-	-	-
3rd	8.0	25.4	52.1	9.9	2.4	2.4	-	-	-	-	-
4th	47.8	5.9	7.3	12.2	11.7	5.9	4.4	4.4	0.5	-	-
1974-1st	10.9	7.6	37.2	41.4	2.9	-	-	-	-	-	-
2nd	-	78.6	20.8	0.6	-	-	-	-	-	-	-
3rd	17.8	75.3	6.9	-	-	-	-	-	-	-	-
4th	-	4.7	11.0	21.4	18.7	8.9	13.3	14.4	6.1	0.5	1.2
1975-1st	19.6	75.8	4.6	-	-	-	-	-	-	-	-
2nd	-	34.2	63.8	2.0	-	-	-	-	-	-	-
3rd[a]	4.9	21.7	32.8	3.3	7.2	13.4	2.2	2.8	8.3	3.3	-

[a] No samples for fourth quarter.

To obtain estimated total numbers landed for the entire stock by year, estimates of numbers landed at age were required for other nations. As length-frequency data for catches by distant-water fleets were unavailable, this information was obtained by prorating total catches (tons) for other nations according to summarized distributions of weight at age for the Canadian and US fisheries and dividing the resulting values by mean weight at age in Canadian catches to give estimates of numbers landed at age. These values were combined with Canadian and US figures to provide estimates of total numbers landed at age for Div. 4VWX and Subarea 5 (Table 5). It is recognized that this method is based on the assumption that the age distribution of the catch by foreign vessels is similar to that of the coastal states, a premise which may be violated in that coastal states take higher proportions of their total catch inshore.

Table 5. Numbers of pollock (000's) landed by age group from Div. 4VWX + Subarea 5, 1973-75.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11	12+
					Canada						
1973	116	771	3,180	2,800	648	523	185	330	321	63	22
1974	240	4,210	1,903	2,227	975	284	166	61	61	35	14
1975	213	2,119	5,218	1,342	1,208	388	87	31	38	26	26
					USA						
1973	645	1,072	745	345	153	82	54	54	6	-	-
1974	401	2,304	778	528	146	57	85	92	39	3	8
1975	564	2,595	1,280	69	103	190	32	40	119	47	-
					Others						
1973	173	411	1,114	919	237	176	69	110	93	18	6
1974	56	745	319	339	138	42	30	19	12	5	3
1975	27	227	402	87	82	37	7	4	9	4	2
					Total						
1973	934	2,254	5,039	4,064	1,038	781	308	494	420	81	28
1974	697	7,259	3,000	3,094	1,259	383	281	172	112	43	17
1975	804	4,941	6,900	1,498	1,393	615	126	75	166	77	28

Data given in Table 4 are consistent in revealing the presence of three relatively strong year-classes. In Canadian catches, the 1968 year-class was a relatively strong one throughout 1973 and the first two quarters of 1974, while the 1969 year-class was consistently strong during both years (Table 4). Together, these year-classes dominated Canadian catches in 1973 (67%) and were again a strong element (31%) in 1974 (Table 5). In addition, the 1971 year-class shows up very strongly in the last two quarters of 1974 and predominated in 1975 (Table 4), indicating that it is a year-class of above average size.

US catches show a similar pattern although relative percentages are less consistent (Table 4). The 1968 and 1969 year-classes are again relatively strong ones and together comprise an important element (35%) of the 1973 total (Table 5). In 1974, however, the corresponding figure dropped to 15%. The 1971 year-class dominated US catches in 1974 (Table 5). It will be noted, however, that, in comparison to the relative percentages computed for Canadian data, values are considerably more variable between quarters for these year-classes (Table 4).

One additional feature of the Canadian and US age composition data in Table 4 is worthy of comment. For the most part, Canadian age distributions appear to be relatively stable between quarters, while striking seasonal differences are apparent for US data; catches in the first and second quarters are composed exclusively of younger age groups, while older fish show pronounced increases in abundance during the latter part of the year. This trend is evidently a consequence of autumn and winter spawning movements into Div. 5Y.

INDICES OF RELATIVE ABUNDANCE

Research Vessel Survey Catches

Due to the relatively large stock area involved, trends for separate divisions were examined in addition to trends for the area as a whole. Stratified mean catch-per-tow values in number and weight (kg) were calculated for *Albatross IV* spring (1968-75) and autumn (1963-75) bottom trawl surveys for Div. 5Y (Gulf of Maine, strata 24, 26-30 and 36-40) and areas corresponding approximately to Div. 4X (Gulf of Maine-Scotian Shelf, strata 31-35, 41, and 42), and Subdiv. 5Ze (Georges Bank, strata 13-23 and 25) (Fig. 5). Values were also calculated for strata 13-42 as a unit. Strata to the west of Subdiv. 5Ze were not considered as *Albatross IV* survey catches have been negligible in that area during 1963-1975. The results are given in Table 6 and Fig. 6.

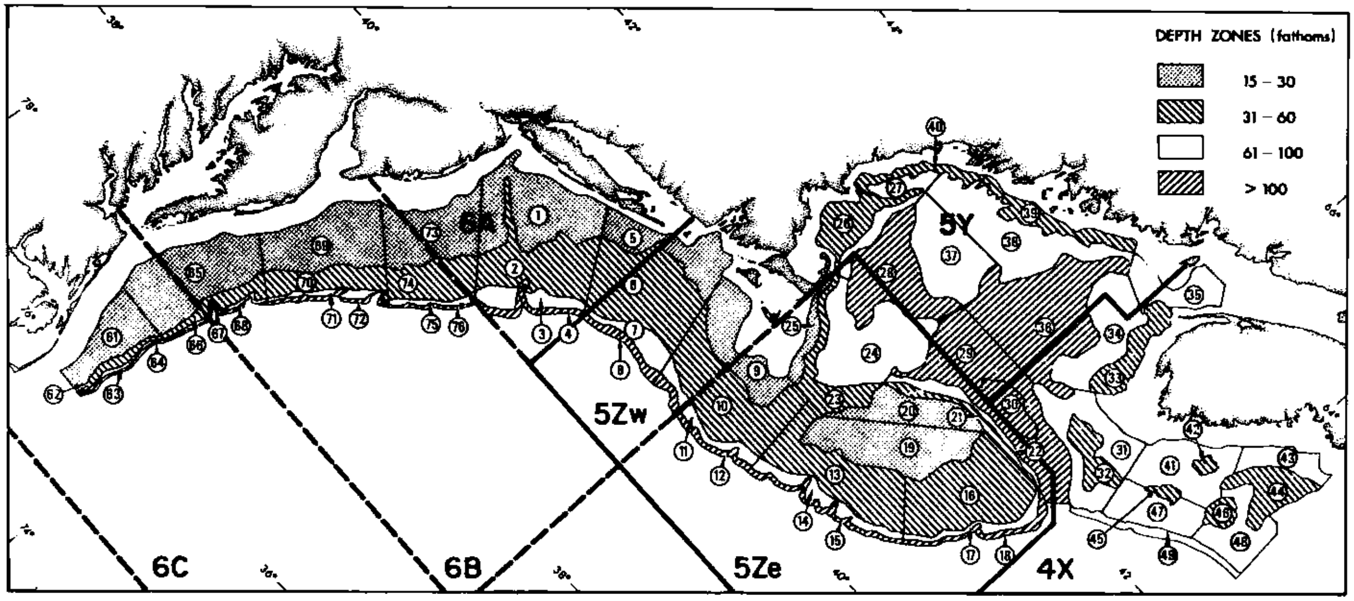

Fig. 5. Strata used in *Albatross IV* spring and autumn bottom trawl surveys with ICNAF division and subdivision boundaries superimposed.

The autumn survey data of Table 6 and Fig. 6 are remarkably consistent for Div. 5Y and 4X and further indicate a close relationship between these areas; data for Subdiv. 5Ze do not agree as well with the combined average, although they would appear to exhibit the same general trends. The combined average for all areas declined from 5.79 kg/tow in 1963 to 1.63 kg/tow in 1967, after which values increased to 4.76 kg/tow in 1972. The

Table 6. Stratified mean catch per tow of pollock in numbers and weight (kg) taken in US spring and autumn bottom trawl surveys in Div. 4X and 5Y and Subdiv. 5Ze, 1963-75.

	Div. 4X		Div. 5Y		Subdiv. 5Ze		All areas combined	
	(Strata 31-35, 41 & 42)		(Strata 24, 26-30, 36-40)		(Strata 13-23 & 25)		(Strata 13-42)	
Year	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)
				Autumn				
1963	1.9	6.23	2.1	8.61	0.3	1.08	1.5	5.79
1964	0.2	0.24	2.7	7.07	0.7	2.15	1.6	4.40
1965	0.5	1.69	1.1	3.70	0.3	1.13	0.8	2.46
1966	0.2	0.93	0.7	2.31	1.8	3.02	0.9	2.18
1967	0.3	0.33	0.7	2.76	0.3	0.92	0.5	1.63
1968	0.5	1.43	1.1	5.22	0.1	0.47	0.7	2.92
1969	3.7	22.11	2.3	12.27	0.2	0.35	2.0	11.22
1970	0.7	3.27	0.8	3.37	0.2	0.20	0.6	2.43
1971	1.1	2.47	0.9	5.63	1.0	1.34	1.0	3.62
1972	4.3	4.21	2.1	7.67	0.7	0.55	2.2	4.76
1973	3.4	6.27	1.4	6.05	0.3	0.45	1.6	4.48
1974	0.6	2.56	1.6	5.52	0.1	0.21	0.9	3.26
1975	0.5	1.41	1.1	3.34	0.1	0.14	0.7	1.94
				Spring[a]				
1968	0.6	2.66	1.7	6.59	0.3	1.70	1.0	4.21
1969	4.2	14.57	1.3	3.25	0.4	1.28	1.7	5.44
1970	3.8	3.40	1.7	7.22	0.6	1.22	1.9	4.55
1971	3.0	7.10	1.1	4.36	0.5	1.16	1.4	4.11
1972	5.7	6.52	2.3	5.65	5.7	3.41	4.1	5.22
1973	6.3	(4.36)	2.5	(2.97)	7.9	(3.85)	5.0	(3.56)
1974	4.6	(10.58)	1.0	(2.81)	1.9	(2.15)	2.1	(4.51)
1975	3.5	(6.79)	1.2	(3.87)	1.7	(3.06)	1.7	(3.93)

[a] Values in parentheses obtained by applying a 1.5 to 1 conversion ratio for the 41 Yankee trawl.

peak values observed in 1969 appear to reflect an unusual influx of large individuals into the survey area rather than recruitment during that year (Table 6). However, the gradual increase observed during 1971-72 does appear to reflect recruitment of the relatively strong 1968 and 1969 year-classes (which also appear in commercial catches, Table 4) as individual weight in the survey data appears to have declined sharply (Table 6). The continued decline observed since 1972 (to 1.94 kg/tow in 1975) is a possible indication of declining stock abundance and would also suggest that the 1971 year-class may not be as strong as anticipated from commercial data (Table 4).

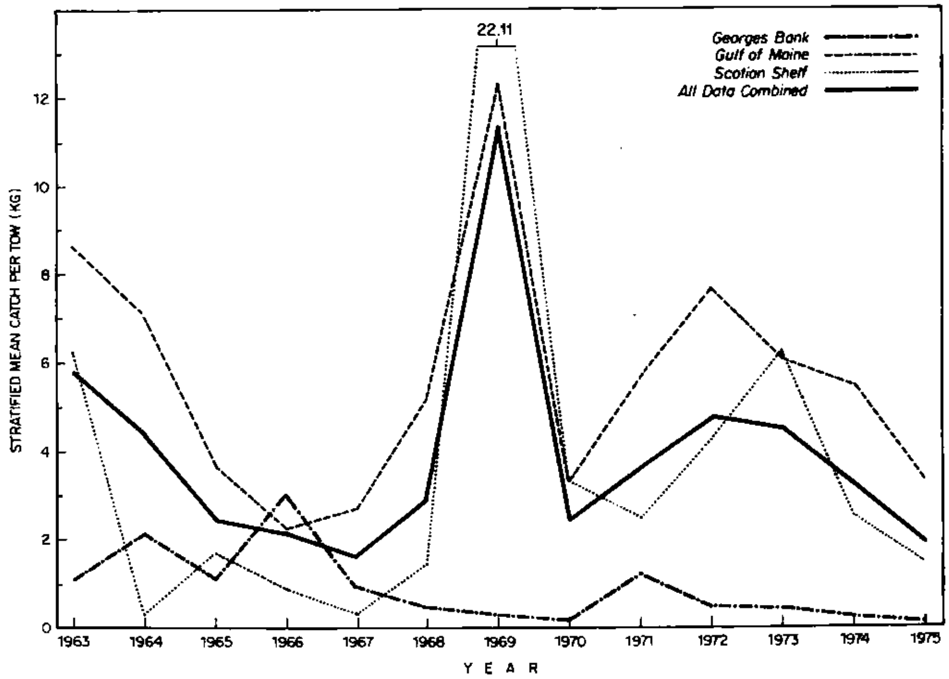

Fig. 6. *Albatross IV* autumn bottom trawl survey abundance indices (stratified mean catch per tow, kg) for Div. 4X (Scotian Shelf), Div. 5Y (Gulf of Maine) and Subdiv. 5Ze (Georges Bank), 1963-75.

The data from spring surveys exhibit the same general trends (Table 6), although trends since 1972 are less clear in that a high-opening trawl (i.e. the 41 Yankee) was used instead of the 36 Yankee used throughout the autumn survey program. As a satisfactory conversion factor has not been obtained for pollock from previous gear-comparison studies, a 1.5 to 1 conversion factor was assumed on the basis of differences in surface area alone and indices were recalculated (Table 6). Again, values decline as for the autumn survey. It is probable that the actual conversion ratio is much higher and that the declines are more pronounced.

Canadian summer survey data for Div. 4VWX during 1970-75 (Table 7) reveal considerable

Table 7. Estimates of population numbers and weight of pollock from Canadian summer bottom trawl surveys in Div. 4VWX, 1970-75.

Year	Number (000's)	Weight (tons)
1970	16,117	29,830
1971	8,133	9,500
1972	11,203	28,080
1973	12,732	28,770
1974	11,493	36,500
1975	5,934	21,490

fluctuation in estimated population numbers and weight with a decline occurring between 1974 and 1975. One of the limitations of the present study lies in the fact that each survey covers only a portion of the stock area and thus results are only generally comparable, but it would appear that, since there is considerable evidence for movement of the adult spawning stock into the western Gulf of Maine during cooler months, trends in US data (taken in autumn and spring) may be more meaningful.

Commercial Indices

Commercial abundance indices for Div. 4VWX (kg/hr fished) have been calculated for Canadian otter trawlers of 151-500 GRT for the period 1965-74 (Table 8). Similar abundance indices have been calculated for US otter trawlers in 1964-75 using catch-effort data for all trips in which pollock constituted 10% or more of the total catch. Both sets of data are plotted in Fig. 7.

Table 8. Commercial abundance indices (kg/hr fished) for Div. 4VWX pollock by Canadian side otter trawlers of 151-500 GRT, 1965-75.

Year	4Vn	4Vs	4W	4X	4VWX
1965	1.6	17.6	260.7	160.1	153.3
1966	0.6	5.3	174.2	86.3	93.3
1967	1.9	7.8	119.6	63.2	66.6
1968	0.1	8.8	93.6	70.8	60.5
1969	0.5	3.2	65.2	73.3	50.4
1970	0.4	2.0	45.8	88.6	49.1
1971	5.2	5.2	22.9	97.3	45.5
1972	0.3	94.0	111.3	233.3	145.3
1973	1.2	20.4	138.6	298.1	162.9
1974	0.6	51.5	309.2	379.9	258.8
1975	2.4	39.7	173.6	228.0	153.2

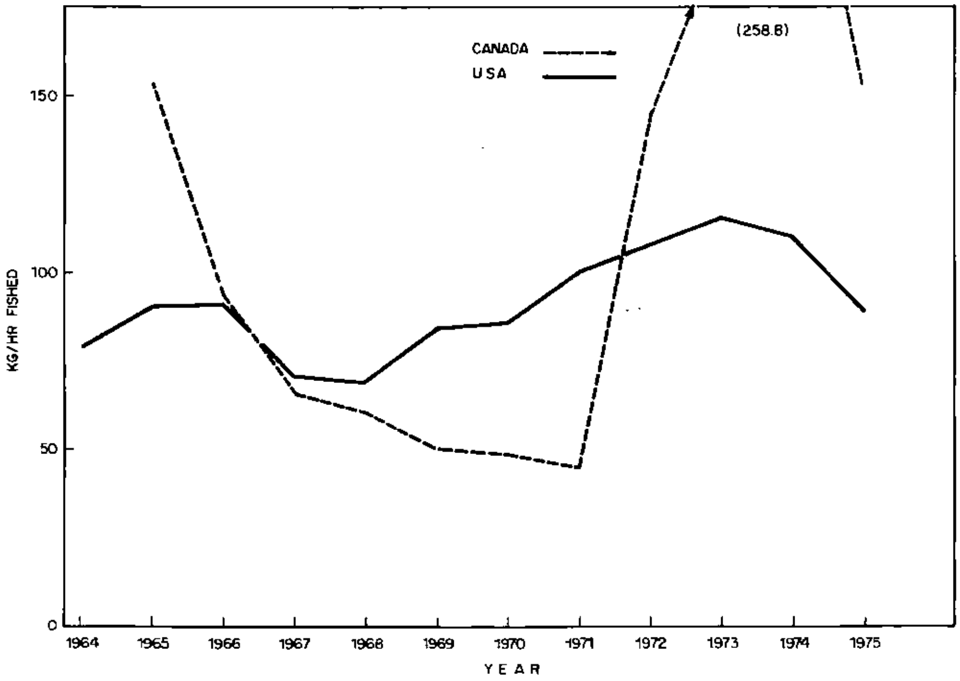

Fig. 7. Canadian and US commercial abundance indices (kg/hr fished) for pollock in Div. 4VWX + Subarea 5, 1964-75. (Canadian indices were computed from catches of otter trawlers of 151-500 GRT; US indices were computed from catches of all otter trawlers landing pollock in amounts equal to or greater than 10% of the total per trip.)

Canadian indices for Div. 4VWX as a unit drop very sharply from 153.3 kg/hr fished in 1965 to 66.6 kg/hr fished in 1967, followed by a more gradual decline to 45.5 kg/hr fished in 1971. Values rose to a high of 258.8 kg/hr fished in 1974 and declined to 153.2 kg/hr in 1975 (Fig. 7, Table 8). As noted by Halliday (MS 1973), substantial changes have occurred in relative abundance of primary species such as cod and haddock in this area in recent years, and this could have affected observed trends considerably; in particular, the shifts in directed effort associated with declining abundance of haddock in the Div. 4X + Subarea 5 area in the mid-1960's and subsequent quota management since 1971 could have led to an increase in the directed fishery for pollock and a subsequent rise in catch rates. However, the consistency of the observed trends does suggest declining stock abundance since the mid-1960's, followed by a subsequent improvement in the early 1970's as noted by Halliday (MS 1973). Also, the increased Canadian catch of pollock in 1975 (Table 3), in spite of sharply declining catch rates (Table 8), suggests that this decline is not a reflection of shifts in directed effort but rather constitutes evidence of declining abundance.

In contrast to Canadian data, US abundance indices are relatively stable up to 1970, increasing to a high of 115.6 kg/hr fished in 1973. Since 1973, values have declined (Fig. 7). Again, the US indices are subject to bias associated with shifts in directed effort as are the Canadian figures, although this factor is probably not as significant due to the more incidental nature of the US fishery. Consequently, the decline observed in recent years again indicates declining stock abundance. In this connection it is worthwhile noting that trends in US commercial abundance indices are in close agreement with trends observed in US research vessel surveys.

YIELD PER RECRUIT

Hylen (1969) estimated a selection factor for pollock of 3.79, which provides a 50% selection length (ℓ_c) of approximately 49 cm for a mesh size of 130 mm. Thus, from the data of Table 2, the mean selection age (t_c) is seen to approximate 3.5 years. In addition,

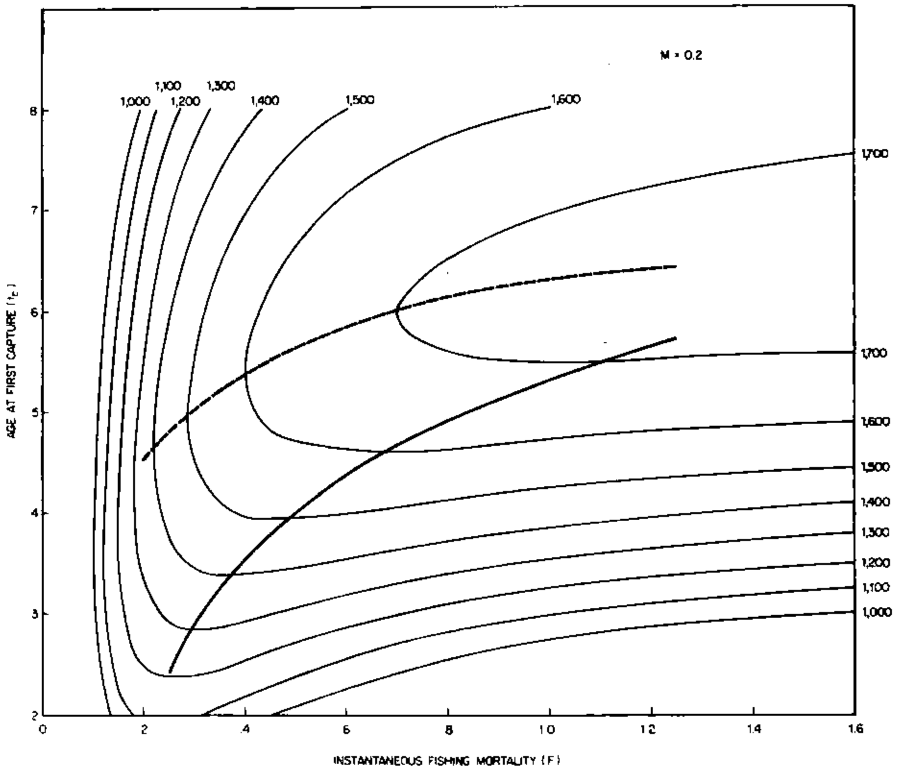

Fig. 8. Yield isopleth diagram for pollock in Div. 4VWX + Subarea 5, assuming W_∞ = 10.9 kg, K = 0.216, t_o = 0.378, t_r = 2.0, t_λ = 16.0, and M = 0.2. (The heavy solid line indicates the F_{max} at a given t_c, while the dashed line indicates the t_c giving the greatest yield per recruit at a given F.)

Canadian and US commercial data indicate recruitment to be essentially completed at age 4. Recent European assessments (ICES, MS 1975) have considered M = 0.2 for pollock in the North Sea.

Using the Beverton-Holt (1957) model, yield-per-recruit values were calculated for Div. 4VWX + Subarea 5 pollock, assuming t_r = 2.0, t_λ = 16.0, and M = 0.2 and using the parameter estimates for L_∞, K, and t_o calculated above (L_∞ = 102 cm, providing a W_∞ of 10.9 kg; K = 0.216, and t_o = 0.378). The resulting yield isopleth diagram (assuming t_c varying between 2 and 8 years, and F varying between 0.1 and 1.8) is given in Fig. 8. Yield-per-recruit curves for t_c values of 3.0, 3.5, and 4.0 are given in Fig. 9. Values of F giving maximum yield per recruit (F_{max}) are 0.33, 0.40, and 0.48, respectively, while the corresponding values of $F_{0.1}$ are 0.21, 0.24, and 0.28. Maximum yield per recruit increases 14% by increasing t_c from 3.0 to 4.0 years and increasing F from 0.30 to 0.50.

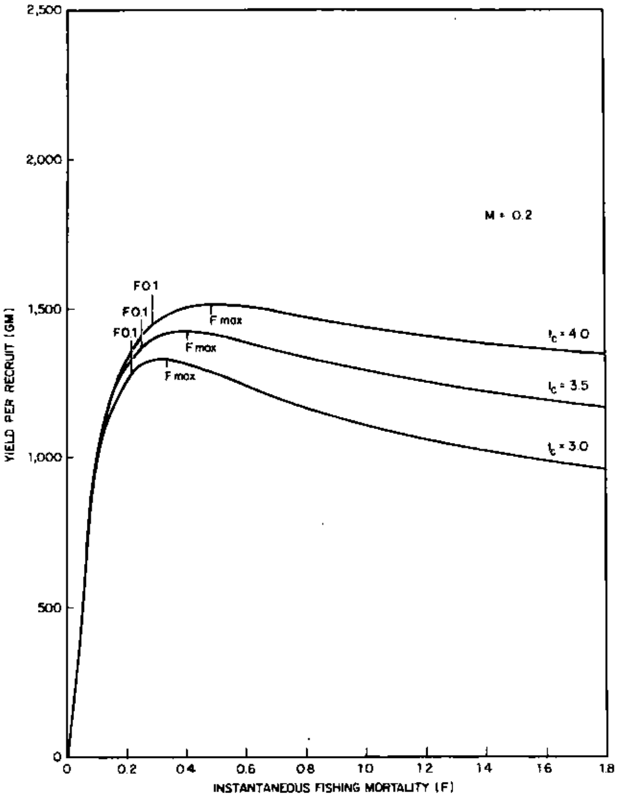

Fig. 9. Yield-per-recruit curves for pollock in Div. 4VWX + Subarea 5, assuming t_c values of 3.0, 3.5 and 4.0 years, W_∞ = 10.9 kg, K = 0.216, t_o = 0.378, t_r = 2.0, t_λ = 16.0, and M = 0.2.

MORTALITY

Stratified mean catch per tow at age and resulting total mortality coefficients for *Albatross IV* autumn bottom trawl surveys in Div. 4X and 5Y (Gulf of Maine-Scotian Shelf, strata 24 and 26-42) for the period 1970-75 are given in Table 9; similar information is given for Canadian summer bottom trawl surveys in Table 10. Mortality coefficients fluctuate considerably but at least for the US data do indicate a substantial increase in mortality in recent years. Weighted estimates of Z are negative between 1971 and 1973 but increase to 0.73 and 0.83 between 1973-74 and 1974-75 respectively (Table 9). Similarly, available data from *Albatross IV* spring bottom trawl surveys (1973-75) also indicate increased mortality (the weighted estimate of Z was negative for 1973-74 but increased to 0.73 for 1974-75). Assuming M = 0.2 for pollock (ICES, MS 1975), the US surveys indicate that F has increased to approximately 0.5 since 1973. Canadian research vessel survey data indicate a somewhat lower value for 1973-75 (Z = 0.47) although the 1970-75 figure was higher (Z = 0.65). Again, assuming M = 0.2, the Canadian data indicate an average F of 0.45 for this period.

Table 9. Stratified mean catch per tow at age (number) and total mortality coefficients (Z) calculated for pollock in US *Albatross IV* autumn bottom trawl surveys in Div. 4X and 5Y (strata 24 and 26-42), 1970-75.

Age	1970	1971	1972	1973	1974	1975
0	0.01	0.03	0.00	0.00	0.00	0.01
1	0.14	0.14	0.58	0.04	0.00	0.28
2	0.06	0.24	1.02	0.88	0.10	0.06
3	0.03	0.07	0.56	0.13	0.34	0.04
4	0.10	0.01	0.08	0.22	0.28	0.13
5	0.10	0.08	0.09	0.15	0.16	0.06
6	0.10	0.12	0.11	0.16	0.12	0.06
7	0.05	0.05	0.07	0.11	0.11	0.08
8	0.04	0.10	0.07	0.07	0.02	0.06
9	0.01	0.03	0.06	0.00	0.03	0.02
10	0.03	0.01	0.03	0.18	0.00	0.01
11	0.01	0.01	0.03	0.02	0.04	0.01
12	0.00	0.02	0.03	0.01	0.00	0.00
13	0.04	0.02	0.02	0.05	0.00	0.01
14+	0.05	0.08	0.07	0.07	0.02	0.03
Z(age 4+)[a]		0.02	-0.09	-0.22	0.73	0.83

[a] Calculated as $\ln\left(\frac{\Sigma \text{ ages 4 and older}}{\Sigma \text{ ages 5 and older}}\right)$.

Table 10. Estimates of population numbers at age (000's) and total mortality coefficients (Z) calculated for pollock in Canadian summer bottom trawl surveys in Div. 4VWX, 1970-75.

Age	1970	1971	1972	1973	1974	1975
1	35	-	51	-	35	-
2	8,867	3,631	465	1,998	209	29
3	2,136	3,023	986	1,859	4,679	89
4	1,326	837	6,146	5,649	1,162	1,624
5	967	194	1,905	2,075	1,421	1,383
6	953	89	551	330	923	1,838
7	766	158	157	76	1,047	307
8	494	54	272	191	464	460
9	106	36	227	290	421	147
10	-	111	177	11	261	20
11	266	-	61	128	641	37
12	66	-	29	56	230	-
13+	-	-	125	-	-	-
NK	135	-	51	69	-	-
Z(age 4+)[a]		2.07	-0.88	1.10	0.50	0.45

[a] Calculated as $\ln\left(\frac{\Sigma \text{ ages 4 and older}}{\Sigma \text{ ages 5 and older}}\right)$.

Given 3 years of commercial removals-at-age data, meaningful results can be expected for the first of these years from cohort analysis, if the assumed F in the last year is reasonably accurate. A starting F = 0.45 (M = 0.20) was applied to the 1973-75 removals at age from Table 5 (Table 11). This gave weighted average F's for ages 4-10 in 1973

Table 11. Cohort analysis for pollock in Div. 4VWX + Subarea 5, assuming M = 0.2 and F = 0.45 for fully recruited ages in 1975.

	Age (years)											
Year	2	3	4	5	6	7	8	9	10	11	12	
Catch at age (000's)												
1973	934	2,254	5,039	4,064	1,038	781	309	494	420	81	28	
1974	697	7,259	3,000	3,094	1,259	383	281	172	112	43	17	
1975	842	5,110	7,044	1,530	1,421	627	129	77	170	79	17	
Population at age (000's)												
1973	42,587	13,439	16,152	9,018	2,246	1,590	1,339	1,053	559	120	40	
1974	(31,773)	34,022	8,963	8,665	3,706	899	595	818	415	78	25	
1975	(31,418)	(25,383)	21,288	4,624	4,294	1,895	390	233	514	239	25	
Fishing mortality (F)												Mean[a]
1973	0.03	0.21	0.42	0.69	0.72	0.78	0.29	0.73	1.78	1.38	0.45	0.56
1974	(0.03)	0.27	0.46	0.50	0.47	0.64	0.74	0.27	0.35	0.95	0.45	0.48
1975	(0.03)	(0.25)	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	

[a] Average F values weighted by stock size (in numbers) for ages 4-10.

and 1974 of F = 0.56 and F = 0.48 respectively. This supports the conclusion that F has been in the order of 0.50 in most recent years.

It is recognized that a variety of interpretations of the above data are possible. In particular, the data of Tables 9 and 10 indicate considerable variability in catch rates of certain year-classes, which may be associated with shifts in distribution resulting from environmental factors; this could be a source of error for this species in the present situation as neither survey covered the Div. 4VWX + Subarea 5 area as a unit. In addition, pollock tend to frequent higher levels of the water column than other groundfish species and are therefore less available to the survey gear. Either of these factors could have biased the computed mortality estimates to some degree. In view of evidence given in preceding sections indicating actual declines in abundance since 1972, however, it would seem logical to assume that F is in fact increasing and to accept the average values indicated (i.e. F ~ 0.5).

CONCLUSIONS

The mortality estimates for the stock in Div. 4VWX + Subarea 5 indicate that F values have increased to above the level of F_{max} in recent years. This trend is corroborated by US commercial and research vessel abundance indices, both of which indicate declines in stock abundance during the same period. Furthermore, catch-at-age data from US research vessel surveys suggest that the 1972 to 1974 year-classes are weaker than those of 1968, 1969 and 1971 and that recruitment prospects are less favourable than during 1968-73 (Table 9). Accordingly, the evidence available indicates that harvesting the existing TAC of 55,000 tons in Div. 4VWX + Subarea 5 would result in an F considerably above F_{max}.

Assuming an F-value of 0.5 for 1975, and assuming an average weight of 2.5 kg per fish in commercial landings, a stock size of 43.5 million fish (108,800 tons) is obtained for Div. 4VWX + Subarea 5 pollock at the beginning of 1975. At present, recruitment indices are not available for this stock and thus estimates for 1976 and 1977 are uncertain, but it appwars that, in view of recent declines in abundance, a reduction from the 1975 figure appears likely. Assuming a modest decline in stock size to 100,000 tons for 1977, a catch of 30,000 tons would result from fishing at F_{max}, whereas a catch of 19,000 tons would result from fishing at $F_{0.1}$.

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Distribution of Atlantic Mackerel in ICNAF Subarea 5 and Statistical Area 6 based on Research Vessel Spring Bottom Trawl Surveys, 1968-76[1]

by

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ABSTRACT

Mackerel were caught during US spring bottom trawl surveys in ICNAF Subarea 5 and Statistical Area 6 in 1968-76 from Cape Hatteras to Georges Bank. There was a progressively northeasterly shift in catches after 1968 which coincided with an increasing trend in mean bottom water temperature. Spring bottom trawl surveys by research vessels from the Federal Republic of Germany (FRG), the German Democratic Republic (GDR), Poland, and USSR sampled only selected portions of the Cape Hatteras-Georges Bank area in 1973-76. The US spring surveys have been conducted for 9 years throughout the entire spring range of mackerel and have provided a sufficient data base for measuring relative abundance, year-class strength, and changes in distribution. Surveys conducted by the other countries have generally substantiated the results of the US surveys within limited geographical areas.

INTRODUCTION

Atlantic mackerel (*Scomber scombrus*) overwinter in deep water along the edge of the continental shelf in ICNAF Subarea 5 and Statistical Area 6 before beginning their annual northerly migration in the spring (Sette, 1950). Mackerel are most heavily concentrated and easily harvested during December-April as evidenced by commercial catches (Anderson, MS 1975a; Moores *et al.*, 1975). The probability of achieving the largest catches of mackerel in research vessel trawl surveys and of determining the most reliable estimates of abundance is greatest during this time.

Estimates of relative stock abundance and strength of recruiting year-classes, obtained independently of commercial fishery statistics using research vessel trawl survey data, are essential for the assessment of mackerel in the Northwest Atlantic. Catch-per-tow indices of mackerel from US spring and autumn trawl surveys in Subarea 5 and Statistical Area 6 have been reported by Anderson (MS 1973, MS 1974, MS 1975b, 1976a). Estimates of mackerel recruitment based on US spring survey catches have been presented by Anderson (MS 1976b).

Spring bottom trawl surveys have been conducted annually since 1968 by the USA. Additional spring bottom trawl surveys, intended primarily for determining recruitment estimates for herring (*Clupea harengus*), have been conducted since 1973 by vessels from FRG, GDR, Poland, and USSR (Dornheim, MS 1973; Anderson and Dornheim, MS 1974; Yudanov *et al.*, MS 1974; Anthony *et al.*, MS 1975; Hennemuth, MS 1975).

The purpose of this paper is to summarize the distribution of mackerel catches from past spring surveys and to relate apparent shifts in distribution to observed temperature changes. This is important in evaluating the catch data obtained from these surveys and in planning future surveys.

MATERIALS AND METHODS

The US spring bottom trawl surveys (*Albatross IV* and *Delaware II*) were based on a stratified random sampling design according to depth and area (Fig. 1). A No. 36 Yankee bottom trawl was used during 1968-72, and a larger, high-opening No. 41 Yankee trawl was used during 1973-76 (Grosslein, MS 1974). The area of coverage extended from Nova Scotia to Cape Hatteras with dates of sampling ranging annually between 4 March and 16 May

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(Table 1). Tows were made at a speed of 3.5 knots for 30 min with operations conducted 24 hours per day.

Table 1. Spring bottom trawl surveys conducted in Subarea 5 + Statistical Area 6, 1968-76.

Country	Vessel	Date	Area	Trawl	Speed (knots)
USA	*Albatross IV*	4 Mar-16 May 1968	Nova Scotia to Cape Hatteras	No. 36 Yankee	3.5
USA	*Albatross IV*	5 Mar-10 Apr 1969	Nova Scotia to Cape Hatteras	No. 36 Yankee	3.5
USA	*Albatross IV*	12 Mar-29 Apr 1970	Nova Scotia to Cape Hatteras	No. 36 Yankee	3.5
USA	*Albatross IV*	9 Mar-1 May 1971	Nova Scotia to Cape Hatteras	No. 36 Yankee	3.5
USA	*Albatross IV*	8 Mar-24 Apr 1972	Nova Scotia to Cape Hatteras	No. 36 Yankee	3.5
FRG	*Walther Herwig*	26 Feb-15 Mar 1973	Gulf of Maine to Cape Hatteras	180-ft herring	5.0
USA	*Albatross IV* and *Delaware II*	16 Mar-15 May 1973	Nova Scotia to Cape Hatteras	No. 41 Yankee	3.5
FRG	*Walther Herwig*	19 Mar-3 Apr 1974	Nantucket Shoals to Browns Bank	180-ft herring	5.0
USA	*Albatross IV*	12 Mar-4 May 1974	Nova Scotia to Cape Hatteras	No. 41 Yankee	3.5
USSR	*Khronometer*	22 Mar-16 Apr 1974	Cape Cod to Maryland	Hake 815	4.0
FRG	*Walther Herwig*	11-26 Mar 1975	So. New England to Browns Bank	180-ft herring	4.0
GDR	*Ernst Haeckel*	11-17 Mar 1975	Nantucket Shoals to Georges Bank	160-ft herring	4.2
Poland	*Wieczno*	2-16 Mar 1975	Southern New England	90-ft herring	4.0
USA	*Albatross IV*	4 Mar-12 May 1975	Nova Scotia to Cape Hatteras	No. 41 Yankee	3.5
FRG	*Anton Dohrn*	1-9 Mar 1976	Georges Bank	180-ft herring	4.0
GDR	*Ernst Haeckel*	2-18 Mar 1976	Nantucket Shoals to Gulf of Maine	HG 490	3.8
Poland	*Wieczno*	6-29 May 1976	Hudson Canyon to Georges Bank	90-ft herring	3.5
USA	*Albatross IV* and *Delaware II*	4 Mar-8 May 1976	Nova Scotia to Cape Hatteras	No. 41 Yankee	3.5

Additional spring surveys were made by the *Walther Herwig* (FRG) in 1973-75, the *Anton Dohrn* (FRG) in 1976, the *Khronometer* (USSR) in 1974, the *Ernst Haeckel* (GDR) in 1975-76, and the *Wieczno* (Poland) in 1975-76 (Table 1). These surveys were based on the US stratified random sampling design (except for the 1973 *Walther Herwig* survey), employed commercial herring bottom trawls, and sampled selected strata between Nova Scotia and Cape Hatteras. Dates of sampling ranged from 26 February to 29 May. Tows of 30 min duration were made at speeds ranging from 3.5 to 5.0 knots. Sampling was conducted 24 hours per day during the *Khronometer* survey, but only in daylight hours during the other surveys.

Catches of mackerel (in numbers) were plotted by station for each survey (Fig. 2-19). The locations of null catches were also plotted to illustrate the sampling area. The numbers caught per tow at age 1, age 2, and age 3+ were also examined separately for each survey to determine if different distribution patterns were evident for those age groups.

RESULTS

Catches of mackerel during US spring surveys (Fig. 2-6, 8, 10, 15, and 19) ranged primarily from the slope waters of Georges Bank to Cape Hatteras. A few mackerel were taken along the edge of the Scotian Shelf and in 1974 (Fig. 10), 1975 (Fig. 15) and 1976 (Fig. 19) from waters north of Georges Bank. Catches generally occurred in depths greater than 50 m with many at 100-200 m.

There was a progressively northeasterly shift in US survey mackerel catches after 1968. Most of the mackerel in 1968 (Fig. 2) and 1969 (Fig. 3) were caught in strata south of Delaware Bay (ICNAF Div. 6B and 6C). The catches in 1970 (Fig. 4) and 1971 (Fig. 5) shifted north to Div. 6B and 6A. The 1972 (Fig. 6) and 1973 (Fig. 8) catches were mainly from Div. 6A and Subdiv. 5Zw, with considerable numbers taken on Georges Bank (Subdiv. 5Ze) in 1973. Catches in 1974 (Fig. 10) were more widespread on Georges Bank and less abundant in Div. 6B and 6C than in 1973. The majority of the mackerel catches in 1975 (Fig. 15) were from Georges Bank with noticeably fewer numbers from Div. 6A compared to 1974. In 1976, mackerel were again caught on Georges Bank, but the catches in Div. 6A and 6B were greatly improved over those in 1975.

Mackerel catches during the other spring surveys (Fig. 7, 9, 11-14, 16-18) were generally obtained from the same areas as during the US surveys, but were larger as the

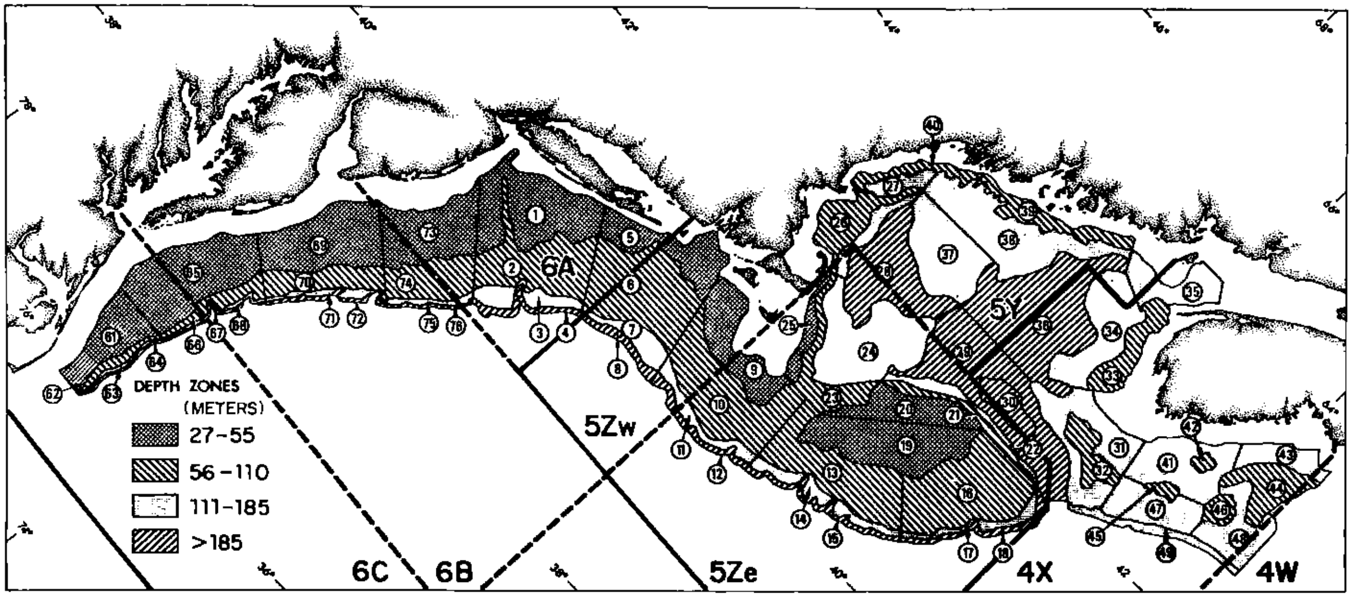

Fig. 1. US bottom trawl survey sampling strata in ICNAF Subarea 5 + Statistical Area 6.

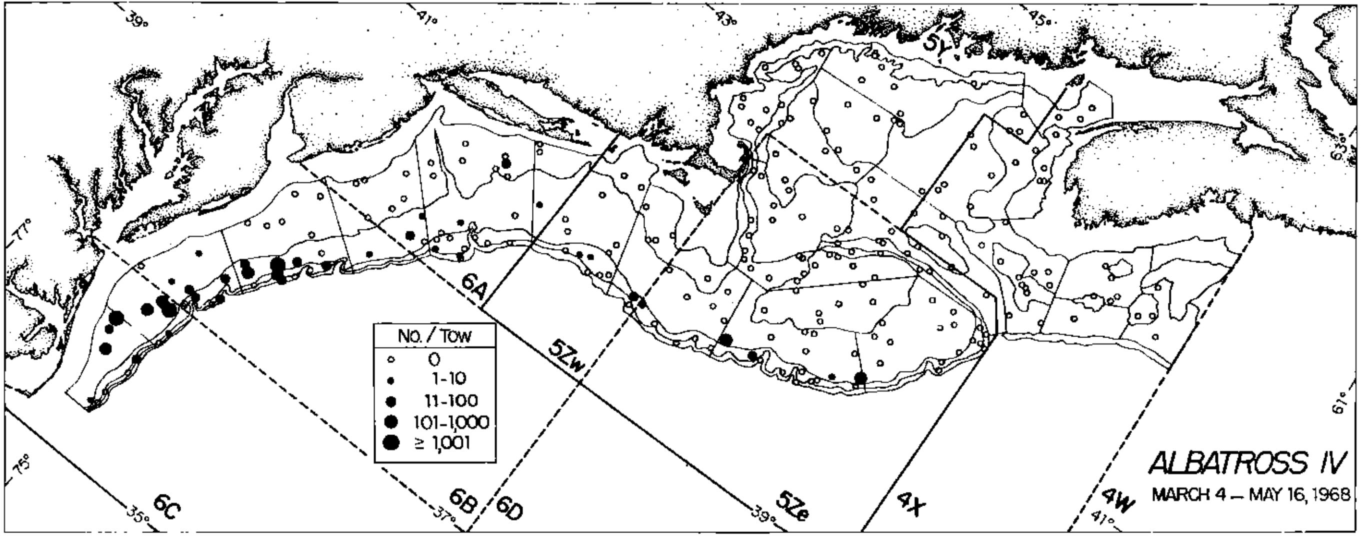

Fig. 2. Distribution of mackerel catches (no./tow) during the 1968 US spring survey.

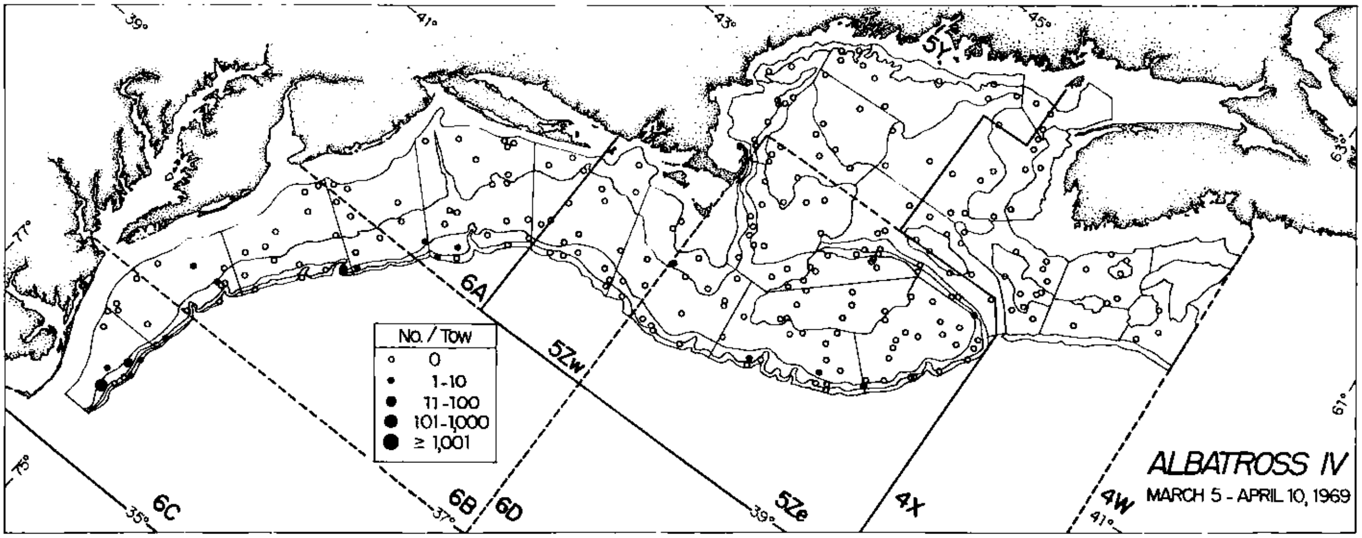

Fig. 3. Distribution of mackerel catches (no./tow) during the 1969 US spring survey.

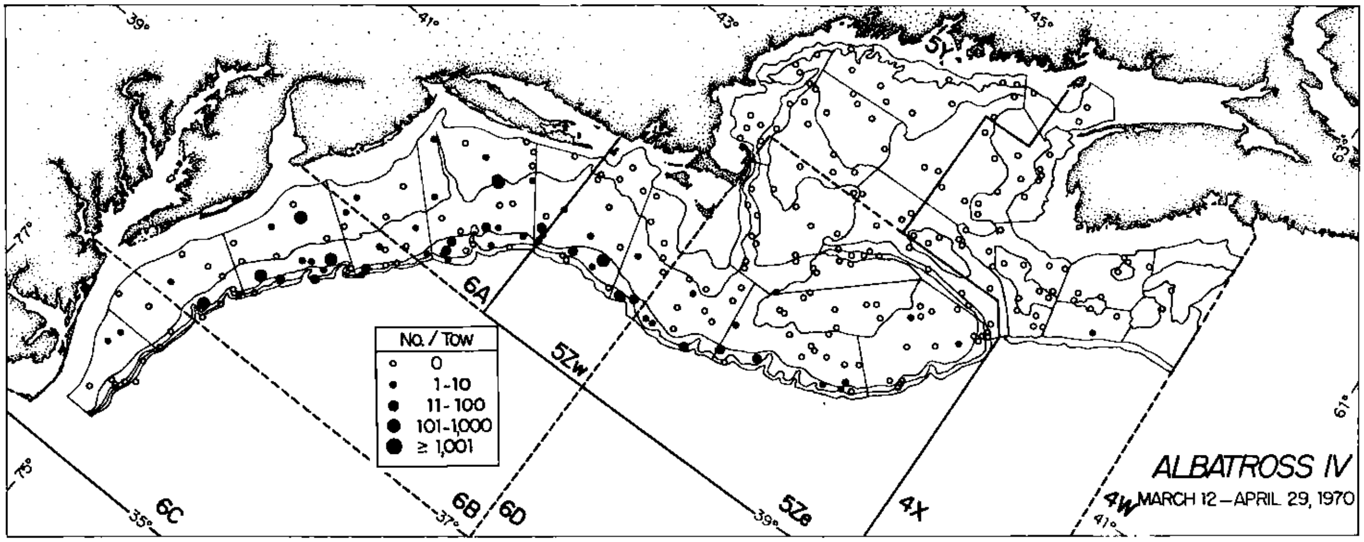

Fig. 4. Distribution of mackerel catches (no./tow) during the 1970 US spring survey.

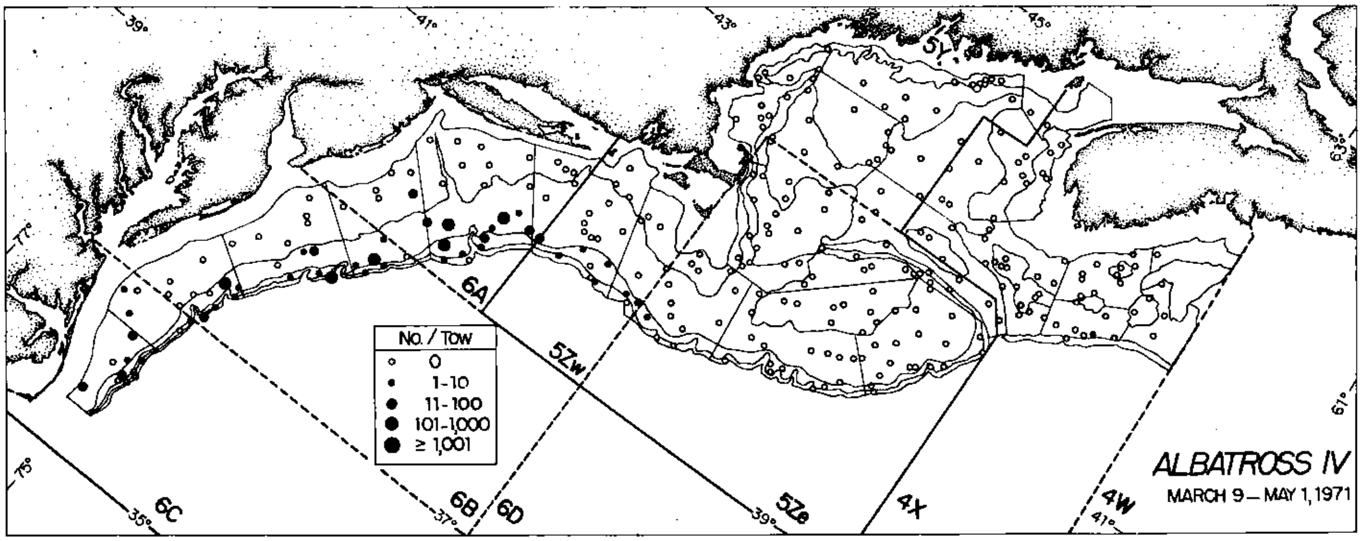

Fig. 5. Distribution of mackerel catches (no./tow) during the 1971 US spring survey.

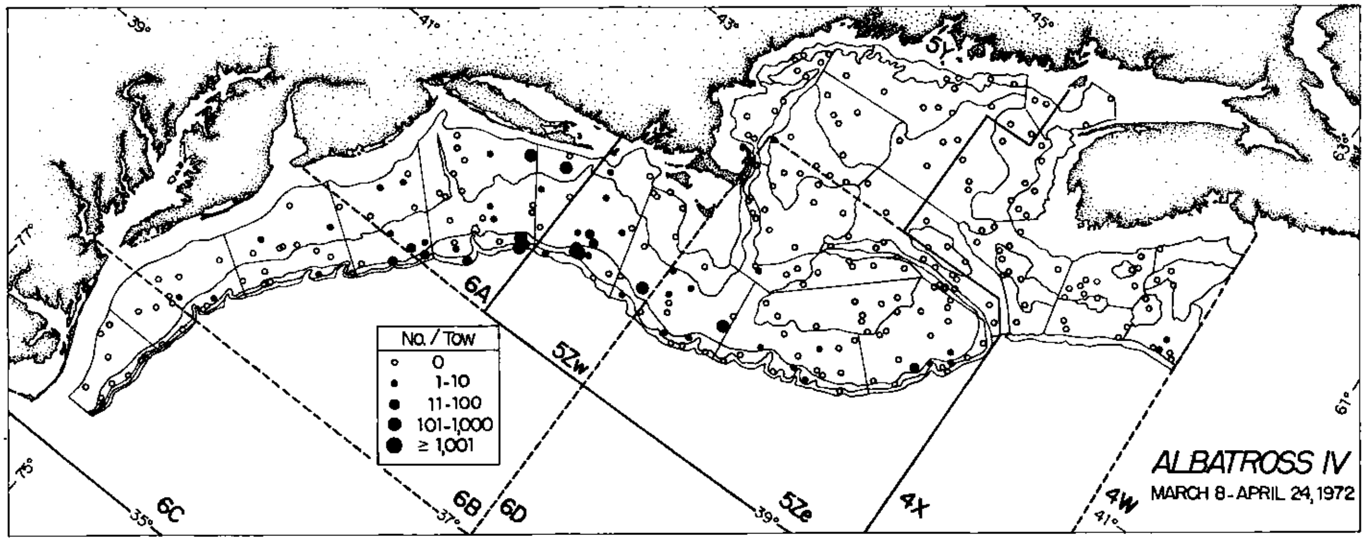

Fig. 6. Distribution of mackerel catches (no./tow) during the 1972 US spring survey.

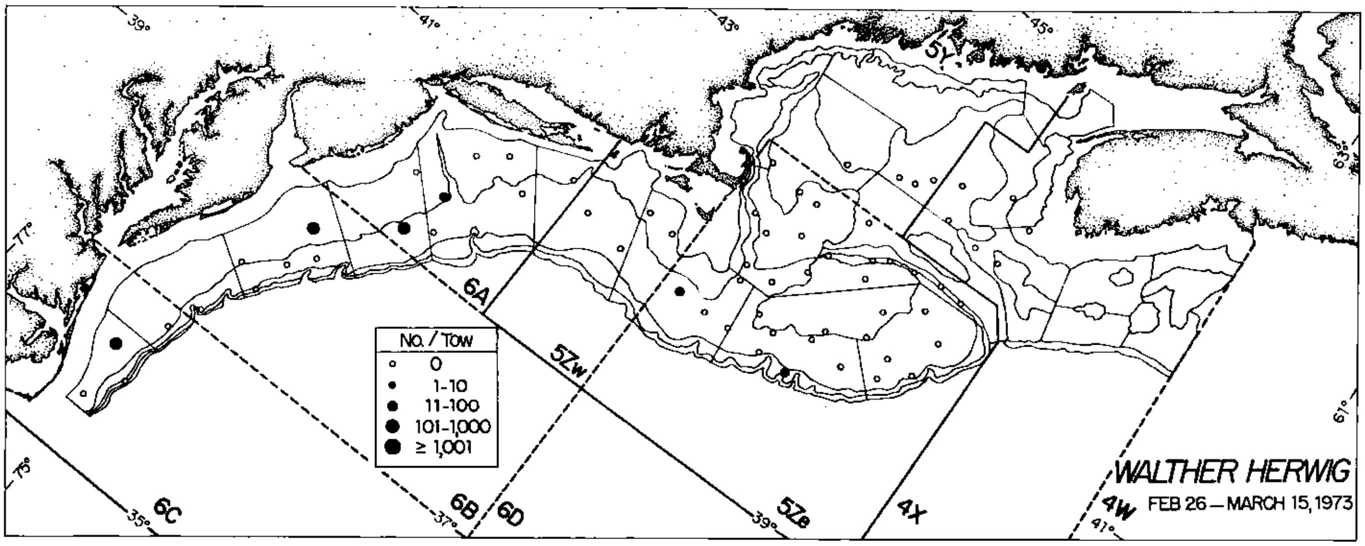

Fig. 7. Distribution of mackerel catches (no./tow) during the 1973 FRG spring survey.

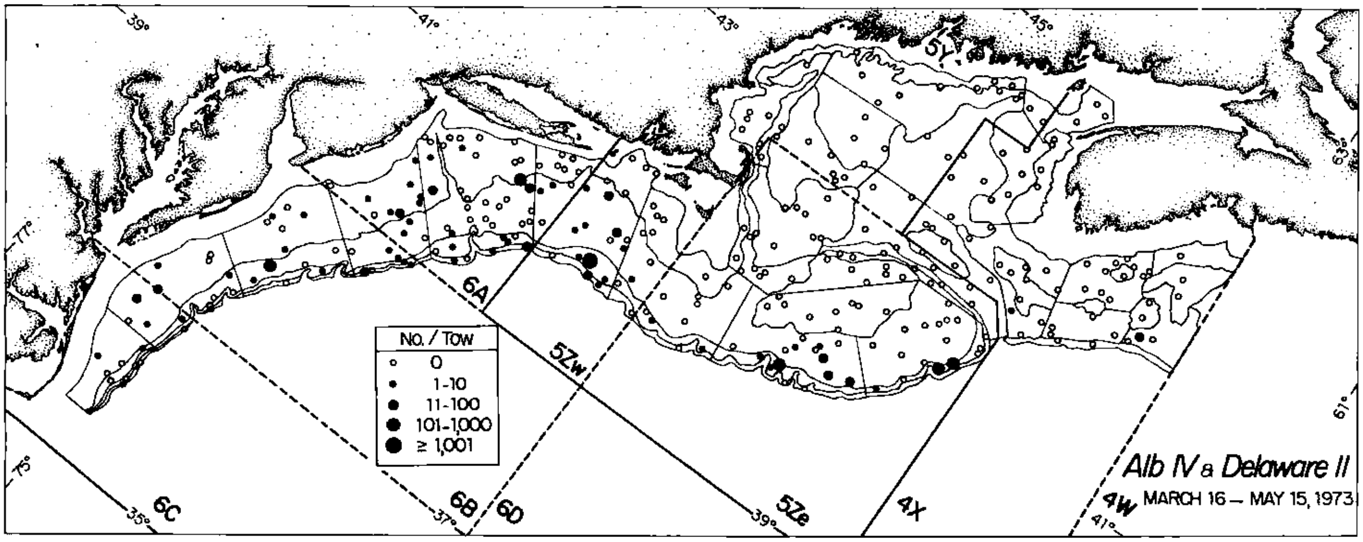

Fig. 8. Distribution of mackerel catches (no./tow) during the 1973 US spring survey.

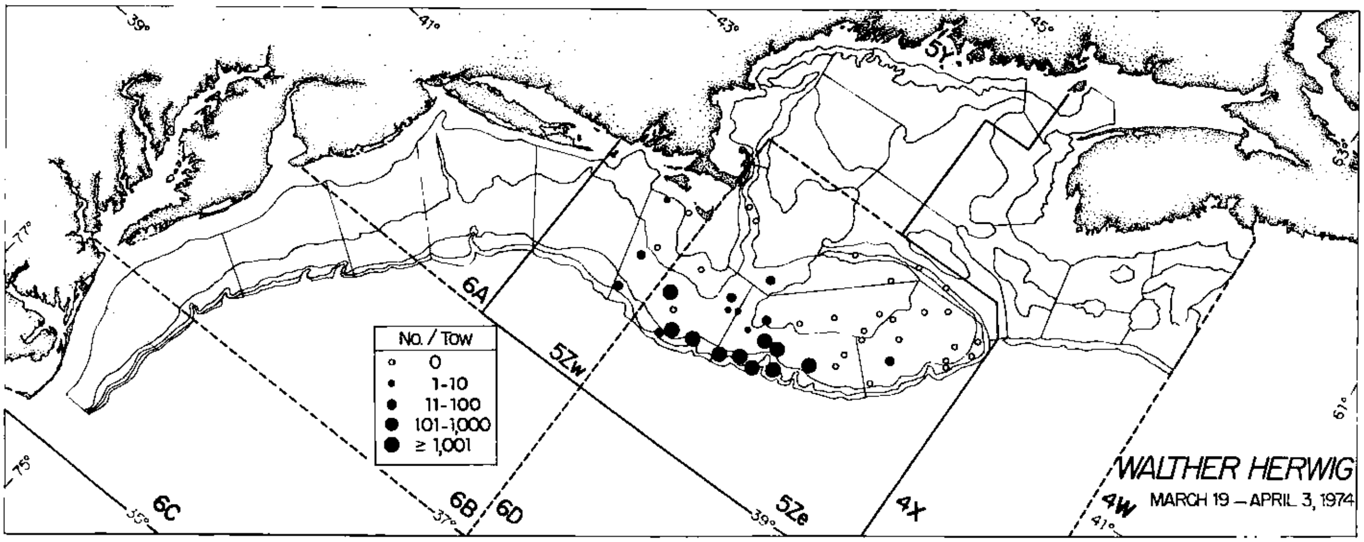

Fig. 9. Distribution of mackerel catches (no./tow) during the 1974 FRG spring survey.

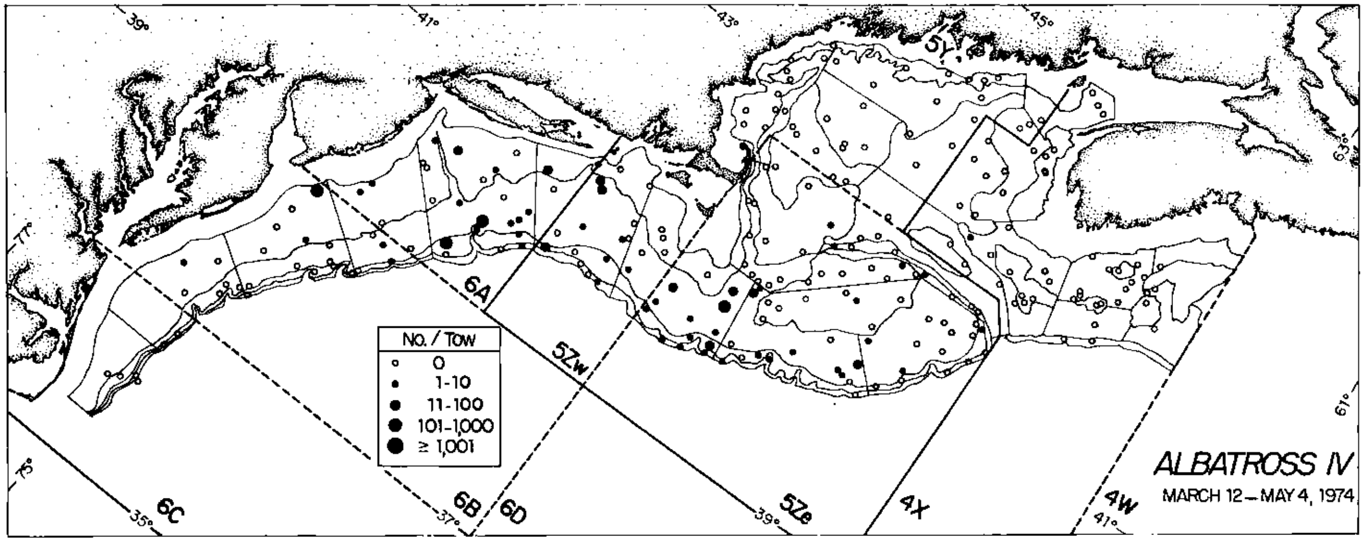

Fig. 10. Distribution of mackerel catches (no./tow) during the 1974 US spring survey.

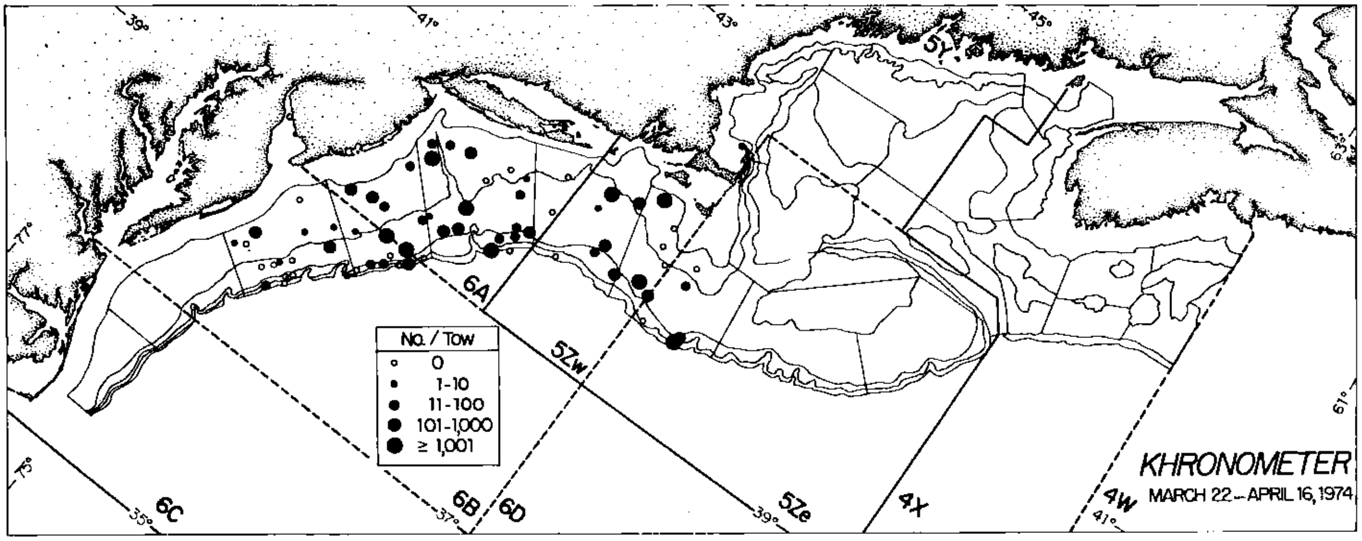

Fig. 11. Distribution of mackerel catches (no./tow) during the 1974 USSR spring survey.

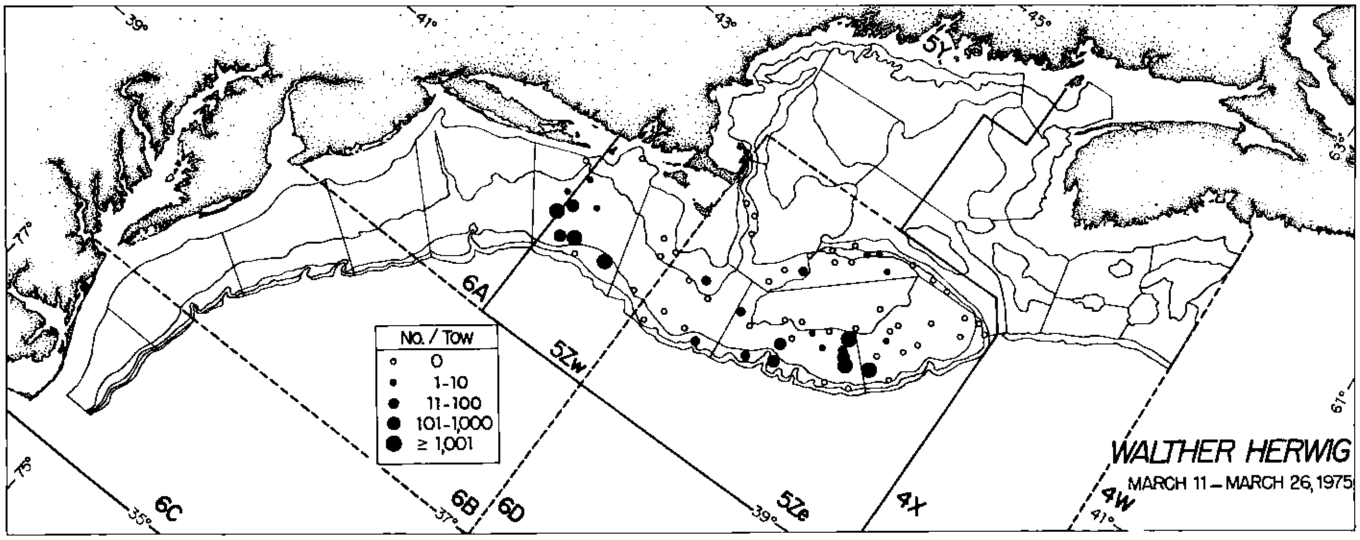

Fig. 12. Distribution of mackerel catches (no./tow) during the 1975 FRG spring survey.

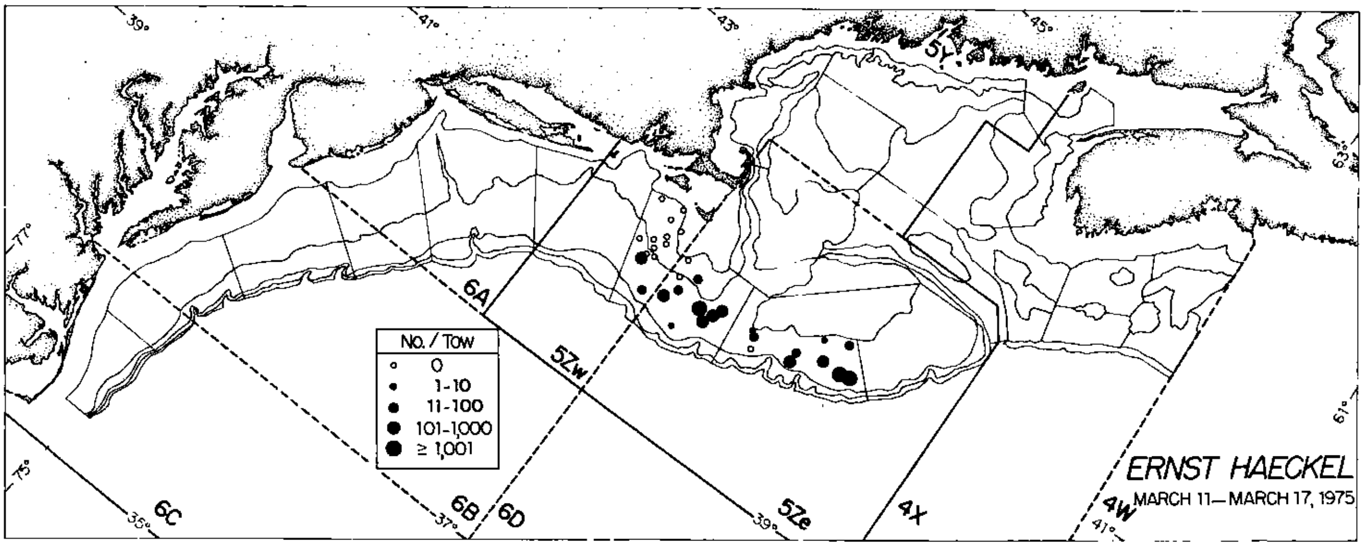

Fig. 13. Distribution of mackerel catches (no./tow) during the 1975 GDR spring survey.

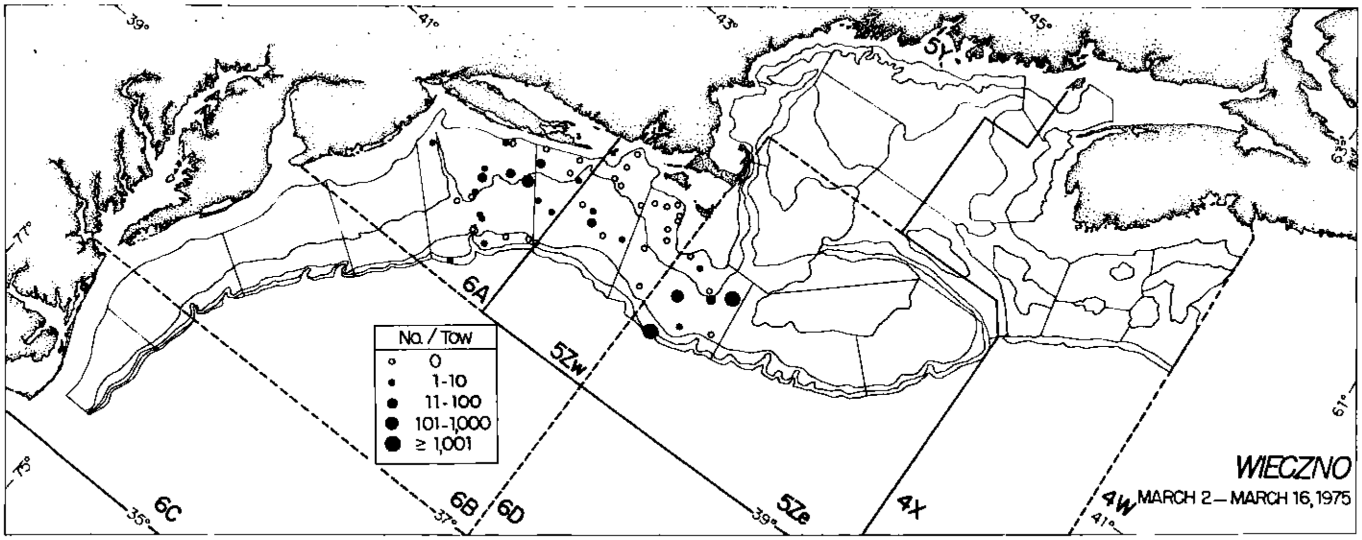

Fig. 14. Distribution of mackerel catches (no./tow) during the 1975 Polish spring survey.

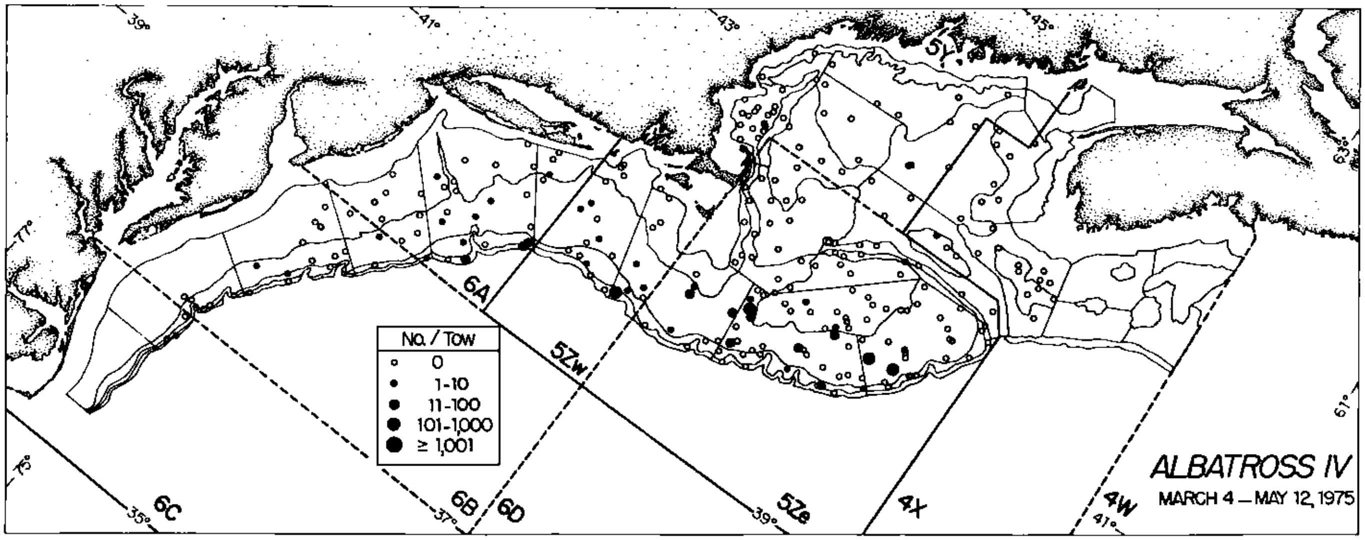

Fig. 15. Distribution of mackerel catches (no./tow) during the 1975 US spring survey.

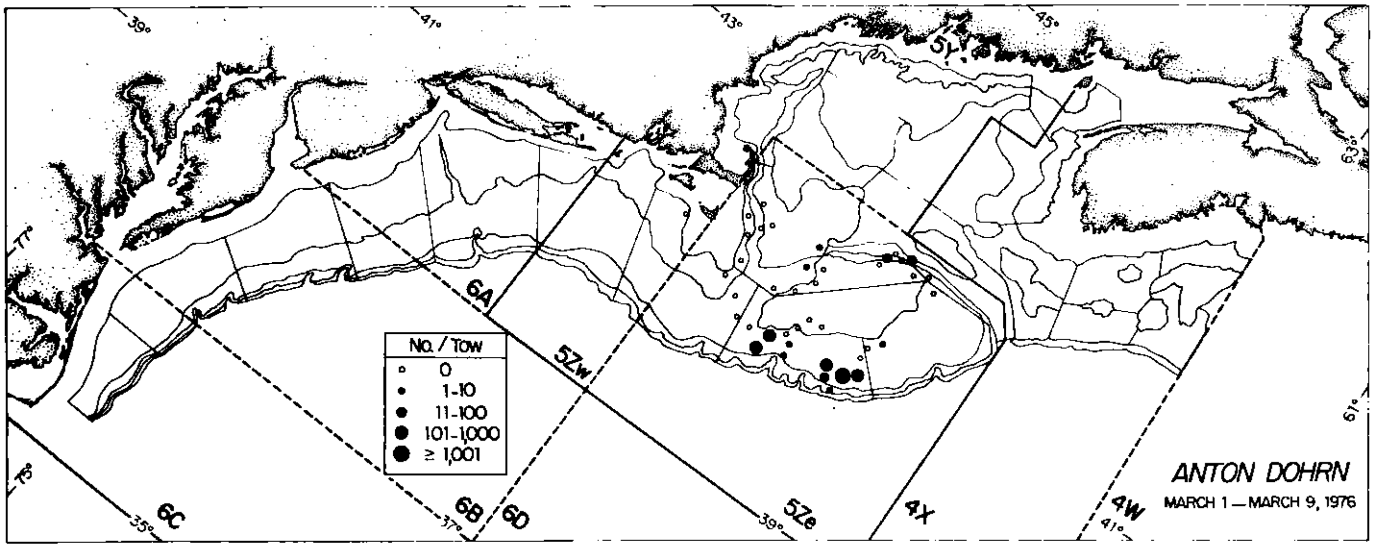

Fig. 16. Distribution of mackerel catches (no./tow) during the 1976 FRG spring survey.

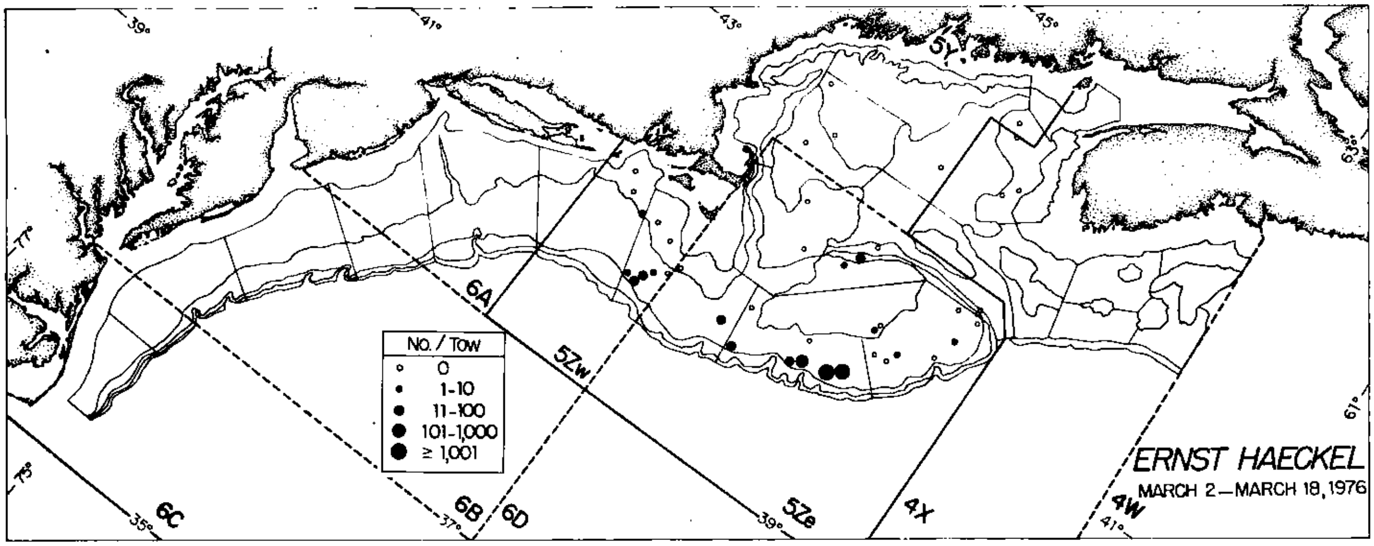

Fig. 17. Distribution of mackerel catches (no./tow) during the 1976 GDR spring survey.

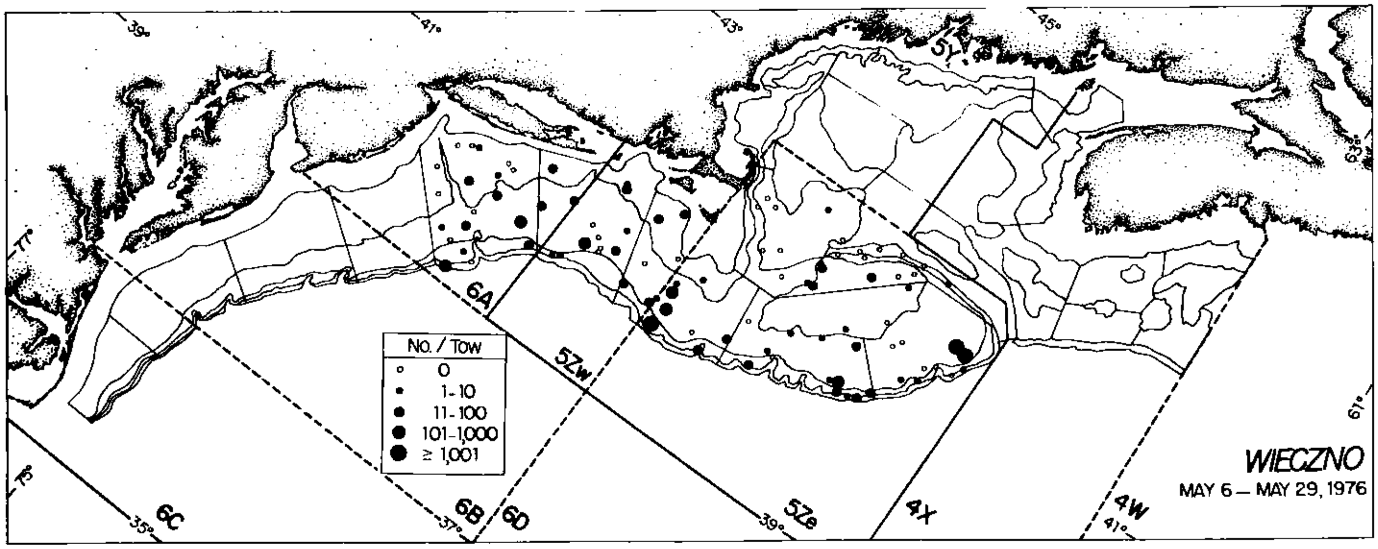

Fig. 18. Distribution of mackerel catches (no./tow) during the 1976 Polish spring survey.

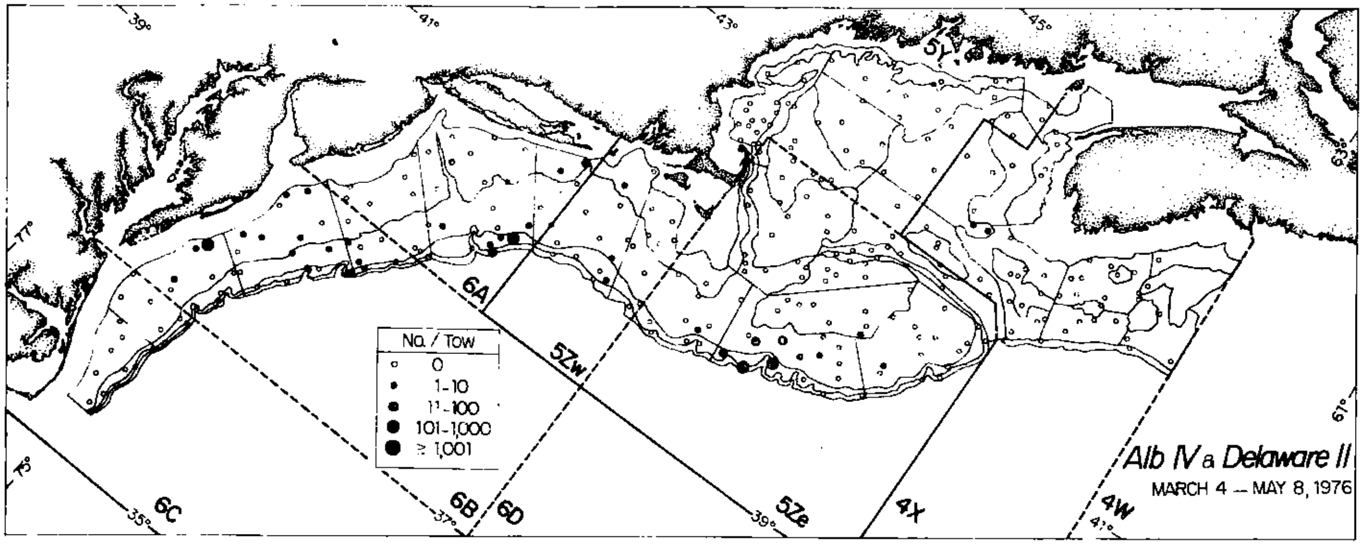

Fig. 19. Distribution of mackerel catches (no./tow) during the 1976 US spring survey.

result of using larger trawls (Table 1). Since these surveys were limited to only portions of the total area sampled by the USA, the results are generally useful only to define depth distribution within a limited area and cannot be used to describe the geographic range.

The 1973 *Walther Herwig* survey (Fig. 7) extended from the Gulf of Maine to Cape Hatteras, but mackerel catches were infrequent and small mainly because very few stations were occupied in deep water where mackerel are generally located in the spring. The 1974 *Walther Herwig* survey (Fig. 9), limited primarily to the Nantucket Shoals-Georges Bank area, caught mackerel at nearly every station in strata 10-15. Most of these catches were from water deeper than 100 m. The 1975 *Walther Herwig* survey (Fig. 12) was extended westward to include the strata in Subdiv. 5Zw. The majority of mackerel catches were from strata 6 and 13 where depths ranged from 56 to 100 m. The 1976 *Anton Dohrn* survey (Fig. 16) was limited to only part of Georges Bank, where mackerel catches occurred primarily on the southwestern part (stratum 13) and, to a lesser extent, along the northern edge.

The *Khronometer* survey in 1974 (Fig. 11), which extended from Maryland (Div. 6B) to Nantucket Shoals, had good mackerel catches throughout the entire area both inshore and offshore. Distribution of catches agreed very closely with those obtained during the US survey that year (Fig. 10).

The 1975 *Ernst Haeckel* survey (Fig. 13) sampled only strata 9, 10, and 13, but caught mackerel at nearly every station in strata 10 and 13. The 1976 *Ernst Haeckel* survey (Fig. 17) covered a much larger area including most of the Nantucket Shoals-Georges Bank area as well as portions of the Gulf of Maine, and, as in 1975, nearly all of the mackerel catches occurred in strata 10 and 13.

The *Wieczno* survey in 1975 (Fig. 14) sampled strata 1-12 and encountered mackerel throughout most of that area with the largest catches in the easternmost part. The 1976 *Wieczno* survey (Fig. 18) extended from Hudson Canyon through Georges Bank (strata 1-24), but was conducted about 2 months later (6-29 May) than the other non-US spring surveys. The results of this survey are therefore not exactly comparable with those from other surveys, but mackerel were found throughout the entire area both in shoal and deep water, with the largest catches taken on the eastern part of Georges Bank (stratum 16) and south of Nantucket (strata 10-11).

The plots of mackerel catches by age (not shown) indicated no discernible patterns of distribution or depth preference for particular age-groups. The results did indicate, however, that age 3+ mackerel were generally not present in catches which contained substantial numbers of age 1 mackerel. Age 2 mackerel were commonly caught either with age 1 or with age 3+ mackerel but rarely with both, suggesting that age 1 mackerel may school discretely from age 3+ mackerel.

DISCUSSION

Catches during the spring surveys confirm Sette's (1950) hypothesis that mackerel overwinter along the edge of the continental shelf from Georges Bank to Cape Hatteras and move both shoreward and northeastward during the annual spring migration. The presence of mackerel in the shallowest strata (27-55 m) in the Middle Atlantic-southern New England area suggests that spawning activity was generally in progress or about to commence at the time the spring surveys were conducted. Sette (1943) reported that spawning occurs as far as 130 km (80 miles) from shore but mostly within 15-50 km (10-30 miles).

A comparison of the location of mackerel catches in the US spring surveys from 1968 to 1976 indicates a definite northeasterly shift in the geographic distribution at that time of the year from the Middle Atlantic area to the southern New England-Georges Bank area. This change was also evident from a general northeasterly shift in mackerel catches by the international fleet in the spring fishery in Subarea 5 + Statistical Area 6 after 1969 (Anderson, MS 1975a). The shift in both survey and commercial catches may reflect an actual relocation of the overwintering grounds, an earlier beginning of the spring migration from the overwintering grounds, or a combination of the two.

The shift in distribution coincides with a general warming trend which occurred during the period of the US spring surveys (Fig. 20). The mean bottom temperatures were taken from Davis (MS 1976, and unpublished data). The same trend and year-to-year fluctuations in bottom temperature were evident for all three of the ecological zones indicated (Middle Atlantic, southern New England, and Georges Bank). Mean temperatures

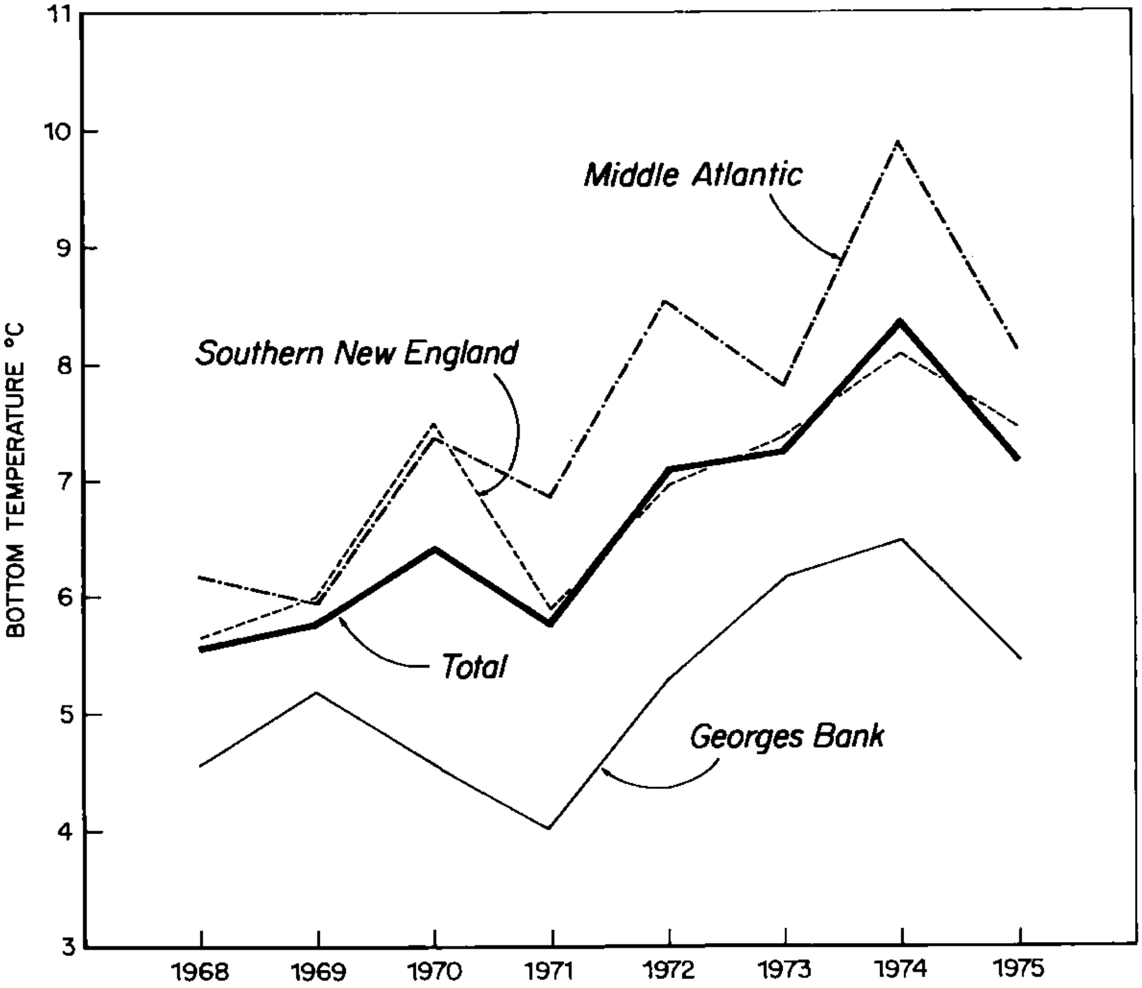

Fig. 20. Mean bottom water temperatures in the Middle Atlantic-Georges Bank area during US spring surveys in 1968-75.

peaked in 1974 and declined in 1975. Data for 1976 have not yet been analyzed. The presence or absence of mackerel catches in the various areas appears to correspond with increases or decreases in temperature. For example, the decrease in mean water temperature in the Middle Atlantic area from 6.2°C in 1968 to 5.9°C in 1969 perhaps explains, in part, the general absence of mackerel catches in 1969, except in stratum 62 off Cape Hatteras (Fig. 3), compared to 1968. In 1970, when the mean temperature increased to 7.4°C, mackerel again appeared in the catches and had also moved farther north than in 1969 and 1968. Temperature dropped in all areas in 1971, and catches showed a definite southward shift in that year compared to 1970. The mean temperature on Georges Bank in 1971 (4°C) was lower than in any other year, and only in 1971 (Fig. 5) were mackerel not caught on Georges Bank. It appears evident, therefore, that the recent northeasterly shift in mackerel distribution was closely related to increased water temperatures and supports results of earlier work relating mackerel distribution and temperature. Sette (1950) concluded that temperatures of 7° to 8°C represented a barrier to movement, although temperatures as low as 4.5°C could be tolerated. The upper limit for distribution is probably about 18° to 20°C (Recksiek and McCleave, 1973). Laboratory studies (Olla *et al.*, 1975) showed that significant increases in mackerel swimming speed occurred when temperature dropped below 6° to 7°C and increased above 14° to 15°C, indicating a preferred range between these extremes.

The non-US spring surveys were not initiated until 1973, by which time the northeasterly shift in distribution was already apparent from the US surveys. Furthermore, the areas sampled by these surveys were insufficient to detect gross changes in distribution.

One of the major problems associated with the non-US spring surveys with respect to mackerel is that they were intended primarily to sample juvenile herring for the purpose of assessing the relative strength of recruiting year-classes. Anthony *et al.* (MS 1975) showed that juvenile herring are generally found in waters less than 60 m in southern New England and less than 80 m on Georges Bank. Mackerel tend to be found in waters deeper than where juvenile herring occur. Examination of survey catches of the two species suggests that their distributions border but do not overlap significantly. Consequently, surveys designed to sample only in areas of likely juvenile herring aggregations would tend to miss the areas of principal mackerel abundance.

Although the mackerel catches from US spring surveys have been smaller than those from the other spring surveys, the indices of stock abundance (all ages) and year-class strength at ages 1 and 2 calculated from those catches are in general agreement with other estimates of stock abundance determined from commercial statistics (Anderson, 1976a) and estimates of year-class size calculated from virtual population analysis (Anderson, MS 1976b). The US surveys are the only surveys that have consistently sampled the entire range of spring mackerel distribution each year. The US time-series beginning in 1968 also provides a year-to-year comparison of abundance indices not yet available from any of the other surveys. Although the FRG surveys have been conducted since 1973, the same area has not been sampled nor has the same vessel been used in each year. However, the non-US surveys have been extremely useful because they have generally substantiated the results of the US surveys (e.g. relative abundance and age composition in selected strata) and have provided samples for use in estimating the age structure of the stock.

In conclusion, the US spring surveys, by virtue of the time-series available and the broad area of coverage, have provided a general description of the geographic distribution of mackerel in each spring in Subarea 5 + Statistical Area 6. Analysis of mackerel catch data also suggests that the US surveys have provided sufficient information to measure changes in relative abundance (Anderson, 1976a) and estimate the strength of recruiting year-classes (Anderson, MS 1976b). The other spring surveys conducted since 1973 have been valuable in providing data which support the US survey results such as defining certain areas of prime concentration, describing the age composition of the stock, and, in the case of the FRG surveys, measuring short-term changes in relative abundance. It is important that spring surveys for estimating the abundance and distribution of mackerel in the Northwest Atlantic be designed so that the entire overwintering range from Georges Bank to Cape Hatteras is sampled to allow for shifts in distribution caused by changes in water temperature such as occurred between 1968 and 1976.

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Stock Assessment of Roundnose Grenadier in the Northwest Atlantic[1]

by

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ABSTRACT

Stock sizes and fishing mortalities for roundnose grenadier in ICNAF Subareas 2 and 3 and in Statistical Area 0 and Subarea 1 were calculated by cohort analyses of both length and age composition data. Yield-per-recruit curves were constructed and sustainable yield estimated for fishing mortality levels of $F_{0.1}$ and F_{max}, using in each case two options of natural mortality at M = 0.1 and M = 0.2. The results of the analyses indicate that the fishing mortalities on the stocks in recent years are in the range of those calculated at $F_{0.1}$ and that the catches are in the range of the estimated sustainable yields at $F_{0.1}$ for the two management areas.

INTRODUCTION

Catches of roundnose grenadier have been reported in the fishery statistics of the Northwest Atlantic since 1967, being in the range of 16,000-83,000 tons annually with an average of 35,400 tons for 1967-74 (ICNAF, 1976). The average annual catch during the 1970-74 period was 42,400 tons, of which 8,400 tons were from Statistical Area 0 and Subarea 1 and 34,000 tons from Subareas 2 and 3. As a precautionary measure to prevent the over-exploitation of the resource, pending the collection and analysis of data to assess the state of the stocks, ICNAF set a total allowable catch (TAC) of 32,000 tons for Subareas 2 and 3 in 1974, and this level of TAC was maintained to 1976. Similarly, a TAC of 10,000 tons was set for Statistical Area 0 and Subarea 1 for 1975. These TACs were set on the basis of approximate average catch levels in the two management areas. In 1974, Pinhorn (MS, 1974) presented preliminary estimates of sustainable yield for the roundnose grenadier stock in Subareas 2 and 3, based on a very limited amount of data available at that time. This paper presents a more complete assessment of the stocks both in Subareas 2 and 3 and in Statistical Area 0 and Subarea 1, based on more substantive data and utilizing "cohort analysis" techniques.

MATERIALS AND METHODS

All calculations are based on biological data collected from the catches of German Democratic Republic vessels mainly in the fourth quarter of the year. For the assessment of the stock in Subareas 2 and 3, data were available only for Subarea 2. Moreover, representative data for the two management areas were not available for the same years, and data for slightly different periods of years were used. Cohort analyses, using length composition data (Jones, 1974) and age composition data (Pope, 1972) were carried out. Length composition data were available for most years during 1969-74, but age composition data, based on the latest age-reading techniques (Foch, MS 1976; Savvatimsky *et al.*, 1976), were available only for 1973 and 1974. In order to calculate the sustainable yields, certain assumptions about recruitment and the mean age of recruits to the fishery had to be taken into account in the analyses. Yield calculations were made using the Beverton and Holt (1957) yield equation solved by the incomplete Beta function.

Input data for the cohort analysis of length compositions consisted of data for 1969-71 and 1973-74 from Subarea 2 and for 1969-70 and 1973-74 for Statistical Area 0 and Subarea 1 (Table 1), from which the mean frequencies summed over 6-cm length groups were used. The mean weights of the various length-groups were obtained from the length-weight relationship shown in Fig. 1. Growth parameters considered to be representative of the

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Table 1. Roundnose grenadier in Subareas 1 and 2 and Statistical Area 0: length compositions (per mille) used in the cohort analyses.

Length (cm)	Subarea 2					Stat. Area 0 + Subarea 1			
	1969	1970	1971	1973	1974	1969	1970	1973	1974
15-17	-	1	-	-	1	-	-	-	1
18-20	-	1	-	-	3	-	-	-	2
21-23	-	2	-	-	4	1	1	-	5
24-26	-	6	-	-	6	-	3	-	10
27-29	-	10	1	-	7	2	8	-	10
30-32	-	16	2	-	5	7	15	1	11
33-35	-	26	4	-	5	8	15	3	17
36-38	2	31	6	-	7	10	16	12	29
39-41	2	35	12	2	9	21	22	23	62
42-44	10	38	17	7	17	35	33	29	91
45-47	26	43	26	9	41	64	59	47	98
48-50	47	61	35	17	64	82	96	62	92
51-53	62	77	57	32	99	125	123	82	85
54-56	75	93	82	49	124	142	151	123	92
57-59	93	106	104	75	124	122	137	150	86
60-62	101	113	127	131	124	88	108	164	103
63-65	124	87	128	149	114	89	79	123	76
66-68	101	77	115	156	88	70	54	86	50
69-71	142	60	103	134	72	41	39	48	38
72-74	83	52	75	101	44	40	21	26	21
75-77	62	29	47	75	24	26	11	13	10
78-80	49	21	31	38	13	19	6	5	7
81-83	21	9	18	18	5	4	2	2	3
84-86	-	3	7	7	-	3	1	1	1
87-89	-	2	2	-	-	1	-	-	-
90-92	-	1	1	-	-	-	-	-	-
No. fish measured	387	4,981	6,244	2,032	2,589	1,200	9,426	7,759	9,654

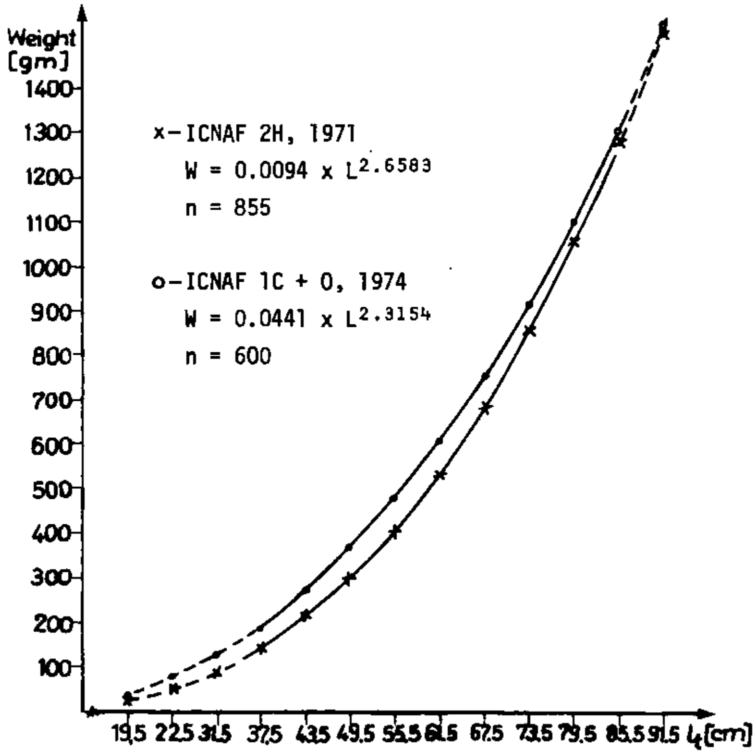

Fig. 1. Length-weight curves for roundnose grenadier in Subareas 1 and 2.

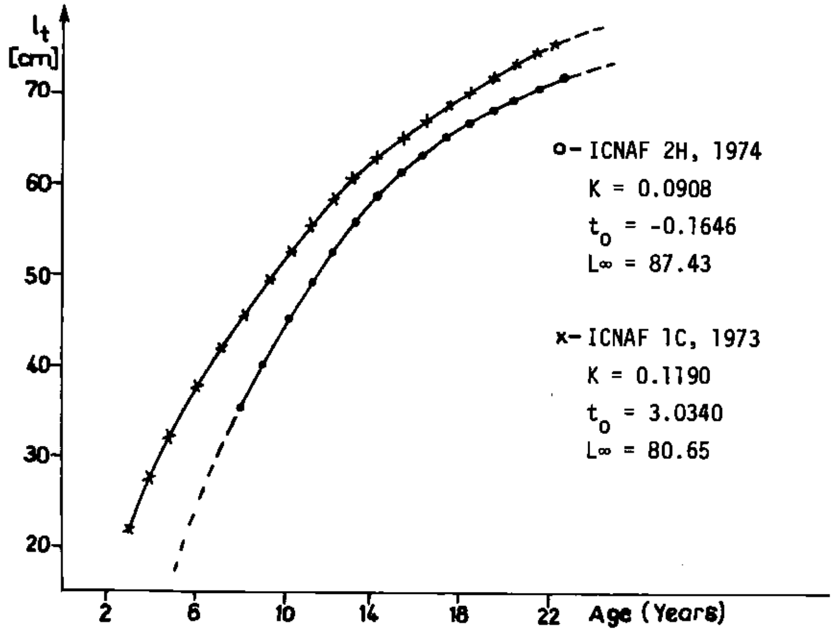

Fig. 2. Growth curves for roundnose grenadier in Subareas 1 and 2.

stocks in the two management areas were calculated from available mean length-at-age data from ICNAF Division 2H for 1974 and from Div. 1C for 1973 (Fig. 2), and are as follows:

Area	L_∞	K	t_o
Subareas 2 + 3	87.4290	0.0908	-0.1646
Stat. Area 0 + Subarea 1	80.6507	0.1190	+3.0340

where L_∞, K and t_o are the parameters of the von Bertalanffy growth equation. The assessments were made using two values of natural mortality, M = 0.1 and 0.2, and the terminal fishing mortality (estimated by the first run) was F = 0.1.

Input data for the cohort analysis of age compositions consisted of data for 1973 and 1974 from both management areas (Table 2). An average "per mille" age composition was obtained by taking the arithmetic mean of the 1973 and 1974 age frequencies, and this was adjusted to the average catch (in numbers) that was estimated for use in the cohort analysis of the length composition data. It is assumed that the resulting age composition is representative of the catch from the stock, the year-classes of which do not appear to vary greatly as evidenced from the length and age composition data. The same values of M and terminal F were used in this analysis as the cohort analysis of length data.

Calculations of yield per recruit were made for M = 0.1 and 0.2, using values of K and t_o as determined from the growth curves. The W_∞ values were determined from the L_∞ values and the length-weight relationships of Fig. 1:

Area	Length-weight equation	W_∞ (g)
Subareas 2 + 3	$W = 0.0094L^{2.6583}$	1,364
Stat. Area 0 + Subarea 1	$W = 0.0441L^{2.3154}$	1,145

The mean age of recruitment to the fishery ($t_{p'}$) was obtained from the expression given in Beverton and Holt (1957), using the F values from the cohort analysis of age composition data:

$$t_{p'} \approx \bar{t}_s = \sum_{y=1}^{Z} t_y \cdot \Delta F_y / \sum_{y=1}^{Z} \Delta F_y$$

Table 2. Roundnose grenadier in Subareas 2 and 3 and Statistical Area 0: age compositions (per mille) used in the cohort analyses.

Age	Subarea 2		Stat. Area 0 + Subarea 1	
(years)	1973	1974	1973	1974
3	-	3	-	4
4	-	6	-	8
5	-	8	-	13
6	-	11	-	15
7	9	13	-	19
8	-	24	8	30
9	-	49	17	58
10	9	104	32	76
11	34	131	57	75
12	66	126	76	67
13	101	126	115	79
14	104	123	242	85
15	184	88	216	96
16	166	60	124	103
17	187	42	20	82
18	77	32	38	77
19	17	12	18	47
20	46	7	32	28
21	-	8	3	12
22+	-	27	2	26
No. measured	2,032	7,291	7,754	9,654
No. aged	84	439	156	2,083

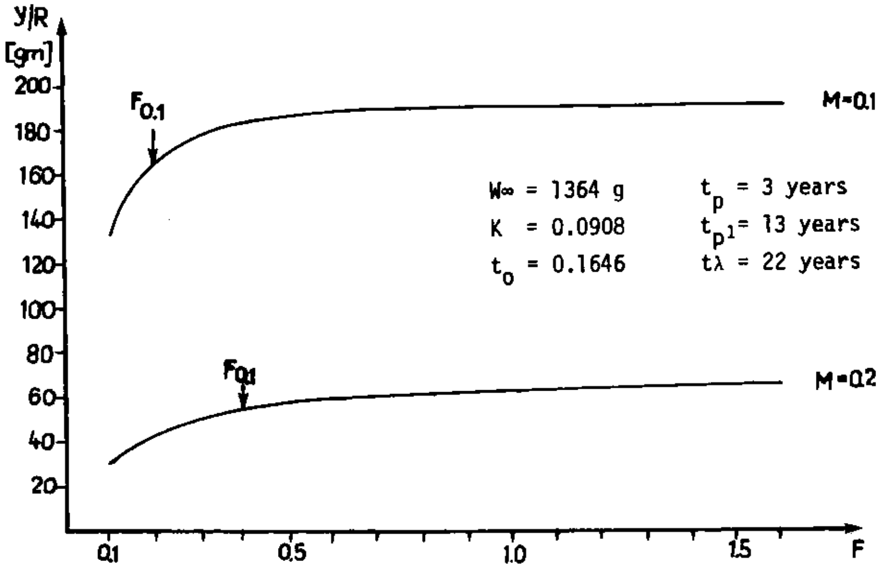

Fig. 3. Yield-per-recruit curves for roundnose grenadier in Subareas 2 and 3 for two levels of natural mortality (M).

The age of full recruitment to the fishery was estimated to be about 15 years and the mean age of recruits to be about 13 years in both stock areas. The age of recruitment to the stock (t_p) and the maximum age (t_λ) were taken as 3 and 22 years respectively, as these ages comprise the range of the available age composition data.

The sustainable yields of $F_{0.1}$ and F_{max} for each management age were estimated by multiplying the number of age 3 fish in the stock (as determined from cohort analysis of age composition data) by the corresponding Y/R values of the yield-per-recruit curves.

Table 3. Roundnose grenadier in Subareas 2 and 3: stock size and fishing mortality (F) for two values of natural mortality (M) from cohort analyses using length composition data for 1969-74 (above) and age composition data for 1973-74 (below).

	Catch	M = 0.1			M = 0.2		
		Stock	F/Z	F	Stock	F/Z	F
Length (cm)[a]	(10^6)	(10^6)			(10^6)		
12-17	0.02	267.98	0.001	0.0001	1,543.05	0.0001	0.00002
18-23	0.11	244.49	0.005	0.0005	1,284.09	0.0005	0.0001
24-29	0.33	220.98	0.014	0.001	1,051.17	0.0016	0.0003
30-35	0.68	197.63	0.029	0.003	843.10	0.004	0.001
36-41	1.31	174.23	0.055	0.006	659.55	0.015	0.003
42-47	2.75	150.59	0.112	0.013	572.26	0.018	0.004
48-53	6.17	126.11	0.230	0.030	415.41	0.046	0.010
54-59	10.68	99.32	0.365	0.057	282.48	0.098	0.022
60-65	13.33	70.08	0.467	0.088	173.12	0.159	0.038
66-71	11.04	41.55	0.501	0.100	89.49	0.203	0.051
72-77	6.09	19.52	0.469	0.088	35.08	0.224	0.058
78-83	2.29	6.53	0.392	0.064	7.93	0.333	0.100
84-89	0.35	0.70	0.500	0.100			
Total	55.15	1,619.71		F = 0.016[b]	6,956.73		F = 0.004[b]
Age (years)							
3	0.08	189.50	0.0046	0.0005	741.80	0.0006	0.0001
4	0.17	171.38	0.010	0.0010	607.26	0.0015	0.0003
5	0.22	154.91	0.015	0.0015	497.03	0.0024	0.0005
6	0.30	139.96	0.022	0.002	406.74	0.004	0.001
7	0.61	126.35	0.048	0.005	332.74	0.010	0.002
8	0.66	113.74	0.058	0.006	271.87	0.013	0.003
9	1.35	102.28	0.123	0.014	221.99	0.033	0.007
10	3.12	91.26	0.267	0.036	180.53	0.088	0.019
11	4.55	79.61	0.382	0.062	144.99	0.150	0.035
12	5.29	67.71	0.461	0.086	114.59	0.207	0.052
13	6.26	56.23	0.554	0.124	89.03	0.287	0.081
14	6.26	44.93	0.612	0.158	67.23	0.351	0.108
15	7.50	34.70	0.719	0.256	49.38	0.476	0.182
16	6.23	24.26	0.756	0.310	33.64	0.531	0.226
17	6.31	16.03	0.838	0.517	21.91	0.652	0.374
18	3.01	8.50	0.819	0.452	12.23	0.609	0.312
19	0.80	4.83	0.655	0.190	7.29	0.391	0.228
20	1.46	3.61	0.843	0.537	5.25	0.643	0.360
21	0.22	1.88	0.568	0.131	2.97	0.299	0.085
22	0.74	1.49	0.500	0.100	2.23	0.333	0.100
Total	55.14	1,433.16	F (3+) = 0.044[b] F(15+) = 0.334[b]		3,810.70	F (3+) = 0.017[b] F(15+) = 0.242[b]	

[a] Growth parameters: L_∞ = 87 cm, K = 0.0908.

[b] Average F weighted by stock size.

RESULTS

Subareas 2 and 3

The results of the cohort analyses are given in Table 3. For M = 0.1, the calculated stock sizes (ages 3+) are 1,620 million fish (using length composition data) and 1,433 million fish (using age composition data), and for M = 0.2 the corresponding stock sizes are 6,957 million and 3,811 million fish respectively. The mean F-values for the stock as a whole at M = 0.1 are 0.016 and 0.044 for length and age composition data respectively, and at M = 0.2 the corresponding values are 0.004 and 0.017. For fully-recruited age-groups (15+), the fishing mortalities are 0.334 at M = 0.1 and 0.242 at M = 0.2.

Table 4. Roundnose grenadier in Subareas 2 and 3: estimates of sustainable yield for fishing mortality levels of $F_{0.1}$ and F_{max} and two levels of natural mortality.

	Natural mortality (M)	Fishing mortality (F)	Yield per recruit (Y/R) (kg)	Sustainable yield (Y) (000 t)
Fishing at $F_{0.1}$	0.1	0.2	0.168	31.8
	0.2	0.4	0.055	40.8
Fishing at F_{max}	0.1	2.0[a]	0.192	36.4
	0.2	2.0[a]	0.067	49.7

[a] F_{max} actually >2.0.

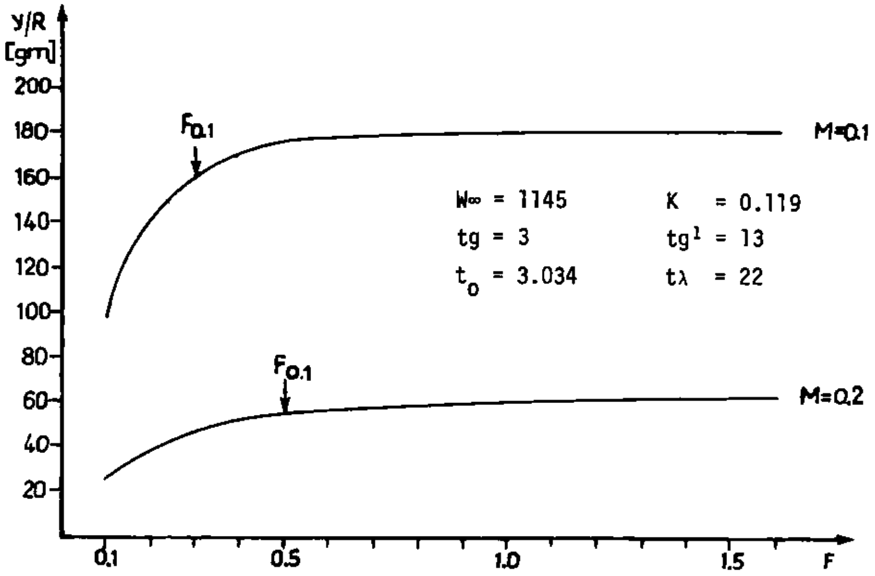

Fig. 4. Yield-per-recruit curves for roundnose grenadier in Subarea 1 and Statistical Area 0 for two levels of natural mortality (M).

The yield-per-recruit curves for M = 0.1 and 0.2 (Fig. 3) are both flat-topped with F_{max} greater than 2.0. Consequently, the sustainable yields were calculated with F_{max} = 2.0, giving 36,400 tons for M = 0.1 and 49,700 tons for M = 0.2 (Table 4). If fishing is conducted at the $F_{0.1}$ level of fishing mortality, the sustainable yields are 31,800 tons for M = 0.1 and 40,800 tons for M = 0.2, the corresponding values of $F_{0.1}$ being 0.2 and 0.4.

Statistical Area 0 and Subarea 1

The results of the cohort analyses for this area are given in Table 5. For M = 0.1, the calculated stock sizes (age 3+) are 211 million fish (using length composition data) and 343 million fish (using age composition data), and for M = 0.2 the corresponding stock sizes are 578 million and 918 million fish respectively. The mean F-values for the total stock (age 3+) are 0.034 and 0.044 for M = 0.1 and are 0.014 and 0.016 for M = 0.2. The fishing mortality on fully-recruited age-groups (15+) averaged 0.316 at M = 0.1 and 0.221 at M = 0.2.

As is the case for Subareas 2 and 3, the yield-per-recruit curves are flat-topped with no well-defined maxima (Fig. 4), the F_{max} value at M = 0.2 being greater than 2.0 and that for M = 0.1 being about 1.6. Thus, for F_{max} at 1.6 and 2.0 the sustainable yields are 8,300 and 11,400 tons with M = 0.1 and 0.2 respectively (Table 6). The corresponding sustainable yields at $F_{0.1}$ of 0.3 and 0.5 are 7,400 and 9,800 tons.

Table 5. Roundnose grenadier in Statistical Area 0 and Subarea 1: stock size and fishing mortality (F) for two values of natural mortality (M) from cohort analysis using length composition data for 1969-74 (above) and age composition data for 1973-74 (below).

		M = 0.1			M = 0.2		
	Catch	Stock	F/Z	F	Stock	F/Z	F
Length (cm)[a]	(10^6)	(10^6)			(10^6)		
18-23	0.05	39.31	0.015	0.002	136.94	0.002	0.0004
24-29	0.17	36.04	0.050	0.005	115.38	0.008	0.002
30-35	0.31	32.61	0.086	0.009	95.32	0.017	0.003
36-41	0.83	28.99	0.200	0.025	76.61	0.048	0.010
42-47	1.82	24.85	0.362	0.057	59.15	0.111	0.025
48-53	2.42	19.82	0.449	0.081	42.74	0.166	0.040
54-59	3.00	14.43	0.548	0.121	28.12	0.241	0.064
60-65	2.60	8.96	0.570	0.133	15.69	0.289	0.081
66-71	1.30	4.40	0.485	0.094	6.69	0.266	0.072
72-77	0.46	1.72	0.319	0.047	1.80	0.333	0.100
78-83	0.14	0.28	0.500	0.100			
Total	13.10	211.41		F = 0.034[b]	578.44		F = 0.014[b]
Age (years)							
3	0.03	45.42	0.006	0.001	178.48	0.001	0.0002
4	0.05	41.07	0.013	0.001	146.11	0.002	0.0004
5	0.08	37.10	0.024	0.002	119.57	0.004	0.0008
6	0.10	33.50	0.030	0.003	97.82	0.005	0.001
7	0.12	30.21	0.039	0.004	80.00	0.009	0.002
8	0.25	27.05	0.089	0.010	65.39	0.021	0.004
9	0.49	24.23	0.177	0.022	53.31	0.049	0.010
10	0.71	21.46	0.261	0.035	43.20	0.084	0.018
11	0.87	18.74	0.332	0.050	34.73	0.122	0.028
12	0.94	16.14	0.386	0.063	27.65	0.160	0.038
13	1.27	13.71	0.506	0.102	21.79	0.249	0.066
14	2.14	11.19	0.690	0.223	16.69	0.431	0.141
15	2.05	8.09	0.753	0.304	11.72	0.515	0.212
16	1.49	5.37	0.772	0.339	7.75	0.541	0.236
17	0.67	3.45	0.694	0.227	5.00	0.443	0.159
18	0.75	2.48	0.791	0.378	3.48	0.574	0.269
19	0.43	1.53	0.773	0.341	2.17	0.547	0.242
20	0.39	0.98	0.842	0.533	1.39	0.646	0.365
21	0.10	0.51	0.690	0.223	0.78	0.424	0.147
22	0.18	0.37	0.500	0.100	0.55	0.333	0.100
Total	13.11	342.60		F (3+) = 0.044[b] F(15+) = 0.316[b]	917.5		F (3+) = 0.016[b] F(15+) = 0.221[b]

[a] Growth parameters: L_∞ = 80 cm, K = 0.119.

[b] Average F weighted by stock size.

Table 6. Roundnose grenadier in Statistical Area 0 and Subarea 1: estimates of sustainable yield for fishing mortality levels of $F_{0.1}$ and F_{max} and two levels of natural mortality.

	Natural mortality (M)	Fishing mortality (F)	Yield per recruit (Y/R) (kg)	Sustainable yield (Y) (000 t)
Fishing at $F_{0.1}$	0.1	0.3	0.164	7.4
	0.2	0.5	0.055	9.8
Fishing at F_{max}	0.1	1.6	0.182	8.3
	0.2	2.0[a]	0.064	11.4

[a] F_{max} actually >2.0.

DISCUSSION

The calculated stock sizes using the two methods of cohort analysis were in some cases very different. This may be due to the sensitivity of the cohort analysis of length composition data to the parameters L_∞ and K of the von Bertalanffy growth equation. For example, the first calculation of the stock size in Subareas 2 and 3 for M = 0.2 (using length composition data) was started at length group 84-89 cm with a resulting stock size of 13,134 million fish. This value seemed too large in contrast to that obtained for M = 0.1, and a second calculation for M = 0.2 starting at length group 78-83 cm gave a stock size of 6,957 million fish (Table 3). The reason for the great difference in stock size is apparently related to the difference between L_∞ and the final length group used.

Considering the nature of the data available, the mean F-values for the total stocks resulting from the two methods of cohort analysis (i.e. for length compositions and age compositions) are not very different, especially for Statistical Area 0 and Subarea 1, thus indicating a good correspondence between the length and age composition data. Also, the results of the cohort analyses of the age composition data gave F-values that are nearly the same for both management areas (Table 3 and 5) not only for the stock as a whole but also for the stock of fully-recruited age-groups.

For Subareas 2 amd 3, the total fishing mortality coefficients (Z) are 0.434 and 0.442 for fully-recruited age-groups (age 15+) using M = 0.1 and M = 0.2 respectively. These values are essentially the same as that estimated by Pinhorn (MS 1974) from the right limb of a catch curve for age 12 and older (Z = 0.44), using age composition data from Savvatimsky (1971). The choice of the age at which full recruitment occurs is determined by the nature of the age composition data. Thus, the difference between the age-groups considered to be fully recruited by Pinhorn (MS 1974) and those in our data may be due to the different methods of age determination or to the fact that the calculations are based on age composition data from different periods and from different parts of the management area.

The average fishing mortalities of the fully-recruited stocks in the most recent years are higher than $F_{0.1}$ only for Subareas 2 and 3 with M = 0.1. It would seem, therefore, that the mean fishing mortalities in recent years have been at about the optimum level of exploitation of the stocks. In Subareas 2 and 3, the estimated sustainable yields at $F_{0.1}$ are 31,800 tons for M = 0.1 and 40,800 tons for M = 0.2, and the corresponding yields for Statistical Area 0 and Subarea 1 are 7,400 tons and 9,800 tons. This implies that the catches during 1970-74 in Subareas 2 and 3 (annual average of 34,000 tons) and in Statistical Area 0 (annual average of 8,000 tons) were in the range of the sustainable yields at $F_{0.1}$. The maximum sustainable yields (MSY) are about 12-22% higher than the sustainable yields at $F_{0.1}$. The MSY, calculated by Pinhorn (MS 1974) for Subareas 2 and 3 using M = 0.2 is about 50% higher than those resulting from our calculations using other methods and input data. Since the yield-per-recruit curves are flat-topped and since the relationship between spawning stock and recruitment is unknown, it would be better to consider the total allowable catch in relation to the sustainable yield at $F_{0.1}$ than at F_{MSY}.

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Growth and Life Cycle of Squid, *Loligo pealei* and *Illex illecebrosus*, from the Northwest Atlantic

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ABSTRACT

Populations of the long-finned squid (*Loligo pealei*) and the short-finned species (*Illex illecebrosus*) in the Northwest Atlantic from Newfoundland to the Long Island, USA, were sampled by trawl and the component size groups of the length frequencies analyzed. Three size groups were found to typify the composition of the populations, particularly in the autumn. It was observed that females are immature when they move offshore in the autumn. Large females participate in the spring spawning, and medium-sized individuals are found to be maturing or mature in late spring br summer. Thus, maturation seems to be induced during the winter months. The third group migrating inshore is composed of very young squid which remain immature during the summer and autumn.

All of these characteristics have been observed in the European cuttlefish, *Sepia officinalis*, and other Northeast Atlantic species, and the physiological mechanisms that support them are now inferred for the two Northwest Atlantic species noted above. Depending on the period between hatching and the first winter, two reproductive cycles are determined. Squid hatching from the early brood (spring) may have their maturation induced during the first winter and they spawn during the following summer (short cycle). Squid hatching from this summer brood are not sufficiently developed to mature during the first winter and they remain immature during the following summer and autumn as environmental factors inhibit maturation. As large squid, they mature during the second winter and spawn in the spring (long cycle). The progeny of this brood will belong to the short cycle. Both cycles are not separated by are crossed.

The proposed life cycles for both species were derived from analyses of size frequencies and growth and maturation patterns, together with inferences from the behavioural patterns of European squids.

INTRODUCTION

The most significant investigations on the age and growth of squids have been carried out by Squires (1957, 1967) for *Illex illecebrosus* and by Summers (1968, 1969 and 1971) for *Loligo pealei*, with important contribution on biology and distribution by Mercer (MS 1973, MS 1975) and Tibbetts (1976, MS 1976). Much of the data used as the basis of the earlier studies were taken during the periods of inshore migration to coastal waters. However, with the recent development of extensive offshore fisheries and the opportunities to collect more extensive material, the age and growth schemes proposed by the two first-mentioned authors have become subject to modification, since their hypotheses do not take account of certain size groups which occur in the offshore areas but were not present in their samples. This paper, therefore, attempts to elucidate more fully the relation of the different size groups to the maturation process and to determine the reproductive cycles of both species.

By inference from previous studies, in particular to that of the author, on European species, the behavioural pattern of the two Northwest Atlantic species appear to be due to similar response to ecological factors, and new schemes are proposed for each species in which two growth and reproductive cycles are differentiated. These account for all of the size components of the length frequencies in relation to the observed maturation stages and estimated growth patterns.

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MATERIALS AND METHODS

The main source of information for this study is data on long-finned and short-finned squids collected by the *R/V Cryos* during squid surveys carried out in May and September-October 1973, September-October 1974, and May and November-December 1975 on the Scotian Shelf, Georges Bank and adjacent areas to the southwest. In August 1975, samples of short-finned squid were caught by *R/V Thalassa* off the south coast of Newfoundland.

Immediately after sorting the catch by species, the squid were sexed and the dorsal mantle length measured to the half-centimeter below. The stage of sexual maturity was recorded after a scale proposed by Mercer (1973, personal communication). When sub-sampling was necessary for length measurements, the length frequencies were adjusted to those of individual catches, so that the analyzed frequencies pertain to the whole catch in a given area and season.

Length frequency distributions were analyzed graphically on probability paper after a method described by Harding (1949) and improved by Cassie (1954), whereby each component of a polymodal distribution is fitted to a normal curve and the modal length, identical to the mean in the normal distribution, is determined. The relative abundance of each size group is also provided, the percentages cited representing the proportion of males (or females) in the particular size group relative to the total number of males (or females) in the samples.

The separation of the specimens by sex is an absolute necessity, as both species of squid show sexual dimorphism in size, particularly those greater than 10 cm mantle length, and the analysis of pooled data would lead to rather inaccurate conclusions. In addition, two analyses are made for each sample in order to see if an extracted group has an equivalent in the other sex.

The graphical estimation of mean lengths is somewhat biased for the groups of small squid most affected by trawl selection. Theoretically, Cassie's (1954) method allows for the determination of the length distribution over the whole range, but the skewness observed in length frequency distributions of these groups often makes the corrections worthless. The estimated mean lengths for groups of small squid are, therefore, exaggerated and probably maximal values.

Mean lengths are used to estimate growth rates and the seasonal progression of size groups. Because of year-to-year differences, it is not so much the absolute values that are important but rather the relative position of the successive modes together with the modal (or mean) values themselves. In any case, the error in age estimation is not likely to be less than one month from this type of analysis.

REVIEW OF RELEVANT LITERATURE

In this investigation of life cycle patterns in *Loligo pealei* and *Illex illecebrosus*, much reference was made to the studies by Summers (1968, 1969, 1971) and Squires (1957, 1967), whose conclusions remain essential even though some improvements to them are proposed. Further assistance was obtained from research documents presented to meetings of the International Commission for the Northwest Atlantic Fisheries, particularly those by Mercer (MS 1973, MS 1975) and Tibbetts (MS 1975). Studies on the population structures of European cephalopods, particularly that by Mangold-Wirz (1963) in the Mediterranean Sea and by Holme (1974) in the English Channel, often provided useful information.

The author's unpublished studies on cephalopods in the Bay of Biscay are referred to in this paper, since the Northwest Atlantic species seem to have similar population dynamics as those of the Northeast Atlantic, which in turn have the same behaviour as Mediterranean species (e.g. *Loligo pealei* and*L. vulgaris*, and, to the lesser degree, *Illex illecebrosus* and *Illex coindetii*).

Comprehensive studies of the cuttlefish, *Sepia officinalis*, have been very helpful in understanding the population structure and life history of *Loligo vulgaris* and now those of *Loligo pealei*, all three species showing similar physiological reactions to variations in the environment. For this reason, a brief account of studies on the cuttlefish is given here.

In the southern part of the bay of Biscay and in the Mediterranean Sea, three successive "generations" migrate inshore every year: very large animals come to spawn in early spring, smaller cuttlefish which spawn during summer, and then the young immature animals. The last group feed abundantly and grow fast during their stay in inshore waters, but, in spite of their large size, they are still immature when they migrate offshore in the autumn, and it was thought that these individuals spawned in deep water during the winter. Each of these successive groups is characterized by a particular shape and structure of the cuttlebone, so that some authors had considered them to be separate species or races. The large spring spawners have type A cuttlebones, the scratched part being longer than the smooth one; the smaller summer spawners also have type A cuttlebones but the two parts are nearly equal; and the young immature *Sepia* have type B cuttlebones with the scratched part shorter than the smooth one. Mature females with type B cuttlebones have never been observed.

In a study of the mechanism of formation and evolution of the cuttlebone, Mangold (1966) has clearly demonstrated the interrelations between these forms, the variation in shape and structure of the cuttlebones being related to the phases of growth and sexual maturation, particularly in females. In winter, when growth is slow and the cuttlefish is maturing, its cuttlebone is transformed from type B to the type A typical of mature animals, so that the large spring spawners are the same individuals which left the inshore waters in the previous autumn. As for the existence of two groups spawning at different ages and sizes, it was for the first time assumed to be determined by ecological factors during the post-hatching period as will be explained below. Thus, the peculiarities of the cuttlebone led to the discovery of the existence of two life cycles, since nearly absolute post-spawning mortality is assumed to occur as in other species of cephalopods.

The physiological background of these phenomena was elucidated by Richard (1966, 1967), who found that two principal external factors are involved: growth and maturation are accelerated by higher water temperature; and a long-night photoperiod releases the inhibition to the ovarian maturation in females by the central nervous system in conjunction with the optic glands, males being rather insensitive to this, whereas long-day photoperiods and/or intense light inhibit ovarian maturation but induce egg-laying by mature females. This explains why maturation in females is observed to be induced in winter. By considering both factors, Richard concluded that the life cycle is determined by the time interval between hatching and the first winter.

For young squid hatched in the spring, high temperatures during the summer allow fast growth and the squid are fairly well-developed by the time they enter the first winter. Maturation may be induced by the decrease in day length, and this, together with the slower growth caused by lower temperatures, induces the transformation of the cuttlebone in *Sepia*. The maturation process continues during the spring and the rather small animals spawn in summer at an age of about 14 months.

For young squid hatched in the summer, their development at the time of the first winter has not reached the stage when the maturation of their gonads may be induced by the favourable light conditions, and their growth is much affected by lower temperatures. During the following summer, the long-day photoperiod and more intense light conditions inhibit maturation but conditions are favourable for feeding and fast growth. Maturation in this group occurs during the second winter and they come inshore in the spring (as large squid) to spawn at an age of about 18 months when the increasing daylight induces egg-laying. Squid hatching from this brood will follow the short cycle and spawn during the following summer.

Rowe and Mangold (1975) found also that starvation releases the inhibition to maturation in *Illex illecebrosus* from the Newfoundland area. Thus, after actively feeding on the continental shelf during the summer, these squid would be expected to mature during the winter in deep water where feeding conditions are less favourable. Since this factor would have an effect in winter only and on large enough animals, it may also lead to distinct reproductive cycles.

The physiological mechanisms described above enable us to understand how, from an extended breeding season, two reproductive cycles become distinct in a temperature environment. Similar phenomena will now be inferred in the explanation of the growth and life cycles of *Loligo pealei* and *Illex illecebrosus* in the Northwest Atlantic.

LONG-FINNED SQUID, *Loligo pealei*

Analysis of Size Frequencies

Histograms representing the size composition of samples, taken during four cruises in 1973 to 1975, are given in Fig. 1. The application of Cassie's (1954) method to the size frequencies resulted in each being broken down into three modal groups, labelled 1 to 3 in association with the letters A, B, C and D representing the chronological order of the cruises. A summary of the results is given in Table 1.

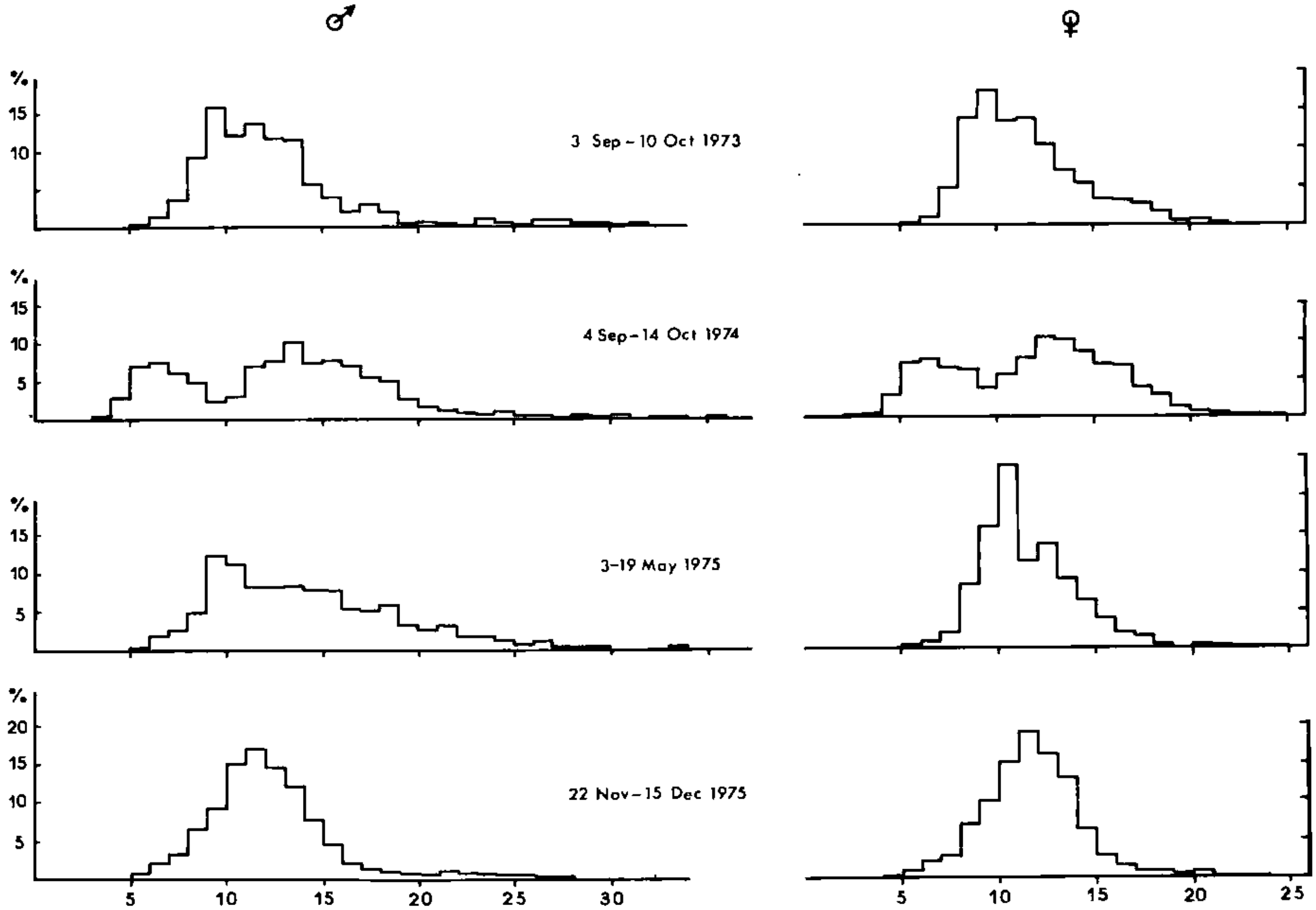

Fig. 1. Size frequency distributions for *Loligo pealei*, 1973-75.

Table 1. Summary of size frequency analyses for *Loligo pealei* in the Georges Bank area, 1973-75. (The values for males (M) and females (F) represent the percent abundance, the length range and the mean length (cm).)

May 1975	M			C1	44% 5-13(10.2)	C2	44% 10-18(15.4)	C3	12% 18-33
	F				57% 5-13(10.0)		42% 10-18(13.2)		1% 20-24
Sep-Oct 1973	M	A1	36% 5-12(9.6)	A2	53% 10-17(12.5)	A3	11% 18-30(19.0)		
	F		44% 5-12(9.1)		45% 9-16(12.2)		11% 14-21(17.1)		
Sep-Oct 1974	M	B1	30% 2-10(6.6)	B2	64% 9-21(14.6)	B3	6% 19-30(23.2)		
	F		33% 2-10(6.8)		60% 9-18(13.5)		7% 16-24(18.4)		
Nov-Dec 1975	M	D1	86% 4-14(11.3)	D2	11% 11-20(15.5)	D3	3% 18-27(22.4)		
	F		70% 4-14(10.9)		27% 11-17(13.5)		3% 18-23(19.3)		

During the first cruise in September-October 1973, trawling stations were occupied on the northern part of Georges Bank and three size groups of the long-finned squid could be determined from the size frequencies. The first group (A1), constituting about 36% of the males and 44% of the females, contained 5-12 cm squid with average mantle lengths of 9.6 and 9.1 cm for males and females respectively. The main component (A2) of the population (53% of the males and 45% of the females) consisted of 9-17 cm animals with mean lengths of 12.5 and 12.2 cm for males and females respectively. These were distributed over the whole area surveyed but the mean size was about 15 cm on the central part of the bank, indicating that the larger animals tended to have a more northerly distribution. The largest individuals (A3), about 11% of the samples for both males and females, consisted of a mixture of age-groups, one with a mean length of 19 cm for males and 17.1 cm for females and the other with larger males of 22-31 cm. This group was also better represented on the shallower part of the bank.

A more extensive survey was carried out during September-early October 1974, and the observations were previously presented by Paulmier and Mesnil (MS 1975). However, the very young specimens were not sexed and thus were not included in the size frequencies. On the basis of the usually observed 1:1 sex ratio in these young squid, 50% of the number at each length interval have now been added to the length distributions of males and females (Fig. 1). Also, the samples taken to the south of Georges Bank, which were excluded from the previous analysis, have now been included. The smallest size group (B1) of the resultant frequencies (30% of the males and 33% of the females) ranged from 2 to 10 cm with a mean length of 6.5 cm. These were found only to the north of 39°30'N latitude and were more abundant in the deeper areas; a decrease in mean length from shallow to deep water was also noticeable. The most important component (B2) of the stock during this cruise (about 60% of the catch) consisted of 9-21 cm males and 9-18 cm females with mean lengths of 14.6 and 13.5 cm respectively. These ranges and mean sizes showed significant geographic variation, decreasing toward the southern areas, particularly to the south of Hudson Canyon. Most members of this group were still immature. Squid larger than 16-19 cm (B3) were irregularly distributed over the surveyed area. The mean lengths of males and females were 23.2 and 18.4 cm respectively, with males ranging up to 30 cm but females only up to 24 cm. A few males of 30-35 cm were also present. Most of the males were mature and the females were beginning their maturation.

The same area was surveyed in May 1975 and three modal groups were again determined from the length frequencies. The first group (C1), consisting of 44% of the males and 57% of the females in the samples, had a size range of 5-13 cm with mean lengths of 10.2 and 10.0 cm for males and females respectively. All of the females and nearly all of the males were immature. These smaller squid were abundant mostly on the edge of the shelf to the south of Georges Bank in 110-180 m. The second group (C2) constituted 44% of the males and 42% of the females. The length range of both sexes was 10-18 cm with mean lengths of 15.4 and 13.2 cm for males and females respectively. Most of the males and females were mature, and most of the females, even immature, had mated. Squid larger than 18-20 cm (C3) were predominately male with a maximum size of 33 cm, the few females reaching a maximum size of 24 cm. All were fully mature and egg clusters were found in 100 m on the southern slope of Georges Bank. It is likely that most of the squid belonging to this group have either migrated to coastal waters or have spawned and died in coastal or deep-water areas. During this May 1975 cruise, observations were made on the maturity stages of squid in relation to length and these are given in Table 2. For both males and females, the three modal groups are readily distinguished: immature, mixture of maturing and mature, and fully mature. Two interesting features of the reproductive behaviour of the species must be stressed: squid mate during the course of their migration to the coast, sometime before spawning, and even females which were not fully mature were observed to carry spermatophores on their buccal membrane; females may spawn in deep water as well as in inshore areas.

The fourth cruise took place on Georges Bank and south of Nantucket Shoals during late November-December 1975. Squid with mantle lengths of 4-14 cm (D1) were widely predominant (80% of the catch) and occurred at every station occupied on the outer shelf areas. Mean lengths of 11.3 and 10.9 cm were estimated for males and females respectively. SQuid forming the second group (D2) in the 11-20 cm size range were difficult to separate from the first group, except in the deep-water strata off Long Island and on the slope to the south of Georges Bank. It is possible that the majority of this size group in the population has migrated from the shelf areas toward deeper water or to the south, with only the smaller members of the group remaining on the shelf. The mean lengths of males and females were 15.5 and 13.5 cm respectively, with their respective abundances at 11% and 27%, but these figures are likely to be all underestimated. The largest squid (D3) represent only about 3% of the size frequencies, with estimated mean lengths of 22.5 and 19.3 cm for males and females respectively.

Table 2. Length distributions of *Loligo pealei* by maturity stages for Georges Bank area, May 1975.

Mantle length (cm)	Male				Females[a]		
	Immature	Stage I	Stage II	Mature	Immature	Maturing	Mature
5	2	-	-	-	4	-	-
6	6	-	-	-	6	-	-
7	6	-	-	2	9	-	-
8	10	2	2	-	18	1	-
9	26	4	5	5	37	8	2
10	15	6	9	11	45	24	16
11	6	8	8	16	26	17	20
12	7	6	5	21	18	43	25
13	2	9	9	19	12	23	26
14	2	12	13	20	4	13	32
15	-	9	8	24	1	11	28
16	-	5	5	18	2	4	13
17	1	4	9	24	1	-	9
18	-	2	6	25	-	2	3
19	-	-	4	18	-	-	-
20	-	-	-	21	-	1	6
21	-	-	2	25	-	-	3
22	-	-	1	12	-	-	1
23	-	-	-	13	-	-	1
24	-	-	-	9	-	-	1
25	-	-	-	5	-	-	-
26	-	-	-	8	-	-	-
27	-	-	-	2	-	-	-
28	-	-	-	2	-	-	-
29	-	-	-	2	-	-	-

[a] Most of the maturing and mature females have mated.

On the basis of the length frequencies from each cruise, the long-finned squid population seems to consist of two main components, with the third component consisting of a mixture of individuals belonging to two or more age-groups.

Growth and Age

The results of the analyses, summarized in Table 1, are arranged so that the differences between years and the changes within the year are apparent. Year-to-year variation in growth are important as indicated by the difference in size compositions of Groups A1 and B1. However, these differences may also be due to the capture of larger squid in the 1973 survey, which covered only the Georges Bank area, whereas the 1974 survey covered a much larger area, particularly to the southwest.

The squid sampled on the northern part of Georges Bank (A1) may be considered to be the larger individuals of a group characterized in the same season of 1974 as group B1, and as D1 about 2 months later in 1975. Groups A2 and B2 have similar mean lengths in the same seasons of 1973 and 1974, these corresponding to D2 in late 1975, and their members show identical variations in size from north to south due to an active offshore migration. If the autumn and spring components are now compared, group C2 in May seems to follow from D1 in November-December, which in turn follows from A1 or B1 in September-October. Since the mean length of Group C1 in May is only 10 cm, it cannot follow from D1 (unless growth ceased during the winter) but must belong to a separate progeny. However, groups A2 and B2 appear to be the grown-ups of Group C1. The first steps in the proposed growth scheme are, therefore,A1 or B1 ——> C2, and C1 ——> A2 or B2 ——> D2.

In considering the problem of age, the presence of mature squid and egg clusters must be taken into account. In the early part of May 1975, fully mature squid of both sexes as well as eggs were found offshore at the time when most of the breeders are supposed to have already migrated to inshore waters and spawned. Thus, near the northern part of the range of the species (Georges Bank), the first spawning period is April-May (probably earlier in more southerly areas) and hatching may begin in June. Young-of-the year appear for the first time in the fall as group A1 or B1, thus being about 5 months old with mean length in the range of 7-9 cm. Their monthly growth during the summer months is therefore 1.7-2.0 cm. Later in the autumn (November-December), group D1 has a mean length of about 11 cm, these squids being 6-7 months old. Growth since hatching is 1.6-1.8 cm per month with only 1.0-1.5 cm per month after Septbember. These growth rates are essentially the same as those calculated by Summers (1968). For Group C2 in May, nearly one year old, males average 15 cm and females 13 cm in mantle length, and both sexes are maturing or mature. The monthly growth increment during the five winter months (December-April) has declined to 0.4-0.6 cm, resulting in an average growth of 1.2-1.3 cm per month between hatching in June and 11 months.

Considering the parallel sequence from group C1 to D2 and taking a monthly growth increment of about 1.2 cm between September-October and May as the basis for calculation, the squid in group C1 (mean length at 10 cm in May) must be about 8 months old, thus indicating that spawning and hatching occurred in August-September of the previous summer. During the progression of this group to A2 or B2, and thence to D2 in the autumn, growth is only about 1 cm per month, an indication that these squids were strongly affected by the low temperatures during the preceding winter. The members of this group will mature during the second winter and will spawn in early spring when they are about 20 months old at an average size of about 20 cm. If the "parents" of this group spawn in later summer, as postulated above, the only mature squid present in the area at the time are those belonging to group C2 in May, their age at spawning being 14 months.

The two reproductive cycles of *Loligo pealei* are illustrated in Fig. 2. Those squid hatching in the spring spawn during the summer more than a year later when they are 14 months old, and their progeny remain immature during the following year and mature for spawning in the succeeding spring at an age of 20 months. The two cycles are therefore crossed, a phenomenon already observed in *Sepia officinalis* and *Loligo vulgaris* of European waters.

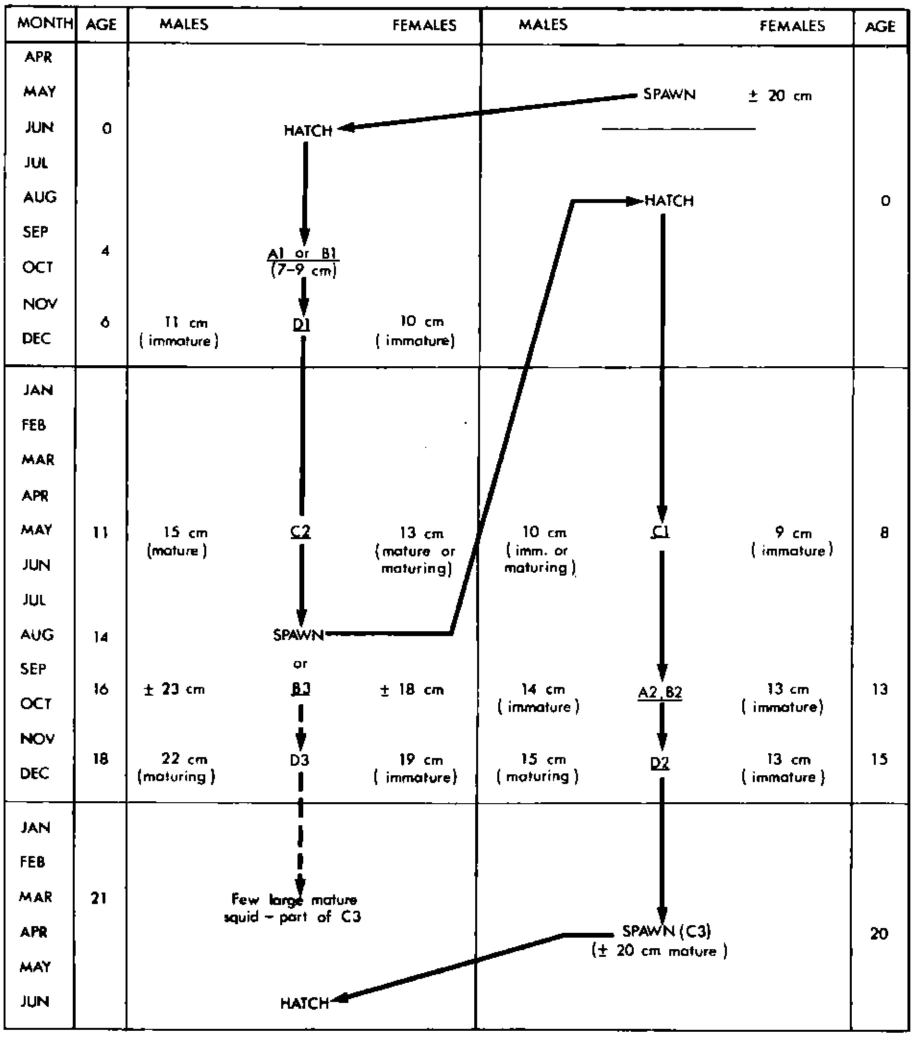

Fig. 2. Growth and reproductive cycles of *Loligo pealei* in the Northwest Atlantic.

Only the main components of each sample are considered in this study with particular attention to females, but the larger-sized squid are also involved in the cycles. Many of them, particularly males, may breed a second time and these are mixed with the younger age-groups on the spawning grounds. Males mature earlier than females and very young males may participate in the early spring breeding. On the other hand, some squid may remain immature for up to two years, as indicated by the presence of large immature individuals in some of the autumn samples.

SHORT-FINNED SQUID, *Illex illecebrosus*

Analysis of Size Frequencies

Histograms representing the length distributions of this species, taken during six cruises in 1973 to 1975, are given in Fig. 3. As was done for *Loligo pealei*, the length frequencies were analyzed by Cassie's (1954) method, and a summary of the results is presented in Table 3, the letters A to F designating the chronological order of the six cruises.

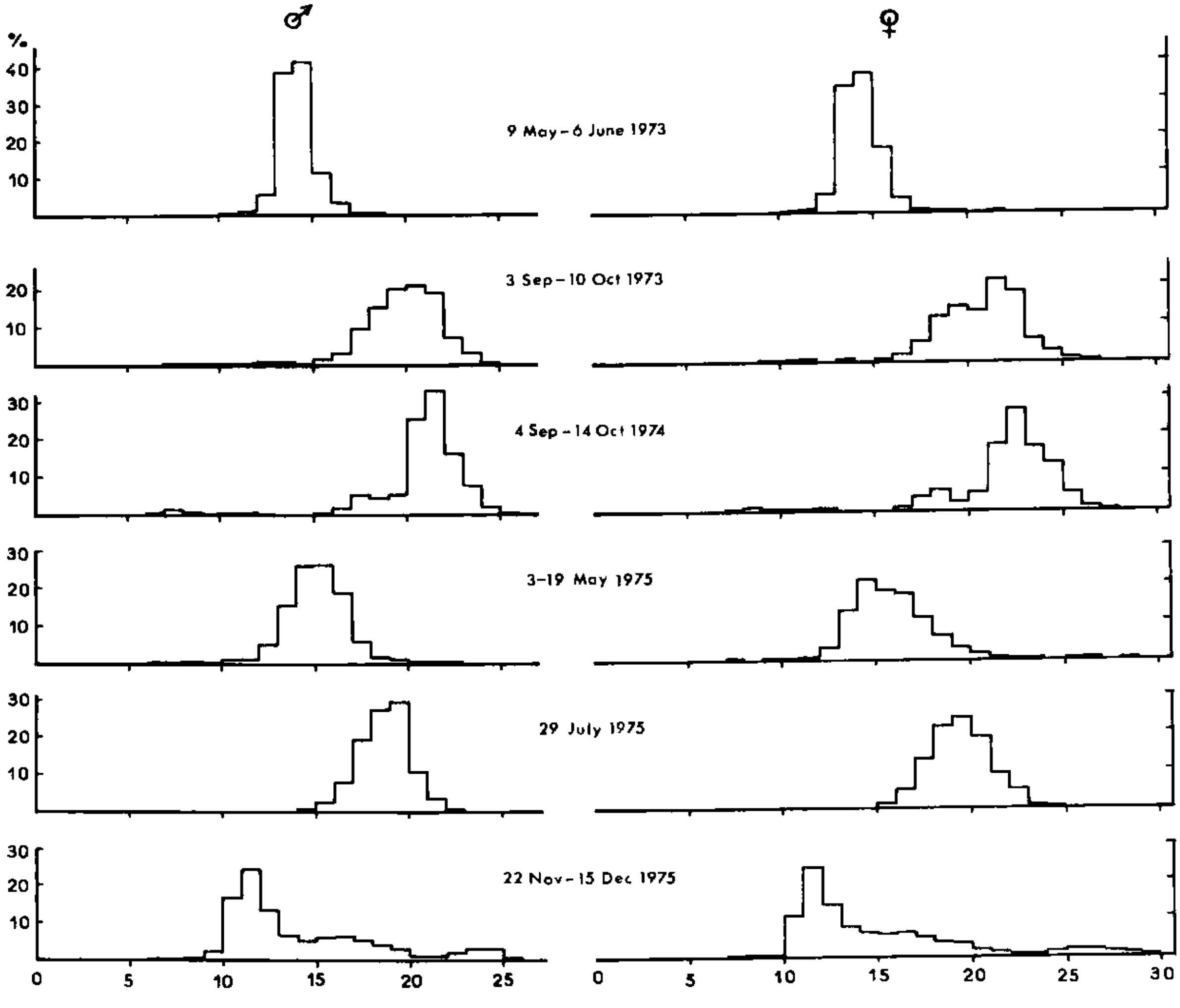

Fig. 3. Size frequency distributions for *Illex illecebrosus*, 1973-75.

During the first cruise in May 1973, short-finned squid were caught on the southern Grand Bank, the Scotian Shelf and the northeastern tip of Georges Bank. Nearly all of the specimens ranged in size (mantle length) from 9 to 18 cm, with the mean length of males and females being 14.1 and 14.3 cm respectively. Mercer and Paulmier (MS 1974) found that mean lengths were significantly higher on the Scotian Shelf and Georges Bank. Within this group (A1), five 14-16 cm males were found to be at maturity stage I while the others were immature. A mature 30 cm female which had mated and two 21 cm females with slightly enlarged nidamental glands were also caught, these belonging to an older age-group.

In the September-October cruise on Georges Bank, three size groups of squid could be identified. The first group (B1), constituting only 1% of the catch, with a size range of 7-15 cm, were taken mostly on shallow parts of the bank. The second group (B2), constituting about 44% of the males and 41% of the females, average 18.5 and 19.0 cm in length for males and females respectively. These also tended to be more abundant in the shallower parts of the bank. The third group (B3), representing 55% of the males and 58% of the females, were found mainly in the deeper areas of the southern slope of the bank, probably in the process of migrating from the shelf. The average length of this group was 21.1 cm for males and 22.0 cm for females.

A similar size structure was observed in the September-October 1974 survey on Georges Bank, but the relative abundance of the size groups were somewhat different from that in 1973. The first group (C1), about 3% of the catch, consisted of young 6-13 cm squid with a mean size of about 8 cm. These were not present in the deep water and more southerly parts of the surveyed area. About 12% of the sampled population constituted the second group (C2), which was present only at trawling stations south of Cape Cod. The mean sizes of males and females were 17.7 and 18.2 cm respectively. All females were immature, but most of the males larger than 18 cm were maturing. The main component (C3) of the population in the surveyed area (about 85%) was composed of larger squid with an average size of 21.5 cm for males and 22.9 cm for females. Most of the males larger than 21 cm were mature or late-maturing.

In May 1975, only one component (D1) was found in the Scotian Shelf and Georges Bank areas, consisting of 6-22 cm males and 7-23 cm females with mean lengths of 15.1 and 15.7 cm respectively. Geographical variation in size was noticeable, with mean lengths of males being 14.3 cm on the Scotian Shelf (similar to group A1), 15.4 cm on Georges Bank and 15.6 cm to the south of 40°30'N latitude and corresponding sizes of females being 14.6, 15.8 and 16.4 cm respectively. All females were immature, but a few males largerger than 13 cm were at maturity stages I and II and some at 14-22 cm were mature.

A sample of squid taken off southern Newfoundland on 29 July 1975 (E1) consisted of 14-22 cm males and 15-24 cm females with mean lengths of 18.7 and 19.4 cm respectively. A few of the males in the upper half of the size range were at maturity stage I. The size distribution in this sample was typical of the group which occurred in great abundance in Newfoundland waters during the summer of 1975.

Table 3. Summary of size frequency analyses for *Illex illecebrosus* in the Northwest Atlantic from southern Newfoundland to Georges Bank, 1973-75. (The values for males (M) and females (F) represent percent abundance, the length range and the mean length (cm).)

May 1973	M					A1	9-18(14.1)
	F						10-18(14.3)
May 1975	M					D1	6-22(15.1)
	F						7-23(15.7)
July 1975	M					E1	14-22(18.7)
	F						15-24(19.4)
Sep-Oct 1973	M	B1	1% 7-15	B2	44% 15-20(18.5)	B3	55% 18-24(21.1)
	F				41% 15-21(19.0)		58% 19-26(22.0)
Sep-Oct 1974	M	C1	3% 6-13 (8.0)	C2	11% 15-20(17.7)	C3	86% 19-26(21.5)
	F		3% 6-13 (8.0)		12% 16-21(18.2)		85% 19-30(22.9)
Nov-Dec 1975	M	F1 60%	6-14(11.5)	F2 32%	13-21(16.5)	F3 8%	21-25(23.7)
	F		7-15(12.0)		14-23(17.2)		22-30(25.9)

In November-December 1975, three size groups were present in the samples taken on the Scotian Shelf and Georges Bank. About 60% of the catch consisted of juveniles (F1) with mean lengths of males and females being 11.5 and 12.0 cm respectively. These were mainly prevalent on the Scotian Shelf and the northern part of Georges Bank, with those taken on the Scotian Shelf being noticeably smaller. The mean lengths given for this group are probably over-estimated, as small squid were often seen escaping from the meshes of the trawl. The second group (F2), constituting 32% of the catch, averaged 16.5 and 17.2 cm for mlaes and females respectively. All females were immature, while most of the males larger than 15 cm were maturing (stages I and II) or mature. Squid in this size group were prevalent on the Scotian Shelf and also on the southern slope of Georges Bank at depths of 110-180 m, but they were less abundant in more southerly areas. The third group (F3), only 8% of the catch, consisted of large animals over 20 cm in length, the averages for males and females being 23.7 and 25.9 cm respectively. These were found mainly in the deep-water areas to the south, particularly near Hudson and Corsair Canyons, and their scarcity in the samples suggest that most of them have migrated from the shelf to deep-water areas. The length frequency distribution of mature males (Table 4) shows two modes, corresponding to groups F2 and F3 respectively.

Table 4. Length distributions of male *Illex illecebrosus* by maturity stages, from samples taken on Georges Bank and vicinity in November-December 1975.

Mantle length (cm)	Males			
	Immature	Stage I	Stage II	Mature
6	1	-	-	-
7	4	-	-	-
8	6	-	-	-
9	30	-	-	-
10	123	-	-	-
11	155	-	-	-
12	138	-	-	-
13	142	-	-	-
14	164	1	-	-
15	206	13	1	-
16	148	50	1	-
17	63	60	2	2
18	18	32	23	13
19	14	22	29	30
20	2	6	13	16
21	-	1	2	28
22	-	1	1	57
23	-	-	2	100
24	-	-	-	80
25	-	-	-	13

For this species, the identification of related groups during the various seasons (Table 3) is relatively simple: groups A1 and D1 in May are equivalent, as are also groups B1, C1 and F1, groups B2, C2 and F2, and finally B3, C3 and F3. Referring to Squires' (1967) scheme, the evolution of some of the groups would be A1 or D1 ——> E1 ——> B3 or C3 ——> F3, with that of the remaining groups being still not understood.

Growth and Age

The seasonal changes in average size of this species, as observed by Squires (1967) and other authors, are confirmed here (Table 3) to occur over a very large area. These changes in size permit the calculation of growth rates during various parts of the year. Between May and the end of July (groups D1 to E1), growth occurs at an average of 1.8 cm per month for both males and females. From late July to late autumn (E1 to F3), the monthly growth increments are 1.2 and 1.6 cm for males and females respectively. The average growth from May to December is therefore estimated at 1.4 cm per month for males and 1.7 cm for females. Higher values are obtained from groups A1 to B3 or C3 between May and September-October (1.8 cm per month for males and 2.0 cm for females). However, as noted in the previous section about geographical variation, the mean lengths for Group A1 (Scotian Shelf) may be under-estimates if the larger individuals of the group have migrated from the area surveyed. The monthly growth increments, calculated by Squired (1967) are 2-3 cm for males and 1-4 cm for females.

From the calculations presented above, average monthly growth rates of 1.6 cm for males and 1.9 cm for females are used to estimate the ages of the various groups. With a mean length of 14-16 cm in May, the squid in group A1 or D1 must be 8-9 months old and therefore were spawned in July or August of the previous year. Assuming that the mean size of group F1 in December is slightly over-estimated, the actual mean length being about 10 cm, these squid are estimated to be about 6 months old, so that they would have hatched in early summer of the same year. Consequently, the medium-sized squid caught in late spring (A1 or D1) are related to the small squid caught in the preceding autumn (C1 and F1), these having hatched in the preceding summer. The sequence would therefore be: July brood ———> C1 ———> F1 ———> A1 or D1 ———> E1 ———> B3 or C3 ———> F3. When they come to the Newfoundland area in May, the squid of groups A1 or D1 would be 10 months old from the previous summer's brood and not 4 months old from a winter brood. They leave the area in November to spawn in the winter, then about 18 months old.

In September-October, the males of group B2 or C2 are on the average about 16-18 cm long and females are 17-19 cm. If their growth rates during the preceding summer were also 1.6 and 1.9 cm per month respectively, they are estimated to be 9-10 months old, so that they would have hatched in January or February of the same year. They would thus be the progeny of group F3 of the preceding sequence. Although group F2 had much shorter mantle lengths than F3, many of the males were maturing or mature and it may be supposed that they will breed during the following summer. Thus the second sequence would be F3 (winter brood) ———> B2 or C2 ———> F2 ———> July brood (following year).

For this species also, crossed generations are found to fit the evolution of the observed size groups. Two life cycles, with nearly identical durations, are suggested, as illustrated in Fig. 4.

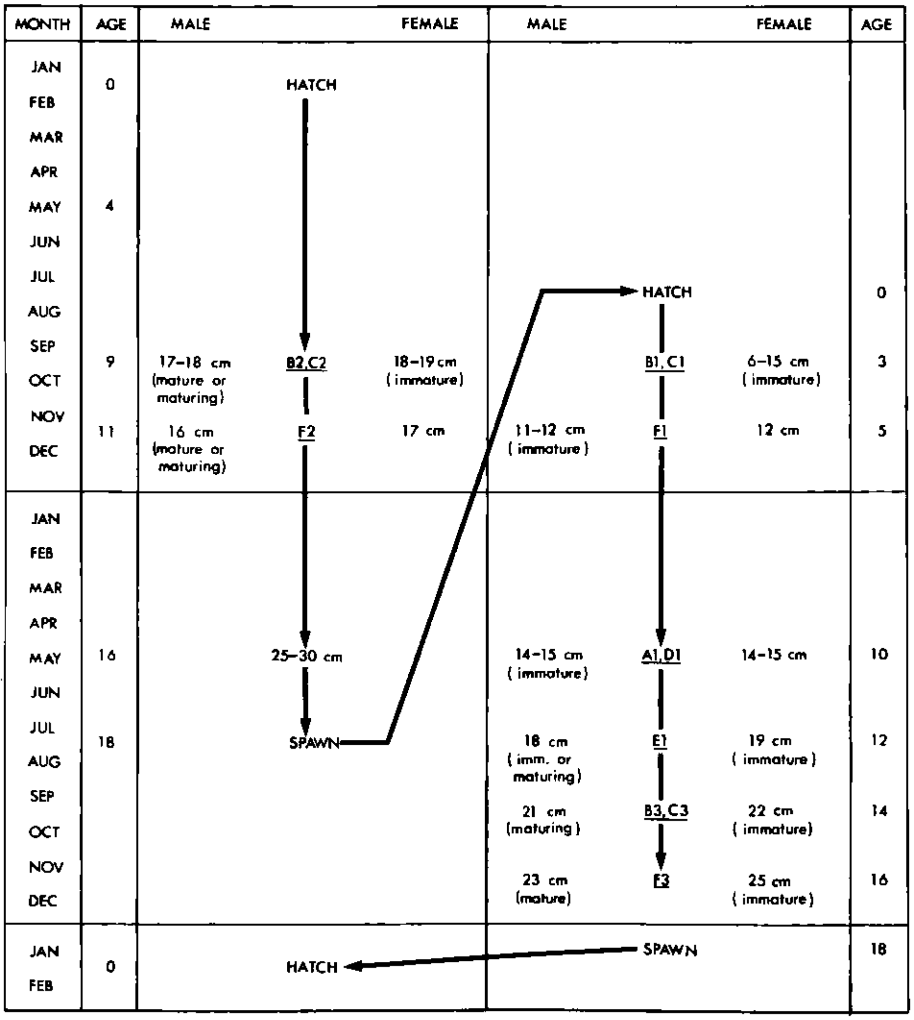

Fig. 4. Growth and reproductive cycles of *Illex illecebrosus* in the Northwest Atlantic.

DISCUSSION

Loligo pealei

On the basis of the analyses presented in this paper, two modifications to the generally accepted life history of this species are suggested: the existence of two life cycles that are not fully separated but are crossed, and a late summer spawning instead of November. The latter is preferred to Summer's (1971) hypothesis, primarily because he does not mention the presence of mature squid in November, only supposing that they remain to the south, and because the latest records of egg clusters are mentioned in September, thus fitting better to our summer brood hypothesis. In this paper, ages are estimated from average growth rates of squid in the parallel cycle during the same period, and reproduction is shown to occur at seasons when fully mature individuals are actually present.

The particularity of the size distributions observed in the spring and autumn, at nearly half-year intervals, is the first clue of the existence of two generations per year and, to a lesser degree, of crossed cycles. In both spring and autumn, the two first components of the population have similar mean lengths (Table 1): 10-11 cm in groups C1 and D1; 13-15 cm in groups A2, B2 or D2 and C2; and larger squid 20-30 cm are present in both seasons. A natural conclusion is that the first component in May (C1) grows to the second component in the autumn (A2 or B2), while, for the other cycle, the second spring component (C2) issues from the small squid present in the autumn (A1, B1 nd D1). The actual link between these groups is finally demonstrated after the analysis of the samples and the study of growth and maturity.

With the knowledge of the existence of two cycles in the life history of *Sepia* and the inference that such may also occur in *Loligo pealei*, we started from two fully separated hatching periods to give a clearer idea of the physiological mechanism, and size was used as a first order index to estimate the probability of maturation. A clear distinction must be made between the induction of maturation that always occurs during winter under the influence of environmental stimuli and the maturation process itself that can develop rapidly in late winter on large animals or more slowly during spring and summer on smaller ones. This leads to an extension of the breeding period which extends from April to September, with peaks in May and July, as younger squid migrate and mature somewhat later than larger ones. The actual process is physiological and depends on the condition of the animal and more on its sensitivity to variations in environmental factors than on its exact age. Thus, some individuals from a particular brood may mature and spawn earlier than usual while others remain immature for a longer period, even up to two years as observed in *Sepia*. Individuals born at both spawning seasons in the year may therefore be mixed in the spawning areas during the following year.

On the basis of geographical variations in size, migration and population structure, all showing a north-south axis, *Loligo pealei* is considered to have primarily a meridional affinity. Considering that Georges Bank is near the northern limit of the range of this species, this zoogeographical affinity may cause delays in the dates of migration and reproduction of large spring spawners, and the smaller summer spawners may be poorly represented in this area. This last point agrees with Summer's (1971) assumption that late spawning occurs mainly in the south, but the data presented in this paper indicate that late born squid have a very wide distribution during the following year.

Similar variations in the structure and behaviour of squid populations in European waters have been observed. In the Bay of Biscay, *Loligo vulgaris* migrates only very short distances between coastal waters and the slopes of the continental shelf. Large spring spawners migrate inshore very early and the offshore migration begins very late; two reproductive cycles are observed and summer breeders are quite well represented in the population. In the North Sea, however, only the large squid migrate and spawn in late spring (May), and individuals from other groups are scarce. The north-south migrations cover long distances, the wintering grounds being located in the northern part of the Bay of Biscay at the southwestern entrance to the English Channel (Holme, 1974). Thus, the observations of Tinbergen and Verwey (1945) may only concern the areas near the northern part of the range of the species, while to the south the species shows the same patterns as in the Mediterranean Sea. Another pattern of behaviour is observed in Northwest African waters, near the southern limit of the range, where *Loligo vulgaris* remains inshore all year long and the breeding period is greatly extended.

Illex illecebrosus

As was done for *Loligo*, approximate ages were estimated from observed growth rate data and the proposed life-history cycles determined. The growth rate data cover those parts of the cycles already described by Squires (1957, 1967) and other authors, but somewhat different values are found. The differences may be due to the fact that Squires estimated the ages by extrapolation from a mathematical model which may not be adequate. The life cycles are demonstrated here to be short and growth rates show considerable seasonal variation relative to the duration of the cycles, the growth curves showing a pronounced step-like profile. Besides, both sexes are combined in his data, and this leads to an over-estimation of the average growth rate. However, monthly growth increments calculated from his observed lengths are quite comparable to those presented in this study. Seasonal variation in growth are important and the growth rate during the summer is assumed to be higher than in other seasons; when the squid migrate to the shelf areas in summer, they find an abundance of food and the optimal conditions for digestion and growth. Even so, the growth rates used to estimate ages lead to higher figures than the ages calculated from Squires" (1967) model and lead to longer cycles.

Actually, the need for modifications to the previous hypothesis on the life cycle of *Illex illecebrosus* arose from observations on particular size-groups which are seldom found in Newfoundland waters, since only a few elements that can be recognized as members of groups <u>B2</u>, <u>C2</u> and <u>F2</u> migrate there in some years. These groups are much better represented in the more southerly areas, and can no longer be considered as later-spawned or slower-growing individuals, especially when their maturity pattern is analyzed.

The basic key to the present conclusions was provided by the important group (<u>F1</u>) of young squid, which were also observed during US groundfish surveys in the autumn as reported by Tibbetts (1976). Since the modal length of these young squid in her size frequencies is less than 10 cm, the mean length of the <u>F1</u> group (Table 3) is likely to be over-estimated. This group is usually abundant in the Georges Bank area in the autumn and should be found in equivalent abundance during the following spring or summer as larger animals. The relation between this <u>F1</u> group and groups <u>A1</u> or <u>D1</u> is thus supported, as the latter groups are also dominant in late spring and summer on all of the Northwest Atlantic shelves. This was particularly well demonstrated in the summers of 1975 and 1976. For several years, squid were very scarce in the Newfoundland area but they came back in great abundance during these 2 years. This seems to be well correlated with the pre-recruit indices from autumn surveys off the US coast: the mean number per tow of young *Illex* less than 10 cm was 0.3 in 1973, 2.1 in 1974 and a high of 9.6 in 1975 (Tibbetts, MS 1976). This kind of variation in the strength of one of the generations, together with environmental effects, might explain the very great year-to-year fluctuations in the abundance of squid in Newfoundland waters during the summer. In addition, the relations between these groups, and between other groups belonging to either cycle, confirm the unicity of the *Illex illecebrosus* population in ICNAF Subareas 3 to 5 and Statistical Area 6.

The presence of maturing and mature males in the May samples (Table 3, groups <u>A1</u> and <u>D1</u>) indicate that these squid were spawned in the preceding year; if they were born in February of the same year, their age would be only 3-4 months and their maturation would be incredibly fast. In the proposed cycle, female squid begin to mature in winter at 12-16 months of age. The duration of the cycle is still rather approximate, since the time of hatching is unknown. Significant catches of the species are made only during the feeding period when the females are immature, but spawning takes place in deep water and eggs have not yet been found. Even the presence of larvae is of little help, as all squid in the family Ommastrephidae have similar planktonic *Rhynchoteuthis*. Thus, the breeding periods can only be estimated from the maturity stages of males, the dates of migrations to and from the shelf areas and the appearance of young squid.

The same problem is found in *Illex coindetii* in the Bay of Biscay, but better estimates of breeding times are possible because maturation begins at a smaller size in both sexes, mature individuals and mated females being found in November and in June before their offshore migration. Large winter spawners are caught by trawlers off the Spanish coast, making it possible to fix the first breeding period in January-February. An equivalent delay may be inferred for summer migrants and breeders. This species also migrates to the continental shelf once or twice at different stages of the life cycle. Usually they are found together with the related species, *Todaropsis eblanae*, which has a similar, but more easily studied, life history.

As was observed for *Loligo pealei*, a primary meridional affinity is assumed for *Illex illecebrosus*, although this species is more tolerant of environmental conditions. The Newfoundland banks represent the northern limit of the range of this species and only one age-group of rather large squid migrates that far north, the presence of smaller maturing individuals being incidental. The smallest size group of squid, found in the autumn on Georges Bank, do not appear to migrate farther north than the Scotian Shelf in their first year. North to south variation in the average size of *Illex* was also observed.

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Simulating the Effect of Fishing on Squid (*Loligo* and *Illex*) Populations of the Northeastern United States[1]

by

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ABSTRACT

Models designed to simulate the effect of fishing on squid (*Loligo* and *Illex*) were developed. The instantaneous growth, fishing and natural mortality rates were varied on a monthly basis. Spawning was simulated over an extended period. Recruitment was described by the Beverton and Holt (1957) stock-recruitment function.

Based on these models, the exploitation rate (over the lifespan of the species, E_{MSY}) that will result in the maximum sustainable yield is 0.75 and 0.63 for *Loligo* and *Illex* respectively, if recruitment is independent of spawning stock size. If recruitment is moderately dependent on spawning stock size, the E_{MSY} is probably about 0.40 and 0.37 for *Loligo* and *Illex*, respectively. E_{MSY} is further reduced to about 0.15 for both species for a population with a stronger stock-recruitment relationship.

INTRODUCTION

Since the late 1960's the fishery for squid (*Loligo pealei* and *Illex illecebrosus*) in ICNAF Subarea 5 + Statistical Area 6 has developed rapidly. In this area, only herring, mackerel, silver hake, menhaden and sea scallop (including shell weight) fisheries produced more yield than the squid fishery during 1974. ICNAF established a total allowable catch (TAC) for both species of 71,000 metric tons for 1974 and 1975 and 74,000 tons for 1976.

Knowledge of the population dynamics of *Loligo* and *Illex* has not kept pace with the growth of the fisheries. Little is known about the natural mortality of either species, particularly about the extent of post-spawning mortality. The accuracy of estimates of stock size (Tibbetts, 1976; Efanov and Puzhakov, MS 1975; Ikeda and Nagasaki, MS 1975) is unknown. Part of the difficulty in understanding squid stocks results from the lack of a method for determining the age of individuals of either species.

Au (MS 1975) estimated natural mortality based on the life expectancy of each species and applied Beverton and Holt's (1957) yield-per-recruit equation to both stocks. He also considered the long-term effect of exploitation by incorporating the Beverton and Holt (1957) stock-recruitment equation into his analysis. While this work filled an important gap, the Beverton and Holt constant parameter yield-per-recruit equation does not adequately describe fisheries for *Loligo* and *Illex*. Both fisheries are highly seasonal, and thus fishing mortality is not constant through the exploited phase of the life cycle. If there is significant post-spawning mortality the assumption of constant natural mortality is not valid. For *Loligo*, weight is not proportional to the cube of length (Tibbetts, MS 1976; Ikeda and Nagasaki, MS 1973) as assumed in the Beverton and Holt equation.

Therefore, a model specifically designed to simulate the effect of fishing on squid was developed. It accepts monthly values of the instantaneous growth rate and the fishing and natural mortality rates. Spawning mortality is simulated and the long-term effect of fishing is assessed by using the Beverton and Holt (1957) stock-recruitment relationship to calculate the number of recruits in successive generations. The model is run for several hypothetical descriptions of the fisheries allowing consideration of the

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validity of the conclusions under various assumptions about the system. In order to describe the seasonal nature of fisheries for *Loligo* and *Illex*, it was necessary to estimate the catch of each species on a monthly basis. This was done for 1974-75.

Table 1A. Estimated monthly nominal catches of *Loligo* and *Illex* in Subarea 5 + Statistical Area 6 by country for 1974 and 1975[a]. If the catches were reported by species, these values were used directly in the table; if the catches were reported as squids (not specified), an estimated breakdown of each catch by species was obtained by the methods indicated in Table 1B.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
							Loligo							
1974	BUL	-	56	74	126	23	8	1	-	-	-	-	12	300
	CAN	27	-	-	-	-	-	-	-	-	-	-	-	27
	ITA	700	800	1,000	-	-	-	-	-	-	-	450	330	3,280
	JAP	2,393	701	2,083	546	200	46	56	168	246	455	2,810	3,789	13,493
	POL	-	-	10	-	197	-	-	-	-	126	521	800	1,653
	SPA	3,657	2,250	1,410	588	424	433	329	160	99	21	-	-	9,371
	USSR	146	-	908	1,027	105	115	96	72	712	673	479	267	4,485
	USA	137	67	58	328	533	278	139	95	105	141	128	130	2,141
	Total	7,060	3,874	5,543	2,615	1,482	880	621	495	1,162	1,416	4,388	5,328	34,750
							Illex							
	BUL	-	12	8	164	60	13	35	-	-	-	-	1	293
	ITA	250	200	250	-	-	-	-	-	-	-	180	100	980
	JAP	1	-	111	368	390	160	320	258	924	250	105	430	3,314
	POL	-	-	79	2,544	1,596	628	87	-	-	68	22	28	5,052
	ROM	-	1	-	1	2	4	1	-	-	-	-	-	9
	SPA	229	398	972	1,397	938	1,243	937	581	64	10	-	-	6,769
	USSR	8	-	48	54	942	1,032	862	653	126	119	84	17	3,945
	USA	-	-	-	-	-	32	14	15	29	36	21	1	148
	Total	488	607	1,468	4,528	3,928	3,112	2,256	1,507	1,143	483	412	577	20,510
							Loligo							
1975	BUL	-	-	-	29	20	25	-	-	-	-	-	-	74
	FRG	-	-	-	-	-	-	-	-	-	-	1	-	1
	GDR	-	-	-	14	9	370	60	162	-	-	4	1	620
	ITA	540	580	500	162	-	390	-	-	105	205	505	403	3,390
	JAP	3,085	863	878	1,031	44	-	-	4	8	41	1,443	3,348	10,745
	POL	940	756	179	122	23	-	3	147	9	3	417	1,191	3,790
	SPA	914	2,502	1,887	973	-	595	-	-	22	-	582	615	8,090
	USSR	255	160	593	2,983	258	-	-	-	24	14	396	420	5,103
	USA	86	113	134	109	314	136	75	11	62	125	238	190	1,593
	Total	5,820	4,974	4,171	5,423	668	1,516	138	324	230	388	3,586	6,168	33,406
							Illex							
	BUL	-	15	6	4	48	47	-	-	-	-	-	-	120
	FRG	-	-	-	-	-	-	-	45	-	20	1	-	66
	GOR	-	-	-	-	-	-	-	278	-	-	-	-	278
	ITA	140	130	120	40	-	-	160	-	89	107	87	70	943
	JAP	306	40	39	114	157	210	449	667	309	261	429	255	3,236
	POL	-	-	-	40	1,032	1,524	416	37	2	-	-	-	3,051
	ROM	-	-	-	-	-	-	-	48	-	-	-	-	48
	SPA	45	120	84	108	-	-	852	306	106	-	123	54	1,798
	USSR	80	51	6	124	774	300	1,418	832	118	2	83	37	3,825
	USA	-	-	-	-	-	20	7	69	5	3	3	-	107
	Total	571	356	255	430	2,011	2,101	3,302	2,282	629	393	726	416	13,472

[a] Data for 1974 from ICNAF (1975); data for 1975 from preliminary reports to ICNAF for assessments.

Table 1B. The catches of squid by species and country from Subarea 5 and Statistical Area 6 were estimated in Table 1A by one or more of the four criteria indicated. Details of the criteria are given in the text.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1974	BUL	-	3	3	3	3	3	3	-	-	-	-	3
	CAN	3	-	-	-	-	-	-	-	-	-	-	-
	ITA	1	1	1	-	-	-	-	-	-	1	1	1
	JAP	1	1	1	1	1	1	1	1	1	1	1	1
	POL	-	-	2	2	2	2	2	-	-	3,4	3,4[a]	3,4[a]
	ROM	-	3	-	3	3	3	3	-	-	-	-	-
	SPA	1	1	1	1	1	1	1	1	1	1		
	USSR	4	-	4	4	3,4	3,4	3,4	3,4	4	4	4	3,4
	USA	4	4	4	4	4	1,4	1,4	1,4	4	4	4	4
1975	BUL	-	3	3	3	3	3	-	-	-	-	-	-
	FRG	-	-	-	-	-	-	-	3,4	-	3	3	
	GDR	-	-	-	1	1	1	1	1	-	-	1	1
	ITA	1	1	1	1	-	1	1	-	1	1	1	1
	JAP	1	1	1	1	1	1	1	1	1	1	1	1
	POL	1	1	1	1	1	1	1	1	1	1	1	1
	ROM	-	-	-	-	-	-	-	2	-	-	-	-
	SPA	1	1	1	1	-	1	1	1	1	-	3	3
	USSR	2	2	2	2	3	4	2	2	2	4	-	4
	USA	1	1	1	1	1	1	1	1	1	1	1	1

[a] Catch of *Loligo* and *Illex* for November and December is based on the difference between total species catch reported for the year and the sum of estimated monthly catches prior to November.

MONTHLY ESTIMATES OF SQUID CATCH BY COUNTRY AND SPECIES

Squid were traditionally landed in ICNAF Subarea 5 + Statistical Area 6 as by-catch to other major fisheries, and not reported separately as *Loligo* and *Illex*. In recent years with the development of directed fisheries for squid, some countries have reported catches by species but others have not. Table 1 shows the estimated catch of *Loligo* and *Illex* for 1974 and 1975, using the following criteria to allocate the catch by species, applied in the order listed:

1. If reported by species, the reported values were used (Japan, Spain and Italy in 1974, and German Democratic Republic, Italy, Japan, Poland, Spain and USA for 1975).
2. If any catch in the squid fishery of a country was sampled (by the country or by international inspection) then the species composition of the sample was applied to the squid catch of the country during the month of the sample.
3. The species composition obtained by 1 or 2 was applied to other vessels operating in a similar area during the month reported or sampled.
4. For catches not covered by 1, 2 or 3, the US bottom trawl species composition by area, season and depth zone (<60 fathoms or >60 fathoms) was applied.

SIMULATION MODEL

Let N1 be the number of squid from a single cohort that have not yet spawned, N2 the number that have already spawned, P the cumulative weight that has spawned, YN the cumulative catch in numbers, Y the cumulative catch in weight and w the average weight of an individual at time t. Then

$$\frac{dN1}{dt} = -\ (F + M + s)N1 \qquad (1)$$

$$\frac{dN2}{dt} = rsN1 - (F + M)N2 \qquad (2)$$

$$\frac{dw}{dt} = gw \tag{3}$$

$$\frac{dYN}{dt} = F(N1 + N2) \tag{4}$$

$$\frac{dY}{dt} = Fw(N1 + N2) \tag{5}$$

$$\frac{dP}{dt} = sN1 \tag{6}$$

where F, M, s and g are the instantaneous fishing mortality, natural mortality, spawning and growth rates, and r is the proportion surviving spawning. The solution of each equation is given below:

$$N1 = N1_o e^{-(F+M+s)t} \tag{7}$$

$$N2 = (N1_o+N2_o)e^{-(F+M)t} - N1_o e^{-(F+M+rs)t} \tag{8}$$

$$w = w_o e^{gt} \tag{9}$$

$$YN = \frac{FN1_o}{F+M+s}\left[1-e^{-(F+M+s)t}\right] + \frac{F}{F+M}\left[(N1_o+N2_o)(1-e^{-(F+M)t})\right] - \frac{FN1_o}{F+M+rs}\left[1-e^{-(F+M+rs)t}\right] \tag{10}$$

$$Y = \frac{FN1_o w_o}{F+M+s-g}\left[1-e^{-(F+M+s-g)t}\right] + \frac{Fw_o}{F+M-g}\left[(N1_o+N2_o)(1-e^{-(F+M-g)t})\right] - \frac{FN1_o w_o}{F+M+rs-g}\left[1-e^{-(F+M+rs-g)t}\right] \tag{11}$$

$$P = \frac{sN1_o w_o}{M+F+s-g}\left[1-e^{-(M+F+s-g)t}\right] \tag{12}$$

$N1_o$, $N2_o$, and w_o are initial conditions. Following Au (MS 1975), the relationship between stock and recruitment is assumed to be according to Beverton and Holt (1957):

$$R = \frac{P'}{1 + P(P'-1)} \tag{13}$$

R is the size of a cohort when it enters the exploited phase of its life cycle relative to the number of recruits to the unexploited fishery. P' is the weight that spawn relative to weight spawning in the virgin fishery. A is a parameter ranging from 0 to 1. Recruitment is independent of spawning stock for A = 1.0 and recruitment is linearly related to spawning stock for A = 0. For a graphic representation of equation (13) at several levels of A, the reader is referred to Au (MS 1975).

Let t = 0 at the time (in months) when the stock first becomes vulnerable to fishing. Vulnerability may result from migration onto the fishing ground and/or from growth to the minimum size retained by the fishing gear. The number of individuals at t = 0 was assumed to be 1,000 for the virgin stock. Equations (7) to (12) were then applied to the stock on a monthly basis (assuming F, M, s and g constant within months) through the hypothetical lifespan of the species. Recruitment to the next generation relative to the 1,000 individuals assumed for the virgin stock, is then calculated by equation (13), and survival and spawning of this cohort is simulated. Each generation of the stock was simulated until the recruitment to successive generations differed by less than 1%. The yield from the last generations simulated is assumed to approximate the equilibrium yield per 1,000 individuals recruited to the virgin stock for a specific exploitation rate (proportion of recruits eventually captured, E). This procedure was repeated for each species and several combinations of hypothetical representations of growth, mortality and spawning on a monthly basis. The equilibrium yield and the average weight of the catch is determined for several levels of exploitation rate.

Hypothetical Representation of Fisheries

Loligo pealei

A lifespan of approximately 2 years was assumed for *Loligo*. Some may survive for 3 years, but a lifespan of 2 years is more frequent (Summers, 1971). Monthly values of g, and several sets of values of s and F_r (fishing mortality relative to the highest monthly value) are given in Table 2. For each set of values of s, a single constant value of r and M is also given.

Table 2. *Loligo pealei*: hypothetical monthly values of the instantaneous growth rate (g), relative fishing mortality rate (F_r), and spawning mortality rate with associated constant values of natural mortality rate (M) and spawning survival rate (r).

	F_r for set			s for set			g
	1	2	3	1	2	3	
Dec	1	0.8	0.9	0	0	0	.38
Jan	1	1.0	1.0	0	0	0	.21
Feb	1	1.0	1.0	0	0	0	.21
Mar	1	1.0	1.0	0	0	0	.22
Apr	1	0.8	0.9	0	0	0	.22
May	0	0.4	0.6	0.22	0.17	0.13	.18
Jun	0	0.1	0.2	0.29	0.21	0.16	.18
Jul	0	0.1	0.2	0.41	0.27	0.19	.16
Aug	0	0.1	0.2	0.69	0.37	0.23	.16
Sep	0	0.1	0.2	∞	0.59	0.29	.11
Oct	0	0.1	0.2	0	0	0	.11
Nov	0	0.4	0.6	0	0	0	.08
Dec	1	0.8	0.9	0	0	0	.08
Jan	1	1.0	1.0	0	0	0	.12
Feb	1	1.0	1.0	0	0	0	.12
Mar	1	1.0	1.0	0	0	0	.09
Apr	1	0.8	0.9	0	0	0	.09
May	0	0.4	0.6	0.22	0.22	0.22	.08
Jun	0	0.1	0.2	0.29	0.29	0.29	.08
Jul	0	0.1	0.2	0.41	0.41	0.41	.08
Aug	0	0.1	0.2	0.69	0.69	0.69	.07
Sep	0	0.1	0.2	∞	∞	∞	.07
M				0.13	0	0.05	
r				1.00	0	0	

Values of g are based on bimonthly average lengths of *Loligo* (of a July brood) reported by Summers (1971) and the length-weight equation reported by Ikeda and Nagasaki (MS 1975). The instantaneous growth rate is calculated by taking the natural log of the ratio of weight at successive points in time. An initial weight of 22.6 g corresponding to a length of 8.5 cm is assumed for 1 December, which is about the size at recruitment (Au, MS 1975).

Reduced catches of *Loligo* during the warmer months (Table 1) probably reflect a decrease in vulnerability (except to inshore fishermen) and in fishing mortality. Therefore, fishing mortality is assumed to be primarily concentrated during December-April. For 1974-75, 75% of the estimated catch of *Loligo* was during December-April and 90% during November-May. Three sets of values of monthly relative fishing mortality were considered. These were based on trends in the commercial catch. Various levels of E were generated by multiplying each value of F_r by a constant. Set 1 of F_r assumes all fishing mortality during December-April, while sets 2 and 3 assume substantial fishing mortality during November and May and some throughout the year.

There is evidence of an extended summer spawning period for *Loligo* (Summer, 1971; Tibbetts, 1976). Spawning was assumed to occur during May-September, although the results are not sensitive to this assumption since there is little question that spawning occurs during a period of reduced fishing mortality. The instantaneous monthly spawning rates were established such that the ratio of N1 to N2 at the end of May, June, July and August would be 20, 40, 60 and 80% (respectively) of the ratio at the end of the spawning season if r = 1. The result is that the number spawning in each month is nearly uniform. It is not known if *Loligo* spawn more than once. For set 1 of s, all individuals are assumed to survive spawning and are assumed to spawn each season. Thus for this set of s, some *Loligo* spawn more than once. Tibbetts (1976) noted that, in some years, the number reaching the second spawning season of their life may be 25% of the number at the first spawning season. M was therefore selected so that the annual survival rate for the unexploited stock would be 20%. The stock represented by N2 is transferred to N1 during the winter following the first spawning season to permit simulation of a second spawning season. All individuals are assumed to have perished by the end of the second spawning season.

For set 2 of s, all non-fishing mortality is assumed to result from spawning (M = 0.0, r = 0.0). Values of s are selected so that the number spawning during the second spawning season will be 20% of the number spawning during the first spawning season for the unexploited fishery. Set 3 of s represents a compromise between sets 1 and 2; here, M = 0.05, r = 0.0 and monthly values of s are again set so the ratio of second season to first season spawners is 20%. Since r = 0.0 for sets 2 and 3 of s, *Loligo* are assumed to spawn only once in these cases.

Illex illecebrosus

According to Squires (1967), spawning and subsequent mortality (r = 0) of *Illex* most probably occurs at about 1 year of age. Spawning is believed to occur at great depth during winter although ripe individuals have been captured on Georges Bank (Tibbetts, 1976). The growth equation of Efanov and Puzhakov (MS 1975) and Mercer's (MS 1973) length-weight equations (averaged for both sexes) were used to calculate monthly values of g in a similar manner as was described for *Loligo*. An initial length of 7.8 cm (6.5 g) was assumed for t = 0. Monthly values of g, s and F_r and constant values of M are given in Table 3. Efanov and Puzhakov estimated M = 0.1 (actually 0.6 for 6 months). M = 0.0 and 0.2 were considered here to indicate the sensitivity of the results to M. Values of s were set so that the number spawning during each month of the hypothetical spawning season would be nearly uniform for a low mortality rate. Two sets of values of F_r were again selected to parallel monthly estimates of the nominal catch of *Illex* for 1974-75 (Table 1).

Table 3. *Illex illecebrosus*: hypothetical monthly values of the instantaneous growth rate (g), relative fishing mortality rate (F_r) and spawning rate (s). Simulations were run with spawning mortality r = 0 and constant (lifespan) values of instantaneous natural mortality rates of M = 0.0, 0.1 and 0.2.

	F_r for set		s	g
	1	2		
Apr	0.3	0.3	0	1.17
May	1.0	1.0	0	0.78
Jun	1.0	1.0	0	0.55
Jul	1.0	1.0	0	0.41
Aug	1.0	1.0	0	0.32
Sep	0.3	0.6	0	0.25
Oct	0	0.2	0	0.22
Nov	0	0.2	0	0.17
Dec	0	0.2	0	0.14
Jan	0	0.2	0.41	0.13
Feb	0	0.2	0.69	0.10
Mar	0	0.2	∞	0.08

RESULTS

The simulated equilibrium yield of *Loligo* in weight per 1,000 individuals recruited to the virgin fishery (Y) is plotted (Fig. 1-3) against exploitation rate over the lifespan of the species (E) for M = 0.13, 0.0 and 0.05 (and corresponding sets of s), A = 1.0, 0.8 and 0.4, and set 2 of the monthly values of F_r. The results are quite similar for sets 1 and 3 of F_r. The maximum equilibrium yield in weight per 1,000 individuals recruited to the virgin fishery (Y_{max}) for each combination of F_r, M and A are given in Tables 4-6 along with the corresponding yield in numbers (YN), exploitation rate (E_{MSY}) and average weight of individuals in the catch (W_{MSY}).

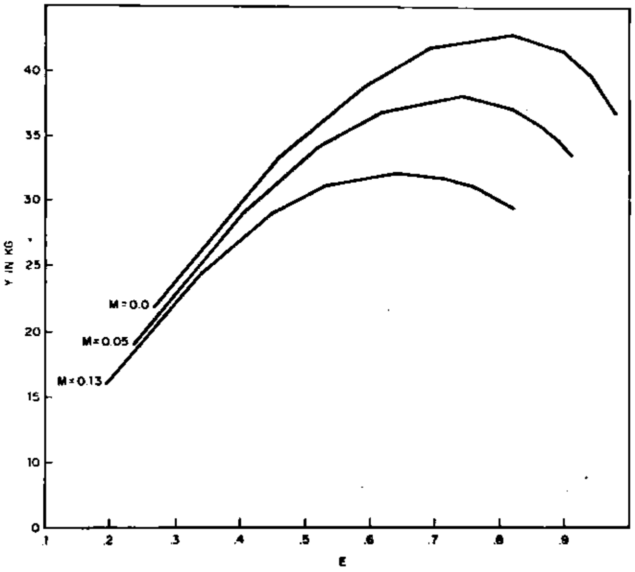

Fig. 1. *Loligo pealei*: equilibrium yield per 1,000 recruits to virgin fishery for set 2 of F_r and A = 1.0.

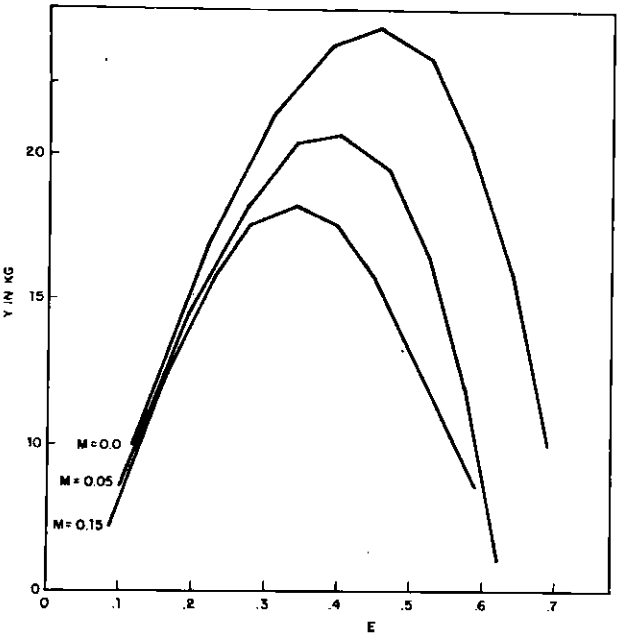

Fig. 2. *Loligo pealei*: equilibrium yield per 1,000 recruits to virgin fishery for set 2 of F_r and A = 0.8.

Table 4. *Loligo pealei*: maximum equilibrium values of Y and corresponding values of A, E, YN, and W for set 1 of s (M = 0.13, r = 1.0).

F_r	A	E	YN	Y(kg)	W(g)
Set 1	1.0	0.65	645.3	31.0	48.0
	0.8	0.34	256.8	17.1	66.7
	0.4	0.16	84.6	6.4	75.5
Set 2	1.0	0.64	639.3	32.3	50.6
	0.8	0.34	251.4	18.2	72.3
	0.4	0.13	81.9	6.9	85.1
Set 3	1.0	0.66	661.1	32.8	49.6
	0.8	0.36	254.8	18.7	73.5
	0.4	0.14	81.9	7.3	88.6

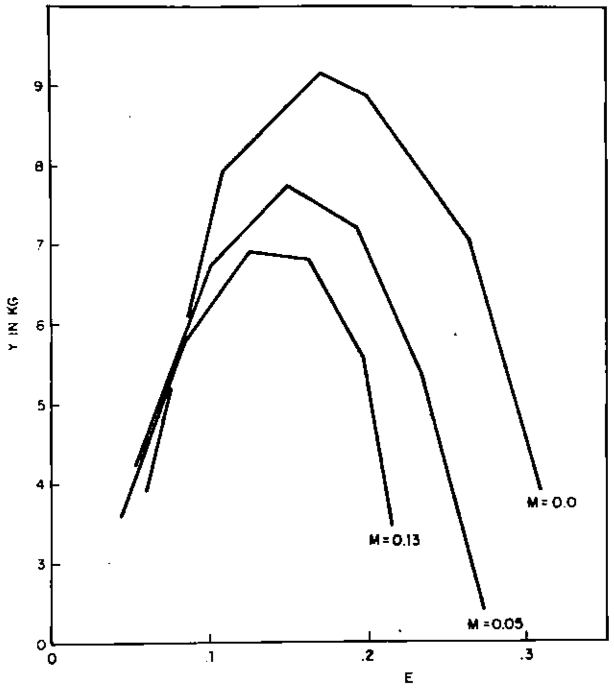

Fig. 3. *Loligo pealei*: equilibrium yield per 1,000 recruits to virgin fishery for set 2 of F_r and A = 0.4.

Table 5. *Loligo pealei*: maximum equilibrium values of Y and corresponding values of A, E, YN, and W for set 2 of s (M = 0.0, r = 0.0).

F_r	A	E	YN	Y(kg)	W(g)
Set 1	1.0	0.81	811.5	40.6	50.1
	0.8	0.44	335.1	23.1	68.8
	0.4	0.21	110.5	8.6	77.6
Set 2	1.0	0.82	820.0	43.0	52.5
	0.8	0.45	331.5	24.4	73.5
	0.4	0.17	107.0	9.2	85.8
Set 3	1.0	0.72	725.2	43.9	60.5
	0.8	0.42	322.0	25.1	78.1
	0.4	0.19	107.5	9.5	88.6

Table 6. *Loligo pealei*: maximum equilibrium values of Y and corresponding values of A, E, YN, and W for set 3 of s (M = 0.05, r = 0.0).

F_r	A	E	YN	Y(kg)	W(g)
Set 1	1.0	0.74	740.1	36.4	49.2
	0.8	0.39	290.9	19.7	67.8
	0.4	0.14	93.6	7.3	78.1
Set 2	1.0	0.74	740.9	38.1	51.5
	0.8	0.40	286.7	20.7	72.4
	0.4	0.15	91.4	7.7	84.6
Set 3	1.0	0.77	765.5	38.7	50.5
	0.8	0.37	275.4	21.1	76.8
	0.4	0.17	90.6	7.9	87.3

For *Illex*, the simulated equilibrium yield in weight per 1,000 individuals recruited to the virgin fishery is plotted against exploitation rate (Fig. 4-6) for M = 0.0, 0.1, 0.2; A = 1.0, 0.8, 0.4 and set 2 of F_r. The results are similar for set 1 of F_r although the yield curves are somewhat lower than those plotted in Fig. 4-6. The maximum equilibrium yield in weight per 1,000 individuals recruited to the virgin fishery for each combination of A, F_r and M with corresponding values of YN, E_{MSY} and W_{MSY} are given in Table 7.

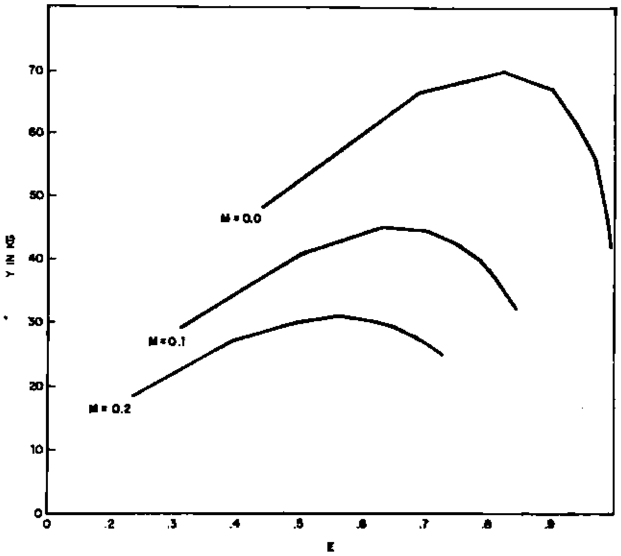

Fig. 4. *Illex illecebrosus*: equilibrium yield per 1,000 individuals recruited to the virgin fishery for A = 1.0 and set 2 of F_r.

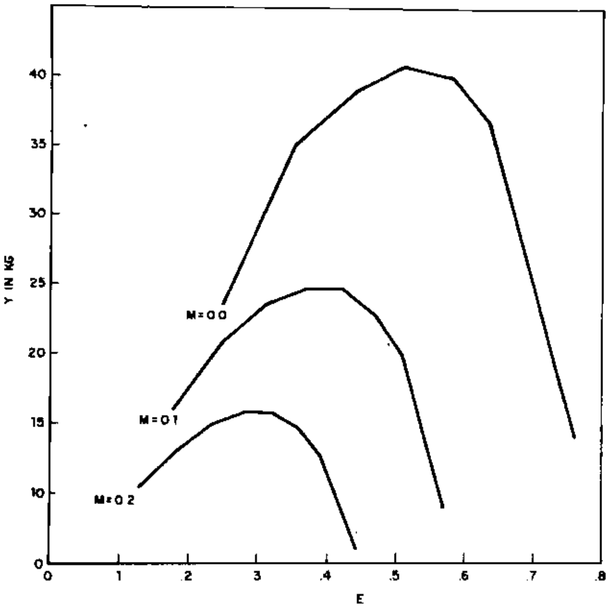

Fig. 5. *Illex illecebrosus*: equilibrium yield per 1,000 individuals recruited to the virgin fishery for A = 0.8 and set 2 of F_r.

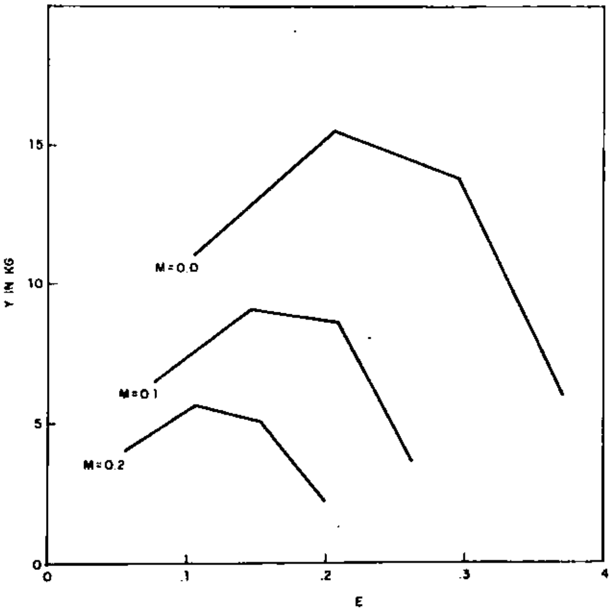

Fig. 6. *Illex illecebrosus*: equilibrium yield per 1,000 individuals recruited to the virgin fishery for A = 0.4 and set 2 of F_r.

Table 7. *Illex illecebrosus*: maximum equilibrium values of Y and corresponding values of A, E, YN, and W for each set of F_r.

M	F_r	A	E	YN	Y	W
0.1	Set 1	1.0	0.68	674.5	37.1	55.0
		0.8	0.38	292.7	20.1	68.6
		0.4	0.18	100.03	7.4	74.1
	Set 2	1.0	0.63	626.6	45.0	71.8
		0.8	0.37	275.5	24.7	89.7
		0.4	0.15	91.3	9.1	99.9
0.0	Set 1	1.0	0.84	841.2	50.9	60.5
		0.8	0.50	380.6	28.6	75.2
		0.4	0.24	132.2	10.7	81.0
	Set 2	1.0	0.82	822.2	69.8	84.9
		0.8	0.51	380.5	40.7	107.1
		0.4	0.206	129.7	15.5	119.3
0.2	Set 1	1.0	0.60	604.7	27.9	46.1
		0.8	0.34	235.1	14.4	61.1
		0.4	0.14	77.2	5.2	67.6
	Set 2	1.0	0.56	564.0	31.2	55.3
		0.8	0.28	207.4	15.8	76.4
		0.4	0.11	67.1	5.7	84.8

DISCUSSION

Loligo pealei

Of the factors considered (over the range of values considered) the maximum equilibrium yield of the fishery for *Loligo* per 1,000 virgin recruits appears to be most sensitive to A then to M (and corresponding sets of s and values of r) and finally to the sets of monthly values of F_r. If A = 1.0, Y_{max} is probably about 38 kg (E_{MSY} = 0.74, W_{MSY} = 51.5 g). Y_{max} as low as 32 kg, where M = 0.13 (no spawning mortality), or as high as 44 kg, where M = 0.0 (only spawning mortality), seems less likely.

Au (MS 1975) argued that recruitment can be expected to be strongly dependent on spawning stock size for squid, since there is little competition between generations because of their short lifespan. If this is the case, Y_{max} should be considerably less than when A = 1.0. For A = 0.4, Y_{max} is probably about 8 kg (E_{MSY} = 0.15, W_{MSY} = 72.4 g), while for a more moderate degree of density dependence (A = 0.8) Y_{max} is probably about 22 kg (E_{MSY} = 0.40, W_{MSY} = 84.6 g). The level of E yielding Y_{max} is considerably higher than was reported by Au (MS 1975) where recruitment is independent of spawning stock size, but E_{MSY} is more sensitive to A than Au's results indicated.

Tibbetts (1976) estimated the biomass of *Loligo* in Subarea 5 + Statistical Area 6 for 1967-74 by areal expansion, based on the US autumn bottom trawl survey. The catch per tow for night samples was adjusted upward to correspond to samples taken during daylight when the gear is more effective at catching squid, and all tows were adjusted upward to correspond to a more efficient trawl. These estimates were recalculated for Subarea 5 + Statistical Area 6 (1968-75) with updated day-night and trawl conversion factors. An estimate of stock size in numbers was obtained by dividing by mean weight (Table 8). The mean weight per individual in the survey catch indicates the age composition of the stock. For *Loligo* growth as described by Summers (1971) using Ikeda and Nagasaki's (MS 1973) length-weight equation, at least 90% of the stock would be young-of-the-year for a mean weight per individual in the survey catch of less than 40 g. Since stock size estimates based on the areal expansion method usually underestimate the true stock size, an annual recruitment of at least 1.5 billion *Loligo* for Subarea 5 + Statistical Area 6 seems likely. If recruitment were independent of spawning stock size (A = 1.0), then a catch of at least 56,800 tons ($1.5\text{x}10^{9} \cdot 0.74 \cdot 51.5\text{x}10^{-6}$ for M = 0.05 and set 2 of F_r) appears possible. It seems more likely that there is some relationship between recruitment and spawning stock size; therefore a catch of 43,400 tons ($1.5\text{x}10^{9} \cdot 0.40 \cdot 72.4\text{x}10^{-6}$ for M = 0.05, set 2 of F_r and A = 0.8) may be more rational.

Table 8. *Loligo pealei*: stock size estimates by areal expansion, in Subarea 5 and Statistical Area 6 for the autumn of each year, and the mean weight of individuals in the catch.

Year	Biomass (tons)	Number (10^6)	Weight (g)
1968	72,700	1,800	40.4
1969	57,400	1,400	41.0
1970	35,400	1,000	35.4
1971	22,100	1,200	18.5
1972	29,500	1,200	24.6
1973	77,500	2,700	28.7
1974	72,300	2,400	30.1
1975	97,300	5,600	17.4

This is approximately the 1976 TAC. If recruitment is strongly dependent on spawning stock size then a catch exceeding 19,000 tons ($1.5x10^9 \cdot 0.15 \cdot 84.6x10^{-6}$ for M = 0.05, set 2 of F_r and A = 0.4) may be dangerous. The simulated equilibrium recruitment relative to the virgin stock at E_{MSY} (R_{EQ}) is given in Table 9. Recruitment and catch should (theoretically) decline by 28 and 39% for A = 0.8 and 0.4 (respectively) at E_{MSY}.

Table 9. Equilibrium recruitment at E_{MSY} as a percent of recruitment to the virgin fishery (R_{EQ}) for *Loligo* with M = 0.05 and set 2 of F_r, and for *Illex* with M = 0.1 and set 2 of F_r, and with A = 0.4, 0.8 and 1.0 for both species.

	Loligo		*Illex*	
A	E_{MSY}	R_{EQ}	E_{MSY}	R_{EQ}
1.0	0.74	100.0%	0.63	100.0%
0.8	0.40	71.6%	0.37	74.5%
0.4	0.15	60.9%	0.15	60.9%

Since it is difficult to estimate recruitment or exploitation rate for a squid population, it might be useful to assess the appropriateness of the recent level of catch by comparing the mean weight of individuals in the catch to the mean weight of the simulated catch reported in Tables 4-6. For A = 1.0, a mean weight of the catch (W) of about 50 g (at most 60 g) seems appropriate. If A = 0.8, W should be from 65 to 78 g, and, for A = 0.4, W should be from 75 to 88 g. Graphs relating the mean weight of the catch of E (set 2 of F_r, M = 0.05 for *Loligo* and set 2 of F_r, M = 0.1 for *Illex*) are given in Fig. 7.

Ikeda and Nagasaki (MS 1975) estimated the mean weight per individual of the *Loligo* catch for the 1968-69 to 1973-74 seasons as 71, 70, 65, 77, 59, and 68 g, respectively. Japan has produced a larger catch of *Loligo* than any other country in recent years and in many years has produced more than 50% of the entire catch (Tibbetts, 1976). Therefore these estimates should be representative of the mean weight in the total catch. Since at least one length-frequency sample from the commercial catch was reported to ICNAF for Subarea 5 + Statistical Area 6 *Loligo* for each month during 1974, it was possible to crudely estimate the mean weight of the catch for that year. Using a length-weight equation (Ikeda and Nagasaki, MS 1973), the mean weight per individual of each sample was calculated and the overall mean weight for 1974 was calculated as 89 g based on these samples and the estimated catch of *Loligo* during each month (Table 1). The difference between this estimate and those reported by Ikeda and Nagasaki may in part reflect the fact that the Japanese catch during summer months (when the mean weight of individuals in the *Loligo* population is higher) is a smaller proportion of the total monthly catch than during winter months. The difference may also result from sampling error.

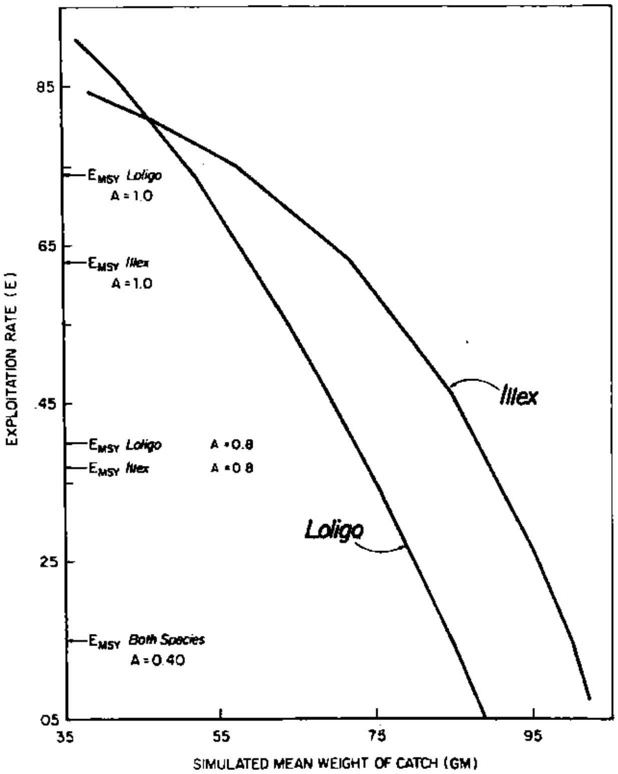

Fig. 7. Relationship between E and the mean weight per individual of the catch of *Loligo* (set 2 of F_r and M = 0.05) and *Illex* (set 2 of F_r and M = 0.1).

Based on the above discussion, it appears that the mean weight of *Loligo* in the catch during recent years was greater than 60 g. Thus, according to Fig. 7, for a population where recruitment is independent of spawning stock size, E could be increased, but, if recruitment is moderately dependent on spawning stock size (A = 0.8), the exploitation rate during some recent years may have been too high. If the mean weight of the catch during 1974 were in fact greater than 85 g, then the rate of exploitation during 1974 would be below E_{MSY} for even a population where recruitment is strongly dependent on spawning stock.

Illex illecebrosus

As for *Loligo*, the equilibrium yield per 1,000 recruits to the virgin *Illex* fishery is less sensitive to the sets of F_r considered, than to M or A. Y is plotted against E for combinations of A and M and for set 2 of F_r. The maximum equilibrium yield per 1,000 recruits to the virgin fishery for all combinations of F_r, A and M with the corresponding value of E_{MSY}, YN and W_{MSY} is given in Table 7.

Unlike *Loligo*, Y_{max} for *Illex* is quite sensitive to M. Y_{max} at M = 0.0 is from 2 to 3 times as large as for M = 0.2. If only Efanov and Puzhakov's (MS 1975) estimate of natural mortality (M = 0.1) is considered and some catch is assumed during all months (set 2 of F_r), then Y_{max} = 45 kg (E_{MSY} = 0.63, W_{MSY} = 72 g) for A = 1.0, Y_{max} = 25 kg (E_{MSY} = 0.37, W_{MSY} = 90 g) for A = 0.8 and Y_{max} = 9 kg (E_{MSY} = 0.15, W_{MSY} = 100 g) for A = 0.4.

Based on the 1971 cruise of the R/V *Argus*, Efanov and Puzhakov (MS 1975) estimated the minimum biomass of *Illex* on the southern Nova Scotia shelf and Georges Bank as 110,000 tons. Since this cruise occurred during June (Noskov and Rikhter, MS 1972) the estimate of biomass was divided by the approximate mean weight of *Illex* for that month (reported by Efanov and Puzhakov for 1974 as about 88 g) to obtain a stock size estimate of 1.25

billion individuals. Since Efanov and Puzhakov (MS 1975) give no description of the method used, the accuracy of the results cannot be judged. Since some mortality must occur prior to June, the number of recruits may substantially exceed this value. Therefore, if recruitment is insensitive to spawning stock size, a yield of at least 56,700 tons ($1.25 \times 10^9 \cdot 0.63 \cdot 72 \times 10^{-6}$) may be possible. Since recruitment is probably at least somewhat sensitive to spawning stock size, a catch of 41,630 tons ($1.25 \times 10^9 \cdot 0.37 \cdot 90 \times 10^{-6}$) would be prudent unless there is reason to believe the stock exceeded 1.25 billion individuals. If recruitment is strongly dependent on spawning stock size, a catch of 19,000 tons ($1.25 \times 10^9 \cdot 0.15 \cdot 100 \times 10^{-6}$) would be proper. Recruitment and catch should (theoretically) decline by 26 and 39% for $A = 0.8$ and 0.4 at E_{MSY} (Table 9). Since Efanov and Puzhakov's stock size estimate includes parts of Subareas 4 and 5, the proper level of catch for Subarea 5 + Statistical Area 6 cannot be ascertained directly from the above discussion. According to Noskov and Rikhter (MS 1972, their figure 8), substantial numbers of *Illex* were taken in Subarea 5 + Statistical Area 6 other than on Georges Bank. From these data it should be possible to estimate minimum stock size within several areas separately.

The mean weight of individuals in the *Illex* catch was estimated as 85 g during 1974. The mean weight of the catch during each month was calculated from length samples reported to ICNAF, using Mercer's (MS 1973) length-weight equation. The annual mean was estimated by summing the product of the estimated mean monthly average weights and estimated monthly catch and then dividing by the total catch. The result is only a crude estimate of the annual average weight of the catch, since it is based on several preliminary stages of estimation. According to Fig. 7 and this estimate of mean weight, E was about 20% above E_{MSY} for $A = 0.8$ (where some *Illex* are taken during all months, set 2 of F_r) and $M = 0.1$. If our estimate of the mean weight of the catch and parameters of the model are realistic, then the rate of exploitation (and level of catch) in recent years may have been too high for a stock with a moderately strong stock-recruitment relationship ($A = 0.8$).

CONCLUSION

Two major obstacles to more rational management of squid in Subarea 5 + Statistical Area 6 are the lack of knowledge about the number of individuals recruited annually and about the nature of stock-recruitment relationships. In the absence of data adequate to determine the stock-recruitment relationships, it is prudent to assume that recruitment is at least moderately dependent on spawning stock (perhaps $A = 0.8$) and manage accordingly. Where only a minimum estimate of annual recruitment is available, catch should only gradually be permitted to exceed the level indicated by applying E_{MSY} and W_{MSY} to that estimate.

The possibility of using the mean weight of the catch as a criterion for judging the appropriateness of a particular level of exploitation (based on Fig. 7) is appealing although this approach may be premature considering the uncertainty of available estimates of growth and mean weight. Typically, growth and mean weight of the catch are among the easiest fisheries parameters to estimate.

Based on an annual recruitment of 1.5 billion *Loligo* to Subarea 5 + Statistical Area 6, a catch of about 44,000 tons (which is the 1976 TAC) would be reasonable for $A = 0.8$, although according to stock size estimates from the US autumn bottom trawl survey a higher catch may be possible during some years. Since exploiting the stock at a rate above E_{MSY} will have a long-term detrimental effect on the fishery, while exploiting at below E_{MSY} only results in a lower catch than is possible during the years when E is too low, it is prudent to restrict the catch so that E will seldom exceed E_{MSY}. The mean weight per individual of the catch estimated from 1974 length frequency samples indicates that E (and the catch) during that year could have been increased for even a population with a strong stock-recruitment relationship ($A = 0.4$), but the mean weight per *Loligo* of the Japanese catch during recent fishing seasons indicates that for some years E may have been too high for $A = 0.8$. A catch of 42,000 tons of *Illex* from southern Nova Scotia and Georges Bank (for $A = 0.8$) is indicated by Efanov and Puzhakov's (MS 1975) estimate of stock size. A very crude estimate of the mean weight of the catch in Subarea 5 + Statistical Area 6 indicates that the exploitation rate (which produced an estimated catch of 20,500 tons) during that year was about 20% too high for $A = 0.8$. The 1974 catch was below the 1976 TAC. The expected precision of this estimate of mean weight is inadequate to conclude that the stock was overfished (for $A = 0.8$) from this evidence alone.

If it assumed that $A = 0.8$, recruitment should gradually decline even at E_{MSY} (Table 9). Therefore the catch (and TAC), in theory, must also decline in order to maintain the proper exploitation rate. If the relative abundance of the stock is reduced by more than is expected (about 28 and 26% for *Loligo* and *Illex* respectively for A = 0.8) as a result of fishing, then E should be reduced since this would indicate that A is smaller than was assumed. If relative abundance remains constant or increases, then E should be increased since this would indicate that A is larger than was assumed or that annual recruitment is higher than was estimated. Unfortunately, changes in relative abundance of the magnitude expected as a result of fishing at E_{MSY} probably cannot be distinguished from natural fluctuations or sampling error. Therefore the philosophy described above could only be applied on a long-term basis.

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Squid Fisheries (*Loligo pealei* and *Illex illecebrosus*) off the Northeastern Coast of the United States of America, 1963-74[1]

by

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ABSTRACT

The biology of the two commercially important squid species in the Northwest Atlantic (*Loligo pealei* and *Illex illecebrosus*) is reviewed. Commercial catch and effort statistics are presented and discussed as indicators of the increased interest of various countries in this fishery in the International Commission for the Northwest Atlantic Fisheries (ICNAF) Subarea 5 and Statistical Area 6. Monthly nominal catches and survey cruise data, used to estimate species composition of the catches, indicate that *Loligo* is the more available species in this area. Length frequencies of both commercial and research catches, and catch-per-tow indices from research cruises are analyzed to document seasonal and annual trends in abundance. Commercial catch-per-effort indices for those countries reporting catch and effort statistics indicate a possible decrease in abundance of squid. Survey abundance indices provide estimates of biomass of about 58,000 tons for *Loligo* and about 10,500 tons for *Illex* for 1967 to 1974.

INTRODUCTION

Squid species (essentially *Loligo pealei* and *Illex illecebrosus*) off the northeastern coast of the USA (Fig. 1), until the late 1960's supported only a small coastal fishery primarily for bait (1,000-2,000 metric tons per year). Since the entry of distant-water fleets to the fishery in 1964, reported catches have increased from 1,000 tons to about 56,000 tons in 1974 (Table 1).

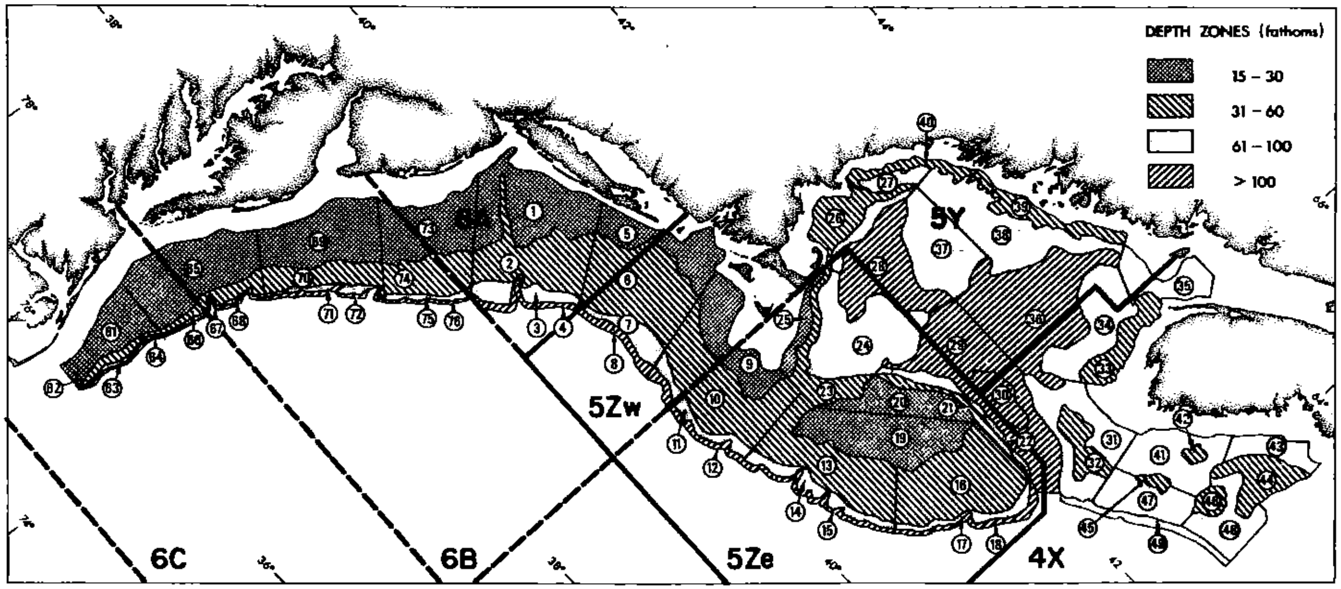

Fig. 1. International Commission for the Northwest Atlantic Fisheries (ICNAF), Subarea 5 and Statistical Area 6, by divisions, with US bottom trawl survey strata.

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[1] Submitted to the 1975 Annual Meeting as Res.Doc. 75/60.

Table 1. Annual nominal catches (metric tons) of squid by country[a] in Subarea 5 + Statistical Area 6, 1963-74.

Areas	Year	BUL	CAN	FRA	FRG	GDR	ITA	JAP	POL	ROM	SP	USSR	USA	TOTAL
5	1963	-	-	-	-	-	-	-	-	-	-	-	1,210	1,210
	1964	-	-	-	-	-	-	-	-	-	-	4	189	193
	1965	-	-	-	-	-	-	-	-	-	-	176	387	563
	1966	-	-	-	-	-	-	-	-	-	-	341	193	534
	1967	-	-	-	-	-	-	-	-	-	-	330	913	1,243
	1968	-	-	-	-	10	-	112	-	-	-	2,415	903	3,440
	1969	-	-	-	-	1	-	3,724	-	-	-	1,182	739	5,646
	1970	-	-	-	-	20	-	5,363	-	-	-	655	483	6,501
	1971	80	1	-	-	-	-	4,661	-	-	256	5,659	711	11,368
	1972	480	-	6	63	14	-	7,862	5,042	28	5,797	6,381	459	26,138
	1973	396	-	403	136	313	-	5,811	9,157	18	10,147	8,631	873	36,161
	1974	196	3	-	-	-	1,010	7,267	6,229	2	7,448	5,612	1,117	28,884
6	1963	-	-	-	-	-	-	-	-	-	-	-	895	895
	1964	-	-	-	-	-	-	-	-	-	-	-	740	740
	1965	-	-	-	-	-	-	-	-	-	-	-	767	767
	1966	-	-	-	-	-	-	-	-	-	-	48	980	1,028
	1967	-	-	-	-	-	-	6	-	-	-	503	916	1,425
	1968	-	-	-	-	-	-	1,619	-	-	-	761	859	3,239
	1969	-	-	-	-	-	-	3,398	-	-	-	158	722	4,278
	1970	-	-	-	-	-	-	8,276	-	-	-	-	578	8,854
	1971	10	-	-	-	-	-	5,941	-	-	3,941	479	471	10,842
	1972	19	-	290	400	-	3,200	10,829	836	39	6,063	595	748	22,569
	1973	14	-	417	1,505	-	3,165	9,715	42	132	4,785	346	762	20,492
	1974	396	24	-	-	-	3,250	9,553	480	7	8,696	2,883	1,305	26,594
5+6	1963	-	-	-	-	-	-	-	-	-	-	-	2,105	2,105
	1964	-	-	-	-	-	-	-	-	-	-	4	929	933
	1965	-	-	-	-	-	-	-	-	-	-	176	1,154	1,330
	1966	-	-	-	-	-	-	-	-	-	-	389	1,173	1,562
	1967	-	-	-	-	-	-	6	-	-	-	833	1,829	2,662
	1968	-	-	-	-	10	-	1,731	-	-	-	3,176	1,762	6,679
	1969	-	-	-	-	1	-	7,122	-	-	-	1,340	1,461	9,924
	1970	-	-	-	-	20	-	13,639	-	-	4,510	655	1,061	19,885
	1971	90	1	-	-	-	-	10,602	-	-	4,197	6,138	1,182	22,210
	1972	499	-	296	463	14	3,200	18,691	5,878	67	11,860	6,976	1,207	48,707
	1973	410	-	820	1,641	313	3,165	15,526	9,199	150	14,932	8,977	1,635	56,768
	1974	592	27	-	-	-	4,260	16,820	6,709	9	16,144	8,495	2,422	55,528

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[a] Country abbreviations as in ICNAF Statistical Bulletin.

Concern that these stocks might reach an overfished condition if catches continued to increase in an unrestricted way prompted ICNAF to adopt measures that would provide for the orderly development of this fishery. The total allowable catch (TAC) of between 50,000 and 80,000 tons, recommended by the Standing Committee on Research and Statistics (STACRES) for 1974 (ICNAF, 1974a) was based primarily on an estimate of stock size and possible yield of *Loligo* by Ikeda *et al.* (MS 1973). The TAC set by ICNAF, for both species combined, for 1974 and 1975 was 71,000 tons. For 1976, STACRES recommended that ICNAF adopt a TAC of 30,000 tons of *Illex* and 44,000 tons of *Loligo* (ICNAF, 1975a).

This paper reviews the biology, catches, research vessel survey results, length composition, and estimates of stock size of both species of squid which occur in ICNAF Subarea 5 + Statistical Area 6.

BIOLOGY

The two species of squid of commercial importance in Subarea 5 + Statistical Area 6 are *Loligo pealei* (common or long-finned squid) and *Illex illecebrosus* (short-finned squid). *Loligo* has been reported as far north as New Brunswick (Summers, 1969) but is promarily distributed from Cape Hatteras to Georges Bank (as illustrated in Fig. 2, (a) to (f), based on US bottom trawl survey cruises; Grosslein, 1969). *Illex* is a more northern species, ranging to Greenland but with autumn concentrations as far south as Cape Hatteras (Squires, 1957) [Fig. 2, (g) to (l)].

Seasonal differences in distributions are evident in both species (Fig. 2). *Loligo* probably forms one stock which migrates as much as 200 km, generally remaining in waters where the temperature is above 8°C (Table 7). From US winter research cruises (Lux *et al.*, 1974), spring survey distributions reported in this paper and analysis of survey catches by Summers (1969), it may be presumed that in winter *Loligo* are offshore, primarily in 8° to 12°C water along the upper continental slope, from western Georges Bank to Cape Hatteras. By about April, larger mature *Loligo* move inshore as far north as Long Island (Fig. 2). US commercial catches from ICNAF Subdivision 5Zw (1973, 1974) indicate that large individuals arrive in the Massachusetts area by late April and early May. Smaller individuals, in much greater numbers, arrive by summer (Fig. 5a).

The greatest number of eggs are spawned during May and hatch in July (Summers, 1971). Size differences in young-of-the-year (YOY) and observations of ripe adults from samples of US commercial catches in ICNAF Subdiv. 5Zw in July and from autumn groundfish survey cruises in September, indicate an extended breeding season of about 6 months (April to September).

Table 2. Fish predators of squid.

Pelagic	Benthic	Inshore
Bonito	Haddock	Silverside
Bluefin tuna	Cod	Smelt
Skipjack tuna	Pollock	Three-spine stickleback
Mackerel	Red hake	Weakfish
Swordfish	Silver hake	
	Spotted hake	**Other**
Semi-pelagic	Tom cod	
	Searobin	Spiny dogfish
Alewife	Four-spot flounder	Smooth dogfish
Butterfish	Summer flounder	Mackerel shark
Scup	Sand flounder	Thresher shark
Bluefish	Barndoor skate	Barrelfish
Striped bass	Little skates	
Redfish	Big skate	
	Tilefish	
	Longhorn sculpin	
	White perch	
	Toadfish	
	Sea bass	
	Goosefish	

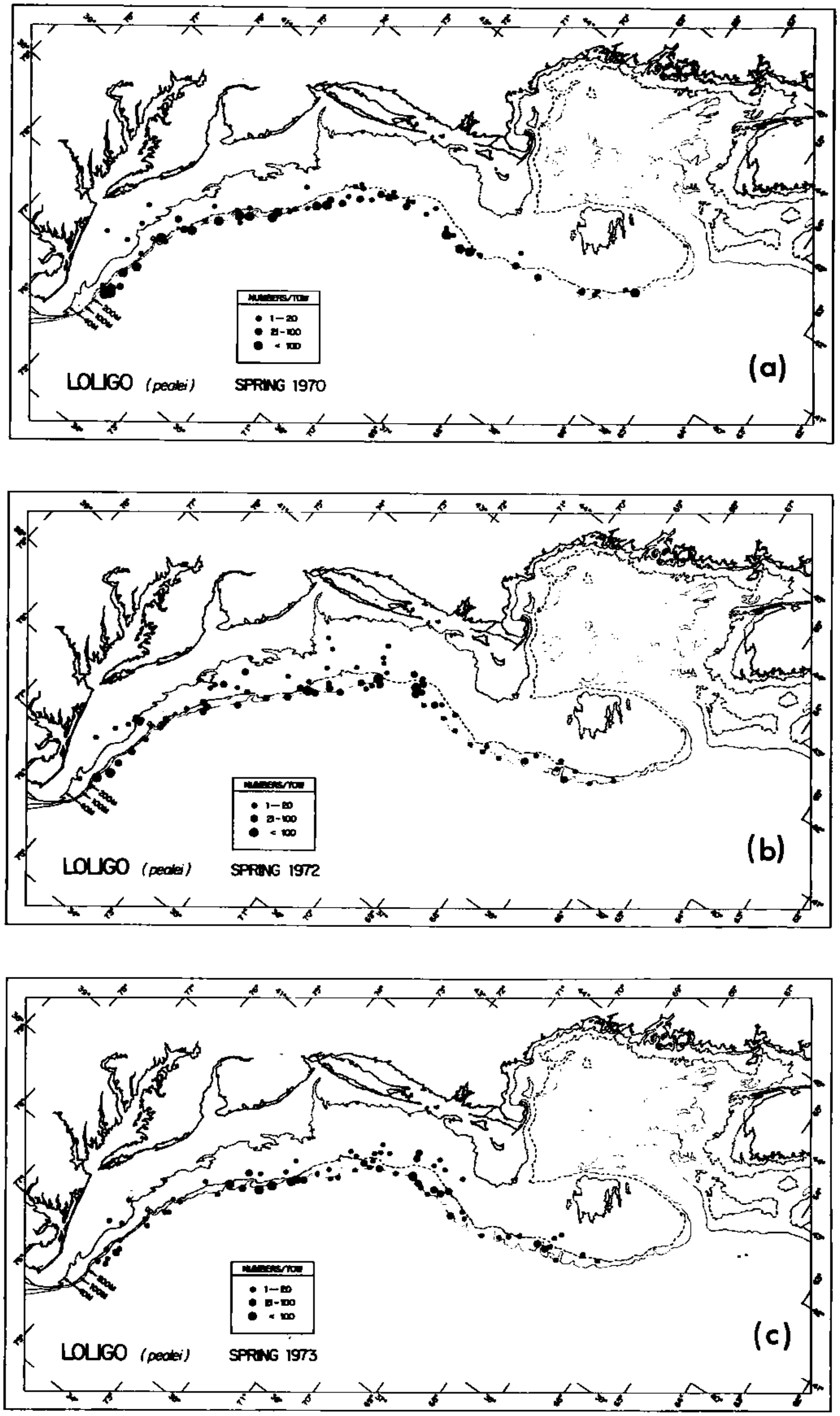


Fig. 2(a-1). Distribution of *Loligo pealei* and *Illex illecebrosus* from USA bottom trawl survey for spring and autumn cruises, 1970, 1972 and 1973.

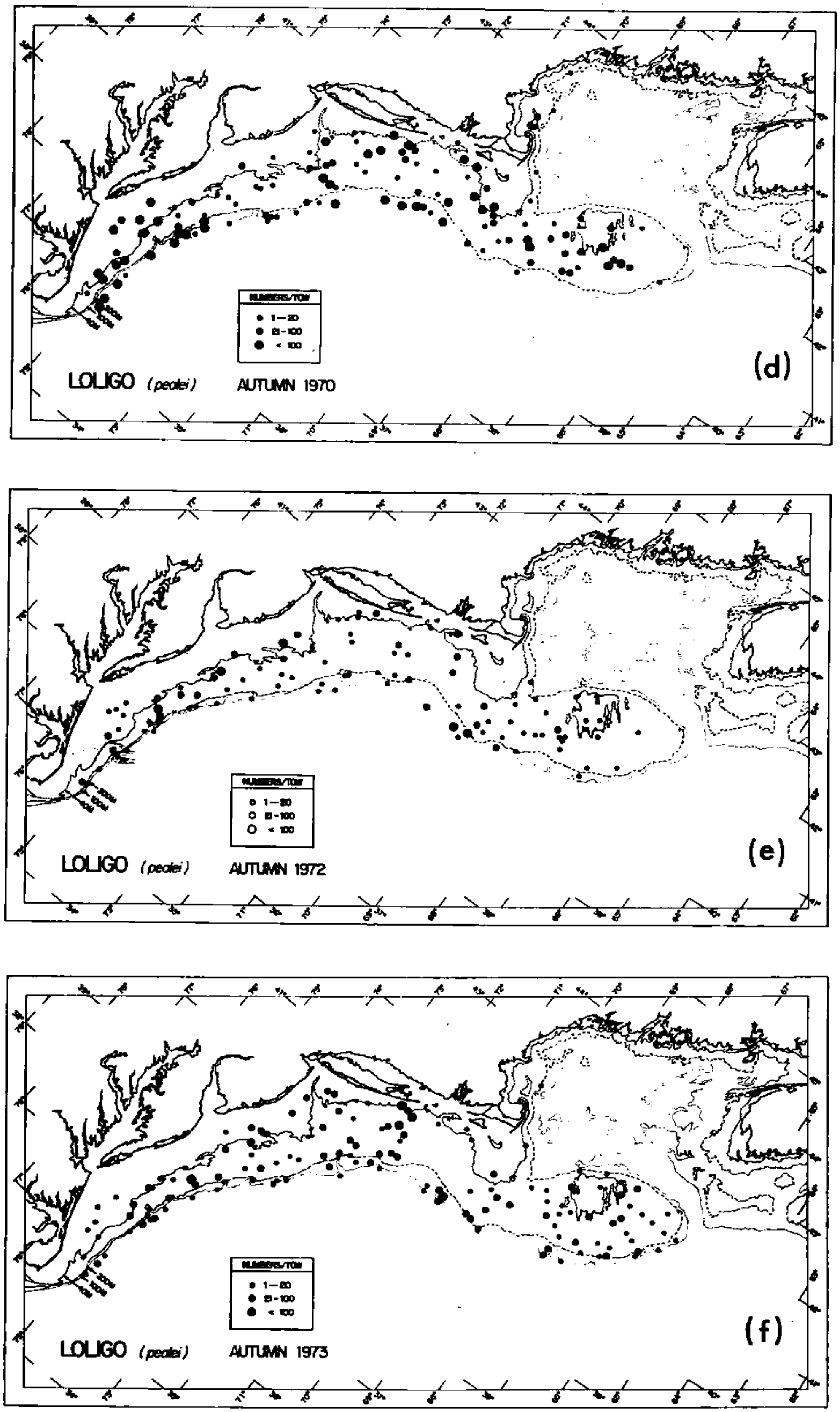
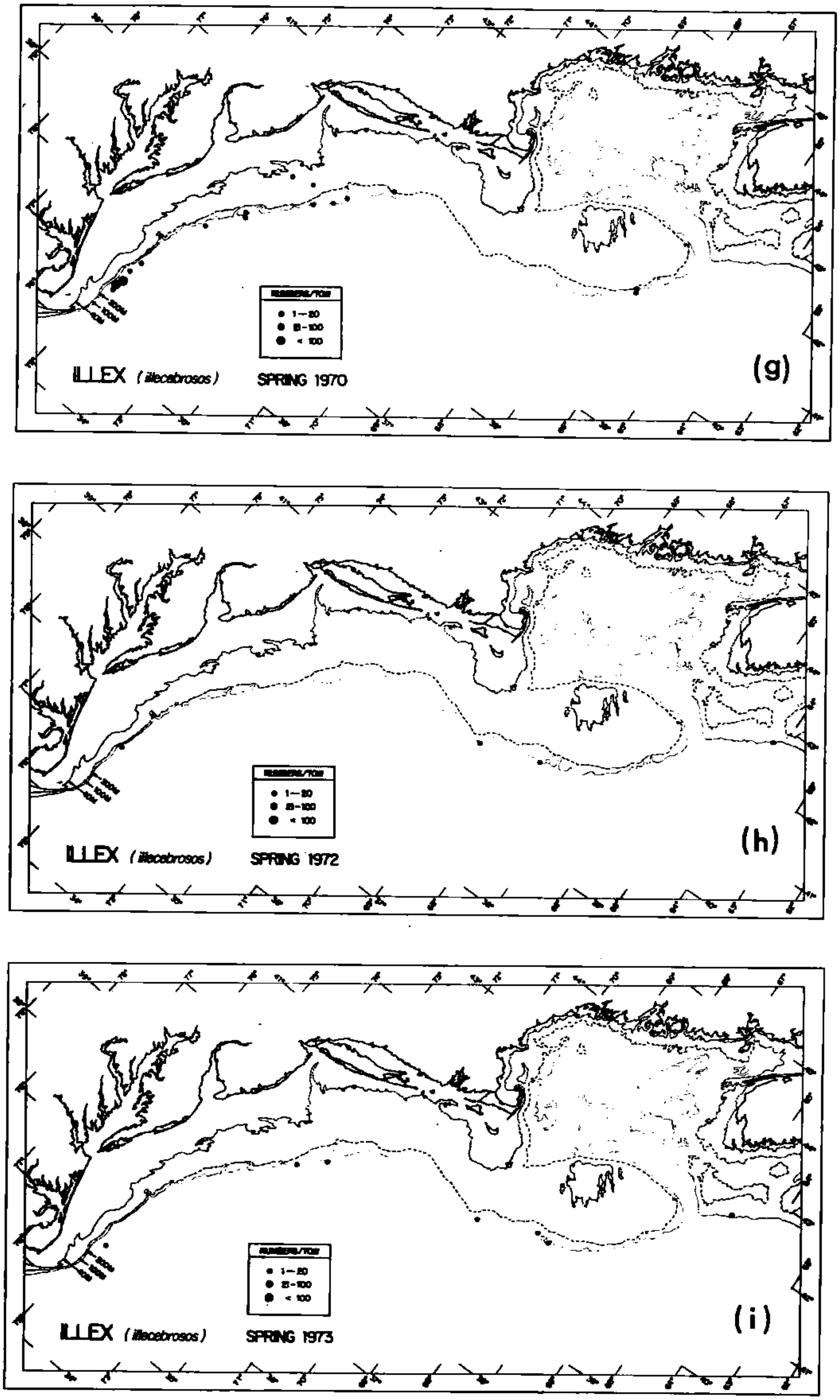


Fig. 2. (Continued)



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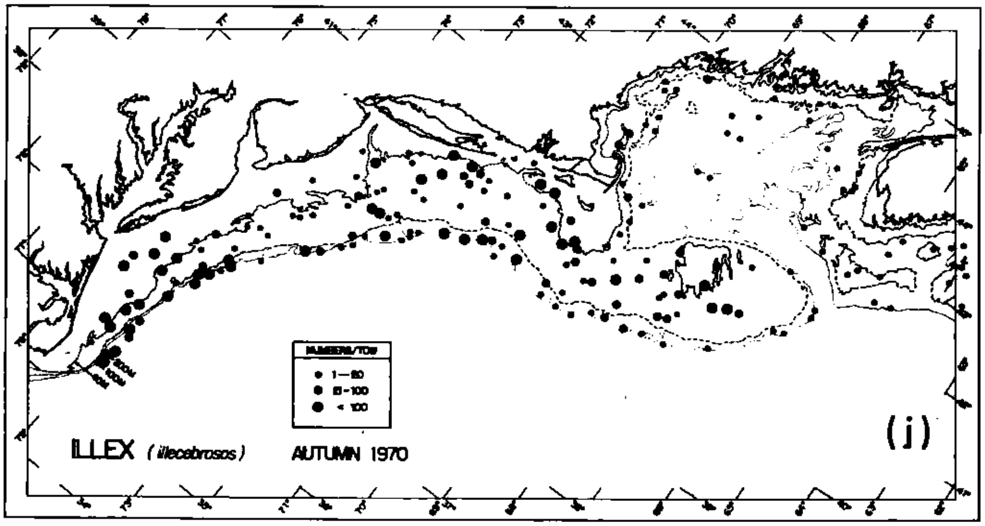

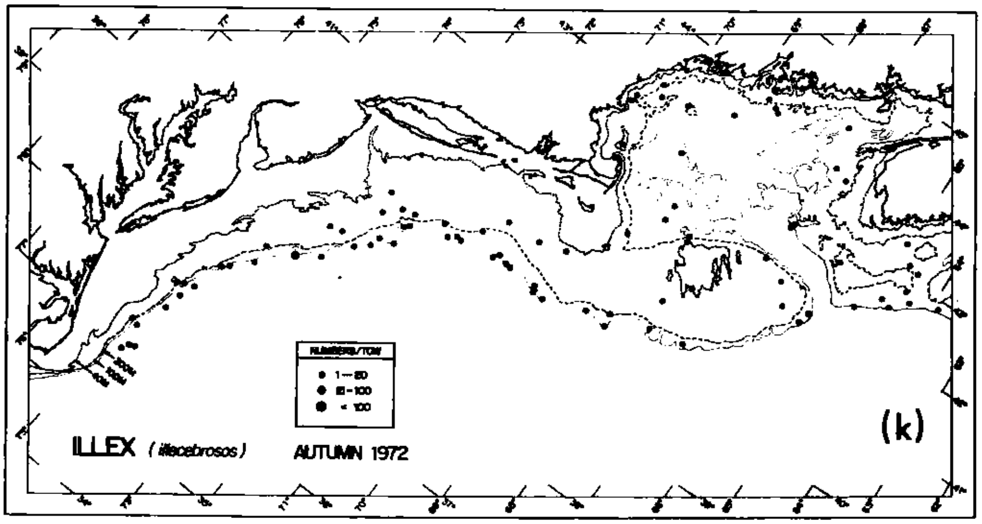

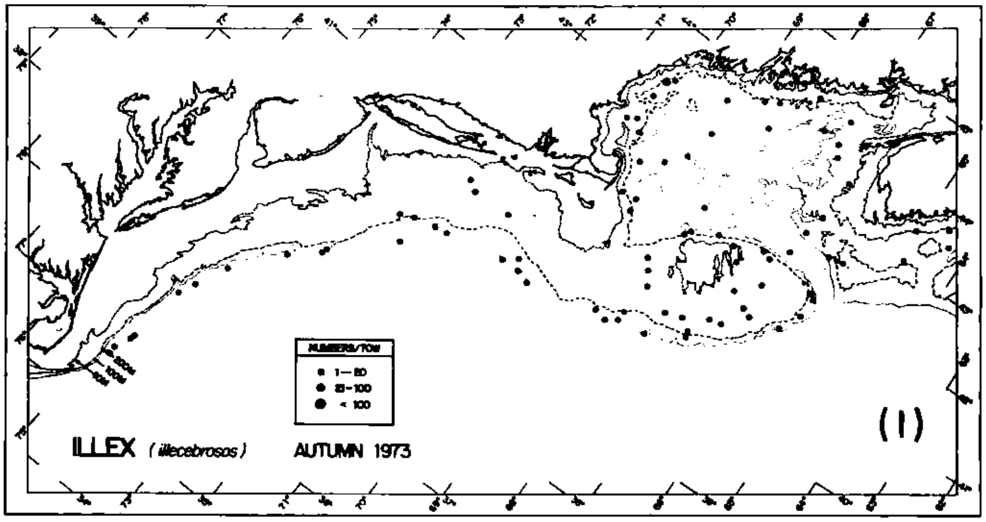

Fig. 2. (Continued)

The lifespan of *Loligo* was estimated by Summers (1971) to be 14-24 months with a maximum length of 18-28 cm (dorsal mantle length), although he found that some males survive to about 36 months and grow to greater than 40 cm. There may also be a significant number of 2-year-olds that survive two spawning seasons, as seen in April 1973 where about 24% of the US commercial samples were 30 cm or over and presumably about 1-1/2 years old. It is not known whether these individuals spawned in their first season.

Loligo grows an average 1.0-1.5 cm per month, with males growing faster and larger than females (Ikeda and Nagasaki, MS 1975; Summers, 1971). Length-weight equations, derived for males and females separately and combined from least squares regression of the $\log_e$ of weight (gm) on $\log_e$ of length (mm) for 766 *Loligo* collected during May-November 1975 in inshore waters of Southern New England, are as follows:

Males: $W = 0.005592\ L^{1.86345}$

Females: $W = 0.000931\ L^{2.26429}$

Sexes combined: $W = 0.001919\ L^{2.09541}$

Analysis of covariance indicates significant difference between these regression lines.

Illex belongs to an oceanic family, the *Ommastrephiadae*, and little is known of its biology or life history. Seasonal migrations to coastal Newfoundland, Nova Scotia and New England, into shallow water (10-150 m) (Squires, 1957) during the spring and summer allow for an inshore fishery. In late autumn (October-December) movement is to the southeast and open ocean from Newfoundland, and offshore in Subarea 5 and Statistical Area 6. Mercer (MS 1973a) found *Illex* in concentrations along the edge of the continental shelf in waters with temperatures greater than 5°C. Spawning is believed to occur offshore at great depths from December to June (primarily December to March), with most *Illex* dying after spawning (Squires, 1957). However, mature individuals have been collected on Georges Bank in August (1963) (Roland Wigley, National Marine Fisheries Service, personal communication). *Illex* are faster growing and shorter lived than *Loligo*, generally surviving about one year, with monthly growth increments of about 2 cm for both sexes. They attain a size of up to 33 cm (Squires, 1967).

Konstantinov and Noskov (MS 1973) state that generally one generation of *Illex* is found, with mean length of 14 cm in May and growing to 22 cm in October. They report that in October male gonads are 60-80% developed while females are just beginning to ripen, and they feel that the females will reach maturity during their spawning migration to open ocean.

Table 3. US catch (for major New England ports) of *Loligo*, *Illex* and all squid by month expressed as percent of the total for 1970-74.

Month	Percentage monthly catch		
	Loligo	*Illex*	Squid
January	1.4	0.0	2.6
February	3.0	0.0	3.0
March	0.0	0.0	2.4
April	0.1	0.0	4.7
May	54.8	0.0	23.6
June	30.9	17.1	18.5
July	2.2	12.0	6.8
August	0.5	31.0	9.4
September	1.0	14.4	8.4
October	3.0	8.7	11.8
November	3.0	16.4	8.1
December	0.1	0.5	0.3

Mercer (MS 1973b) gives the length-weight equations as:

Males: $W = 0.004034\ L^{3.511}$

Females: $W = 0.01301\ L^{3.109}$

with constants derived from a least squares linear fit of weight in grams and length in mm.

Both *Illex* and *Loligo* feed on small fish, crustaceans and squid of their own or other species (Roland Wigley, personal communication). Squid themselves are preyed upon in varying degrees by about 40 fish species (Maurer, MS 1975) and by marine mammals such as the pilot whale (Mercer, MS 1974), indicating great importance in the food web of the continental shelf (Table 2).

COMMERCIAL FISHERY

US squid catches off New England have been reported since the late 1800's (ranging from 500-2,000 tons per year), but until recently there has been no separation of species in reported catches. Interest in squid in Subarea 5 + Statistical Area 6 by other countries (Fig. 3) has increased since the USSR first reported by-catches in 1964. In 1974 there were nine countries reporting squid catches totalling about 56,000 tons (Table 1). Aside from a US trap fishery for *Illex* (as bait), squid in Subarea 5 + Statistical Area 6 are fished with otter trawls. Monthly percentages of US squid catches by species are given in Table 3.

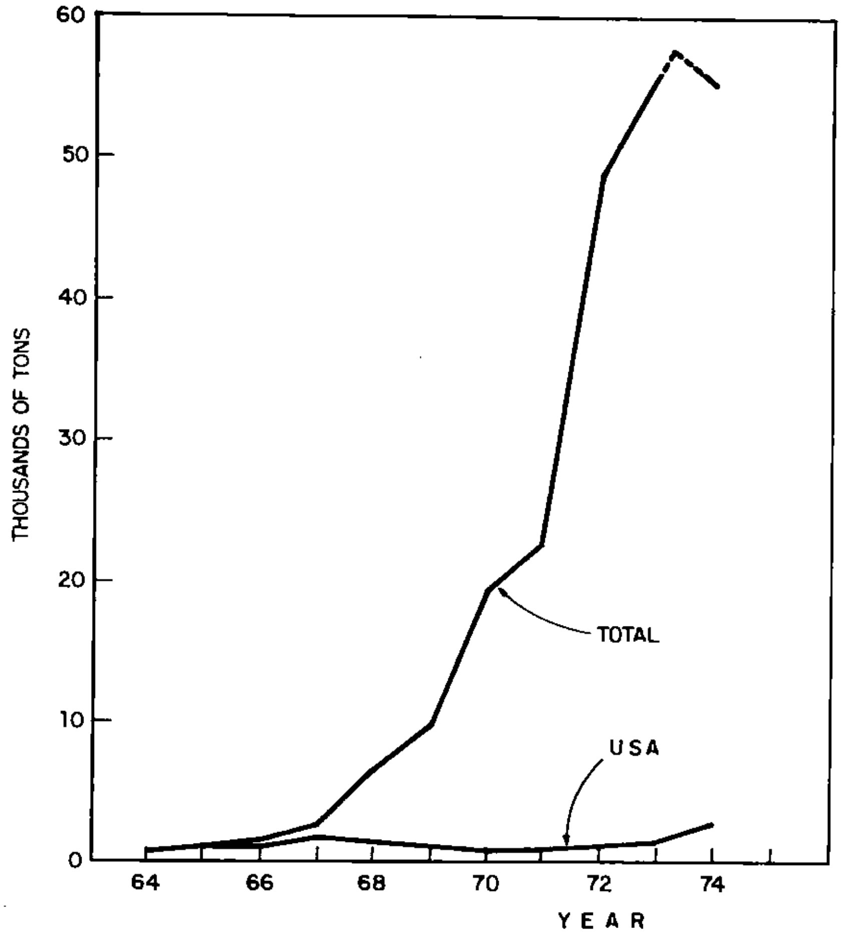

Fig. 3. Total and US squid catches (1964-74) in thousand metric tons, ICNAF Subarea 5 and Statistical Area 6.

Japan, Spain and Italy are the primary participants in the offshore directed squid fishery, initiated by Japan in 1967, with Spain entering the fishery in 1970 and Italy in 1972 (Table 1). Japan and Italy fish for *Loligo* from October to March along the edge of the continental shelf. Japan has a butterfish fishery associated with its fishery for *Loligo* and may take more butterfish than squid during any given month (ICNAF, 1975b, 1976b). Spain has, in addition to its winter fishery for *Loligo*, steadily increased its effort in the summer months exploiting *Illex* in the same offshore waters (E.C. Lopez-Veiga, Instituto de Investigaciones Pesqueras, Spain, personal communication). The Spanish squid fishery produces a substantial by-catch of species such as butterfish and mackerel (up to 65% in March and April) (E.C. Lopez-Veiga, personal communication), most of which is discarded.

Except for catches by Japan, Spain, Romania and Bulgaria in 1973 and 1974, squid catches have not been separated into species; therefore, total estimated catches by species (Fig. 4) and catches by species and country (Table 4) were calculated for 1963 to 1973 as follows: based on US survey cruise distributions of percent species composition by weight (Table 5), October through March catches were considered as entirely *Loligo*, and April through September catches were separated as follows: 40% of the offshore directed (Japan, Spain, Italy) catches and 50% of the inshore catches were assumed to be *Loligo* (see Table 4 for details). Species separation for 1974 also included observed percent composition of squid from courtesy boardings of vessels participating in the squid fishery, actual reported catches and percent composition in US surveys by area, season and depth.

FISHING EFFORT AND CATCH PER EFFORT

Table 6 shows the catch per day fished by Japan and Spain with squid (both species) as the main species sought (*i.e.*, either reported as main species or composing greater than 50% of the total monthly catches of a gear type in an area) (ICNAF, 1974b, 1975b).

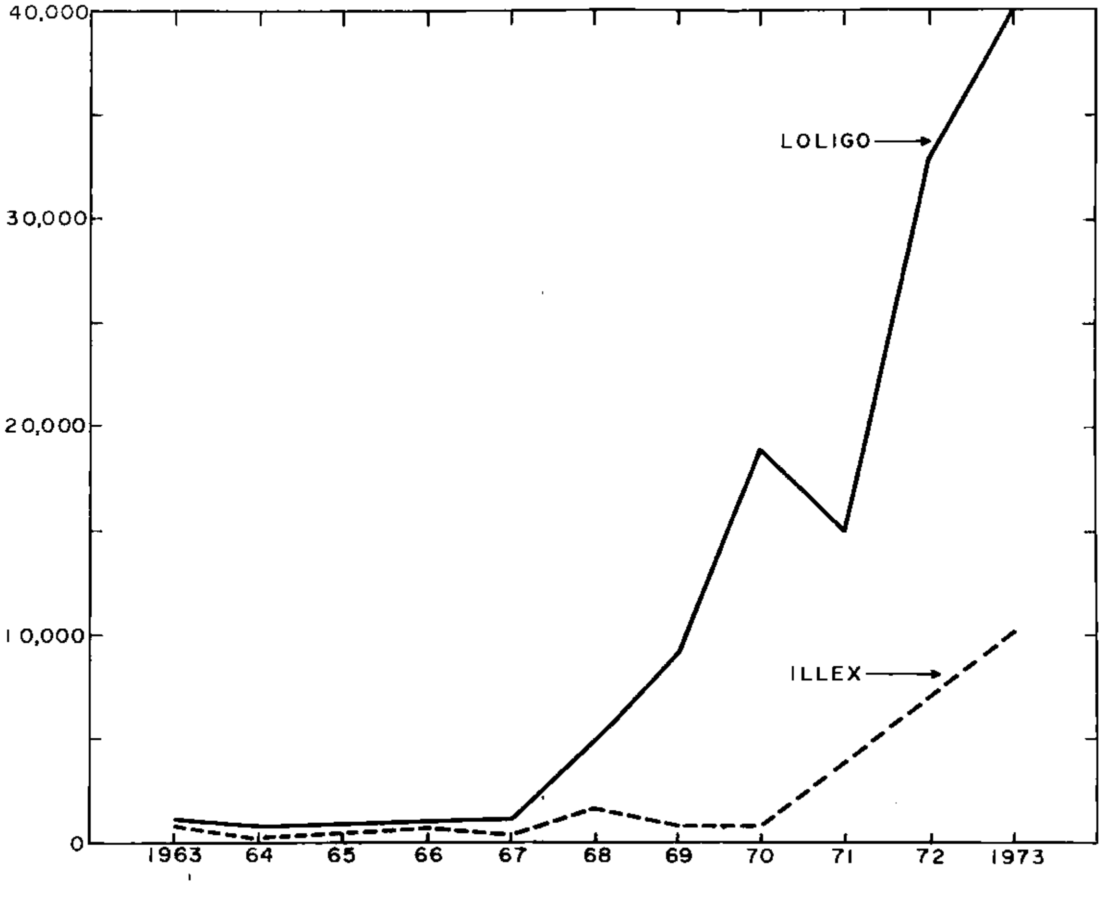

Fig. 4. Estimates of total squid catches (all countries) by species in ICNAF Subarea 5 and Statistical Area 6, 1963-73.

Table 4. Estimated breakdown of squid catches by country[a] and species for Subarea 5 + Statistical Area 6, 1963-74[b] (* - as reported to ICNAF).

Year	BUL	CAN	CUBA	FRA	FRG	GDR	ITA	JAP	POL	ROM	SP	USSR	USA	TOTAL
							Loligo							
1963	-	-	-	-	-	-	-	-	-	-	-	-	1,294	1,294
1964	-	-	-	-	-	-	-	-	-	-	-	-	576	576
1965	-	-	-	-	-	-	-	-	-	-	-	99	709	808
1966	-	-	-	-	-	-	-	-	-	-	-	226	722	948
1967	-	-	-	-	-	-	-	5*	-	-	-	548	1,125	1,678
1968	-	-	-	-	-	5	-	177*	-	-	-	2,184	1,083	3,449
1969	-	-	-	-	-	-	-	7,125*	-	-	-	1,080	898	9,103
1970	-	-	-	-	-	10	-	13,557	-	-	4,483	482	652	36,184
1971	50	-	-	-	-	-	-	10,528	-	-	1,881	3,561	727	16,747
1972	254	-	7	296	463	-	2,928	17,102	2,754	33	8,165	4,045	742	36,789
1973	410*	-	-	820	1,639	163	2,994	14,396*	5,134	139*	11,145*	5,000	1,100	42,940
1974	300	-	-	27	-	-	3,280*	13,493*	1,653	-	9,375*	4,485	2,141	34,754
							Illex							
1963	-	-	-	-	-	-	-	-	-	-	-	-	810	810
1964	-	-	-	-	-	-	-	-	-	-	-	-	358	358
1965	-	-	-	-	-	-	-	-	-	-	-	78	444	522
1966	-	-	-	-	-	-	-	-	-	-	-	118	452	570
1967	-	-	-	-	-	-	-	2*	-	-	-	286	704	992
1968	-	-	-	-	-	5	-	1,655*	-	-	-	1,052	678	3,390
1969	-	-	-	-	-	1	-	586*	-	-	-	260	562	1,409
1970	-	-	-	-	-	10	-	82*	-	-	27	174	408	701
1971	40	1	-	-	-	-	-	48	-	-	2,317	2,578	455	5,439
1972	245	-	7	-	-	-	272	1,589	2,674	33	3,694	2,927	472	11,913
1973	-	-	-	-	-	156	171	1,009*	4,070	-	3,784*	3,976	530	13,696
1974	293	-	-	-	-	-	980*	3,327*	5,052	9	6,769*	3,945	148	20,523

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[a] Country abbreviations as in ICNAF Statistical Bulletin.

[b] Estimated species breakdown (except asterisked values) based on assuming 60% of April-September squid catches as *Illex* for Japan, Spain and Italy and 50% of April-September squid catches as *Illex* for remaining countries.

Table 5. Percent composition by weight of *Illex* in catches of squid from US and USSR bottom trawl surveys by season, area and depth range, 1969-74.

Year	Country	Season	Mid-Atlantic[a]		S. New England[a]		Georges Bank[a]		Total	
			<60 Fm[b]	>60 Fm	<60 Fm	>60 Fm	<60 Fm	>60 Fm	<60 Fm	>60 Fm
1969	USA	Summer	3.0	39.0	73.0	100.0	35.0	100.0	43.0	79.0
1970	USA	Spring	1.0	14.5	0.0	1.0	0.0	1.2	0.0	8.1
1971	USA	Spring	1.5	2.9	0.6	0.8	0.0	1.1	0.8	2.1
1972	USA	Spring	0.0	0.1	0.0	0.2	0.0	0.8	0.0	0.2
1973	USA	Spring	0.0	1.0	0.0	1.0	0.0	3.8	0.0	1.0
1974	USA	Spring	0.1	9.9	1.3	14.9	0.0	0.0	0.3	12.4
1975	USA	Spring	0.2	2.0	0.3	0.5	0.0	4.0	0.2	1.5
1970	USA	Autumn	5.0	23.0	2.0	24.0	8.0	91.0	4.0	25.0
1971	USA	Autumn	4.0	89.0	3.0	11.0	21.0	72.0	7.0	26.0
1972	USSR	Autumn	2.0	74.0	5.0	16.0	14.0	11.8	6.0	42.0
1972	USA	Autumn	2.0	71.0	7.0	12.0	5.0	79.0	4.0	21.0
1973	USSR	Autumn	1.0	73.0	0.2	6.0	26.4	-	2.1	63.0
1973	USA	Autumn	0.0	14.0	0.4	3.2	6.7	15.2	1.4	9.0
1974	USSR	Autumn	0.5	15.0	1.0	13.0	9.0	34.0	2.5	14.6
1974	USA	Autumn	0.4	25.0	0.7	19.0	3.0	22.0	0.9	21.6

[a] See Fig. 9.

[b] One fathom = 1.82 metres.

Table 6. Catch-per-day fished by area and gear for Spain and Japan, 1970-74.

Area	Country	Gear and tonnage class[a]	Catch per day fished (metric tons)				
			1970	1971	1972	1973	1974
5Ze	Spain	OTSN 5	-	-	14.8	9.2	6.9
	Japan[b]	OTSN 5	-	-	-	-	28.7
		OTSN 6	22.6	6.3	-	16.3	15.0
		OTSN 7	37.3	26.3	24.4	33.6	17.9
5Zw	Spain	OTSN 5	-	4.0	8.5	7.6	5.5
	Japan[b]	OTSN 5	-	-	-	-	12.6
		OTSN 6	19.7	14.9	-	14.1	8.6
		OTSN 7	28.4	11.3	19.9	18.6	12.8
6A	Spain	OTSN 5	-	7.8	7.9	7.1	7.0
	Japan[b]	OTSN 5	-	-	-	-	7.8
		OTSN 6	24.3	13.8	18.7	14.4	10.4
		OTSN 7	32.5	13.4	17.3	13.2	12.4
6B	Spain	OTSN 5	-	11.9	12.3	-	6.9
	Japan[b]	OTSN 5	-	-	-	-	10.9
		OTSN 6	24.9	12.9	-	10.0	10.3
		OTSN 7	25.3	16.2	17.2	14.4	11.9
6C	Spain	OTSN 5	-	8.6	12.9	-	7.0
	Japan[b]	OTSN 5	-	-	-	-	12.5
		OTSN 6	-	-	-	16.4	15.3
		OTSN 7	-	-	15.4	14.6	16.1
Total	Spain	OTSN 5	-	9.0	11.3	7.4	6.8
	Japan[b]	OTSN 5	-	-	-	-	17.8
		OTSN 6	22.8	12.2	18.7	13.4	12.9
		OTSN 7	29.9	16.9	18.8	19.7	14.8

[a] OTSN = otter trawl stern; tonnage class 5 = 500-999 GRT, 6 = 1000-1999 GRT and 7 = 2000 GRT and over.

[b] All Japanese C/E data based on 24 hours/day.

The changes in catch per effort (C/E) (1972-73) of the two major countries with a directed fishery (Japan and Spain) are consistent. Increases in effort by these two countries as reported in the 1973 ICNAF Statistical Bulletin (ICNAF, 1975b) are not reflected in similar increases in catches (except in ICNAF Subdiv. 5Ze for Japan), resulting in decreases in C/E. These changes in C/E for Japan are only an indicator of relative abundance changes, since they have a butterfish fishery associated with their *Loligo* fishery. Japanese medium (1000-2000 GRT) stern trawler effort increased from 26 to 226 days fished while catches only increased from 480 to 3,018 tons, producing a 28% drop in C/E from 1972 to 1973. In 1974, effort decreased to 93 days while the catch dropped to 917 tons, a 26% decrease in C/E. Spanish small (500-1000 GRT) stern trawlers participating in a directed squid fishery also reported a decrease in C/E from 1972 to 1973 (35%), with increases in effort from 1,048 to 2,024 days fished and catches of 11,861 tons in 1972 increasing only to 14,932 tons. Spanish C/E in 1974 dropped an additional 9% over that of 1973. Japanese large stern trawlers (>2000 tons) did exhibit a 3% increase in C/E from 1972 to 1973 though catches by this vessel class decreased from 15,779 to 9,597 tons (dropping from 84 to 61% of the total Japanese catch). In 1974, however, C/E dropped 33% though catches increased to 12,833 tons. Spanish reports of sample C/E increased from 1969 to 1973 for *Loligo* and until 1972 for *Illex*, after which there was about a 30% drop for both species (E.C. Lopez-Veiga, personal communication). These decreases in C/E may imply that the entire squid stocks (Primarily *Loligo*) in Div. 5Z and SA 6 are under substantial exploitation (*i.e.*, F is a significant part of the total mortality on the stock). The C/E ratio for squid for those countries with no directed fisheries fluctuates by year in the different areas.

LENGTH AND AGE COMPOSITION

US commercial length samples were taken for each species of squid between July 1972 and December 1974 (Fig. 5). Adequate ageing techniques have not yet been developed for either species, However, size at age and spawning schedules have been described by Summers (1971) and Squires (1967) for *Loligo* and *Illex* respectively, both based on the assumption of heavy post-spawning mortality after one year of age. It should be noted, however, that age 2+ *Loligo* (over 30 cm) have made up as much as 24% of the individuals taken in spring samples (Fig. 5).

Modal values for *Loligo*, based on commercial length frequencies (Fig. 5a, b) are generally similar to those described by Summers (1971). Generally, two or three modes are observed during the year. In the January samples, the first mode probably represents 6-7 month-old individuals, hatched during the previous summer, which will probably spawn late in the summer; the second and third modes of larger age 2+ squid will probably spawn during the spring. In spring, the larger groups (18 cm and greater) are mature and spawning begins; those greater than about 28 cm tend to dsiappear from the fishery by summer (note exception in August 1972 sample), whereas some of the smaller 2-year-olds, 20-25 cm (probably 16-17 months of age), survive until autumn. Spawning continues through September. By the end of May, smaller *Loligo* (9-11 cm, probably 5-6 months) recruit to the fishery. The earliest spawned young-of-the-year first appear in the fishery in September at about 6 cm.

Length frequencies of *Loligo* from Japanese, USSR and Polish commercial catches from 1970 to 1974, based on sample data supplied to ICNAF (Fig. 6), are consistent with US 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. Japanese and Soviet samples indicate that sizes decreased in April of 1972 and 1974.

Monthly length samples of *Illex* from the US commercial fishery in Div. 5Y for 1974 (Fig. 7) indicate a single mode through most of the year. In May and June, however, the distribution was skewed to the right due to the presence of large individuals (23-40 cm). As *Illex* 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 year-class. It has not been explained why mature-sized individuals are in the inshore fishery as late as June, when all spawning has been assumed to be offshore. Large *Illex* are infrequent during summer. Generally, small individuals appear in autumn catches (Fig. 11b, autumn bottom trawl survey length frequencies).

Polish and USSR length frequencies of *Illex* taken in 1973 and 1974 (ICNAF samples, 1973 and 1974, Fig. 8) showed 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 21 cm by August, but in September the new recruiting year-class (5-12 cm) has a mean length of 17 cm. In October large *Illex* are assumed to move offshore to spawn, and the average length in the commercial catches drops to 11.5 cm in November.

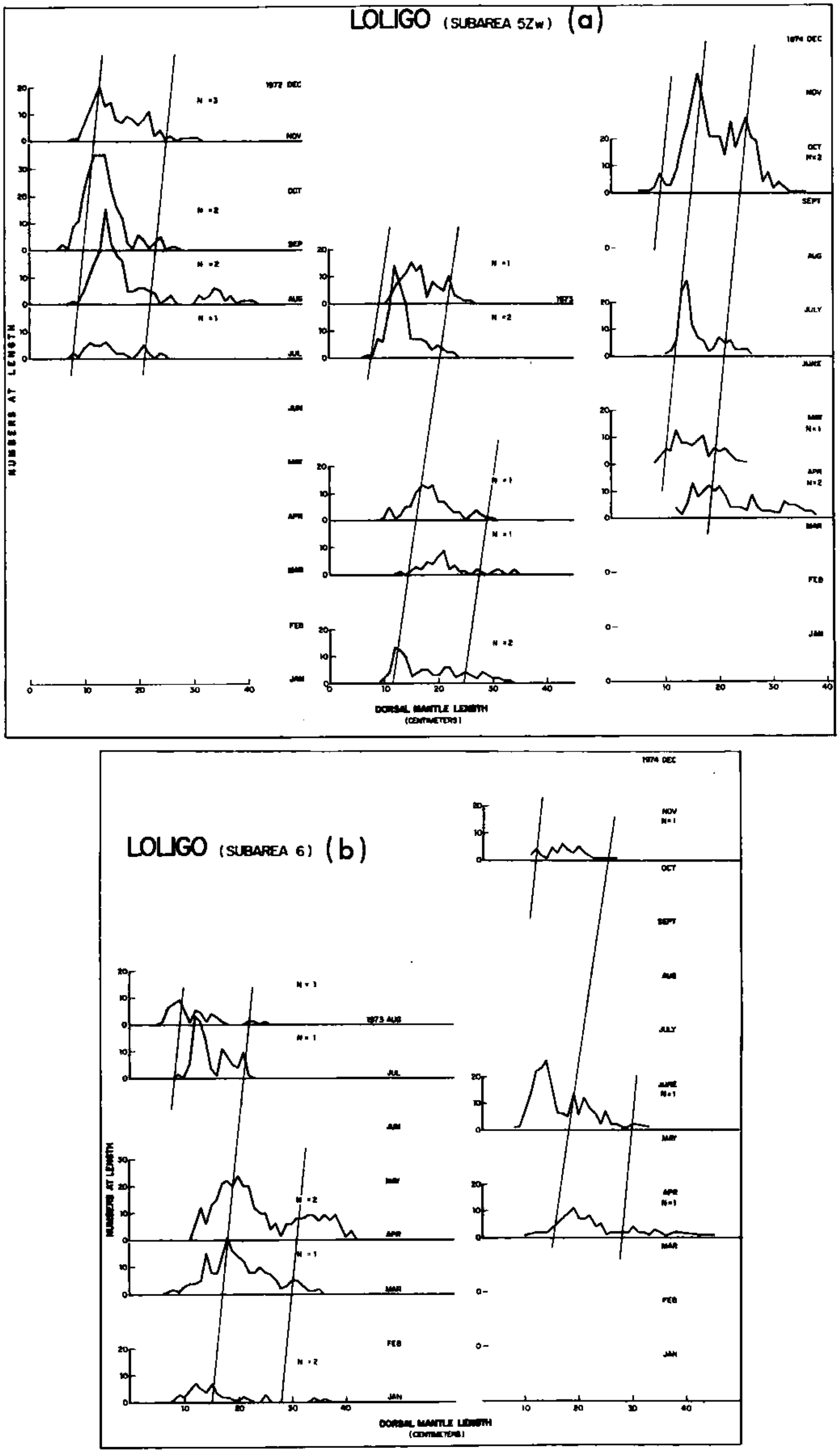


Fig. 5(a-b). US commercial length frequencies of *Loligo pealei* in (a) ICNAF Subdiv. 5Zw, 1972-74 and (b) ICNAF Statistical Area 6, 1973-74. N is the number of samples; slanted lines indicate growth modes described by Summers (1971).

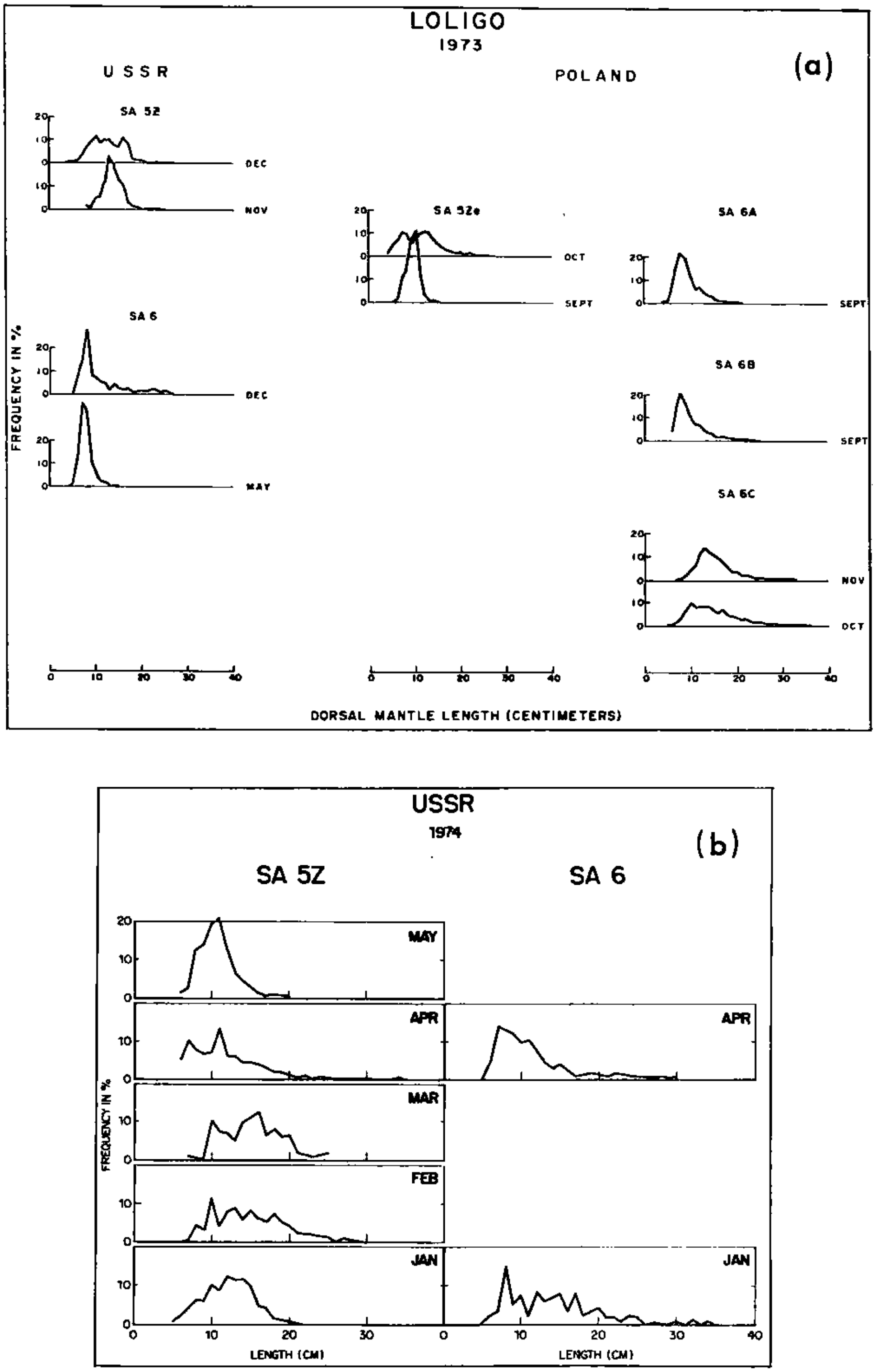


Fig. 6(a-e). USSR, Poland and Japan commercial length frequencies of *Loligo pealei*, 1970-74.

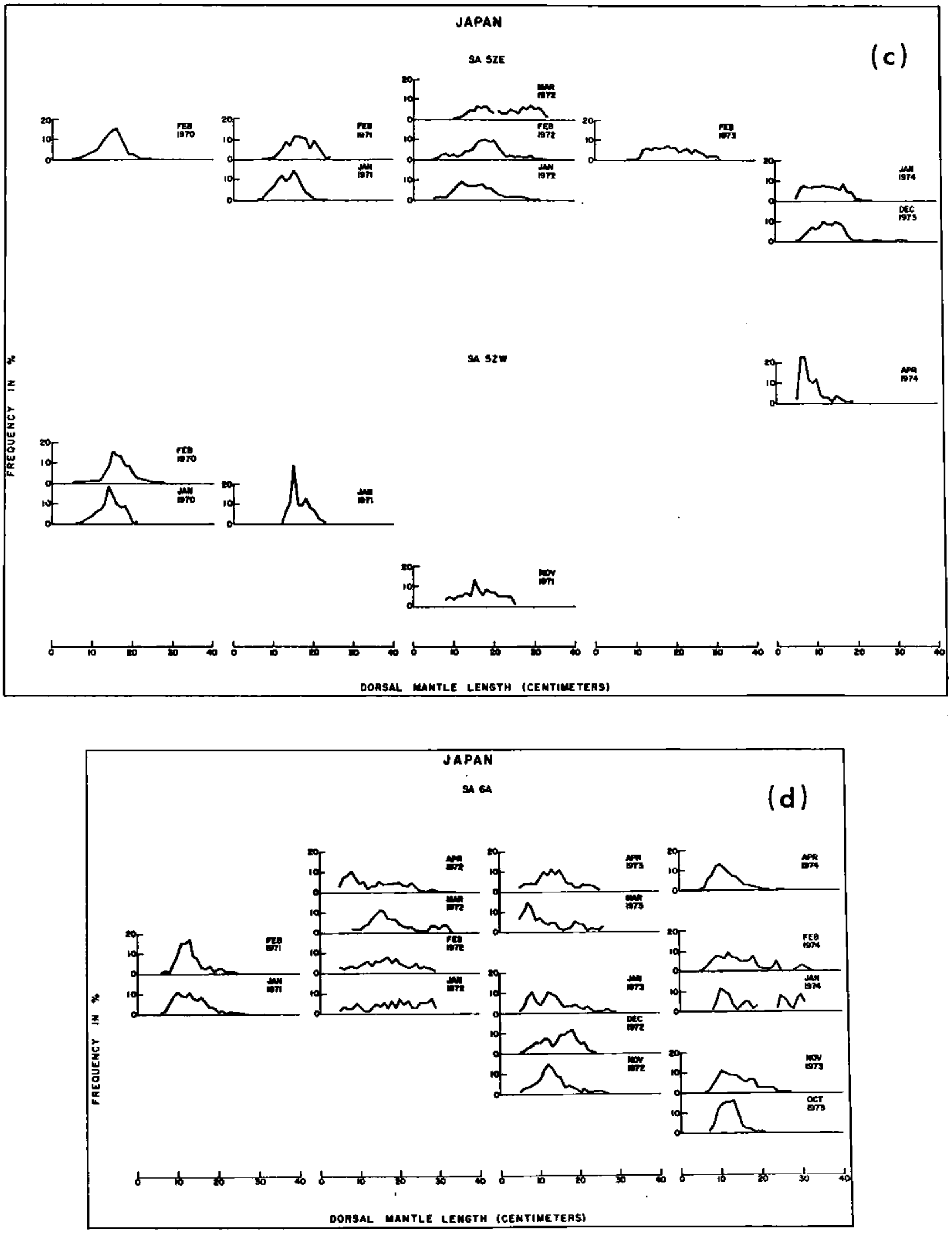


Fig. 6. (Continued)

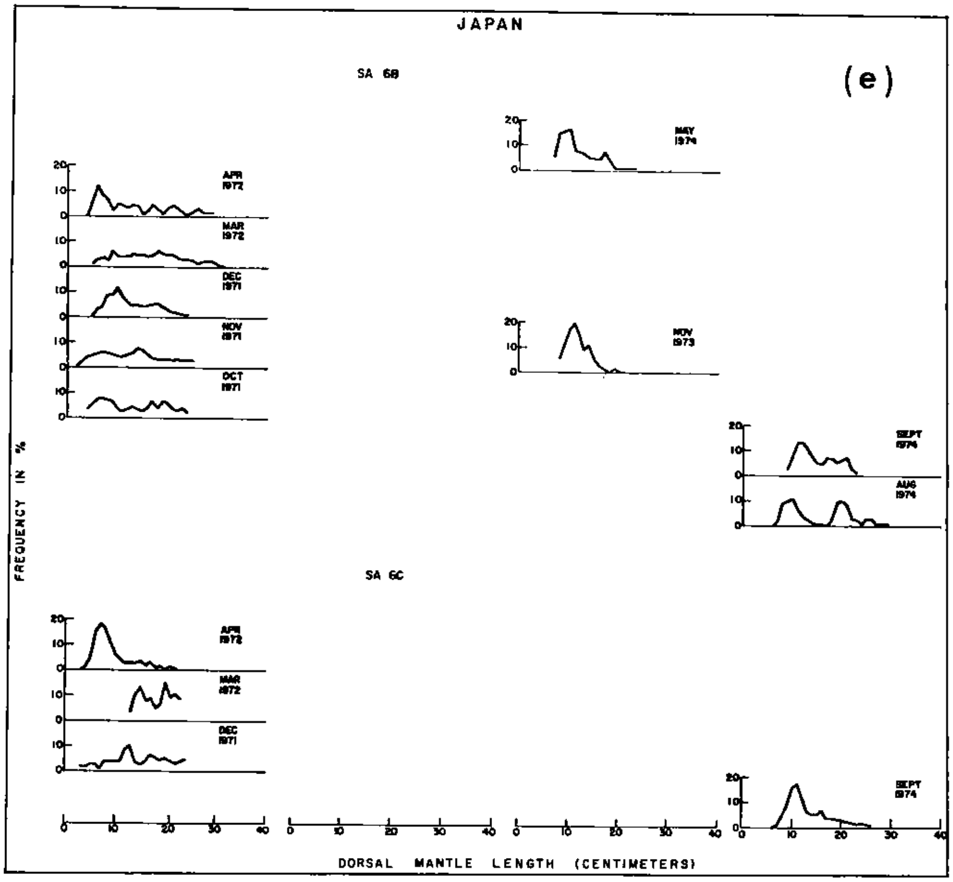


Fig. 6. (Continued)

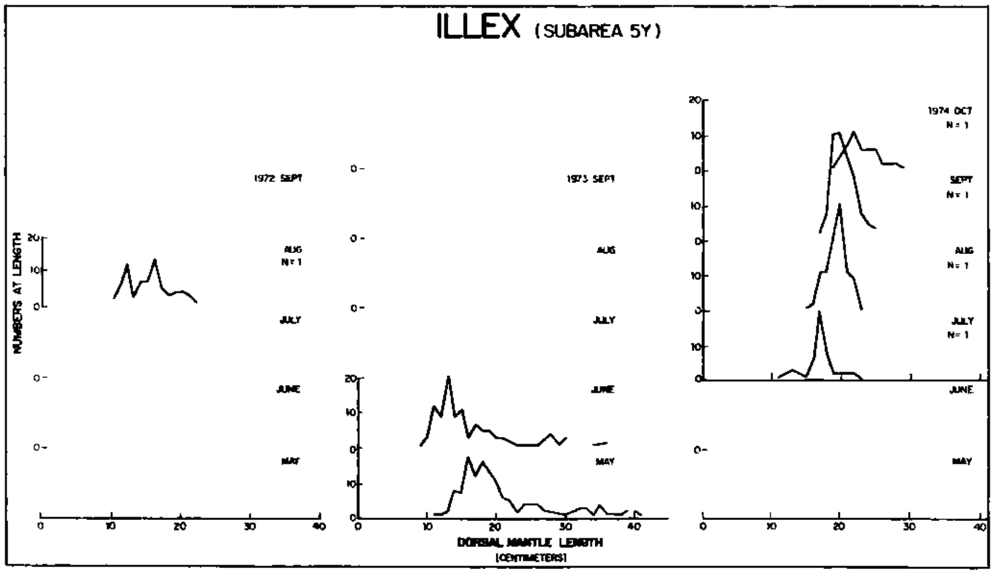


Fig. 7. US commercial length frequencies of *Illex illecebrosus* in ICNAF Div. 5Y, 1972-74.

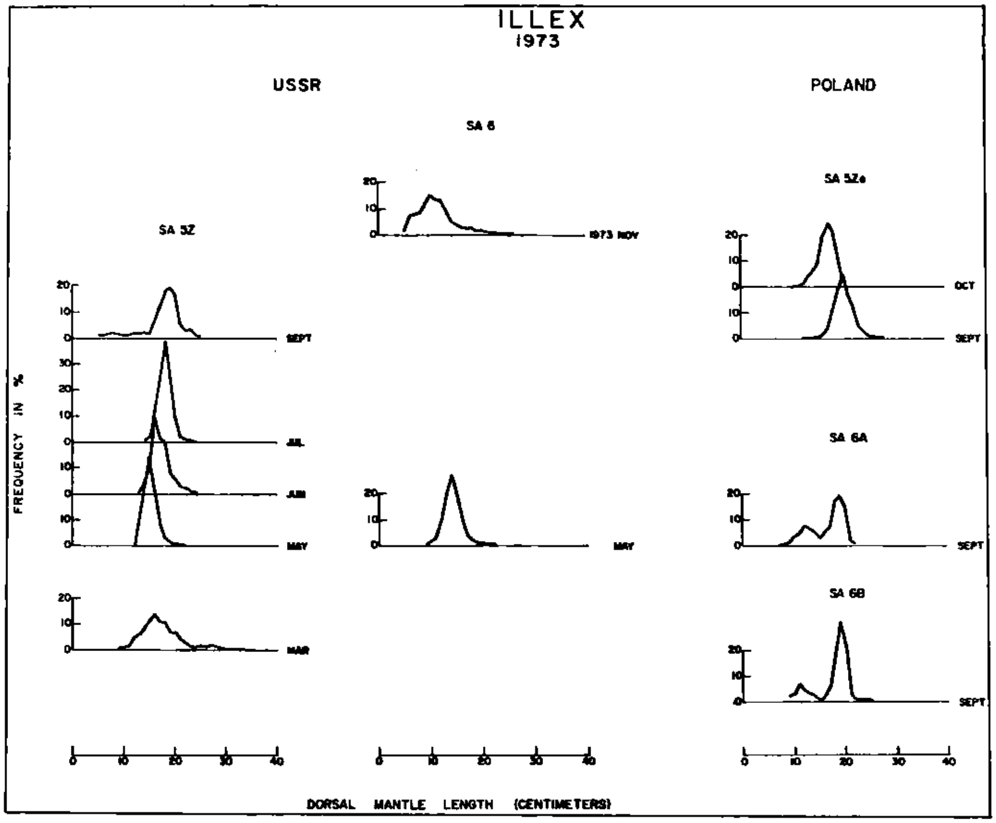


Fig. 8. USSR and Poland commercial length frequencies of *Illex illecebrosus*, 1973.

In general the commercial length frequencies of both species show the progression of the main group of individuals hatched the previous year. But in *Loligo* 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 2 and 3.

RESEARCH VESSEL CRUISES

Abundance index

Estimates of relative abundance were made using sets of strata from US bottom trawl survey cruises (Grosslein, 1969), which approximate the areas of the Middle Atlantic (strata 61-76), Southern New England (1-12), southern (13-15), eastern (16-18) and northern Georges Bank (19-25) (Fig. 1 and 9), for autumn (September-November) and spring (March-April) cruises (autumn 1967 to spring 1975). Prior to the autumn 1967 cruise, complete records of squid species were not kept. Stratified mean of $\log_e$ of catch per tow (plus 1) of *Illex* and *Loligo* were calculated for these areas (Table 7). *Loligo* is abundant primarily in the Middle Atlantic and Southern New England areas in autumn, but is also consistently found on Georges Bank. *Illex* concentrations were greater in Southern New England and Georges Bank than in the Middle Atlantic area in autumn and they were relatively unavailable to surveys in spring.

Plots of locations of squid catches during survey cruises for 1970, 1972 and 1973 (Fig. 2) indicate that both species are distributed across the width of the shelf during autumn surveys, although the extent of onshore distribution of *Illex* is variable between years (note 1970 *vs* 1973 autumn). The 1971 distribution was not greatly different from 1972. During the spring, *Loligo* is concentrated along the continental slope from Cape

Hatteras to Georges Bank, and *Illex* is rarely found in the survey area. However, the few *Illex* caught are generally taken from southern Georges Bank south. Autumn surveys were consequently chosen as the best measure of relative abundance of these two species in this area (Div. 5Z + Statistical Area 6).

The natural log of the mean weight per tow (plus 1) for autumn survey cruises for all areas was plotted (Fig. 10) to illustrate overall trend of squid abundance (1964-74). The *Loligo* index of abundance shows a general increase during this period. However, the least squares linear regression of these indices by year was not significant at the 5% level.

Table 7. Relationship between the average of the natural logarithms of catch per tow (weight in pounds + 1) of *Loligo* and *Illex* and temperature from US stratified spring and autumn trawl surveys in Subarea 5 and Statistical Area 6, 1967-74.

Area[a] and Strata	Year	Spring Ln (weight per tow)		Temp.[b] (°C)	Autumn Ln (weight per tow)		Temp.[b] (°C)
		Loligo	*Illex*		*Loligo*	*Illex*	
Mid-Atlantic (61-76)	1967	-	-	-	2.18	0.16	13.3
	1968	0.28	0.00	5.7	2.32	0.12	13.6
	1969	0.14	0.10	5.5	2.29	0.06	15.5
	1970	0.35	0.04	7.5	1.46	0.23	10.0
	1971	0.44	0.03	6.9	1.18	0.21	13.1
	1972	1.47	0.00	8.7	2.68	0.25	16.0
	1973	0.82	0.01	8.0	2.62	0.04	14.4
	1974	1.92	0.07	10.3	2.63	0.11	14.8
Southern New England (1-12)	1967	-	-	-	0.74	0.39	9.6
	1968	0.45	0.04	5.0	1.92	0.47	11.1
	1969	0.49	0.01	5.7	2.47	0.13	12.1
	1970	0.41	0.01	6.1	1.41	0.22	10.6
	1971	0.76	0.01	6.3	1.45	0.34	10.8
	1972	0.85	0.00	7.0	1.48	0.41	12.7
	1973	0.75	0.01	6.8	2.71	0.12	13.0
	1974	0.93	0.08	8.3	2.50	0.17	12.7
Southern Georges Bank (13-15)	1967	-	-	-	0.66	0.29	8.4
	1968	0.63	0.00	6.3	0.57	0.42	12.6
	1969	1.02	0.00	6.8	1.26	0.13	12.7
	1970	0.36	0.00	5.9	0.80	0.38	10.8
	1971	0.63	0.02	5.8	0.89	0.95	11.9
	1972	0.89	0.02	7.3	0.69	0.28	11.8
	1973	1.23	0.09	8.9	1.81	0.16	13.2
	1974	0.12	0.07	7.8	0.99	0.30	12.6
Eastern Georges Bank (16-18)	1967	-	-	-	0.41	0.05	8.2
	1968	0.00	0.01	3.9	0.54	0.50	10.3
	1969	0.18	0.00	5.4	0.60	0.08	10.1
	1970	0.13	0.02	4.8	0.85	0.18	9.2
	1971	0.05	0.00	4.6	0.37	0.20	10.8
	1972	0.06	0.00	5.8	0.19	0.14	10.2
	1973	0.00	0.00	6.2	1.87	0.34	11.9
	1974	0.00	0.00	6.9	0.92	0.22	12.0
Northern Georges Bank (19-25)	1967	-	-	-	0.02	0.05	7.1
	1968	0.00	0.00	4.7	0.18	0.24	9.7
	1969	0.00	0.00	4.7	0.36	0.01	8.9
	1970	0.00	0.00	5.0	0.39	0.16	9.9
	1971	0.00	0.00	4.8	0.60	0.38	11.2
	1972	0.00	0.00	5.0	0.73	0.23	10.5
	1973	0.00	0.00	5.4	1.25	0.40	11.0
	1974	0.00	0.00	6.6	0.94	0.08	10.9

[a] See Fig. 9.

[b] Mean bottom temperature per strata set.

Illex indices are lower than *Loligo* by a factor of 5 or more each year. The *Illex* abundance shows a decrease from 1971 to 1973, when *Loligo* was increasing, and an increase in 1974 as *Loligo* decreased.

Autumn abundance indices for 1967 to 1972 are also available for USSR research cruises, performed jointly with US bottom trawl surveys. Different gears were used by the two countries (the Yankee 36 net by the USA and the Soviet 21.1 or 24.6 by the USSR), but overall trends of relative abundance appear similar (Table 7, 8).

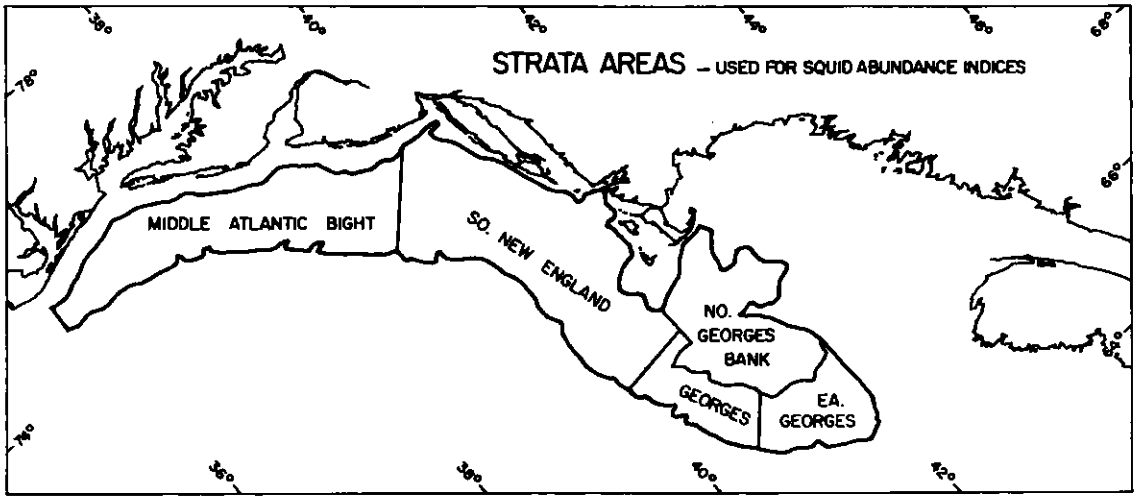


Fig. 9. Strata areas, Middle Atlantic to Georges Bank, used in analysis of US groundfish survey abundance indices.

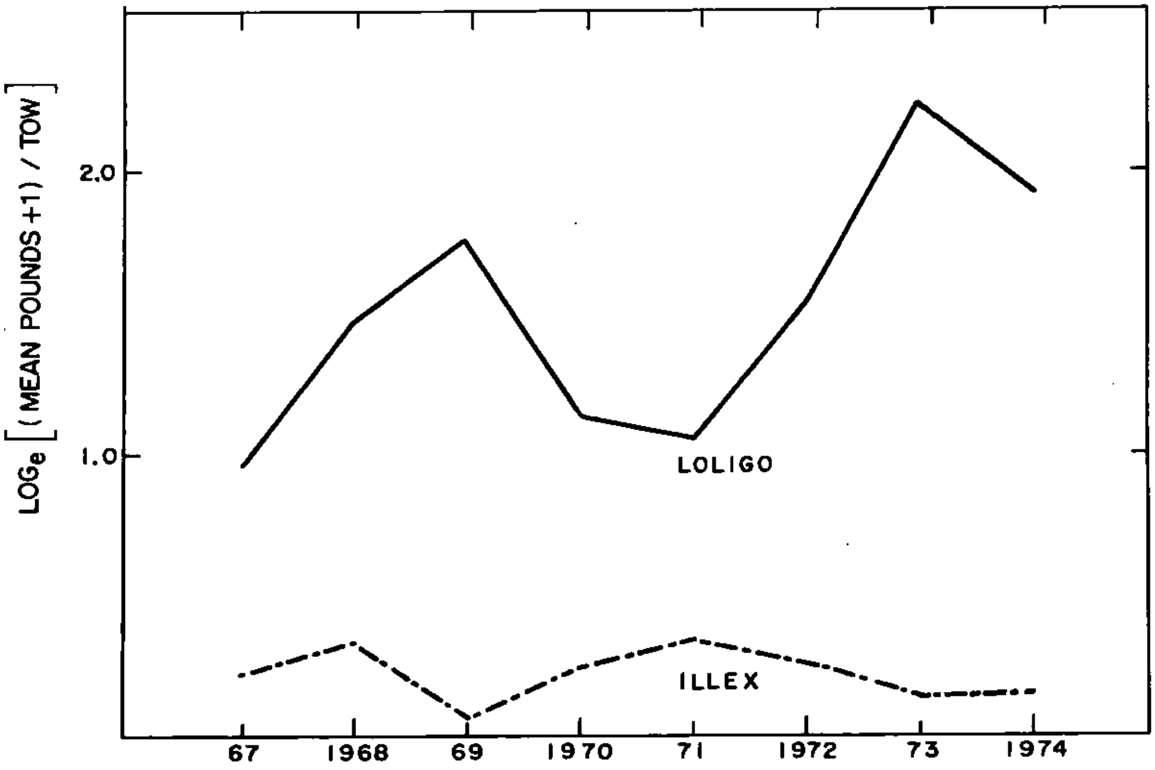


Fig. 10. Autumn survey abundance (Log_e of mean catch per tow) for squid, *Loligo pealei* and *Illex illecebrosus*, from Middle Atlantic to Georges Bank, 1967-74.

Table 8. Average of natural logarithms of catch per tow (weight in pounds + 1) for *Loligo* and *Illex* from USSR stratified autumn trawl surveys, 1967-72.

		Strata areas (see Fig. 9)				
Year	Gear	S. New England (1-12)	Mid-Atlantic (61-76)	S. Georges Bank (13-15)	E. Georges Bank (16-18)	N. Georges Bank (19-25)
Loligo						
1967	Sov. 27.1	1.31	2.69	-	-	-
1968	Sov. 27.1	1.87	2.50	1.23	0.13	0.30
1969	Sov. 24.6	4.14	3.24	2.16	1.25	1.16
1970	Sov. 27.1	1.19	0.95	0.92	0.15	0.52
1971	Sov. 27.1	2.35	2.23	1.02	0.52	0.53
1972	Sov. 27.1	1.95	2.07	1.31	0.00	0.60
Illex						
1967	Sov. 27.1	0.26	0.10	-	-	-
1968	Sov. 27.1	0.23	0.07	0.39	0.17	0.03
1969	Sov. 24.6	0.37	0.12	0.19	0.17	0.33
1970	Sov. 27.1	0.31	0.09	0.22	0.10	0.00
1971	Sov. 27.1	0.64	0.41	1.06	0.54	0.38
1972	Sov. 27.1	0.61	0.14	0.28	0.39	0.13

Table 9. Pre-recruit indices from autumn survey cruises for *Loligo* and *Illex* in Mid-Atlantic to Georges Bank areas.

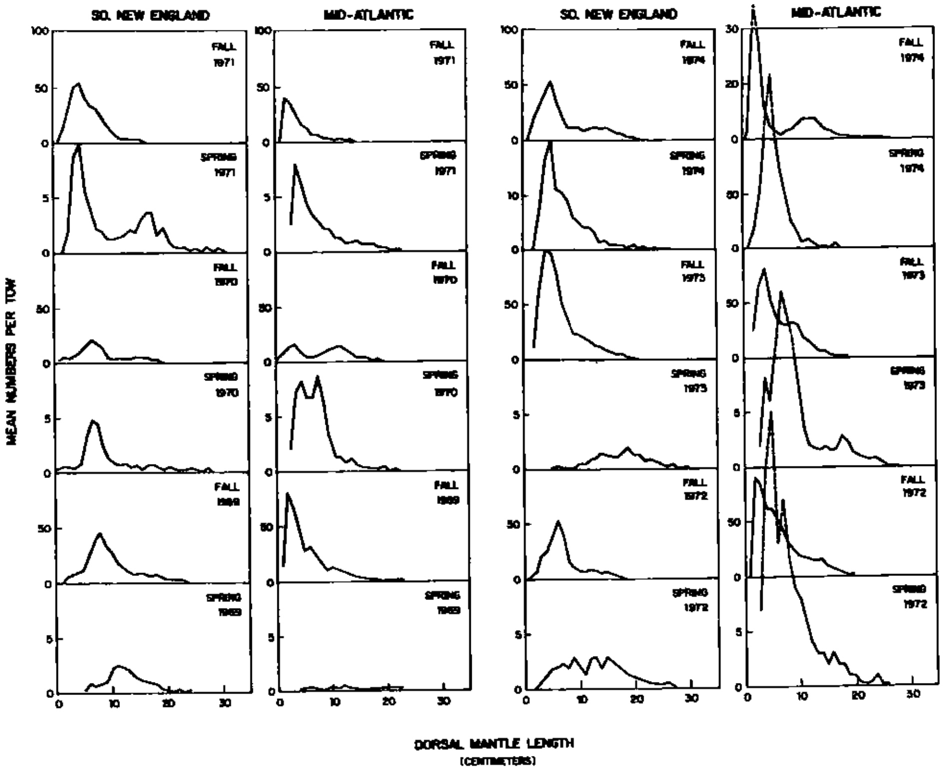
	Loligo (≤8 cm)		*Illex* (≤10 cm)	
Year	Mean no/tow	Mean wt/tow	Mean no/tow	Mean wt/tow
1967	126.9	6.8	0.7	0.10
1968	159.9	12.2	0.6	0.10
1969	217.4	16.5	0.3	0.03
1970	79.3	5.2	0.2	0.10
1971	161.5	6.1	0.6	0.05
1972	258.5	11.6	1.8	0.10
1973	353.9	19.6	0.3	0.04
1974	233.3	13.6	2.1	0.03

Length composition

Length composition of *Loligo*, from stratified mean number (at length) per tow, for Southern New England and Middle Atlantic autumn and spring cruises (*Albatross IV*, 1969-74) (Fig. 11a), was examined. These indicate the presence of fewer individuals ranging in length from 3 to 30 cm during the spring, prior to spawning, than in the autumn. In autumn, with recruitment of the 0-group squid, numbers increase, especially for sizes between 3 and 10 cm.

Availability of *Illex* in the survey area during spring is low, as shown in the distribution charts (Fig. 2, g to i). In 1972 and 1973 there were too few *Illex* 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. 11b), ranging from 5 cm in 1969 to 17 cm in 1971. Autumn samples generally have broader size ranges (4-23 cm) with one or two modes. Combining the two areas gives a single mode in 1969 at 20 cm; in 1970-73 there were two modes at 5-7 and 17-18 cm. These modes probably represent two groups of *Illex* spawned early (December-January) and late (May-June). Absence of larger *Illex* in these cruises is due primarily to the time of year that the surveys are made. Spring cruises are conducted in late March and early April, after many of the larger *Illex* have spawned and presumably died. In autumn (late September and October), it is assumed that large individuals have begun to move offshore to spawn.

LOLIGO (a)



ILLEX (b)

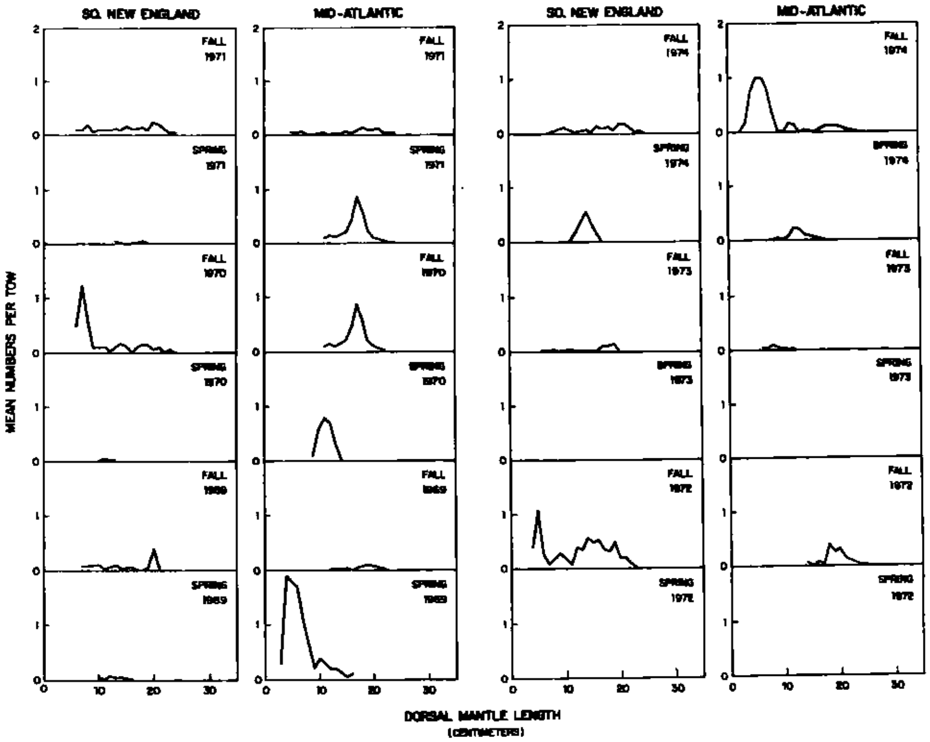


Fig. 11(a-b). Mean numbers at length per tow of (a) *Loligo pealei* and (b) *Illex illecebrosus* from US groundfish surveys, spring 1960 to autumn 1974, in the Middle Atlantic and Southern New England strata.

Table 10. Stock size estimates (metric tons) (see text for definitions of B_1, B_2, and B_3) for *Loligo* and *Illex* in Subarea 5 + Statistical Area 6, 1968-74.

Year	*Loligo*			*Illex*		
	B_1	B_2	B_3	B_1	B_2	B_3
1968	28,063	59,259	72,693	1,480	1,448	1,250
1969	37,586	46,788	57,395	311	4,131	5,068
1970	12,025	28,883	35,431	1,079	6,942	8,516
1971	11,694	18,013	22,097	1,351	7,602	9,325
1972	25,396	24,016	29,461	1,423	8,217	10,079
1973	42,250	63,160	77,479	883	6,059	7,432
1974	31,083	62,993	77,273	2,110	12,972	15,913

Comparisons of US and USSR length frequencies from groundfish surveys, all strata combined, indicate consistency in modes from autumn *Loligo* samples. In 1974, the USSR also participated in the spring groundfish survey, and lengths of *Loligo* from this cruise were larger than those of the US survey. US data indicated a strong mode at 5 cm with maximum length reaching 27 cm, while the USSR data showed a strong mode at 9-10 cm and a maximum length of 39 cm. Length frequencies of *Illex*, obtained by each country, were generally similar with consistent autumn modes at 19-21 cm (from 1969 to 1974).

Pre-recruit abundance indices

Commercial catches of *Loligo* indicate that recruitment of individuals, 8 cm and less, had not begun by autumn survey time; the mean number per tow in this size range was therefore used as an index of relative strength of incoming year-classes (Table 9). Commercial data indicate that catches of *Illex* less than or equal to 10 cm are minimal before the autumn survey cruises, so 10 cm was used as a pre-recruit length for *Illex*.

It does not appear from the survey indices that total catches in the *Loligo* fishery have been noticeably influenced by the size of the autumn pre-recruited stock (*i.e.*, even though autumn pre-recruit indices have dropped, as in 1970 and 1971, catches have continued to increase). There does, however, appear to be a general correlation between these autumn indices and the US commercial length frequencies in the spring, as in the spring of 1973 and 1974, when US commercial catches contained high proportions of 0-group *Loligo*, also indicated by increased pre-recruit indices in autumn 1972 and 1973. Japanese and USSR samples also reflect greater amounts of smaller *Loligo* (less than 15 cm) from January and February catches of 1970 and 1974, when the 1969 and 1973 autumn indices were high, than in 1972, when the autumn 1971 index is lower.

Illex pre-recruit and length frequency relationships were based on very few individuals, so trends relating these indices to catches have not been established.

Stock size estimates

Abundance indices from autumn survey cruises can be used to provide a minimum estimate of squid biomass in Subarea 5 and Statistical Area 6 using the equation

$$B = \frac{WA}{a},$$

where B = estimate of biomass; W = stratified mean weight per tow; A = strata area sampled (in square miles); and a = area swept by each tow (0.011 square miles). A first approximation of the minimum biomass B_1 was made using the raw catch per tow data (Table 10).

Diel variations (caused by vertical migrations) in relative apparent abundance of *Loligo* are large, with daytime (0800 to 1600 hrs) survey catches (mean catch per tow) 2 to 12 times greater than nighttime (2000-0400 hrs) catches (1968-74, from analysis of spring and autumn survey data). Therefore, to use the data collected from areas sampled at night, another estimate (B_2) of *Loligo* biomass was made using the ratio of the total daytime mean-catch-per-tow to the total nighttime mean-catch-per-tow (6.372:1), calculated from three gear comparison cruises using both the No. 36 and No. 41 Yankee trawls as a correction factor to increase night abundance indices to a level equivalent to times when *Loligo* were most available to the bottom gear. As gear comparison and diel variations in *Illex* catches have not been examined, this same ratio was also applied to *Illex* night catches to provide a base estimate of the biomass of this species. This second estimate (B_2) of biomass was obtained using the average of the gear comparison day/night ratio times the mean nighttime weights per tow and the daytime mean weight per tow, as W in the above equation (Table 10). A third estimate (B_3), took into consideration the information that the No. 36 net used in the autumn had a lower catchability than the No. 41 net used in trawl comparison studies. Therefore, B_2 was raised by the ratio of the catchability of the No. 41 net to that of the No. 36 net (1.41) (E. Bowman, National Marine Fisheries Service, personal communication) to produce B_3 (Table 10).

It should be noted that *Illex* has a distribution (Fig. 2, g to l) beyond the strata examined, *i.e.*, north of Georges Bank and the Gulf of Maine. Consequently, the abundance indices observed in the survey areas may reflect yearly distributional differences for this species. The abundance of *Illex* by these indices is about 17% of that of *Loligo*; the abundance of *Loligo* averaged 51,047 tons for 1967-74 (according to the B_3 estimate).

These biomass estimates for *Loligo* have also been calculated from abundance indices of USSR cruises. The 1968-72 average for *Loligo* was 35,392 tons for the US (B_2) and 77,324 tons for the USSR, with the annual estimates, between the two countries, having a correlation coefficient of 0.8. For *Illex* the USSR 5-year average for Div. 5Z + Statistical Area 6 only was 16,365 tons, while that of the US was only 5,668 tons (B_2). The correlation coefficient for *Illex* was 0.66 for the two countries over the 5 years. Wide variations occur in USSR indices for *Illex*, again suggesting great variations in availability of *Illex* to survey gear.

DISCUSSION

Squid catches of the two species, *Loligo* and *Illex*, have increased about 50-fold since entry of the first distant-water fleet to the fishery in 1964. The steady increase from incidental catches to about 56,000 tons in 1974 reflects the growing interest of the 12 countries which to date have reported squid catches. However, it was not until the 1973 statistics were reported that some of these catches were broken down to species. Accurate assessment of the squid stocks in this area is hindered by this absence of catch data and also by insufficient information on effort exerted in this fishery (since most countries report squid catches as by-catch to other fisheries).

Data from the inshore commercial fishery indicate that *Loligo* are taken during the spring and summer when they are inshore to spawn, while the major fishery occurs offshore in the winter when they are immature, and prior to onshore migration. US, USSR and Polish length samples, and observations of maturity of *Illex*, indicate that this species is fished primarily in the summer while it has moved inshore and onto Georges Bank. Since spawning occurs in the winter and spring, the *Illex* fishery is concentrated on immature individuals.

Biomass estimates of *Loligo* in this area, from expansion of relative abundance indices from research vessel surveys, averaged 51,000 tons from 1967 to 1974. Similar areal estimates by Ikeda *et al.* (MS 1973) for 1968 to 1973 averaged 44,000 tons. In addition, Ikeda *et al.* (MS 1975) estimated the *Loligo* biomass during the 1972-73 Japanese fishing season to be 88,000 tons, based on Pope's cohort analysis method, while our estimate for the 1973 biomass was 77,500 tons. Although there is general agreement in the estimates for *Loligo*, availability of *Illex* is so variable that accurate estimates of biomass for that species have not been accomplished. *Illex* biomass estimates vary from an average of about 10,000 tons for Subarea 5 + Statistical Area 6 during 1967-74 (this paper) to about 110,000 tons for Div. 4X and 5Z (Efanov and Puzhakov, MS 1975).

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Variability of "q" as Measured by Variation in Daily Catch per Effort[1]

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ABSTRACT

Daily catch and effort records of tonnage class 7 (1801+ gross tons) vessels of Federal Republic of Germany (FRG), Japan, and Poland, fishing in ICNAF Division 5Z and Statistical Area 6 in 1971-1973, were examined for variability in catchability. A generalized linear covariable model was hypothesized (on logged catch and logged effort data) with hours fished as a covariable, and year, season, 30 x 30 minute unit area, and vessel as factors. For the data of FRG and Japan, the relationship between catch and hours fished was found to be non-linear. The implication of this result is that in some cases a proposed reduction in fishing mortality would not be achieved by a proportional reduction in days fished. In areas where the species composition of catches was similar over years and seasons, year and season factors in the model were more significant than 30 x 30 minute unit area factors or vessel factors. Estimated changes in catchability between years was in all cases closer to the calculated changes in total catch/total days fished (using the same data) than to the calculated changes in total catch/total hours fished. Calculations of fishing power of individual vessels showed great variation in the fishing power of the vessel in a fleet regardless of which vessel was used as the standard vessel.

INTRODUCTION

At the 1974 Annual Meeting of the International Commission for the Northwest Atlantic Fisheries (ICNAF) the *ad hoc* Effort Working Group requested that Member Countries fishing in Div. 5Z and Statistical Area 6 each submit for analysis the daily records of 20 vessels of tonnage class 7 [over 1800 gross registered tons (GRT)] which fished during March-April and/or September-October of 1971-1972 (or 1972-1973) (ICNAF, 1974a). The daily records were to include species catches, effort (hours fished, number of tows, etc.), and average daily position by 30 x 30 minute unit areas (henceforth called "areas"). By the time of the 1975 Annual Meeting, data for tonnage class of vessels had been submitted by FRG, Japan, and Poland (ICNAF, 1975a).

Among the studies proposed for these data, when the original request was made, were investigations of variation in the catchability coefficient (q) over years and seasons among vessels within tonnage classes. However, equally important, if a knowledge of variability of q was to be meaningful, was an investigation of the relation of fishing effort to catch (and hence to fishing mortality, F) for these data. The relation has been assumed to be proportional, and this assumption was tested during the course of the analysis of variation in q. Further, trends in fishing power of the vessels in each fleet were examined to assess the influence of fishing power differences on catchability. Implications of the findings on the setting of effort quotas were examined.

DATA BASE

Data submitted for analysis are presented in summary form in Appendix Tables A, B and C. Defining the main species sought (MS) as the species for which the catch was greatest, the catch of each species by main species (calculated from daily records) is presented for the month and years for which each country submitted data. The FRG data (Appendix Table A) represent herring and mackerel catches of over 70% of the total catches of these species during the months listed. On the other hand, the Polish data (Appendix

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[1] Submitted to the 1976 Annual Meeting as Res.Doc. 76/VI/106 and 117.

Table B) represent only a small percentage of the catches reported for the months listed. The Japanese data are fairly representative of the annual catch data (Appendix Table C).

The areal distribution of these catches are shown in Fig. 1 to 3. Within each area the ratios of catch in area i to total catch over all areas (in Pilot Study data) and of days fished in area i to total days fished over all areas (Pilot Study data) are given by year according to the designated scheme. Correlations between these two ratios by area (Table 1), especially for data of FRG and Poland, suggest consistent levels of catch per day between areas. However, since the data submitted do not necessarily represent the entire fleet of any country, observed changes in the distribution of catch or number of observations from year to year cannot be attributed to changes in fishing areas.

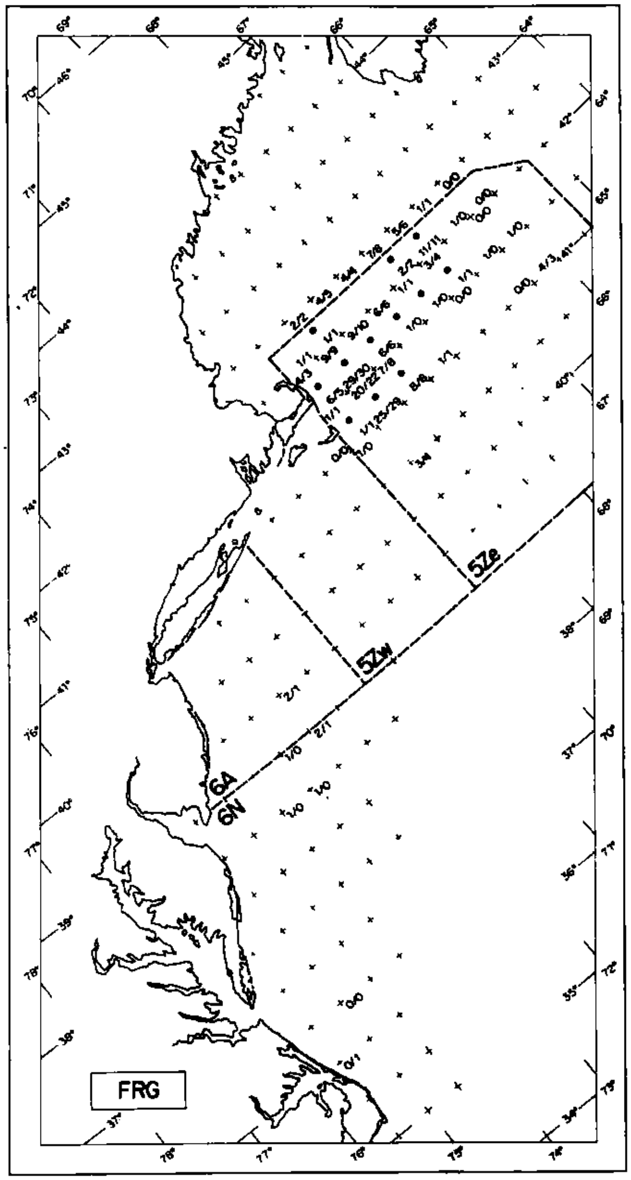

Fig. 1. Percentage catch (C) and percentage number of observations (D) (= days fished) for FRG, denoted in each 30-minute unit area by the ratio (%C/%D) with 1972 data in the upper part of the unit area and 1973 data in the lower part. (An entry of "0" indicates <0.5%.)

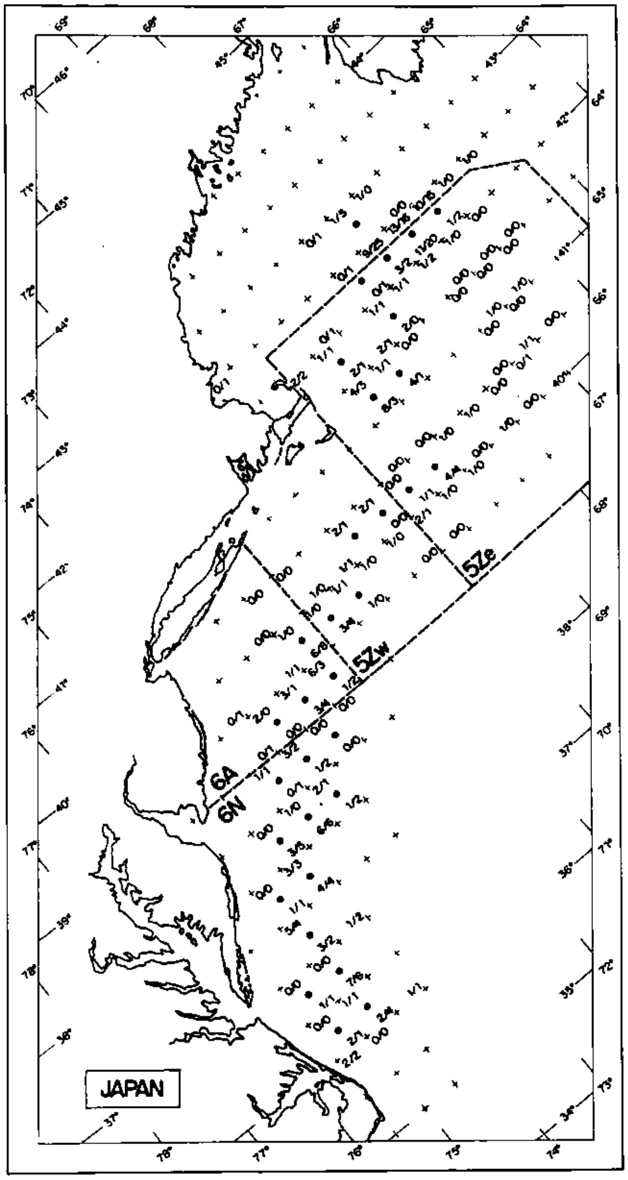

Fig. 2. Percentage catch (C) and percentage number of observations (D) (= days fished) for Japan, denoted in each 30-minute unit area by the ratio (%C/%D) with 1971 data in the upper part of the unit area and 1972 data in the lower part. (An entry of "0" indicates <0.5%.)

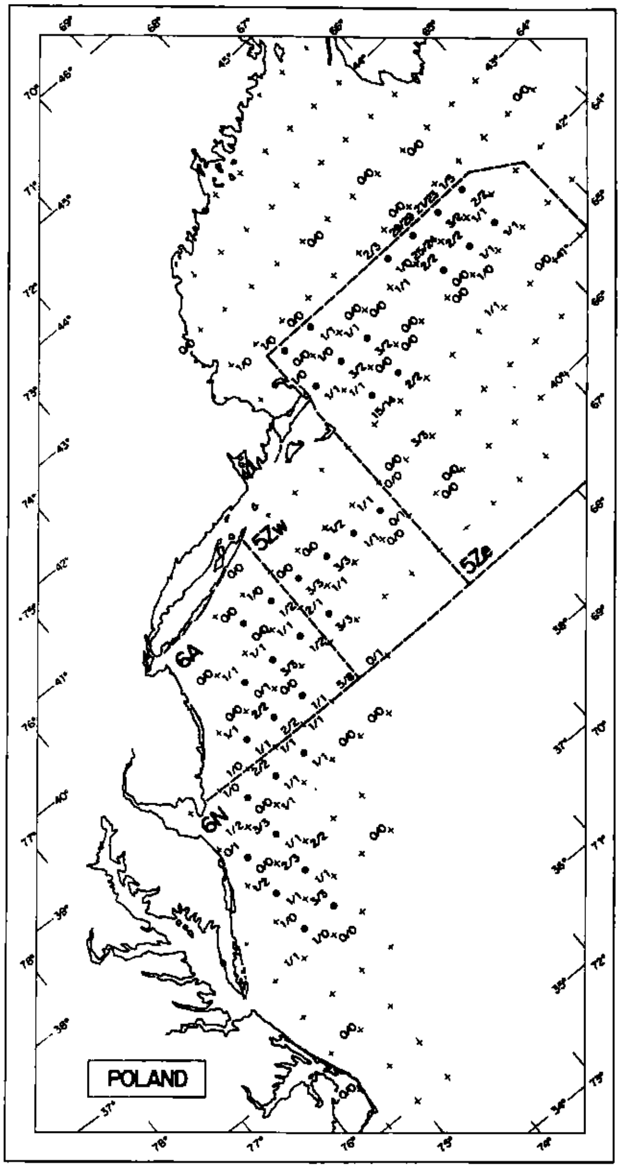

Fig. 3. Percentage catch (C) and percentage number of observations (D) (= days fished) for Poland, denoted in each 30-minute unit area by the ratio (%C/%D) with 1971 data in the upper part of the unit area and 1973 data in the lower part. (An entry of "0" indicates <0.5%.)

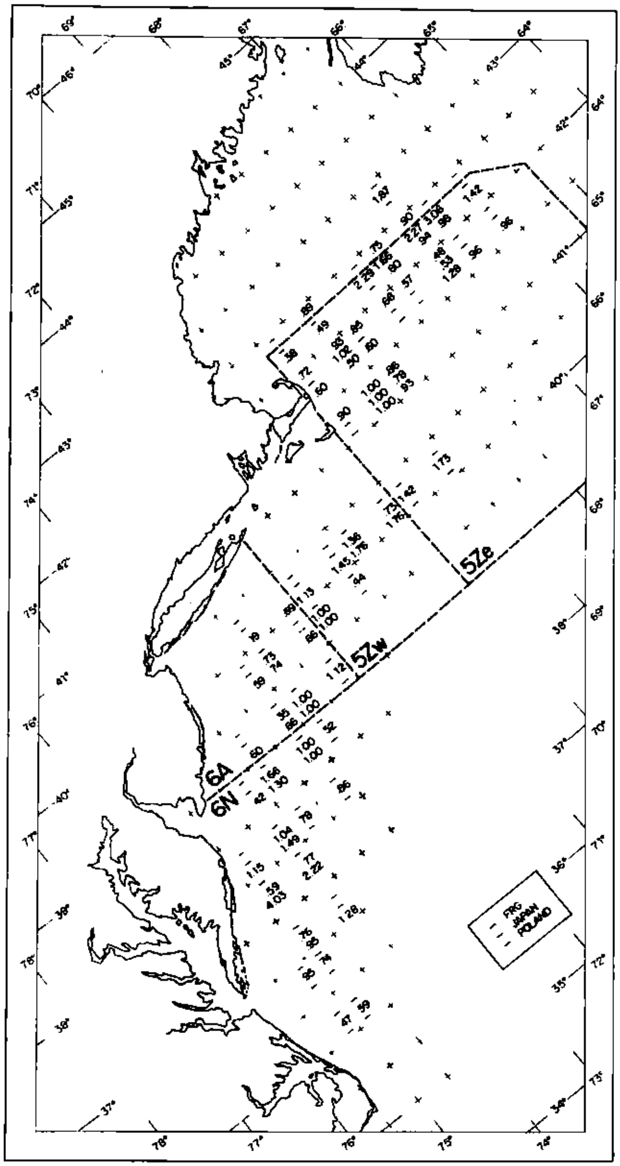

Fig. 4. Ratio of area effect for area 1 to area effect for an arbitrarily selected standard area within each ICNAF division (or subdivision) as estimated from the analysis of covariance. The standard area in each case is characterized by the presence of entries of 1.00. Within each 30-minute unit area the effects are listed (upper to lower) by country (FRG, Japan, and Poland).

For purposes of analyses, a subset of the available data was used in order to make comparisons more meaningful. Areas considered are those designated by a dot in Fig. 1 to 3. In general, the selection was made according to whether the area was fished in both years, whether the percentage catch and/or percentage number of observations[2] was greater than zero in both years, and whether there was more than one vessel fishing in the area. The resultant data base included total percentages of catch and of number of observations given in Table 2 by year and country. The low percentages for FRG in 1973 resulted largely from the exclusion of the data submitted for the areas south of 40° latitude, for which comparable 1972 data were not available.

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[2] See footnotes to Table 1.

Table 1. Statistics on correlation between percentage catch[a] and percentage number of observations[b] by country and year (* indicates probability ($r^2 = 0$) less than 0.05 and ** indicates probability ($r^2 = 0$) less than 0.01).

	FRG		Japan		Poland	
	1972	1973	1971	1972	1971	1972
r^2	0.99	0.99	0.74	0.68	0.97	0.97
F	1,468**	2,468**	173*	110*	2,023*	1,927**

[a] Percentage catch = catch in area i/catch over all areas for which data were submitted for Pilot Study.

[b] Percentage number of observations = number of observations (= number of days fished) in area i/number of observations over all areas for which data were submitted for Pilot Study.

Table 2. Percentage of total catch in Pilot Study data and percentage of total number of observations used in this study, by country and year.

	FRG		Japan		Poland	
	1972	1973	1971	1972	1971	1972
Percentage catch	94%	80%	89%	92%	91%	82%
Percentage number of observations	92%	74%	82%	86%	90%	88%

BASIC COVARIABLE MODEL

The standard formula (Gulland, 1975) used in discussing the catchability coefficient q is:

$$F \cdot N \cdot \Delta t = \Delta C = q \cdot \Delta f \cdot N/A \qquad (1)$$

where

F = fishing mortality,
Δt = arbitrary time interval,
ΔC = catch when effort Δf is exerted, during time Δt,
N = mean stock abundance,
A = area inhabited by the stock, and
$q = q_1 \cdot q_2 \cdot q_3 \cdot q_4 \cdot q_5$

with q_1 and q_2 as time factors (season and year respectively) which allow N/A to be considered constant over time, q_3 as the area factor which allows N/A to be considered constant over areas, q_4 as the adjustment for differences in mortality induced by one unit of effort of different vessels, (i.e. fishing power), and q_5 as representing other factors.

In this analysis, a modification of Equation (1) was considered, namely

$$\Delta C = q \cdot \Delta f^a \cdot N/A \qquad (2)$$

where a is a constant to be determined. Effort Δf is hours fished and Δt is taken to be a day. In order to estimate the parameters of the model a logged version of Equation (2) was used, namely

$$z_{i'j'k'\ell'm} = \hat{M} + \hat{a} \cdot U_{i'j'k'\ell'm} + q_{ijk\ell} + e_{i'j'k'\ell'm} \qquad (3)$$

where

$Z_{i'j'k'\ell'm}$ = m^{th} observation of log (catch) = log (c) at the i, j, k and ℓ levels of factors I, J, K and L respectively, at the corresponding level of the concomitant variable log (hours fished) = log (f),

$\hat{M}$ = estimated mean of log (c) over all observations,

$U_{i'j'k'\ell'm}$ = m^{th} observation of the concomitant variable log (f) at the i, j, k and ℓ levels of factors I, J, K and L respectively,

$X_{ijk\ell}$ = a (1×n) vector $(x_1, x_2 \ldots x_n)$ of zeros and ones, where $n = n_i + n_j + n_k + n_\ell$ for n_i levels of factor I, n_j levels of factor J, n_k levels of factor K, and n_ℓ levels of factor L;

and where $x_p = 1$ (if p = i' or j' or k' or ℓ'), $x_p = 0$ (otherwise),

$e_{i'j'k'\ell'm}$ = estimated error with the m^{th} observation, where e follows a $N(0,\sigma^2)$ distribution, and e is derived from the day-to-day variation in log (c) at a cell i' -j' -k' -ℓ',

$q_{ijk\ell}$ = a (1×n) vector $(\hat{b}_1, \hat{b}_2 \ldots \hat{b}_n)$, where $\hat{b}_p$ = estimated effect of level i of factor I, if $p \leq n_i$; $\hat{b}_p$ = estimated effect of level j of factor J, if $n_i + 1 \leq p \leq n_i + n_j$; $\hat{b}_p$ = estimated effect of level k of factor K, if $n_i + n_j + 1 \leq p \leq n_i + n_j + n_k$; $\hat{b}_p$ = estimated effect of level ℓ of factor L, if $n_i + n_j + n_k + 1 \leq p \leq n$; and

a = constant to be estimated.

Separate analyses were run for each country's data (henceforth called a "data set") by ICNAF division (Fig. 1 to 3), except for area 6N, which included all of Statistical Area 6 except for Div. 6A. For each data set analyzed, factor I was year, factor J season, factor K vessel and factor L area. Factors I, J and L were considered fixed factors and factor K random. Interaction terms were estimated where possible and the results of these analyses are given in Appendix Table D. In general, only the main factors were included in the models from which the main conclusions were drawn, since the nature of the data (cells with no observations or unequal numbers of observations) did not allow for reliable estimates of the interaction terms. Moreover, since the sum of squares associated with the factors was not independent, the usual pooling procedure of non-significant interaction, sum of squares and error sum of squares was not used. In all cases, the error mean square, against which mean squares of main effects was measured, was that resulting from the covariable adjustment.

The model [Equation (3)] was fitted for each data set, using a generalized linear hypothesis model which allows for covariable adjustments and unbalanced designs. The general procedure is outlined by Sheffe (1969). The sum of squares attributable to each factor (I, J, K, L) was calculated by a reduction in sum of squares technique, a common procedure for unbalanced designs. Since orthogonality assumptions are no longer valid with such a design, the total sum of squares is not a total of the sums of squares assigned to each main effect plus the error sums of squares.

For each data set, a confidence interval ($\mathcal{I}$) about the estimated slope ($\hat{a}$) of Equation (3) was calculated to determine whether the data indicated that a = 1.00 was within this confidence belt. In cases where a = 1.00 was within $\mathcal{I}$, estimates of areal effects could be considered representative of log (catch/effort) data. Otherwise, these differences could be considered as representative only when the hours fished of daily catch data from the areas were the same.

The confidence interval of $\hat{a}$ was calculated as

$$\mathcal{I} = (\hat{a} - s \times z,\ \hat{a} + s \times z) \qquad (4)$$

derived from the statistic (Sheffe, 1969, p. 108)

$$t = \hat{a} \,/\, (SSe/SSu)^{\frac{1}{2}} = \hat{a} \,/\, s \qquad (5)$$

where

$\hat{a}$ = constant estimated in Equation (3),
SSe = error mean square, as calculated by the analysis of covariance,
SSu = sum of squares of the covariable $U_{ijk\ell}$, and
z = standard normal deviate for a specified level of α.

For each level of α, the power of the test of the hypothesis H_1 : a = 1.00 was calculated using the approximation (Sheffe, 1969, p. 415)

$$\Pr\ (t_{n,a} \leq x) = \Pr\ (z \leq z^*) \tag{6}$$

where

$\Pr\ (t_{n,a} \leq x)$ = probability that a noncentral Student's-t variable with noncentrality parameter a and n degrees of freedom is less than/equal to x, and

$\Pr\ (z \leq z^*)$ = probability that the standardized normal deviate z is less than/equal to z*, where

$$z^* = (a-x)\ [1+x^2/(2n)]^{-\frac{1}{2}}.$$

SERIAL CORRELATIONS

In order to achieve more balanced designs for each data set, in cases where there was an unequal number of vessels in each year, a subset of the vessels was randomly selected to equalize the number of vessels in each year. This procedure does not alter the conclusions of the analyses, since the vessel factor was considered random. For a subset of these data (in particular, FRG and Japanese data), serial correlation coefficients of log (catch) data were calculated (Hoel, 1962) on successive observations within each i-j-k-ℓ cell to determine whether there was a lack of independence in the data caused by similarity between sequential days' fishing. In less than 5% of the cases considered was the correlation coefficient significant at the α = 0.05 level, although in many cases the coefficient of variation of the logged catch data was less than 10%, indicating that the variation in the logged catch data could be very small for a vessel fishing within an area, even though a day-to-day dependency could not be detected. This lack of dependency could perhaps be due to the fact that there may have been days during which the vessel fished in another area and then returned to the area under study. The observations were subsequently considered without a time trend on a daily basis.

ANALYSIS OF COVARIANCE RESULTS

Table 3 lists the results of the analysis of covariance runs. In all but one case (Table 3B) the covariable proved to be significant at the α = 0.05 or the α = 0.10 level. Where the species composition of a country's catches was similar by season and/or year (Table 4), the year and season factors consistently had higher mean squares than the area and vessel mean squares. An example of this is Subdiv. 5Ze data (Table 3A, B and F). This trend was also true of the data of Poland (Div. 6A and area 6N), where the species compositions were about the same in each year (Table 4) and where the year factor had the highest mean square. The only exception to this trend was the data of Poland for Subdiv. 5Zw. However, the results of the fit to the model are suspect; very little variability in the data could be attributed to any of the main effects. These results are comparable to those of Pope and Garrod (1975) who investigated the variation of catchability between and within vessels fishing at Iceland and the Northeast Arctic (presumably for cod), and concluded that the identity of the vessel played a minor role in total variation relative to that contributed by year-to-year variation. For the remaining analyses, where species composition varied considerably by season and/or year, the mean squares attributable to vessels (i.e. data of Japan in Subdiv. 5Zw, Div. 6A and area 6N) were the largest.

When interaction terms were included in the models, the associated mean squares were small compared to those of the main effects (Appendix Table D). These results support the selection of the models with no interaction terms.

The probabilities associated with the F-values in the analysis of variance tables are questionable due to the violation of the assumption of equality of cell variances.

Table 3. **Analysis of covariance results for data of FRG in 1972-73 and of Japan and Poland in 1971-72 by divisions.**

Country	Area	Source	Sum of squares	Degrees of freedom	Mean square	F
A. FRG	5Ze	Mean	134.02	1	134.02	468.68
		Years	35.43	1	35.43	123.88
		Areas	13.68	11	1.24	4.35
		Vessels in Years	29.00	18	1.61	5.63
		Covariable	16.95	1	16.95	59.29
		Error	247.35	865	0.29	
B. Japan	5Ze	Mean	40.39	1	40.39	47.58
		Years	28.09	1	28.09	33.10
		Seasons	15.07	1	15.07	17.75
		Areas	60.76	10	6.07	7.16
		Vessels	38.08	10	3.81	4.49
		Covariable	1.24	1	1.24	1.45
		Error	261.44	308	0.85	
C. Japan	5Zw	Mean	1.81	1	1.81	10.14
		Years	1.05	1	1.05	5.81
		Seasons	0.57	1	0.57	3.18
		Areas	2.65	3	0.88	4.94
		Vessels	10.32	9	1.15	6.41
		Covariable	7.99	1	7.99	44.66
		Error	5.73	32	0.18	
D. Japan	6A	Mean	4.24	1	4.24	13.54
		Years	0.19	1	0.19	0.60
		Seasons	0.44	1	0.44	1.39
		Areas	2.69	3	0.90	2.87
		Vessels	18.44	13	1.42	4.53
		Covariable	17.02	1	17.02	54.36
		Error	24.11	77	0.31	
E. Japan	(6N)	Mean	7.60	1	7.60	16.35
		Years	0.05	1	0.05	0.10
		Seasons	0.43	1	0.43	0.92
		Areas	9.51	12	0.79	1.70
		Vessels	20.20	15	1.35	2.90
		Covariable	39.65	1	39.65	85.30
		Error	100.87	217	0.46	
F. Poland	5Ze	Mean	7.19	1	7.19	7.61
		Years	9.69	1	9.69	10.26
		Areas	20.57	13	1.58	1.67
		Vessels in Years	31.27	14	2.23	2.37
		Covariable	55.71	1	55.71	58.98
		Error	510.88	541	0.94	
G. Poland	5Zw	Mean	0.52	1	0.52	0.58
		Years	0.32	1	0.32	0.36
		Areas	3.06	4	0.77	0.85
		Vessels in Years	3.01	6	0.50	0.55
		Covariable	20.84	1	20.84	23.04
		Error	55.17	61	0.90	
H. Poland	6A	Mean	2.48	1	2.48	4.39
		Years	2.21	1	2.21	3.91
		Areas	6.23	7	0.89	1.57
		Vessels in Years	3.35	6	0.56	0.99
		Covariable	12.13	1	12.13	21.45
		Error	36.19	64	0.57	
I. Poland	(6N)	Mean	0.66	1	0.66	1.10
		Years	5.44	1	5.44	9.02
		Areas	14.86	8	1.86	3.08
		Vessels in Years	17.29	6	2.88	4.78
		Covariable	8.20	1	8.20	13.60
		Error	37.40	62	0.60	

Table 4. Species composition of catches and fishing effort used in the analysis from data reported by FRG, Poland and Japan.

Country	Area	Season	Year	Percentage species composition[a]							Total catch	Hours fished	Days fished
				Her	Mac	But	Gad	Arg	OF	Squ			
FRG	5Ze	-	1972	96	2	-	-	-	2	-	20,867	6,445	540
		-	1973	88	12	-	-	-	-	-	20,391	4,865	357
Poland	5Ze	Autumn	1971	94	4	-	-	-	-	2	11,038	3,383	294
			1972	89	9	-	1	-	1	-	7,233	3,335	277
	5Zw	Autumn	1971	1	99	-	-	-	-	-	927	337	26
			1972	-	95	-	-	-	5	-	1,500	497	48
	6A	Spring	1971	36	64	-	-	-	-	-	905	394	33
			1972	-	91	-	3	-	7	-	1,716	427	47
	(6N)	Spring	1971	21	76	-	-	-	-	3	1,758	584	53
			1972	1	85	-	3	-	11	-	794	272	26
Japan	5Ze	Spring	1971	-	5	9	-	48	31	7	2,685	488	44
			1972	-	9	1	16	26	24	29	486	303	22
		Autumn	1971	94	-	-	1	-	5	-	2,447	1,350	113
			1972	64	10	7	-	-	19	-	1,967	1,764	153
	5Zw	Spring	1971	-	24	4	-	-	14	58	166	321	20
			1972	-	-	13	-	-	18	69	326	373	24
		Autumn	1971	-	-	95	-	-	5	-	8	8	1
			1972	-	15	-	-	-	1	84	3	15	3
	6A	Spring	1971	3	52	3	-	-	7	35	334	543	40
			1972	-	21	7	-	-	20	52	961	780	52
		Autumn	1971	47	-	51	-	-	-	2	17	36	3
			1972	-	-	-	-	-	6	94	81	20	2
	(6N)	Spring	1971	-	21	25	-	-	20	34	340	391	27
			1972	-	31	9	-	-	4	56	1,331	1,198	80
		Autumn	1971	-	1	61	-	-	19	19	639	602	43
			1972	-	-	7	-	-	14	79	1,158	1,500	98

[a] Abbreviations refer to herring, mackerel, butterfish, gadoids, argentine, other fish and squids.

Further complicating the interpretation of the F-values is the fact that there was not always a detectable linear trend in the ratio of cell means and variances. If such a trend were present, conclusions could be drawn on the actual significance level of these F-values based on the coefficient of variation of the cell variances (Box, 1954). As the results stand, however, the F-values should be interpreted qualitatively rather than quantitatively.

GEOMETRIC RELATION BETWEEN CATCH AND EFFORT

Increases in the slope (a) of the concomitant variable [log (hours fished)] by ICNAF division (Table 5) appear to be related to decreases in average percent of herring caught for the data of both Poland and Japan (Table 4); for example, the low value of $\hat{a} = 0.15$ occurred for the catch data of Japan with the highest percent of herring. These data suggest then that the functional relation between catch and effort in terms of hours fished per day depends on the catch composition and is not a constant function.

The confidence intervals (I) of the estimated slope ($\hat{a}$) of the covariable at $\alpha = 0.10$ and $\alpha = 0.05$, and the associated power of the test H_1 : a = 1.00, are given in Table 5. Only for the data of Poland was a = 1.00 within the confidence interval of $\hat{a}$. For these

Table 5. Estimates of slope (a) of concomitant variable [log (hours fished)], standard errors (s) of the slope, and the α and β levels of tests of $\hat{a}$, together with the confidence interval (I) of $\hat{a}$ at α = 0.10 and α = 0.051 Estimates of s were calculated from Equation (3) and $\hat{\beta}$ as in Equation (5), and n is the number of observations.

Country	Area	Year	$\hat{a}$	$\hat{s}$	n	α = 0.10		α = 0.50	
						I	$\hat{\beta}$	I	$\hat{\beta}$
FRG	5Ze	1972-73	0.37	0.06	865	(0.27, 0.47)	>0.98	(0.26, 0.48)	>0.98
Japan	5Ze	1971-72	0.15	0.13	308	(-0.07, 0.37)	>0.98	(-0.11, 0.41)	0.97
	5Zw	"	1.27	0.12	32	(1.08, 1.46)	0.67	(1.04, 1.50)	0.59
	6A	"	1.42	0.16	77	(1.14, 1.70)	0.77	(1.10, 1.74)	0.71
	(6N)	"	1.46	0.14	217	(1.22, 1.70)	0.92	(1.18, 1.74)	0.88
Poland	5Ze	1971-72	0.85	0.11	541	(0.67, 1.03)	0.39	(0.64, 1.06)	0.30
	5Zw	"	1.18	0.22	61	(0.81, 1.55)	0.21	(0.74, 1.62)	0.13
	6A	"	0.92	0.18	64	(0.63, 1.21)	0.19	(0.57, 1.27)	0.11
	(6N)	"	0.88	0.22	62	(0.44, 1.32)	0.12	(0.36, 1.40)	0.07

Table 6. Catch per effort predicted (*) from analysis of covariance model compared with observed catch-per-effort data for FRG, Japan and Poland.

Country	Area	Effort class[a]	Spring			Autumn		
			1971	1972	% increase	1971[b]	1972[b]	% increase
FRG	5Ze	c/hf*	-	-	-	0.79	1.26	58
		c/hf	-	-	-	3.24	4.19	29
		c/df	-	-	-	38.64	57.12	48
Japan	5Ze	c/hf*	1.48	0.68	-54	1.48	0.68	-54
		c/hf	5.45	1.60	-71	1.81	1.12	-38
		c/df	61.02	22.16	-64	21.65	12.86	-41
	5Zw	c/hf*	1.56	0.64	-59	1.56	0.64	-59
		c/hf	0.52	0.87	69	0.96	0.20	-79
		c/df	8.31	13.57	63	7.50	2.51	-67
	6A	c/hf*	0.93	1.08	17	0.93	1.08	17
		c/hf	0.62	1.23	100	0.47	4.05	760
		c/df	8.35	18.49	122	5.70	40.50	611
	(6N)	c/hf*	1.02	0.98	-4	1.02	0.98	-4
		c/hf	0.87	1.11	28	1.06	0.77	-27
		c/df	12.59	16.64	32	14.87	11.81	-21
Poland	5Ze	c/hf*	-	-	-	1.19	0.84	-28
		c/hf	-	-	-	3.26	2.17	-34
		c/df	-	-	-	37.54	26.11	-30
	5Zw	c/hf*	-	-	-	1.11	0.90	-18
		c/hf	-	-	-	2.75	3.02	10
		c/df	-	-	-	35.65	31.25	-12
	6A	c/hf*	0.82	1.22	49	-	-	-
		c/hf	2.29	4.02	75	-	-	-
		c/df	27.42	36.51	33	-	-	-
	(6N)	c/hf*	1.57	0.64	-59	-	-	-
		c/hf	3.01	2.92	-3	-	-	-
		c/df	33.16	30.52	-8	-	-	-

[a] c/hf = catch per hour fished; c/df = catch per day fished.

[b] For FRG, the data pertain to the years 1972 and 1973 respectively.

data, the power of a test to distinguish between a = 1.00 and a = â is very low, as expected. Letting â = 1.00, the estimated main effects are comparable at any values of effort (hours fished per day). This is in contrast to the data of FRG and Japan for which meaningful comparisons of catch per effort between areas can be made only if hours fished values are alike.

ESTIMATED CHANGES IN CATCHABILITY *versus* CALCULATED CHANGES IN CATCH PER EFFORT

Table 6 shows the estimates of annual percentage decrease or increase in the three available measures of catch per effort by country and division: (a) using the catch-per-hour estimates derived from the analyses based on the estimate of the year effect, (b) using the ratio of total catch to total hours fished for the data used in the analyses, and (c) using the ratio of total catch to total days fished for the data used in the analyses. Where the year effect was important (Subdiv. 5Ze for all countries and Div. 6A and area 6N for Poland), there is agreement in all three measures on the trend of the change, although there is a marked difference in the magnitude of the change in area 6N. In these cases, moreover, the ratio of total catch to total days fished provided a closer estimate to that predicted by the analyses than the ratio of total catch to total hours fished. With respect to the covariance analysis results, this indicates that, where the species composition of the catches was similar from year to year, changes in catch per day fished or catch per hour fished could be assumed to be indicative of changes in catchability associated with yearly changes in abundance (independent of vessel and area characteristics). For the other areas, where year effect had a smaller mean square associated with it, there was no consistency in the three estimates.

ESTIMATES CHANGES IN CATCHABILITY BETWEEN AREAS

Since there is interest in determining whether catchability varied across areas, the estimated main effects by country and area were retransformed to show percentage differences between areas relative to pre-selected (arbitrary) standard areas within each division (Fig. 4). Marked differences in values within an area can be associated with differences in species composition within the area; for example, the high coefficients near the northern boundary of Subdiv. 5Ze for Japan can be attributed to large catches of gadoids and argentine. Confidence intervals about these coefficients can be calculated but are not given here.

FISHING POWER OF INDIVIDUAL VESSELS

In the preceding analyses, the vessel factor was assumed random since there was no interest in estimating differences between these particular vessels. Moreover, the data requirements for the Pilot Study requested Member Countries to select a random sample of 20 vessels from their respective fleets. It is useful, however, to examine the fishing power of the vessels for which data were submitted, since these data provide a unique opportunity to examine the behavior of vessels fishing on the same stock(s) at the same time.

The data from each country was sorted into "area-date" blocks. An "area-date" block is a block of data containing catch and effort data for all vessels from one country that fished in the same area on the same day. Areas for this study are 1° x 1° unit areas and a day is the 24-hour period from midnight to midnight. Overall blocks of the coefficients of relative fishing power were calculated as follows:

$$\text{RFP (vessel x)} = \frac{1}{n} \sum_{i=1}^{n} \frac{\text{CPUE (vessel x)}_i}{\text{CPUE (vessel y)}_i} \qquad (7)$$

$$\frac{\text{Mean CPUE (x)}}{\text{Mean CPUE (y)}} = \sum_{i=1}^{n} \text{CPUE (vessel x)}_i / \sum_{i=1}^{n} \text{CPUE (vessel y)}_i \qquad (8)$$

where

RFP = relative fishing power of vessel,
n = total number of times vessel x and vessel y appears simultaneously in an "area-date" block,
vessel x or y = reference vessel (each vessel being used interchangeably as the reference vessel), and
CPUE = metric tons of fish caught per hour of fishing.

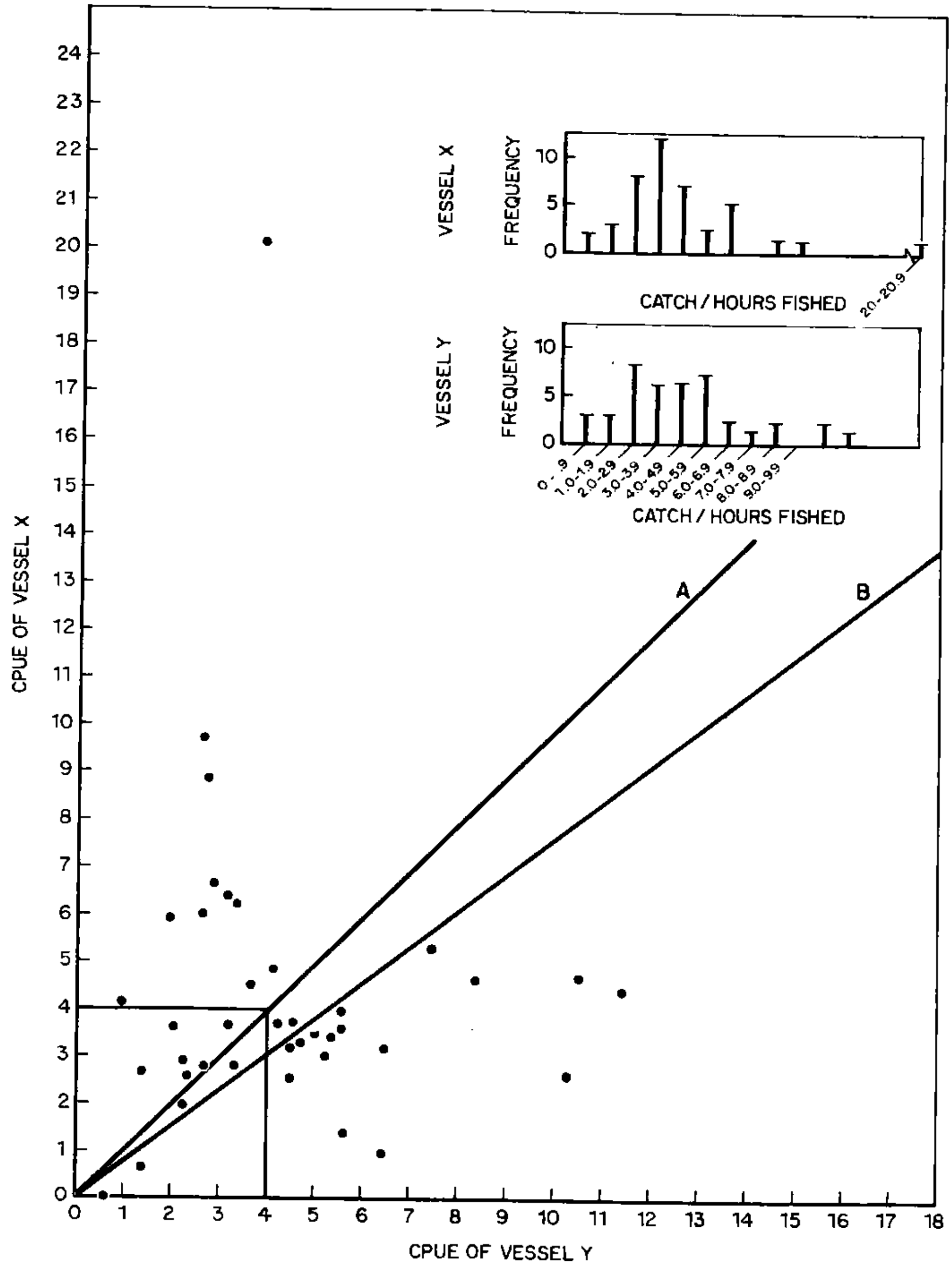

Fig. 5. Plot of distribution of CPUE by vessel and of CPUE of vessel X *versus* vessel Y. This is a sample plot of the vessels having the highest number of observations (n = 41). Vessel Y is 2 and vessel X is 5 from FRG 1972 data of Appendix Table E.

Equation (7) gives a measure of fishing power of vessel x relative to vessel y according to the definition of fishing power. Equation (8) gives a ratio of mean CPUE for vessel x to mean CPUE for vessel y using the same data as in Equation (7). Comparison of Equations (7) and (8) would thus give an indication of the consistency of RFP over all "area-date" observations included in the calculation of RFP.

Calculated values of Equations (7) and (8) are listed in Appendix Tables E, F and G by country. The indices calculated from Equation (7) are consistently greater than or equal to those resulting from Equation (8). This consistent difference suggests independence between the CPUE of vessel x and the reciprocal of CPUE of the standard vessel. Although this independence was not tested statistically, if it could be assumed to be true, then using Jensen's inequality it could be deduced that

$$E\left[\frac{\text{CPUE (x)}}{\text{CPUE (y)}}\right] = E\ [\text{CPUE (x)}] \cdot E\left[\frac{1}{\text{CPUE (y)}}\right] \geq E\ [\text{CPUE (x)}]/E\ [\text{CPUE (y)}] \qquad (9)$$

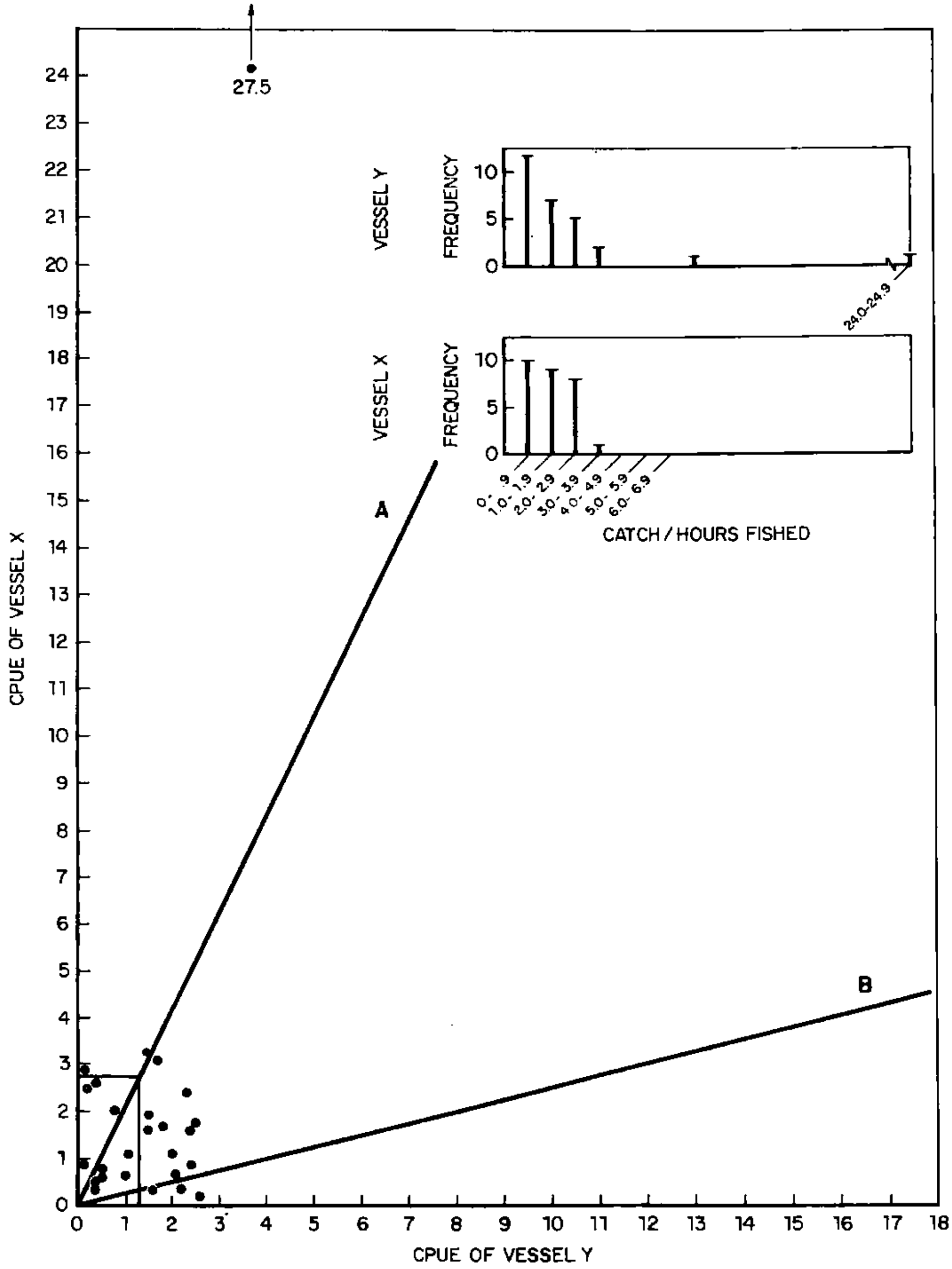

Fig. 6. Plot of distribution of CPUE by vessel and of CPUE of vessel X *versus* vessel Y. This is a sample plot of the vessels having the highest number of observations (n = 28). Vessel Y is 13 and vessel X is 12 from Japanese 1971 data of Appendix Table I.

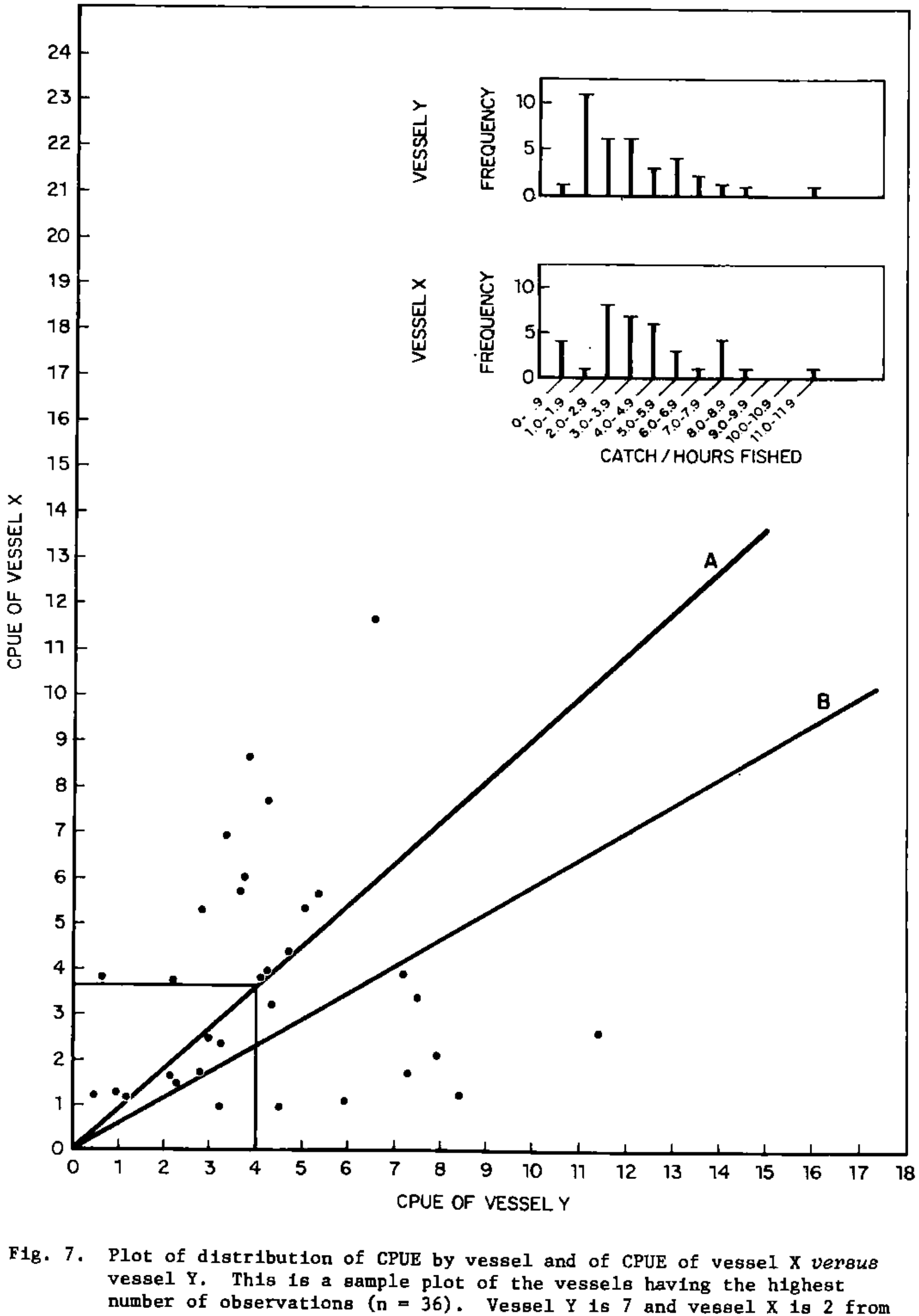

Fig. 7. Plot of distribution of CPUE by vessel and of CPUE of vessel X *versus* vessel Y. This is a sample plot of the vessels having the highest number of observations (n = 36). Vessel Y is 7 and vessel X is 2 from Polish 1971 data of Appendix Table G.

where E ( ) refers to the expected value of the variables within the parenthesis. Equation (9) reflects the trend observed in the data. Jensen's inequality states that for any convex function f (James and James, 1959),

$$f\left(\sum_{1}^{n}\lambda_i x_i\right) \leq \sum_{1}^{n}\lambda_i \cdot f\,(x_i),\ \text{where}\ \lambda > 0\ \text{and}\ \sum_{1}^{n}\lambda_i = 1 \qquad (10)$$

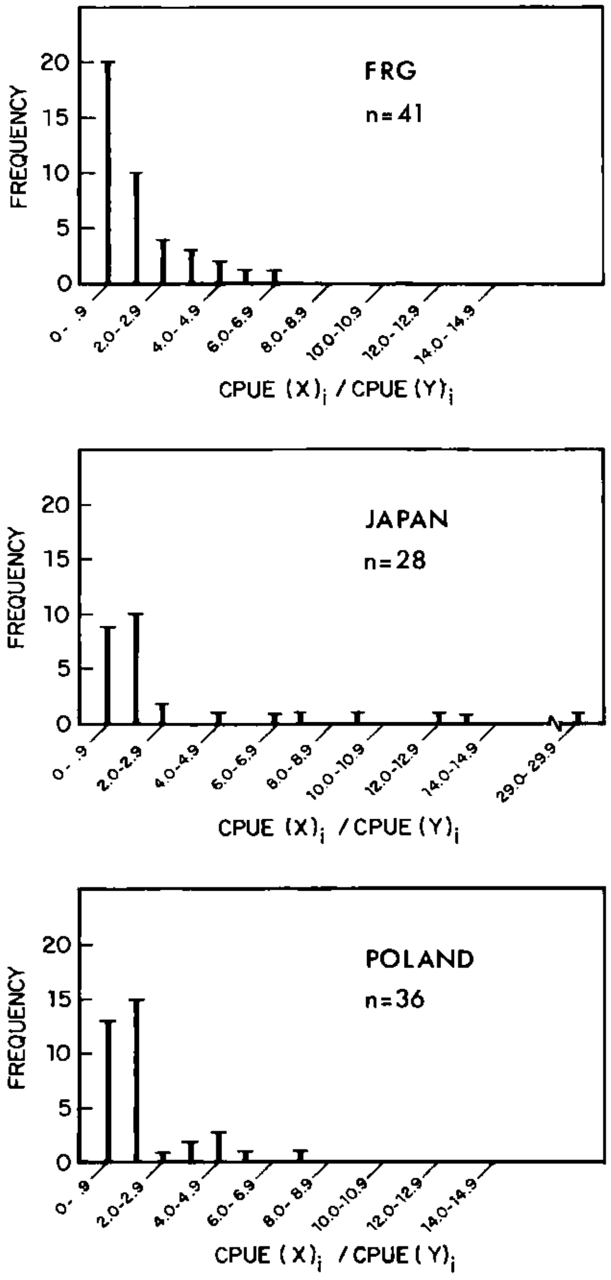

Fig. 8. Distribution of CPUE (X)/CPUE (Y) for data of FRG, Japan and Poland used in Fig. 5 to 7.

In the present context, $\lambda_i = (1/n)_i > 0$ and $\sum_{i=1}^{n} (1/n)_i = 1$, and f is the reciprocal function. If the assumed independence is not true, then values of Equation (7) are greater than or equal to values of Equation (8) only coincidentally.

For situations where there were at least 20 observations for Japanese vessels, fishing power coefficients varied 200% of the smallest RFP. As expected, the percentage increased as the number of observations in the sample decreased. This phenomenon did not occur with FRG or Polish data. In both FRG and Polish data sets, the RFP's varied from 100% to 500% of the smallest fishing power regardless of which vessel was the reference vessel y and the sample size involved.

The standard deviation and coefficient of variation of each fishing power coefficient [Equation (7)] were computed (Appendix Tables E to J). These statistics also show a great amount of variation in the fishing power of a vessel. The coefficients of variation were often above 100% and seldom below 50%. To examine this variability more fully for each country, plots of CPUE of vessel x *vs* CPUE vessel y, used in calculating Equation (7) for data constituting the largest sample (n), were examined to assess the consistency and variability over time and area of RFP (Fig. 5 to 7). In neither of the three cases did the points fall along the line with slope determined from Equation (8). The scattering was also not along the line with slope determined from Equation (7). For the data used in these plots, distributions were drawn for vessel CPUE (Fig. 5 to 7). The distributions differed for the three cases considered: the distributions of the FRG vessels approached a normal distribution, the data of Poland was much more skewed for each vessel, and that of Japan had little variance. Moreover, the distributions within country were more similar than those between country.

Figure 8 shows a plot of the distribution of CPUE $(x)_i$/CPUE $(y)_i$ for three pairs of vessels used in Fig. 5 to 7. In each plot, 30-50% of the observations were less than 1.00. The reciprocal relationship would be the case in plotting the distribution of this ratio with x and y interchanged. Thus, the plots indicate the lack of consistency in RFP of the three vessels x, with y as the standard.

CONCLUSIONS

The results of the preceding analyses suggest a considerable degree of variability in daily catches by area, vessel, time and species composition of catches. The dependency of the importance of these factors on the species composition of the catch data is intuitively acceptable and suggest the importance of reporting catch and effort data on a fine enough scale so that directed fisheries can be distinguished. With such data available, changes in catchability associated with year and season changes can be more precisely measured. Although some of the covariance analyses results showed vessel and area characteristics to be important, differences in species abundance of the catches could be contributing to this phenomena. This is a reasonable hypothesis since, where the species composition was similar, time characteristics (year, season) were more important than vessel or area characteristics.

The covariance analyses also indicated that daily catches and hours fished were statistically related in an exponential way for catches of Japan and FRG, and in a proportional way for catches of Poland. This finding has extremely important implications on the regulation of fishing mortality through the regulation of fishing effort. For example, if a vessel of Japan fishing in area 6N inflicted a specified mortality (F) by fishing for d days and f hours of fishing per day, a halving of d to achieve a mortality of F/12 would be nullified by a less than doubling of f. Table 7 lists the various combinations of d and f which inflict the same mortality $F_{actual} = 0.5$, although a one-half or one-quarter reduction in days of fishing (d) was suggested to achieve a corresponding reduction in F.

For the situations where year or season mean squares were greater than mean squares associated with vessels or areas, changes in catchability were calculated and were

Table 7. Predicted and actual fishing mortality (F) resulting from various combinations of days fished (d) and hours of fishing per day (f) for a hypothetical catchability coefficient (q). (Relationship between catch and f based on data of Japan, area 6N.)

F_{pred}	q	d	f	F_{actual}
0.50	0.1×10^{-3}	500	5.2	0.50
0.375	0.1×10^{-3}	375	6.4	0.50
0.25	0.1×10^{-3}	250	8.5	0.50
0.50	0.4×10^{-4}	500	10.0	0.50
0.375	0.4×10^{-4}	375	12.3	0.50
0.25	0.4×10^{-4}	250	16.4	0.50

closer to changes in total catch/total days fished rather than to changes in total catch/total hours fished, using the same data. Because of the exponential relation between catch and hours fished for the data of Japan and FRG, the lack of agreement between change in catchability and change in total catch/total hours fished seems reasonable. Agreement between change in catchability and change in total catch/total days fished would be coincidental. For the data of Poland, the lack of agreement between change in catchability and change in total catch/total hours fished and the closer agreement between the former and total catch/total days fished could be explained by a change in the number of hours of fishing per day.

Changes in catchability by area could be associated with differences in species composition of the catches. For areas where the species composition of the catches of each country were similar, catchability was comparable.

Since the vessels, for which data were submitted, were all of the same tonnage class, changes in catchability due to differences in tonnage class could not be evaluated. In a series of calculations of fishing power, where each vessel was used as the standard vessel in a separate set of calculations, there was no trend to the fishing power of the vessels in a fleet; i.e. the ordering of the vessels (from largest to smallest fishing power) changed with the changing of the vessel which was the standard. This vessel to vessel variability, for vessels fishing in the same area or the same day, will hamper attempts in the future to get precise estimates of catchability and changes in catchability due to other factors.

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APPENDIX

Table A. Data for FRG in 1972 and 1973 from Div. 5Z and Statistical Area 6: effort and catch for the species[a] caught by main species category (MS) and month.

Year	MS	Month	Hours fished	Her	Mac	S H	R H	Cod	Red	Flo	Had	O F	Squ	Total
1972	Her	Jul	149.3	320.3	17.8	2.1	-	-	-	-	-	6.3	-	346.5
		Aug	1,730.3	5,134.4	39.3	19.8	-	-	0.8	-	-	5.4	-	5,199.7
		Sep	2,999.0	9,848.2	50.4	62.1	-	-	-	-	-	9.9	-	9,970.6
		Oct	2,008.4	6,462.5	41.5	44.0	-	-	-	-	-	3.5	-	6,551.5
	Total		6,887.0	21,765.4	149.0	128.0	-	-	0.8	-	-	25.1	-	22,068.3
	Mac	Jul	7.1	-	6.3	1.3	-	-	-	-	-	-	-	7.6
		Sep	18.0	-	28.0	17.5	-	-	-	-	-	3.0	-	48.5
		Oct	15.0	10.3	47.5	35.0	-	-	-	-	-	3.8	-	96.6
	Total		40.1	10.3	81.8	53.8	-	-	-	-	-	6.8	-	152.7
	S H	Sep	6.0	-	4.0	4.0	-	-	-	-	-	-	-	8.0
		Oct	28.0	6.2	2.0	25.0	-	-	-	-	-	-	-	33.2
	Total		34.0	6.2	6.0	29.0	-	-	-	-	-	-	-	41.2
Total	(1972)[b]		6,961.1	21,781.9 (29,911.0)	236.8 (255.0)	210.8	-	-	0.8	-	-	31.9	-	22,262.2
1973	Her	Jul	541.0	1,878.7	-	-	-	-	-	-	-	-	-	1,878.7
		Aug	2,892.5	12,291.5	4.7	-	-	-	-	-	-	-	-	12,311.2
		Sep	3,189.9	12,394.4	2.2	-	-	-	-	-	-	-	-	12,389.1
		Oct	657.0	2,965.6	59.2	-	-	-	-	-	0.8	-	-	3,025.6
	Total		7,280.4	29,530.2	66.1	-	-	-	-	-	0.8	-	-	29,604.6
	Mac	Sep	2.3	-	0.9	-	-	-	-	-	-	-	-	0.9
		Oct	77.0	-	205.7	-	-	-	-	-	-	-	-	205.7
		Nov	124.0	-	221.5	-	-	-	-	-	-	-	-	221.5
	Total		203.3	-	428.1	-	-	-	-	-	-	-	-	428.1
	O F	Sep	82.0	127.1	-	-	-	-	-	-	-	301.8	-	428.9
		Nov	76.0	-	-	-	-	-	-	-	-	72.5	30.9	103.4
	Total		158.0	127.1	-	-	-	-	-	-	-	374.3	30.9	523.3
	Squ	Jul	13.0	-	-	-	-	-	-	-	-	-	-	-
		Nov	724.0	-	-	-	-	-	-	-	-	41.5	373.3	414.8
		Dec	95.0	-	-	-	-	-	-	-	-	2.5	40.7	43.2
	Total		832.0	-	-	-	-	-	-	-	-	44.0	414.0	458.0
Total	(1973)[b]		8,473.7	29,657.3 (31,501.0)	494.2 (583.0)	-	-	-	-	-	0.8	418.3	444.9	31,023.0

[a] Species abbreviations refer to: herring, mackerel, silver hake, red hake, redfish, flounders, haddock, other fish and squids.

[b] Catches in parentheses are from ICNAF Statistical Bulletin, Vol. 22 and 23 for the years 1972 and 1973 respectively for the designated months.

Table B. Data for Poland in 1971 and 1972 from Div. 5Z and Statistical Area 6: effort and catch for the species[a] caught by main species category (MS) and month.

Year	MS	Month	Hours fished	Her	Mac	S H	R H	Cod	Red	Flo	Had	O F	Squ	Total
1971	Her	Mar	120.4	262.0	41.0	-	-	-	-	-	-	-	2.0	305.0
		Apr	310.4	511.6	88.9	-	-	-	-	-	-	-	2.5	603.0
		Sep	2,528.3	8,648.4	67.7	1.5	-	-	-	-	-	-	7.0	8,724.6
		Oct	1,508.5	4,497.5	14.0	-	-	-	-	-	-	-	-	4,511.5
	Total		4,467.6	13,919.5	211.6	1.5	-	-	-	-	-	-	11.5	14,144.1
	Mac	Mar	444.9	66.0	1,999.0	-	-	-	-	-	-	-	0.1	2,065.1
		Apr	1,109.1	185.8	3,148.2	-	-	-	-	-	-	-	9.5	3,343.5
		Sep	34.3	65.4	94.6	-	-	-	-	-	-	-	-	160.0
		Oct	32.5	-	14.0	-	-	-	-	-	-	-	-	14.0
	Total		1,620.8	317.2	5,255.8	-	-	-	-	-	-	-	9.6	5,582.6
Total	(1971)[b]		6,143.9	14,236.7 (43,344.0)	5,467.4 (22,738.0)	1.5	-	-	-	-	-	-	21.1	19,726.7
1972	Her	Mar	12.4	14.0	-	-	-	-	-	-	-	-	-	14.0
		Sep	1,609.4	3,338.5	7.3	-	-	-	-	-	-	53.8	-	3,399.6
		Oct	1,669.2	4,304.5	14.0	9.0	-	-	-	-	-	44.0	-	4,371.5
	Total		3,291.0	7,657.0	21.3	9.0	-	-	-	-	-	97.8	-	7,785.1
	Mac	Mar	736.6	14.1	3,145.2	-	-	-	-	-	-	62.0	-	3,221.3
		Apr	818.7	47.0	2,522.2	-	-	-	-	-	-	42.0	-	2,611.2
		Oct	64.7	7.0	65.0	-	-	-	-	-	-	-	-	72.0
	Total		1,620.0	68.1	5,732.4	-	-	-	-	-	-	104.0	-	5,904.5
	S H	Apr	13.6	8.6	-	80.1	-	-	-	-	-	-	-	88.7
		Oct	12.4	-	-	3.0	-	-	-	-	-	2.0	-	5.0
	Total		26.0	8.6	-	83.1	-	-	-	-	-	2.0	-	93.7
	O F	Mar	7.5	-	[c]10.0	-	-	-	-	-	-	15.0	-	25.0
		Apr	41.2	-	44.0	-	-	-	-	-	-	84.0	-	128.0
		Sep	36.2	13.0	-	2.0	-	-	-	-	-	23.0	-	38.0
		Oct	8.2	5.0	-	-	-	-	-	-	-	14.0	-	19.0
	Total		93.1	18.0	54.0	2.0	-	-	-	-	-	136.0	-	210.0
	Squ	Mar	24.4	-	-	-	-	-	-	-	-	-	-	-
		Apr	12.4	-	-	-	-	-	-	-	-	-	-	-
		Sep	65.8	-	-	-	-	-	-	-	-	-	-	-
		Oct	81.9	-	-	-	-	-	-	-	-	-	-	-
	Total		184.5	-	-	-	-	-	-	-	-	-	-	-
Total	(1972)[b]		5,214.6	7,751.7 (33,007.0)	5,807.7 (43,349.0)	94.1	-	-	-	-	-	339.8	-	13,993.3

---

[a] Species abbreviations refer to: herring, mackerel, silver hake, red hake, redfish, flounders, haddock, other fish and squids.

[b] Catches in parentheses are from ICNAF Statistical Bulletin, Vol. 21 and 22 for the years 1971 and 1973 respectively for the designated months.

Table C. Data for Japan in 1971 and 1972 from Div. 5Z and Statistical Area 6: effort and catch for the species[a] caught by main species category (MS) and month.

Year	MS	Month	Hours fished	Her	Mac	S H	Cod	Red	Flo	Had	O F	Squ	But	Arg	Total
1971	Her	Sep	767.9	1,260.1	-	0.9	-	-	0.7	9.4	16.2	6.9	-	-	1,294.2
		Oct	882.5	1,627.1	-	2.3	3.5	1.8	2.0	0.3	21.6	-	-	-	1,658.6
	Total		1,650.4	2,887.2	-	3.2	3.5	1.8	2.7	9.7	37.8	6.9	-	-	2,952.8
	Mac	Mar	491.8	2.7	341.5	7.3	-	-	-	-	18.6	115.5	5.2	-	490.8
	S H	Mar	15.0	-	-	2.6	-	-	-	-	0.1	1.1	-	-	3.8
	Cod	Oct	7.5	0.3	-	-	1.4	-	-	-	0.2	-	-	-	1.9
	Flo	Mar	13.5	-	-	-	-	-	7.4	-	3.5	-	-	-	10.9
		Apr	141.0	-	146.1	-	-	-	266.2	-	-	-	-	-	412.3
	Total		154.5	-	146.1	-	-	-	273.6	-	3.5	-	-	-	423.2
	O F	Mar	95.5	0.2	4.1	-	-	-	-	-	33.5	7.2	0.4	-	45.4
		Apr	48.3	-	-	-	-	-	-	-	116.6	-	-	102.5	219.1
		Sep	12.7	-	-	-	-	-	-	0.2	0.6	-	-	-	0.8
		Oct	80.8	1.4	-	9.6	-	-	-	-	34.8	13.1	9.6	-	68.5
	Total		237.3	1.6	4.1	9.6	-	-	-	0.2	185.5	20.3	10.0	102.5	333.8
	Squ	Mar	967.5	3.7	53.4	3.6	-	-	0.2	-	28.4	314.8	20.6	-	424.7
		Sep	29.0	-	-	-	-	-	-	-	0.2	3.9	0.9	-	5.0
		Oct	139.7	-	-	-	-	-	-	-	29.6	52.8	16.2	-	98.6
	Total		1,136.2	3.7	53.4	3.6	-	-	0.2	-	58.2	371.5	37.7	-	528.3
	But	Mar	153.2	-	3.9	-	-	-	-	-	15.0	33.5	103.1	-	155.5
		Sep	379.5	-	-	-	-	-	-	-	3.6	9.9	512.0	-	525.5
		Oct	193.8	-	0.3	-	-	-	-	-	8.5	23.9	103.7	-	136.4
	Total		726.5	-	4.2	-	-	-	-	-	27.1	67.3	718.8	-	817.4
	Arg	Mar	86.9	-	-	-	-	2.0	-	-	38.0	2.2	1.0	664.6	707.8
		Apr	235.6	-	-	-	-	-	-	-	464.2	-	-	1,081.4	1,545.6
		Oct	52.1	0.2	-	-	-	-	-	0.2	6.8	-	-	40.3	47.5
	Total		374.6	0.2	-	-	-	2.0	-	0.2	509.0	2.2	1.0	1,786.3	2,300.9
Total (1971)[b]			4,793.8	2,895.7	549.3	26.3	4.9	3.8	276.5	10.1	840.0	584.8	772.7	1,888.8	7,852.9
				(2,392.0)											(6,911.0)
1972	Her	Sep	937.7	459.6	-	0.3	4.4	2.8	-	-	36.8	6.9	11.9	-	522.7
		Oct	848.3	783.8	-	-	5.6	2.1	-	-	38.4	2.1	1.1	-	833.1
	Total		1,786.0	1,243.4	-	0.3	10.0	4.9	-	-	75.2	9.0	13.0	-	1,355.8
	Mac	Mar	170.5	-	256.2	6.7	-	-	-	-	78.6	87.0	39.8	-	468.3
		Apr	258.0	-	195.3	17.3	-	-	0.1	-	4.3	76.4	40.1	-	333.5
		Sep	57.5	-	66.9	-	1.6	-	-	-	3.0	0.5	39.6	-	111.5
		Oct	43.0	-	64.7	-	-	-	-	-	7.2	8.1	2.4	-	82.4
	Total		529.0	-	583.1	24.0	1.5	-	0.1	-	93.1	172.0	121.9	-	995.7
	S H	Apr	37.2	0.8	-	3.7	-	-	-	-	0.1	1.4	0.4	-	6.4
		Oct	76.8	-	0.2	29.3	-	-	0.4	-	7.4	16.1	2.5	-	55.9
	Total		114.0	0.8	0.2	33.0	-	-	0.4	-	7.5	17.5	2.9	-	62.3
	Cod	Oct	141.7	26.9	-	1.2	77.3	-	2.6	3.3	6.9	-	-	-	118.2
	O F	Mar	73.7	-	16.0	-	-	-	-	-	77.8	27.0	16.7	0.3	137.8
		Apr	71.9	-	10.3	4.2	0.8	0.4	0.3	0.2	169.9	6.7	0.9	-	193.7
		Sep	15.0	-	13.1	-	-	-	-	-	15.6	1.2	9.1	-	39.0
		Oct	62.4	0.2	-	-	-	-	-	-	52.1	5.9	-	-	58.2
	Total		223.0	0.2	39.4	4.2	0.8	0.4	0.3	0.2	315.4	40.8	26.7	0.3	428.7
	Squ	Mar	1,707.1	-	120.7	19.5	-	0.2	1.2	-	162.4	1,301.9	95.2	-	1,701.1
		Apr	740.5	1.2	65.9	52.6	-	-	1.2	-	18.0	411.4	17.2	-	567.5
		Sep	318.0	-	-	-	-	-	-	-	1.5	437.8	-	-	439.3
		Oct	1,119.5	-	1.9	37.9	-	-	1.2	-	24.9	582.7	30.9	-	679.5
	Total		3,885.1	1.2	188.5	110.0	-	0.2	3.6	-	206.8	2,733.8	143.3	-	3,387.4
	But	Mar	15.8	-	5.0	-	-	-	-	-	3.0	7.3	27.5	-	42.8
		Apr	14.7	-	-	1.2	-	-	-	-	0.5	1.2	3.1	-	6.0
		Sep	29.6	-	13.0	-	0.7	-	-	-	1.6	-	20.6	-	35.9
		Oct	82.5	-	-	0.2	-	-	0.1	-	0.1	7.7	10.0	-	18.1
	Total		142.6	-	18.0	1.4	0.7	-	0.1	-	5.2	16.2	61.2	-	102.8
	Arg	Mar	15.9	-	-	-	-	0.1	-	-	1.6	-	-	42.0	43.7
		Apr	15.3	-	2.0	1.8	-	-	0.1	-	8.6	1.2	0.5	21.5	35.7
	Total		31.2	-	2.0	1.8	-	0.1	0.1	-	10.2	1.2	0.5	63.5	79.4
Total (1972)[b]			6,852.6	1,272.5	831.2	175.9	90.3	5.6	7.2	3.5	720.3	2,990.5	369.5	63.8	6,530.3
				(1,117.0)	(637.0)										(7,289.0)

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[a] Species abbreviations refer to: herring, mackerel, silver hake, redfish, flounders, haddock, other fish, squids, butterfish and argentine.

[b] Catches in parentheses are from ICNAF Statistical Bulletin, Vol. 21 and 22 for the years 1971 and 1972 respectively for the designated months.

Table D. Analysis of covariance for Pilot Study data for FRG, Japan and Poland.

Data	Area	Source	Sum of squares	Degrees of freedom	Mean square	F
FRG, 1972-73	5Ze	Years	18.06	1	18.06	63.48
		Areas	13.34	11	1.21	4.26
		Vessels in years	30.61	18	1.70	5.98
		Years x areas	4.44	11	0.40	1.42
		Covariable	14.08	1	14.08	49.52
		Error	242.91	854	0.28	
Japan, 1971-72	5Ze	Years	11.70	1	11.70	13.74
		Seasons	14.66	1	14.66	17.22
		Areas	60.29	10	6.03	7.08
		Vessels	36.26	10	3.63	4.26
		Years x seasons	0.01	1	0.01	0.01
		Covariable	1.24	1	1.24	1.46
		Error	261.42	307	0.86	
Japan, 1971-72	5Zw	Mean	1.84	1	1.84	10.47
		Years	0.14	1	0.14	0.78
		Seasons	0.61	1	0.61	3.50
		Areas	2.93	3	0.98	5.56
		Vessels	10.39	9	1.15	6.56
		Years x seasons	0.28	1	0.28	1.61
		Covariable	7.61	1	7.61	43.33
		Error	5.46	31	0.18	
Japan, 1971-72	(6N)	Mean	7.84	1	7.84	16.97
		Years	0.29	1	0.29	0.62
		Seasons	1.23	1	1.23	2.67
		Areas	9.32	12	0.78	1.68
		Vessels	17.81	15	1.18	2.57
		Years x seasons	1.11	1	1.11	2.41
		Covariable	39.91	1	39.91	86.41
		Error	99.75	216	0.46	
Poland, 1971-72	5Zw	Mean	0.74	1	0.74	0.82
		Year	0.11	1	0.11	0.12
		Areas	3.36	4	0.84	0.54
		Vessels in years	2.93	6	0.49	0.93
		Years x areas	3.67	4	0.92	1.01
		Covariable	15.82	1	15.82	17.51
		Error	51.50	57	0.90	
Poland, 1971-72	6A	Mean	2.99	1	2.99	5.90
		Year	4.32	1	4.32	8.54
		Areas	6.30	7	0.90	1.77
		Vessels in years	4.82	6	0.84	1.59
		Years x areas	7.30	7	1.04	2.06
		Covariable	10.38	1	10.38	20.48
		Error	28.89	57	0.51	

Table E. FRG, 1972: fishing power coefficients of individual vessels. (The five entries in the cell of the matrix represent for vessel x and y (a) the number of days vessel x and vessel y fished simultaneously in the same "area-date" block, (b) the relative fishing power (RFP) of vessel x with vessel y as the reference vessel, (c) the ratio of CPUE of vessel x to CPUE of vessel y, (d) the standard deviation of the observations constituting RFP of vessel x, and (e) the coefficient of variation of observations constituting RFP, i.e. standard deviation divided by RFP.)

Vessel X	Vessel Y									
	1	2	3	4	5	6	7	8	9	10
1	48.0 1.0 1.0 0.1 14.7	33.0 2.5 1.4 3.3 130.6	34.0 1.5 1.5 1.2 80.5	35.0 1.5 1.5 1.3 88.4	28.0 1.8 1.3 2.3 129.2	25.0 2.3 2.0 1.5 65.2	25.0 3.3 3.0 3.2 96.5	27.0 2.4 2.2 1.4 59.6	12.0 3.2 1.9 4.3 134.0	21.0 3.8 2.7 4.2 109.9
2	33.0 1.0 0.7 1.0 104.5	59.0 1.0 1.0 0.2 18.9	40.0 1.6 1.2 3.1 190.2	36.0 1.4 1.3 1.8 129.7	41.0 1.3 1.0 1.2 94.7	25.0 2.4 1.6 3.8 160.0	34.0 2.6 2.4 3.2 123.7	33.0 2.9 1.9 3.7 128.9	16.0 1.4 1.4 0.9 66.6	25.0 2.4 2.0 2.2 94.8
3	34.0 0.8 0.7 0.6 77.3	40.0 1.3 0.8 2.2 171.5	63.0 1.0 1.0 0.3 29.6	39.0 1.1 1.0 1.2 106.3	39.0 1.0 0.8 0.9 90.6	29.0 1.6 1.3 1.6 102.9	38.0 2.5 2.3 3.8 149.0	38.0 2.1 1.6 2.2 104.2	24.0 2.0 1.8 2.8 134.9	24.0 2.2 1.6 2.2 99.6
4	35.0 0.8 0.8 0.5 59.6	36.0 1.2 0.8 1.2 105.5	39.0 1.1 1.0 1.0 91.4	58.0 1.0 1.0 0.3 27.5	36.0 1.1 0.9 0.8 71.0	31.0 1.3 1.3 0.8 60.2	27.0 1.7 2.1 1.7 105.2	32.0 1.6 1.6 1.1 69.2	15.0 2.9 1.5 6.6 224.4	23.0 2.7 1.8 2.4 88.2
5	28.0 1.0 0.8 0.8 75.4	41.0 1.3 1.0 1.2 95.2	39.0 1.2 1.2 1.0 86.3	36.0 1.3 1.1 1.6 119.9	60.0 1.0 1.0 0.1 13.1	24.0 1.6 1.5 1.2 71.6	32.0 1.6 2.3 1.5 91.5	33.0 2.5 2.1 1.7 68.7	22.0 1.9 1.5 2.0 105.5	32.0 2.6 2.3 1.7 66.2
6	25.0 0.6 0.5 0.4 78.5	25.0 1.0 0.6 0.8 86.1	29.0 0.8 0.8 0.7 87.1	31.0 0.9 0.8 0.5 62.1	24.0 1.0 0.7 1.1 118.2	46.0 1.0 1.0 0.0 0.1	20.0 1.5 1.1 1.7 117.0	18.0 1.4 1.1 0.9 66.6	15.0 1.5 1.1 1.7 114.1	12.0 1.3 1.2 0.5 37.4
7	25.0 0.3 0.3 0.3 87.8	34.0 0.5 0.4 0.6 104.2	38.0 0.5 0.4 1.0 181.8	27.0 0.4 0.5 0.5 115.8	32.0 0.5 0.4 0.4 88.0	20.0 1.0 0.9 1.0 105.3	48.0 1.0 1.0 0.4 55.1	37.0 1.0 0.8 1.1 109.3	12.0 0.6 0.7 0.5 84.5	25.0 1.5 1.0 2.1 142.2
8	27.0 0.5 0.5 0.3 51.7	33.0 0.8 0.5 0.8 102.0	38.0 0.9 0.6 0.9 102.7	32.0 0.7 0.6 0.4 66.8	33.0 0.6 0.5 0.3 56.0	18.0 1.0 0.9 0.6 59.1	37.0 1.0 1.2 1.0 97.2	56.0 1.0 1.0 0.1 13.6	16.0 1.0 0.8 0.9 87.2	28.0 1.5 1.3 1.0 68.9
9	12.0 0.7 0.5 0.8 113.8	16.0 0.7 0.7 0.5 69.2	24.0 0.7 0.6 0.7 92.9	15.0 0.9 0.7 0.6 66.4	22.0 0.8 0.7 0.6 72.3	15.0 1.1 0.9 0.9 85.1	12.0 0.8 1.4 0.7 85.5	16.0 1.4 1.2 1.0 70.9	35.0 1.0 1.0 0.2 25.0	11.0 2.0 1.5 2.0 100.6
10	21.0 0.5 0.4 0.3 63.3	25.0 0.6 0.5 0.5 82.7	24.0 0.8 0.6 0.8 99.1	23.0 1.0 0.5 2.0 203.0	32.0 0.5 0.4 0.3 61.0	12.0 0.9 0.9 0.3 35.3	25.0 0.7 1.0 0.7 98.6	28.0 0.9 0.8 0.5 58.8	11.0 1.1 0.7 1.0 90.4	43.0 1.0 1.0 0.2 15.6

Table F. FRG, 1973: fishing power coefficients of individual vessels. (See heading Table E for explanation of entries in the matrix.)

	Vessel Y												
Vessel X	11	12	13	14	15	16	17	18	19	20	21	22	23
11	43.0	10.0	27.0	16.0	25.0	23.0	12.0	9.0	22.0	3.0	16.0	0.0	0.0
	1.0	2.1	1.7	1.4	1.7	1.0	2.8	1.4	1.3	1.0	1.6	0.0	0.0
	1.0	1.9	1.6	1.3	1.3	0.8	1.3	1.1	1.0	1.1	1.3	0.0	0.0
	0.0	0.7	0.7	0.6	1.4	0.6	5.3	1.1	1.0	0.9	1.7	0.0	0.0
	0.0	31.2	40.8	45.7	81.0	63.6	189.7	74.9	80.2	92.8	106.4	0.0	0.0
12	10.0	19.0	13.0	7.0	11.0	6.0	1.0	3.0	3.0	0.0	5.0	0.0	0.0
	0.5	1.0	0.9	0.4	1.0	0.6	0.5	1.5	0.6	0.0	1.0	0.0	0.0
	0.5	1.0	0.8	0.4	0.7	0.4	0.5	0.7	0.4	0.0	0.8	0.0	0.0
	0.2	0.0	0.5	0.1	0.8	0.4	0.0	1.8	0.4	0.0	0.7	0.0	0.0
	38.2	0.0	58.9	32.9	80.2	66.7	0.0	120.8	67.0	0.0	70.2	0.0	0.0
13	27.0	13.0	40.0	18.0	27.0	21.0	6.0	7.0	18.0	0.0	12.0	0.0	0.0
	0.7	1.5	1.0	0.9	1.2	0.5	0.8	1.3	1.1	0.0	1.3	0.0	0.0
	0.6	1.3	1.0	0.8	0.9	0.4	0.7	1.1	0.7	0.0	0.9	0.0	0.0
	0.2	0.6	0.0	0.4	0.9	0.3	0.4	0.9	1.2	0.0	1.3	0.0	0.0
	36.9	40.9	0.1	41.7	72.8	50.7	45.6	64.4	105.4	0.0	99.1	0.0	0.0
14	16.0	7.0	18.0	31.0	21.0	21.0	5.0	5.0	15.0	2.0	10.0	0.0	2.0
	0.9	2.6	1.5	1.0	1.7	0.7	2.6	2.1	1.4	1.3	1.6	0.0	0.7
	0.8	2.4	1.2	1.0	1.2	0.6	1.2	1.7	0.9	1.3	1.3	0.0	0.7
	0.4	0.9	1.3	0.0	1.1	0.5	3.2	1.4	1.3	0.0	0.8	0.0	0.0
	49.8	34.1	83.4	0.1	63.6	61.6	123.5	66.9	90.8	2.1	53.0	0.0	2.3
15	25.0	11.0	27.0	21.0	48.0	26.0	10.0	10.0	25.0	4.0	14.0	0.0	3.0
	0.9	1.7	1.3	0.9	1.0	0.8	0.9	1.2	1.1	1.4	1.6	0.0	0.5
	0.8	1.4	1.2	0.8	1.0	0.6	0.8	1.0	0.7	1.2	0.8	0.0	0.5
	0.5	1.4	0.9	0.6	0.0	0.6	0.4	0.7	0.9	1.3	3.1	0.0	0.2
	58.9	84.4	67.1	72.3	0.1	76.8	49.8	57.7	82.4	94.2	192.3	0.0	34.1
16	23.0	6.0	21.0	21.0	26.0	48.0	15.0	9.0	26.0	4.0	14.0	0.0	2.0
	1.7	2.8	2.7	2.0	2.5	1.0	2.1	2.3	1.9	1.1	1.7	0.0	0.9
	1.3	2.3	2.4	1.8	1.6	1.0	1.2	2.0	1.5	1.1	1.5	0.0	0.9
	1.4	2.3	1.7	1.4	2.4	0.0	3.3	1.1	1.5	0.5	1.2	0.0	0.0
	82.1	81.0	62.5	69.2	96.9	0.1	158.2	46.2	76.2	40.1	70.5	0.0	3.2
17	12.0	1.0	6.0	5.0	10.0	15.0	24.0	7.0	11.0	3.0	10.0	0.0	0.0
	1.0	2.0	1.5	0.8	1.4	1.2	1.0	1.1	1.3	0.8	2.1	0.0	0.0
	0.8	2.0	1.4	0.8	1.3	0.9	1.0	1.0	0.9	0.8	1.1	0.0	0.0
	0.7	0.0	0.7	0.6	0.6	1.0	0.0	0.5	1.2	0.1	3.4	0.0	0.0
	68.5	0.0	45.5	69.4	42.1	84.5	0.1	43.2	92.9	11.1	162.1	0.0	0.0
18	9.0	3.0	7.0	5.0	10.0	9.0	7.0	36.0	18.0	14.0	16.0	5.0	10.0
	1.2	1.6	1.0	0.6	1.2	0.5	1.2	1.0	1.4	1.0	0.9	0.7	0.8
	1.0	1.4	0.9	0.6	1.0	0.5	1.0	1.0	0.5	0.9	0.8	0.7	0.8
	1.0	1.2	0.5	0.2	0.7	0.2	0.7	0.0	2.0	0.4	0.7	0.2	0.3
	83.6	73.3	54.5	37.2	57.2	43.3	63.5	0.0	143.9	39.1	84.8	23.7	35.3
19	22.0	3.0	18.0	15.0	25.0	26.0	11.0	18.0	46.0	9.0	16.0	3.0	10.0
	1.3	3.0	1.5	1.3	2.7	0.8	1.4	2.4	1.0	2.5	1.6	0.7	1.7
	1.0	2.6	1.3	1.2	1.5	0.7	1.1	1.9	1.0	2.4	1.3	0.7	1.3
	1.0	3.0	1.1	0.8	6.4	0.5	1.0	3.8	0.0	4.0	1.9	0.7	3.5
	82.0	99.3	71.7	64.2	237.5	66.4	68.6	158.0	0.1	162.2	118.5	100.4	201.7
20	3.0	0.0	0.0	2.0	4.0	4.0	3.0	14.0	9.0	28.0	11.0	3.0	19.0
	2.1	0.0	0.0	0.8	1.3	1.0	1.3	1.3	1.6	1.0	0.8	0.4	0.9
	0.9	0.0	0.0	0.8	0.8	0.9	1.3	1.1	0.4	1.0	0.8	0.4	0.7
	2.1	0.0	0.0	0.0	1.0	0.5	0.1	0.8	2.2	0.0	0.4	0.0	0.7
	98.9	0.0	0.0	2.1	76.7	52.1	11.5	65.1	131.4	0.2	46.5	6.8	86.0
21	16.0	5.0	12.0	10.0	14.0	14.0	10.0	16.0	16.0	11.0	37.0	2.0	8.0
	1.0	1.5	1.1	0.8	1.6	0.8	1.0	1.6	1.5	1.5	1.0	0.8	1.2
	0.8	1.2	1.1	0.7	1.2	0.7	0.9	1.3	0.7	1.3	1.0	0.8	1.1
	0.8	1.1	0.5	0.3	1.2	0.4	0.6	0.7	1.5	0.8	0.0	0.3	0.5
	82.0	73.8	46.1	44.4	72.5	52.8	54.7	46.3	100.8	54.4	0.1	31.9	39.7
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	3.0	3.0	2.0	14.0	10.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	6.1	2.3	1.3	1.0	1.4
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.5	2.3	1.2	1.0	1.4
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	8.4	0.2	0.4	0.0	0.8
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.4	138.5	7.0	31.9	0.1	54.1
23	0.0	0.0	0.0	2.0	3.0	2.0	0.0	10.0	10.0	19.0	8.0	10.0	28.0
	0.0	0.0	0.0	1.4	2.2	1.1	0.0	1.4	2.7	1.8	1.0	0.9	1.0
	0.0	0.0	0.0	1.4	1.9	1.1	0.0	1.3	0.8	1.4	0.9	0.7	1.0
	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.5	2.8	1.5	0.6	0.4	0.0
	0.0	0.0	0.0	2.3	31.2	3.2	0.0	36.2	106.8	87.5	58.1	49.2	0.2

Table G. Poland, 1971: fishing power coefficients of individual vessels. (See heading of Table E for explanation of entries on the matrix.)

	Vessel Y											
Vessel X	1	2	3	4	5	6	7	8	9	10	11	12
1	39.0 1.0 1.0 0.0 0.1	28.0 1.2 0.8 1.2 100.3	27.0 1.2 0.9 1.0 82.6	11.0 1.5 0.7 2.1 143.0	30.0 0.9 0.7 0.9 103.6	0.0 0.0 0.0 0.0 0.0	33.0 1.7 0.5 5.9 351.8	0.0 0.0 0.0 0.0 0.0	12.0 2.3 1.5 2.3 102.8	0.0 0.0 0.0 0.0 0.0	9.0 1.4 0.7 3.0 212.6	26.0 0.9 0.5 1.1 123.4
2	28.0 2.9 1.2 4.3 147.1	46.0 1.0 1.0 0.0 0.1	35.0 2.4 1.2 3.9 164.3	16.0 2.4 1.1 2.6 109.5	32.0 1.5 1.0 1.3 85.6	0.0 0.0 0.0 0.0 0.0	36.0 1.7 1.1 1.6 97.0	0.0 0.0 0.0 0.0 0.0	13.0 2.9 1.2 4.6 158.4	0.0 0.0 0.0 0.0 0.0	9.0 1.2 1.0 1.1 92.1	24.0 0.8 0.6 0.9 111.0
3	27.0 1.4 1.1 1.1 74.7	35.0 1.1 0.8 1.1 100.6	45.0 1.0 1.0 0.1 15.2	14.0 1.4 0.9 1.3 96.9	34.0 1.3 0.9 1.1 86.2	0.0 0.0 0.0 0.0 0.0	32.0 0.8 0.7 0.7 85.6	0.0 0.0 0.0 0.0 0.0	12.0 2.2 1.4 2.9 131.0	0.0 0.0 0.0 0.0 0.0	7.0 0.9 0.8 0.7 77.6	26.0 0.8 0.5 1.2 161.4
4	11.0 2.0 1.3 1.7 85.9	16.0 1.2 0.9 1.3 109.4	14.0 1.4 1.1 1.3 94.1	21.0 1.0 1.0 0.0 0.1	13.0 1.2 0.9 1.0 79.9	0.0 0.0 0.0 0.0 0.0	16.0 0.8 0.7 0.6 78.0	0.0 0.0 0.0 0.0 0.0	9.0 3.6 2.3 3.6 101.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	11.0 0.9 0.8 0.7 83.1
5	30.0 3.0 1.3 4.8 159.1	32.0 1.5 1.0 1.5 105.4	34.0 2.3 1.1 4.9 216.8	13.0 1.7 1.1 1.5 87.9	41.0 1.0 1.0 0.0 0.1	0.0 0.0 0.0 0.0 0.0	35.0 0.8 0.8 0.6 77.1	0.0 0.0 0.0 0.0 0.0	12.0 1.5 1.5 1.0 67.6	0.0 0.0 0.0 0.0 0.0	9.0 2.3 1.1 3.2 137.2	24.0 0.8 0.6 0.7 93.8
6	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	11.0 1.0 1.0 0.0 0.0	3.0 1.2 0.8 1.2 99.6	9.0 0.8 0.6 0.6 75.0	0.0 0.0 0.0 0.0 0.0	2.2 0.4 0.4 0.1 22.4	0.0 0.0 0.0 0.0 0.0	5.0 1.2 0.8 0.6 52.2
7	33.0 3.7 2.1 4.4 120.7	36.0 1.2 0.9 1.1 97.0	32.0 3.0 1.4 5.8 192.8	16.0 2.5 1.5 2.4 93.8	35.0 1.7 1.2 1.3 75.2	3.0 1.7 1.3 1.5 89.3	61.0 1.0 1.0 0.1 13.0	12.0 0.8 0.6 0.7 78.8	14.0 3.4 2.2 4.7 135.7	6.0 2.4 1.3 2.3 98.8	9.0 1.0 0.8 0.8 81.3	33.0 0.9 0.6 0.7 84.6
8	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	9.0 2.0 1.6 1.3 64.2	12.0 2.1 1.6 1.5 73.6	20.0 1.0 1.0 0.0 0.1	0.0 0.0 0.0 0.0 0.0	4.0 5.5 1.5 9.5 172.0	0.0 0.0 0.0 0.0 0.0	11.0 1.3 0.8 1.2 92.7
9	12.0 1.3 0.7 2.0 153.7	13.0 1.0 0.8 0.7 74.7	12.0 0.7 0.7 0.5 80.1	9.0 0.4 0.4 0.3 59.6	12.0 1.2 0.7 1.2 98.1	0.0 0.0 0.0 0.0 0.0	14.0 0.5 0.5 0.4 67.5	0.0 0.0 0.0 0.0 0.0	17.0 1.0 1.0 0.0 0.1	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	10.0 0.4 0.4 0.3 71.6
10	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	2.0 2.3 2.5 0.5 22.4	6.0 0.9 0.8 0.9 93.3	4.0 1.0 0.7 0.7 66.5	0.0 0.0 0.0 0.0 0.0	18.0 1.0 1.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	12.0 0.6 0.6 0.3 54.2
11	9.0 3.2 1.4 4.1 126.1	9.0 1.6 1.1 1.4 87.5	7.0 3.4 1.2 5.3 157.1	0.0 0.0 0.0 0.0 0.0	9.0 0.9 0.9 0.8 88.9	0.0 0.0 0.0 0.0 0.0	9.0 0.9 1.2 0.9 101.9	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	0.0 0.0 0.0 0.0 0.0	12.0 1.0 1.0 0.3 31.5	5.0 0.8 0.9 0.7 83.5
12	26.0 4.5 1.8 5.3 118.9	24.0 2.4 1.8 2.3 94.9	26.0 3.7 2.1 4.7 126.1	11.0 1.7 1.2 1.6 90.8	24.0 2.3 1.6 2.3 102.1	5.0 1.9 1.3 2.7 143.9	33.0 1.9 1.5 1.3 67.8	11.0 1.5 1.3 1.0 71.1	10.0 3.9 2.5 3.2 81.8	12.0 3.2 1.7 4.8 150.3	5.0 4.1 1.2 6.0 147.5	60.0 1.0 1.0 0.1 13.1

Table H. Poland, 1972: fishing power coefficients of individual vessels. (See heading of Table E for explanation of entries in the matrix.)

	Vessel Y									
Vessel X	13	14	15	16	17	18	19	20	21	22
13	31.0	18.0	21.0	21.0	19.0	10.0	22.0	0.0	0.0	16.0
	1.0	0.8	1.3	1.2	1.4	0.7	1.0	0.0	0.0	0.6
	1.0	0.7	1.2	0.7	1.2	0.7	0.9	0.0	0.0	0.4
	0.2	0.9	1.1	1.4	3.1	0.8	0.9	0.0	0.0	0.6
	18.6	105.7	84.4	118.8	215.4	115.1	88.5	0.0	0.0	98.5
14	18.0	26.0	19.0	15.0	16.0	9.0	15.0	0.0	0.0	13.0
	2.4	1.0	1.5	1.9	1.6	1.5	2.1	0.0	0.0	1.3
	1.4	1.0	1.3	1.2	1.4	1.5	1.7	0.0	0.0	0.8
	2.1	0.0	1.1	2.3	2.3	1.5	1.6	0.0	0.0	1.0
	86.7	0.0	72.5	119.6	142.1	105.6	75.1	0.0	0.0	77.7
15	21.0	19.0	52.0	25.0	24.0	11.0	15.0	6.0	6.0	26.0
	1.8	1.2	1.0	1.3	1.1	0.9	1.5	5.7	1.7	1.2
	0.8	0.7	1.0	0.8	1.1	1.0	1.0	1.3	1.1	0.8
	2.2	1.0	0.1	1.4	1.7	0.8	1.0	7.5	1.6	1.4
	124.7	81.1	14.1	110.2	143.8	87.1	67.8	132.3	95.1	115.7
16	21.0	15.0	25.0	36.0	19.0	9.0	16.0	0.0	0.0	23.0
	2.5	1.3	1.7	1.0	1.2	1.8	2.2	0.0	0.0	1.1
	1.4	0.9	1.2	1.0	1.1	1.5	1.9	0.0	0.0	0.7
	2.7	1.4	1.5	0.2	1.2	2.9	1.8	0.0	0.0	1.3
	108.9	109.5	86.8	17.1	99.4	161.2	82.3	0.0	0.0	122.7
17	19.0	16.0	24.0	19.0	33.0	11.0	12.0	0.0	0.0	15.0
	2.3	1.1	1.7	1.5	1.0	2.3	1.0	0.0	0.0	2.3
	0.9	0.7	0.9	0.9	1.0	1.4	1.3	0.0	0.0	1.1
	3.5	1.1	2.5	1.6	0.4	2.9	1.3	0.0	0.0	3.0
	156.1	107.1	147.6	103.5	47.9	124.7	134.3	0.0	0.0	132.8
18	10.0	9.0	11.0	9.0	11.0	24.0	8.0	0.0	0.0	19.0
	2.6	1.0	1.5	1.1	0.6	1.0	1.7	0.0	0.0	2.4
	1.4	0.7	1.0	0.7	0.7	1.0	1.4	0.0	0.0	0.9
	3.6	1.2	2.1	1.2	0.5	0.3	1.7	0.0	0.0	3.3
	135.3	125.2	140.3	102.5	87.8	38.6	101.1	0.0	0.0	134.1
19	22.0	15.0	15.0	16.0	12.0	8.0	25.0	0.0	0.0	14.0
	1.5	1.0	1.2	0.7	0.9	0.6	1.0	0.0	0.0	1.0
	1.1	0.6	1.0	0.5	0,8	0.7	1.0	0.0	0.0	0.4
	1.4	1.2	0.9	0.6	1.0	0.8	0.2	0.0	0.0	2.0
	91.7	123.2	81.2	91.9	118.1	124.7	20.8	0.0	0.0	200.6
20	0.0	0.0	6.0	0.0	0.0	0.0	0.0	15.0	9.0	8.0
	0.0	0.0	0.7	0.0	0.0	0.0	0.0	1.0	0.6	1.5
	0.0	0.0	0.8	0.0	0.0	0.0	0.0	1.0	0.7	0.8
	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.3	0.8	2.6
	0.0	0.0	137.3	0.0	0.0	0.0	0.0	27.7	124.0	173.8
21	0.0	0.0	6.0	0.0	0.0	0.0	0.0	9.0	23.0	15.0
	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2.4	1.0	2.5
	0.0	0.0	0.9	0.0	0.0	0.0	0.0	1.4	1.0	1.0
	0.0	0.0	0.6	0.0	0.0	0.0	0.0	1.8	0.0	4.1
	0.0	0.0	66.3	0.0	0.0	0.0	0.0	77.6	0.1	168.3
22	16.0	13.0	26.0	23.0	15.0	19.0	14.0	8.0	15.0	60.0
	3.2	1.6	1.8	2.3	0.8	1.1	3.2	3.0	1.5	1.0
	2.4	1.2	1.3	1.5	0.9	1.2	2.3	1.3	1.0	1.0
	3.2	1.6	1.5	2.3	1.0	2.1	3.6	4.2	1.0	0.0
	99.0	101.7	83.0	103.4	132.2	185.4	110.6	139.7	68.3	0.1

Table I. Japan, 1971: fishing power coefficients of individual vessels. (See heading of Table E for explanation of entries in the matrix.)

		Vessel Y														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Vessel X	1	18.0	0.0	0.0	0.0	1.0	5.0	0.0	0.0	2.0	6.0	0.0	0.0	0.0	0.0	9.0
		1.0	0.0	0.0	0.0	0.8	2.4	0.0	0.0	1.1	0.7	0.0	0.0	0.0	0.0	1.8
		1.0	0.0	0.0	0.0	0.8	1.7	0.0	0.0	1.3	0.6	0.0	0.0	0.0	0.0	1.7
		0.0	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.6
		0.0	0.0	0.0	0.0	0.0	118.9	0.0	0.0	40.2	73.3	0.0	0.0	0.0	0.0	34.2
	2	0.0	7.0	0.0	0.0	1.0	1.0	1.0	2.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	1.0	0.0	0.0	2.0	2.3	7.9	3.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	1.0	0.0	0.0	2.0	2.3	7.9	2.7	1.5	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.1	0.0	0.0	0.0	0.0	0.0	52.4	55.8	0.0	0.0	0.0	0.0	0.0	0.0
	3	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.0	3.0	2.0	0.0	4.0
		0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.3	0.4	0.2	0.0	4.6
		0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.3	0.2	0.3	0.0	2.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.8	0.6	0.1	0.0	7.4
		0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	162.3	60.5	144.1	47.7	0.0	160.8
	4	0.0	0.0	0.0	1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	1.0	1.4	1.3	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	1.0	1.4	1.3	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5	1.0	1.0	0.0	1.0	16.0	12.0	0.0	8.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
		1.2	0.5	0.0	0.7	1.0	0.8	0.0	2.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0
		1.2	0.5	0.0	0.7	1.0	0.7	0.0	1.8	0.6	0.3	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	37.1	0.0	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	6	5.0	1.0	0.0	1.0	12.0	16.0	0.0	4.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
		1.2	0.4	0.0	0.8	1.7	1.0	0.0	4.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
		0.6	0.4	0.0	0.8	1.4	1.0	0.0	3.3	0.0	0.5	0.0	0.0	0.0	0.0	0.0
		1.3	0.0	0.0	0.0	1.2	0.0	0.0	2.2	0.0	0.3	0.0	0.0	0.0	0.0	0.0
		108.9	0.0	0.0	0.0	73.3	0.0	0.0	55.9	0.0	60.8	0.0	0.0	0.0	0.0	0.0
	7	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.1	0.0	0.0	0.0	0.0	1.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.1	0.0	0.0	0.0	0.0	1.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.0	2.0	0.0	1.0	8.0	4.0	0.0	11.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.4	0.0	0.5	0.7	0.3	0.0	1.0	0.8	0.2	0.0	0.0	0.0	0.0	0.0
		0.0	0.4	0.0	0.5	0.6	0.3	0.0	1.0	0.8	0.2	0.0	0.0	0.0	0.0	0.0
		0.0	0.2	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	52.4	0.0	0.0	57.9	60.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	9	2.0	4.0	0.0	0.0	1.0	0.0	1.0	1.0	7.0	1.0	0.0	0.0	0.0	0.0	0.0
		1.0	1.0	0.0	0.0	1.8	0.0	3.4	1.3	1.0	0.7	0.0	0.0	0.0	0.0	0.0
		0.8	0.7	0.0	0.0	1.8	0.0	3.4	1.3	1.0	0.7	0.0	0.0	0.0	0.0	0.0
		0.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		40.2	72.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	10	6.0	0.0	5.0	0.0	1.0	3.0	0.0	1.0	1.0	39.0	2.0	26.0	20.0	1.0	2.0
		6.7	0.0	8.1	0.0	3.0	2.2	0.0	4.6	1.4	1.0	2.9	2.1	4.3	0.8	5.9
		1.7	0.0	2.1	0.0	3.0	2.0	0.0	4.5	1.4	1.0	2.0	1.4	2.4	0.8	2.2
		12.3	0.0	10.4	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2.9	1.7	3.8	0.0	7.2
		184.9	0.0	128.1	0.0	0.0	45.1	0.0	0.0	0.0	0.1	101.4	81.0	88.5	0.0	122.7
	11	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	5.0	0.0	0.0	1.0	0.0
		0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	0.0	0.0	1.0	0.0
		0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	0.0	0.0	1.0	0.0
		0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	81.5	0.0	0.0	0.0	0.0	0.0	0.0	101.4	0.1	0.0	0.0	0.0	0.0
	12	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	26.0	0.0	38.0	28.0	0.0	8.0
		0.0	0.0	10.4	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	1.0	4.0	0.0	2.8
		0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.0	2.1	0.0	2.8
		0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	7.7	0.0	2.1
		0.0	0.0	80.2	0.0	0.0	0.0	0.0	0.0	0.0	106.8	0.0	0.0	193.3	0.0	73.4
	13	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	28.0	31.0	0.0	5.0
		0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.2	1.0	0.0	3.4
		0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.5	1.0	0.0	0.7
		0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.3	0.0	0.0	6.1
		0.0	0.0	47.7	0.0	0.0	0.0	0.0	0.0	0.0	91.5	0.0	107.6	0.1	0.0	179.4
	14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.0	0.0	0.0	1.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.0	0.0	0.0	1.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	15	9.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	8.0	5.0	0.0	18.0
		0.6	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.6	1.3	0.0	1.0
		0.6	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.4	1.4	0.0	1.0
		0.2	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.4	0.8	0.0	0.0
		34.5	0.0	98.0	0.0	0.0	0.0	0.0	0.0	0.0	122.7	0.0	65.4	63.2	0.0	0.0

Table J. Japan, 1972: fishing power coefficients of individual vessels. (See heading Table E for explanation of entries in the matrix.)

	Vessel Y											
Vessel X	16	17	18	19	20	21	22	23	24	25	26	27
16	8.0	0.0	0.0	0.0	0.0	2.0	5.0	3.0	7.0	0.0	1.0	1.0
	1.0	0.0	0.0	0.0	0.0	0.6	1.1	4.0	1.1	0.0	1.3	0.8
	1.0	0.0	0.0	0.0	0.0	0.6	1.1	2.2	1.0	0.0	1.3	0.0
	0.0	0.0	0.0	0.0	0.0	0.1	0.5	4.3	0.4	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	17.5	39.6	107.9	41.1	0.0	0.0	0.0
17	0.0	14.0	7.0	0.0	1.0	8.0	6.0	4.0	0.0	1.0	0.0	7.0
	0.0	1.0	8.2	0.0	0.3	5.5	3.6	4.8	0.0	0.3	0.0	3.7
	0.0	1.0	2.4	0.0	0.3	1.4	0.2	0.9	0.0	0.3	0.0	1.4
	0.0	0.0	8.1	0.0	0.0	6.6	3.3	3.6	0.0	0.0	0.0	3.6
	0.0	0.1	99.6	0.0	0.0	120.3	90.5	74.5	0.0	0.0	0.0	97.7
18	0.0	7.0	28.0	6.0	2.0	6.0	19.0	7.0	0.0	4.0	1.0	9.0
	0.0	0.5	1.0	5.8	3.2	1.0	0.8	0.3	0.0	1.1	1.5	0.8
	0.0	0.4	1.0	2.5	2.8	1.4	0.3	0.3	0.0	0.9	1.5	0.8
	0.0	0.6	0.0	11.2	1.1	0.5	0.6	0.2	0.0	0.5	0.0	0.7
	0.0	116.5	0.2	193.9	35.7	53.3	79.1	60.5	0.0	47.2	0.0	90.2
19	0.0	0.0	6.0	14.0	2.0	1.0	7.0	0.0	0.0	2.0	5.0	9.0
	0.0	0.0	0.8	1.0	3.3	0.1	0.8	0.0	0.0	0.4	1.4	0.8
	0.0	0.0	0.4	1.0	2.0	0.1	0.7	0.0	0.0	0.4	1.3	0.4
	0.0	0.0	0.5	0.0	3.5	0.0	0.2	0.0	0.0	0.2	0.3	0.6
	0.0	0.0	64.8	0.1	104.3	0.0	32.4	0.0	0.0	54.7	25.6	78.1
20	0.0	1.0	2.0	2.0	10.0	3.0	3.0	2.0	0.0	7.0	0.0	2.0
	0.0	3.5	0.3	0.7	1.0	2.2	0.6	0.2	0.0	0.9	0.0	0.3
	0.0	3.5	0.4	0.5	1.0	0.8	0.4	0.2	0.0	0.9	0.0	0.3
	0.0	0.0	0.1	0.7	0.0	3.1	0.6	0.1	0.0	3.0	0.0	0.3
	0.0	0.0	35.7	104.3	0.1	143.4	107.1	41.0	0.0	31.8	0.0	95.0
21	2.0	8.0	6.0	1.0	3.0	37.0	12.0	13.0	13.0	3.0	0.0	14.0
	1.7	0.6	1.3	15.6	1.8	1.0	1.6	1.1	2.2	1.9	0.0	1.4
	1.8	0.7	0.7	15.6	1.2	1.0	1.5	0.8	2.1	1.3	0.0	1.1
	0.3	0.9	0.6	0.0	1.5	0.0	0.9	0.9	1.1	1.7	0.0	1.0
	17.5	141.1	48.9	0.0	78.8	0.1	58.4	80.3	50.1	89.4	0.0	68.1
22	5.0	6.0	19.0	7.0	3.0	12.0	40.0	10.0	10.0	2.0	1.0	12.0
	1.0	9.7	4.1	1.5	3.6	0.8	1.0	1.1	1.3	1.6	2.7	1.2
	0.9	6.4	3.8	1.4	2.6	0.7	1.0	0.9	1.1	1.5	2.7	5.2
	0.4	22.0	9.5	0.5	3.1	0.3	0.0	0.8	0.6	0.9	0.0	1.0
	38.8	227.0	230.0	34.2	84.5	33.9	0.1	73.5	43.9	61.0	0.0	78.3
23	3.0	4.0	7.0	0.0	2.0	13.0	10.0	45.0	2.0	2.0	1.0	29.0
	0.5	0.9	2.7	0.0	6.1	1.3	1.0	1.0	0.7	5.8	0.1	1.3
	0.4	1.1	3.0	0.0	5.6	1.2	1.1	1.0	0.6	5.7	0.1	1.2
	0.4	1.4	1.6	0.0	2.5	0.8	0.7	0.1	0.3	0.6	0.0	0.6
	72.3	161.3	61.7	0.0	41.0	58.6	68.5	15.2	42.0	10.6	0.0	49.2
24	7.0	0.0	0.0	0.0	0.0	13.0	10.0	2.0	22.0	0.0	0.0	6.0
	1.1	0.0	0.0	0.0	0.0	0.5	0.9	1.7	1.0	0.0	0.0	0.9
	1.0	0.0	0.0	0.0	0.0	0.5	0.9	1.6	1.0	0.0	0.0	0.8
	0.4	0.0	0.0	0.0	0.0	0.2	0.2	0.7	0.0	0.0	0.0	0.3
	38.4	0.0	0.0	0.0	0.0	38.8	25.4	42.0	0.0	0.0	0.0	36.8
25	0.0	1.0	4.0	2.0	7.0	3.0	2.0	2.0	0.0	12.0	0.0	3.0
	0.0	2.9	1.2	3.0	1.2	1.9	0.8	0.2	0.0	1.0	0.0	1.8
	0.0	2.9	1.1	2.8	1.1	0.7	0.7	0.2	0.0	1.0	0.0	1.5
	0.0	0.0	0.8	1.7	0.3	2.5	0.5	0.0	0.0	0.0	0.0	0.9
	0.0	0.0	66.1	54.7	25.8	136.7	61.0	10.6	0.0	0.1	0.0	47.5
26	1.0	0.0	1.0	5.0	0.0	0.0	1.0	1.0	0.0	0.0	7.0	3.0
	0.8	0.0	0.7	0.8	0.0	0.0	0.4	6.8	0.0	0.0	1.0	1.1
	0.8	0.0	0.7	0.8	0.0	0.0	0.4	6.8	0.0	0.0	1.0	1.1
	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	0.0	0.0	0.0	27.7	0.0	0.0	0.0	0.0	0.0	0.0	0.1	39.1
27	1.0	7.0	9.0	9.0	2.0	14.0	12.0	29.0	6.0	3.0	3.0	58.0
	1.3	0.6	1.6	5.1	5.9	1.0	1.0	1.0	1.3	0.7	1.1	1.0
	1.3	0.7	1.2	2.3	3.7	0.9	0.2	0.8	1.3	0.7	0.9	1.0
	0.0	0.8	1.1	10.9	5.6	0.6	0.8	0.4	0.5	0.4	0.5	0.1
	0.0	135.1	69.0	215.8	95.0	58.8	72.9	40.8	38.8	58.8	48.2	13.4

The Effect of Random Fluctuations on a Hypothetical Fishery[1]

by

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ABSTRACT

The Schaefer (1954) stock-production model was stochastically simulated numerous times for several combinations of the ratio of maximum equilibrium catch (CE_{max}) to maximum population size, the ratio of initial population size to maximum population size, the variance of deviations from the model, the autocorrelation of the deviations and the rate of fishing mortality. The results indicate that the long-term average catch is likely to be below CE_{max} for realistic values of the variance of the deviations from the model. The probability of a population declining to extremely low levels increases as the autocorrelation of the deviations increase. The variability of the catch decreases when fishing mortality declines below the rate that would produce the maximum equilibrium catch for the deterministic version of the Schaefer model.

INTRODUCTION

Most fisheries' models do not explicitly incorporate random variations in population parameters resulting from fluctuations of the environment. Researchers generally assume that the time-span over which data were collected to estimate model parameters is long enough so that these estimates are adequate for representing the fishery at average environmental conditions. If the fishery is conducted so as to maintain fishing mortality at the level corresponding to the maximum equilibrium catch (CE_{max}), it is usually assumed that the long-term average catch will be about CE_{max}. The validity of this assumption is the topic considered here.

Doubleday (1976) also considered the role of random fluctuations in fisheries management using a similar approach. The research reported in this paper was conducted in ignorance of Doubleday's work (which was in press). There are several differences between the two studies which are discussed later.

METHODS

The following equation is assumed to describe the population dynamics of an exploited species:

$$\frac{dP}{dt} = P\tilde{A}(a-bB) - FP \qquad (1)$$

where P is a measure of population size, F is the instantaneous fishing mortality rate, a and b are species specific model parameters, and $\tilde{A}$ is a random variable (assuming a constant value during each time interval) with an expected value of 1. Equation (1) is identical to the Schaefer (1954) model for $\tilde{A} = 1$, where CE is the catch that results in $dP/dt = 0$ and CE_{max} and P_{max} are the maximum levels of CE and P. For the Schaefer model, CE_{max} occurs when P is half its maximum level (P_{MSY}) and F_{MSY} is the fishing mortality rate that will maintain the population at this level. These terms describing the hypothetical fishery are related in the following manner:

$$a = 4(CE_{max})/P_{max} \qquad (2)$$

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[1] Submitted to the 1976 Annual Meeting as Res.Doc. 76/VI/34.

$$b = a/P_{max} \tag{3}$$

$$P_{MSY} = P_{max}/2 \tag{4}$$

$$F_{MSY} = a/2 \tag{5}$$

If F is constant over an interval of time (from i to i+1), then

$$P_{i+1} = \frac{\alpha}{\beta}\left(1 + e^{-\alpha}\left(\frac{\alpha/\beta - P_i}{P_i}\right)\right)^{-1} \tag{6}$$

$$C \approx F(P_{i+1} + P_i)/2 \tag{7}$$

where $\alpha = a \cdot \tilde{A} - F$, $\beta = bA$, and C is catch during the interval. The length of the interval can be reduced until equation (7) reaches an acceptable level of accuracy.

The random variable $\tilde{A}$ may be assumed to represent a biotic response to the fluctuation of an environmental factor, $\tilde{W}$. According to Ricker (1958, p. 232), the relationship between $\tilde{A}$ and $\tilde{W}$ should be multiplicative, since for a specific environmental anomaly each individual in the population (not a fixed number) may be affected. This being the case, the relationship between $\log_e \tilde{A}$ and $\tilde{W}$ should be additive (or linear). It is reasonable to assume that $\tilde{W}$ is normally distributed, particularly if it is the average state of an environmental factor over some time (for example, annual average temperature or annual average wind velocity). Therefore, it is appropriate to assume that $\tilde{A}$ is log-normally distributed with mean 1. The range of the log-normal distribution is from 0 to ∞, which is the logical range of $\tilde{A}$.

Let $\tilde{X} = \log_e \tilde{A}$ (a linear function of $\tilde{W}$) be normally distributed with mean μ and variance σ^2, that is $\tilde{X}$ is $N(\mu,\sigma^2)$. If $\tilde{X}$ is autocorrelated then

$$\tilde{X}_{i+1} \sim N[\mu + \rho(\tilde{X} - \mu),\ \sigma^2(1 - \rho^2)] \tag{8}$$

where ρ is the first order autocorrelation coefficient of $\tilde{X}$ (correlation between $\tilde{X}_{i+1}$ and $\tilde{X}_i$ where the subscript refers to time). Equation (8) is based on the conditional probability density function of a bivariate normal distribution (Hogg and Craig, 1970). The mean and variance of $\tilde{A}$ [$E(\tilde{A})$ and $V(\tilde{A})$] where $\rho = 0$ or where the previous value of A is unknown (Brownlee, 1965) are as follows:

$$E(\tilde{A}) = e^{\mu+\sigma^2/2} \tag{9}$$

$$V(\tilde{A}) = e^{2\mu+\sigma^2}(e^{\sigma^2} - 1). \tag{10}$$

Since $E(\tilde{A}) = 1$, then $\mu = -\sigma^2/2$ and $V(\tilde{A}) = e^{\sigma^2} - 1$. Therefore it is possible to generate an autocorrelated log-normal random variable with mean 1 for use in simulating a fishery described by equation (1) by the following transformation:

$$\tilde{A}_{i+1} = \exp[\tilde{Z}_{i+1}(\sigma\sqrt{(1 - \rho^2)} - \sigma^2/2 + \rho^2(\tilde{X}_i + \sigma^2/2)] \tag{11}$$

where $\tilde{Z}_{i+1}$ is the standard normally distributed [N(0,1)] random variable used to calculate $\tilde{A}$ for time period i+1 and $\tilde{X}_i$ is the natural log of $\tilde{A}$ from the previous time period.

Pseudo-standard normal random numbers can be generated by a computer algorithm described by IBM (1970). It is possible to generate random numbers because of the modular arithmetic used by digital computers. If m is the largest positive integer number that can be accommodated by a single computer register, then the product of any multiplication exceeding m results in some residual being stored in another register. For certain multipliers the residuals have the property of uniform random numbers. The average of several of these converges to a normal distribution.

Using computer-generated random numbers and equations (6), (7) and (11), a hypothetical fishery described by equation (1) was simulated. Since each simulation was stochastic in nature, it was repeated (with different random numbers) numerous times to estimate the probability of particular outcomes. Several values of the ratio of CE_{max} to P_{max} (R), σ^2, ρ, F and the initial condition of P relative to P_{max} (P_o) were considered (Table 1). Note that the shape of dP/dt as a function of P is uniquely determined by R and that μ is determined by σ^2. The probability of $\tilde{A} \geq 2$ for each value of σ^2 is also given. For

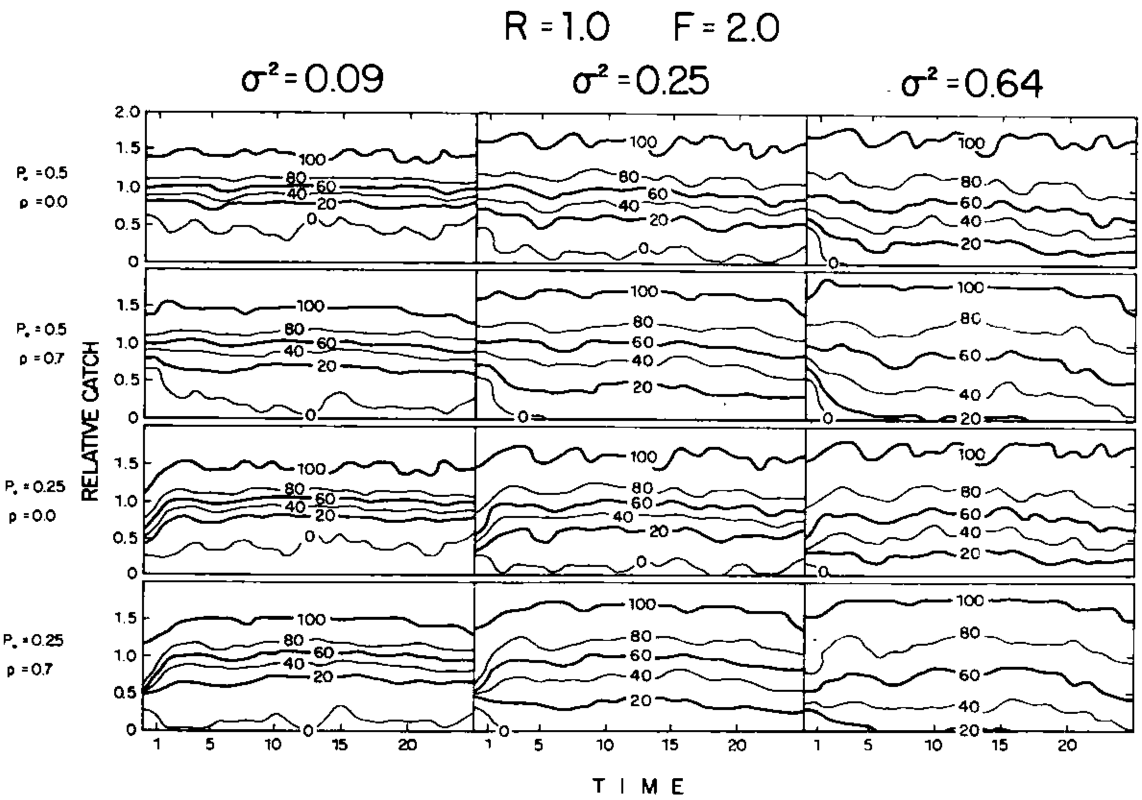

Fig. 1. Simulated catch isopleths, where the percentage of observations below each curve is indicated.

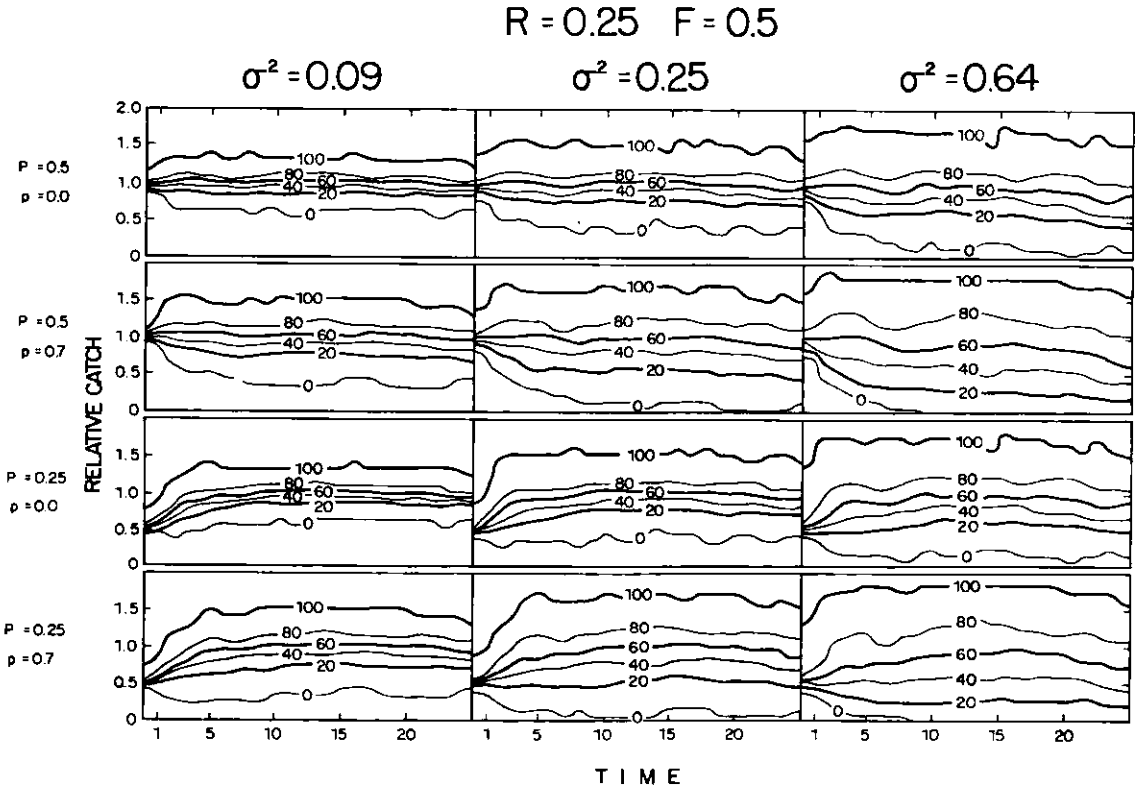

Fig. 2. Simulated catch isopleths, where the percentage of observations below each curve is indicated.

each combination of R, σ^2, ρ, F and P_o, equation (1) was simulated 100 times for 25 time intervals (years, for example). In order to calculate $\tilde{A}$ for the first interval simulated, a seed value of $\tilde{X}$ ($\tilde{X}_o$) was needed for use in equation (11). $\tilde{X}_o = \log_e \tilde{A}_o$ was selected randomly for $P_o = 0.50$. When $P_o = 0.25$, X_o was determined by solving equation (1) where $dP/dt = 0$ for $F = F_{MSY}$. This implies that the stock had declined as a result of unfavourable environmental factors and that for $\rho > 0$, conditions will tend to remain unfavourable at the onset of the simulations. Clearly, for $\tilde{A} = 1$ ($\sigma^2 = 0$) catch converges to CE_{max} for any value of P_o (between 0 and P_{max}) when $F = F_{MSY}$. The results of these simulations were intended to demonstrate the likelihood of this outcome when $\tilde{A}$ is a random variable.

Table 1. Values of R, σ^2, ρ, F and P_o used to simulate a fishery described by equation (1). The probability of $\tilde{A} \geq 2$ is also given for each value of σ^2.

R	P_o	ρ	F	σ^2	Prob(A≥2)
1.00	0.50	0.0	2.0[a]	0.09	0.005
	0.25	0.7		0.25	0.05
				0.64	0.10
0.25	0.50	0.0	0.6	0.09	0.005
	0.25	0.7	0.5[a]	0.25	0.05
			0.4	0.64	0.10
			0.3		

[a] F_{MSY}

RESULTS AND DISCUSSION

The catch relative to CE_{max} (C_r) during each time interval was used to construct catch frequency isopleths for all 24 combinations of R, P_o, ρ and σ^2 when $F = F_{MSY}$ (Fig. 1 and 2). The isopleths indicate the proportion of the time that C_r is below a particular line. For the Schaefer model (where $\tilde{A} = 1.0$) all isopleths converge to a straight line at $C_r = 1.0$. The catch frequency isopleths of each figure are for a single value of R. The sensitivity of the results to σ^2 is indicated by comparing within columns and the sensitivity to ρ is indicated by comparing within rows.

C_r is more variable for R = 1.0 than for R = 0.25. This is more obvious for $\sigma^2 = 0.09$ than for larger values of σ^2. For larger values of σ^2, it is clear that the probability of complete collapse of the fishery is higher for R = 1.0 than for R = 0.25.

There does not seem to be any long-term effect of a low initial value of P_o (0.25 *vs* 0.50 = P_{MSY}). Note that the fishery recovers to $C_r = 1.0$ at times 3 and 7 for R = 1.0 and 0.25, respectively, when $\sigma^2 = 0.0$ ($\tilde{A} = 1$), $P_o = 0.25$ and $F = F_{MSY}$.

There is little question that the outlook is for lower values of C_r as σ^2 increases. This is most clear for R = 1.0, $P_o = 0.5$ and $\rho = 0.0$. For autocorrelated random variations ($\rho \neq 0.0$), C_r appears more likely to reach extreme levels (high and particularly low). The 20% isopleth of C_r is considerably higher for $\sigma^2 = 0.64$, R = 1.0 and $\rho = 0.0$ than for $\sigma^2 = 0.64$, R = 1.0 and $\rho = 0.7$.

The simulated catch frequency (summed over 25 time intervals) is plotted for R = 0.25, $P_o = 0.50$ and several values of F in Fig. 3 to 6 ($F_{MSY} = 0.5$). As F decreases, the catch frequency curves become more peaked indicating a smaller variance of C_r. The mean of C_r should approach 1 as σ^2 becomes small for F = 0.5 and the mean of C_r should be smaller than 1 for $F \neq F_{MSY}$. This appears to be the case for $\sigma^2 = 0.09$ and $\rho = 0.0$. For higher values of σ^2, it is difficult to judge the ranking of the means of C_r for each value of F. It appears that the variance of C_r is higher for $\rho = 0.7$ than for $\rho = 0.0$ when all other parameters are the same.

The mean and standard deviation of C_r was calculated (Table 2) for each combination of R, P_o, σ^2, F, and ρ for all years after the recovery period for the deterministic model (from $P_o = 0.25$ if $\tilde{A} = 1$). These statistics of C_r confirm the discussion above. The mean and standard deviation of C_r decrease as σ^2 and R increase. The mean of C_r decreases as P_o decreases and as ρ increases but these differences are minor. The standard

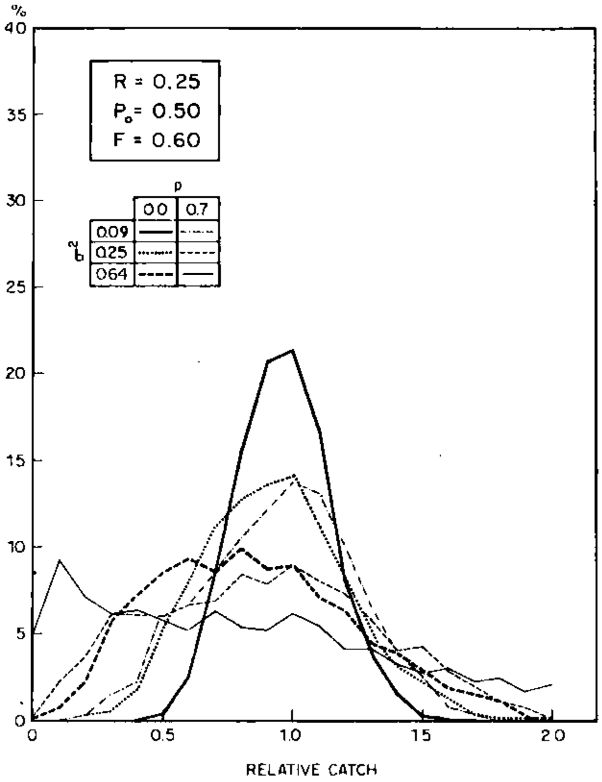

Fig. 3. Simulated catch frequency summed over 25 time intervals.

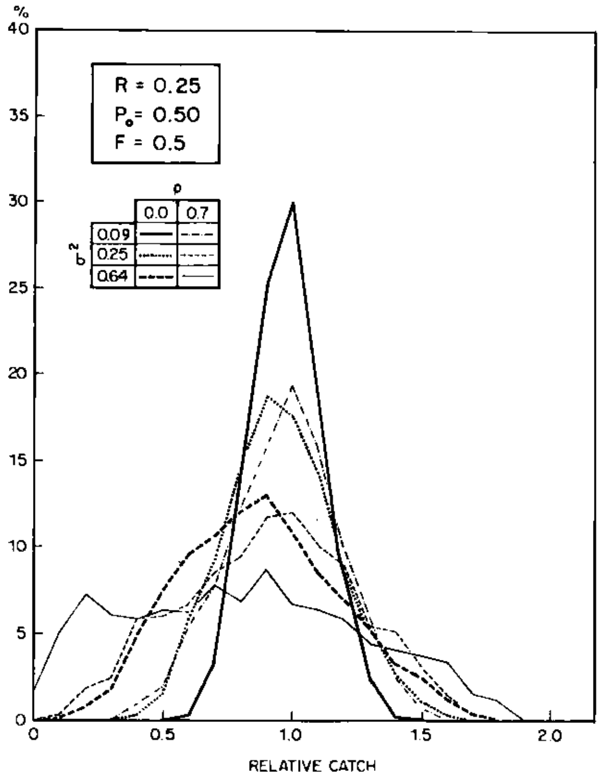

Fig. 4. Simulated catch frequency summed over 25 time intervals.

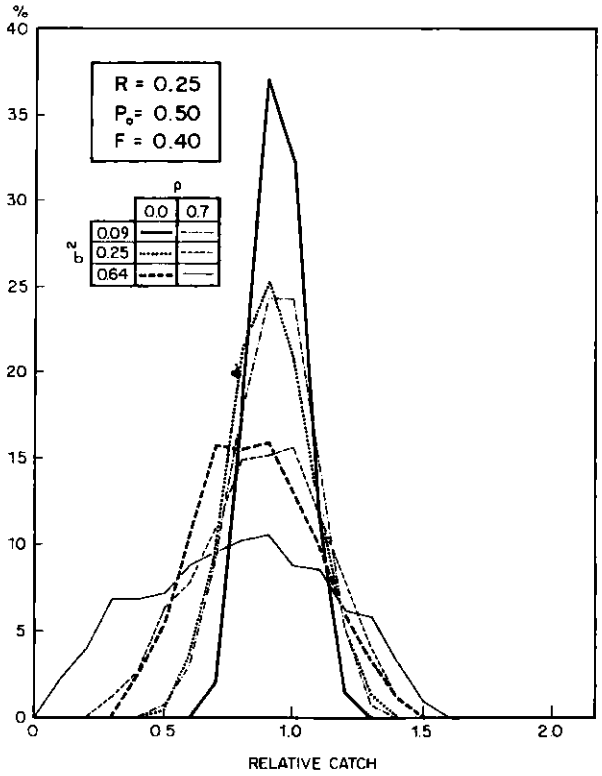

Fig. 5. Simulated catch frequency summed over 25 time intervals.

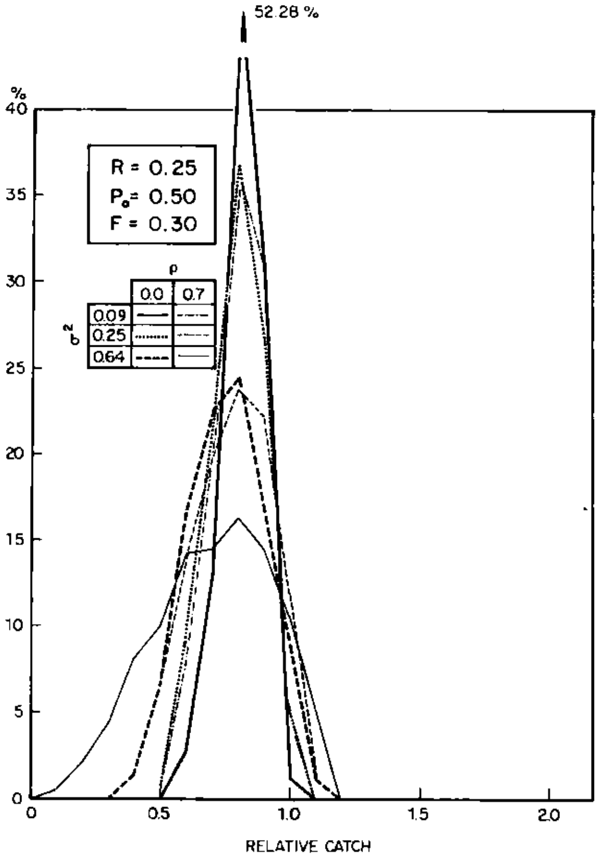

Fig. 6. Simulated catch frequency summed over 25 time intervals.

Table 2. Mean value and standard deviation (in parentheses) of relative catch (C_r) after the period required to recover to F_{MSY} (when $\tilde{\lambda} = 1.0$) from $P_o = 0.25$.

R	F	ρ	P_0	$\sigma^2 = 0.09$	$\sigma^2 = 0.25$	$\sigma^2 = 0.64$
1.0	2.0	0.0	0.50	0.95 (0.20)	0.88 (0.31)	0.73 (0.43)
			0.25	0.95 (0.20)	0.87 (0.32)	0.72 (0.44)
		0.7	0.50	0.94 (0.27)	0.84 (0.43)	0.68 (0.55)
			0.25	0.92 (0.28)	0.81 (0.43)	0.64 (0.55)
0.25	0.6	0.0	0.50	0.97 (0.18)	0.93 (0.27)	0.86 (0.39)
			0.25	0.93 (0.18)	0.90 (0.28)	0.81 (0.40)
		0.7	0.50	0.95 (0.29)	0.89 (0.42)	0.79 (0.55)
			0.25	0.90 (0.30)	0.82 (0.45)	0.69 (0.57)
	0.5	0.0	0.50	0.98 (0.13)	0.96 (0.21)	0.88 (0.31)
			0.25	0.98 (0.13)	0.94 (0.22)	0.86 (0.32)
		0.7	0.50	0.97 (0.21)	0.91 (0.33)	0.80 (0.45)
			0.25	0.95 (0.23)	0.87 (0.36)	0.74 (0.48)
	0.4	0.0	0.50	0.94 (0.09)	0.91 (0.15)	0.86 (0.22)
			0.25	0.94 (0.09)	0.91 (0.15)	0.85 (0.23)
		0.7	0.50	0.92 (0.15)	0.88 (0.24)	0.79 (0.34)
			0.25	0.92 (0.16)	0.86 (0.26)	0.75 (0.37)
	0.3	0.0	0.50	0.82 (0.07)	0.80 (0.10)	0.76 (0.18)
			0.25	0.83 (0.06)	0.81 (0.09)	0.77 (0.15)
		0.7	0.50	0.81 (0.10)	0.78 (0.15)	0.71 (0.23)
			0.25	0.82 (0.09)	0.78 (0.16)	0.69 (0.25)

deviation of C_r increases as F increases and for autocorrelated random fluctuations ($\rho = 0.7$). The mean of C_r decreases with departures of F from F_{MSY}, but the decrease is minor for $F = 0.4$ (20% below F_{MSY}).

Now that the responses of equation (1) to specific values of R, P_o, σ^2, and ρ have been discussed, it is important to consider the likelihood of these values being applicable to fisheries of interest. Since $P_{MSY} = P_{max}/2$ [equation (4)], then $CE_{max} = F_{MSY}P_{max}/2$ (Gulland, 1971) which implies that $R = F_{MSY}/2$. For $R = 1.0$, F_{MSY} would be 2.0 which could only occur for species having a very high production to standing crop ratio. For $R = 0.25$, F_{MSY} would be 0.5 which may be realistic for many species in the Northwest Atlantic.

The autocorrelation of the environmental factor influencing $\tilde{\lambda}$ is ρ. The effect of temperature on fisheries has been discussed by numerous authors (ICNAF, 1965). The autocorrelation of the annual average surface water temperature at Boothbay Harbor, Maine, is 0.70 for the period 1905-75. Therefore, ρ as large as 0.7 seems realistic.

The variances of $\log_e \tilde{\lambda}$ considered in this work imply a 0.5, 5 and 10% probability of $\tilde{\lambda} \geq 2$. Sissenwine (1974) estimated the annual equilibrium catch (CE) of the Southern New England yellowtail flounder fishery for 1944-65. For these 22 years, CE was more than double its mean (for the period) on two occasions or about 9% of the time. Curves representing the relationship between CE and P and between recruitment and spawning stock have been fitted for several populations. Table 3 gives the number of data points below and above each curve and the percentage of points at least double their expected value for several populations. This summary indicates that $\sigma^2 = 0.25$ (5% probability of $\tilde{\lambda} \geq 2$) is probably commonplace and that $\sigma^2 = 0.64$ (10% probability of $\tilde{\lambda} \geq 2$) may occur. Table 3 also indicates that the distribution of $\tilde{\lambda}$ is likely to be asymmetric as was assumed in this study. In only 3 of 18 cases were there as many deviations above the curve as below.

Thus, any combination of R, P_o, σ^2 and ρ considered here could occur, although $R = 1.0$ is unlikely for commercially exploited species in the Northwest Atlantic. This study indicates that the longer-term average catch at F_{MSY} may be well below CE_{max} even for a fishery perfectly described by equation (1) with the parameters known. As σ^2 increases, the average catch declines; and as ρ increases, the probability of the population declining to extremely low levels increases. One explanation of this result is that the population declines below P_{MSY} more rapidly when $\tilde{\lambda} < 1$ than it grows above P_{MSY} when $\tilde{\lambda} > 1$. When

$\lambda > 1$, F_{MSY} is too low, but as P increases dP/dt decreases, thus slowing population growth. But when $\lambda < 1$, F_{MSY} is too high, and P decreases which in turn decreases dP/dt thus speeding the decline. When $\rho > 0$, the probability of the population growing or declining over several consecutive time intervals is increased; thus extremely high or low levels of catch become more likely.

Table 3. The number of data points above and below curves representing stock-production or stock-recruitment relationships. The percentage of points at least double the expected value (according to the curves) is also given.

Stock	Type of curve	Above	Below	Double
Pacific halibut[a]	stock-production	16	32	4%
Antarctic blue whale[b]	"	8	13	5%
Atlantic herring (Buchen)	stock-recruitment[c]	10	14	8%
Atlantic herring (Oogger)	"	11	18	10%
Pacific herring (Kodiak I.)	"	5	6	9%
Pacific herring (Sakhalin)	"	17	26	16%
Pacific herring (B. Columbia)	"	10	14	13%
Pacific herring (B. Columbia, lower east)	"	13	10	4%
Halibut area 2	"	12	21	3%
Halibut area 3	"	14	15	0%
Petrale sole	"	12	8	15%
Plaice	"	11	13	8%
Arctic cod	"	9	12	0%
St. Lawrence cod	"	3	7	0%
North Sea haddock	"	9	7	6%
Georges Bank haddock	"	11	20	10%

[a] Based on figure 13.2A from Ricker (1975).
[b] Based on figure 8B from Gulland (1972).
[c] All stock-recruitment curves based on figures 42-47 from Cushing (1973).

Conclusions drawn from the simulations discussed in this paper are in general agreement with those reached by Doubleday (1976). There are several noteworthy differences in the methods used in these studies including those considered in the following comments.

1. Doubleday considered a discreet version of the Schaefer model, while equation (1) is a continuous differential equation.

2. Doubleday assumed that the relationship between random fluctuations of the environment and production of a fishery is additive, while a multiplicative relationship is assumed here. Justification for the latter was given earlier in the paper.

3. Doubleday does not consider autocorrelated random fluctuations.

4. For each combination of parameters, Doubleday runs a single simulation for 100 to 1,000 time intervals while the results of this paper are based on 100 runs of 25 time intervals. From a single long run, it is difficult to judge variability since the catch in each year depends on previous years. Consider the following extreme example. If a simulated stock becomes extinct at the beginning of a run the mean catch during the run is very low. But perhaps extinction is a rare event. If the simulation were rerun many times, the mean catch for all runs would certainly be high since the simulated stock would be unlikely to decline to extinction in these additional runs.

5. Doubleday considers fishing schemes of constant catch and constant fishing mortality while only the latter was considered in this paper. The constant catch strategy is difficult to simulate with the continuous differential equation formulation of the model.

The similarity of the results of two independent studies which differ with respect to several important features is reassuring. Both studies indicate that it is prudent to fish somewhat below F_{MSY}, since only a small reduction in the long-term average yield is likely to result, while the variability of the catch and the probability of fishing the stock to economic extinction is substantially reduced.

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Monitoring Effects of Gulf Stream Meanders and Warm Core Eddies on the Continental Shelf and Slope[1]

by

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ABSTRACT

Because Gulf Stream meanders and eddies are a major source of environmental variability in the slope water region adjacent to the continental shelf of New England and the Middle Atlantic states, the National Marine Fisheries Service has started a program to monitor the effects of these oceanographic phenomena on the fishing grounds. Briefly described in this report are: (1) the kinds of effects that meanders and eddies have on the fishing grounds (direct warming of the bottom on the outer shelf and upper slope, injection of warm water onto the shelf, entrainment of water off the shelf, and increases in currents); (2) the uses and limitations of infrared satellite imagery and shipboard observations for the monitoring; (3) efforts to monitor an unusually large eddy and associated meander in March and April 1976 (involving interpretations of satellite imagery by the US Naval Oceanographic Office and the NOAA National Environmental Satellite Service, and the oceanographic observations from research vessels *Ernst Haeckel*, *Wieczno*, *Belogorsk*, and *Albatross IV*); (4) the formation, movements, persistence, and other characteristics of warm core eddies; and (5) possible influences on the fishery resources of the environmental effects of meanders and eddies.

INTRODUCTION

The National Marine Fisheries Service has started a program to monitor the effects of large Gulf Stream eddies ("rings") and meanders on environmental conditions on the fishing grounds off New England and the Middle Atlantic states (ICNAF Subarea 5 and Statistical Area 6). Specifically, the monitoring is directed to meanders on the left (shoreward) side of the stream and to the warm core eddies that sometimes form from these meanders. Although meanders and eddies occur on both sides of the stream, it is only those on the left that sometimes move into the proximity of the fishing grounds of the continental shelf and slope.

These oceanographic features are of interest because they apparently cause the strongest subsurface currents and nonseasonal (aperiodic) variations in water mass properties found in the slope water region adjacent to the outer continental shelf. Although both meanders and eddies are of common occurrence in this region (about 6 warm core eddies per year during 1974 and 1975 (Bisagni, 1976), they characteristically remain in deep water, with apparently little direct effect on environmental conditions in the waters of the continental shelf and slope (Fig. 1). The infrequent meander or eddy, however, which moves close along the continental slope, can have considerable effect on these waters (Iselin, 1939; Chamberlin, 1976) (Fig. 6 and 7). Furthermore, large eddies that remain in deep water can apparently have significant effects by offshore entrainment of shelf water.

Monitoring Program Components

There are two principal components of the monitoring program: (1) utilizing interpretations of infrared-radiometer imagery from NOAA satellites to observe the locations, movements, sizes and other characteristics of meanders and eddies as they appear at the sea surface, and (2) obtaining direct observations in these features from vessel cruises. Interpretations of the satellite imagery and copies of some of the imagery itself are

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[1] Submitted to the 1976 Annual Meeting as Res.Doc. 76/VI/86.

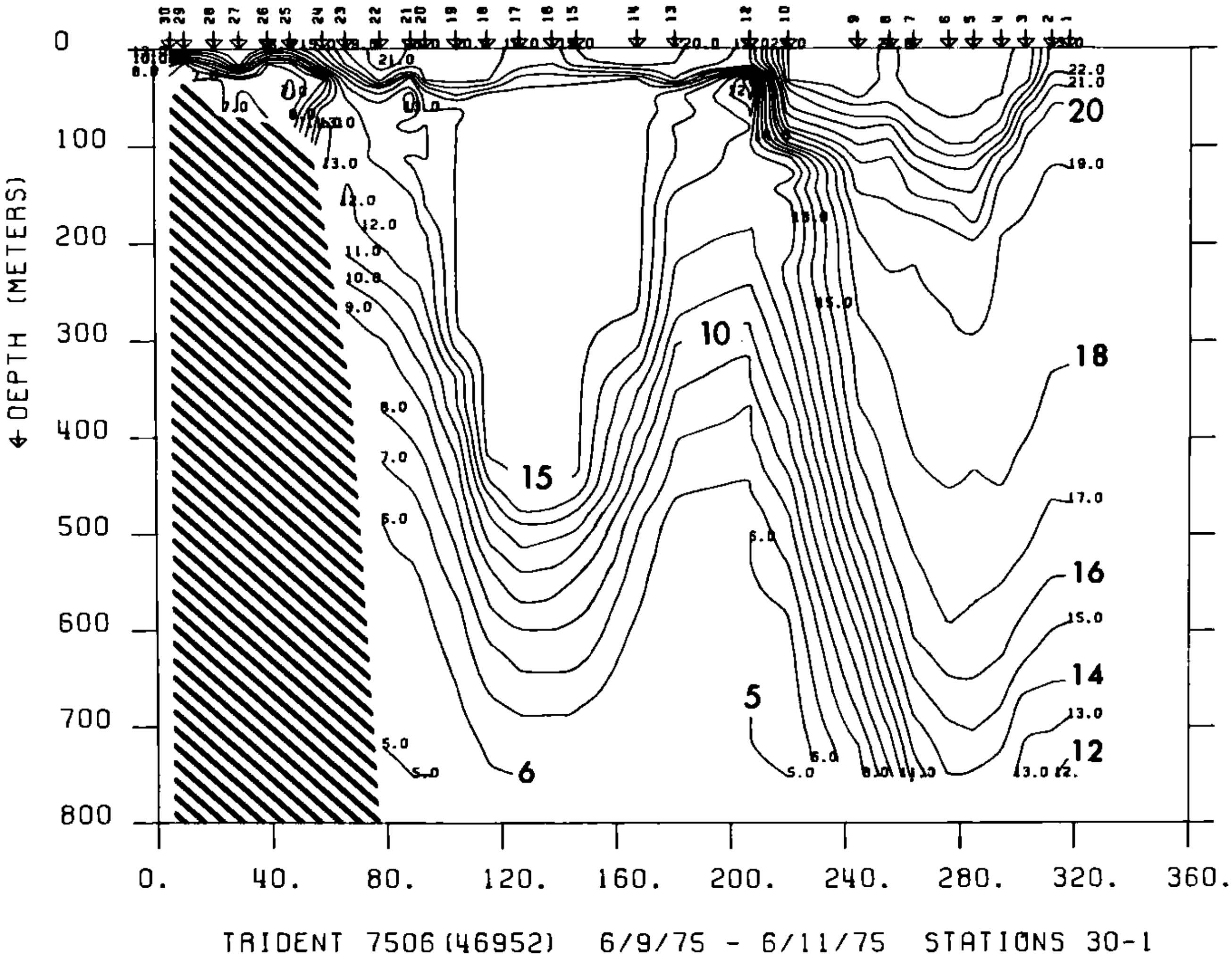


Fig. 1. Vertical temperature section illustrating a large warm core eddy in the slope water region south of New England. This eddy is apparently having little direct effect on continental slope bottom temperatures.

obtained through the cooperation of oceanographers of the US Naval Oceanographic Office and the NOAA National Environmental Satellite Service (see acknowledgements for specific sources). Because the meanders and eddies change position slowly, usually no more than a few miles per day, the weekly interpretations produced are usually a satisfactory basis for the surface monitoring, despite the fact that cloudy weather obscurs the satellite imagery a majority of the time.

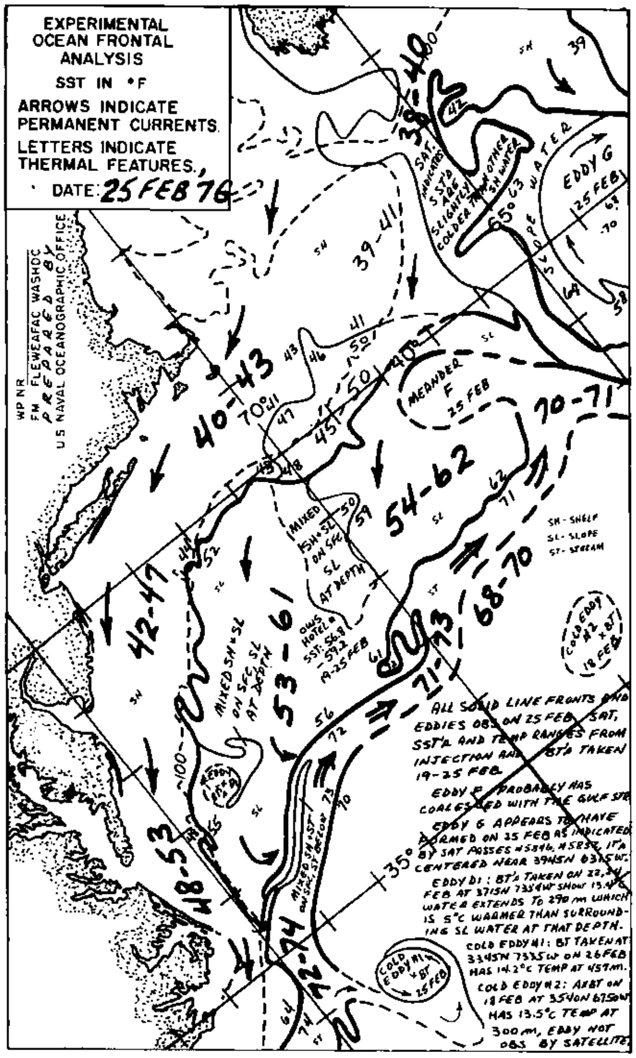
Shipboard observations are needed intermittently rather than on such a regular schedule as that of the satellite interpretations. These observations become essential only when satellite imagery indicates that a particular eddy or meander is having, or soon will have, a significant effect on the fishing grounds. Because satellites reveal only the sea-surface temperature expression of meanders and eddies, the depths and boundary slopes of these features can be reliably determined only from shipboard observations, and to some degree by instrument drops from low-flying aircraft.

Satellites often give an inaccurate measure of both the size and location of meanders and eddies when these features are overridden at the surface by surrounding waters, or chilled at the surface by cold winds. Eddies sometimes seem to entirely disappear in the satellite imagery, for days and perhaps weeks, and then often reappear many miles from where last seen. Following prolonged periods of cloudy weather, the relocation of an eddy may be difficult. A large shallow patch of Gulf Stream water that has overridden the slope water, can be mistaken for an eddy, especially if the patch is fairly round or oval.

Adequate measurement of the effects of meanders and eddies on the fishing grounds is probably feasible at present only with combined observations from ships and satellites. Shipboard observations are paramount for revealing such effects as upwelling adjacent to meanders or eddies, subsurface injection of warm Gulf Stream or eddy water onto the shelf, and subsurface entrainment of shelf water off the shelf. Combined observations should be particularly advantageous for measuring the volume of surface entrainment of shelf water. The areal extent of entrainment can be estimated from satellite imagery and the depth of the entrainment layer from shipboard measurements.

Making observations in meanders and eddies will be a continuing difficult management problem, because these oceanographic phenomena are at present unpredictable regarding their magnitudes, places of origin, and speeds and directions of travel, whereas vessel cruises are ordinarily planned well in advance of operations.

An initial effort to use both satellite imagery interpretations and research vessels in monitoring is described in the following section.



ALL SOLID LINE FRONTS AND EDDIES OBS ON 25 FEB SAT, SST'S AND TEMP RANGES FROM INJECTION AND BT'S TAKEN 19-25 FEB.

EDDY F PROBABLY HAS COALESCED WITH THE GULF STR

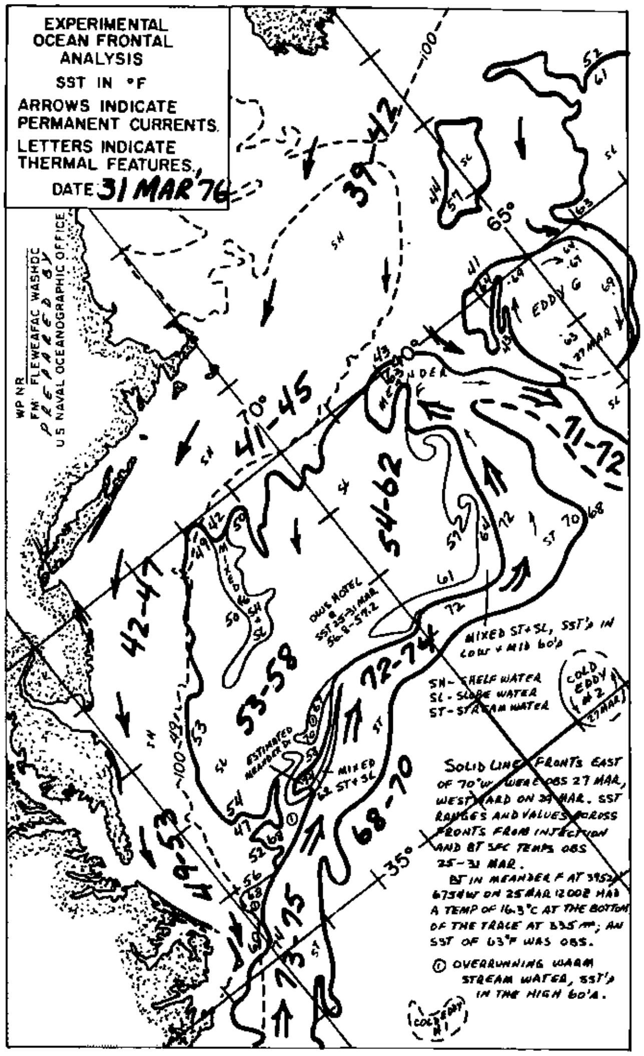
EDDY G APPEARS TO HAVE FORMED ON 25 FEB AS INDICATED BY SAT PASSES #5846, #5852, IT'S CENTERED NEAR 3945N 6315W.

EDDY D1: BT'S TAKEN ON 22,24 FEB AT 3715N 7354W SHOW 13.4°C WATER EXTENDS TO 290 m WHICH IS 5°C WARMER THAN SURROUNDING SL WATER AT THAT DEPTH.

COLD EDDY #1: BT TAKEN AT 3345N 7335W ON 26 FEB HAS 14.2°C TEMP AT 457m.

COLD EDDY #2: AXBT ON 18 FEB AT 3540N 6750W HAS 13.5°C TEMP AT 300 m, EDDY NOT OBS BY SATELLITE.

Fig. 2. US Naval Oceanographic Office interpretation of satellite imagery for 25 February 1976. The large warm core eddy discussed in the text is at the upper right corner of the map (labelled "EDDY G").



MIXED ST+SL, SST'S IN LOW + MID 60'S

SH - SHELF WATER
SL - SLOPE WATER
ST - STREAM WATER

SOLID LINE FRONTS EAST OF 70°W WERE OBS 27 MAR, WESTWARD ON 29 MAR. SST RANGES AND VALUES ACROSS FRONTS FROM INJECTION AND BT SFC TEMPS OBS 25-31 MAR.

BT IN MEANDER F AT 3952N 6754W ON 25 MAR 1200Z HAD A TEMP OF 16.3°C AT THE BOTTOM OF THE TRACE AT 335 m; AN SST OF 63°F WAS OBS.

① OVERRUNNING WARM STREAM WATER, SST'S IN THE HIGH 60'S.

Fig. 3. US Naval Oceanographic Office interpretation of satellite imagery for 31 March 1976. The large eddy discussed in the text is labelled "EDDY G".

OBSERVATIONS RELATING TO A LARGE WARM CORE EDDY SOUTHEAST OF GEORGES BANK IN MARCH AND APRIL 1976

NOAA Satellite Imagery

At the end of February 1976, infrared imagery from NOAA satellites (GOES 1 and NOAA 4) revealed an unusually large warm core eddy, southeast of Georges Bank, where it was estimated to have detached from the Gulf Stream, with its center at 39°45'N latitude, 63°15'W longitude (Fig. 2). By 20 March, it had moved westward about 90 nautical miles (170 km) at an average speed of about 1.4 knots (7 cm/sec), and its center was at about 39°30'N latitude, 65°15'W longitude.

Early in the life of the eddy, on 28 February, unusually clear satellite imagery showed an oval surface configuration, with dimensions of about 140 x 120 nautical miles (260 x 220 km); the surface area was about 13,300 square nautical miles (45,500 square km), which is about 21% larger than the combined area of the Southern New England states (about 25% larger than Georges Bank). This area appeared to decrease moderately during the following month.

Recognition that this eddy, because of its large size, could have marked effects on Georges Bank, led the Northeast Fisheries Center, in mid-March, to initiate requests for observations by research vessels of other ICNAF Member Nations.

Observations by R/V *Ernst Haeckel*

On 20 March, the German Democratic Republic's R/V *Ernst Haeckel*, made a temperature and salinity section, with Nansen bottles, across most of the eddy's diameter in a nearly north-south direction, from south of the center to the northern margin. The data were radioed to the Northeast Fisheries Center on 22 March. Although weather and strong subsurface currents were an obstacle to the *Ernst Haeckel*, data were obtained to depths of over 400m. The temperature section revealed a core of 18°C water about 75 miles across and over 300 m maximum depth near the eddy center. [We are aware of only one previous report of an eddy with an 18° core reaching a comparable depth (US Naval Oceanographic Office, 1974).] Salinity values of over 36.5‰ in the core show it to have been composed of Gulf Stream or Sargasso Sea water. The maximum depths of the observations possible with the length of wire aboard the *Ernst Haeckel* were not sufficient for accurate calculations of geostrophic flow as an estimate of the eddy's speed of rotation. The *Ernst Haeckel* sections also clearly show the entrainment of shelf water (9°C) at the northern margin of the eddy.

Initially the eddy entrained cold surface water from the continental shelf off western Nova Scotia. By the third week in March, the satellites showed it was entraining shelf water from the direction of eastern Georges Bank. At its westernmost position, on 24 March, the eddy had come close to a large meander building up on its west side, and was entraining Gulf Stream water northward from this feature.

By 28 March, the eddy ceased entraining Gulf Stream water, and appeared to have retreated some distance to the east and to be losing water to the Gulf Stream from its southwest margin. At the same time, the Gulf Stream meander to the west of the eddy had thrust far to the northward (Fig. 3) bringing surface water warmer than 17°C to the southern margin of Georges Bank. The meander was also entraining Georges Bank water southward, and simultaneously the western margin of the eddy was "picking up" some of this water and entraining it back northward again.

Observations from R/V *Albatross IV*

On 2-3 April, the NOAA R/V *Albatross IV* was diverted by the Northeast Fisheries Center from Georges Bank, southwestward into the meander west of the eddy (Fig. 3). XBT observations and neuston net samples were obtained.

Observations from R/V *Wieczno*

On 4-7 April, the Polish R/V *Wieczno* made an east to west section with Nansen bottles across the area of both the eddy and the meander at about 38°N. This 260-mile (480-km) section, although impeded by bad weather and limited to 450 m maximum depth, was fully executed. Dramatic hydrographic change, corroborated by satellite imagery (Fig. 4), was revealed. The meander had broken eastward, from its northern extremity, into the northern part of the eddy. As a result, instead of an eddy and a meander, a very wide meander had formed, reincorporating the eddy into the Gulf Stream. Satellite imagery subsequently revealed the persistence of this broad meander for about 2 weeks.

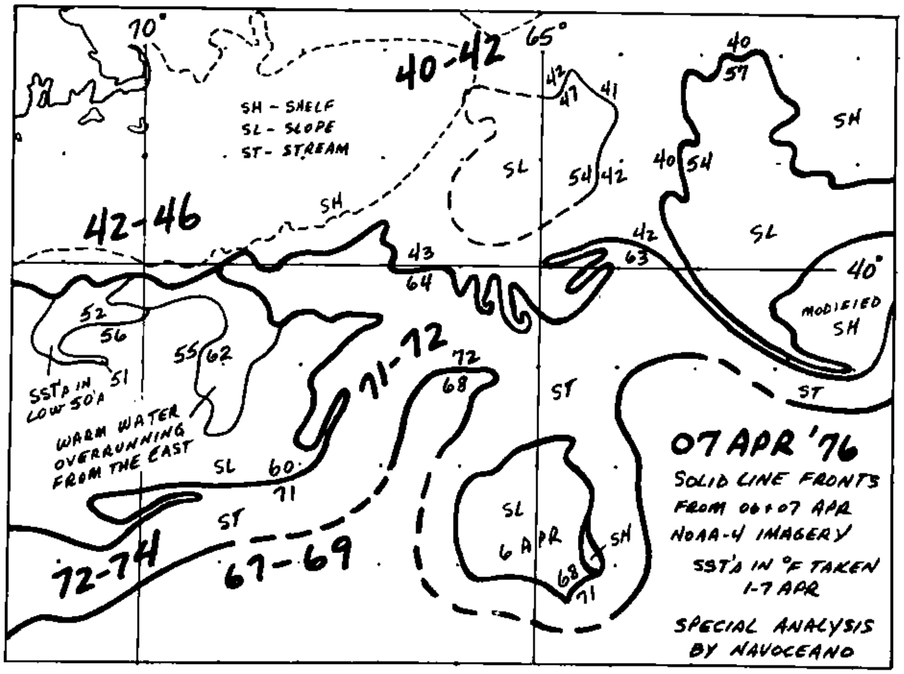


Fig. 4. US Naval Oceanographic Office interpretation of satellite imagery for 7 April 1976. This is a special large scale interpretation of satellite imagery that was initially transmitted by telephone facsimile. It shows resorption of "EDDY G" by the Gulf Stream. See Fig. 3 for the location of "EDDY G" a week earlier.

Observations from R/V *Belogorsk*

The USSR R/V *Belogorsk* made a long Nansen bottle section, on 16-19 April, in a southwestward direction through the meander in the area where the large eddy had been, and then northwestward to Georges Bank. At the time of writing this report, data has not been received from the *Belogorsk*.

Satellite imagery up to 20 April presents a complex situation indicating that at the time of the *Belogorsk* observations the Gulf Stream changed direction toward the southeast at about 39°N latitude, 67°W longitude, releasing a major part of the large meander in the form of a reconstituted eddy. Additional observations from research vessels may be obtained in the area of this apparent eddy, if they appear warranted by the evidence of subsequent satellite imagery.

FORMATION AND CHARACTERISTICS OF WARM CORE EDDIES

Warm core eddies form in the slope water region off the continental shelf by detachment of meanders on the left side of the Gulf Stream (Fig. 5). The detached meander maintains continuity of flow by closing into an eddy ("ring") at the area of detachment. The rotational flow, in a clock-wise (anticyclonic) direction, continues by inertia, at speeds from as low as 0.6-1.0 knots (30-50 cm/sec) (Saunders, 1971) to more than 1.8 knots (90 cm/sec) (Thompson and Gotthardt, 1971). The eddies have a warm core because they enclose Sargasso water that has crossed the Gulf Stream within the originating meander. (Eddies also form from meanders on the right side of the Stream. These eddies, which move off into the warm Sargasso Sea, rotate counterclockwise and contain a cold core of slope water.) The warm core eddies seen off New England and the Middle Atlantic coast mostly form in the slope water region southeast of Georges Bank, where meandering of the Gulf Stream becomes extensive.

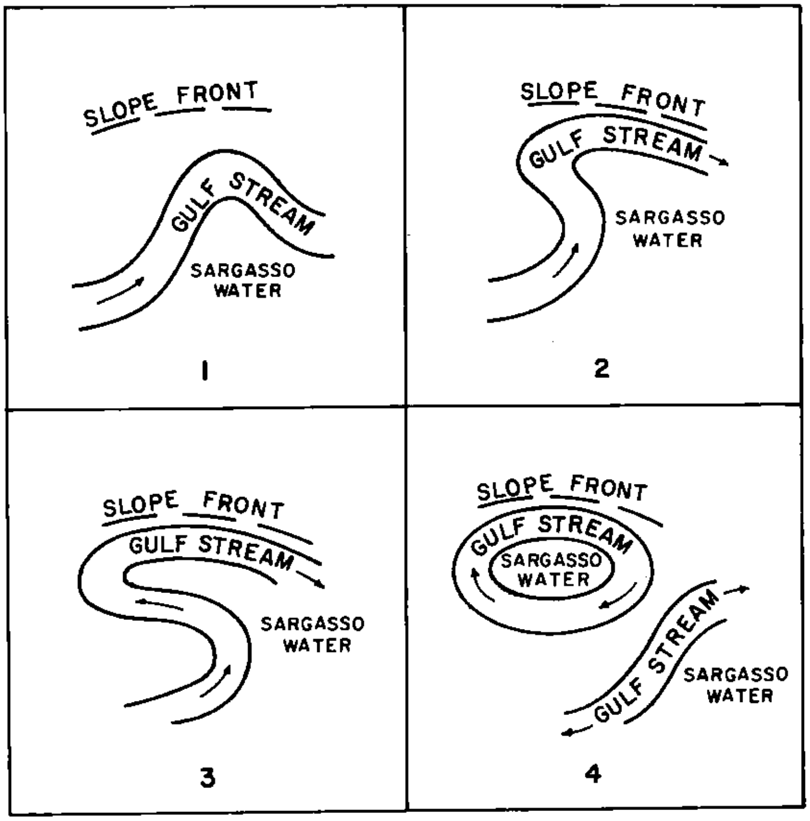


Fig. 5. Schematic of warm core Gulf Stream eddy formation (after Gotthardt, 1973).

Unlike Gulf Stream meanders which move slowly eastward like waves, warm core eddies typically move west and southwest in the slope water region at varying rates up to about 0.2 knots (10 cm/sec), but often halt or move in irregular directions for periods of days or even a few months (Bisagni, 1976). Some eddies recontact the Gulf Stream soon after their formation and are resorbed. However, those which continue to move to the west and southwest may persist for over 6 months, but are eventually trapped and resorbed by the Gulf Stream at about the latitude of Virginia, where the Stream runs close to the continental slope. As an example of a long lived eddy, Fig. 8 shows the pathway of one, in 1974, that traveled from southeast of Georges Bank in January to off Virginia by the end of June. The prolonged "residence" of this eddy in the area south of New England illustrates, to an unusual degree, the kind of periodic irregular movement that Bisagni (1976) found typical of warm core eddies.

EFFECTS OF MEANDERS AND EDDIES ON THE FISHING GROUNDS OF THE CONTINENTAL SHELF AND SLOPE

The effects that Gulf Stream meanders and warm core eddies may have on environmental variability on the fishing grounds have probably been reasonably well observed by oceanographers in the course of various investigations. The magnitudes of the variability produced, however, and the influence of this variability on the fishery resources remain largely conjectural. Five kinds of environmental effects and their possible influences on the fishery resources and on fishing can be identified:

1. Warming of the upper continental slope and outer shelf by direct contact of a meander or eddy (Fig. 6). This may influence the timing of seasonal migrations of fish as well as the timing and location of their spawning.

2. Injection of warm, saline water into the colder less saline waters of the shelf, by turbulent mixing at the inshore boundard of a meander or eddy (Fig. 7). This may have

influences on the fishery resource similar to that of direct warming, and also cause mortality of fish eggs and larvae on the shelf, when the colder water in which they live is warmed beyond their tolerance by the mixing-in of warm slope water.

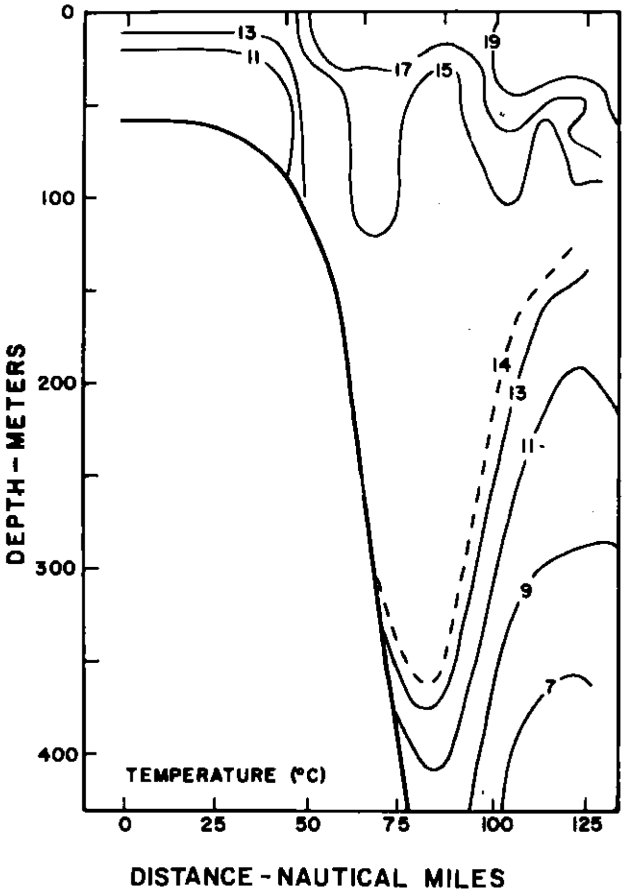


Fig. 6. Vertical temperature section illustrating a warm core eddy contacting the outer continental shelf and upper slope near the Hudson Canyon on 19 May 1974 (from Applications Research Division, NavOceanO, 1974).

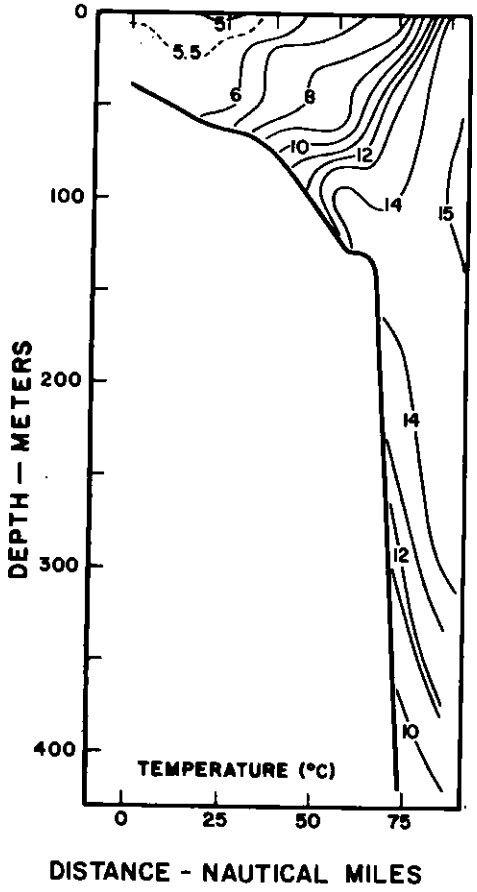


Fig. 7. Vertical temperature section illustrating injection of warm water onto the southern New England continental shelf from a warm core eddy. Only the inshore margin of the eddy appears in the section. Data from NOAA R/V *Albatross IV*, 28-29 March 1974 (after Chamberlin, 1976).

3. Entrainment of shelf water off the shelf, an effect that is frequently seen in satellite imagery (Fig. 2 and 3). Mortality of Georges Bank fish larvae is known to occur, presumably because of temperature elevation, when shelf water in which they occur is carried into the slope water (Colton, 1959). The most profound effects of the entrainment on the fishing grounds may be changes in circulation and in water mass properties resulting from the replacement of the waters lost from the shelf.

4. Upwelling along the continental slope, which may result in nutrient enrichment near the surface and increased primary biological productivity.

5. Strong currents on the outer shelf and upper slope. Prolonged submergence of the surface floats of lobster pots and even losses of gear is a possible result that warrants investigation.

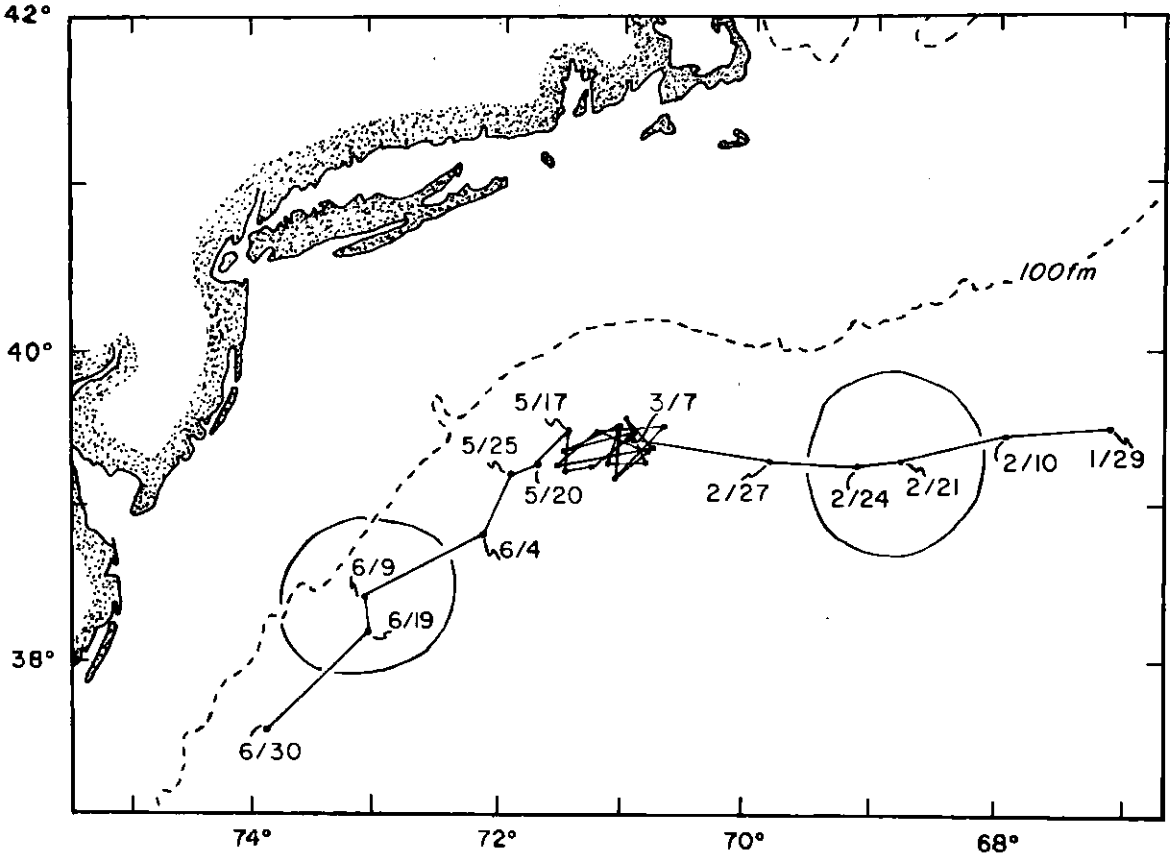


Fig. 8. Example of the pathway of a long-lived warm core eddy in the slope water. Successive positions of the center of the eddy are plotted from NavOceanO interpretations of NOAA 3 satellite imagery. Fig. 6 and 7 are vertical sections in this eddy (after Chamberlin, 1976).

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Report of Ageing Workshop on Cod held at Vigo, Spain, October 1975[1]

Sponsored by

International Commission for the Northwest Atlantic Fisheries
Standing Committee on Research and Statistics

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ABSTRACT

From age readings of cod otoliths by ageing experts at the Workshop, significant variation in age determination was found among the individual readers. Such differences could seriously affect the results of population analyses. The detailed examination of selected otolith photographs was carried out in order to determine some of the reasons for the discrepancies. It was concluded that further work on age determination should be undertaken in an effort to reduce subjective errors in ageing and to develop a set of guidelines for otolith interpretation in cod.

INTRODUCTION

Differences in the age compositions of some fish stocks, as derived from sampling data reported by the various Member Countries of ICNAF, were apparent at the April 1975 Meeting of the Assessments Subcommittee (ICNAF, 1975). Because accurate age determinations are essential for the analytical assessment of fish stocks, an ageing workshop was proposed to ascertain if the discrepancies are due to variation in the interpretation of otoliths among the age-readers of the various countries and, if so, whether the differences are significant. The Workshop was subsequently established by the Standing Committee on Research and Statistics (STACRES) to examine ageing material for both cod and silver hake from various Northwest Atlantic stocks (ICNAF, 1975), with E.C. Lopez-Veiga (Spain) and R. Wells (Canada) as Coordinators.

Problems associated with the age determination of fish are not new to ICNAF. An exchange of cod otoliths started in 1958 (ICNAF, 1958) showed good agreement but pointed out some of the difficulties in interpretation. In 1962 a workshop on ageing techniques was held at Bergen, Norway (ICNAF, 1963), and in the period 1963-67 a series of samples of cod otoliths and photographs were circulated among ICNAF scientists (Kohler, 1964; Blacker, 1968, 1974). Many publications dealing with the biological basis of age determination, ageing techniques, mechanical aids, validation studies and the sources and effects of errors are present in the literature.

This paper describes the proceedings of the Workshop which took place at the Institute of Fisheries Investigations, Vigo, Spain, during 20-25 October 1975, with the

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[1] Submitted to the 1976 Annual Meeting as Summ. Doc. 76/VI/13 (revised July 1976).

participation of experts from Canada, Federal Republic of Germany, Poland, Portugal, Spain and USA (Appendix I). Because of illness, the USSR expert could not attend before 3 November, at which time he had the opportunity to study part of the material on cod which had been examined earlier during the Workshop. In view of the absence of the USSR expert during the scheduled period of the Workshop, the work was devoted entirely to the examination of ageing material for cod, with the problem of attempting to resolve the discrepancies in silver hake ageing having to be necessarily deferred to a later workshop.

MATERIALS AND METHODS

Ageing material for the studies on cod were provided by Canada and Spain as follows:

ICNAF Div.	Sample 1 (Spain)	Sample 2 (Canada)
2J	-	49
3K	55	46
3L	106	49
3NO	-	49
3O	52	49
3Ps	52	49
4Vn	51	-
5Z	52	-

Each age reader was provided with a binocular microscope and the otoliths were read in a darkened room using reflected light. The otoliths, broken across the sulcus, were mounted in blocks of modelling clay and arranged in trays, each containing 25 specimens, so that no delay was encountered in obtaining the otoliths for study.

During the first day of the Workshop, various parts of Sample 1 were aged by those who had arrived by that date. On the following day, after discussion by all participants, it was decided to proceed with Sample 2, since both photographs and projector slides of these otoliths were available. After all of the otoliths were read, sufficient time was available to study about 60 slides in detail, and the various interpretations of age were noted and discussed. The actual age determinations for Samples 1 and 2 by the individual readers are listed in Appendix II (Tables A and B).

COD OTOLITH SAMPLE 1

Agreement between Pairs of Readers

Table 1 shows the percentage agreement between pairs of readers for the various areas separately and combined. Agreement ranged from 0% by readers 3 and 9 for Subdiv. 3Ps to 77% by readers 8 and 9 in the same area. Agreement between pairs of readers for all areas combined ranged from 8% (readers 1-3) to 63% (readers 8-9), the 76% agreement by readers 5 and 8 being for one area only. Out of 84 possible comparisons of reader pairs, 60% or more agreement was achieved by eleven pairs of readers. The average agreement by all pairs of readers for all areas was only 39%.

The frequency distribution of reader pairs in relation to the percentage agreement achieved for each area is given in Table 2. Agreement was slightly better than 50% on the average for the Div. 3K and 5Z otoliths, although in the latter area only three pairs of readers out of 10 achieved agreement at 50% or better. Agreement was relatively poor for Div. 3L and 3O, with only one pair of readers achieving agreement at 50% or better for each area. For Subdiv. 3Ps, the frequency distribution is bimodal with 10 pairs of readers recording less than 30% agreement on the one hand and one-half of the total numbers of pairs achieving 50% or better on the other. The percentage agreements were less variable for Subdiv. 4Vn, but only 3 of 10 pairs of readers achieved agreement at 50% or more. For all areas combined, the frequency distribution tends to be symetrical about the mean (at 39%) with about one-third of the reader pairs achieving less than 30% agreement and about the same number achieving agreement at 50% or better.

An indication of reader bias with respect to pairs of readers and to the group as a whole for all areas combined is shown in Table 3. The bias between readers, defined as the percentage of otoliths over-aged minus the percentage under-aged, ranged from -84 (readers 1 and 3) to +83 (readers 3 and 10). Reader 2 had little bias on the

Table 1. Percentage agreement between pairs of readers by area for Sample 1.

Readers compared	Percentage agreement						
	3K	3L	30	3Ps	4Vn	5Z	Total
1 - 2	-	-	-	56	28	68[a]	55
1 - 3	-	9	-	8	-	-	8
1 - 4	-	35	-	52	58	37	44
1 - 5	-	-	-	-	-	51	51
1 - 7	-	-	-	13	35	-	22
1 - 8	42	9	-	66[a]	35	45	42
1 - 9	51	26	-	66[a]	-	-	50
1 - 10	-	9	-	48	-	-	32
2 - 3	-	-	4	50	-	-	29
2 - 4	-	47	-	38	48	45	45
2 - 5	-	-	-	-	-	47	47
2 - 7	-	41	-	31	35	-	36
2 - 8	-	49	17	57	55	45	48
2 - 9	-	48	38	57	-	-	50
2 - 10	-	46	-	61[a]	-	-	54
3 - 4	-	12	-	15	-	-	14
3 - 6	-	-	25	-	-	-	25
3 - 7	-	-	-	46	-	-	46
3 - 8	-	42	10	12	-	-	18
3 - 9	-	48	6	0	-	-	15
3 - 10	-	20	-	15	-	-	18
4 - 5	-	-	-	-	-	45	45
4 - 7	-	27	-	15	39	-	30
4 - 8	-	30	-	77[a]	43	48	44
4 - 9	-	37	-	69[a]	-	-	45
4 - 10	-	23	-	65[a]	-	-	35
5 - 8	-	-	-	-	-	76[a]	76[a]
6 - 8	-	-	21	-	-	-	21
6 - 9	-	-	33	-	-	-	33
7 - 8	-	33	-	18	51	-	34
7 - 9	-	36	-	22	-	-	29
7 - 10	-	41	-	29	-	-	35
8 - 9	67[a]	57	57	77[a]	-	-	63[a]
8 - 10	-	49	-	63[a]	-	-	54
9 - 10	-	38	-	58	-	-	45
No. of pairs	3	24	9	28	10	10	84
Average (%)	53	34	23	42	43	51	39

[a] Agreement 60% or more.

Table 2. Frequency distribution of pairs of readers by percentage (agreement) groups for Sample 1.

Percentage groups	No. of pairs of readers						
	3K	3L	30	3Ps	4Vn	5Z	Total
0-9	-	3	2	2	-	-	7
10-19	-	1	2	6	-	-	9
20-29	-	4	2	2	1	-	9
30-39	-	6	2	2	4	1	15
40-49	1	9	-	2	2	6	20
50-59	1	1	1	6	3	1	13
60-69	1	-	-	6	-	1	8
70-79	-	-	-	2	-	1	3
Total	3	24	9	28	10	10	84
Average agreement	53	34	23	42	43	51	39

average with respect to the groups as a whole. Readers 1, 4, 5, 8 and 9 tended to under-read with respect to the group, whereas readers 3, 6, 7 and 10 tended to over-read. Reader 5 (55%), followed by readers 2, 8 and 9 achieved the best average agreement with respect to the group, while the poorest results were achieved by readers 3 and 6.

Agreement with Modal Ages

For each specimen, except those for which no clear mode was evident (about 20% of the total), the modal age was determined from the ages estimated by the various readers. The resultant anomalies (estimated age minus modal age) were determined for each reader and area together with the mean deviations and the standard errors (Table 4). With respect to the modal ages, the mean deviation provides an indication of bias and the standard error gives a measure of consistency. For all areas combined, the mean deviation was minimal for readers 2 and 8, followed by readers 1 and 9 who tended to over-read the modal ages. The greatest positive bias was reflected in the ageing of reader 3 who on the average determined the ages at about 1 year older than those pertaining to the modes. Readers 6, 7 and 10 tended to over-read the modal ages but to a lesser extent than reader 3. Consistency in ageing at or close to the modal ages was best for readers 2, 8 and 9 (lowest standard error values) and was poorest for readers 3 and 6 (highest standard error values).

Table 3. Bias between pairs of readers in ageing Sample 1.

Reader	Bias between pairs of readers[a] 1	2	3	4	5	6	7	8	9	10	Average bias	Average agreement
1	●	-26	-84	17	49	-	-71	-24	-22	-68	-29	38
2	26	●	-67	29	45	-	-17	2	12	-23	1	46
3	84	67	●	78	-	50	-30	65	83	42	55	22
4	-17	-29	-78	●	-23	-	-42	-30	-21	-51	-36	38
5	-49	-45	-	23	●	-	-	-16	-	-	-22	55
6	-	-	-50	-	-	●	-	54	59	-	21	26
7	71	17	30	42	-	-	●	37	67	33	42	33
8	34	-2	-65	30	16	-54	-37	●	21	-23	-9	44
9	22	-12	-83	21	-	-59	-67	-21	●	-44	-30	41
10	68	23	-42	51	-	-	-33	23	44	●	19	39

[a] Percentage over-aged minus percentage under-aged.

Percentage agreement with the modal ages was highest for readers 5, 8 and 9 (>80%), with the last two having consistently achieved better than 75% agreement for each of the areas concerned (Table 4). Readers 1, 2, 4 and 10 achieved 62-70% agreement for the combined areas, but there was considerable variation among areas in some cases. Agreement by reader 3 was extremely variable, ranging from 12 to 86% for three areas with a weighted average of 26% for the areas combined. For all readers and areas combined, average agreement with the modal ages was about 65%.

Considering the results for the various areas separately (Table 4), agreement with the modal ages was generally good (63-94%) for the three readers who studied the material for Div. 3K, the overall average being 80%. Agreement was also reasonably consistent among the five readers for Div. 5Z (59-90%) and for Subdiv. 4Vn (52-78%), the averages being 73% and 67% respectively. For the remaining areas, the results were somewhat more variable. For Div. 3L, the percentage agreements by the eight readers (27-90%) averaged 65%; agreements by seven readers were generally good (50-90%), but reader 1 (27%) under-read the modal ages by nearly 1 year on the average. For Div. 3O, agreements by the five readers (14-84%) averaged 56%; agreements by three readers were generally good (58-84%), but reader 3 (14%) over-read the modal ages by 1.7 years on the average and reader 2 (47%) under-read by 0.5 years. For Subdiv. 3Ps, agreements by the eight readers (12-87%) averaged 63%; agreements by six readers were very good (71-87%), but reader 3 (12%) over-read the modal ages by nearly 1 year and reader 7 (23%) over-read by slightly more than 1 year on the average.

COD OTOLITH SAMPLE 2

Agreement between Pairs of Readers

Table 5 shows the percentage agreement between pairs of readers for the various areas separately and combined. Agreement ranged from 0% (readers 8-16 and 14-16) for Div. 3K to 96% (readers 9-14) for Subdiv. 3Ps. Agreement between pairs of readers for all areas combined ranged from 19% (readers 16-17) to 69% (readers 8-9). Out of 629 possible comparisons of reader pairs, 60% or better agreement was achieved by 108 pairs (17%) of readers. The average agreement by all pairs of readers for all areas was 42%, only slightly higher than for Sample 1.

The frequency distribution of reader pairs in relation to the percentage agreement achieved for each area is given in Table 6. For all pairs of readers, agreement ranged from 27% for Div. 3K to 66% for Subdiv. 3Ps, the average for all areas being 42%. The results were relatively poor for Div. 2J and 3K with only 7 and 2 pairs of readers respectively achieving agreement at 50% or more. Agreement was slightly better for Div. 3L, 3NO and 3O but the variation was great, with values ranging from 7 to 72% for Div. 3L, 12 to 75% for Div. 3NO and 11 to 81% for Div. 3O, and with considerably less than one-half of the pairs of readers achieving agreement at 50% or better. For Subdiv. 3Ps, the frequency distribution is bimodal (as for Sample 1) with about one-quarter of the reader pairs recording less than 50% agreement. For the remaining pairs of readers, agreement was reasonably good with the majority achieving 70% or higher.

Table 4. Anomalies from modal ages of otoliths in Sample 1 by reader and area, together with the mean deviations, standard errors and percentage agreements.

Reader	ICNAF Div.	Deviations from modal ages								Total read	Mean deviation	Standard error	Percentage agreement
		-3	-2	-1	0	1	2	3	>3				
1	3K	-	2	9	29	5	1	-	-	46	-0.13	0.110	63
	3L	1	1	8	4	1	-	-	-	15	-0.80	0.240	27
	3Ps	-	-	8	22	1	-	-	-	31	-0.23	0.089	71
	4Vn	-	1	10	12	-	-	-	-	23	-0.52	0.120	52
	5Z	-	-	-	28	8	2	-	-	38	0.32	0.093	74
	Total	1	4	35	95	15	3	-	-	153	-0.16	0.058	62
2	3L	-	-	13	47	4	1	-	-	65	-0.11	0.070	72
	3O	-	2	5	7	1	-	-	-	15	-0.53	0.220	47
	3Ps	-	-	1	32	10	-	-	-	43	0.21	0.071	74
	4Vn	-	-	-	27	10	2	-	-	39	0.36	0.094	69
	5Z	-	-	2	25	11	-	-	-	38	0.24	0.088	66
	Total	-	2	21	138	36	3	-	-	200	0.09	0.044	69
3	3L	-	-	-	12	2	-	-	-	14	0.14	0.097	86
	3O	-	-	-	5	13	12	3	4	37	1.68	0.190	14
	3Ps	-	-	1	3	19	2	-	-	25	0.88	0.120	12
	Total	-	-	1	20	34	14	3	4	76	1.13	0.122	26
4	3L	1	7	20	33	1	-	-	-	62	-0.58	0.099	53
	3Ps	-	-	-	20	5	-	-	-	25	0.20	0.082	80
	4Vn	-	1	7	28	3	1	-	-	40	-0.10	0.110	70
	5Z	-	2	11	24	4	-	-	-	41	-0.27	0.110	59
	Total	1	10	38	105	13	1	-	-	168	-0.27	0.057	63
5	5Z	-	3	1	37	-	-	-	-	41	-0.17	0.085	90
6	3O	-	-	1	11	5	2	-	-	19	0.42	0.180	58
7	3L	-	-	3	19	11	4	1	-	38	0.50	0.118	50
	3Ps	-	-	-	10	21	9	2	1	43	1.14	0.140	23
	4Vn	-	-	8	27	3	2	-	-	40	-0.02	0.110	68
	Total	-	-	11	56	35	15	3	1	121	0.56	0.088	46
8	3K	-	-	-	40	8	-	-	-	48	0.17	0.054	83
	3L	-	-	5	64	10	4	-	-	83	0.16	0.065	77
	3O	-	-	3	30	5	-	-	-	38	0.05	0.075	79
	3Ps	-	2	3	39	1	-	-	-	45	-0.15	0.075	87
	4Vn	-	-	2	31	6	1	-	-	40	0.15	0.084	78
	5Z	-	-	4	31	5	-	-	-	40	0.02	0.076	78
	Total	-	2	17	235	35	5	-	-	294	0.08	0.030	80
9	3K	-	-	2	45	1	-	-	-	48	-0.02	0.036	94
	3L	-	-	15	66	2	-	-	-	83	-0.18	0.053	90
	3O	1	1	3	32	1	-	-	-	38	-0.18	0.110	84
	3Ps	-	-	5	39	1	-	-	-	45	-0.09	0.053	87
	Total	1	1	25	182	5	-	-	-	214	-0.12	0.030	85
10	3L	-	-	3	51	17	2	2	-	75	0.32	0.083	68
	3Ps	-	-	1	33	8	3	-	-	45	0.29	0.093	73
	Total	-	-	4	84	25	5	2	-	120	0.31	0.062	70

Table 5. Percentage agreement between pairs of readers by area for Sample 2.

Readers compared	Percentage agreement 2J	3K	3L	3NO	30	3Ps	Total	Readers compared	Percentage agreement 2J	3K	3L	3NO	30	3Ps	Total
1 - 2	29	30	41	33	57	42	36	5 - 12	19	43	44	50	48	83[a]	52
1 - 3	40	26	47	48	58	70[a]	49	5 - 13	-	38	47	63[a]	56	78[a]	57
1 - 4	38	20	36	38	45	73[a]	42	5 - 14	31	35	42	72[a]	60[a]	88[a]	55
1 - 5	33	35	47	50	48	79[a]	51	5 - 15	25	29	42	50	49	79[a]	49
1 - 7	40	42	26	38	45	70[a]	43	5 - 16	17	12	23	27	49	76[a]	38
1 - 8	29	19	44	55	36	76[a]	43	5 - 17	40	19	12	12	13	43	23
1 - 9	25	28	47	75[a]	38	78[a]	48	7 - 8	33	23	32	44	31	69[a]	39
1 - 11	25	31	47	51	42	79[a]	46	7 - 9	28	27	39	40	33	67[a]	39
1 - 12	50	21	47	55	55	78[a]	51	7 - 11	18	37	41	49	48	71[a]	44
1 - 13	31	24	43	72[a]	81[a]	71[a]	54	7 - 12	41	16	39	48	47	73[a]	44
1 - 14	29	30	45	55	72[a]	77[a]	50	7 - 13	24	33	53	52	44	60[a]	45
1 - 15	35	28	51	53	42	77[a]	48	7 - 14	33	36	45	38	53	67[a]	45
1 - 16	22	23	18	28	46	58	34	7 - 15	23	24	51	60	40	67[a]	45
1 - 17	23	10	30	37	23	33	26	7 - 16	13	5	8	12	25	55	20
2 - 3	40	27	45	33	60[a]	38	40	7 - 17	31	26	12	22	22	53	29
2 - 4	31	12	30	26	46	36	31	8 - 9	76[a]	70[a]	50	70[a]	60[a]	92[a]	69[a]
2 - 5	19	20	35	31	43	44	34	8 - 11	16	32	46	52	44	90[a]	47
2 - 7	35	23	21	16	29	29	25	8 - 12	37	37	47	57	43	80[a]	50
2 - 8	39	16	47	33	41	44	37	8 - 13	48	43	44	70[a]	38	69[a]	53
2 - 9	35	20	45	24	41	44	35	8 - 14	59	33	45	63[a]	44	86[a]	56
2 - 11	31	16	37	18	37	44	31	8 - 15	43	26	46	49	50	80[a]	49
2 - 12	55	29	41	38	56	42	44	8 - 16	30	0	21	31	27	63[a]	29
2 - 13	33	28	42	28	53	43	38	8 - 17	14	23	26	21	19	37	24
2 - 14	41	22	35	36	45	46	37	9 - 11	20	43	44	53	40	88[a]	48
2 - 15	33	13	35	20	45	45	32	9 - 12	29	43	52	57	43	73[a]	50
2 - 16	36	22	20	19	36	39	29	9 - 13	45	38	55	63[a]	38	74[a]	53
2 - 17	27	19	30	43	24	36	30	9 - 14	55	37	67[a]	57	44	96[a]	60[a]
3 - 4	39	34	27	28	55	76[a]	44	9 - 15	38	30	49	54	45	80[a]	50
3 - 5	38	43	40	50	56	74[a]	52	9 - 16	26	5	15	29	33	71[a]	31
3 - 7	44	24	33	35	44	64[a]	41	9 - 17	17	26	12	29	11	45	24
3 - 8	40	27	41	61	46	78[a]	49	11 - 12	31	35	56	48	50	78[a]	50
3 - 9	42	40	52	54	46	73[a]	51	11 - 13	15	24	69[a]	65[a]	56	74[a]	51
3 - 11	17	29	50	50	59	75[a]	47	11 - 14	27	41	56	40	70[a]	86[a]	53
3 - 12	48	63[a]	72[a]	62[a]	72[a]	75[a]	65[a]	11 - 15	31	30	50	63[a]	49	82[a]	51
3 - 13	31	25	50	68[a]	71[a]	78[a]	54[a]	11 - 16	24	5	19	22	39	70[a]	32
3 - 14	39	36	40	45	68[a]	71[a]	50	11 - 17	40	24	27	22	15	38	28
3 - 15	36	30	50	40	58	72[a]	48	12 - 13	33	43	56	68[a]	47	68[a]	53
3 - 16	21	5	13	33	45	51	29	12 - 14	47	33	41	51	56	75[a]	50
3 - 17	22	30	29	26	26	39	29	12 - 15	44	36	54	47	59	78[a]	54
4 - 5	7	20	29	45	44	65[a]	39	12 - 16	20	7	13	26	41	62[a]	29
4 - 7	38	41	43	48	31	76[a]	46	12 - 17	24	23	27	24	30	32	27
4 - 8	49	36	19	39	52	76[a]	45	13 - 14	36	33	50	68[a]	78[a]	79[a]	57
4 - 9	47	36	29	35	37	78[a]	44	13 - 15	33	20	47	58	57	71[a]	48
4 - 11	23	36	46	54	58	84[a]	51	13 - 16	38	8	20	31	50	61[a]	37
4 - 12	32	27	31	28	57	75[a]	43	13 - 17	19	21	31	33	19	28	25
4 - 13	58	44	32	47	68[a]	74[a]	55	14 - 15	55	28	54	43	61[a]	78[a]	53
4 - 14	35	29	31	46	63[a]	82[a]	47	14 - 16	27	0	23	24	55	85[a]	35
4 - 15	32	30	44	46	56	76[a]	48	14 - 17	27	26	17	20	15	40	25
4 - 16	33	5	7	12	28	67[a]	26	15 - 16	23	2	19	14	33	68[a]	28
4 - 17	14	26	23	29	24	39	26	15 - 17	30	21	22	31	20	35	27
5 - 7	33	27	41	48	33	73[a]	44	16 - 17	20	5	16	22	18	31	19
5 - 8	19	35	40	53	48	78[a]	49								
5 - 9	25	43	52	50	47	86[a]	54	No. of pairs	104	105	105	105	105	105	629
5 - 10	38	39	42	52	55	84[a]	54	Average (%)	32	27	38	42	45	66	42

[a] Agreement 60% or more.

Table 6. Frequency distribution of pairs of readers by percentage (agreement) groups for Sample 2.

Percentage groups	No. of pairs of readers						
	2J	3K	3L	3NO	3O	3Ps	Total
0-9	1	11	2	-	-	-	14
10-19	13	10	12	7	7	-	49
20-29	27	40	16	21	10	2	116
30-39	38	30	16	18	15	12	129
40-49	18	12	38	19	36	12	135
50-59	6	-	18	24	24	4	76
60-69	-	1	2	11	7	14	35
70-79	1	1	1	5	5	44	57
80-89	-	-	-	-	1	14	15
90-99	-	-	-	-	-	3	3
Total	104	105	105	105	105	105	629
Average agreement	32	27	38	42	45	66	42

Indication of reader bias with respect to pairs of readers for all areas combined is given in Table 7. Variation was quite large, ranging from -75 (readers 7 and 16) to +65 (readers 2 and 7). Reader 16 consistently over-read with respect to the group, while readers 7, 11 and 15 under-read relative to most of the other readers. Reader 13 (49%) achieved the best average agreement with respect to the group, followed closely by readers 14, 12, 3, 8 and 9, while the poorest results were recorded by readers 16 and 17.

Table 7. Bias between pairs of readers in ageing Sample 2.

Reader	Bias between pairs of readers (% over-aged minus % under-aged)															Average bias	Average agreement
	1	2	3	4	5	7	8	9	11	12	13	14	15	16	17		
1	●	21	9	-31	-6	40	1	1	22	11	-1	7	20	-54	5	3	45
2	-21	●	-34	-56	-26	65	19	20	44	36	30	32	42	-37	32	10	34
3	-9	34	●	-32	11	35	-10	-15	16	1	-7	-1	13	-62	-9	-3	46
4	31	56	32	●	33	4	-38	-40	-12	-28	-32	-24	-13	-72	-17	-9	42
5	6	26	-11	-33	●	40	0	-2	13	4	9	7	19	-55	4	2	47
7	-40	-65	-35	-4	-40	●	-43	-46	-18	-37	-38	-36	-23	-75	-27	-38	39
8	-1	-19	10	38	0	43	●	-3	29	12	0	15	23	-16	8	10	46
9	-1	-20	15	40	2	46	3	●	30	16	0	13	27	-55	7	9	46
11	-22	-54	-16	12	-13	18	-29	-30	●	-15	-22	-17	-5	-66	-15	-20	45
12	-11	-36	-1	28	-4	37	-12	-16	15	●	-9	-1	13	-66	1	-4	47
13	1	-30	7	52	-9	38	0	0	22	9	●	21	22	-52	8	6	49
14	-7	-32	1	29	-7	36	-15	-13	17	1	-21	●	14	-60	0	-4	48
15	-20	-42	-13	13	-19	23	-23	-27	5	-13	-22	-14	●	-65	-10	-16	45
16	54	37	62	72	55	75	60	55	66	66	52	60	65	●	44	59	30
17	-5	32	9	17	-4	27	-8	-7	15	-1	-8	0	10	-44	●	2	26

Agreement with Modal Ages

Modal ages were derived in the same way as for Sample 1, except that no clear mode was evident for about 10% of the specimens examined. Anomalies (estimated age minus modal age) were determined for each reader and area, together with the mean deviations and standard errors (Table 8). For all areas combined, the average deviation was minimal for readers 3, 12 and 14, although in each case there was considerable variation between areas. Readers 1, 5, 8, 9, 13 and 17 tended to over-read the modal ages (0.08-0.17) while readers 11 and 15 tended to under-read to a somewhat greater extent (0.20-0.28). The greatest positive bias was reflected in the ageing of reader 16 who

Table 8. Anomalies from modal ages of otoliths in Sample 2 by reader and area, together with the mean deviations, standard errors and percentage agreements.

Reader	ICNAF Div.	Deviations from modal ages									Total read	Mean deviation	Standard error	Percentage agreement
		<-3	-3	-2	-1	0	1	2	3	>3				
1	2J	-	-	2	9	17	6	1	-	-	35	-0.14	0.15	49
	3K	-	-	-	5	11	8	5	2	-	31	0.61	0.21	35
	3L	-	-	-	3	24	10	1	-	-	38	0.24	0.10	63
	3NO	-	-	-	2	27	1	4	2	-	36	0.36	0.16	75
	30	-	-	1	7	25	8	1	-	-	42	0.02	0.12	60
	3Ps	-	-	-	3	35	5	-	-	-	43	0.05	0.07	81
	Total	-	-	3	29	139	38	12	4	-	225	0.17	0.06	62
2	2J	-	1	1	3	20	13	1	-	-	39	0.18	0.15	51
	3K	-	-	-	3	9	14	10	1	-	37	0.92	0.16	24
	3L	-	-	-	5	24	12	2	1	-	44	0.32	0.13	55
	3NO	-	-	1	2	17	10	8	2	-	40	0.70	0.17	43
	30	-	-	2	2	24	9	3	2	-	42	0.36	0.10	57
	3Ps	-	-	-	1	19	24	1	-	-	45	0.56	0.09	42
	Total	-	1	4	16	113	82	25	6	-	247	0.50	0.06	46
3	2J	1	1	3	11	22	1	-	-	-	39	-0.59	0.15	56
	3K	-	-	-	7	19	9	1	-	-	36	0.11	0.12	53
	3L	-	1	-	3	31	8	1	1	-	45	0.16	0.13	69
	3NO	-	-	1	1	32	12	-	-	-	46	0.20	0.09	70
	30	-	-	-	3	34	5	-	-	-	42	0.05	0.07	81
	3Ps	-	-	-	8	33	1	-	-	-	42	-0.17	0.07	79
	Total	1	2	4	33	171	36	2	1	-	250	-0.03	0.05	68
4	2J	-	-	3	7	22	5	-	-	-	37	-0.22	0.13	59
	3K	1	1	3	13	18	1	-	-	-	37	-0.68	0.16	49
	3L	-	2	8	12	18	4	-	-	-	44	-0.68	0.16	41
	3NO	-	1	4	16	20	2	-	-	-	43	-0.58	0.13	47
	30	-	-	2	12	29	-	1	-	-	44	-0.32	0.10	66
	3Ps	-	-	3	2	41	-	-	-	-	46	-0.17	0.08	89
	Total	1	4	23	62	148	12	1	-	-	251	-0.44	0.05	59
5	2J	1	1	1	2	6	1	-	-	-	12	-0.83	0.42	50
	3K	-	-	1	4	20	7	2	1	-	35	0.23	0.16	57
	3L	-	-	-	6	22	14	1	-	-	43	0.23	0.11	51
	3NO	-	-	-	2	20	6	-	-	-	28	0.14	0.10	71
	30	-	-	1	2	29	9	2	2	-	45	0.33	0.13	64
	3Ps	-	-	-	1	44	-	1	-	-	46	0.02	0.05	96
	Total	1	1	3	17	141	37	6	3	-	209	0.13	0.06	67
7	2J	1	-	4	11	21	2	1	-	-	40	-0.48	0.16	53
	3K	-	1	4	12	13	5	-	-	-	35	-0.51	0.17	37
	3L	-	2	4	15	22	-	-	-	-	43	-0.67	0.13	51
	3NO	-	1	2	20	22	-	-	-	-	45	-0.60	0.10	49
	30	-	2	7	16	19	1	-	-	-	45	-0.78	0.13	42
	3Ps	-	-	1	8	37	-	-	-	-	46	-0.22	0.07	80
	Total	1	6	22	82	134	8	1	-	-	254	-0.54	0.05	53
8	2J	-	-	-	2	30	3	3	2	-	40	0.33	0.14	75
	3K	1	-	1	3	22	6	4	-	-	37	0.05	0.24	59
	3L	-	-	-	2	29	9	3	2	-	45	-0.42	0.13	64
	3NO	-	-	-	4	35	5	2	-	-	46	0.11	0.09	76
	30	-	-	2	11	25	7	1	-	-	46	-0.13	0.12	54
	3Ps	-	-	-	2	40	4	-	-	-	46	0.04	0.05	87
	Total	1	-	3	24	181	34	13	4	-	260	0.15	0.05	70
9	2J	-	-	-	3	29	3	2	3	-	40	0.33	0.15	73
	3K	1	-	-	3	26	5	1	-	1	37	0.05	0.25	70
	3L	-	-	1	3	30	10	1	-	-	45	0.16	0.10	67

Table 8. (continued)

Reader	ICNAF Div.	Deviations from modal ages									Total read	Mean deviation	Standard error	Percentage agreement
		<-3	-3	-2	-1	0	1	2	3	>3				
	3NO	-	-	-	2	37	4	3	-	-	46	0.17	0.09	80
	30	-	-	1	6	24	12	2	1	-	46	0.24	0.13	52
	3Ps	-	-	-	1	43	1	1	-	-	46	0.04	0.05	93
	Total	1	-	2	18	189	35	10	4	1	260	0.17	0.04	73
11	2J	-	3	8	10	13	4	1	-	-	39	-0.74	0.19	33
	3K	-	-	1	8	22	1	1	1	-	34	-0.12	0.15	65
	3L	-	-	1	6	33	3	1	1	-	45	0.00	0.11	73
	3NO	1	1	1	10	27	3	2	-	-	45	-0.27	0.15	60
	30	-	1	5	8	30	1	-	-	-	45	-0.44	0.12	67
	3Ps	-	1	-	2	43	-	-	-	-	46	-0.11	0.07	93
	Total	1	6	16	44	168	12	5	2	-	254	-0.28	0.06	66
12	2J	1	-	2	7	23	4	1	-	-	38	-0.24	0.16	61
	3K	-	-	-	3	24	9	1	-	-	37	0.22	0.10	65
	3L	-	-	1	7	31	6	-	-	-	45	-0.07	0.09	69
	3NO	-	1	1	3	32	7	-	-	-	44	-0.02	0.11	73
	30	-	-	3	3	36	3	1	-	-	46	-0.09	0.10	78
	3Ps	-	-	-	3	39	2	-	-	-	44	-0.02	0.05	89
	Total	1	1	7	26	195	31	3	-	-	254	-0.04	0.04	73
13	2J	-	-	-	-	14	10	3	-	-	27	0.59	0.13	52
	3K	-	-	-	6	17	5	4	1	-	33	0.30	0.18	52
	3L	-	-	-	5	20	3	1	-	-	29	0.00	0.12	69
	3NO	-	-	-	2	26	2	-	-	-	30	0.00	0.07	86
	30	-	-	-	5	19	2	2	-	-	28	0.04	0.14	68
	3Ps	-	-	-	7	35	3	-	-	1	46	0.02	0.13	76
	Total	-	-	-	25	131	25	10	1	1	193	0.14	0.05	68
14	2J	-	-	2	5	28	2	3	-	-	40	-0.03	0.13	70
	3K	-	1	5	7	22	2	-	-	-	37	-0.49	0.15	59
	3L	-	-	-	9	27	6	3	-	-	45	0.07	0.12	60
	3NO	-	-	-	7	29	9	1	-	-	46	0.09	0.10	63
	30	-	-	-	2	23	3	1	-	1	30	0.23	0.16	77
	3Ps	-	-	-	1	42	2	1	-	-	46	0.07	0.06	91
	Total	-	1	7	31	171	24	9	-	1	244	-0.01	0.05	70
15	2J	-	-	-	10	22	5	3	-	-	40	0.03	0.13	55
	3K	1	1	4	11	16	3	1	-	-	37	-0.62	0.22	43
	3L	-	1	1	8	31	2	2	-	-	45	-0.16	0.12	69
	3NO	1	1	2	12	28	2	-	-	-	46	-0.46	0.13	61
	30	-	1	1	7	32	3	-	-	1	45	-0.11	0.14	71
	3Ps	-	-	-	2	41	3	-	-	-	46	0.02	0.05	89
	Total	2	4	8	50	170	18	6	-	1	259	-0.20	0.05	66
16	2J	-	-	-	-	12	16	5	2	-	35	0.91	0.14	34
	3K	-	1	-	-	1	13	9	4	6	34	1.91	0.26	3
	3L	-	-	-	-	9	14	8	5	4	40	1.53	0.20	23
	3NO	-	-	-	-	11	15	4	7	2	39	1.36	0.21	28
	30	-	-	-	-	18	12	4	2	6	42	1.23	0.24	43
	3Ps	-	-	-	-	34	7	1	3	-	45	0.40	0.12	76
	Total	-	1	-	-	85	77	31	23	18	235	1.18	0.08	36
17	2J	-	-	6	12	9	4	-	3	-	34	-0.32	0.24	26
	3K	-	2	5	6	12	4	1	3	-	33	-0.21	0.27	36
	3L	-	-	-	8	7	7	3	3	3	31	0.90	0.32	23
	3NO	-	-	1	6	11	8	4	2	-	32	0.44	0.22	34
	30	-	1	4	9	6	9	6	-	-	35	0.03	0.24	17
	3Ps	-		1	15	21	4	3	-	-	44	-0.16	0.13	48
	Total	-	3	17	56	66	36	17	11	3	209	0.08	0.10	32

on the average over-read the modal ages by more than 1 year (1.18). Reader 2 over-read by 0.5 years, while readers 4 and 7 under-read by about the same value. The average deviation from modal ages ranged from -0.83 by reader 5 for Div. 2J to +1.91 by reader 16 for Div. 3K. While some readers (2, 9 and 16) consistently over-read the modal age for all areas and some (readers 4 and 7) consistently under-read, others (e.g. readers 3, 5 and 17) had large positive deviations for some areas and negative deviations for others.

Considering the results for the various areas separately (Table 8), agreement with the modal ages was generally good for Subdiv. 3Ps (42-96%) with 13 of the 15 readers achieving better than 75% agreement with the modal ages, the average for all readers being 81%. For the specimens examined from Div. 3NO and 3O, the percentage agreements by the 15 readers (17-86%) averaged about 60%, with nine of the readers achieving better than 60%. For Div. 3L (23-73%), eight readers recorded better than 60% agreement with the modal ages, the overall average being 56%. The percentages for Div. 2J and 3K were somewhat less, averaging 53 and 47% respectively, with only four readers achieving better than 60% agreement. Readers 9 and 12 achieved the highest percentage agreement (73%) with the modal ages over all areas, while the lowest values were recorded by readers 16 and 17 (36 and 32% respectively).

Differences in Age Composition and Average Length-at-age

An age-length key for each reader of Sample 2 was derived from the age determinations listed in Appendix II (Table B). These keys were each applied to an arbitrary length frequency, resulting in the age frequencies listed for the various readers in Table 9. Also listed in the last column of Table 9 is the age frequency derived from the age-length key of modal ages of the Sample 2 specimens. The Kolmogorov-Smirnov two-sample test (Siegel, 1956) was used to test whether the individual age frequencies were significantly different from that of the modal ages. The age frequencies for readers 3, 5, 8, 9, 12 and 13 were not significantly different from the modal age frequency at $p = 0.05$, all others being significantly different even at $p = 0.01$. The same test was used to determine whether these six age compositions were significantly different from each other. None were different at the $p = 0.01$ level of significance, but the results at the $p = 0.05$ level are as follows:

	Reader						Significance	
Reader	3	5	8	9	12	13	No	Yes
3	-	No	Yes	No	No	Yes	3	2
5	No	-	Yes	No	No	Yes	3	2
8	Yes	Yes	-	No	No	No	3	2
9	No	No	No	-	No	No	5	0
12	No	No	No	No	-	Yes	4	1
13	Yes	Yes	No	No	Yes	-	2	3

It is obvious from this analysis that age composition data, derived from the age determinations of different age readers, may differ significantly, and that such discrepancies would greatly affect stock assessment calculations, particularly if only a limited amount of data was available. Although the differences displayed in the above table for the six readers whose age frequencies were not significantly different from the modal age frequency would probably not be critical to assessment work, a very different result would accrue if the only age composition data available were those of reader 14 on the one hand or reader 16 on the other (modal ages 5 and 7 respectively, Table 9). Similarly, recruitment prospects for age-groups 2 and 3 would appear to be much better from the age frequency of reader 11, for example, than would be the case if the only data available were those of readers 2 and 16.

Average length-at-age values, derived from the age determinations of the various readers for Sample 2 (Appendix II, Table B), are given in Table 10. Considerable variation in average length-at-age is apparent for some readers when compared with the values pertaining to the modal ages. As was indicated for the age compositions, variation from the modal ages is minimal for readers 3, 5, 8, 9, 12 and 13. The greatest negative bias relative to the modal ages is exhibited by readers 2 and 16, and the greatest positive bias by readers 7 and 11.

Table 9. Length distributions derived from age-length keys constructed from the age determinations of the various readers for Sample 2 (see Appendix II).

Age (yr)	Age reader															Modal age
	1	2	3	4	5	7	8	9	11	12	13	14	15	16	17	
2	-	-	-	-	4	-	-	-	14	-	-	12	5	-	22	-
3	27	18	38	54	52	56	38	31	80	30	32	52	69	15	44	35
4	143	64	101	213	126	199	146	128	144	131	177	164	196	54	82	141
5	235	127	196	244	154	277	222	219	244	197	193	225	201	130	225	201
6	194	310	342	273	297	261	279	265	270	313	276	202	258	154	211	304
7	193	242	185	127	197	123	154	217	122	197	138	183	131	232	177	182
8	111	143.	95	49	72	40	62	59	56	77	59	67	64	192	156	73
9	57	52	21	24	60	35	60	45	32	40	67	52	39	81	27	41
10	33	21	10	15	21	3	24	21	16	6	34	28	21	68	22	9
11	5	12	7	1	5	5	10	8	20	8	10	11	13	41	18	13
12	1	6	4	-	7	-	4	7	1	1	7	3	3	7	4	2
13	1	-	-	-	-	-	1	1	-	-	2	1	-	14	4	-
14	-	4	-	-	-	-	-	-	-	-	-	-	-	2	8	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-
NK	-	-	-	-	5	-	-	-	-	-	5	-	-	5	-	-

Table 10. Mean length-at-age values derived from the ageing data of the various readers for Sample 2 (see Appendix II).

Age (yr)	Age reader															Modal age
	1	2	3	4	5	7	8	9	11	12	13	14	15	16	17	
2	-	-	-	-	40.0	-	-	-	40.3	-	-	38.0	54.2	-	35.3	
3	37.1	35.3	37.2	40.1	37.4	38.9	38.2	36.9	39.9	37.4	35.8	39.1	41.0	34.9	39.9	36.8
4	43.7	40.2	45.4	46.4	45.2	46.5	42.2	42.0	46.3	43.8	43.9	44.4	45.8	45.2	46.4	43.0
5	49.0	47.0	46.7	51.2	48.9	51.5	48.0	47.5	50.7	48.6	51.8	50.0	51.3	46.4	51.2	48.1
6	53.4	50.8	54.8	57.9	54.2	57.6	55.3	54.4	57.5	54.7	53.6	55.1	55.8	52.0	55.1	55.4
7	61.7	57.8	60.2	62.2	60.0	65.8	60.6	60.2	61.2	60.3	60.4	60.7	64.0	52.9	57.4	61.3
8	63.4	64.3	68.8	72.7	63.5	71.8	70.1	72.0	70.9	69.7	67.7	70.5	62.7	56.4	60.0	69.0
9	66.9	66.1	73.2	68.3	67.1	63.3	72.1	72.4	73.8	70.0	67.5	68.2	74.0	59.2	68.6	73.0
10	66.5	70.5	67.9	70.1	71.5	79.2	71.4	71.7	70.8	69.2	69.1	68.8	62.8	66.9	65.6	66.7
11	66.1	75.5	81.4	82.0	84.1	70.1	74.1	78.1	60.4	60.0	57.0	74.5	72.9	69.5	68.1	62.1
12	79.0	70.3	43.0	-	51.4	-	81.2	77.3	82.0	82.0	70.3	83.4	80.3	72.9	75.4	82.0
13	82.0	-	-	-	-	-	79.0	79.0	-	-	82.0	76.0	-	68.3	81.4	-
14	-	43.0	-	-	-	-	-	-	-	-	-	-	-	82.0	55.9	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	43.0	-	-

Examination of Differences in Age Reading Through Photographs

Following the interpretation of the otoliths and the assignment of ages by the various readers, about 60 otoliths were reviewed by means of slides and the various interpretations noted on photographs. After the Workshop concluded, the Coordinators carried out a more detailed examination of the major discrepancies in the age readings in order to better point out the sources of the discrepancies. Photographs of the selected otoliths, containing notations of the interpretations, are presented in Appendix III, together with brief descriptions of the main differences between the various interpretations. Comments of a more general nature are given in the following paragraphs.

Some otoliths offered no difficulty and agreement was unanimous (e.g. otoliths 2J-58, 3L-55 and 3L-268), but many of the specimens were subject to two or more different interpretations.

Difficulties were encountered in determining the first annulus. Often a check occurs in the opaque zone before the first annulus is laid down (3Ps-127), and in some cases it was difficult to agree whether the ring is a check or the first annulus (e.g. 3L-189 and 3Ps-101). This difficulty may be compounded by cutting the otolith off-centre, thus giving a deformed annulus such as the figure-eight shape in otolith 3Ps-192. Typical first year annuli are shown in otoliths 3Ps-37, 3Ps-104 and 3Ps-155. The second annulus often appears to be characteristically clear (e.g. 3L-268 and 3Ps-104).

Different interpretations of splits or checks were the main reasons for much of the disagreement. Some otoliths (e.g. 2J-12) show many checks. In otoliths 2J-58 and 3L-134, it was agreed that a definite check occurs in the opaque zone before the second annulus and that otolith 3L-189 shows a check before the third annulus. Definite checks are also present in the second annulus of otolith 3Ps-48 and in the third annulus of otoliths 2J-85 and 3L-102. Doubtful checks are very common (e.g. otoliths 3L-6, 3L-183 and 3NO-27).

A problem was also encountered in determining whether the edge of the otolith was opaque or hyaline (e.g. 3L-183, 3L-268 and 3Ps-101). In a number of cases it was difficult to determine if there are one or more annuli at the edge (e.g. 2J-300, 3L-189, 3NO-1, 3O-65 and 3Ps-37).

DISCUSSIONS AND CONCLUSIONS

The Workshop participants concluded that the discrepancies in age reading between readers were due to the absence of clear criteria for otolith interpretation. A major source of variation in age reading is associated with the interpretation of particular rings as checks or annuli. Other difficulties involve the determination of the first annulus and the recognition of annuli at or near the edge of the otolith for older specimens. Some of the major problems are summarized as follows:

a) Splits and checks and how these may be distinguished from annuli.

b) The nucleus and determination of the first annulus.

c) Otolith edge - recognition of type (hyaline or opaque) and seasonal deposition of opaque and hyaline material.

d) The effects of cutting the otolith "off centre".

e) Peculiarities in the otoliths from specific areas (e.g. a very small first annulus in Subdiv. 4Vn cod; a very strong check before the second annulus in Div. 5Z cod).

In order to minimize the variation in interpretation and reduce subjective errors in ageing, studies should be made as the basis for establishing guidelines for otolith interpretation. These guidelines should be clearly described and illustrated by photographs, sketches, etc. In order to establish objectivity in ageing among different readers, such studies will require a great deal of tedious work. Initially, the emphasis could be placed on studies for a particular area or stock and a set of guidelines developed which could be modified as required for other areas or even for other species. Until such studies are made and guidelines adopted by age readers, the variation in interpretation of cod otoliths will not likely diminish to any significant extent.

As has been the concern of the Assessments Subcommittee in its analyses of practically all fish stocks, ageing data are in many cases incomplete, and age compositions for various areas and time periods have to be derived from age-length keys of only one or two readers. Consequently, differences in age reading of the magnitude resulting from this Workshop could seriously affect the results of population analyses. The ageing problems seem to be more critical for the northern divisions (2J, 3K and 3L) than further south, and the importance of resolving them is further stressed by the fact that nearly one-half of the annual cod catch in the Northwest Atlantic is taken in these three divisions.

In view of the urgency to resolve the problems associated with age determination of cod in various areas, the Workshop participants recommend (a) that STACRES urge its scientists to initiate studies and present papers on the interpretation of ages of, including validation of ages, seasonal deposition of material at the otolith edge, effects of cutting otoliths off-centre, and peculiarities in the otoliths of specific areas; and (b) that STACRES take whatever action is necessary to ensure that discrepancies in age composition data are eliminated or reduced as much as possible, perhaps by establishing a workshop to study the problems in a specific area and to develop a set of guidelines for otolith interpretation.

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APPENDIX I

LIST OF PARTICIPANTS IN AGEING WORKSHOP AT VIGO, SPAIN, OCTOBER 1975

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[1] Did not participate during the scheduled period of the Workshop but examined some of the material later.

APPENDIX II

Table A. Age readings for otolith sample 1.

Area	Spec. No.	Len. (cm)	Readers										Age mode
			1	2	3	4	5	6	7	8	9	10	
3K	586	58	6	-	-	-	-	-	-	6	6	-	6
	587	61	6	-	-	-	-	-	-	7	6	-	6
	588	61	6	-	-	-	-	-	-	6	6	-	6
	589	61	7	-	-	-	-	-	-	8	6	-	-
	590	61	6	-	-	-	-	-	-	7	7	-	7
	591	61	5	-	-	-	-	-	-	6	5	-	5
	592	61	-	-	-	-	-	-	-	6	6	-	6
	593	61	6	-	-	-	-	-	-	6	6	-	6
	594	61	7	-	-	-	-	-	-	8	7	-	7
	595	61	5	-	-	-	-	-	-	6	6	-	6
	596	61	6	-	-	-	-	-	-	6	6	-	6
	597	64	7	-	-	-	-	-	-	8	6	-	-
	598	64	7	-	-	-	-	-	-	8	7	-	7
	599	64	8	-	-	-	-	-	-	6	6	-	6
	600	40	4	-	-	-	-	-	-	6	5	-	-
	601	40	5	-	-	-	-	-	-	5	5	-	5
	602	40	3	-	-	-	-	-	-	4	4	-	4
	603	40	4	-	-	-	-	-	-	4	4	-	4
	604	40	4	-	-	-	-	-	-	5	4	-	4
	605	40	5	-	-	-	-	-	-	5	5	-	5
	606	40	4	-	-	-	-	-	-	4	4	-	4
	607	40	-	-	-	-	-	-	-	5	4	-	-
	608	40	2	-	-	-	-	-	-	4	4	-	4
	609	40	-	-	-	-	-	-	-	5	4	-	-
	610	43	5	-	-	-	-	-	-	5	5	-	5
	611	43	5	-	-	-	-	-	-	5	5	-	5
	612	43	4	-	-	-	-	-	-	5	5	-	5
	613	43	6	-	-	-	-	-	-	5	5	-	5
	614	43	6	-	-	-	-	-	-	6	5	-	6
	615	43	4	-	-	-	-	-	-	5	5	-	5
	616	43	5	-	-	-	-	-	-	5	5	-	5
	617	43	5	-	-	-	-	-	-	5	5	-	5
	618	43	6	-	-	-	-	-	-	5	5	-	5
	619	43	5	-	-	-	-	-	-	5	5	-	5
	620	43	5	-	-	-	-	-	-	5	5	-	5
	621	43	-	-	-	-	-	-	-	5	5	-	5
	622	43	4	-	-	-	-	-	-	5	5	-	5
	623	46	5	-	-	-	-	-	-	6	5	-	5
	624	46	5	-	-	-	-	-	-	5	6	-	5
	625	46	4	-	-	-	-	-	-	5	5	-	5
	626	46	5	-	-	-	-	-	-	6	5	-	5
	627	46	4	-	-	-	-	-	-	5	5	-	5
	628	46	4	-	-	-	-	-	-	5	5	-	5
	629	46	4	-	-	-	-	-	-	6	6	-	6
	630	46	5	-	-	-	-	-	-	5	5	-	5
	631	46	7	-	-	-	-	-	-	6	6	-	6
	632	46	7	-	-	-	-	-	-	6	6	-	6
	633	46	6	-	-	-	-	-	-	6	6	-	6
	634	46	6	-	-	-	-	-	-	6	5	-	6
	635	46	7	-	-	-	-	-	-	5	4	-	-
	636	46	6	-	-	-	-	-	-	7	5	-	-
	637	46	5	-	-	-	-	-	-	6	5	-	5
	638	43	5	-	-	-	-	-	-	6	6	-	6
	639	49	6	-	-	-	-	-	-	6	6	-	6
	640	49	6	-	-	-	-	-	-	6	6	-	6
3L	1	61	5	-	6	4	-	-	-	5	5	5	5
	2	61	6	-	7	5	-	-	-	7	6	7	7
	3	61	6	-	5	5	-	-	-	7	5	6	5
	4	64	6	-	7	7	-	-	-	7	7	7	7
	5	64	5	-	5	5	-	-	-	7	5	8	5

Table A. (continued)

Area	Spec. No.	Len. (cm)	Readers 1	2	3	4	5	6	7	8	9	10	Age mode
3L (cont'd)	6	64	6	-	6	5	-	-	-	6	6	8	6
	7	64	5	-	8	6	-	-	-	7	7	7	7
	8	73	6	-	9	5	-	-	-	7	6	7	-
	9	73	6	-	7	5	-	-	-	9	7	7	7
	10	73	5	-	7	5	-	-	-	8	6	7	-
	11	73	6	-	8	6	-	-	-	8	7	7	-
	12	73	6	-	7	5	-	-	-	7	7	8	7
	13	73	7	-	8	6	-	-	-	8	8	9	8
	14	73	3	-	7	5	-	-	-		6	7	7
	15	73	-	-	9	5	-	-	-	7	7	9	-
	16	73	6	-	8	5	-	-	-	7	7	7	7
	17	76	8	-	10	7	-	-	-	9	9	10	-
	18	76	-	-	7	5	-	-	-	8	7	10	7
	19	76	8	-	10	6	-	-	-	10	8	11	-
	20	76	6	-	8	6	-	-	-	9	8	10	-
	21	76	5	-	8	5	-	-	-	8	7	7	-
	22	76	6	-	7	6	-	-	-	8	7	7	7
	23	76	8	-	9	7	-	-	-	9	9	9	9
	24	76	6	-	8	6	-	-	-	7	7	11	-
	25	76	6	-	9	6	-	-	-	9	9	8	9
	26	76	-	9	-	-	-	-	9	8	8	10	-
	27	76	-	9	-	-	-	-	7	7	7	8	7
	28	58	-	7	-	-	-	-	7	6	6	9	-
	29	79	-	9	-	-	-	-	11	11	10	10	-
	30	79	-	8	-	-	-	-	9	10	8	9	-
	31	40	-	6	-	-	-	-	6	4	5	5	-
	32	40	-	5	-	-	-	-	5	4	5	5	5
	33	40	-	6	-	-	-	-	6	5	4	5	-
	34	40	-	5	-	-	-	-	5	5	4	5	5
	35	43	-	6	-	-	-	-	7	7	7	7	7
	36	43	-	-	-	-	-	-	6	4	4	5	4
	37	43	-	4	-	-	-	-	6	4	4	6	4
	38	43	-	4	-	-	-	-	6	5	5	5	5
	39	43	-	5	-	-	-	-	6	5	4	5	5
	40	58	-	5	-	-	-	-		5	5	4	5
	41	43	-	5	-	-	-	-	5	5	5	5	5
	42	43	-	5	-	-	-	-	4	5	4	5	5
	43	43	-	5	-	-	-	-	5	5	5	5	5
	44	43	-	5	-	-	-	-	5	4	5	4	5
	45	43	-	4	-	-	-	-	5	4	4	4	4
	46	43	-	5	-	-	-	-	8	5	5	5	5
	47	46	-	5	-	-	-	-	-	4	5	4	-
	48	46	-	5	-	-	-	-	5	5	4	5	5
	49	46	-	5	-	-	-	-	5	5	5	5	5
	50	46	-	5	-	-	-	-	5	4	5	5	5
	51	46	-	5	-	-	-	-	7	5	5	5	5
	52	46	-	5	-	-	-	-	6	5	5	5	5
	686	61	-	5	-	5	-	-	-	6	6	7	-
	687	61	-	5	-	5	-	-	-	6	6	6	6
	688	61	-	5	-	6	-	-	-	7	6	-	6
	689	61	-	6	-	6	-	-	-	7	6	-	6
	690	61	-	6	-	6	-	-	-	6	6	-	6
	691	61	-	7	-	6	-	-	-	6	6	-	6
	692	64	-	6	-	6	-	-	-	7	6	-	6
	693	64	-	6	-	5	-	-	-	6	6	-	6
	694	67	-	6	-	7	-	-	-	7	7	8	7
	695	67	-	5	-	5	-	-	-	6	6	6	6
	696	67	-	5	-	5	-	-	-	6	6	7	-
	697	67	-	6	-	6	-	-	-	7	6	-	6
	698	70	-	7	-	6	-	-	-	9	6	8	6
	699	70	-	7	-	7	-	-	-	9	8	7	7
	700	76	-	7	-	7	-	-	-	8	7	7	7
	701	34	-	3	-	2	-	-	-	3	3	3	3
	702	37	-	3	-	3	-	-	-	4	3	4	3

Table A. (continued)

Area	Spec. No.	Len. (cm)	Readers										Age mode
			1	2	3	4	5	6	7	8	9	10	
3L (cont'd)	703	37	-	4	-	4	-	-	-	4	3	4	4
	704	37	-	4	-	5	-	-	-	5	3	4	-
	705	40	-	4	-	4	-	-	-	4	3	4	4
	706	40	-	5	-	6	-	-	-	5	4	5	5
	707	40	-	4	-	5	-	-	-	5	4	5	5
	708	40	-	5	-	5	-	-	-	5	5	5	5
	709	40	-	3	-	4	-	-	-	4	5	4	4
	710	40	-	3	-	3	-	-	-	4	4	4	4
	711	40	-	4	-	5	-	-	-	5	4	5	5
	712	40	-	4	-	5	-	-	-	6	5	5	5
	713	40	-	4	-	3	-	-	5	4	4	4	4
	714	40	-	5	-	5	-	-	6	5	5	6	5
	715	40	-	5	-	4	-	-	5	5	5	5	5
	716	40	-	4	-	4	-	-	4	4	4	5	4
	717	40	-	5	-	5	-	-	5	5	4	5	5
	718	40	-	6	-	5	-	-	5	4	5	6	5
	719	43	-	6	-	6	-	-	7	5	5	6	6
	720	43	-	5	-	4	-	-	5	4	4	5	-
	721	43	-	5	-	5	-	-	6	5	5	6	5
	722	43	-	5	-	5	-	-	5	5	5	6	5
	723	43	-	3	-	3	-	-	4	4	4	5	4
	724	43	-	5	-	5	-	-	6	5	5	5	5
	725	43	-	5	-	4	-	-	-	5	5	5	5
	726	43	-	5	-	6	-	-	6	4	4	5	-
	727	43	-	6	-	5	-	-	5	6	6	6	6
	728	43	-	5	-	5	-	-	6	5	5	5	5
	729	43	-	5	-	4	-	-	6	5	4	6	-
	730	43	-	5	-	4	-	-	5	5	4	5	5
	731	43	-	7	-	5	-	-	6	6	6	6	6
	732	43	-	5	-	4	-	-	6	4	4	4	4
	733	46	-	5	-	4	-	-	5	5	5	5	5
	734	46	-	6	-	6	-	-	7	6	6	-	6
	735	46	-	6	-	6	-	-	5	6	5	6	6
	736	46	-	5	-	4	-	-	-	5	5	6	5
	737	46	-	4	-	5	-	-	-	5	5	6	5
	738	46	-	5	-	4	-	-	-	5	4	5	5
	739	46	-	-	-	-	-	-	-	5	5	6	5
30	201	55	-	-	7	-	-	7	-	5	5	-	-
	202	55	-	-	6	-	-	7	-	5	5	-	5
	203	55	-	-	7	-	-	7	-	6	6	-	-
	204	55	-	-	7	-	-	6	-	5	5	-	5
	205	58	-	-	7	-	-	7	-	6	5	-	7
	206	58	-	-	10	-	-	-	-	5	5	-	5
	207	58	-	-	9	-	-	6	-	6	5	-	6
	208	58	-	-	7	-	-	6	-	5	5	-	5
	209	58	-	-	7	-	-	6	-	5	5	-	5
	210	58	-	-	7	-	-	-	-	5	5	-	5
	211	58	-	-	7	-	-	6	-	5	6	-	6
	212	58	-	-	6	-	-	6	-	5	5	-	-
	213	58	-	-	7	-	-	6	-	5	5	-	5
	214	61	-	-	6	-	-	5	-	5	5	-	5
	215	61	-	-	6	-	-	5	-	5	5	-	5
	216	61	-	-	6	-	-	6	-	5	5	-	-
	217	61	-	-	7	-	-	8	-	6	6	-	6
	218	61	-	-	6	-	-	6	-	5	5	-	-
	219	61	-	-	6	-	-	7	-	6	5	-	6
	220	61	-	-	7	-	-	6	-	5	6	-	6
	221	61	-	-	7	-	-	5	-	6	5	-	5
	222	61	-	-	7	-	-	5	-	5	5	-	5
	223	61	-	-	7	-	-	5	-	6	6	-	6
	224	61	-	-	8	-	-	6	-	7	6	-	6
	225	73	-	-	8	-	-	7	-	6	6	-	6
	226	73	-	-	8	-	-	7	-	7	7	-	7

Table A. (continued)

Area	Spec. No.	Len. (cm)	Readers										Age mode
			1	2	3	4	5	6	7	8	9	10	
30 (cont'd)	227	73	-	6	12	-	-	-	-	7	-	-	-
	228	73	-	6	12	-	-	-	-	7	8	-	-
	229	76	-	5	14	-	-	-	-	6	7	-	-
	230	76	-	6	8	-	-	-	-	7	7	-	7
	231	76	-	4	9	-	-	-	-	6	7	-	-
	232	76	-	-	14	-	-	-	-	7	6	-	-
	233	76	-	-	13	-	-	-	-	8	7	-	-
	234	76	-	7	13	-	-	-	-	8	7	-	7
	235	76	-	5	14	-	-	-	-	7	7	-	7
	236	76	-	6	13	-	-	-	-	7	7	-	7
	237	76	-	6	14	-	-	-	-	8	7	-	-
	238	79	-	6	6	-	-	-	-	7	6	-	6
	239	79	-	6	8	-	-	-	-	7	7	-	7
	240	79	-	5	9	-	-	-	-	7	7	-	7
	241	79	-	-	10	-	-	-	-	7	7	-	7
	242	79	-	8	9	-	-	-	-	8	9	-	-
	243	79	-	7	8	-	-	-	-	6	7	-	7
	244	82	-	6	8	-	-	-	-	7	6	-	6
	245	82	-	8	9	-	-	-	-	9	8	-	-
	246	82	-	7	8	-	-	-	-	8	8	-	8
	247	85	-	8	9	-	-	-	-	7	7	-	7
	248	82	-	8	9	-	-	-	-	9	6	-	9
	249	79	-	8	10	-	-	-	-	8	8	-	8
	250	79	-	8	9	-	-	-	-	8	7	-	8
	251	73	-	6	7	-	-	-	-	7	6	-	-
	252	73	-	6	7	-	-	-	-	6	6	-	6
3P	301	64	4	6	6	5	-	-	5	5	5	5	5
	302	31	1	3	3	2	-	-	2	2	2	2	2
	303	34	2	3	3	2	-	-	3	2	2	3	-
	304	34	1	3	3	2	-	-	3	2	2	2	2
	305	34	2	3	3	2	-	-	3	2	2	2	2
	306	34	2	3	3	2	-	-	4	2	2	2	2
	307	37	2	3	3	2	-	-	3	2	2	2	2
	308	37	2	3	3	2	-	-	4	2	2	2	2
	309	37	2	3	3	2	-	-	3	2	2	2	2
	310	37	2	3	4	3	-	-	4	3	3	3	3
	311	37	4	4	4	5	-	-	6	3	3	5	4
	312	37	-	3	3	3	-	-	4	3	2	3	3
	313	49	3	3	4	4	-	-	5	3	3	3	3
	314	55	4	4	3	5	-	-	7	4	4	4	4
	315	55	4	4	5	4	-	-	6	5	4	6	4
	316	55	5	5	6	5	-	-	7	5	5	6	5
	317	55	4	5	5	4	-	-	5	4	4	4	4
	318	55	4	4	5	4	-	-	5	4	4	6	4
	319	55	5	5	5	5	-	-	7	5	4	5	5
	320	55	5	5	6	6	-	-	6	5	5	5	5
	321	55	4	4	6	5	-	-	8	4	4	4	4
	322	55	4	4	5	4	-	-	5	4	4	4	4
	323	55	5	5	6	5	-	-	6	5	5	5	5
	324	55	4	5	7	5	-	-	5	5	5	5	5
	325	55	4	5	6	5	-	-	6	5	5	5	5
	326	55	5	5	7	6	-	-	8	6	6	8	6
	327	55	5	5	-	-	-	-	5	4	4	6	5
	328	58	4	5	-	-	-	-	5	4	5	5	5
	329	58	5	5	-	-	-	-	6	3	5	6	5
	330	58	5	5	-	-	-	-	5	5	5	5	5
	331	58	5	5	-	-	-	-	5	5	5	5	5
	332	58	5	5	-	-	-	-	5	5	5	6	5
	333	58	5	5	-	-	-	-	6	5	5	6	5
	334	58	-	-	-	-	-	-	4	4	5	5	-
	335	58	-	4	-	-	-	-	6	4	5	6	-
	336	58	-	5	-	-	-	-	8	5	5	6	5
	337	58	-	5	-	-	-	-	5	5	5	5	5

Table A. (continued)

Area	Spec. No.	Len. (cm)	Readers										Age mode
			1	2	3	4	5	6	7	8	9	10	
3P (cont'd)	338	58	-	6	-	-	-	-	7	5	5	6	-
	339	58	-	5	-	-	-	-	5	5	5	5	5
	340	61	-	5	-	-	-	-	6	5	5	5	5
	341	61	-	5	-	-	-	-	6	5	6	7	-
	342	40	-	-	-	-	-	-	-	2	2	3	2
	343	40	-	4	-	-	-	-	5	2	3	4	4
	344	40	-	3	-	-	-	-	3	2	2	2	2
	345	40	-	2	-	-	-	-	4	2	3	2	2
	346	40	-	-	-	-	-	-	-	3	3	2	3
	347	40	-	3	-	-	-	-	4	3	3	3	3
	348	40	-	3	-	-	-	-	4	3	3	3	3
	349	40	-	2	-	-	-	-	5	3	2	3	-
	350	40	-	3	-	-	-	-	3	3	3	3	3
	351	40	-	2	-	-	-	-	-	3	2	3	-
	352	43	-	4	-	-	-	-	5	4	4	4	4
4Vn	401	40	3	3	-	3	-	-	3	4	-	-	3
	402	43	4	3	-	3	-	-	5	4	-	-	-
	403	43	3	3	-	4	-	-	4	3	-	-	3
	404	43	3	4	-	5	-	-	4	4	-	-	4
	405	43	3	4	-	3	-	-	4	4	-	-	4
	406	46	2	-	-	4	-	-	4	3	-	-	4
	407	46	4	4	-	4	-	-	6	4	-	-	4
	408	46	3	4	-	3	-	-	3	4	-	-	3
	409	49	4	5	-	3	-	-	5	5	-	-	5
	410	49	5	5	-	5	-	-	5	5	-	-	5
	411	49	4	6	-	4	-	-	5	4	-	-	4
	412	52	3	5	-	3	-	-	4	4	-	-	-
	413	52	5	6	-	4	-	-	5	5	-	-	5
	414	52	4	6	-	4	-	-	5	5	-	-	-
	415	52	4	5	-	5	-	-	4	5	-	-	5
	416	52	5	5	-	5	-	-	4	5	-	-	5
	417	55	5	6	-	5	-	-	4	5	-	-	5
	418	55	4	5	-	5	-	-	4	5	-	-	5
	419	55	4	5	-	4	-	-	4	5	-	-	4
	420	55	4	5	-	4	-	-	5	5	-	-	5
	421	55	4	5	-	5	-	-	5	5	-	-	5
	422	55	4	4	-	4	-	-	4	4	-	-	4
	423	55	4	5	-	4	-	-	5	5	-	-	5
	424	58	5	6	-	6	-	-	6	6	-	-	6
	425	58	6	7	-	7	-	-	6	7	-	-	7
	426	58	6	6	-	6	-	-	8	8	-	-	6
	427	58	-	6	-	4	-	-	5	5	-	-	5
	428	58	-	7	-	7	-	-	7	8	-	-	7
	429	58	-	7	-	5	-	-	6	6	-	-	6
	430	58	-	5	-	5	-	-	5	5	-	-	5
	431	58	-	6	-	5	-	-	5	5	-	-	5
	432	58	-	6	-	5	-	-	5	5	-	-	5
	433	61	-	8	-	9	-	-	8	8	-	-	8
	434	61	-	6	-	4	-	-	5	5	-	-	5
	435	61	-	7	-	7	-	-	6	7	-	-	7
	436	61	-	6	-	-	-	-	7	8	-	-	-
	437	61	-	7	-	7	-	-	7	7	-	-	7
	438	61	-	7	-	6	-	-	6	7	-	-	-
	439	61	-	6	-	6	-	-	5	5	-	-	-
	440	61	-	7	-	5	-	-	5	5	-	-	5
	441	61	-	6	-	6	-	-	5	5	-	-	-
	442	61	-	6	-	6	-	-	5	5	-	-	-
	443	64	-	-	-	-	-	-	9	8	-	-	-
	444	64	-	7	-	7	-	-	8	7	-	-	7
	445	64	-	6	-	5	-	-	5	4	-	-	5
	446	64	-	9	-	9	-	-	8	9	-	-	9
	447	64	-	8	-	7	-	-	8	8	-	-	8
	448	64	-	7	-	6	-	-	6	7	-	-	-

Table A. (continued)

Area	Spec. No.	Len. (cm)	Readers										Age mode
			1	2	3	4	5	6	7	8	9	10	
4Vn	449	64	-	7	-	7	-	-	7	8	-	-	7
(cont'd)	450	64	-	5	-	5	-	-	4	5	-	-	5
	451	64	-	6	-	5	-	-	6	5	-	-	-
5Z	486	70	4	4	-	3	4	-	-	4	-	-	4
	487	70	4	5	-	4	4	-	-	4	-	-	4
	488	70	6	6	-	4	5	-	-	5	-	-	-
	489	70	5	5	-	4	4	-	-	4	-	-	4
	490	70	8	7	-	6	8	-	-	8	-	-	8
	491	70	5	5	-	4	4	-	-	4	-	-	4
	492	70	5	5	-	4	4	-	-	4	-	-	4
	493	70	5	5	-	4	5	-	-	4	-	-	5
	494	70	4	4	-	3	4	-	-	4	-	-	4
	495	70	4	4	-	3	4	-	-	4	-	-	4
	496	70	5	5	-	4	5	-	-	5	-	-	5
	497	73	7	6	-	6	7	-	-	7	-	-	7
	498	73	4	4	-	3	4	-	-	4	-	-	4
	499	73	5	6	-	4	5	-	-	5	-	-	5
	500	73	4	4	-	3	4	-	-	4	-	-	4
	501	19	-	-	-	2	1	-	-	1	-	-	1
	502	28	2	2	-	2	2	-	-	2	-	-	2
	503	34	2	2	-	2	2	-	-	2	-	-	2
	504	34	3	2	-	2	2	-	-	2	-	-	2
	505	34	3	2	-	2	2	-	-	2	-	-	2
	506	37	4	3	-	3	2	-	-	2	-	-	-
	507	37	3	2	-	2	2	-	-	2	-	-	2
	508	37	4	2	-	3	2	-	-	2	-	-	2
	509	37	3	3	-	3	2	-	-	2	-	-	3
	510	37	3	3	-	2	2	-	-	2	-	-	2
	511	37	2	2	-	2	2	-	-	2	-	-	2
	512	37	3	3	-	2	2	-	-	2	-	-	2
	513	40	-	3	-	3	2	-	-	2	-	-	-
	514	40	2	3	-	3	2	-	-	2	-	-	2
	515	40	2	3	-	2	2	-	-	2	-	-	2
	516	40	4	-	-	2	2	-	-	2	-	-	2
	517	40	3	3	-	2	2	-	-	2	-	-	2
	518	40	4	4	-	3	2	-	-	3	-	-	-
	519	40	3	3	-	2	2	-	-	2	-	-	2
	520	40	4	4	-	2	2	-	-	3	-	-	-
	521	40	3	2	-	3	2	-	-	3	-	-	3
	522	40	4	4	-	3	2	-	-	3	-	-	-
	523	40	5	-	-	2	2	-	-	3	-	-	2
	524	40	3	3	-	3	2	-	-	2	-	-	3
	525	40	3	3	-	2	2	-	-	2	-	-	2
	526	40	-	2	-	2	2	-	-	3	-	-	2
	527	43	3	3	-	3	3	-	-	3	-	-	3
	528	43	2	2	-	2	2	-	-	3	-	-	2
	529	43	2	2	-	2	2	-	-	3	-	-	2
	530	43	2	2	-	2	2	-	-	3	-	-	2
	531	43	2	2	-	2	2	-	-	2	-	-	2
	532	43	2	2	-	2	2	-	-	2	-	-	2
	533	43	2	3	-	2	2	-	-	3	-	-	2
	534	43	2	2	-	2	2	-	-	2	-	-	2
	535	43	4	3	-	3	2	-	-	2	-	-	-
	536	43	3	3	-	3	2	-	-	2	-	-	3
	537	43	2	3	-	2	2	-	-	2	-	-	2

Table B. Age readings for otolith sample 2.

Area	Spec. No.	Len. (cm)	Sex. mat.	Readers 1	2	3	4	5	7	8	9	11	12	13	14	15	16	17	Age mode
2J	1	34	10	4	4	3	4	-	4	4	4	3	4	4	4	3	5	3	4
	2	37	10	4	3	3	4	-	5	4	4	2	4	4	2	3	-	2	4
	3	37	10	5	4	4	5	-	4	4	4	3	4	4	4	3	5	4	4
	6	40	10	4	3	4	4	-	3	4	4	2	3	4	4	3	4	3	4
	12	40	11	5	6	5	-	-	5	5	5	3	5	6	4	4	6	3	5
	13	43	11	6	5	5	5	-	6	5	5	2	6	6	4	4	7	4	5
	14	46	11	5	6	5	6	-	6	6	6	3	6	6	4	5	7	4	6
	17	49	11	5	7	6	6	-	5	6	6	3	6	7	6	6	-	-	6
	20	49	11	7	7	6	6	7	5	6	6	7	7	-	6	7	7	7	7
	24	52	11	7	7	7	6	7	6	7	7	7	7	-	7	7	8	6	7
	25	52	11	5	6	6	4	5	5	6	6	5	5	-	5	6	6	5	5
	27	55	11	-	9	6	7	6	7	7	7	8	7	-	7	7	-	-	7
	33	58	11	4	4	4	5	-	4	7	7	5	4	5	4	3	4	4	4
	34	58	11	6	6	7	6	-	7	9	8	5	5	9	8	7	-	-	-
	36	61	11	7	8	8	8	-	8	8	7	8	8	8	8	8	8	8	8
	37	61	11	6	7	6	7	-	6	7	7	7	7	9	7	7	9	10	7
	38	64	11	7	-	7	7	-	7	7	7	5	6	9	7	7	7	-	7
	42	67	11	-	8	7	8	-	8	8	8	8	7	10	9	10	11	11	8
	43	67	11	9	11	10	10	-	9	10	10	10	9	10	10	10	10	11	10
	49	70	11	7	8	7	8	-	8	8	8	8	7	9	8	10	8	-	8
	50	70	11	9	8	8	9	-	8	9	10	8	8	9	8	9	9	11	-
	53	73	11	10	8	8	6	7	8	10	9	10	8	-	10	9	-	8	8
	54	76	11	-	10	11	7	12	10	10	11	11	10	-	13	12	11	-	-
	58	37	50	4	5	4	4	-	4	4	4	3	4	4	4	4	5	4	4
	59	40	50	-	4	4	4	-	3	4	4	2	4	4	4	4	4	3	4
	60	43	50	3	5	4	4	-	3	4	4	3	4	4	4	4	4	3	4
	62	43	50	-	5	4	4	-	4	4	7	-	6	-	6	5	7	5	4
	63	46	50	6	6	6	7	-	6	5	7	4	6	7	6	6	7	4	6
	66	49	50	7	6	6	5	6	5	6	6	7	7	-	6	7	7	5	6
	67	52	50	7	7	6	5	6	6	6	6	5	7	-	6	8	8	5	6
	74	55	51	7	6	7	7	-	7	7	7	6	6	7	6	6	8	6	7
	79	58	51	6	6	6	8	-	7	8	7	5	6	10	8	8	9	10	-
	85	61	51	7	7	7	7	-	6	8	7	7	7	7	7	7	7	7	7
	92	64	51	6	8	5	7	-	6	8	7	6	5	7	7	7	8	8	7
	94	64	51	9	9	9	10	-	11	11	10	10	9	12	11	11	11	10	11
	99	67	51	9	9	9	10	-	9	9	9	8	9	10	9	9	10	-	9
	105	70	51	10	8	7	7	9	8	10	9	9	8	-	10	10	11	9	-
	107	73	50	-	7	6	6	6	6	8	8	7	7	-	7	7	-	6	-
	108	73	51	9	9	8	9	10	9	9	9	10	9	-	9	9	10	8	9
	121	76	51	8	10	8	7	9	9	12	12	9	8	-	9	9	10	10	9
	122	76	51	9	10	8	8	7	8	11	11	9	9	-	11	9	10	7	9
	129	79	51	9	8	8	-	-	7	11	11	9	-	11	10	11	13	9	11
	130	79	51	-	9	7	9	7	7	13	13	9	8	-	8	8	9	8	-
	135	82	51	8	9	-	8	-	6	10	10	8	-	9	9	8	-	7	8
	136	82	51	-	12	8	-	9	10	12	12	11	8	-	12	11	13	-	12
	178	79	51	12	11	9	9	7	9	11	11	11	11	-	11	12	11	14	11
	243	46	10	6	6	5	6	-	7	5	5	3	6	6	5	5	7	5	5
	299	85	51	10	11	11	10	-	11	12	12	11	11	12	12	12	13	13	-
	300	85	51	8	10	8	8	-	8	9	9	10	-	10	9	9	11	-	-
3K	317	34	10	4	4	4	3	3	4	3	3	3	4	3	2	2	5	-	3
	318	34	10	4	4	4	4	4	4	4	4	3	4	4	2	4	5	3	4
	320	37	10	-	6	5	5	5	5	4	5	5	6	-	4	6	5	-	5
	321	37	10	7	6	5	5	4	5	4	4	-	4	7	3	4	5	4	4
	322	37	10	-	-	7	4	8	6	4	5	5	7	-	3	3	8	-	-
	326	40	10	4	6	5	3	2	3	4	4	3	4	4	3	3	7	5	-
	327	40	10	4	6	5	4	6	4	5	5	4	5	-	2	4	6	6	4
	328	40	10	4	6	-	5	3	4	5	5	5	5	4	2	4	8	6	5
	330	43	10	5	6	6	5	5	5	5	5	5	6	5	5	5	7	5	5
	331	43	10	-	14	12	9	12	9	4	4	11	11	11	10	10	15	14	11
	332	43	10	4	6	4	4	4	4	5	4	4	4	4	4	4	-	7	4
	334	46	10	8	7	5	5	6	6	6	4	4	5	5	4	8	7	4	-
	335	46	10	5	7	6	4	5	4	6	5	5	5	4	5	3	9	6	5
	336	49	10	4	7	6	6	4	-	5	5	4	6	6	4	3	9	-	-

Table B. (continued)

Area	Spec. No.	Len. (cm)	Sex. mat.	Readers															Age mode
				1	2	3	4	5	7	8	9	11	12	13	14	15	16	17	
3K	337	49	10	6	6	5	5	6	6	5	5	6	7	7	4	5	7	6	6
(cont'd)	339	49	11	7	7	7	5	8	4	5	5	7	5	5	3	4	9	8	5
	340	52	11	8	8	7	5	7	6	6	6	7	7	6	7	5	8	6	-
	345	49	11	5	6	6	6	5	5	6	6	5	6	6	6	6	8	6	6
	348	55	11	8	7	7	7	8	7	7	7	7	6	7	7	8	8	7	7
	349	61	11	10	8	6	7	9	8	7	7	7	6	9	7	4	11	6	7
	350	64	11	11	12	10	9	10	9	10	10	11	10	10	9	10	11	9	10
	351	70	11	7	7	7	6	8	7	8	8	7	7	9	7	7	10	7	7
	352	61	11	8	7	6	4	6	5	7	7	7	6	5	5	4	10	6	-
	361	52	10	-	5	6	5	6	5	6	6	6	6	5	4	6	9	-	6
	366	34	50	4	6	5	4	3	4	4	4	4	6	3	4	3	6	5	4
	398	55	50	4	6	6	5	4	4	5	6	5	6	5	5	4	7	5	5
	399	55	50	8	8	7	6	7	5	6	6	5	7	-	5	6	8	6	6
	401	52	51	10	10	8	7	9	9	6	7	11	8	-	9	8	13	8	8
	403	58	51	8	7	7	7	-	6	7	7	7	7	7	7	5	8	6	7
	404	61	51	9	9	8	7	-	9	8	8	8	8	8	8	2	10	7	8
	405	61	51	8	7	7	6	7	6	7	7	6	7	9	7	7	8	5	7
	406	55	51	-	7	5	5	5	4	6	7	6	6	5	6	6	7	4	6
	422	67	51	10	8	7	7	8	6	9	9	6	7	8	8	9	10	6	8
	423	79	51	9	7	8	-	10	7	10	10	7	9	-	8	6	11	-	
	428	82	51	9	9	8	6	8	7	10	8	8	8	9	8	7	9	5	8
	429	58	51	-	7	6	6	6	7	7	7	6	6	7	7	6	-	-	-
	430	76	51	8	7	6	6	7	-	8	8	5	6	6	6	5	7	5	6
	464	58	11	8	8	6	7	8	7	7	7	6	7	7	7	7	4	7	7
	465	67	11	-	8	9	5	9	6	9	9	9	9	11	9	9	10	7	9
	470	64	51	7	8	7	6	7	7	7	7	6	8	8	7	6	8	7	7
	517	58	51	7	9	7	6	7	7	6	7	-	7	8	7	5	-	4	7
	530	82	11	13	12	7	-	10	-	10	9	8	7	10	9	7	14	9	-
	531	67	51	-	9	8	6	9	7	10	8	-	9	9	9	11	-	-	9
	548	64	11	6	8	7	6	7	6	9	7	7	7	6	8	7	11	7	7
	583	79	11	6	7	6	6	6	6	8	11	5	7	7	6	4	9	7	6
	635	70	51	8	8	8	7	9	-	9	9	9	9	9	8	8	10	7	9
3L	1	34		5	4	4	3	4	3	4	4	3	4	3	3	3	6	3	3
	2	34		3	4	3	4	3	3	3	4	3	3	3	3	3	3	2	3
	6	37		5	4	5	5	5	4	4	5	4	4	4	3	4	8	5	4
	7	37		4	4	4	4	3	3	4	4	4	4	3	4	4	5	-	4
	10	37		-	5	5	5	6	4	6	6	5	4	4	5	4	8	5	5
	24	40		5	5	6	5	6	5	5	6	5	6	6	5	5	5	4	5
	25	40		5	4	5	4	4	4	4	4	4	5	4	4	4	7	5	4
	26	40		6	5	6	6	6	6	5	6	6	5	6	6	6	6	5	6
	39	43		5	5	5	4	5	4	5	6	4	5	-	4	5	6	5	5
	40	43		6	6	7	6	6	5	5	5	6	7	6	5	5	7	6	6
	41	43		6	6	6	6	6	5	6	5	5	6	5	5	6	7	-	6
	55	46		4	4	7	4	4	3	4	4	4	4	4	4	4	5	-	4
	56	46		5	6	6	5	4	4	5	5	5	5	6	5	5	8	6	5
	57	46		6	6	6	6	6	6	6	6	6	6	6	6	6	7	8	6
	66	49		5	5	6	4	4	4	4	5	4	4	4	5	5	5	-	4
	67	49		6	6	6	6	6	6	6	6	6	6	6	6	6	7	7	6
	68	49		-	7	7	5	7	5	7	7	7	5	6	7	7	8	8	7
	88	52		5	6	6	4	-	6	6	6	5	5	6	5	4	-	-	6
	89	52		5	7	5	4	6	4	5	5	4	4	5	5	4	7	-	5
	90	52		5	7	4	4	5	6	7	6	5	4	5	6	4	8	8	-
	101	55		6	6	5	4	5	5	6	6	6	5	6	5	6	6	6	6
	102	55		7	6	6	6	6	6	7	6	6	6	6	6	6	6	7	6
	103	55		7	7	4	4	7	4	7	5	6	6	6	7	4	7	6	7
	112	58		-	7	6	5	8	-	6	6	6	7	7	6	6	8	-	6
	113	58		-	6	6	5	7	5	6	6	6	6	6	5	5	-	-	6
	114	58		7	6	6	5	6	6	7	6	6	6	6	6	5	-	5	6
	132	61		7	6	6	6	7	5	7	6	6	6	6	6	5	7	-	6
	133	61		6	7	6	5	6	6	6	6	6	6	6	6	6	6	6	6
	134	61		7	8	6	5	6	5	6	6	6	6	6	6	6	8	5	6
	155	64		-	8	7	6	8	7	9	8	7	7	-	7	7	-	-	7
	156	64		7	7	6	4	5	5	6	7	6	6	-	7	6	8	-	6

Table B. (continued)

Area	Spec. No.	Len. (cm)	Sex. mat.	Readers 1	2	3	4	5	7	8	9	11	12	13	14	15	16	17	Age mode
3L (cont'd)	157	64		8	8	6	-	9	5	8	7	6	7	8	7	7	10	-	-
	169	67		7	9	6	5	7	6	6	6	6	6	8	6	7	8	9	6
	170	67		9	9	9	8	10	8	10	9	9	9	9	9	9	10	8	9
	171	67		8	7	8	-	9	6	9	10	9	8	-	10	8	-	11	8
	177	70		6	7	7	6	6	6	9	6	6	6	-	8	6	8	11	6
	178	70		7	8	8	6	8	7	8	8	9	8	-	9	7	8	-	8
	179	70		6	7	7	6	6	6	7	6	8	7	-	6	6	8	7	6
	183	73		8	8	8	6	9	6	8	7	8	8	-	7	8	9	8	8
	184	73		8	7	8	7	7	-	8	8	7	8	-	7	8	11	-	8
	185	73		10	9	8	7	10	9	9	9	7	8	-	10	11	11	12	9
	188	76		7	-	7	6	8	7	9	8	7	7	-	8	9	11	9	7
	189	76		10	9	10	8	-	-	11	11	10	10	-	11	8	11	13	-
	191	79		6	7	6	7	6	6	9	6	9	6	-	6	6	10	10	6
	192	79		8	9	8	8	8	8	9	8	8	8	-	9	8	9	-	8
	193	79		7	8	7	7	9	9	9	9	7	7	-	9	10	10	14	-
	258	82		-	7	7	8	7	7	9	7	8	7	-	9	7	11	12	7
	268	82		10	10	11	9	-	8	11	11	11	11	-	11	11	12	10	11
	269	82		-	11	11	9	11	10	12	12	12	12	-	12	11	12	14	12
3NO	1	37		4	6	4	4	-	4	4	4	4	4	4	4	4	5	6	4
	2	40		4	6	4	3	4	4	4	4	3	4	4	4	4	5	6	4
	5	40		4	7	5	4	4	4	4	4	4	4	4	4	4	4	7	4
	8	40		4	6	5	4	4	4	4	4	4	4	4	4	4	5	5	4
	9	43		-	6	4	4	5	4	4	4	5	5	4	4	4	7	4	4
	11	43		4	7	5	4	4	4	4	4	4	5	4	4	4	6	7	4
	13	43		4	5	4	4	4	4	4	4	4	4	4	4	4	4	5	4
	15	46		4	5	4	4	4	4	4	4	4	4	4	4	4	5	5	4
	16	46		4	5	4	3	-	4	3	4	4	4	4	3	3	5	5	4
	17	46		-	7	5	-	4	-	5	5	-	5	-	4	5	8	6	5
	26	49		4	-	5	4	-	5	5	5	4	5	4	5	4	7	-	5
	27	49		4	6	5	4	4	4	4	4	4	5	5	4	4	7	5	4
	28	49		5	-	6	5	6	5	4	5	5	5	5	5	5	9	5	5
	38	52		-	8	6	5	6	5	6	6	6	6	6	5	5	7	8	6
	40	52		5	-	5	4	4	4	5	5	5	5	5	4	5	8	5	5
	41	52		-	8	6	5	7	5	6	6	6	6	6	7	6	9	8	6
	43	55		5	5	6	3	6	4	5	7	4	5	5	6	4	-	5	5
	45	55		6	5	6	4	7	4	5	7	4	-	6	5	4	6	-	
	46	58		7	7	8	6	7	6	7	7	8	7	8	7	6	8	6	7
	47	58		-	7	8	7	7	6	7	7	7	8	7	7	5	8	-	7
	49	61		7	8	7	6	8	5	7	7	7	7	7	7	7	7	7	7
	50	61		7	7	7	7	7	6	7	7	7	7	7	7	6	7	7	7
	51	61		9	6	6	6	6	6	6	7	6	6	6	6	6	7	-	6
	54	64		-	-	6	-	-	6	6	6	6	6	5	5	6	-	-	6
	57	64		8	7	6	6	6	6	6	6	6	7	6	6	6	7	-	6
	59	64		10	8	8	6	8	7	7	7	6	9	8	8	8	9	8	8
	60	67		9	7	8	6	7	7	7	9	6	7	7	7	6	12	-	7
	61	67		9	-	6	5	6	5	7	7	5	6	-	7	6	-	-	6
	64	67		8	8	7	6	7	7	7	8	7	7	7	7	8	7	8	7
	66	70		-	6	7	5	8	6	7	7	6	7	7	7	6	8	-	7
	67	70		7	7	7	6	7	7	7	7	7	7	7	7	7	7	6	7
	68	70		8	6	6	6	6	6	7	7	7	6	6	7	7	9	-	6
	70	73		7	5	6	5	7	6	6	7	6	6	7	7	7	7	8	7
	71	73		7	7	7	7	-	6	9	9	7	-	-	7	5	8	-	7
	72	73		8	8	8	9	-	7	10	8	8	8	-	8	8	10	7	8
	74	76		8	8	8	7	-	7	8	8	7	8	-	8	7	-	7	8
	75	76		8	9	8	8	-	7	8	8	8	9	-	9	7	10	8	8
	76	76		7	7	7	7	-	6	7	7	6	6	-	7	6	7	7	7
	77	79		7	8	8	6	-	6	7	7	6	7	-	7	7	8	7	7
	78	79		7	7	7	6	-	7	7	7	7	-	-	8	7	7	7	7
	79	79		11	12	11	8	-	9	11	11	8	9	-	10	8	11	-	11
	82	82		10	10	11	10	-	8	11	11	11	9	-	10	9	11	10	-
	83	82		-	11	9	11	-	8	11	10	7	8	-	10	7	11	10	11
	84	82		8	7	7	6	-	7	7	8	6	8	-	8	7	8	-	-
	85	85		9	8	9	8	-	8	10	9	9	8	-	10	9	10	-	9

Table B. (continued)

Area	Spec. No.	Len. (cm)	Sex. mat.	Readers															Age mode
				1	2	3	4	5	7	8	9	11	12	13	14	15	16	17	
3NO	86	85		-	-	9	-	-	9	9	9	9	9	-	11	9	-	8	9
(cont'd)	87	88		-	8	8	7	-	7	8	7	9	7	-	8	7	-	-	7
	88	88		7	7	8	8	-	6	8	7	9	7	-	8	7	10	-	7
	89	91		7	8	8	8	-	7	8	8	8	8	-	8	7	-	6	8
30	1	34		4	4	5	4	5	5	4	4	5	5	4	5	5	5	7	5
	2	34		3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	3
	3	34		5	4	5	5	5	5	4	4	5	5	5	5	4	5	5	5
	4	37		4	4	4	3	4	4	4	4	3	4	4	4	4	4	-	4
	5	40		6	4	5	5	6	6	4	5	5	6	6	6	6	6	7	6
	6	40		4	4	5	4	5	5	5	5	4	5	4	4	4	4	5	4
	7	40		5	5	5	4	5	5	5	5	5	5	4	5	4	5	6	5
	15	43		5	5	5	5	5	5	5	5	5	5	5	5	4	5	-	5
	16	43		6	6	5	4	6	5	5	5	5	7	6	5	5	6	7	5
	17	43		-	6	6	4	4	5	4	4	5	5	6	5	4	5	7	-
	25	46		6	6	6	6	6	6	5	6	6	6	6	6	6	6	5	6
	26	46		5	5	5	5	6	5	4	5	5	5	-	5	5	6	-	5
	27	46		5	6	5	4	5	5	5	5	5	6	5	5	6	6	6	5
	35	49		5	6	6	5	6	5	5	6	6	6	5	5	6	6	8	6
	36	49		6	6	6	4	6	5	5	5	6	6	6	6	6	6	7	6
	48	52		8	8	8	8	7	5	6	6	6	8	-	-	5	8	8	8
	55	55		9	9	7	7	9	5	6	6	4	7	-	-	5	8	7	7
	56	55		-	-	7	6	7	5	6	7	5	6	-	-	5	8	-	-
	57	55		-	8	7	6	6	5	6	6	6	6	-	-	6	7	7	6
	65	58		6	6	6	6	6	5	6	7	6	6	-	-	5	6	5	6
	66	58		6	6	6	5	7	6	6	6	5	6	-	-	6	7	5	6
	67	58		7	7	7	6	7	5	6	6	5	7	-	-	6	10	8	7
	76	61		5	5	7	6	6	5	6	7	6	7	-	-	7	7	-	7
	77	61		-	6	6	6	7	5	6	7	5	6	-	-	6	8	6	6
	78	61		6	6	7	4	-	4	5	6	4	6	-	-	5	-	-	6
	86	64		7	6	6	6	7	5	6	7	5	6	-	-	6	7	6	6
	87	64		8	-	7	6	7	-	7	7	-	7	-	-	7	11	9	7
	88	64		7	6	6	6	6	6	7	7	6	6	-	-	6	7	-	6
	102	67		8	7	6	7	6	6	6	7	6	7	-	-	7	8	-	-
	103	67		7	6	6	6	6	6	6	6	6	6	-	-	6	6	5	6
	108	67		7	6	7	6	6	6	6	6	5	6	-	-	6	7	8	6
	113	70		7	7	7	7	7	6	7	8	7	7	-	-	7	9	-	7
	115	70		8	7	7	7	8	5	7	7	7	7	-	-	8	9	7	7
	119	70		-	11	10	10	10	7	9	12	10	8	10	10	10	10	8	10
	120	73		6	7	6	6	6	5	6	7	6	6	6	6	6	6	-	6
	121	73		7	8	7	7	7	6	8	8	7	7	7	7	7	-	8	7
	122	76		7	11	7	8	8	7	8	8	8	7	10	8	7	12	9	8
	123	76		7	10	7	9	10	7	7	7	7	7	9	9	7	10	-	7
	124	76		5	7	6	6	7	6	6	6	6	6	6	6	6	8	5	6
	131	79		6	7	6	6	6	5	6	7	6	6	6	6	6	6	5	6
	132	79		7	7	-	7	8	7	8	8	8	7	7	7	7	8	6	7
	133	79		9	9	-	9	9	7	9	9	8	7	9	9	9	13	-	9
	140	82		10	10	8	8	9	8	9	9	9	8	10	10	9	14	7	9
	141	85		8	9	9	9	7	8	9	10	9	9	8	8	9	10	8	9
	142	85		8	-	-	8	11	7	9	8	8	8	8	8	9	13	-	8
	143	85		8	-	-	-	9	7	9	9	7	7	8	10	9	13	8	9
	146	88		-	-	8	-	8	7	9	10	6	8	-	9	-	-	6	8
	147	88		7	10	8	8	8	7	9	9	8	7	8	8	8	9	5	8
	149	88		7	8	8	7	9	7	9	10	7	8	7	11	11	-	5	7
3Ps	1	31	10	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3
	2	34	50	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3
	3	34	10	4	4	-	3	3	3	3	3	3	4	3	3	3	4	2	3
	4	34	10	3	3	3	3	3	3	3	3	3	3	3	3	3	4	2	3
	5	37	10	3	4	3	3	3	3	3	3	3	3	3	3	3	3	2	3
	6	37	10	4	4	3	3	3	3	3	3	3	4	4	3	3	6	3	3
	7	37	50	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3
	9	40	50	4	4	3	4	3	4	4	4	4	4	4	4	4	7	3	4

Table B. (continued)

Area	Spec. No.	Len. (cm)	Sex. mat.	Readers 1	2	3	4	5	7	8	9	11	12	13	14	15	16	17	Age mode
3Ps	10	40	10	-	-	3	3	3	3	3	3	3	3	3	3	4	4	3	3
(cont'd)	11	40	10	3	4	3	3	3	3	3	3	3	3	3	3	3	3	2	3
	23	43	10	5	5	4	4	4	4	4	4	4	4	4	4	4	7	3	4
	25	43	50	-	4	3	3	3	3	3	3	3	3	4	4	3	5	3	3
	33	43	10	5	5	5	5	5	4	5	5	5	5	5	5	5	6	4	5
	37	46	50	6	6	-	7	7	5	5	5	6	6	7	7	6	7	5	-
	41	46	10	5	5	5	5	5	4	5	5	5	5	5	5	5	5	4	5
	45	46	11	5	5	5	5	5	4	5	5	5	4	5	5	5	5	4	5
	52	49	50	-	-	6	6	6	6	5	5	5	6	-	5	4	10	5	-
	53	49	50	4	5	4	4	4	4	4	4	4	4	4	4	4	4	-	4
	58	49	50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	67	52	51	5	6	-	5	5	5	5	5	5	5	4	5	5	5	6	5
	73	52	11	6	6	-	6	6	6	6	6	6	5	6	6	6	6	6	6
	77	52	11	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	82	55	10	5	5	4	5	5	4	5	5	5	5	4	5	5	5	5	5
	86	55	11	6	7	6	6	6	6	6	6	6	6	6	6	6	6	8	6
	93	55	50	5	7	5	5	5	5	5	5	5	5	5	5	5	5	7	5
	101	58	11	5	6	4	5	5	5	6	5	5	4	4	5	5	5	5	5
	102	58	50	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5
	104	58	11	7	8	6	5	7	7	6	6	6	7	6	6	7	7	7	7
	117	61	50	6	7	6	5	7	7	6	6	6	7	5	7	6	7	8	-
	120	61	11	5	6	5	5	5	5	5	5	5	5	5	5	6	5	6	5
	126	61	11	6	7	6	6	6	6	6	6	6	6	5	6	6	6	7	6
	127	64	11	-	6	5	6	6	6	6	6	6	-	5	6	5	6	6	6
	143	64	51	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	148	64	51	9	8	8	7	9	7	8	9	6	9	9	9	9	9	7	9
	155	67	11	5	7	6	6	6	6	6	6	5	6	7	6	6	-	6	6
	163	67	51	6	7	6	6	6	6	6	6	6	6	6	6	6	6	5	6
	170	67	51	6	7	7	6	6	6	7	7	6	6	6	7	6	6	7	6
	173	70	51	6	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	174	70	51	6	7	6	6	6	6	6	6	6	6	6	6	6	6	8	6
	175	70	11	9	9	8	7	9	8	9	9	9	-	9	9	8	9	9	9
	178	73	11	8	8	8	7	8	8	8	8	8	8	8	8	8	8	8	8
	179	73	11	7	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	180	73	51	9	10	9	9	9	9	9	9	9	9	9	9	9	9	8	9
	183	76	11	7	8	7	7	7	6	7	7	7	7	7	7	7	7	6	7
	184	76	11	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	185	76	51	7	7	7	7	7	7	7	7	7	7	7	7	7	8	-	7
	188	79	51	7	8	7	7	8	7	8	8	8	8	7	8	8	8	7	8
	189	79	11	7	8	-	8	8	7	9	8	8	8	8	8	8	8	8	8
	190	82	51	9	9	8	8	10	8	9	10	8	8	13	10	9	9	8	8

APPENDIX III

SELECTED OTOLITHS AND THEIR INTERPRETATIONS

Otolith 2J-1 (modal age 4)

Nine of the 14 readers aged this otolith as 4, 4 recorded age 3 and one reader gave age 5. Those suggesting age 3 (o) consider the third annulus of the age 4 reading (●) to be a check. The age 5 interpretation was withdrawn after examination of the photograph.

Otolith 2J-2 (modal age 4)

Six of the 13 readers agreed to age 4 and 3 recorded age 3, with other interpretations being withdrawn following discussion of the photograph. The second annulus of the age 4 reading (o) was considered as a check by those recording age 3.

Otolith 2J-12 (modal age 5)

Six of the 13 readers recorded age 5 and 3 indicated age 6, the other interpretations being withdrawn after studying the photograph. Those suggesting age 5 (o) considered the second annulus of the age 6 reading (●) to be a check.

Otolith 2J-13 (modal age 5)

Out of 14 readers, 3 recorded age 4, 5 readers indicated age 5 and 4 gave age 6. Those who suggested age 4 (●) considered the second annulus of the other readings (o and x) to be a check, and those readers who preferred age 5 (o) treated the third annulus of the age 6 reading (x) as a check or split.

Otolith 2J-14 (modal age 6)

Seven of the 14 readers indicated age 6, 2 readers suggested age 4 and 3 favoured age 5. Those recording age 4 (o) considered the third and fifth annuli of the age 6 reading (x) to be checks, whereas the age 5 reading (●) treats the third annulus of the age 6 reading (x) as a check.

Otolith 2J-58 (modal age 4)

Eleven of the 14 readers agreed to age 4, with one suggesting age 3 and 2 favouring age 5. These latter interpretations were withdrawn after studying the photograph.

Otolith 2J-63 (modal age 6)

Seven of the 14 readers recorded age 6 and 4 readers indicated age 7, with the others suggesting ages 4 and 5. The only discrepancy between those recording ages 6 and 7 relates to the interpretation of the innermost ring as a check or an annulus.

Otolith 2J-74 (modal age 7)

Seven of the 14 readers agreed to age 7 and 6 readers favoured age 6, the difference being in the interpretation of the innermost ring (●). The agreed interpretation as age 7 from the photograph (—) includes an annulus not considered by any of those previously recording the age as 6 or 7.

Otolith 2J-85 (modal age 7)

Twelve of the 14 readers recorded age 7, with one suggesting age 8 and another age 6, the last being withdrawn following a study of the photograph. The only discrepancy was in the interpretation of the innermost ring.

Otolith 2J-122 (modal age 9)

Interpretation of this otolith ranged from ages 7 to 11, with 3 of the 14 readers recording age 8, 4 readers favoured age 9, 2 indicated age 10 and 3 preferred age 11. A major problem was in the interpretation of the innermost ring (o and ●). Other discrepancies include the consideration of additional annuli at the edge by some readers and the interpretation of certain rings as checks by some and as annuli by others.

Otolith 2J-300 (modal age 9?)

Out of 12 readers, 4 recorded age 8, 4 indicated age 9 and 3 suggested age 10. The main difference between those recording age 8 on the one hand (o) and ages 9 and 10 on the other (● and x) is the inclusion of an additional annuli at the edge by the latter. The other difference is that the seventh annulus of the age 10 reading (x) is considered as a split by the other groups.

Otolith 3K-317 (modal age 3)

Six of the 14 readers agreed to age 3 and 5 readers indicated age 4, with the others suggesting ages 2 and 5. The third annulus of the age 4 reading (●) was considered as a check in the age 3 reading.

Otolith 3K-318 (modal age 4)

Eleven of the 15 readers recorded age 4, with 2 readers giving age 3 by interpreting the second annulus of the age 4 reading (o) as a check.

Otolith 3K-321 (modal age 4)

Six of the 14 readers agreed to age 4, with 4 readers indicating age 5 and 3 suggesting age 7. The fourth annulus of the age 5 reading (o) is considered as a check in that of age 4 (●). Relative to the age 4 reading, those recording age 7 (x) included three additional annuli in the zone between the third and fourth annuli of the age 4 reading.

Otolith 3K-328 (modal age 5)

Out of 14 readers, 4 recorded the age as 4, 5 readers indicated age 5 and 2 suggested age 6. The remaining readers recorded the age as low as 2 and as high as 8. The third annulus of the age 5 reading (●) was considered as a check in the age 4 reading (o), and the second annulus of the age 6 reading (x) was interpreted as a check by the others.

Otolith 3K-337 (modal age 6)

Out of 15 readers, 5 recorded age 5, 6 readers indicated age 6 and 3 suggested age 7. Of the ages indicated in the photograph, the third annulus of the age 6 reading (●) was considered as a check by those favouring age 5 (o).

Otolith 3K-339 (modal age 5)

Out of 15 readers, 2 indicated age 4, 5 readers recorded age 5, 4 favoured age 7, 2 readers preferred age 8 and the others gave ages 3 and 9. Relative to the modal age (x), variation in interpretation was great. This otolith is a typical example of the problem of interpreting annuli and checks.

Otolith 3K-352 (modal age 6 or 7)

The ageing of this otolith ranged from ages 4 to 10, with ages 5, 6 and 7 being recorded by 3, 4 and 4 readers respectively. The two readers recording age 4 (–) considered the first annulus of the other readers to be a check. The second and fifth annuli of the age 8 reading (x) were treated as checks by the other groups. The major difference between those recording ages 6 and 7 (o and ●) was in the interpretation of the fourth ring as a check on the one hand and as an annulus on the other.

Otolith 3K-366 (modal age 4)

Out of 15 readers, 7 recorded the age as 4, with 3 readers indicating age 3, 2 giving age 5 and 3 recording age 6. The third and fifth annuli of the age 6 readings (●) were considered as checks by those recording age 4 (–) and the third annulus (●) as a check or split by those giving age 5 (o).

Otolith 3K-404 (modal age 8)

Out of 14 readers, 2 recorded age 7, 7 indicated age 8 and 3 suggested age 9. Following a discussion of the photograph, two interpretations were held (ages 7 and 8). The second annulus of the age 8 reading (o) was considered to be a check by those recording the age as 7.

Otolith 3K-429 (modal age 6 or 7)

Out of the 12 readers, 6 indicated age 6 and 7 recorded age 7, the difference in all cases being the interpretation of the fifth annuli of the age 7 reading (o) as a check by the others.

Otolith 3K-548 (modal age 7)

Out of 15 readers, 4 recorded the age as 6, 7 recorded age 7, 2 suggested age 8 and 1 gave age 9. Following a study of the photograph, discussion centred on interpretation as ages 7, 8 and 9. The main discrepancies were: designation of the innermost ring as an annulus in the age 9 reading (●); the second and third annuli in the age 8 reading (o) were treated as checks by the other groups; the fourth annulus in the age 7 reading (—) was considered a check by the others; and the sixth and eighth annuli in the age 9 reading (●) were read as checks by readers recording ages 7 and 8.

Otolith 3L-6 (modal age 4)

This specimen was read as age 4 by 7 readers and age 5 by 6 readers, with one reader suggesting age 3 and another age 8. Discussion of the photograph centred on interpretation as age 4 or age 5. Those indicating age 4 arrived at that age by considering as the second annulus (— and x) rings which are not coincident, whereas the age 5 reading (●) treated both of these rings as annuli.

Otolith 3L-24 (modal age 5)

Out of 15 readers, 9 recorded the age as 5 and 5 readers indicated age 6. Among the readers recording age 5, one group (o) considered the second annulus of the other group (—) as a check but included an annulus at the edge. Those who recorded the age as 6 (x) included both of these rings as annuli.

Otolith 3L-55 (modal age 4)

Following discussion of the photograph all readers agreed unanimously on age 4, although 3 out of the 14 readers recorded the age as 3, 5 or 7 previously.

Otolith 3L-68 (modal age 7)

Out of 14 readers, 8 recorded the age as 7, 3 readers indicated age 5 and 2 readers gave age 8. Those suggesting age 5 (x) considered as checks the second and third annuli (—) of the age 8 reading and omitted the annulus at the edge. The majority, however, in deciding on age 7 (o), considered the second annulus of the age 8 reading as a check.

Otolith 3L-102 (modal age 6)

This specimen was interpreted as age 6 by 12 of the 15 readers, with the remainder suggesting age 7. The only difference in interpretation involved the innermost ring which was considered as a check by most of the readers.

Otolith 3L-134 (modal age 6)

Nine of the 15 readers recorded age 6, 3 readers indicated age 5 and the remaining 3 suggested ages 7 or 8. The age 7 reading (—) agrees with that of age 6 (x), except that the innermost ring is considered as a check in the latter interpretation. Those recording age 5, however, considered the second annulus of the age 6 reading (x) as a check.

Otolith 3L-170 (modal age 9)

This specimen was recorded as age 9 by 9 of the 15 readers, with 3 suggesting age 8 and 3 indicating age 10. The main differences were that the ninth annulus of the age 10 reading (—) was considered a check by the other groups and that the second annulus of the age 9 reading (●) was treated as a check by the readers recording the age as 8 (x).

Otolith 3L-183 (modal age 8)

Eight of 14 readers recorded the age as 8, with 2 readers indicating age 7, 2 others age 8 and one suggesting age 6. The readers who recorded age 7 (x) considered the second annulus of the age 8 reading (o) as a check, and those suggesting age 9 (●) interpreted the rings in the same way as the age 8 reading but added an additional annulus at the edge.

Otolith 3L-189 (modal age 10 or 11)

Out of 12 readers, 4 agreed on age 10 and 4 indicated age 11, with the others variously suggesting 8, 9 or 13. Two interpretations of the otolith as age 10 are indicated (● and x), the first including the innermost ring as an annulus, and the third annulus (x) is considered as a check by the other group (●). In the age 11 reading (o), the tenth annulus is considered to be a check by those giving age 10 (●).

Otolith 3L-268 (modal age 11)

Seven of 13 readers initially recorded age 11 for this specimen, with 3 indicating age 10 and the others variously suggesting 8, 9 or 12. Following a discussion of the photograph, age 11 was agreed to by all readers.

Otolith 30-1 (modal age 5)

Eight of the 15 readers indicated age 5 and 6 readers suggested age 4. The difference in interpretation was due to one group (—) including the second ring as an annulus and the other group (●) treating the ring as a check.

Otolith 30-16 (modal age 5)

Seven of the 15 readers recorded age 5 but arrived at the result in different ways (x and o), whereas 5 readers indicated age 6 and one gave age 4. For both groups giving age 5, the sole difference was in the location of the first annulus. Those readers who suggested age 6 included both of the first two rings as annuli.

Otolith 30-17 (modal age ?)

Out of 14 readers, 5 indicated age 4, 5 recorded age 5 and 3 suggested age 6. The difference between the age 4 and age 5 readings is in the interpretation of the third annulus of the latter age (o) as a check in the case of the age 4 reading (—). The last 4 annuli of the age 5 reading (o) are the same as those of age 6 (●), but the first annulus of the former does not coincide with either of the first 2 annuli of the latter reading.

Otolith 30-48 (modal age 8)

Seven of the 13 readers interpreted this otolith as age 8, 1 as age 7, 3 as age 6 and 2 as age 5. Only ages 6 and 8 warranted consideration in the subsequent study of the photograph, the major difference being the consideration of the fourth and sixth annuli of the age 8 reading (o) as checks in the age 6 reading (—).

Otolith 30-55 (modal age 7)

The 13 readers recorded ages ranging from 4 to 9, with 2 readers favouring age 5, 2 for age 6, 4 for age 7 and 3 for age 9. Relative to the modal age (o), the age 9 reading (—) includes two annuli (fourth and fifth) which were considered to be checks in the age 7 reading. The difference between the age 6 and age 7 reading is that the second annulus of the latter (o) is treated as a check in the former (●). Regarding the age 5 reading (x), the fifth and sixth annuli of the age 7 reading (o) are considered to be checks.

Otolith 30-65 (modal age 6)

The modal age of 6 was recorded by 9 of the 13 readers, with 3 indicating age 5 and one suggesting age 7. The fifth annulus of the age 7 reading (●) was considered to be a check by those who recorded age 6 (—), and the fifth annulus of the age 6 reading (—) was treated as a check in the age 5 reading (o).

Otolith 30-115 (modal age 7)

Eight of the 13 readers interpreted the age of this otolith as 7 but they arrived at the result in different ways (— and x), the location of the second and third annulus being different for the two groups. The 3 readers who suggested age 8 arrived at their results in somewhat different ways (● and o).

Otolith 30-119 (modal age 10)

The ageing of this otolith ranged from 7 to 12, with 8 of the 14 readers recording age 10 (x). Other interpretations were suggested, but most agreed, following discussion of the photograph, that the differences were due to considering some checks as annuli and *vice versa*.

Otolith 30-121 (modal age 7)

Nine of the 14 readers recorded age 7, with 4 suggesting age 8 and one favouring age 6. The seventh annulus of the age 8 reading (x) is considered to be a check by those who preferred age 7 (o).

Otolith 30-132 (modal age 7)

Eight of the 14 readers aged this otolith as 7, with 5 readers suggesting age 8 and one favouring age 6. The seventh annulus of the age 8 reading (x) is considered to be a check by those preferring age 7 (o).

Otolith 30-140 (modal age 9)

The ageing of this otolith ranged generally from 7 to 10 but one reader suggested age 14. Out of 15 readers, 4 indicated age 8, 5 gave age 9 and 4 were for age 10. Those suggesting age 9 arrived at the result in two different ways (o and x), the third annulus in each case not being coincident. Relative to the age 9 reading, those suggesting age 8 (●) considered the fifth annulus (x) to be a check. In the age 10 reading (—), the fifth annulus is treated as a check by the others.

Otolith 3NO-11 (modal age 4)

Ten of the 15 readers aged this otolith as 4 years, 2 readers recorded age 5 and the others suggested 6 or 7. The age 5 reading was arrived at in different ways (o and x), the innermost ring being treated as an annulus in one case (o) and the second ring from the edge (x) considered as an annulus in the other. All readers who indicated age 4 (—) considered the innermost ring (o) and the fourth ring near the edge (x) as checks or splits.

Otolith 3NO-27 (modal age 4)

Nine of the 15 readers recorded age 4, with 4 readers indicating age 5 and the others suggesting 6 or 7. In the age 5 reading (x), the fourth annulus is considered to be a split by those recording age 4 (—). The single age 6 reading (o) includes, as the second annulus, a ring which was treated as a check by the others.

Otolith 3NO-38 (modal age 6)

Seven of the 14 readers agreed on age 6, with 4 favouring age 5 and the others suggesting 7 or 8. The only difference between the age 5 and the age 6 readings is whether the innermost ring is a check on the one hand (x) or an annulus on the other (—). The age 7 reading includes as the second annulus (o) a ring which was considered a check by the other groups.

Otolith 3NO-46 (modal age 7)

Seven of the 15 readers recorded age 7, with 4 readers indicating age 6 and 4 others suggesting age 8. The only difference between the age 7 and age 8 readings is whether the innermost ring is a check in the first case (x) or an annulus in the other (o). Those suggesting age 6 (—) considered as checks both the innermost ring and one near the edge of the otolith.

Otolith 3NO-51 (modal age 6)

Eleven of the 14 readers agreed on age 6 with 2 readers favouring age 7 and one suggesting age 9. The third annulus of the age 7 reading (x) is considered to be a check by those recording age 6 (—).

Otolith 3NO-60 (modal age 7)

Seven of the 14 readers recorded age 7, with 3 readers suggesting age 6, one indicating age 8 and the remainder giving age 9 or 12. The fourth annulus of the age 8 reading (o) is considered as a check in the age 7 reading (—), and those recording age 6 (x) considered both the fourth and sixth annuli of the age 8 reading (o) as checks.

Otolith 3NO-68 (modal age 6)

Seven of the 14 readers agreed to age 6, with 5 readers indicating age 7 and the remaining 2 readers suggesting 8 or 9. Relative to the age 6 reading (x), the second and third annuli of the age 8 reading (●) are considered as checks. The age 7 reading was arrived at in three different ways (–, x and o), with particular rings being treated as checks by some readers and as annuli by others.

Otolith 3NO-71 (modal age 7)

Of the 11 readers who aged this otolith, 6 recorded age 7 and the others variously indicated the age as low as 5 and as high as 9. The innermost ring was included as an annulus by those recording age 8 (+) and age 9 (●) but not by the other groups. The other major difficulty in interpretation relates to consideration of certain rings as checks or annuli.

Otolith 3NO-72 (modal age 8)

Eight of the 13 readers agreed on age 8, with others suggesting age 7, 9 or 10. There was no problem with the first 5 annuli but the sixth annulus of the age 10 reading (●) was considered to be a check by the others, as was also one or two other annuli near the edge. The seventh annulus of the age 8 reading (–) is considered as a check in the age 7 reading (x).

Otolith 3NO-75 (modal age 8)

Seven of the 13 readers recorded age 8, with 2 readers favouring age 7, 3 suggesting age 9 and one for age 10. The two ways of arriving at age 8 (x and –) are different only to the extent that the first annulus is split and its location may vary from reader to reader. Relative to the age 8 reading (–), both the age 9 reading (●) and the age 10 reading (o) include an additional annulus at the edge, and the fourth annulus of the latter (o) is considered as a check by all others.

Otolith 3Ps-10 (modal age 3)

Eleven of the 13 readers indicated age 3 and 2 readers suggested age 4. The third annulus of the age 4 reading (o) is considered to be a split of the third growth zone by all others.

Otolith 3Ps-25 (modal age 3)

Ten of the 14 readers agreed on age 3, with 3 readers recording age 4 and one favoured age 5. Those suggesting age 4 arrived at their result in two different ways (o and x), the innermost ring being considered as an annulus in one case (o) and a split being considered as an annulus in the other (x). Those who recorded age 3 (–) were consistent in their interpretation.

Otolith 3Ps-37 (modal age ?)

Out of 14 readers, ages 6 and 7 were each favoured by 5 readers, with 4 recording age 5. The first 5 annuli (o and x) presented no difficulty for those who read the ages as 6 or 7, but the sixth annulus of the latter (x) was considered as a check in the age 6 reading. The age 5 reading (–) treated the second annulus of the age 6 reading (o) as a check.

Otolith 3Ps-45 (modal age 5)

Twelve of the 15 readers agreed on age 5, with 3 readers suggesting age 4. The third annulus of the age 5 reading (–) is considered as a check by the others.

Otolith 3Ps-82 (modal age 5)

As for the previous otolith, 12 readers recorded age 5 and 3 indicated age 4. The third annulus of the age 5 reading (–) is considered as a check by those favouring age 4.

Otolith 3Ps-101 (modal age 5)

Ten of the 15 readers recorded age 5, with 3 readers suggesting age 4 and 2 favouring age 6. The sole difference between the age 5 (–) and the age 6 (o) readings is that the innermost ring was considered as an annulus by the latter group. The fourth annulus of the age 5 reading (–) was treated as a check by those favouring age 4 (x).

Otolith 3Ps-104 (modal age 7)

Seven of the 15 readers agreed on age 7 and 6 readers indicated age 6, with one suggesting age 5 and another age 8. The third annulus of the age 7 reading (x) was considered as a check in the age 6 reading (o). This annulus as well as the fifth were treated as checks by the reader favouring age 5 (–).

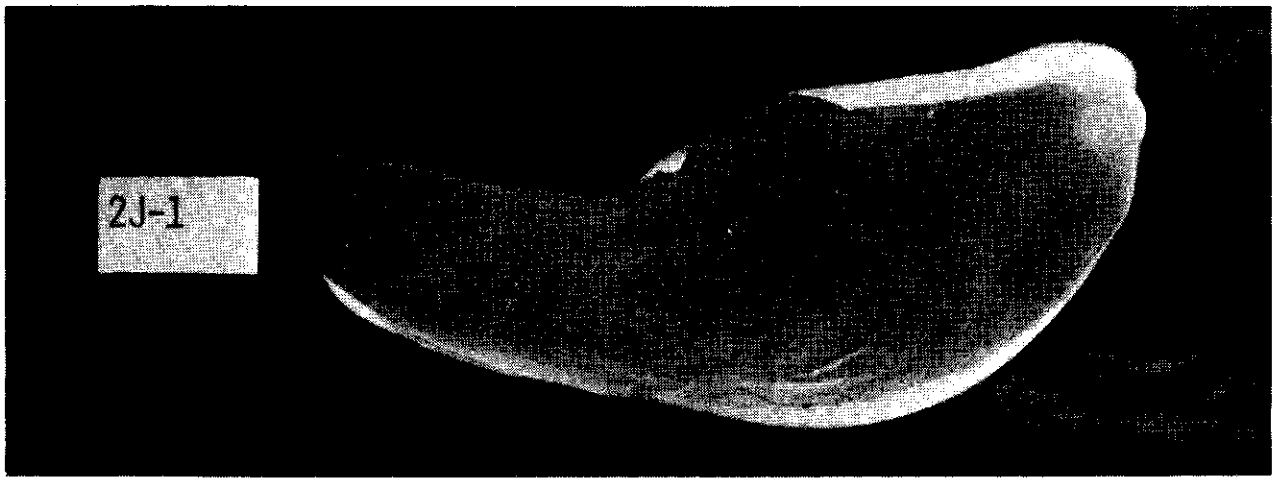
Otolith 3Ps-127 (modal age 6)

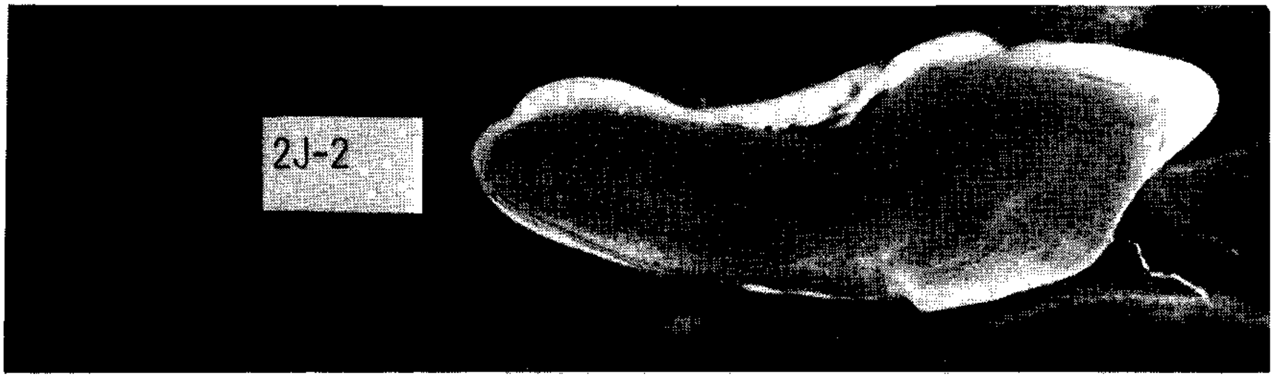
Ten of the 13 readers indicated age 6 and 3 readers favoured age 5, with the fourth annulus of the age 6 reading (o) being considered as a check in the age 5 reading.

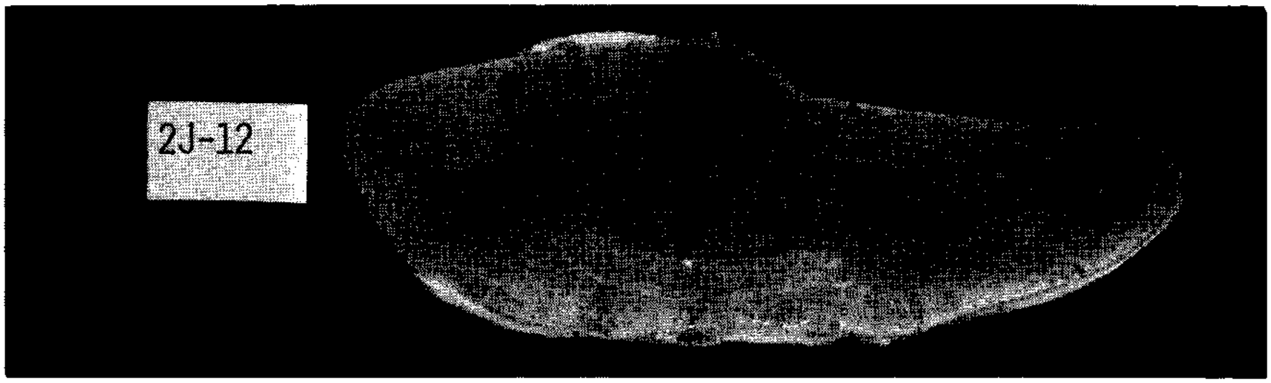
Otolith 3Ps-155 (modal age 6)

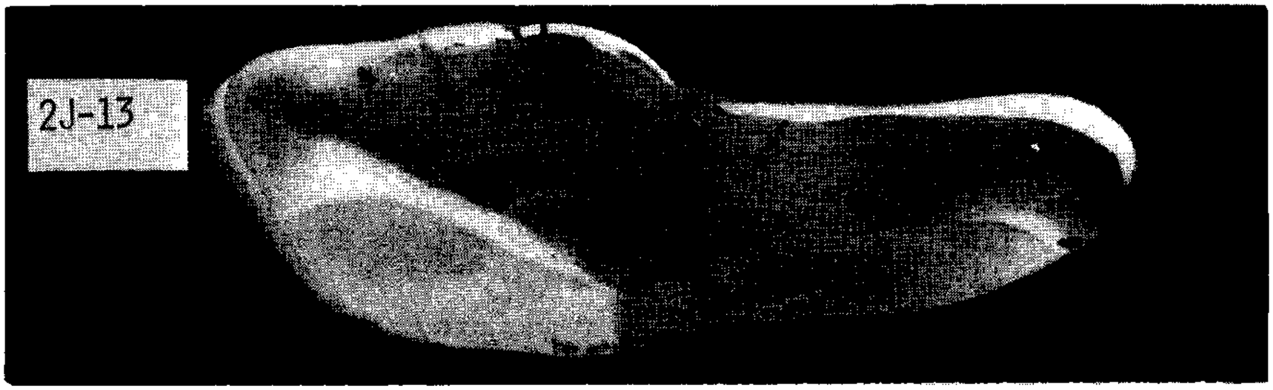
Ten of the 14 readers agreed to age 6, with 2 readers each suggesting age 5 and age 7. The fifth annulus of the age 6 reading (x) is considered as a check by those favouring age 5 (–). The age 7 reading (o) includes an additional annulus (fourth) which was considered a check by the other readers.

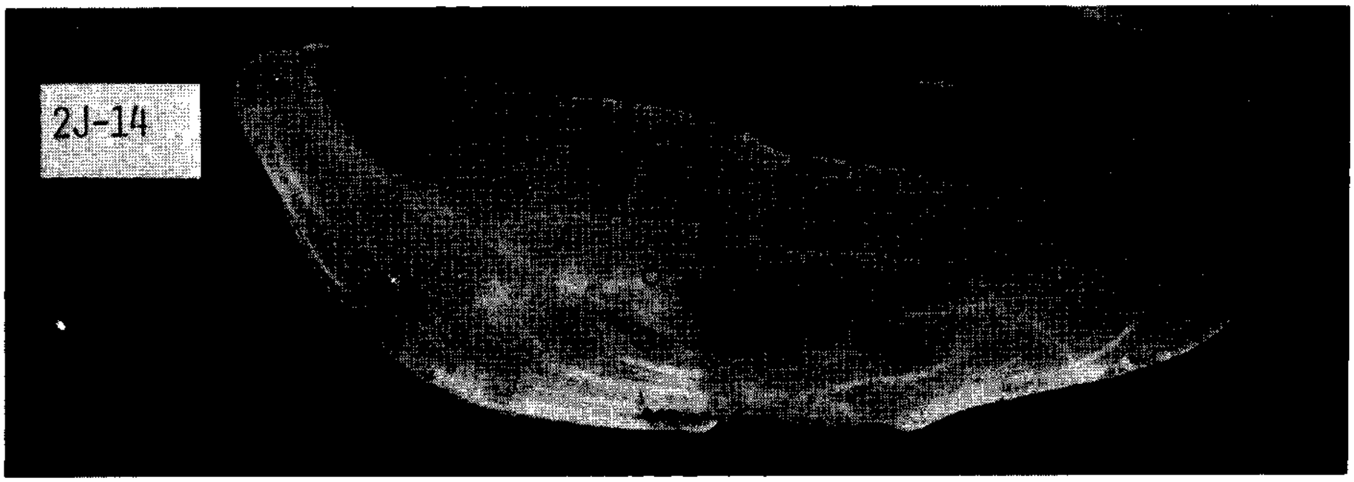
DIVISION 2J

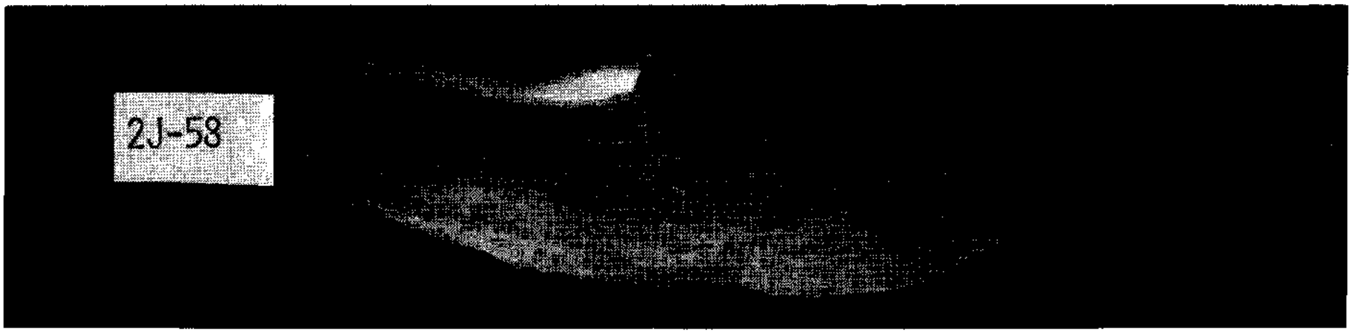

2J-1


2J-2

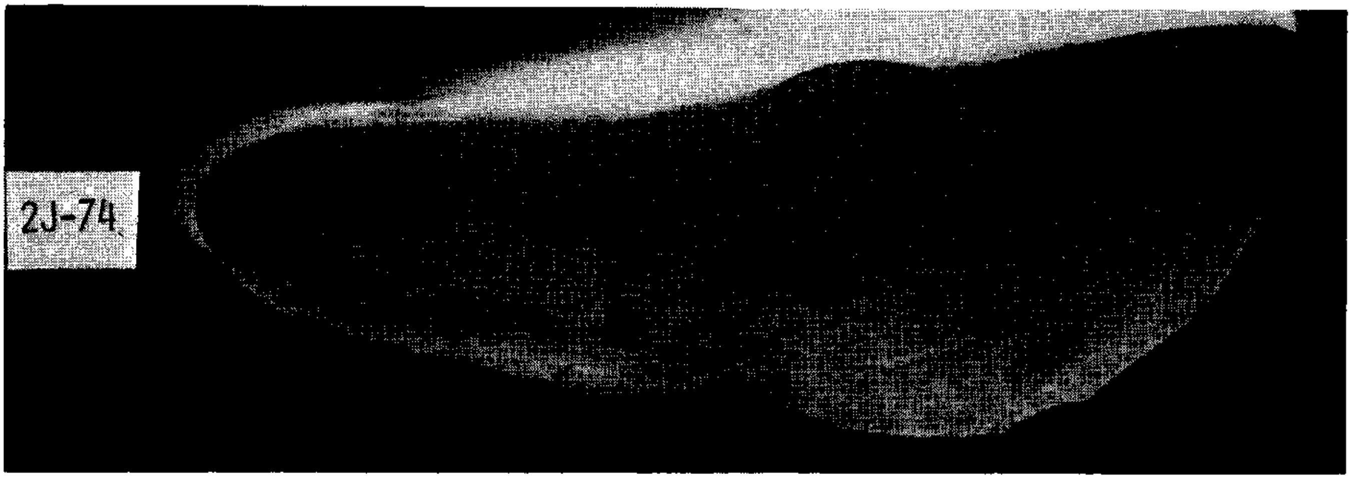

2J-12

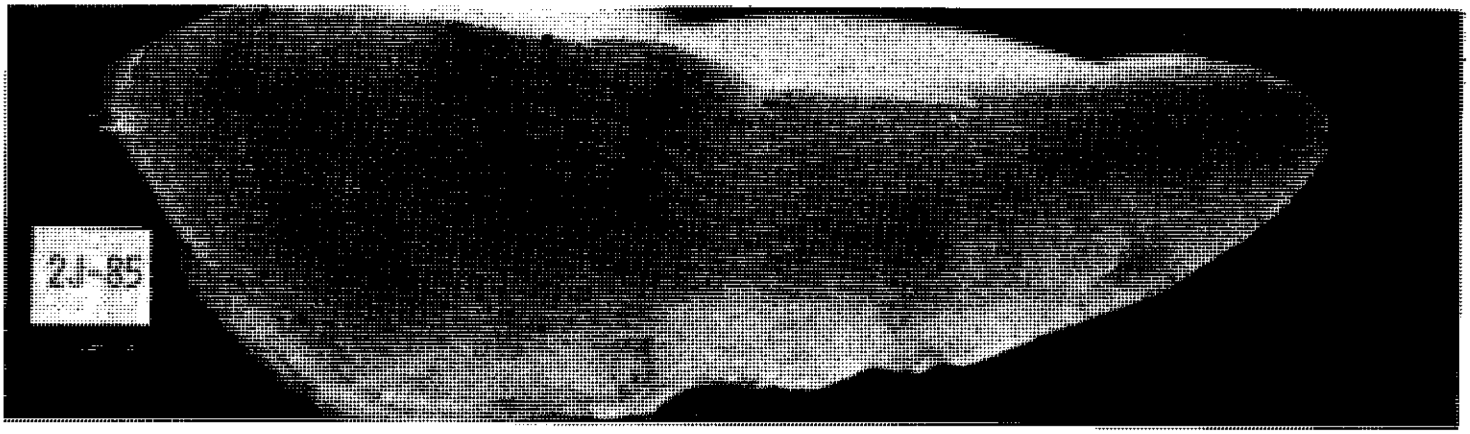

2J-13


2J-14

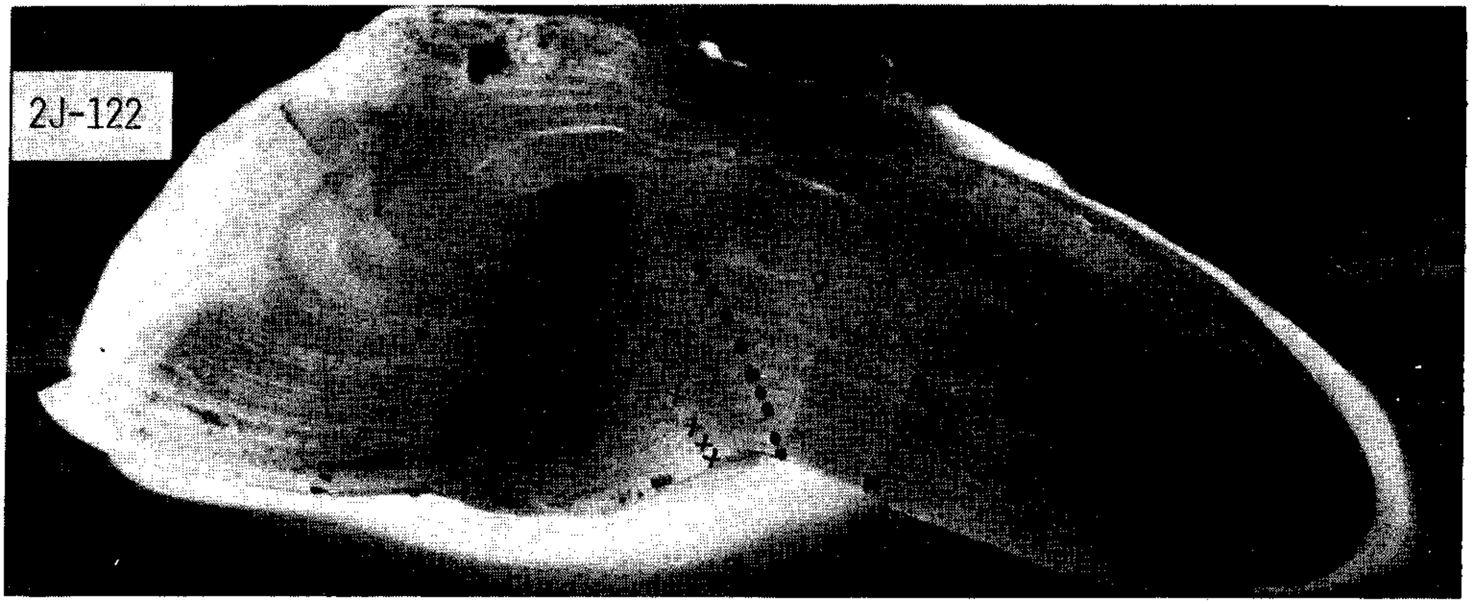

2J-58


2J-63

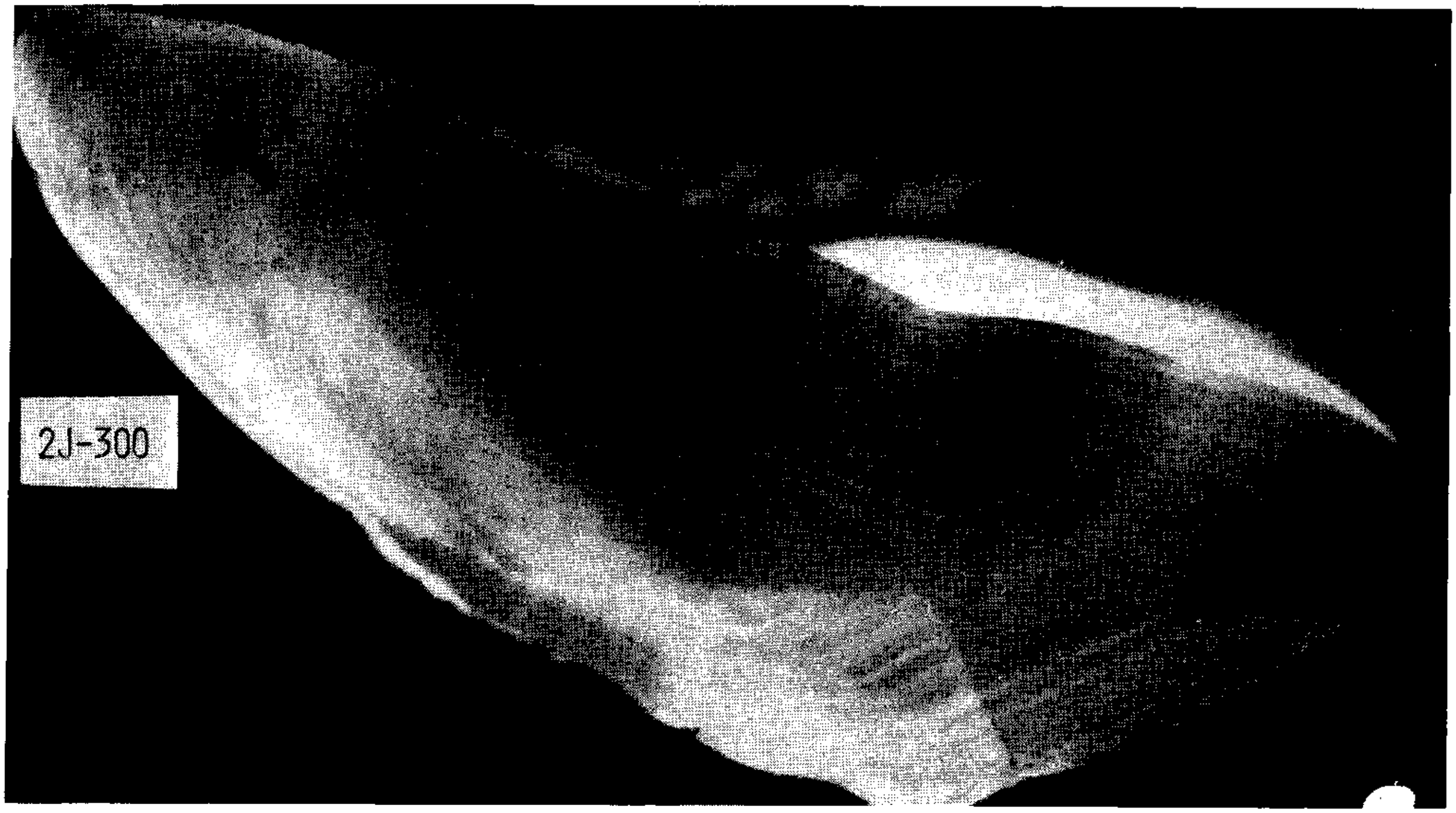

2J-74



2J-85

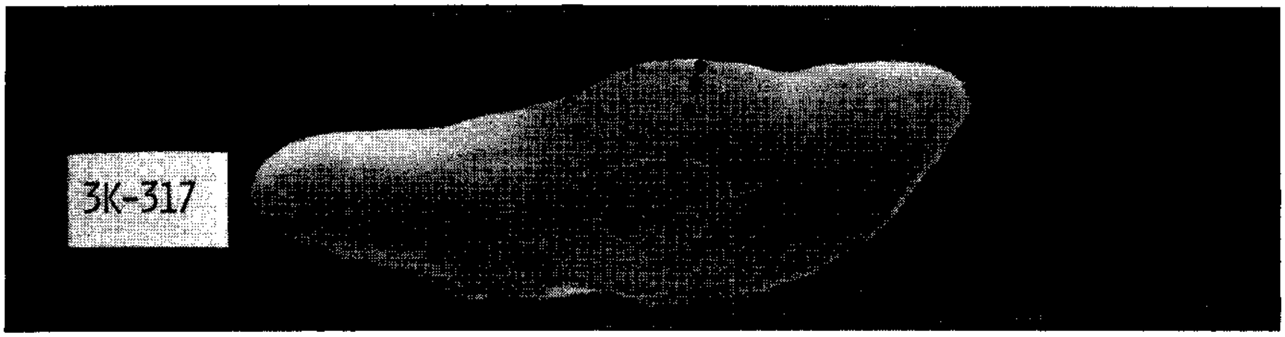


2J-122

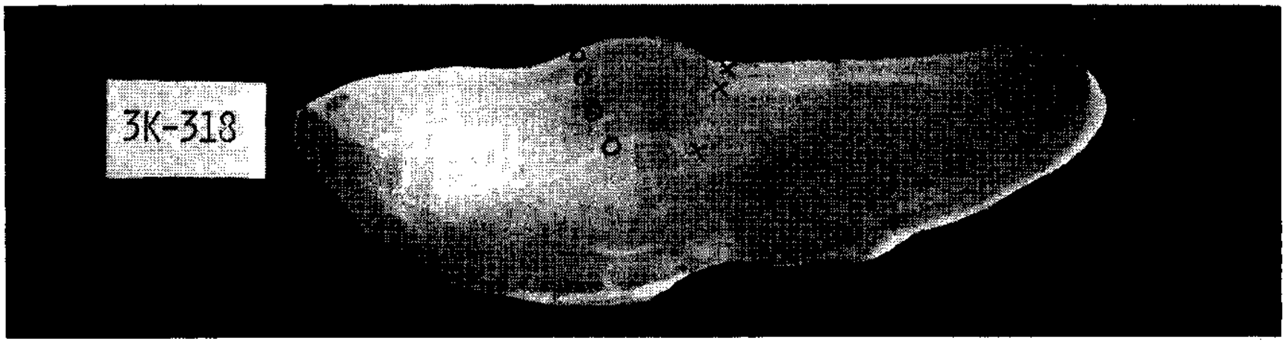


2J-300

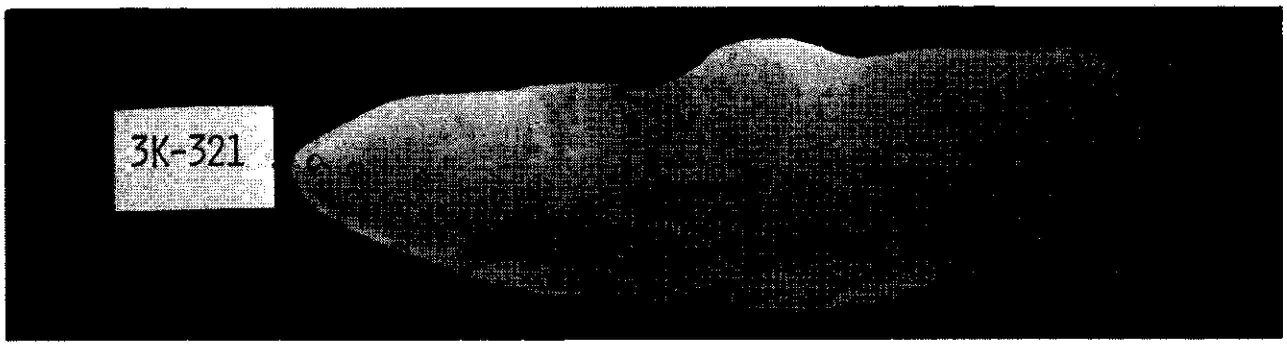
DIVISION 3K



3K-317



3K-318



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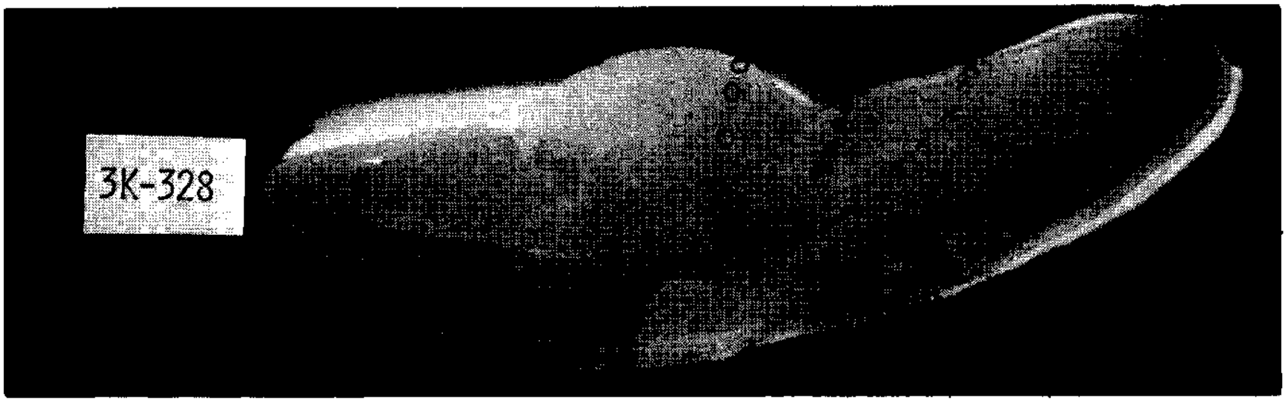

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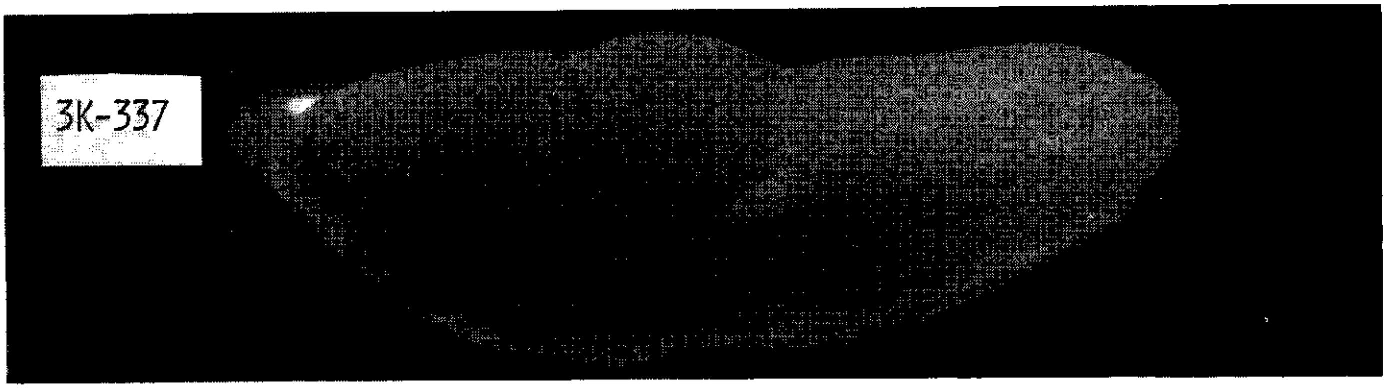
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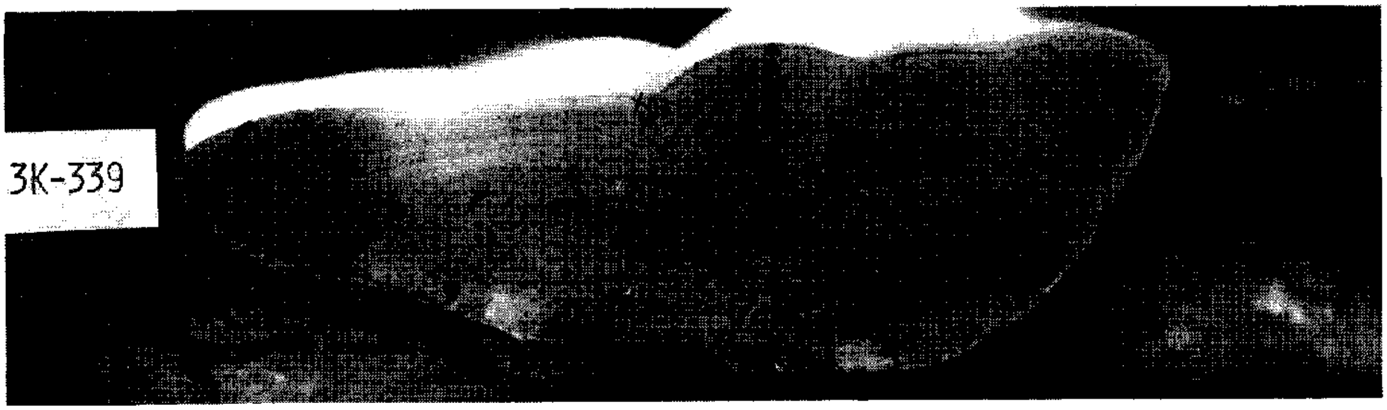
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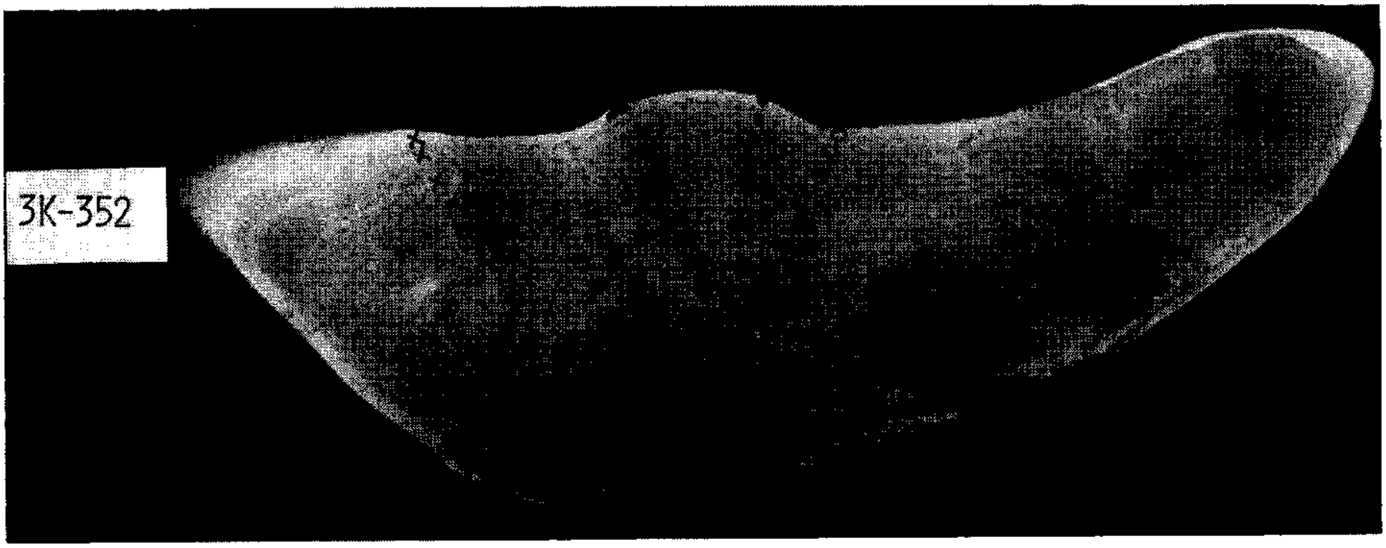
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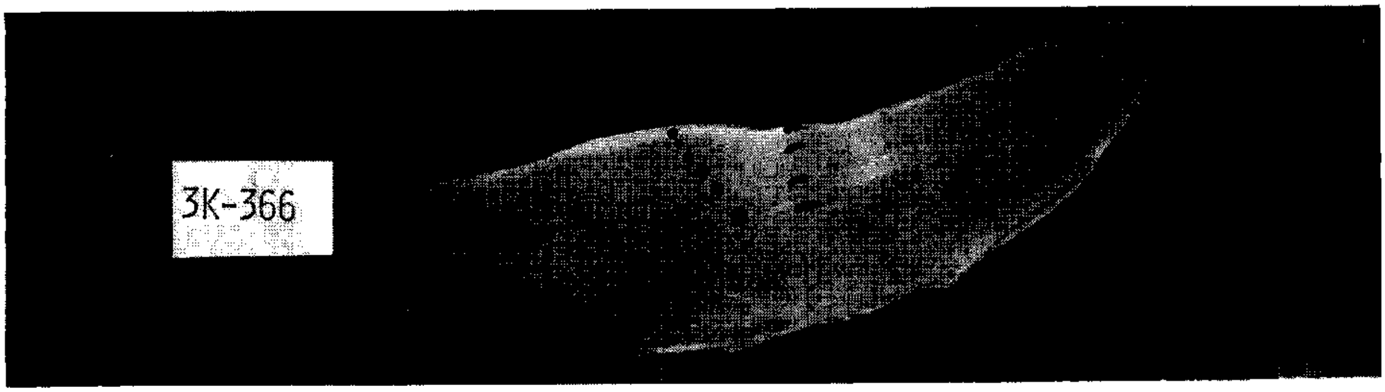
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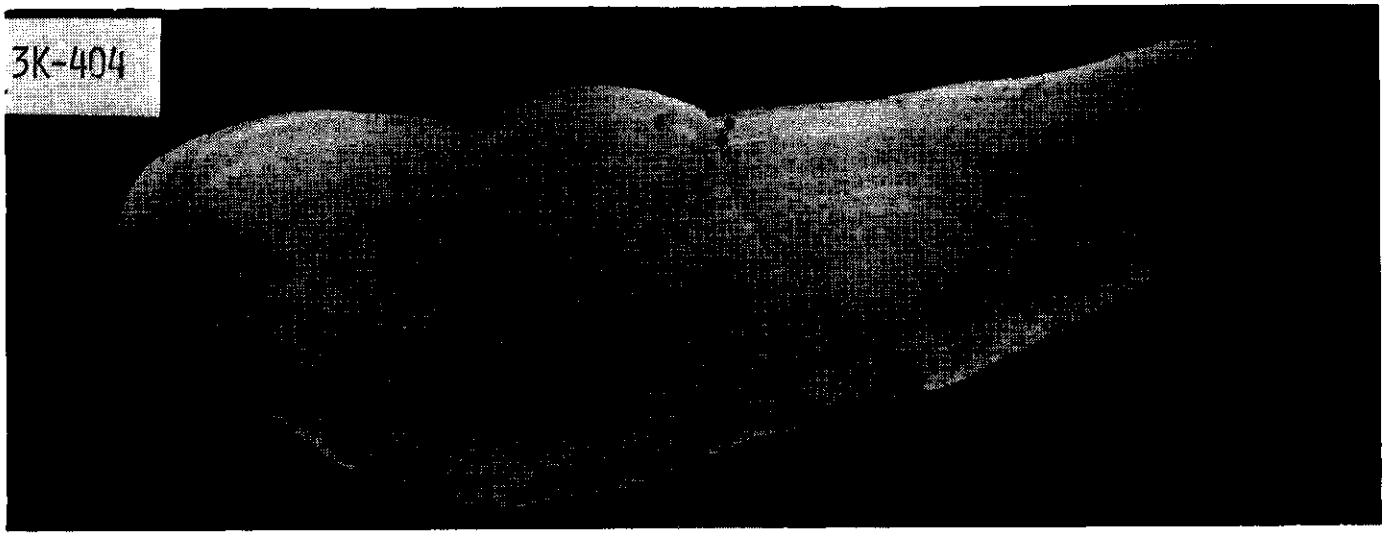

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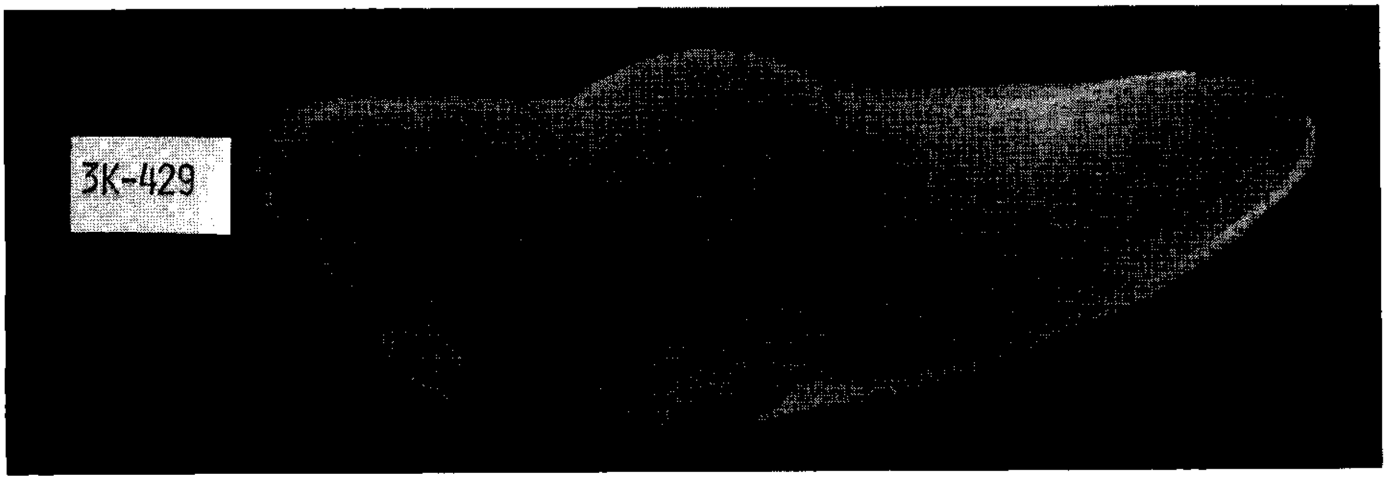
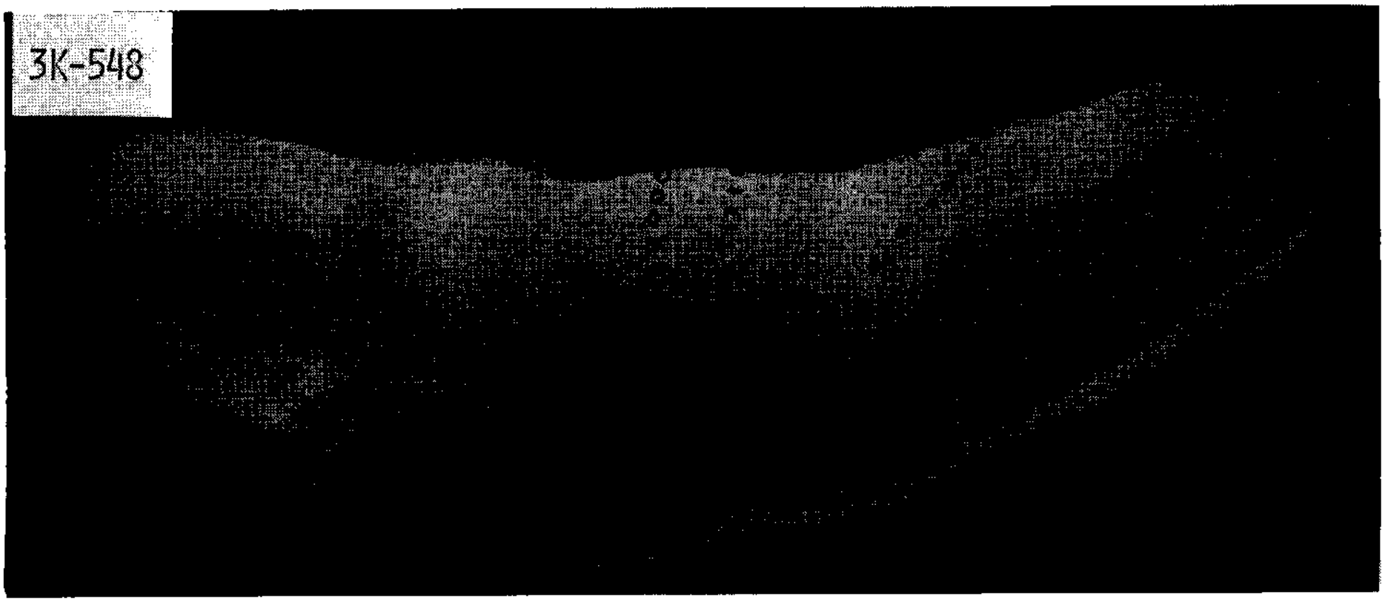
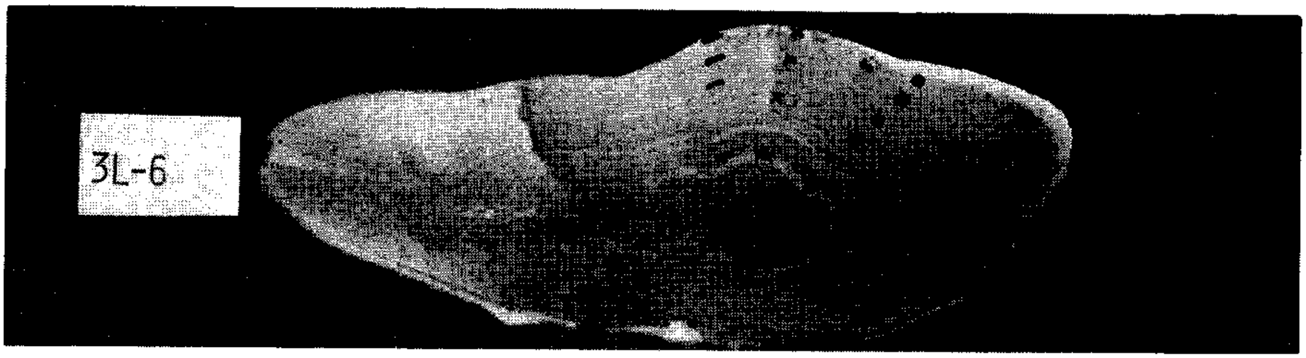


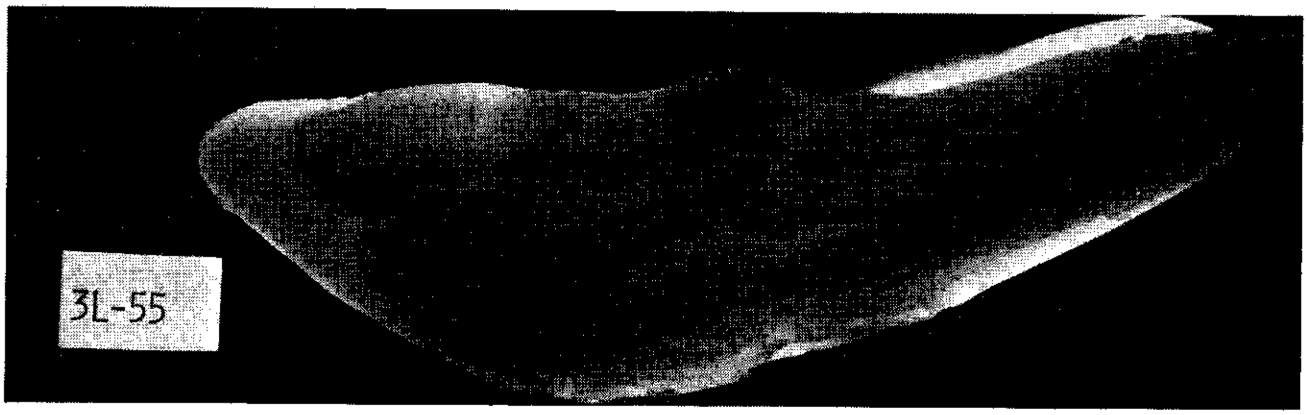
3K-429

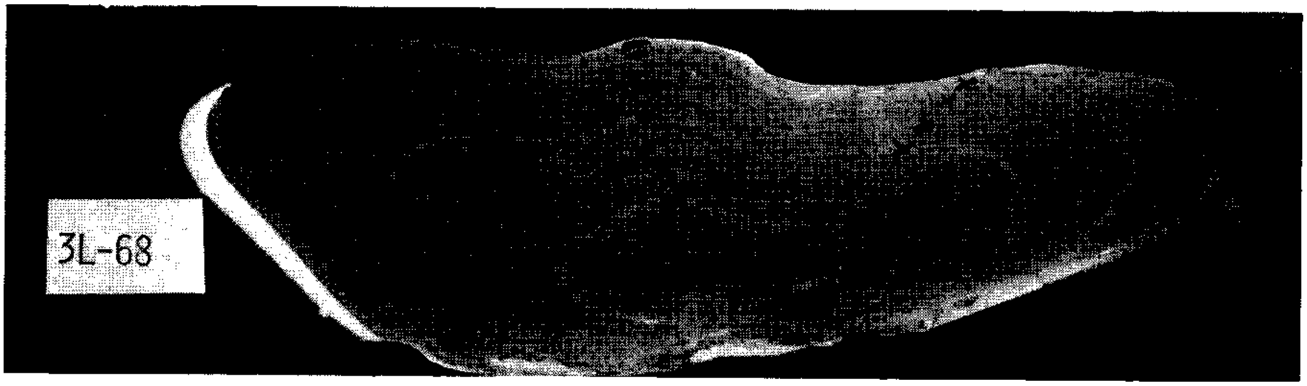


3K-548

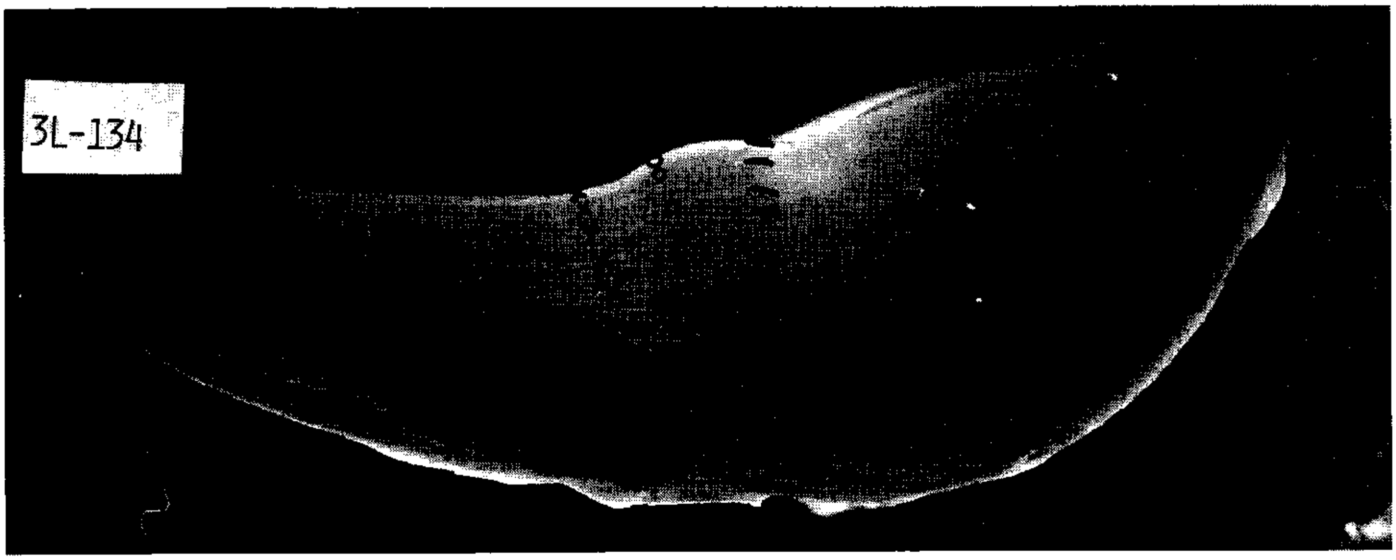
DIVISION 3L








3L-102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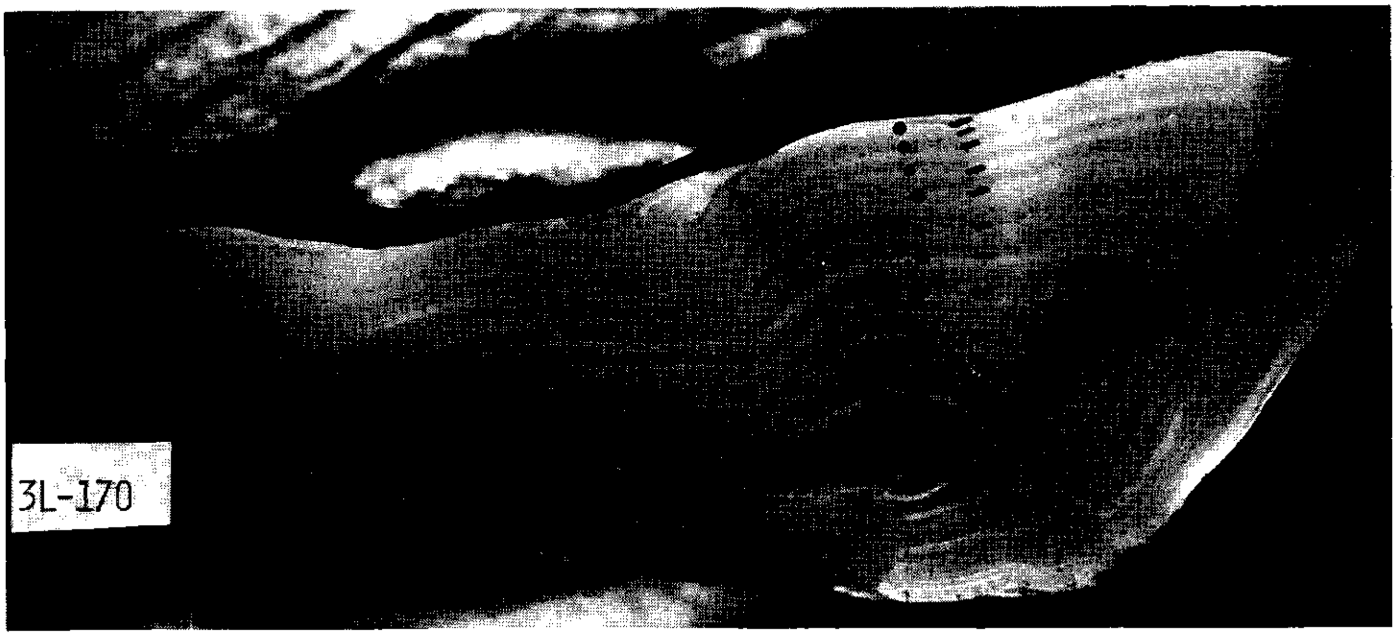
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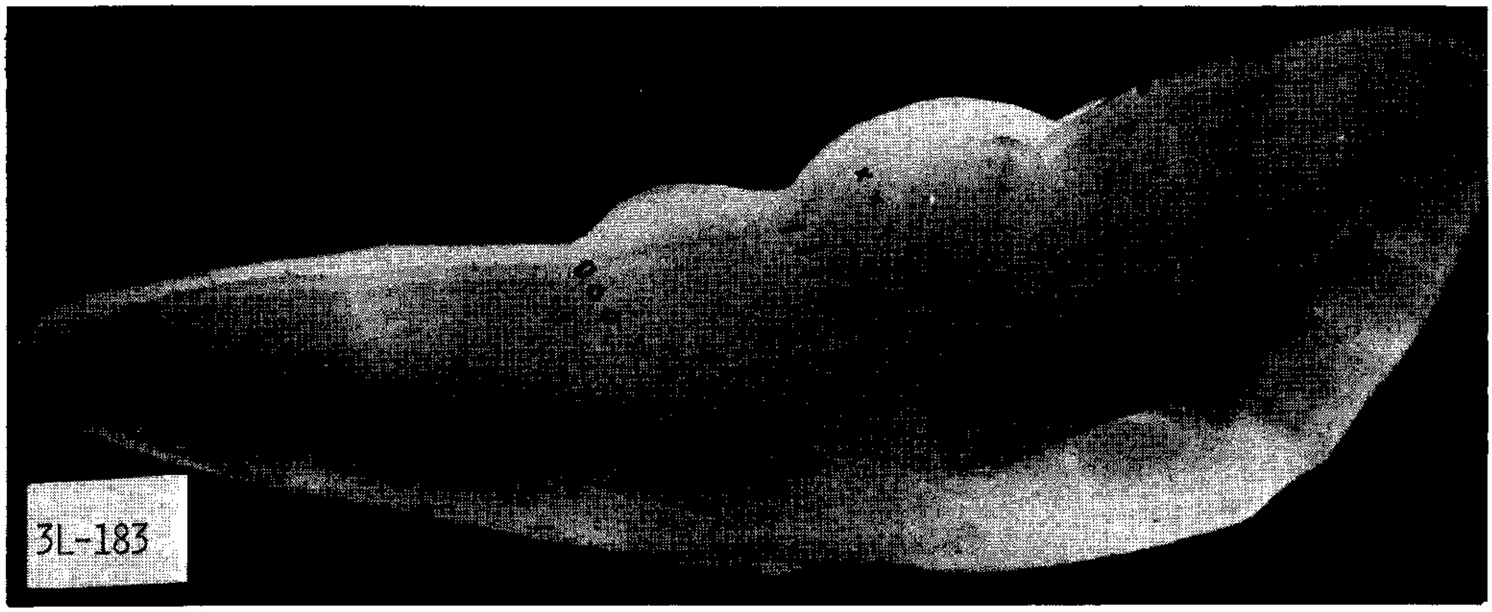

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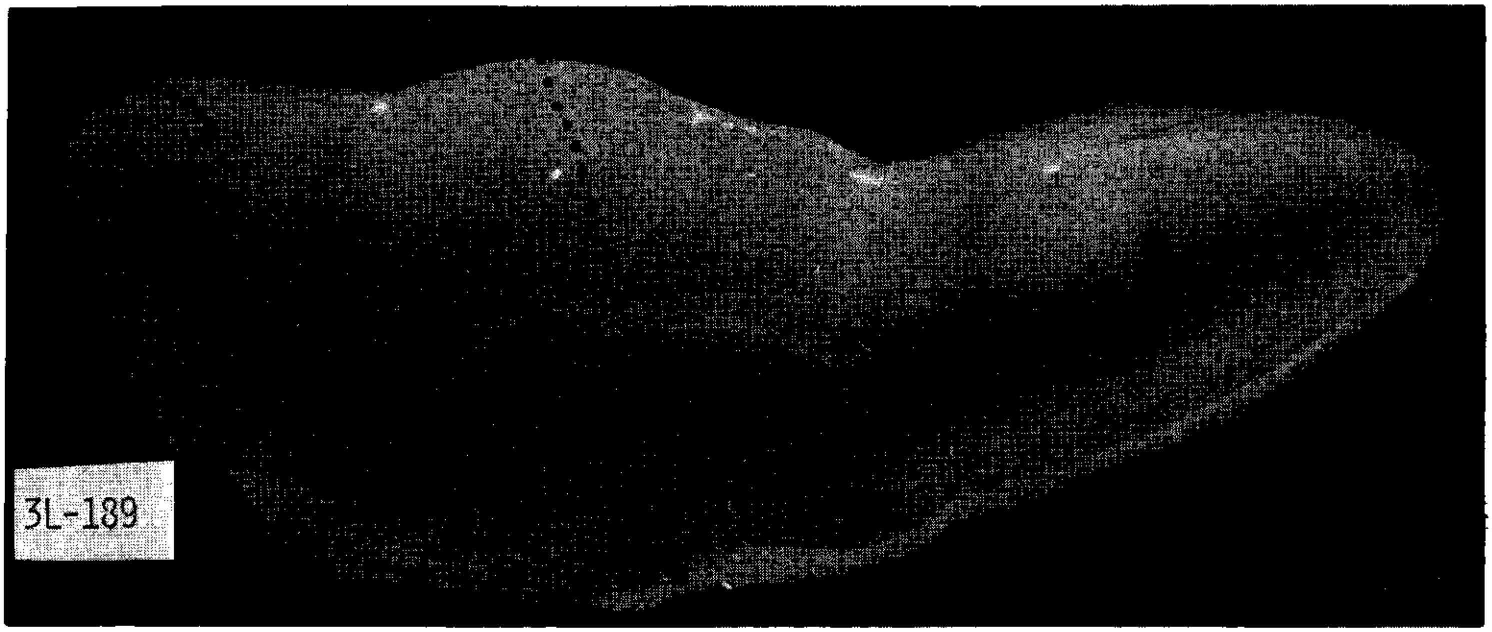

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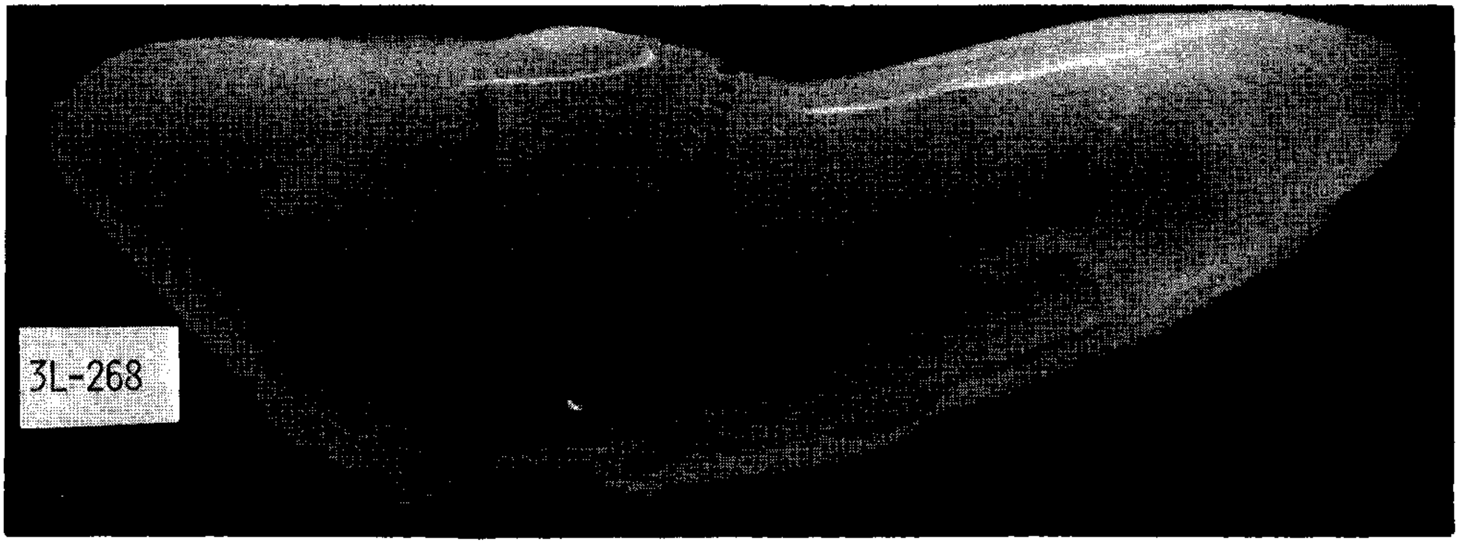
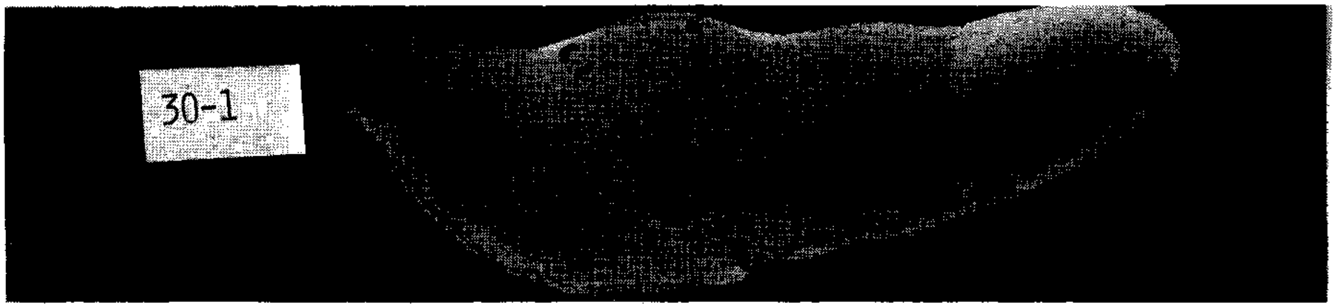


3L-268

DIVISION 30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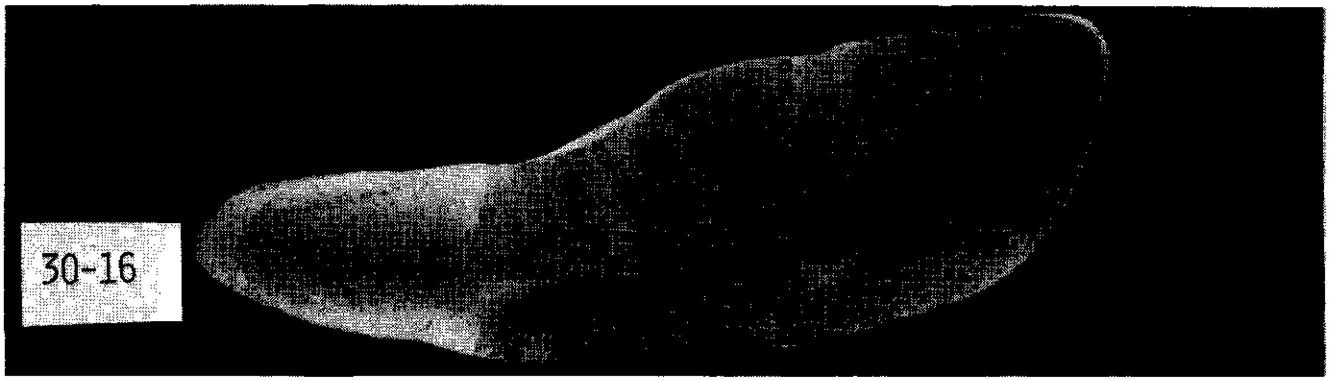
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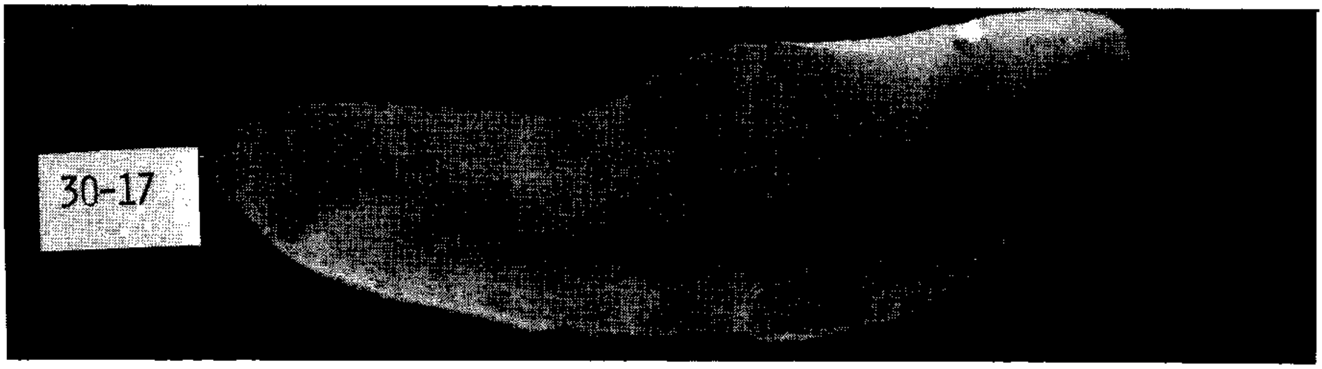
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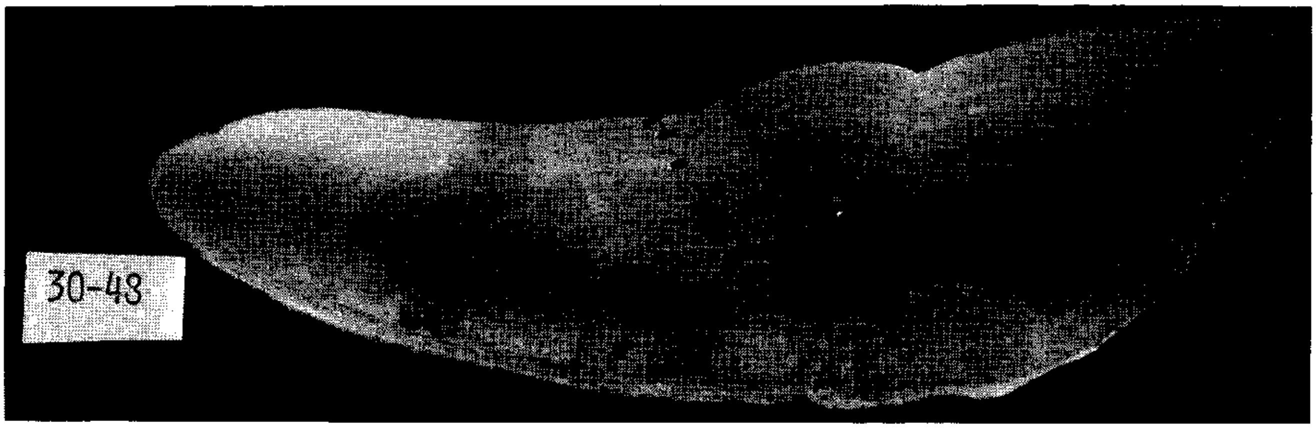
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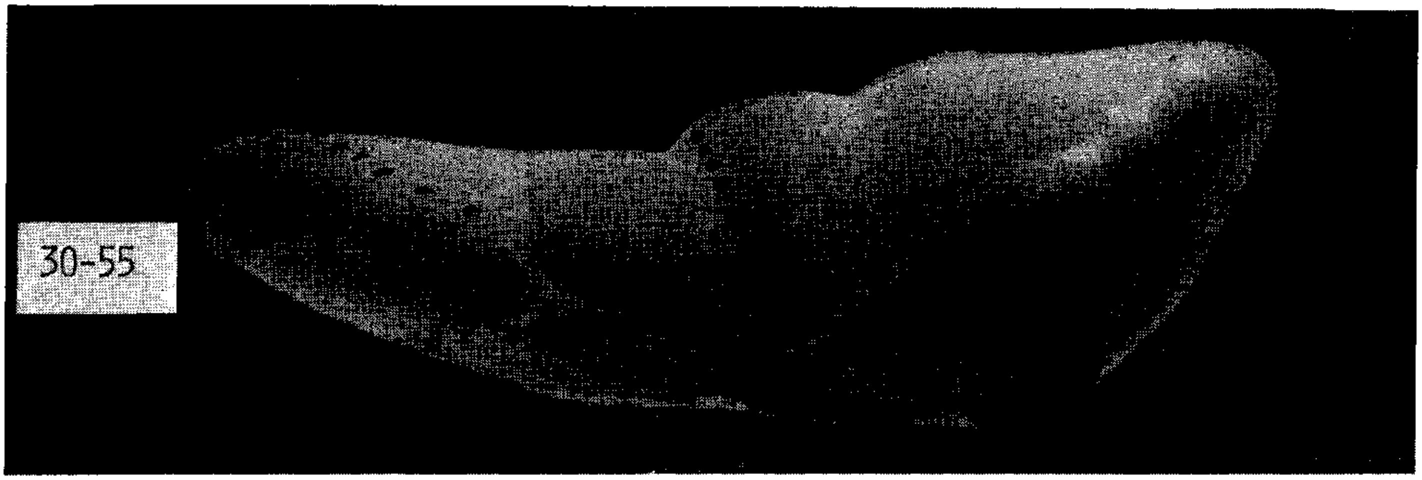

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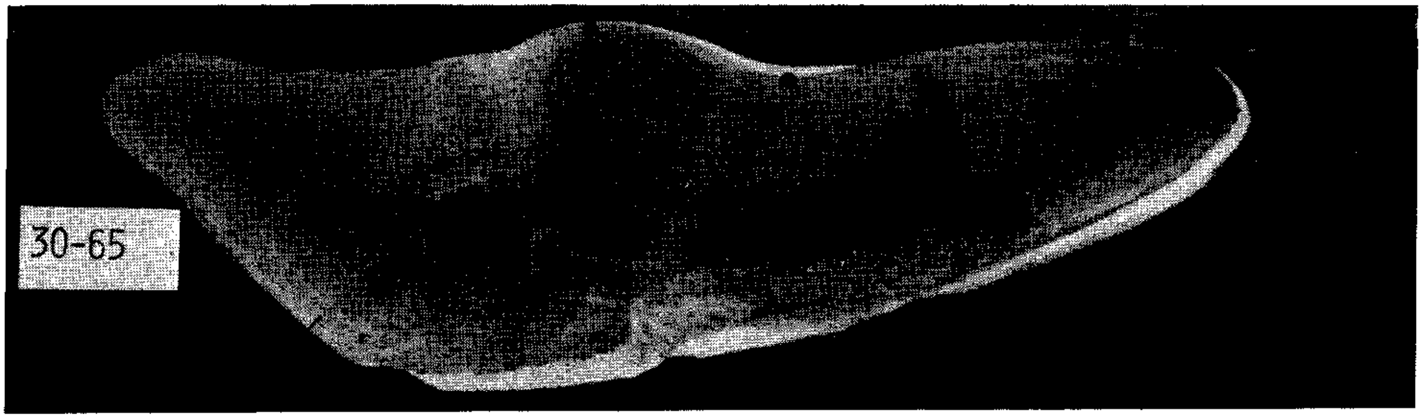

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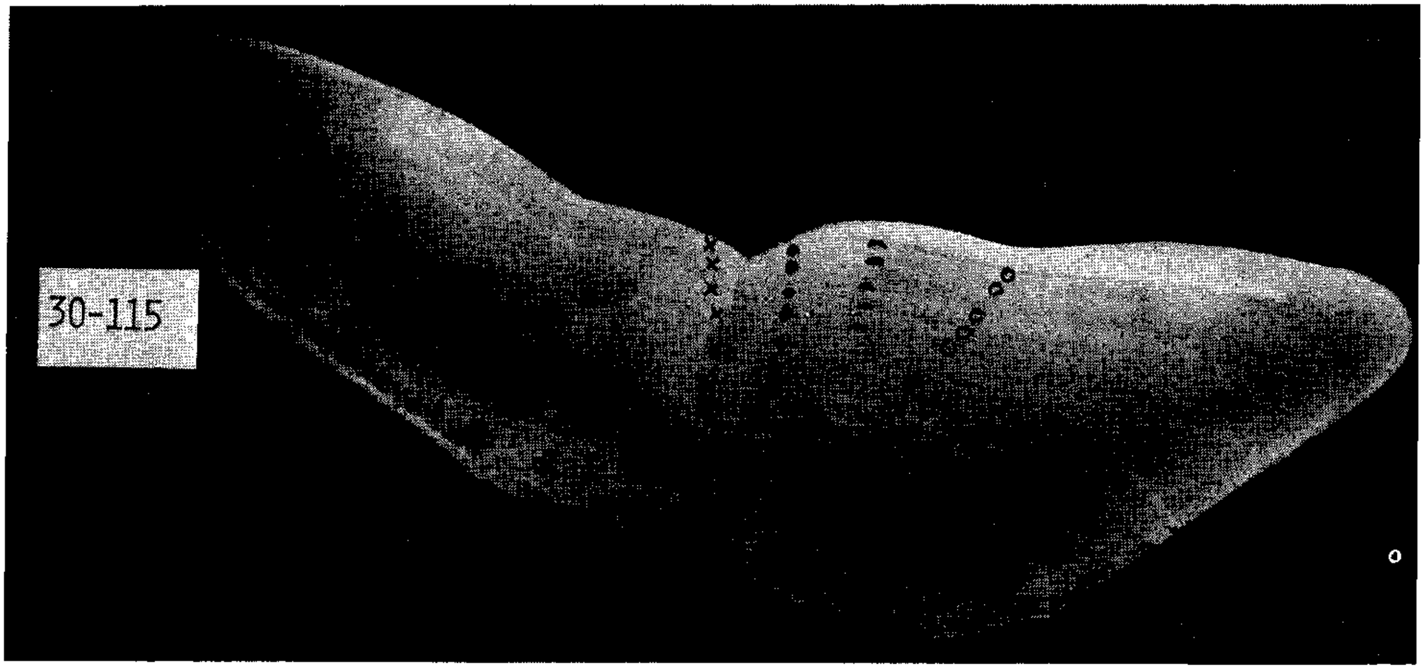

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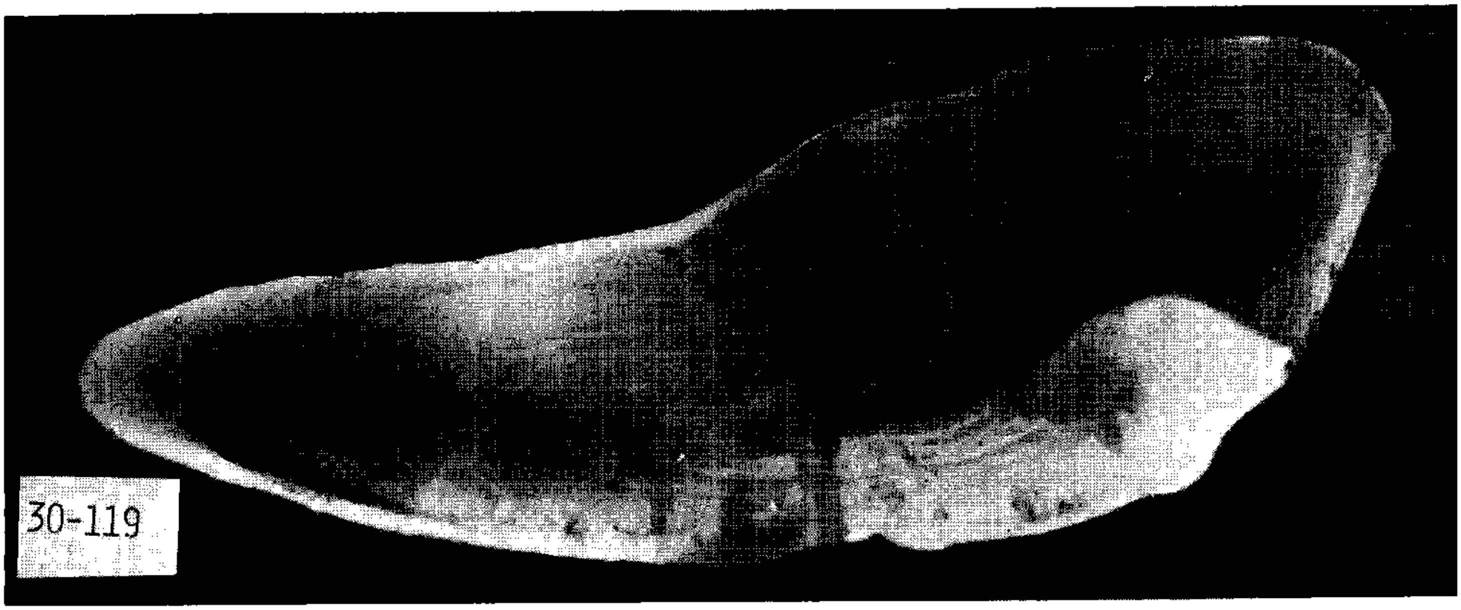
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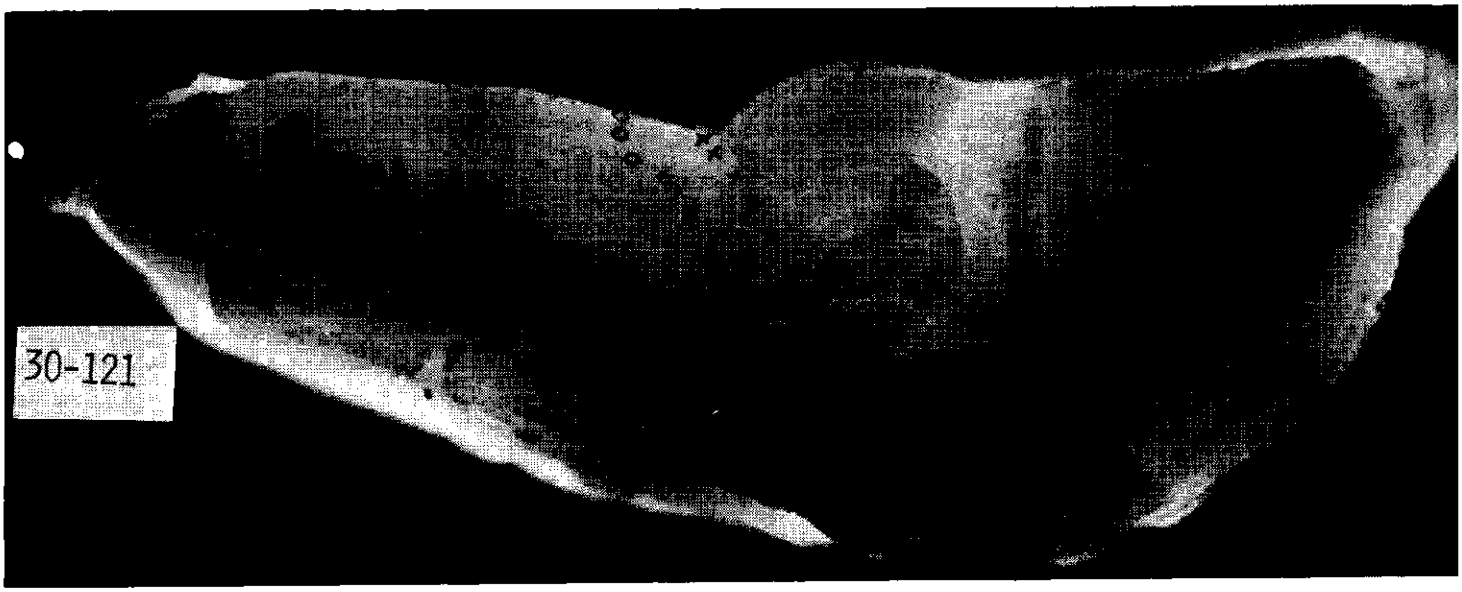
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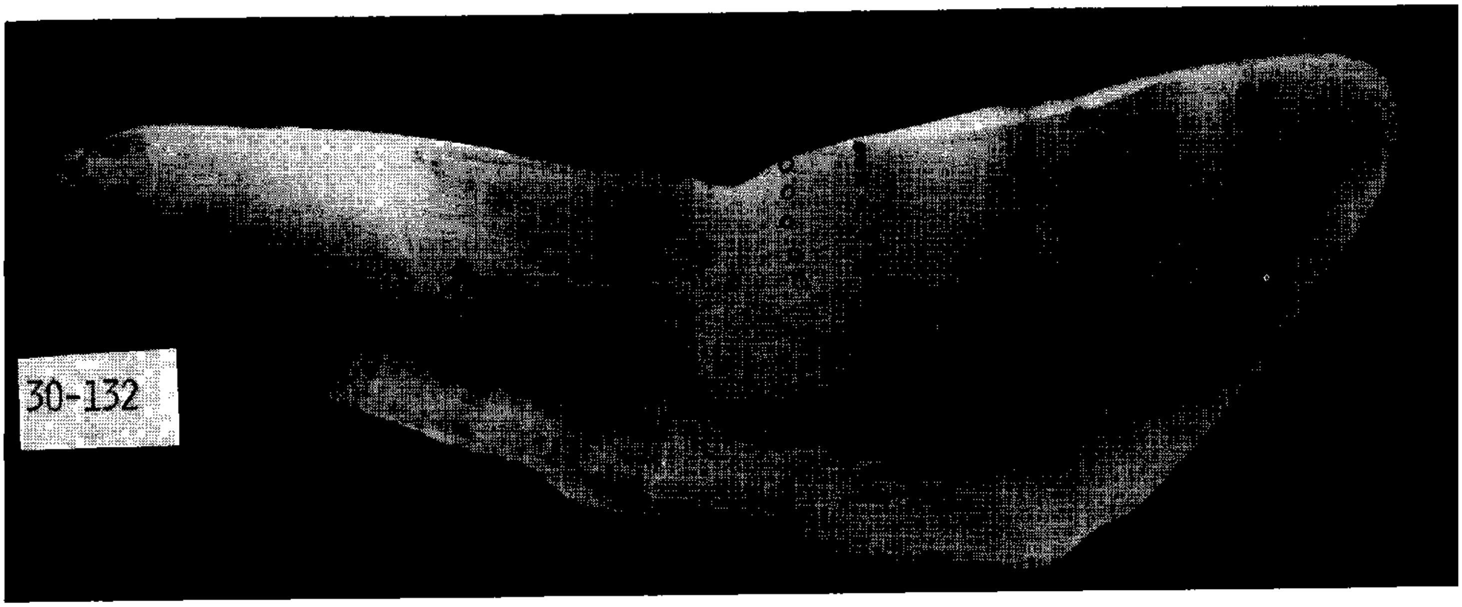
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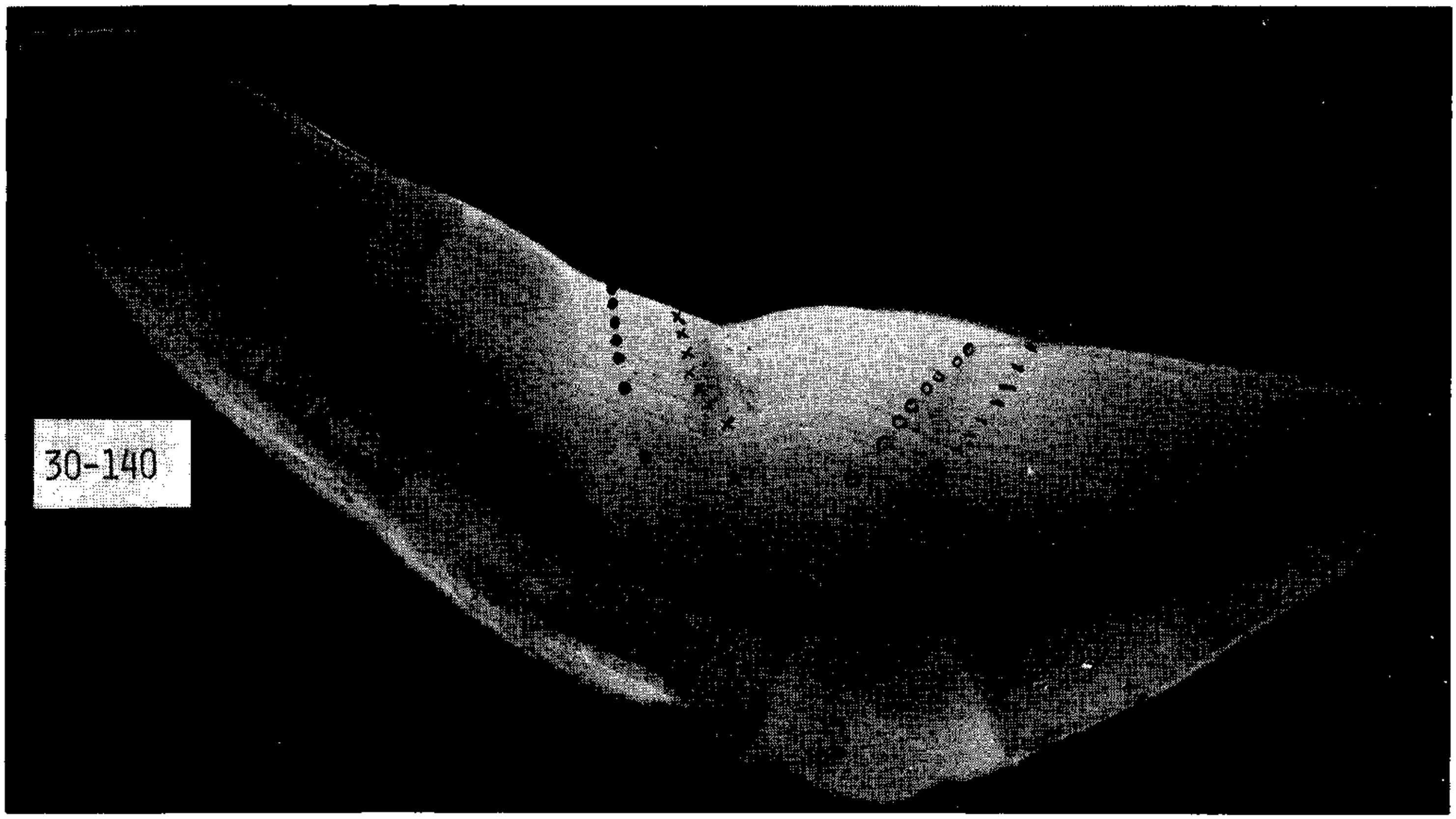
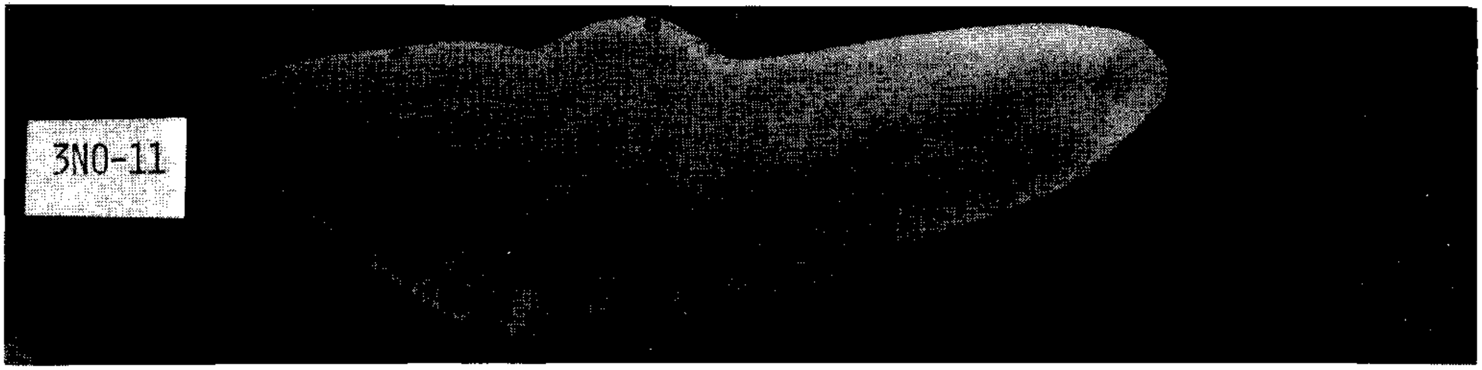


3O-140

DIVISION 3NO



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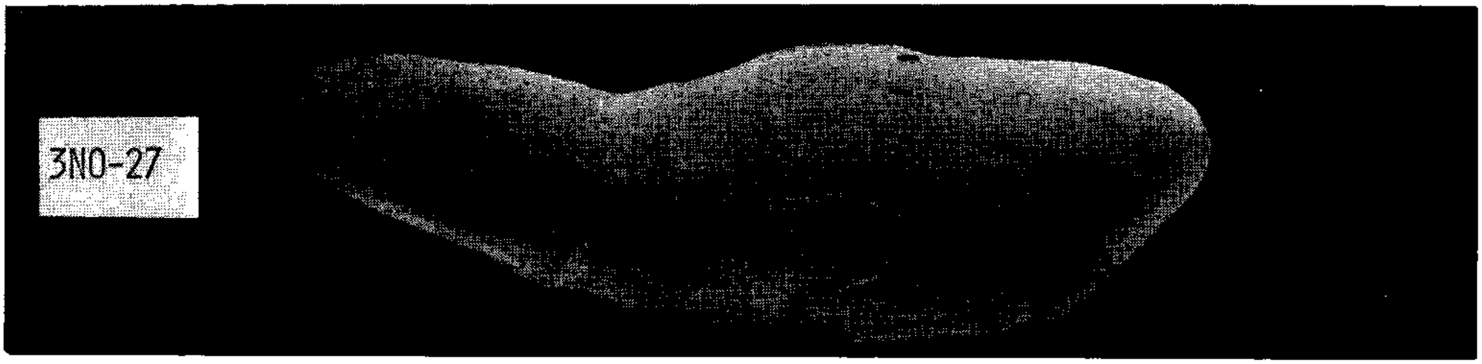
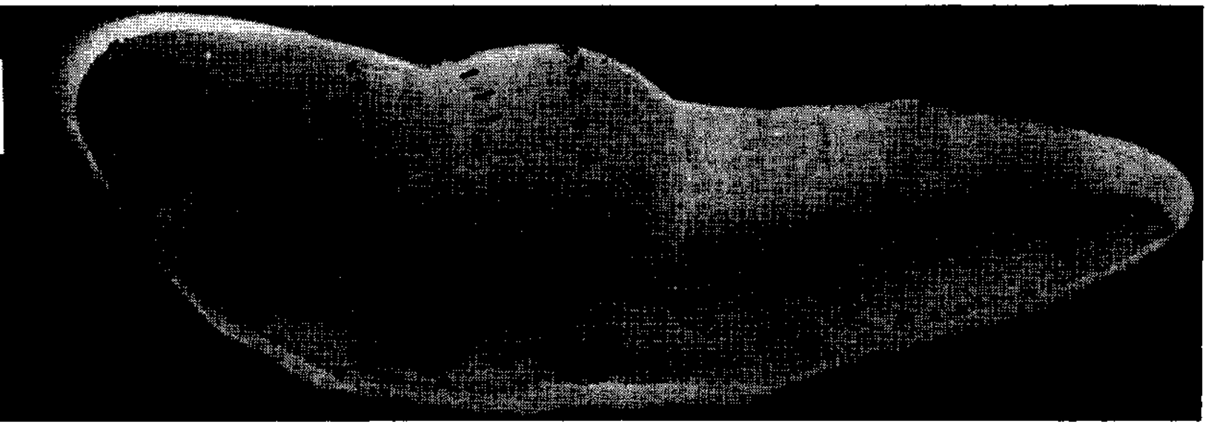


3NO-27

3NO-38



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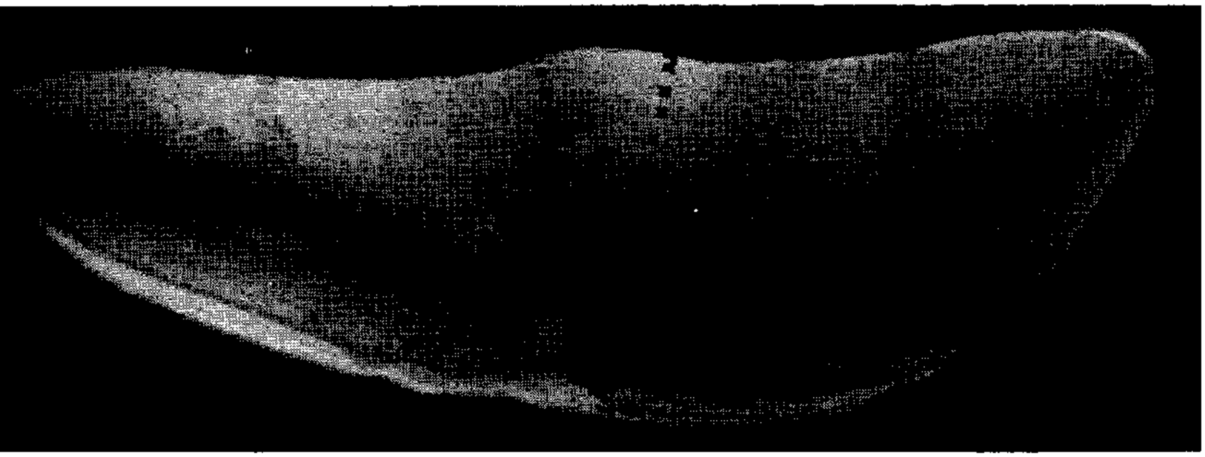
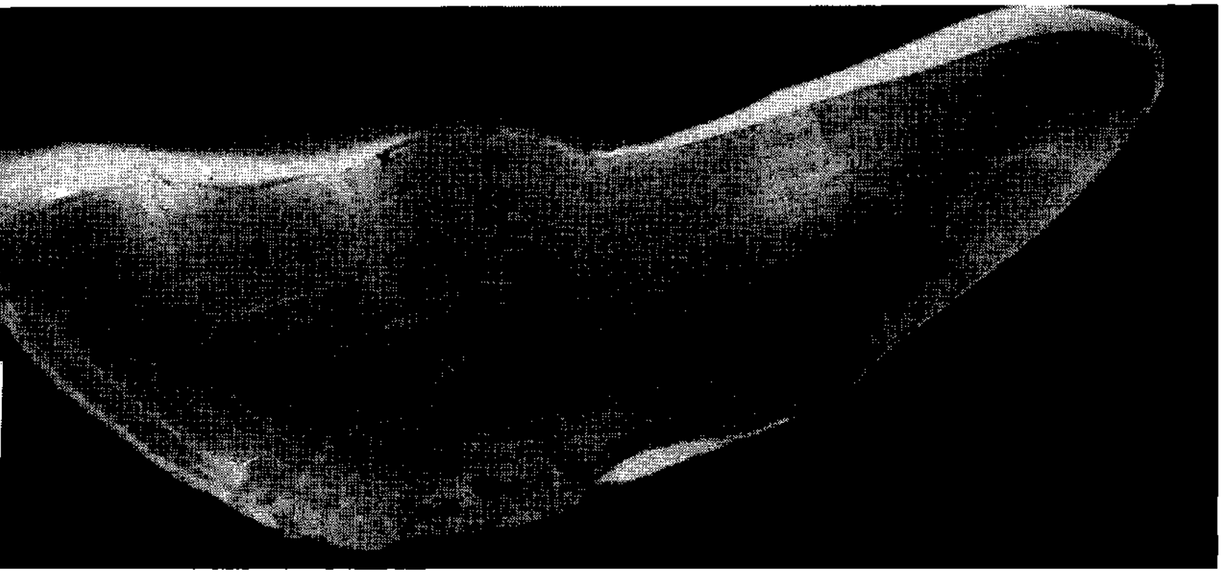
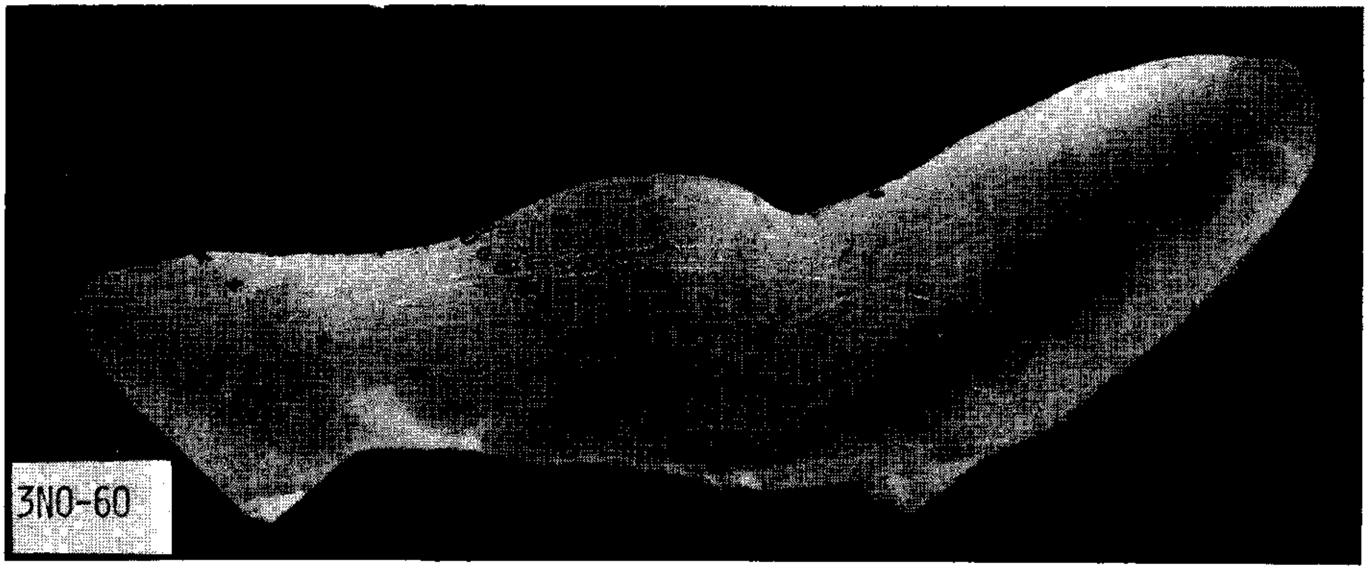
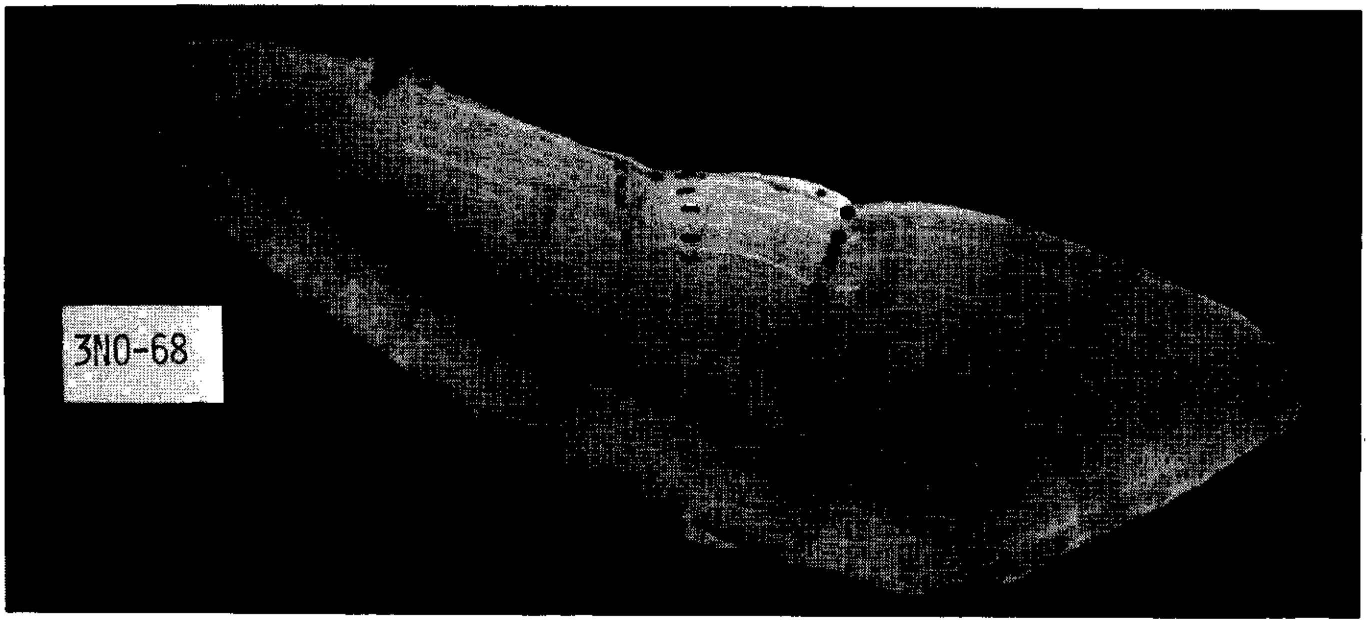


3NO-51

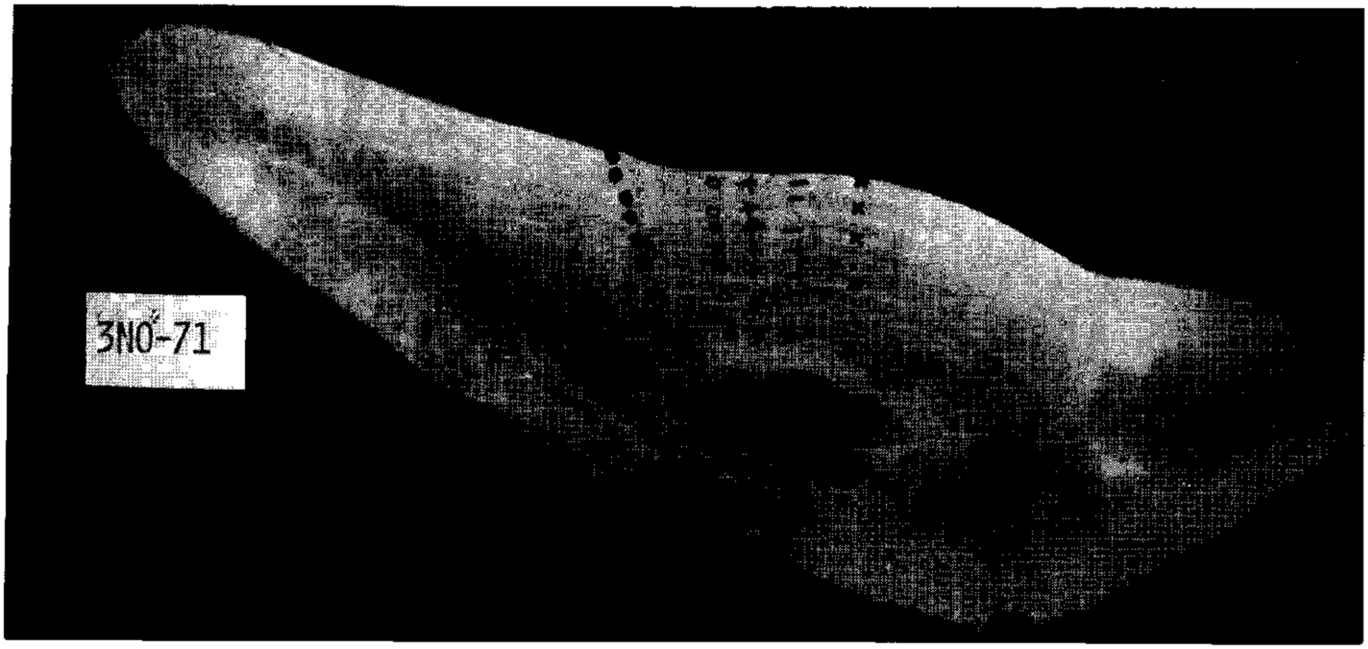




3NO-60



3NO-68



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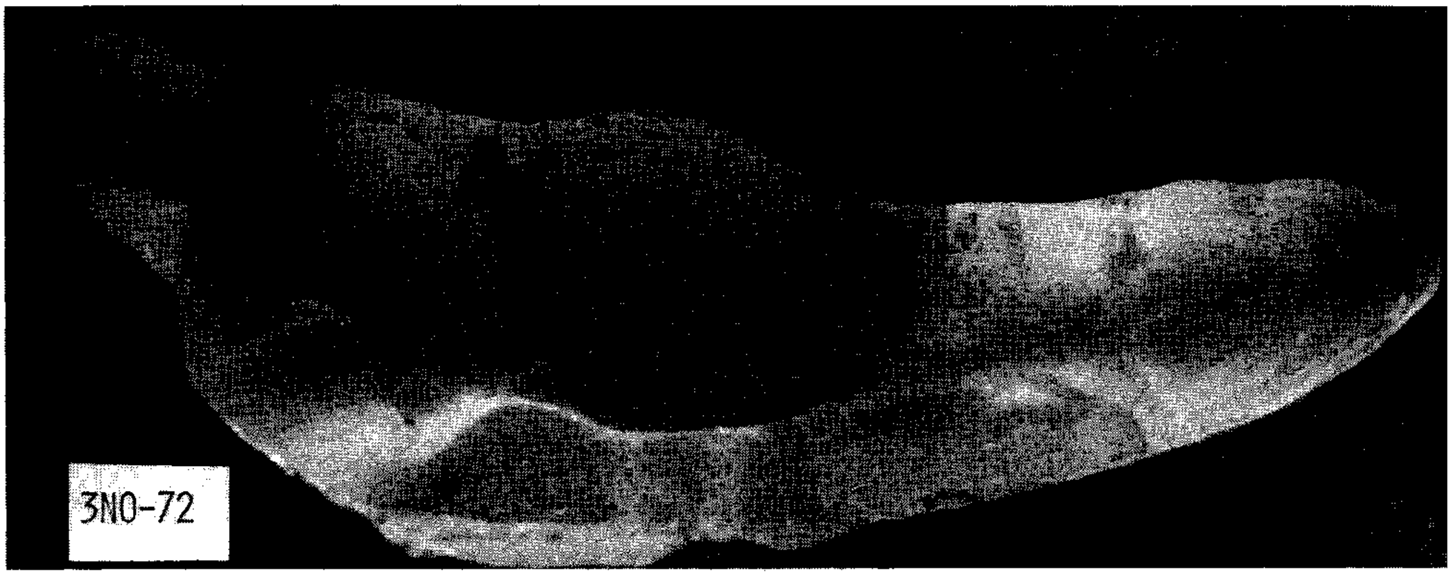
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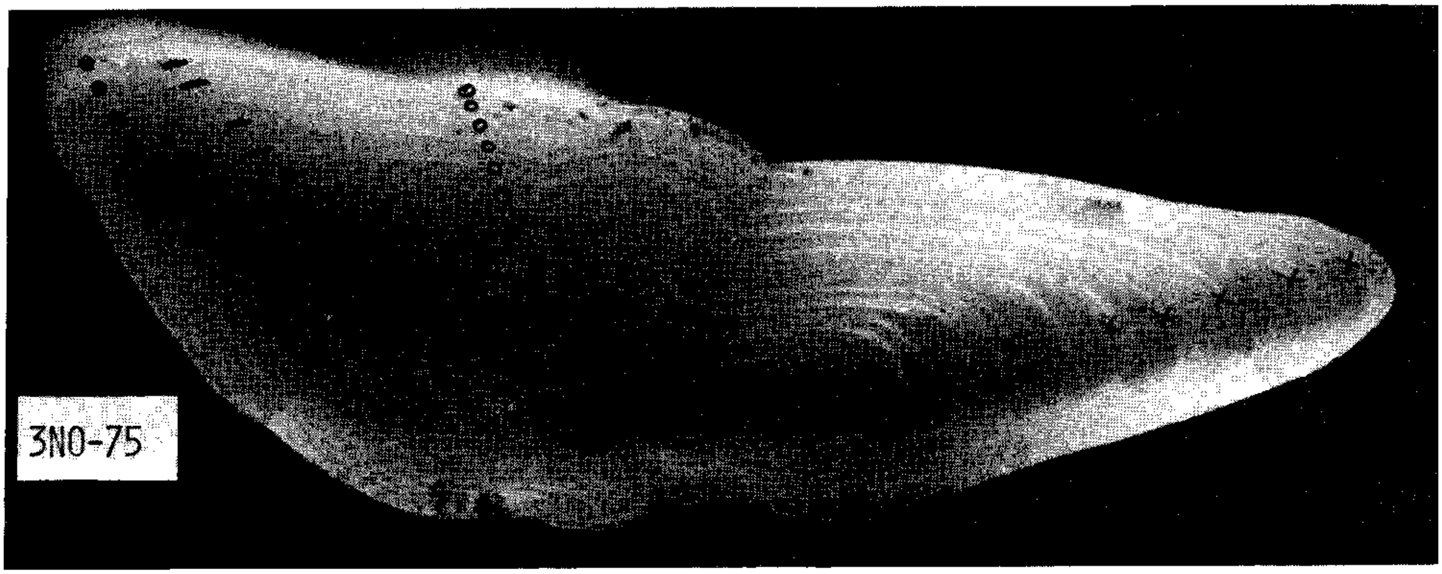
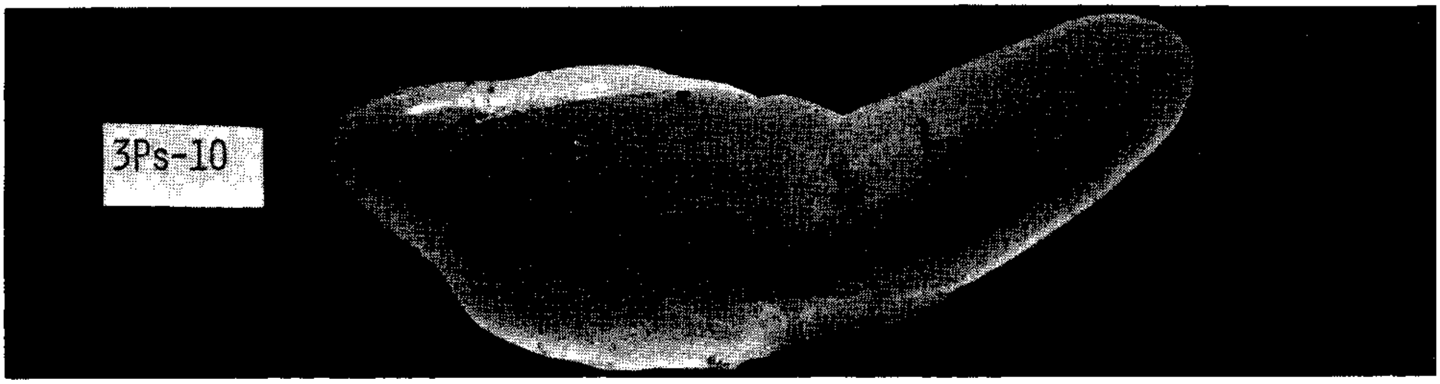
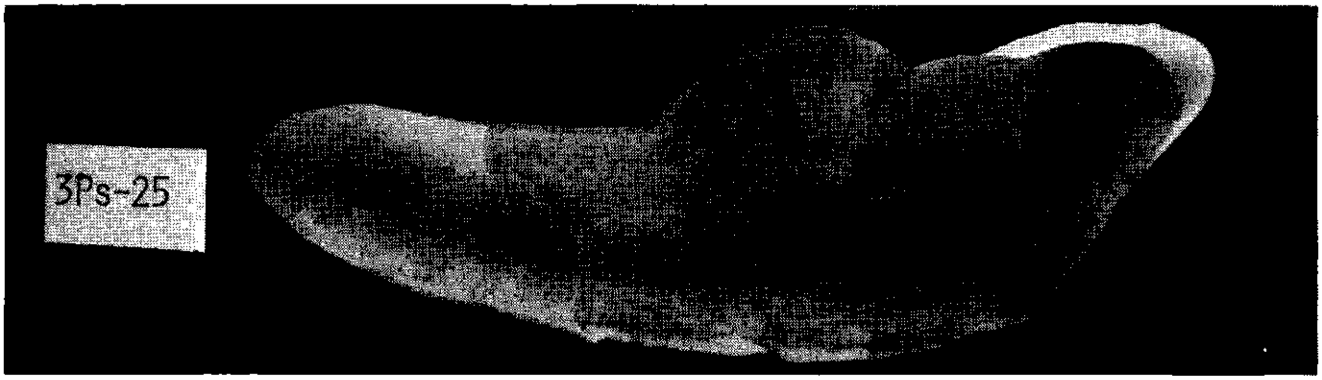

3NO-75

DIVISION 3Ps


3Ps-10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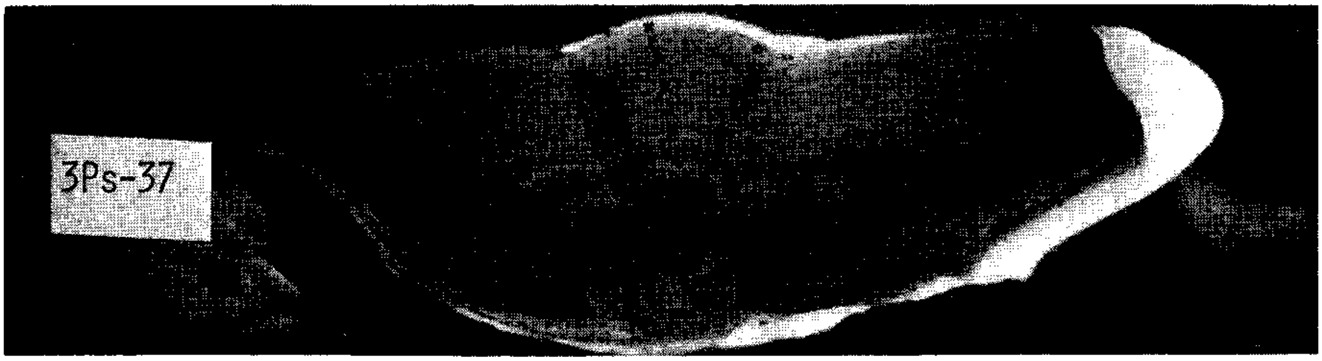
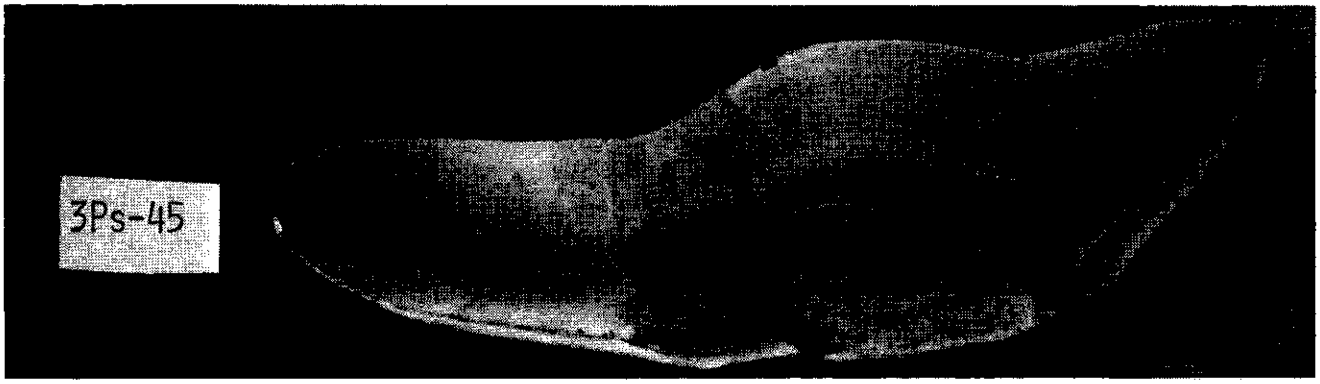

3Ps-37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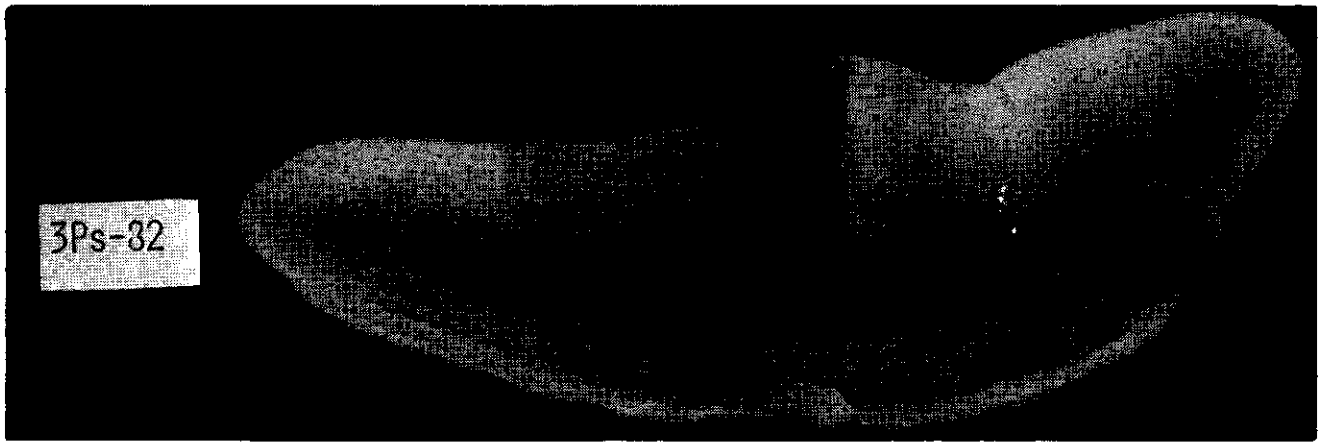
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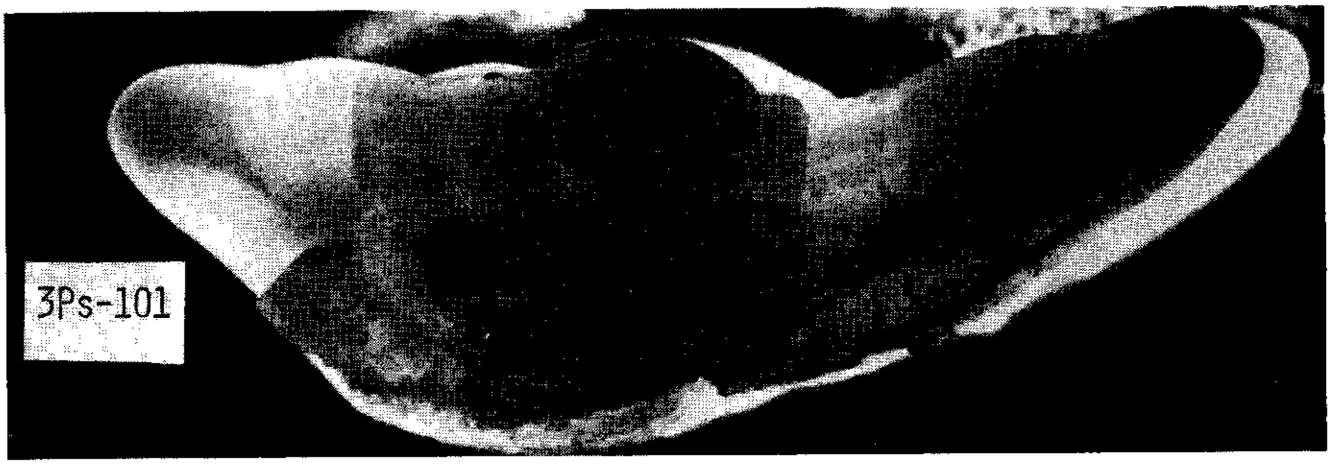
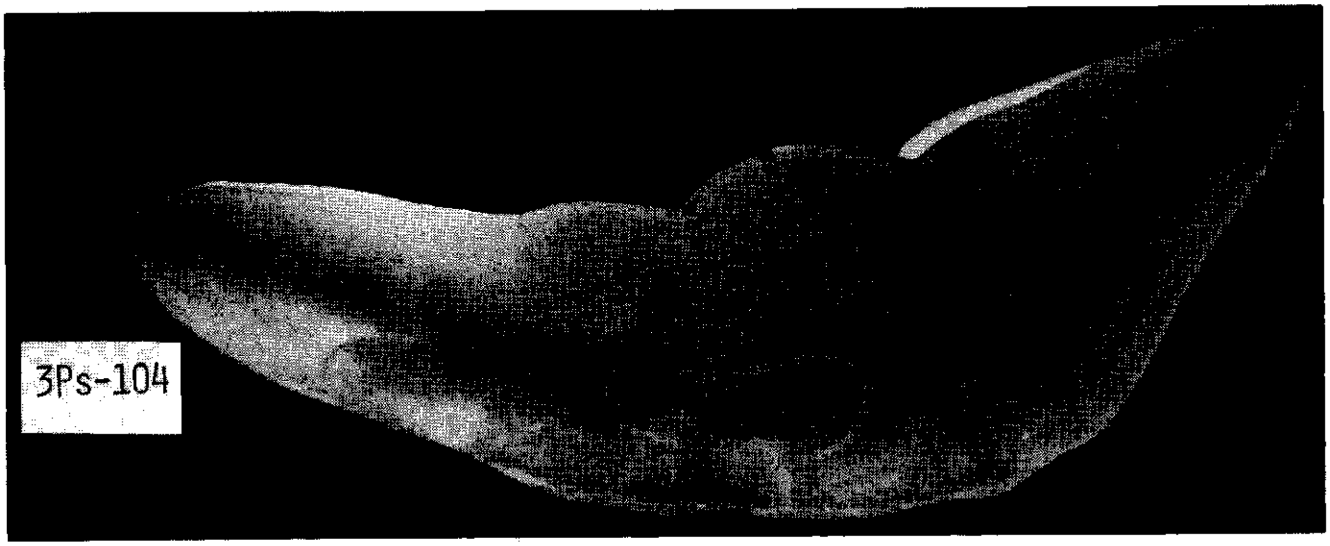
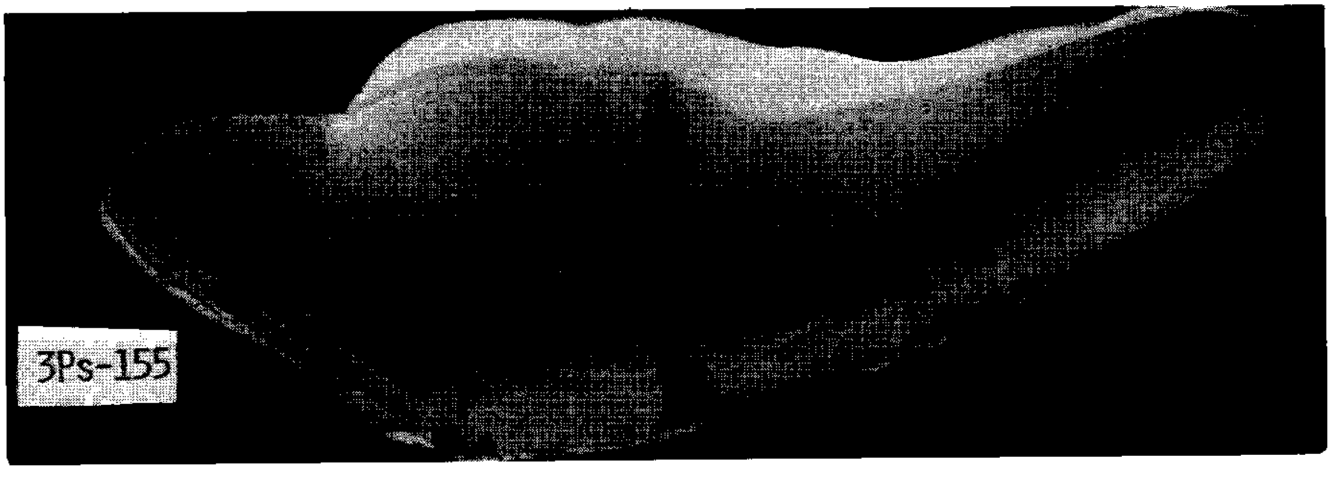


3Ps-101



3Ps-104

3Ps-127



3Ps-155