ISSN 0074 - 2651

INTERNATIONAL COMMISSION

FOR THE

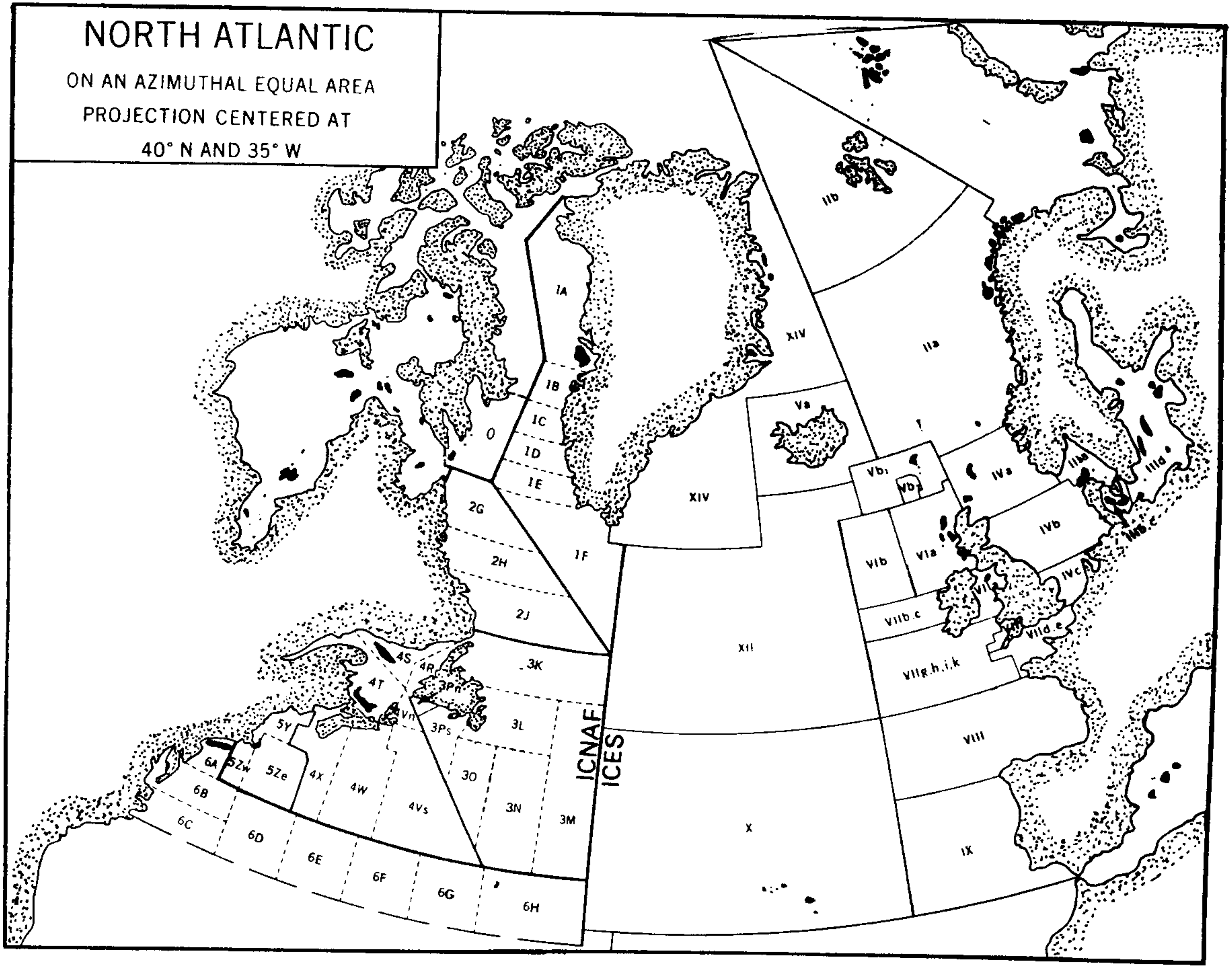
NORTHWEST ATLANTIC FISHERIES

RESEARCH BULLETIN

NUMBER 12

Issued from the Headquarters of the Commission
Dartmouth, N. S., Canada

October 1976


NORTH ATLANTIC

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

Contents

Review Papers

Note

Measures of Abundance of Atlantic Mackerel off the Northeastern Coast of the United States

E. D. Anderson[1]

Abstract

The historical mackerel fishery off the northeastern United States coast from 1804 to 1974 is reviewed, with particular emphasis on recent international catches which increased from 1,049 tons in 1962 to a peak of 387,364 tons in 1972. Changes in mackerel abundance during 1963-75 are described by four research vessel survey and commercial fishery indices. These are evaluated in terms of similarity to biomass estimates based on results of virtual population analysis (VPA). The VPA estimates increased from 1968 to 1970 and then declined thereafter. The US spring survey catch per tow index indicated a 92% decline in abundance from 1968 to 1975. The autumn survey index increased from 1963 to 1967 and then showed an 80% decline in abundance from 1967 to 1973-74. The US commercial standardized catch per day index increased steadily until 1968 and then declined by 94% to 1974. The distant water fleet (DWF) standardized catch per hour index increased from 1968 to 1970, declined in 1971-72, and then increased in 1973-74. Analyses suggested that changes in DWF vessel efficiency occurred during 1968-74 due to learning or technological improvements, or both. It was concluded that the US commercial index and the spring survey index were better indicators of changes in mackerel abundance than the DWF index.

Introduction

In the Northwest Atlantic, Atlantic mackerel *(Scomber scombrus)* range from Labrador (Parsons, 1970) southward to North Carolina. Sette (1950) hypothesized the existence of southern and northern migrating contingents which spawn during late spring-early summer south of Cape Cod and in the Gulf of St. Lawrence respectively, and overwinter along the edge of the continental shelf between Sable Island and Cape Hatteras (Fig. 1). He concluded that the northern contingent overwinters from Long Island and eastward and the southern contingent from Long Island and southward, and that the two groups mix briefly during spring and autumn. Recent tagging experiments (Beckett *et al.*, MS 1974; Parsons and Moores, 1974; Moores *et al.*, 1975) have confirmed that some of the mackerel present in Newfoundland and Gulf of St. Lawrence waters during summer and autumn overwinter south of Long Island. Therefore, both contingents apparently support the winter and spring international fishery that occurs off the US coast. Moores *et al.* (1975) suggested that the proportion of northern-spawned mackerel in the catch in ICNAF Subarea 5 and Statistical Area 6 (SA 5-6) (Fig. 2), may be substantial although no estimate was given. Lett *et al.* (MS 1975) (citing unpublished data by P. F. Lett and R. G. Halliday) suggested that, based on a simulation study involving the total mackerel and herring *(Clupea harengus)* biomass, perhaps 50-60% of the total mackerel biomass in the Northwest Atlantic spawns in the Gulf of St. Lawrence.

The international catch of mackerel off the northeastern coast of the USA in SA 5-6 increased from 1,049 tons (metric) in 1962 to 387,364 tons in 1972 (Table 1). Prior to the arrival of the distant water fleets in the early 1960's, the mackerel fishery was characterized by small catches by US vessels, although a much more intensive fishery had existed during most of the 1800's with a maximum catch of 81,300 tons in 1884 (Sette and Needler, 1934). Intensive fisheries were initiated by the USSR in 1967, Poland in 1968, and the German Democratic Republic (GDR) and Bulgaria in 1971. The 1966 and 1967 year-classes, the latter approximately twice as abundant as the former, provided the major portion of the 1968-72 catches (ICNAF, 1974b).

Nationally-allocated total allowable catches (TACs) were established for mackerel in SA 5-6 by ICNAF at 450,000, 304,000, and 285,000 tons for 1973, 1974, and 1975 respectively. The 1973 TAC was not based on a firm assessment of maximum sustainable yield (MSY) but was set to limit the rapidly developing fisheries by distant water fleets until an adequate assessment could be completed. The 1974 and 1975 TACs were, however, established from scientific advice to stabilize fishing mortality at the 1973 level, which was near the point of maximum yield per recruit (ICNAF, 1974a, 1974b).

An unproven, but generally-accepted hypothesis has prevailed suggesting that mackerel stock abundance has fluctuated widely historically. These fluctuations were assumed (Sette and Needler, 1934; Taylor *et al.*, 1957) to

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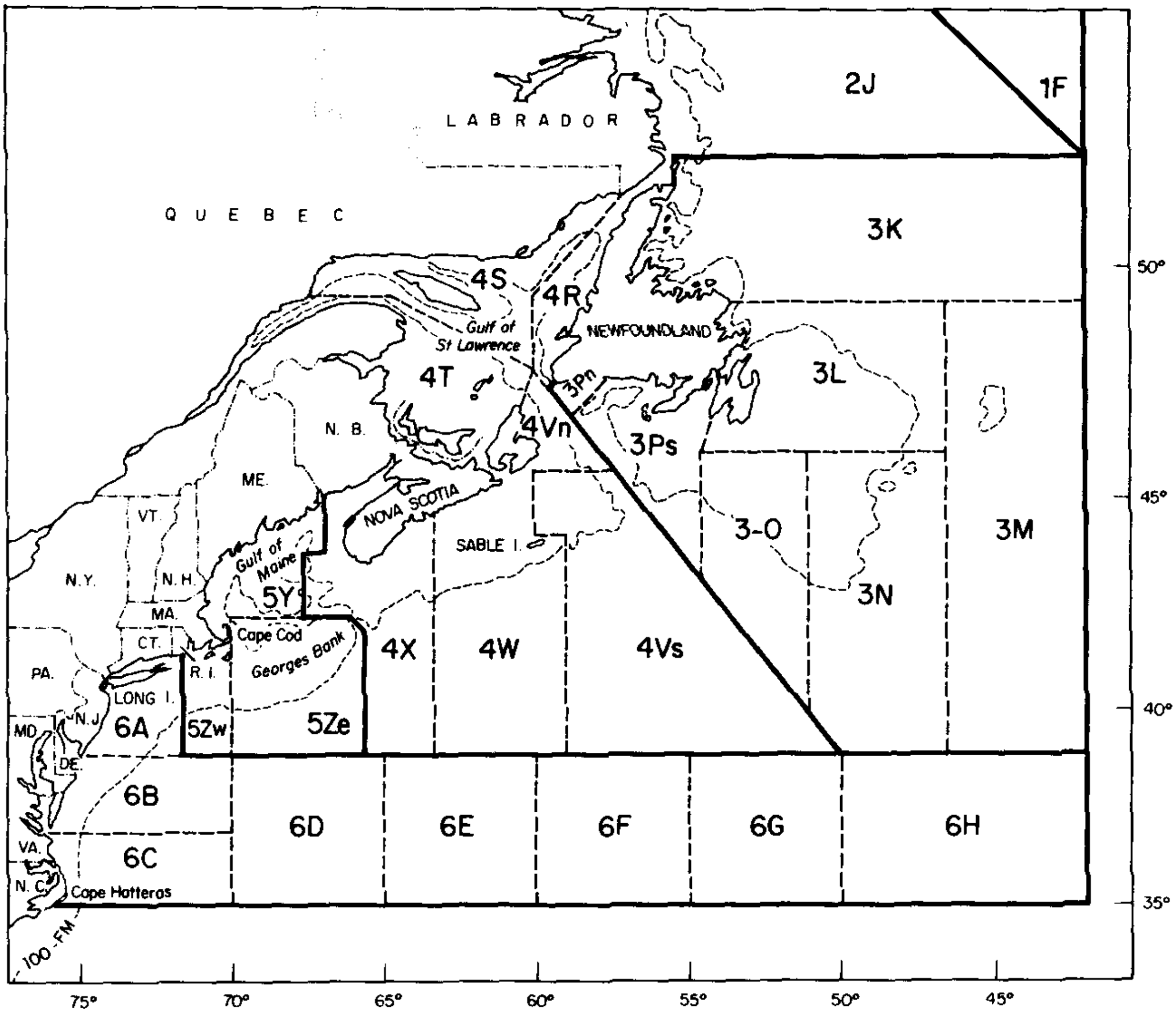

Fig. 1. Northwest Atlantic from North Carolina to Labrador showing ICNAF SA 3-6.

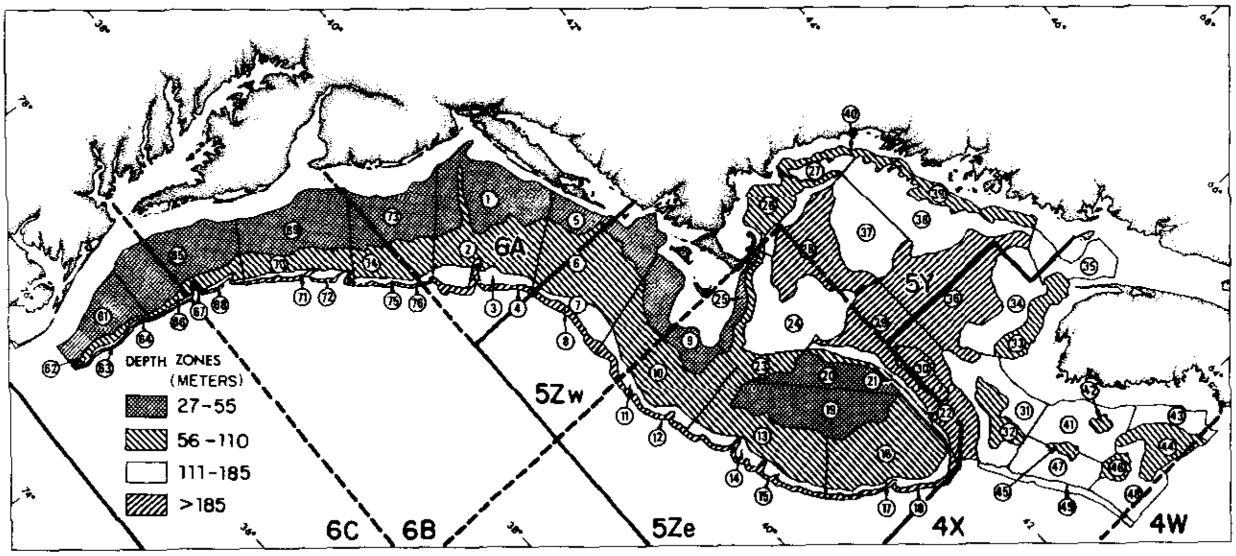

Fig. 2. Northwest Atlantic off the US coast showing bottom trawl survey sampling strata and ICNAF SA 5-6.

TABLE 1. Mackerel catch (tons) in ICNAF SA 5-6 in 1961-74.

Year	Bulgaria	GDR	Poland	Romania	USSR	USA	Others	Total
				Subarea 5				
1961	—	—	—	—	—	1,027	—	1,027
1962	—	—	111	—	—	822	—	933
1963	—	—	—	—	896	1,202	—	2,098
1964	—	—	—	—	533	1,264	—	1,797
1965	—	—	1	—	2,475	1,467	11	3,954
1966	—	—	6	3	5,446	1,903	—	7,358
1967	—	48	507	138	11,907	3,216	91	15,907
1968	—	3,184	10,160	283	33,961	3,001	188	50,777
1969	1,966	2,021	13,421	151	47,547	3,873	549	69,528
1970	1,949	2,920	40,987	758	56,457	3,092	1,472	107,635
1971	1,632	7,090	43,682	1,774	59,074	1,593	1,595	116,440
1972	7,452	25,372	61,486	515	103,686	1,025	982	200,518
1973	24,369	54,874	100,729	905	132,335	621	1,463	315,296
1974	3,615	10,509	38,542	1,719	96,324	475	825	152,009
				Statistical Area 6				
1961	—	—	—	—	—	334	—	334
1962	—	—	—	—	—	116	—	116
1963	—	—	—	—	293	118	—	411
1964	—	—	—	—	94	380	—	474
1965	—	—	—	—	53	531	—	584
1966	—	—	—	—	1,252	821	—	2,073
1967	—	163	—	—	6,087	675	45	6,970
1968	—	158	448	—	7,333	928	329	9,196
1969	117	193	4,977	—	37,563	491	326	43,667
1970	2,058	2,711	27,153	—	68,026	957	1,082	101,987
1971	26,875	62,083	68,612	2,747	68,754	813	2,420	232,304
1972	16,104	55,165	80,513	2,004	30,371	981	1,708	186,846
1973	7,374	21,884	16,525	4,971	13,461	715	938	65,868
1974	17,108	49,468	57,561	5,247	12,816	567	148	142,915
				Total				
1961	—	—	—	—	—	1,361	—	1,361
1962	—	—	111	—	—	938	—	1,049
1963	—	—	—	—	1,189	1,320	—	2,509
1964	—	—	—	—	627	1,644	—	2,271
1965	—	—	1	—	2,528	1,998	11	4,538
1966	—	—	6	3	6,698	2,724	—	9,431
1967	—	211	507	138	17,994	3,891	136	22,877
1968	—	3,342	10,608	283	41,294	3,929	517	59,973
1969	2,083	2,214	18,398	151	85,110	4,364	875	113,195
1970	4,007	5,631	68,140	758	124,483	4,049	2,554	209,622
1971	28,507	69,173	112,294	4,521	127,828	2,406	4,015	348,744
1972	23,556	80,537	141,999	2,519	134,057	2,006	2,690	387,364
1973	31,743	76,758	117,254	5,876	145,796	1,336	2,401	381,164
1974	20,723	59,977	96,103	6,966	109,140	1,042	973	294,924

be primarily instrumental in causing the substantial variation in commercial landings recorded since the early 1800's. Bigelow and Schroeder (1953) associated fluctuations in landings in the Gulf of Maine area during 1910-32 with marked differences in year-class strength. Various environmental factors such as temperature, wind movements, food (plankton) abundance, and epizootics (caused by the fungus, *Ichthyosporidium hoferi*) have been correlated or associated with year-class strength and stock abundance (Sette, 1943; Taylor *et al.*, 1957; Sindermann, 1958; MacKay, 1967). Lett *et al.* (MS 1975) recently demonstrated from a simulation study of the mackerel fishery that recruitment, stock abundance, and catch vary most under conditions of low fishing mortality such as possibly occurred prior to the late 1960's. Although fluctuations in stock abundance have undoubtedly occurred historically, they remain undocumented except by changes in catch.

Assessments of mackerel require some measure or index of stock abundance which may be determined from commercial catch per unit effort or research vessel survey catch per tow. The purpose of this paper is to document the changes in mackerel abundance in SA 5-6 since the early 1960's from US research vessel survey catch per tow, US commercial fishery catch per day fished, and distant water fleet catch per hour fished, and to evaluate the validity of these various indices. Analyses include the standardization of effort by different fishing gears and vessel classes and a determination of the possible extent of learning and technological improvements in the distant water fleets.

Historical Fishery

The Atlantic mackerel has been harvested off the northeastern US coast since the 1600's. Commercial US landings (equivalent to ICNAF nominal catches and hereafter referred to as catch) from 1804 (the first year for which statistics are available) to 1965 underwent considerable fluctuation (Sette and Needler, 1934; Hoy and Clark, 1967) (Fig. 3). During the period 1804-18 the fishery was restricted to coastal waters and annual catches were low, averaging only 3,100 tons. Catches then increased sharply as the fishery expanded to offshore waters due to the development of a large market for salted mackerel. From 1819 to 1885 catches averaged 41,700 tons annually but fluctuated greatly from 10,500 tons in 1840 to 81,300 tons in 1884. Fishing methods during the latter part of this period changed from the traditional hook and line to purse seine. Catches declined during 1886-1924 and averaged only 9,300 tons annually. During this time the fishing vessels changed from sail to motor power and a market for fresh mackerel developed. Catches increased again to average 23,500 tons per year in 1925-49 with a peak of 33,600 tons in 1944, but dropped during 1950-64 to average only 1,500 tons annually. The US catch increased each year from 938 tons in 1962 to 4,365 tons in 1969 (Table 1) but then declined annually thereafter to 1,042 tons in 1974.

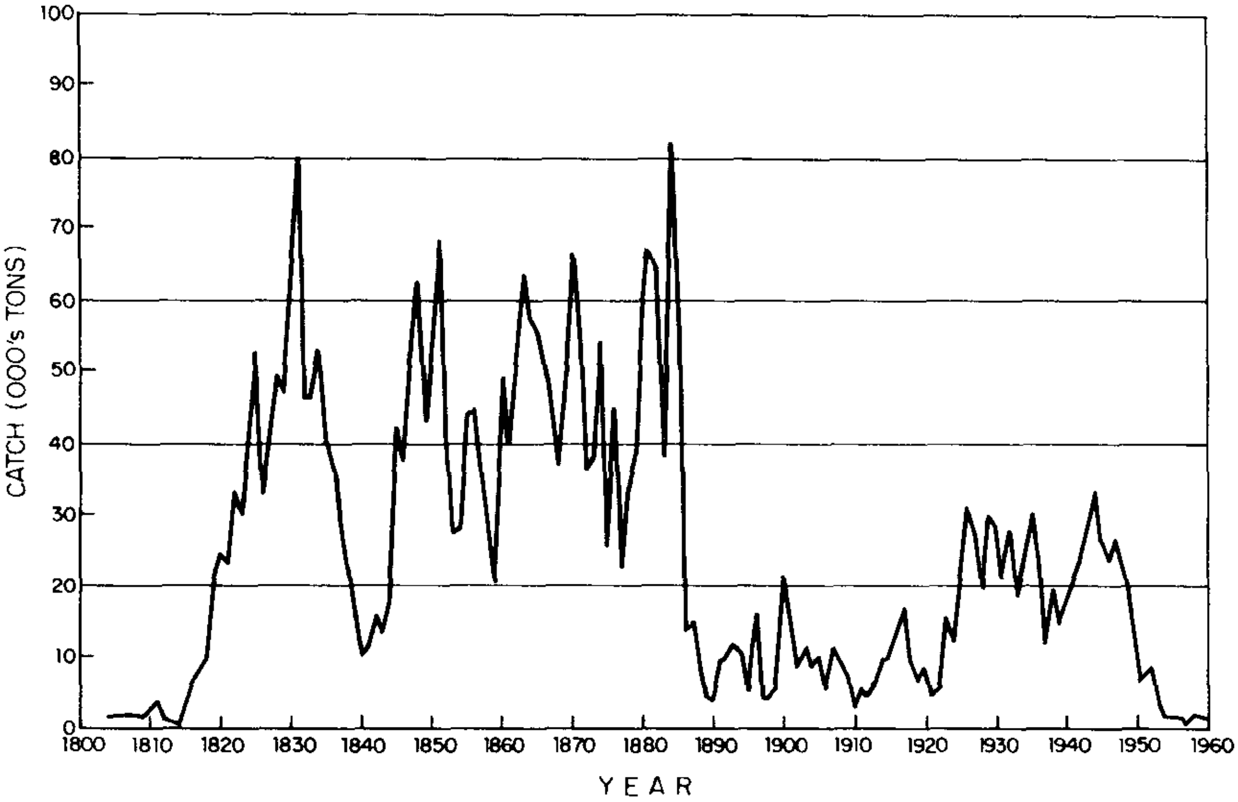

Fig. 3. US mackerel catch, 1804-1960 (Sette and Needler, 1934; Hoy and Clark, 1967).

The total international catch after 1964 virtually doubled each year (114% average annual increase) until 1970 (Table 1 and Fig. 7). It then increased from 209,622 tons in 1970 to 348,744 tons in 1971 (66% increase) and to a peak of 387,364 tons in 1972 (11% increase). The catch diminished slightly to 381,164 tons in 1973 before dropping substantially to 294,924 tons in 1974, the latter catch having been restricted by the TAC of 304,000 tons, which included 13,000 tons allocated to USA and Canada of which USA took 1,042 tons and Canada took nothing.

The international mackerel fishery in SA 5-6 during 1967-74 was dominated by the USSR, Poland, and GDR, whose combined catches annually averaged over 90% of the total. Catches by the USSR exceeded those of any other country during 1965-74 except in 1972, averaging 68% of the yearly total during 1965-70 and 37% in 1971-74. The USSR catch reached a peak in 1973 of 145,796 tons. Catches by Poland and GDR both peaked in 1972 at 141,999 and 80,537 tons respectively, with the Polish catch in that year surpassing that of any other country. The number of different nations reporting mackerel catches in SA 5-6 reached a maximum of 12 in 1972.

Subarea 5 produced 52-89% of the annual catch from SA 5-6 during 1961-70. Statistical Area 6 provided 67% of the 1971 catch but the 1972 catch was nearly the same from the two areas (SA 5 = 52%, SA 6 = 48%). The SA 5 catch increased to 83% of the total in 1973 but dropped again to 52% in 1974.

The fishery in SA 5-6 since the late 1960's exhibited a pronounced seasonal pattern that coincided with the migratory scheme proposed by Sette (1950). Catches were greatest during January-April primarily in ICNAF Divisions 6A and 6B (Anderson, MS 1975; Moores *et al.*, 1975) as the result of the presence of overwintering concentrations. Catches in SA 6 were negligible during June-November as the mackerel moved north. Catches in ICNAF Subdivisions 5Zw and 5Ze generally peaked in May and then declined, suggesting the further movement north of some fish towards the Gulf of St. Lawrence. The relatively large summer and autumn catches in 5Ze (Anderson, MS 1975) suggests, however, that substantial numbers remain in that general area. They may have been less available to the fishery following spawning, perhaps due to dispersal or movement to coastal waters, or both, particularly in the Gulf of Maine, as reported by Sette (1950). In addition, many vessels switched to herring in Subdivision 5Ze during August-October. Catches then increased again in SA 5-6 during November-December as the fish moved south and concentrated for overwintering.

A substantial US recreational fishery for mackerel has existed from Maine to North Carolina. Since yearly recreational catches were not known, they are not included in the US statistics shown in Table 1. Angler surveys conducted at 5-year intervals beginning in 1960 provided estimates of 4,957, 8,583, and 32,078 tons of mackerel for 1960, 1965 and 1970 respectively (Clark, 1962; Deuel and Clark, 1968; Deuel, 1973). The estimated number of mackerel anglers in those years was 235,000, 220,000, and 605,000 respectively, indicating an increase of over 150% in the number of anglers and in the catch per angler from 1960 to 1970. The increase in the number of anglers reflects the expansion of recreational fishing in the USA, whereas the increase in the catch per angler suggests improved mackerel abundance. The estimated 1970 recreational catch constituted 13% of that year's total reported harvest (international plus recreational catches). It is therefore important that future consideration be given to the increasing US recreational catch in the assessment and management of the mackerel stock.

Materials and Methods

US research vessel survey catch per tow

Research vessel bottom trawl surveys by the USA (Grosslein, 1969) have been conducted between Nova Scotia and Hudson Canyon (Div. 6A) annually since 1963 and were extended south to Cape Hatteras in the autumn of 1967. Autumn surveys (September-December) have provided a continuous time-series since 1963, while spring surveys (March-May) have constituted an unbroken sequence since 1968. Sampling was based on a stratified random design (Cochran, 1953) with strata (Fig. 2) constituting different depth zones and areas (Grosslein, MS 1968). Tows were made at randomly selected stations within each stratum at a speed of 3.5 knots for 30 minutes, with operations encompassing 24 hours per day. The autumn surveys, as well as the 1968-72 spring surveys, employed a No. 36 Yankee otter trawl with a headrope height of 3 m and equipped with a 13 mm stretched mesh codend liner (Grosslein, MS 1968). The 1973-75 spring surveys were conducted with a modified No. 41 Yankee high-opening bottom trawl with a headrope height of 4 m. In order to maintain continuity with the 1968-72 series, the 1973-75 station catches were adjusted to equivalent No. 36 trawl catches, utilizing a catch ratio for mackerel of 3.25:1 between the No. 41 and No. 36 trawls. This ratio was determined from analysis of catch data obtained during 1973-74 joint US-USSR trawl surveys.

Stratified mean catch (kg) per tow, standard deviation, and coefficient of variation were calculated for each survey (Table 2) based on selected strata. A $\log_e (x + 1)$ transformation, where x was the individual station catch, was used which normalized the frequency distribution and stabilized the variance of the individual catches. The results were retransformed to the linear scale for comparison with other indices of abundance (Fig. 8) using the relation (Finney, 1941)

$$\bar{y} = \exp(\bar{x} + \frac{S^2}{2}) - 1$$

where $\bar{y}$ = stratified mean catch per tow on the linear scale, $\bar{x}$ = mean catch per tow, and S^2 = the variance on the $\log_e$ scale. The spring index was calculated from catches in sampling strata 1-14 and 61-76 (Fig. 2) and

TABLE 2. Stratified mean catch (kg) per tow of mackerel from US research vessel bottom trawl surveys in the spring (strata 1-14, 61-76) and autumn (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26) determined from a $\log_e(x + 1)$ transformation where x is the individual catch with standard deviation (SD) and coefficient of variation (CV).

	Spring				Autumn			
Year	Date	Mean	SD	CV	Date	Mean	SD	CV
1963	—	—	—	—	13 Nov.-14 Dec.	0.013	0.009	69.2
1964	—	—	—	—	22 Oct.-4 Dec.	< 0.001	< 0.001	—
1965	—	—	—	—	6 Oct.-9 Nov.	0.046	0.021	45.6
1966	—	—	—	—	13 Oct.-13 Nov.	0.057	0.021	36.8
1967	—	—	—	—	25 Oct.-9 Dec.	0.195	0.053	27.2
1968	2-14 Mar.	0.567	0.119	21.0	10 Oct.-20 Nov.	0.117	0.039	33.3
1969	5-22 Mar.	0.023	0.007	30.4	8 Oct.-22 Nov.	0.154	0.066	42.9
1970	18 Mar.-29 Apr.	0.407	0.074	18.2	15 Oct.-20 Nov.	0.068	0.026	38.2
1971	9 Mar.-12 Apr.	0.386	0.076	19.7	29 Sept.-19 Nov.	0.052	0.018	34.6
1972	8-25 Mar.	0.306	0.074	24.2	28 Sept.-19 Nov.	0.070	0.024	34.3
1973	16 Mar.-17 Apr.	0.170	0.051	30.0	26 Sept.-19 Nov.	0.034	0.014	41.2
1974	13 Mar.-7 Apr.	0.210	0.067	31.9	23 Sept.-25 Oct.	0.046	0.033	71.7
1975	4 Mar.-24 Apr.	0.063	0.017	27.0	—	—	—	—

the autumn index from strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, and 25-26. These strata sets comprised the areas where mackerel were consistently caught during those surveys. The spring set included all strata from the southwest part of Georges Bank to Cape Hatteras and the autumn set included all strata ≤110 m from Hudson Canyon to east of Cape Cod including Georges Bank.

US commercial fishery catch per day fished

Catch and effort statistics from handlines, otter trawls, floating traps, sink gillnets, drift gillnets, purse seines, pound nets, and midwater pair trawls, fished by US vessels landing in New England ports during 1964-74, were used to compute catch per day fished. Statistics from only those individual vessel trips in which the mackerel catch formed ≥ 50% of the total were included in the analysis. The reported effort was actual fishing time recorded to the nearest tenth of a day.

Annual fishing effort of all the different types of gear was standardized by using a two-factor analysis of variance procedure described by Robson (1966) [method summarized by Brown *et al.* (1976)]. The two factors used in the analysis of variance were gear type and vessel tonnage class. Gear types were those listed above and tonnage classes were 0-50, 51-150, and 151-630 gross tons (GT). A separate analysis was performed for each year with data from a single trip constituting one observation. Effort standardization coefficients were computed for each gear-tonnage class (Table 3) in relation to a standard.

Catch per standardized US day fished was computed for each year by multiplying the days fished used in the analysis for each gear-tonnage class by the appropriate effort standardization coefficient and dividing the summed products into the total annual US catch used in the analysis. International effort expressed as standardized

TABLE 3. Effort standardization coefficients calculated for US gear-tonnage classes in ICNAF SA 5-6 for 1964-74.

Gear	Tonnage class	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	Mean
Handline	0-50	—	0.30	—	—	0.08	—	—	—	0.35	—	0.60	0.33
Otter trawl	0-50	—	3.78	2.61	0.89	4.36	1.34	1.61	3.24	28.50	14.99	28.65	9.00
	51-150	26.53	—	—	1.20	3.38	17.29	4.45	7.10	—	19.96	28.35	13.53
Floating trap	0-50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	51-150	—	—	—	—	—	—	—	2.19	—	—	—	2.19
Sink gillnet	0-50	—	1.60	—	—	—	—	—	—	—	0.42	0.90	0.97
	51-150	31.97	—	—	—	—	—	—	—	—	—	—	31.97
Drift gillnet	0-50	1.43	0.39	0.43	0.21	0.16	0.10	0.39	0.24	0.23	0.61	3.10	0.66
Purse seine	0-50	6.83	20.20	2.74	—	—	—	17.11	26.51	30.75	3.97	—	15.44
	51-150	79.62	52.28	34.24	81.89	35.17	150.92	47.22	58.01	0.43	5.29	—	54.51
	151-630	—	—	—	126.68	0.28	—	—	—	—	—	—	63.48
Pound net	0-50	5.29	3.18	2.16	0.64	0.87	1.95	1.75	1.20	2.88	0.25	1.78	2.00
Midwater pair trawl	0-50	—	—	—	—	—	—	—	—	—	18.32	26.59	22.46
	51-150	—	—	—	—	—	—	—	—	—	24.39	26.30	25.35

US days fished was calculated by dividing international catch by catch per standardized US day fished (Table 8).

Distant water fleet catch per hour fished

Catch and effort statistics submitted to ICNAF by Bulgaria, GDR, Poland, Romania and USSR for 1968-74 were analyzed to determine mackerel catch per hour fished. Otter trawl statistics reported by each of these countries were examined by tonnage class, ICNAF division or subdivision, and month, with effort defined as directed towards mackerel if the mackerel catch exceeded that of any other species. Tonnage classes were 151-500, 501-900, 901-1800, and > 1800 GT. Since statistics for GDR, Poland, and the USSR were reported by several vessel classes within each tonnage class, monthly data by vessel class and ICNAF division or subdivision constituted individual observations.

Annual observed catch per hour for each country-tonnage class was computed as the mean of the monthly catch per hour values for each vessel class in each ICNAF division or subdivision (Table 5); standard deviations and coefficients of variation were also calculated. These data were analyzed to determine the extent of learning and/or technological improvements as reflected by catch per hour. A model developed by Brown *et al.* (1976) was used which assumed that learning or technological improvements, or both, continued until the ratio (learning index = L) of observed to predicted catch per hour decreased from one year to the next (Table 5). Predicted catch per hour was defined as observed catch per hour in the first year of the fishery and proportional in succeeding years to stock biomass (tons) of age 1 and older mackerel (Table 6), as determined from population numbers calculated by virtual population analysis (VPA) (ICNAF, 1975). The first year in the fishery for each country-tonnage class was considered to be the first year having directed mackerel effort.

Annual fishing effort of the various vessel tonnage classes from the five countries was standardized using the same analysis of variance procedure as cited earlier. Factors considered in the analysis were tonnage class and country. A separate analysis was performed for each year. Effort standardization coefficients were computed for each country-tonnage class (Table 7) in relation to one category selected as a standard.

Catch per hour fished, standardized for the distant water fleet (DWF), was computed for each year by multiplying the number of hours fished for each country-tonnage class by the appropriate effort standardization coefficient and dividing the summed products into the total catch. International effort, expressed as standardized DWF hours fished, was determined by dividing international catch by catch per standardized DWF hour fished (Table 8).

Results

Abundance indices from US research vessel surveys

Survey catches of mackerel varied considerably, largely due to the distributional characteristics of the species. Spring catches at the various stations ranged from 0 to 4,806 fish (0 to 1,593 kg) while autumn catches varied from 0 to 4,495 fish (0 to 255 kg). Mackerel were caught on the average in 34% of the spring tows and in 15% of the autumn tows. The mackerel catch from tows producing mackerel averaged 61 and 29 fish per tow from spring and autumn surveys respectively, whereas the average catch from all tows was 21 and 6 fish per tow respectively.

The spring catch (kg) per tow index ($\log_e$ scale) decreased from a high of 0.567 in 1968 to 0.063 in 1975 (Table 2 and Fig. 4), corresponding to a linear decline of 92% (Fig. 8). The downward trend from 1968 was relatively steady except for an extremely low value in 1969. Virtually all of the mackerel were caught during the spring of 1969 in stratum 62 (Fig. 2) off Cape Hatteras, suggesting that the annual northerly migration to inshore waters (Sette, 1950) had not yet begun. Water temperatures did not appear to differ from those in adjacent years. Catch per tow for other pelagic species did not exhibit a similar drop in 1969, suggesting that the survey trawl and shipboard operation functioned normally. The high 1968 value resulted primarily from fish of the 1967 year-class at age 1 which comprised 80-90% of the total survey catch.

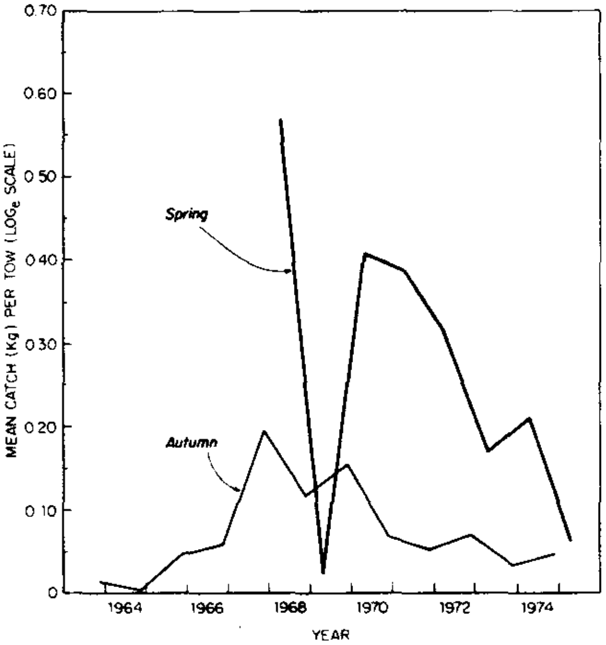

Fig. 4. Stratified mean catch (kg) per tow of mackerel, $\log_e (x + 1)$ transformation where x equaled individual catch, from US spring (1968-75) and autumn (1963-74) bottom trawl surveys.

The index declined in every year after 1970 except for an increase in 1974. The coefficient of variation ranged from 18 to 32% and averaged 25%.

The autumn catch (kg) per tow index ($\log_e$ scale) increased from < 0.001 in 1964 to a high of 0.195 in 1967 (Table 2, Fig. 4). The index then trended downward with slight increases in 1969, 1972, and 1974. These data indicated an overall decline of about 80% on the linear scale (Fig. 8) from 1967 to 1973-74. Statistical variability associated with the mean value was higher than that of the spring indices. The coefficient of variation varied from 27 to 72% and averaged 43%.

Abundance indices from US commercial fishery statistics

The catch and effort statistics, used to calculate catch per day fished, represented 13-64% of the annual US mackerel catch and averaged 36% yearly over the 11-year period. The catches, however, comprised only a small proportion of the international catch after 1964 (46% in that year), averaging 10.7% in 1965-67, 2.3% in 1968-69, and 0.2% in 1970-74. The US catches, although taken in all quarters of the year, were limited to coastal waters. Pound nets, floating traps and purse seines accounted for the majority of the catch.

Effort by the various gear-tonnage classes was standardized to that of the floating trap tended by vessels of 0-50 gross tons. This vessel size category was selected because (a) it contained observations in all years, (b) it contained a larger number of observations in all years than other categories also meeting criterion (a), and (c) it provided greater catches than other gear-tonnage classes satisfying both criteria (a) and (b).

Analysis of variance indicated that gear differences in each of the eleven years and tonnage-class differences in six of the years were significant at the 0.05 probability level. A significant gear-tonnage class interaction was apparent in only 1 year and this was disregarded in the analysis.

Effort standardization coefficients are given in Table 3. Coefficients were greatest for purse seines, followed by midwater pair trawls, otter trawls, pound nets, floating traps, drift gillnets and handlines. They also increased with tonnage class. Coefficients for some categories were generally consistent over the years, whereas others varied considerably. Some of the larger deviations were associated with a small number of trips producing small catches.

Catch per standardized US day fished increased steadily from 0.43 tons in 1964 to 2.80 tons in 1968, but then dropped in each year except in 1970 to a low of 0.17 tons in 1974 (Table 8 and Fig. 7), an overall decline of 94%. International effort, expressed as standardized US days fished, increased exponentially from 5,281 days in 1964 to 1,734,847 days in 1974, a 330-fold increase, at an average annual rate of 86%.

Abundance indices from distant water fleets

Mackerel catches reported by Bulgaria, GDR, Poland, and Romania during 1968-74 were taken entirely by otter trawl, whereas about 95% of the USSR catches were taken annually by otter trawl. The remaining portion of the USSR catches was caught by purse seine with a small amount by pair trawl in 1970. Catches representing directed fisheries varied from 27% of the international total in 1968 to 91% in 1974 (Table 4) and averaged 70% per

TABLE 4. Mackerel catch (tons) from directed mackerel effort by DWF country-tonnage classes in ICNAF SA 5-6 in 1968-74.

Tonnage class	Country	1968	1969	1970	1971	1972	1973	1974
151-500	GDR	12	—	—	—	—	—	—
	USSR	10,690	28,240	48,018	31,148	31,544	6,249	5,446
501-900	GDR	624	347	912	1,624	879	1,550	91
	Poland	756	5,108	7,771	7,868	16,317	10,911	6,865
	USSR	—	7,020	25,553	15,761	7,375	8,619	8,947
901-1800	GDR	1,024	—	216	441	1,881	—	792
	Poland	108	—	—	30,868	37,478	45,123	42,569
> 1800	Bulgaria	—	1,966	4,007	27,269	23,395	30,702	20,664
	GDR	—	499	3,238	65,269	73,889	74,491	58,949
	Poland	1,272	2,936	49,690	56,826	76,600	49,198	40,477
	Romania	—	—	444	4,043	2,213	5,876	6,555
	USSR	1,569	9,136	26,065	58,593	44,527	68,519	76,128
Total (A)		16,055	55,252	165.914	299,710	316,098	301,238	267,483
International catch (B)		59,973	113,195	209.622	348,744	387,364	381,164	294,924
(A)/(B)		.268	.488	.792	.859	.816	.790	.907

TABLE 5. Observed catch (tons) per hour of mackerel ($\bar{x}$) including number of observations (n), standard deviation (SD), and coefficient of variation (CV); predicted catch per hour; and learning index (L) for DWF country-tonnage classes in ICNAF SA 5-6, 1968-74.

		Observed catch (tons) per hour						
Tonnage class	Country	Year	n	$\bar{x}$	SD	CV	Predicted catch (tons) per hour	L
151-500	USSR	1968	4	0.52	0.114	21.9	0.52	1.00
		1969	10	0.84	0.500	59.5	0.67	1.25
		1970	18	1.01	0.415	41.1	0.77	1.31
		1971	22	0.73	0.320	43.8	0.73	1.00
		1972	21	0.50	0.218	43.6	0.62	0.81
		1973	13	0.58	0.245	42.2	0.51	1.14
		1974	8	0.95	0.525	55.3	0.45	2.11
501-900	GDR	1968	2	0.90	0.615	68.3	0.90	1.00
		1969	3	0.63	0.250	39.7	1.16	0.54
		1970	13	2.44	2.823	115.7	1.33	1.83
		1971	10	1.58	1.007	63.7	1.27	1.24
		1972	17	0.68	0.687	101.0	1.08	0.63
		1973	11	1.33	1.633	122.8	0.87	1.53
		1974	4	0.55	0.205	37.3	0.78	0.71
	Poland	1968	2	1.28	0.764	59.7	1.28	1.00
		1969	6	0.96	0.319	33.2	1.65	0.58
		1970	15	1.02	0.467	45.8	1.89	0.54
		1971	13	0.88	0.566	64.3	1.80	0.49
		1972	22	0.82	0.608	74.1	1.53	0.54
		1973	13	1.19	0.578	48.6	1.24	0.96
		1974	5	1.80	0.987	54.8	1.11	1.62
	USSR	1969	14	1.17	0.738	63.1	1.17	1.00
		1970	34	1.18	0.805	68.2	1.34	0.88
		1971	39	0.81	0.349	43.1	1.28	0.63
		1972	25	0.68	0.309	45.4	1.08	0.63
		1973	20	0.74	0.452	61.1	0.88	0.84
		1974	9	1.20	0.537	44.8	0.79	1.52
901-1800	GDR	1968	2	2.79	1.244	44.6	2.79	1.00
		1970	8	2.39	2.095	87.7	4.13	0.58
		1971	1	5.80	0.000	0.0	3.92	1.48
		1972	7	4.02	3.695	91.9	3.34	1.20
		1974	8	1.89	1.289	68.2	2.42	0.78
	Poland	1968	1	1.86	0.000	0.0	1.86	1.00
		1971	35	3.00	1.481	49.4	2.62	1.15
		1972	46	3.51	2.154	61.4	2.22	1.58
		1973	32	4.15	1.462	35.2	1.81	2.29
		1974	33	2.77	1.504	54.3	1.61	1.72
>1800	Bulgaria	1969	5	1.12	0.299	26.7	1.12	1.00
		1970	5	2.69	2.168	80.6	1.29	2.09
		1971	9	4.02	2.326	57.9	1.22	3.30
		1972	10	2.09	1.337	64.0	1.04	2.01
		1973	21	4.37	1.664	38.1	0.84	5.20
		1974	18	4.10	1.172	28.6	0.75	5.47
	GDR	1969	1	1.59	0.000	0.0	1.59	1.00
		1970	12	2.67	1.925	72.1	1.82	1.47
		1971	29	8.87	5.445	61.4	1.73	5.13
		1972	20	7.90	4.876	61.7	1.47	5.37
		1973	20	8.84	5.239	59.3	1.20	7.37
		1974	20	5.96	3.286	55.1	1.07	5.57
	Poland	1968	3	1.25	0.070	5.6	1.25	1.00
		1969	5	1.12	0.509	45.4	1.61	0.70
		1970	27	3.71	2.051	55.3	1.85	2.01
		1971	31	4.42	2.771	62.7	1.76	2.51
		1972	36	5.02	2.508	50.0	1.49	3.37
		1973	28	5.00	2.324	46.5	1.21	4.13
		1974	21	5.17	2.759	53.4	1.08	4.79
	Romania	1970	3	1.16	1.041	89.7	1.16	1.00
		1971	15	2.08	3.076	147.9	1.10	1.89
		1972	9	1.15	0.538	46.8	0.94	1.22
		1973	10	1.96	0.781	39.8	0.76	2.58
		1974	19	2.27	1.515	66.7	0.68	3.34
	USSR	1968	2	0.84	0.212	25.2	0.84	1.00
		1969	16	1.24	0.433	34.9	1.08	1.15
		1970	30	3.51	4.328	123.3	1.24	2.83
		1971	59	2.44	2.372	97.2	1.18	2.07
		1972	36	2.46	1.736	70.6	1.00	2.46
		1973	39	2.91	1.531	52.6	0.82	3.55
		1974	54	3.61	1.557	43.1	0.73	4.95

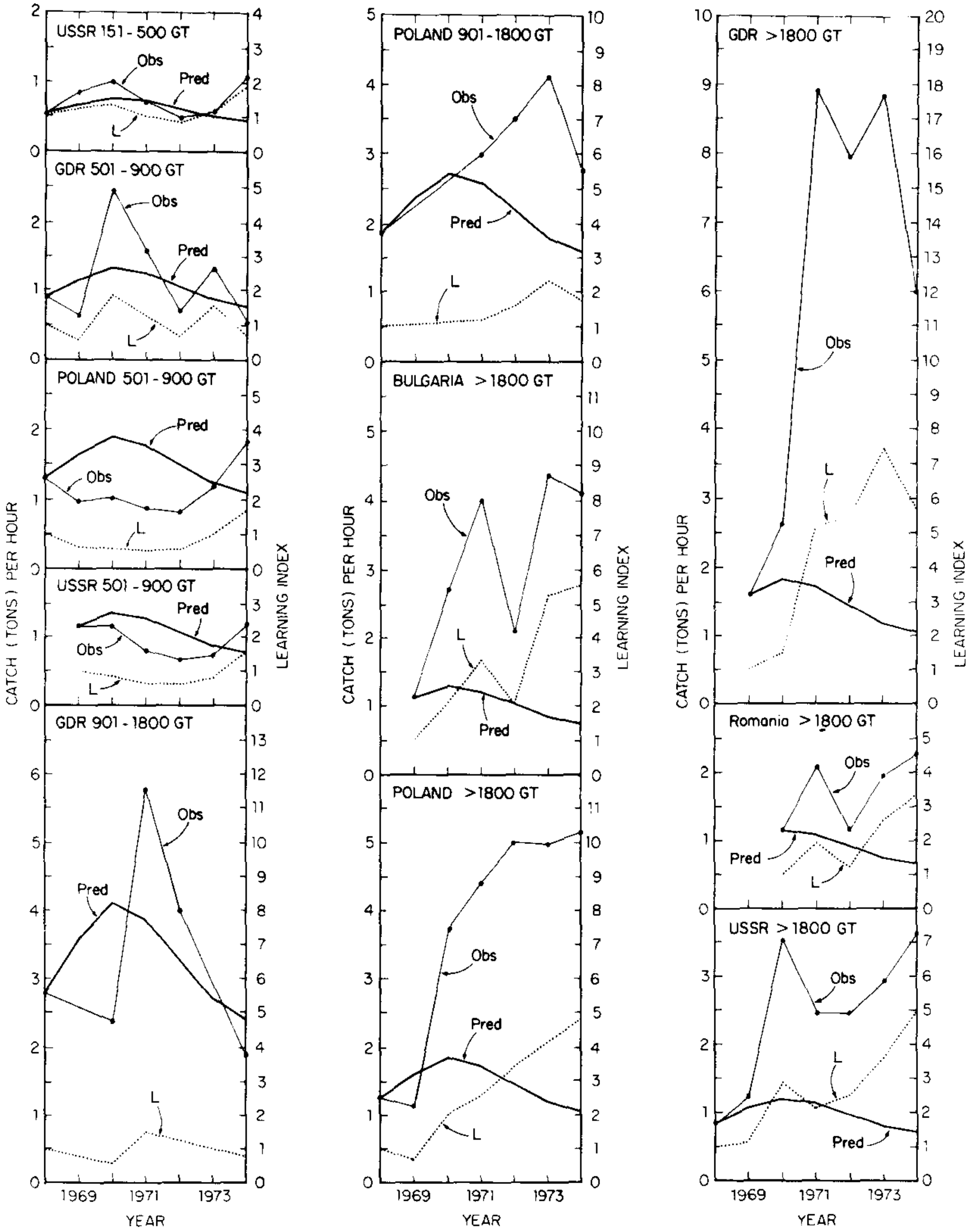

Fig. 5. Observed catch (tons) per hour (Obs) of mackerel, predicted catch per hour (Pred), and learning index (L) for country-tonnage classes in ICNAF SA 5-6, 1968-74. Years for which observed catch per hour was available are indicated by dots.

year for the period. Observations represented all months of the year, but 90% of the total (1,160) were from January-May and November-December, with April providing more than any other month (16%). Observations were taken nearly equally from SA 5 (54%) and SA 6 (46%).

The number of observations per country-tonnage class ranged from 1 to 59 per year (Table 5) and averaged 17. Coefficients of variation of the annual observed catch per hour for the country-tonnage classes ranged from 0 to 148% (Table 5) and averaged 56%. Coefficients of variation by tonnage class averaged 44% for 151-500 GT, 49% for 901-1800 GT, 57% for > 1800 GT, and 63% for 501-900 GT, and by country averaged 47% for Poland, 49% for Bulgaria, 54% for USSR, 64% for GDR, and 78% for Romania.

Observed catch per hour for most country-tonnage classes, particularly the larger classes, exhibited patterns divergent from predicted catch per hour (Table 5 and Fig. 5). Predicted catch per hour, which was proportional to annual VPA biomass estimates (Table 6), increased from 1968 to a peak in 1970 and then declined each year thereafter. Most country-tonnage classes experienced marked increases in catch per hour after 1970 even though stock biomass declined steadily, but several classes did undergo a decrease in 1974. The 151-500 and 501-900 GT classes, particularly the USSR 151-500 GT class, showed the closest agreement between observed and predicted catch per hour, although several of these exhibited increases in catch per hour in 1973 and 1974.

TABLE 6. Biomass (000 tons) of mackerel (age 1 and older) in ICNAF SA 3-6 in 1968-75 as calculated from virtual population analysis (ICNAF, 1975).

Year	Biomass (000 tons)
1968	1,330.6
1969	1,715.8
1970	1,969.2
1971	1,871.8
1972	1,590.9
1973	1,293.0
1974	1,153.3
1975	1.084.6

Some country-tonnage classes (USSR 151-500 and > 1800 GT, GDR 501-900 and 901-1800 GT, Bulgaria > 1800 GT, and Romania > 1800 GT) showed increases in the learning index (L) in their second and/or third years followed by a drop in the succeeding year (Table 5 and Fig. 5). This suggests that a 1-2 year learning period occurred during which the fleets improved their knowledge pertaining to the seasonal and areal distribution of mackerel and their expertise necessary to efficiently locate and catch the fish. A learning period of this duration for new fisheries was proposed previously (Borkowska-Kwinta, MS 1964; Anthony, 1972; Schumacher and Anthony, MS 1972; Dunin-Kwinta, 1975) and was demonstrated for the DWF fisheries in SA 5-6 by Brown *et al.* (1976). Several country-tonnage classes were characterized by learning indices which decreased below 1.0 in the second and sometimes third years. This occurred because observed catch per hour in the first year was higher than expected in relation to that in the ensuing several years. The first-year values may have been in error due to inadequate numbers of observations or insufficient catches from which to calculate a realistic catch per hour value. The Polish 901-1800 and > 1800 GT and GDR > 1800 GT classes showed continuous increases in L throughout the period with the Polish 901-1800 GT and GDR > 1800 GT classes decreasing only in 1974. All of the other country-tonnage classes, except the GDR 501-900 and 901-1800 GT classes, exhibited secondary increases in L during 1972-74. The continuous increases in L for several of the country-tonnage classes and the secondary increases in L for most of the others suggest that technological improvements (as distinct from learning) occurred following or, perhaps in some cases, during the initial learning period and that these resulted in increases in observed catch per hour even though stock biomass decreased. These improvements may have been achieved in various ways such as by the conversion from bottom to midwater trawls, introduction of larger or more efficient vessels and nets, implementation of better electronic fish-locating gear, improvements in shipboard processing, etc. Such changes are poorly documented, although a conversion from bottom to midwater trawls did occur. Only GDR (1968-74) and USSR (1974) statistics were reported separately for bottom and midwater trawls. These data indicated superior catch rates for midwater trawls. It was concluded, therefore, that observed catch per hour by most country-tonnage classes was not suitable as a year-to-year measure of mackerel stock abundance because of the apparent inequivalence in vessel efficiency and, hence, in a unit of fishing effort throughout the 1968-74 period.

It was decided to standardize the DWF fishing effort to that of the USSR 151-500 GT class, which exhibited closer agreement between observed and predicted catch per hour than any other country-tonnage class. The learning index (L) deviated little from 1.0 in 1969-73 (with mean of 1.10 in the range 0.81-1.31), suggesting minimal learning and technological improvements except in 1974 (L = 2.11). This country-tonnage class contained observations in all years (Table 5) and provided a substantial proportion of the total catch included in the analysis, at least up to 1970 (Table 4). The proportions were 67% in

1968, 51% in 1969, 29% in 1970, 10% in 1971-72, and 2% in 1973-74. Although catches by the USSR 151-500 GT class decreased in the latter part of the period while those by the larger vessel classes increased, this class was involved in the mackerel fishery throughout the entire period. Mackerel comprised 50% of the annual catch taken by otter trawl by this tonnage class during 1970-74 and 70% of the annual catch from directed mackerel effort by this class during 1968-74.

Analysis of variance for the computation of effort standardization coefficients indicated significant ($p < 0.05$) tonnage class differences in all years and significant country differences in 1971-74. Significant country-tonnage class interactions also occurred in 1971-74. Detailed examination of the data indicated that the interactions were caused mainly by classes (GDR 501-900 and 901-1800 GT in 1972 and 1974 and GDR 501-900 GT in 1973) which contributed little to the catch (0.6%) and effort (1.2%) used in the 1972-74 analyses. The interaction F value in the 1971 analysis, although significant ($p < 0.05$), was only 10% and 21% of the magnitude of the F values for tonnage class and country respectively. The interactions were not assumed to be important and were disregarded.

GDR, Poland, and USSR had vessels in several tonnage classes, with GDR and Poland each having vessels in the same three classes, whereas Bulgaria and Romania had vessels only in the > 1800 GT class. Effort standardization coefficients exhibited an increase with vessel size and year (Table 7 and Fig. 6). Mean values for 1968-74 and GDR and Poland were 1.60 for the 501-900 GT class (based on 1.00 for the standard USSR 151-500 GT class), 4.77 for the 901-1800 GT class, and 5.83 for the > 1800 GT class.

There was considerable variation in coefficients among countries within a given tonnage class (Table 7 and Fig. 6). GDR vessels had the highest average value over years in the 501-900 and > 1800 GT classes, while Polish vessels averaged slightly higher in the 901-1800 GT class. In the > 1800 GT class, represented by vessels from all five countries, Poland had the second highest mean coefficient over years, followed by Bulgaria, USSR and Romania.

The 901-1800 and > 1800 GT vessels generally exhibited an increasing trend in coefficients until 1973-74 when a decrease occurred. The most evident increases were shown for > 1800 GT vessels. These results indicate that the fishing ability or efficiency of the vessels harvesting the bulk of the mackerel in recent years underwent a pronounced increase relative to that of the standard class. This further supports the earlier suggestion that significant improvements occurred in the distant water fleets as the result of learning or technological advancements, or both.

Standardization of fishing effort by the various country-tonnage classes, utilizing the calculated effort

TABLE 7. Effort standardization coefficients calculated for DWF country-tonnage classes in ICNAF SA 5-6, 1968-74.

Tonnage class	Country	1968	1969	1970	1971	1972	1973	1974	Mean
151-500	GDR	1.48	—	—	—	—	—	—	1.48
	USSR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
501-900	GDR	1.79	1.03	1.13	2.71	1.55	2.22	1.32	1.68
	Poland	1.92	1.25	1.21	1.31	1.63	1.73	1.63	1.53
	USSR	—	1.40	1.03	0.90	0.95	1.02	1.09	1.07
901-1800	GDR	4.48	—	2.01	8.26	5.71	—	2.30	4.55
	Poland	4.79	—	—	4.00	6.01	7.33	2.82	4.99
> 1800	Bulgaria	—	1.54	2.21	4.82	3.59	7.55	4.84	4.09
	GDR	—	1.23	2.87	9.63	9.13	11.34	5.12	6.55
	Poland	2.46	1.50	3.07	4.66	9.60	8.84	6.29	5.20
	Romania	—	—	0.92	1.89	2.31	3.42	2.18	2.14
	USSR	1.56	1.68	2.60	3.19	5.61	5.21	4.23	3.44

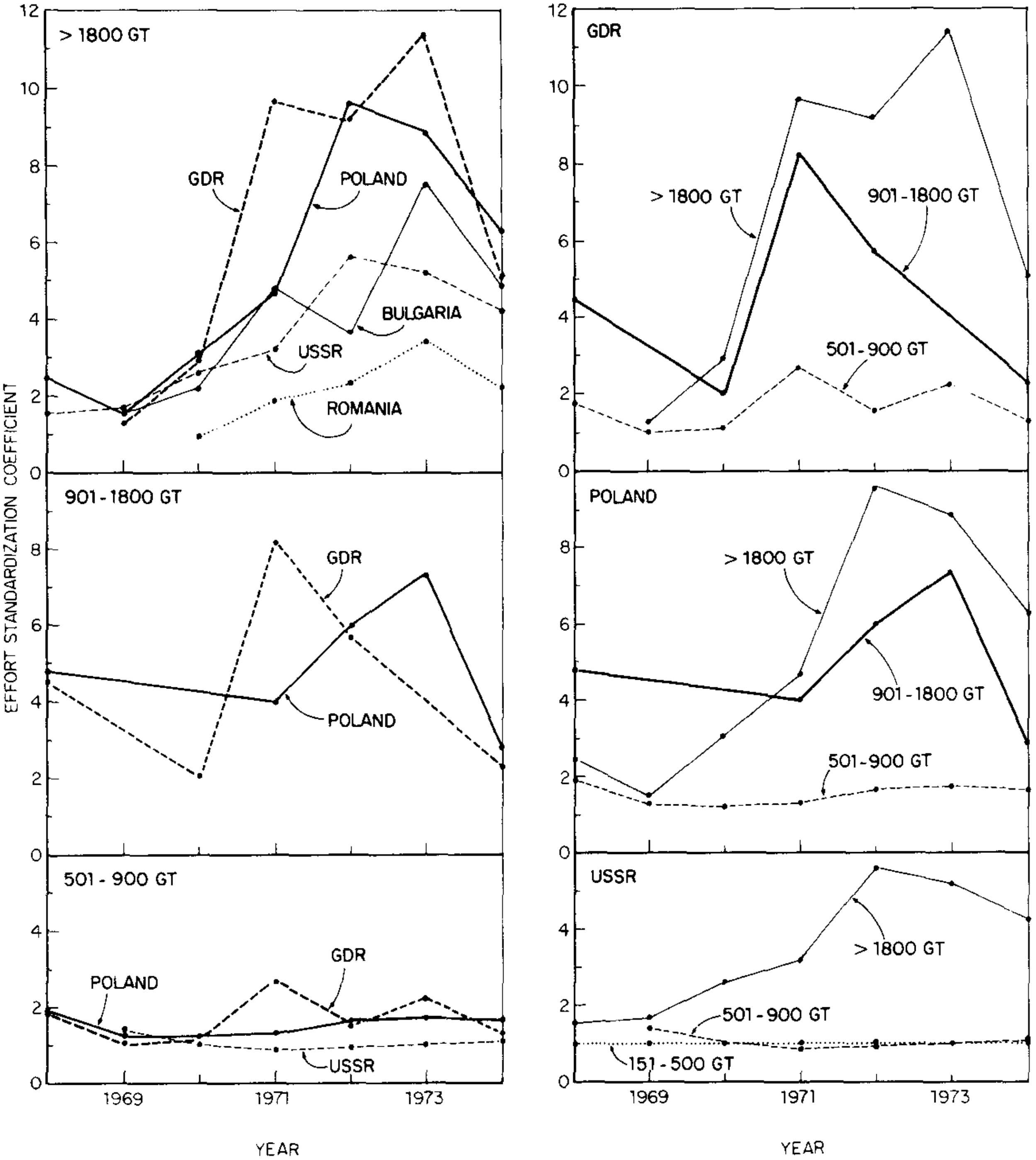

Fig. 6. Effort standardization coefficients by country for the 501-900, 901-1800, and > 1800 GT classes (left) and by tonnage class for GDR, Poland, and the USSR (right). Years for which coefficients were calculated are indicated by dots.

standardization coefficients, produced the results shown in Table 8 and Fig. 7. Catch per standardized DWF hour fished increased from 0.50 tons in 1968 to 0.99 tons in 1970, declined to 0.53 tons in 1972 and then increased again to 0.88 tons in 1974. International effort expressed as standardized DWF hours fished increased from 120,000 hours in 1968 to 731,000 hours in 1972 and then declined about 55% to 335,000 hours in 1974.

TABLE 8. International mackerel catch, US and DWF standardized catch per unit effort, and international standardized effort in ICNAF SA 5-6.

Year	Catch (tons)	Catch per standard US day fished	Catch per standard DWF hour fished	International effort as standard US days fished	International effort as DWF hours fished
1964	2,271	0.43	—	5,281	—
1965	4,538	0.49	—	9,261	—
1966	9,431	0.84	—	11,227	—
1967	22,877	1.75	—	13,073	—
1968	59,973	2.80	0.50	21,419	119,946
1969	113,195	1.92	0.77	58,956	147,006
1970	209,622	2.07	0.99	101,267	211,739
1971	348,744	1.29	0.77	270,344	452,914
1972	387,364	0.84	0.53	461,148	730,875
1973	381,164	0.53	0.55	719,177	693,025
1974	294,924	0.17	0.88	1,734,847	335,141

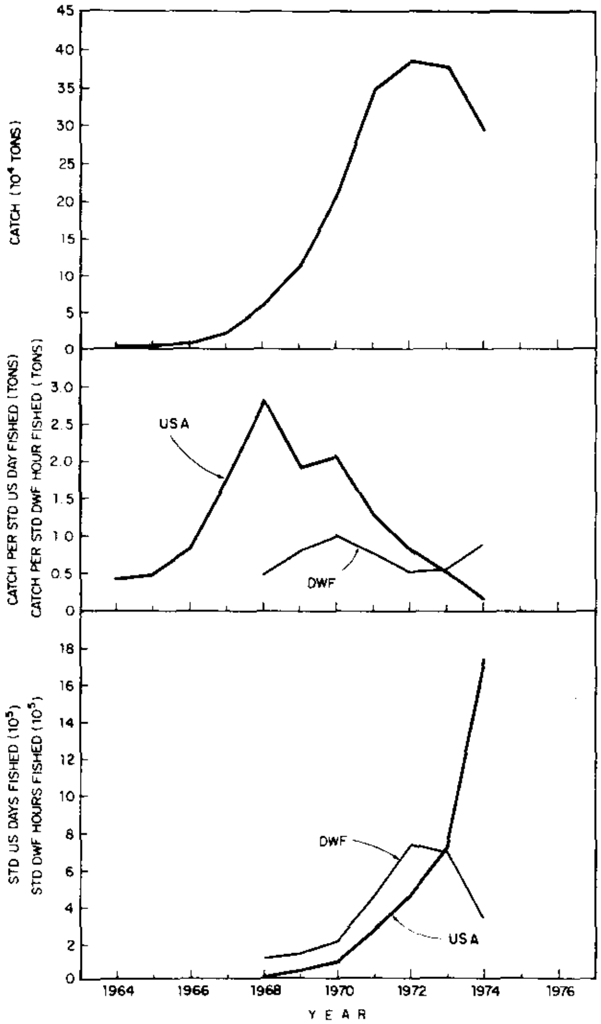

Fig. 7. International mackerel catch (1964-74), catch per standardized US day fished (1964-74), catch per standardized DWF hour fished (1968-74), and international effort expressed as standardized US days fished and as standardized DWF hours fished in ICNAF SA 5-6.

Discussion

According to estimates based on VPA (since 1968), mackerel abundance increased due to the recruitment of the strong year-classes of 1966 and 1967, reached peak abundance in 1970, and then declined steadily thereafter (Table 6 and Fig. 8). The US spring and autumn survey catch per tow indices, the US commercial catch per day index, and the DWF catch per hour index were generally similar in indicating the recent downward trend in mackerel abundance until 1973-74 when the DWF index diverged from the other estimates and increased (Fig. 8). The decrease as measured by the various indices was greater than the change in biomass calculated from VPA results. Each index, however, merits some consideration as an acceptable measure of relative mackerel stock abundance. The DWF index was based on selecting the country-tonnage class most closely following the VPA trends and cannot be evaluated in the same manner as the other indices.

The survey indices both peaked two seasons prior to the time when stock biomass was greatest according to VPA results (Fig. 8). The autumn index peaked in 1967 and the spring index in 1968 (the first point) when the catches consisted primarily of mackerel of the 1967 year-class at ages 0 and 1 respectively. The VPA estimate peaked in 1970 when the 1967 year-class at age 3 attained maximum biomass. Both survey indices likewise indicated an increase in abundance from 1969 to 1970. After 1970 both the VPA results and the survey indices demonstrated a decline in mackerel abundance, the latter indicating a greater decline then the former. Neither survey index evidenced a marked increase in abundance as suggested by the DWF index in 1974, although the autumn index did undergo a slight increase in 1972 and 1974 and the spring index did increase slightly in 1974 but fell sharply in 1975.

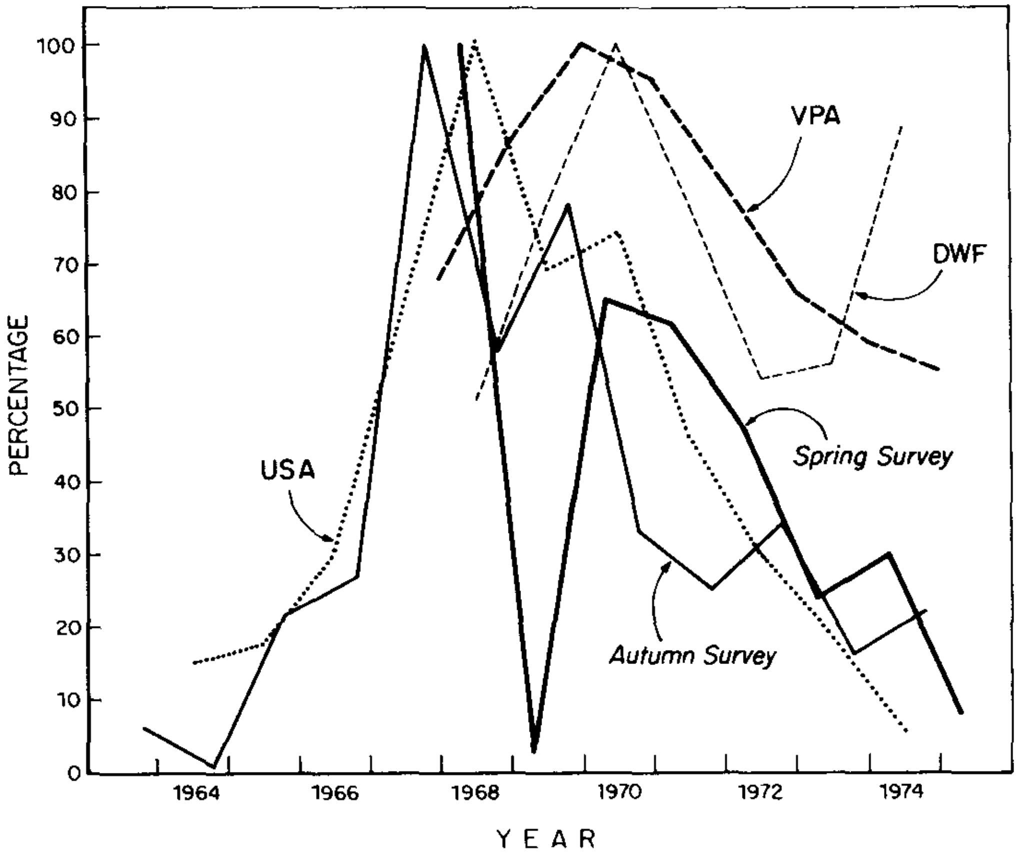

Fig. 8. Changes in mackerel stock abundance as measured by (1) US autumn survey catch per tow (retransformed from $\log_e$ scale) (1963-74), (2) US spring survey catch per tow (retransformed from $\log_e$ scale) (1968-75), (3) US commercial catch per std. day fished (1964-74), (4) DWF catch per std. hour fished (1968-74), and (5) biomass calculated from VPA (1968-75). Each index is plotted as a percentage of its maximum point.

The US commercial standardized catch per day index might be limited as a measure of overall stock abundance because it was based solely on small inshore catches. Virtually all of the international catch was taken by the distant water fleets operating farther offshore. The US index would be reasonably valid, however, if the proportion of the total stock subject to the inshore fishery remained constant over time. The index indicated that the decline in abundance after 1970 was greater than that determined from VPA. The abundance of mackerel may have decreased more in coastal waters than offshore because of differential age distribution, except that the US commercial index exhibited virtually an identical decline to that indicated by the US spring survey (Fig. 8), which was based on catches taken primarily from the offshore area. It is not known why the US commercial index peaked in 1968 compared to 1970 for the VPA estimate although the former did increase slightly from 1969 to 1970. Age data were not available to determine if the US catch in 1968 consisted largely of fish of the abundant 1967 year-class (age 1), which was responsible for the peaks in the autumn and spring survey indices in 1967 and 1968.

Catch per hour by the distant water fleets, which harvested the bulk of the mackerel catch in recent years, might be expected to constitute the most logical measure of stock abundance. Analysis of the DWF statistics revealed, however, that the various country-tonnage classes experienced different patterns of catch per hour during 1968-74 (Fig. 5), most of which were not in agreement with the change in biomass measured by VPA. Furthermore, variability associated with the annual catch per hour indices was shown to be substantial (Table 5) with coefficients of variation averaging 56%, compared to 25 and 43% for the spring and autumn survey indices respectively. Analysis further suggested that learning or technological improvements, or both, occurred in varying degrees for nearly all country-tonnage classes, thus invalidating year-to-year changes in observed catch per hour as a means of accurately monitoring stock abundance changes. The probability, q, that an individual fish would be caught by a given unit of fishing effort, did not remain constant over the period of analysis but instead appeared to increase. From the relationship

$$\text{Stock abundance} = \frac{1}{q} \times \text{catch per unit effort},$$

it is evident that catch per unit effort is not proportional to stock abundance over time if q changes. A time-series of catch per unit effort must be adjusted to incorporate in some way any increased efficiency of a unit of effort (Gulland, 1964).

Changes in efficiency by the individual country-tonnage classes were collectively adjusted by standardizing all effort to that of the USSR 151-500 GT class which appeared to undergo minimal increases in efficiency through learning or technological improvements, at least until 1974. The resulting catch per standardized DWF hour fished agreed closely with the VPA biomass estimate until 1973-74 (Fig. 8). Observed catch per hour by the USSR 151-500 GT class (and accordingly catch per standardized DWF hour) increased sharply in 1974, continuing the upward trend that began in 1973. The slight increase in observed catch per hour by the USSR 151-500 GT class from 0.50 tons in 1972 to 0.58 tons in 1973 (catch per standardized DWF hour increased from 0.53 to 0.55 tons) coincided with a marked drop in otter trawling by that class and a shift to the use of purse seines. It is possible that the trawlers most efficient in catching mackerel were not converted to seiners which could account for the increase in catch per hour. In 1974, however, the observed catch per hour climbed sharply to 0.95 tons (catch per standardized DWF hour was 0.88 tons). Such an improvement would have required a sudden increase in either stock abundance or in catchability (q) as a result of increased efficiency. All other indices of abundance indicates that stock abundance did not increase 65% from 1972 to 1974 as implied by the DWF index. Even some of the individual DWF country-tonnage classes (*i.e.* all GDR classes, the Polish 901-1800 GT class, and the Bulgarian > 1800 GT class) showed decreases in observed catch per hour in 1974. It would appear, therefore, that factors other than increased abundance caused the increase in catch per hour. It is suggested that technological improvements occurred, but there is insufficient information available to verify this hypothesis.

The various indices of abundance presented in this paper were evaluated in terms of their similarity to the biomass estimates which were calculated from population numbers determined from VPA, with the implication that the VPA estimates represented, at least proportionally from year to year, reasonably accurate measures of abundance for all but the last 2 or 3 years. The 1974 and 1973 estimates were, however, quite dependent on the fishing mortality value (F) selected for the terminal year (1974). Year-class numbers, calculated beginning with the terminal year, are subject to errors if F is either underestimated or overestimated, but the errors converge rapidly to small values as the cumulative fishing mortalities (from oldest to youngest ages) increase (Pope, 1972). The terminal F (0.60) used in the VPA (ICNAF, 1975) was determined from several separate analyses and agreed as reasonable for 1974, and was probably sufficiently close to the actual F to eliminate the likelihood of major errors in estimating year-class numbers. If a lower value of F (*e.g.* 0.5) had been used instead of 0.6, year-class numbers would have been larger, but the overall decrease in biomass from 1970 to 1974 would not have changed much (38% for F = 0.5 and 41% for F = 0.6). Furthermore, the 1974 and 1975 biomass estimates assumed that the 1973 and 1974 year-classes were strong based on survey and commercial catches as well as stock-recruitment curves. Therefore, it was considered that the VPA biomass estimates used in this paper (Table 6) provided a satisfactory measure of mackerel abundance.

In conclusion, none of the measures of abundance presented were completely consistent and accurate over the recent decade as year-to-year indicators of mackerel abundance. The survey indices demonstrated an overall decline in abundance but were not consistent in all years due perhaps in part to the variability of the catches. The US commercial index showed an uninterrupted decline after 1970 greater than that indicated by the VPA estimates, but the former was based on a small inshore fishery. The DWF index paralleled the VPA estimate until 1972 after which it indicated a marked increase in abundance. Analyses showed greater variability about the DWF catch per hour indices than for the survey indices, and also indicated that changes in DWF vessel efficiency occurred annually due to learning and/or technological improvements. Changes in vessel efficiency essentially invalidate the DWF index as an accurate measure for monitoring year-to-year changes in mackerel abundance. Bearing in mind the advantages and limitations of the various indices as demonstrated by the data presented in this paper, the US commercial index and the spring survey index were better overall indicators of trends in mackerel abundance than the DWF index.

Acknowledgements

The author thanks V. C. Anthony, J. A. Brennan, B. E. Brown, and R. C. Hennemuth for their constructive suggestions and comments.

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Food of Yellowtail Flounder on the Grand Bank and a Comparison with American Plaice

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Abstract

Polychaetes and amphipods were the main food components of yellowtail, but nevertheless a wide range of other forms, principally invertebrates, were also present. Only slight differences were found between food taken by yellowtail from northern (Division 3L) and southern (Division 3N) portions of the Grand Bank. Although yellowtail and American plaice contained many of the same prey groups, the greater utilization of fish and echinoderms by American plaice and annelids by yellowtail were the principal differences.

Introduction

In recent years yellowtail flounder, *Limanda ferruginea,* became of major importance especially to the Newfoundland sector of the Canadian Atlantic fishery. A study of the food of this species was included as part of a research program designed to provide biological information for the management of flatfish stocks.

In a previous paper (Pitt, 1973) information was presented on food of American plaice *(Hippoglossoides platessoides),* a species occupying roughly the same habitat as yellowtail, although its distribution extends to deeper water. Some of these data were used here to make comparisons of food selected by the two flatfish species.

The only published information on food and feeding of yellowtail flounder in the Northwest Atlantic is Bigelow and Schroeder (1953) for the Gulf of Maine, and Efanov and Vinogradov (1973) for two New England stocks. No published information is available on this topic for Grand Bank stocks.

Material and Methods

Approximately 1,100 stomachs were collected during 1968-73 on research cruises of the *A. T. Cameron* designed primarily to study distribution and abundance of groundfish on the Grand Bank. Prior to 1971, sampling stations were on transects at 20-25 fathoms (37-46 m) across the slope of the bank, with fishing stations shallower than 50 fathoms (91 m) spaced at 10-15 mile intervals. From 1971, stations were selected at random from a number of strata into which the whole Grand Bank has been divided (Grosslein and Pinhorn, MS 1971). Samples were collected only from ICNAF Div. 3L and 3N. Data from these divisions were combined in the presentation of details of yellowtail stomach contents, and in comparison with American plaice. Only American plaice caught during sets in which yellowtail were taken and in depths less than 51 fathoms (93 m) were used in this comparison.

Details of methods of collection, and of identifying, measuring and tabulating contents were similar to those described by Pitt (1973) for American plaice. As in the latter paper, the primary objective was to classify food according to major groups. Percentage occurrences at various size groups were calculated using total number examined, including empty stomachs. Insufficient data were available to calculate reliable average weights of contents on a seasonal basis, but some indication of relative proportion of empty stomachs is presented.

Standard methods of testing differences between proportions were used.

Results

Comparison between ICNAF Div. 3L and 3N

A comparison of samples from ICNAF Div. 3L and 3N indicated very little difference between the occurrence of food items (Table 1). With respect to weight, the only consistent pattern appeared to be in greater quantities of annelids taken from Div. 3L than in 3N with an opposite pattern observed for crustaceans.

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TABLE 1. Comparison of principal food groups of yellowtail for ICNAF Div. 3L and 3N (*indicates significantly greater at 5% level).

	Occurrence						Percent of total weight					
	20-29 cm		30-39 cm		40-49 cm		20-29 cm		30-39 cm		40-49 cm	
ICNAF Division:	3L	3N	3L	3N	3L	3N	3L	3N	3L	3N	3L	3N
No. examined or wt of contents (g)	41	157	150	291	144	336	10.7	81.1	118.0	356.0	202.5	741.3
Porifera	—	—	5.3*	0.6	6.3	4.2	—	—	2.5	0.3	2.6	3.2
Coelentenata	—	0.6	4.0	2.1	1.7	3.0	—	0.1	0.8	1.0	0.6	2.5
Echinodermata	4.9	2.5	14.0	8.9	13.2	19.0	2.8*	0.6	3.6*	2.3	6.2	10.8
Mollusca	7.3	2.5	0.7	7.9*	4.2	8.0	2.8*	0.5	0.1	2.0	0.3	4.2*
Annelida	34.1	24.8	45.3	39.9	54.9	39.3	57.0*	26.0	72.7*	34.9	58.7*	28.7
Crustacea	51.2	49.7	33.3	51.2*	34.7	53.3*	37.4	46.9*	19.6	43.3*	12.8	37.8*
Other Inv.	—	1.3	0.7	4.5	—	3.9	—	3.2	0.2	2.5*	0	3.5*
Pisces	—	1.3	—	1.4	0.7	2.1	—	3.8	—	5.2*	18.3*	7.7
Other (includes unidentified material)	—	1.3	0.7	0.6	1.4	0.3	—	18.9*	0.7	8.2*	0.3	1.6
Empty	31.7	31.8	38.7*	28.2	36.8	28.3	—	—	—	—	—	—

Food composition

Of the stomachs examined, approximately 40% contained polychaetes and 43% amphipods (Table 2). If empty stomachs are excluded, then these groups were found in 58% and 64% respectively of fish with food. As proportion of total contents weight, polychaetes accounted for 38.4% and amphipods 29.3%. Polychaete species were not identified but free-living, burrowing, and tube-building forms were observed. Because of the rapidity of digestion some difficulty was encountered in identifying the amphipods; however, *Haploops* sp. and *Caprella* sp. were recognized. Echinoderms, made up almost exclusively of small brittle stars *Ophiura sarsi* and *O. robusta*), sand dollars *(Echinarachnius parma)*, and sea urchins *(Strongylocentrotus drobaciensis)* occurred in about 12% of the stomachs examined and represented approximately 7% of the total weight of food (Table 2).

Isopoda were found in 7.2% and bivalve molluscs in 5.2%, but both represented a fairly minor proportion of the total weight (2.8 and 0.8% respectively). Very few stomachs contained fish (1.2%) but the latter accounted for 7.5% of total food weight. Capelin and lance were present in approximately equal amounts (Table 2).

Except for echinoderms, which were less common in smaller fish (up to 29 cm), there were no major differences in food taken by different size groups. Although the 10-19 cm group had fewer annelids and crustaceans, the number of fish examined at this size range was too small to give reliable percentage calculations (Table 2).

Seasonal comparison of empty stomachs

The percentage of empty stomachs as an indication of seasonal feeding did not reveal a significant pattern. Although there was a higher proportion of empty stomachs for January -March, this was not significantly different ($P > 0.05$) from the other periods possibly because of the small number of observations. The following text table indicates the similarity of the percentage of empty stomachs except for the winter period.

	Jan.-March	April-June	July-Sept.	Oct.-Dec.
Percentage empty	60.0	31.4	35.1	28.1
No. examined	10	803	168	153

Comparison with the stomach contents of American plaice

Differences in food selected by the two species both with respect to occurrence and as percentage of the total

TABLE 2. Details of yellowtail stomach contents including both percentage occurrence and percentage of total food at various length categories and a comparison with American plaice from the same localities and depth for ICNAF Div. 3L and 3N combined. (*indicates significantly greater at 5% level; + = less than 0.1%.)

	Percent occurrence										Percent of total weight									
	10-19 cm		20-29 cm		30-39 cm		40-49 cm		TOTAL		10-19 cm		20-29 cm		30-39 cm		40-49 cm		TOTAL	
Food type	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice	Yellow-tail	American plaice
Porifera	—	—	—	0.7	2.3	4.1	4.8	0.8*	3.8*	0.6	—	—	—	0.4	0.8	0.1	3.1*	+	0.5	0.1
Coelenterata	—	—	0.5	2.2	2.7	2.9	3.1	3.1	2.5	2.8	—	—	0.1	1.2	1.0	2.7	2.1	1.7	1.6	1.9
Echinodermata	—	3.3	3.0	13.1*	10.7	27.4*	17.3	28.1*	12.1	24.1*	—	6.0	0.9	12.3*	2.6	18.7*	9.8	16.7*	6.9	17.2*
Ophiuroidea	—	3.3	0.5	7.7*	3.2	12.8*	5.8	14.2*	3.8	12.1*	—	6.0	0.2	7.5*	1.0	10.1*	6.7	8.8	4.5	9.1*
Echinoidea	—	—	2.5	5.8	7.7	14.6*	12.7	15.4	9.0	12.8*	—	—	0.7	4.8*	1.5	8.5*	2.6	7.9*	2.1	8.0*
Holothuroidea	—	—	—	—	0.2	0.2	0.6	—	0.4	+	—	—	—	—	0.1	-	0.6	—	0.4	+
Mollusca	—	—	3.5	1.8	5.4	4.1	6.9	6.2	5.7	4.4	—	—	0.8	1.1	1.9	2.3	3.4	4.3	2.8	3.8
Pelecypoda	—	—	2.5	1.8	4.8	3.9	6.7	5.4	5.2	4.0	—	—	0.6	1.1	1.8	2.3	3.4	3.2	2.8	3.0
Scaphopoda	—	—	0.5	—	—	—	0.2	—	0.2	—	—	—	+	—	—	—	+	—	+	—
Gastropoda	—	—	0.5	—	0.7	0.2	—	0.8	0.4	0.4	—	—	0.1	—	0.1	0.2	—	1.0	+	0.8
Annelida	6.7	—	26.8*	6.2	41.7*	8.3	44.0*	3.1	40.0*	5.6	22.2	—	30.0*	3.2	45.0*	3.6	35.3*	0.6	38.0*	1.4
Polychaeta	6.7	—	26.8*	6.2	41.3*	8.3	43.8*	2.9	39.5*	5.5	22.2	—	30.0*	3.2	44.9*	3.6	25.2*	0.5	38.0*	1.3
Gephyrea	—	—	—	—	0.5	—	0.8	+	0.5	+	—	—	—	—	0.1	—	0.1	0.1	+	+
Crustacea	20.0	33.3	50.0	34.7*	45.1*	26.6	46.9	17.7	47.0*	24.9	55.5	87.5	46.4	58.8*	38.1*	18.5	32.6*	14.1	35.1*	16.9
Copepoda	—	—	—	—	0.5	—	0.6	—	0.4	—	—	—	—	—	+	—	+	—	+	—
Mysidacea	—	—	—	—	0.2	—	—	—	0.1	—	—	—	—	—	+	—	—	—	+	—
Cumacea	—	6.7	4.5	5.1	6.1	3.9	4.4*	0.8	0.5	3.0*	—	31.3	1.3	5.1	1.7	0.4	0.4	+	0.1	0.3
Amphipoda	13.3	26.7	44.9*	19.0	41.5*	15.9	45.0*	6.4	43.5*	13.0	44.4	56.2	42.9*	9.5	30.8*	3.3	27.3*	1.0	29.3*	1.9
Euphausiacea	6.7	—	0.5	9.1*	1.6	4.3*	1.2	2.7	1.3	4.6*	11.1	—	0.1	33.0*	4.5	8.2*	4.2	5.6	4.0	7.3*
Decapoda	—	—	0.5	3.3	0.2	3.7*	0.6	6.4*	0.3	4.6*	—	—	0.1	10.8*	+	3.6*	0.1	7.1*	+	6.5*
Isopoda	—	—	8.6*	1.5	7.5*	3.9	6.7	3.5	7.2*	3.1	—	—	1.9	0.4	1.1	0.9	0.5	0.3	0.8	0.4
Other Invert.	—	3.3	1.0	0.7	3.2	1.4	2.7	—	2.6*	0.8	—	6.0	2.9	0.1	2.0	0.4	2.7*	—	2.5*	0.1
Pisces	—	—	1.0	3.0	0.9	10.9*	1.6	16.7*	1.2	11.4*	—	—	3.4	23.1*	3.8	55.4*	10.0	62.0*	7.5	59.4*
Mallotus	—	—	1.0	0.3	0.2	4.5*	0.8	6.0*	0.5	4.1*	—	—	3.4	1.7	3.2	24.4*	4.1	24.7*	3.7	23.9*
Ammodytes	—	—	—	1.1	0.5	4.3*	0.6	11.7*	0.4	6.5*	—	—	—	13.3*	0.6	25.0*	5.9	36.0*	3.8	33.0*
Other	—	—	—	1.8	0.2	2.1*	0.2	0.4	0.3	1.3*	—	—	—	7.3*	+	6.0*	+	1.3	+	2.5*
Unid. Material	13.3	—	6.6*	1.5	5.0	1.2	2.1	1.0	4.1*	1.1	22.2	—	14.5	0.3	6.3*	0.2	1.3*	0.3	3.6*	0.3
Plants, stones, etc.	—	—	1.0	—	0.7	0.4	0.6	0.6	0.7	0.4	—	—	2.4	+	0.1	+	0.1	—	0.2	0.2
Empty	60.0	60.0	31.8	44.9*	31.7	39.2	30.8	41.7	32.8	41.9	—	—	—	—	—	—	—	—	—	—
Number or weight	15	30	198	274	441	485	480	520	1134	1309	0.9	1.6	90.6	157.4	465.9	871.0	939.9	2999.0	1497.3	3999.0

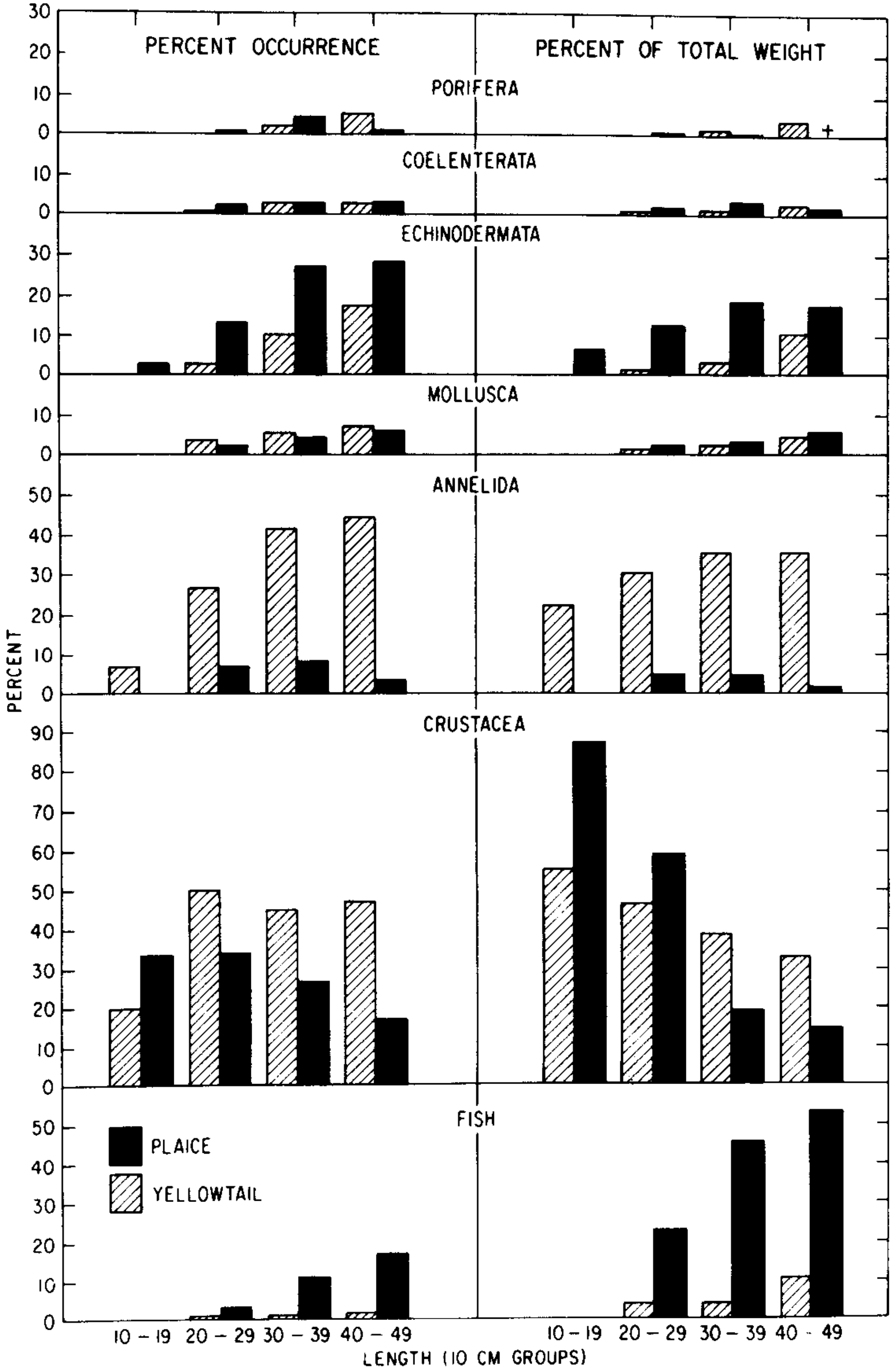

Fig. 1. Diet composition of yellowtail for the main food components at various size groups, and a comparison with American plaice (ICNAF Div. 3L and 3N combined).

food weight (Table 2, and Fig. 1) can be summarized as follows: (i), Porifera, Coelenterata or Mollusca are of relatively little importance to either species, and, except for the occurrence of sponge in yellowtail, there are no major differences between the two species; (ii) American plaice selected echinoderms more frequently and in greater quantity than yellowtail; (iii) annelids and crustaceans occurred more frequently in yellowtail, but smaller American plaice take proportionally larger quantities of crustaceans in relation to the total food than did yellowtail, the difference being largely due to the selection of euphausiids by American plaice in the 20-29 cm range, (numbers and quantities for the 10-19 cm range were too small to be of any significance); and (iv) fish were selected more frequently by American plaice and, for those greater than 30 cm, comprised the largest proportion of total food weight.

Discussion

A major proportion of the food from Grand Bank yellowtail flounder was polychaete worms and amphipods, although their total food included representatives of a wide range of phyla and orders (Table 2, and Fig. 1). Seasonal differences were difficult to demonstrate because of lack of January-March specimens, but there was some evidence of a lower rate of feeding during the winter.

In a previous paper (Pitt, 1970), it was shown that yellowtail flounder on the Grand Bank were primarily found in depths 25-45 fathoms (45-90 m) and practically none were found beyond 55 fathoms (100 m). The variety of food selected is hence somewhat restricted to prey species indigenous to "shallow" water.

Bigelow and Schroeder (1953) indicated that yellowtail in the Gulf of Maine fed primarily on small crustaceans, molluscs and polychaetes. Efanov and Vinogradov (1973) showed that amphipods, principally *Microdeutopus damonesis,* were by far the most important prey species of two New England stocks with polychaetes of nearly equal importance. De Groot (1971) in summarizing information of the food of a closely related eastern Atlantic species, *Limanda limanda,* indicated that crustaceans, molluscs and polychaetes were dominant items.

Beamish (1966) found that night tows by research vessels produced twice as many yellowtail as daylight sets. I have reached a similar conclusion from the rough examination of some commercial records and from conversations with captains fishing on the Grand Bank. Parrish *et al.* (1964) reported that *Limanda limanda* remain partially buried in the sand during the day and become active feeders at night. This is also probably the case with yellowtail.

American plaice is apparently a day feeder as indicated from differences in catch rates (Beamish, 1966; Pitt, 1967) and diurnal differences in feeding (Beamish, 1966). De Groot (1971) classified some day feeders as using both visual and chemical stimuli in their search for food. Yellowtail, on the other hand, are active at night and appear to fall into the non-visual night-feeder category which feed on slow-moving invertebrates. However, the American plaice has a larger mouth than yellowtail with a digestive system apparently adapted to the utilization of larger food items (De Groot, 1971). American plaice hence select more large species such as echinoderms (sand dollars and sea urchins), but the major difference between the two species is the large quantities of fish, principally capelin and sand lance, utilized by American plaice (Table 2, and Fig. 1).

Thus while there is considerable overlap in the prey group selected, except at the smaller sizes, competition between the two species is probably not extensive, provided capelin and lance are available for American plaice. Yellowtail are, however, restricted to shallow localities, whereas American plaice can range to greater depths and hence have a larger potential food supply. To properly assess the extent of competition between these two species, a knowledge of the actual available food is required which is beyond the scope of this paper.

Acknowledgments

I am particularly indebted to Mr C. A. Rose for the determination of stomach contents and Messrs C. Butt and T. Collier for the compilation of tables and figures in the preparation of the manuscript.

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Growth and Mortality Rates for Cod from the Georges Bank and Gulf of Maine Areas

J. A. Penttila[1] and V. M. Gifford[1]

Abstract

Growth rates for the Georges Bank and Gulf of Maine areas were estimated by fitting a von Bertalanffy growth curve to pooled length at age data from US research vessel survey cruises for the years 1970 to 1974. The values obtained for the Georges Bank area were: $K = .120$, $L_\infty = 148.1$, and $t_0 = -0.616$. For the Gulf of Maine area, the values obtained were: $K = .116$, $L_\infty = 146.5$, and $t_0 = 0.285$. Total instantaneous mortality rates for these areas were estimated from research vessel survey data from 1970 to 1974. An average of the estimates given by a linear regression analysis of the catch curve and a Robson-Chapman analysis of a segment of the catch curve gives a Z of .56 for ICNAF Division 5Z and .68 for ICNAF Division 5Y.

Introduction

This paper presents the results of studies of growth and mortality rates for cod in ICNAF Subarea 5. The first assessment of cod stocks in this area was done for Div. 5Z (Brown and Heyerdahl, MS 1972). At that time very little age data were available and no estimates of mortality were calculated. An assessment of the cod stock in Div. 5Y has not yet been done. The present studies of growth and mortality rates for Div. 5Z and 5Y were carried out to provide the basis for improved assessments of the status of the fisheries in these areas.

Materials and Methods

Areas of study

Wise (1962) proposed the existence of four separate groups of cod in the New England area (Fig. 1): Georges Bank, Gulf of Maine, Southern New England and South Channel (the area called South and Nauset in this paper), and New Jersey coastal cod which spend the summer in Southern New England. In our study, all of the data from Chesapeake Bay north to Long Island were combined with the South and Nauset data because of the difficulty of separating the New Jersey cod from the Nauset cod in the autumn. Data from sampling strata in the Gulf of Maine greater than 100 fathoms (182 m) deep were not included in the analyses since very few cod were caught there.

Data collection

The data used for these studies were obtained from spring and autumn bottom trawl surveys in 1970 to 1973 and the spring survey in 1974 by the R/V *Albatross IV*. The survey area extends from Cape Hatteras to the Scotian Shelf. Details of survey procedures and gears used are described by Grosslein (1969). However, the 1973 and 1974 spring surveys were carried out using the No. 41 Yankee trawl, in contrast to the No. 36 Yankee trawl used on the other cruises, and the mean catch per tow for these two cruises was adjusted on the basis of gear comparison studies (unpublished data, Northeast Fisheries Center, Woods Hole, Mass., USA) which have indicated a 3:1 ratio in the groundfish catches of the No. 41 and No. 36 trawls respectively.

Length frequencies of the survey catches were recorded and otoliths for age determination were collected routinely. In most cases the entire catch of cod was measured, but, in those instances where the catch was quite large, a representative subsample was measured and the length frequency of the entire catch estimated. The fish from which otoliths were taken were usually subsamples stratified by length, except where the catches were small enough to permit total sampling.

Determination of age and length composition

The otoliths were prepared for ageing by baking them at about 275°C (525°F) for 6 minutes. The baking enhances the visibility of the annuli by turning the hyaline zones brown while the opaque zones remain white. The otoliths were then broken in half at the sulcus and aged under a binocular microscope at a magnification of about 15X using reflected light.

Age-length keys were used to assign ages to the length composition data of all cod caught during the

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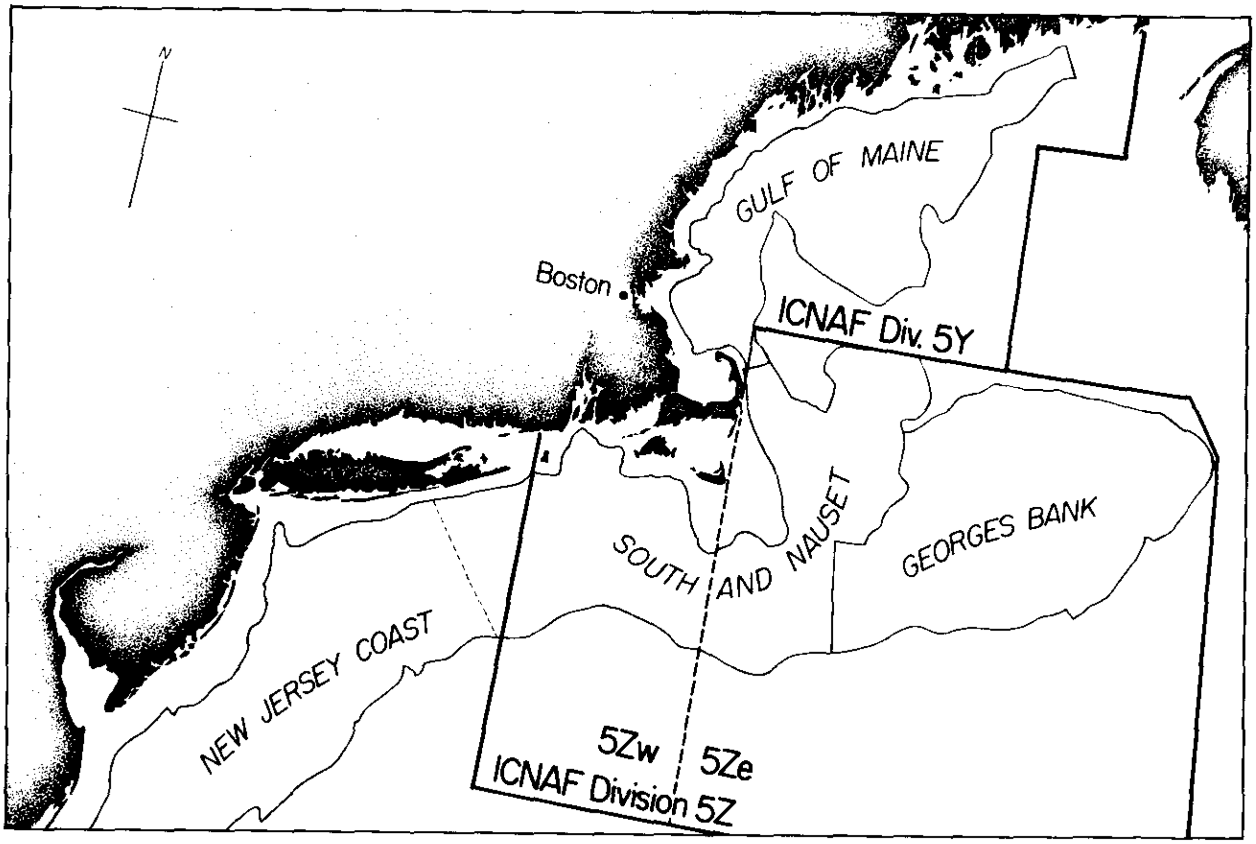

Fig. 1 Areas used in the preliminary studies of growth and mortality rates for cod in the New England area.

surveys. The number of cod caught at each age and the number actually aged for the data pooled over seasons are given in Table 1 for Georges Bank and the Gulf of Maine separately. The ratio of number aged to number caught is considerably lower for ages 1 to 4 than for older ages because of the larger catches of fish in the younger age groups. Zero age-group fish were not used because of possible bias due to incomplete recruitment of the smaller fish to the gear used.

In Table 1 the ages are given in years plus the proportion of the year from 1 January until the time of the survey. For example, age 3.10 refers to age 3 fish caught on an early spring cruise, age 3.25 refers to age 3 fish taken later in the spring and age 3.80 refers to age 3 fish caught in the autumn. Data from the early spring cruise (a special survey of Georges Bank in 1972) were used only in the growth study. They were not used in the mortality studies as the stations were not randomly selected.

Mortality estimation procedures

Mortality rates were estimated for only two areas, Div. 5Z (comprising the Georges Bank and the South and Nauset areas) and Div. 5Y (the Gulf of Maine), as the available data for the southern areas were inadequate for separate analyses. Only the data from the spring cruises of 1970-74 were used as the autumn catches were smaller and less adequate for analyses. Estimates of the mean catch (in numbers) per tow by age-group for each area in each year were obtained by the application of the appropriate age-length key to the length composition of the mean catch per tow for each of the five cruises. Estimates of the total instantaneous mortality coefficient (Z) were then obtained from the analysis of catch curves depicting the natural logarithms of the mean catch per tow for each year-class plotted against age.

Results

Mean length-at-age comparisons

After assigning ages to the length composition of the catch for each cruise, the data were pooled over years for each season (spring and autumn) and mean lengths for ages 1 to 3 were calculated for spring and autumn for each of the 3 areas: South and Nauset (including data from Long Island to Chesapeake Bay), Georges Bank, and the Gulf of Maine (Table 2). The Gulf of Maine fish are consistently smaller than cod from the other two areas

TABLE 1. Data used to fit the von Bertalanffy growth curves for cod from Georges Bank and Gulf of Maine areas.

Area	Age (years)	Mean length at age (cm)	Standard deviation	Total number caught	Number aged	Fitted length (cm)
Div. 5Z	1.25	22.43	4.31	262	191	29.76
	1.80	34.96	4.43	309	223	37.33
	2.10	42.89	3.50	89	65	41.26
	2.25	44.09	4.15	2351	692	43.17
	2.80	52.03	4.83	242	196	49.88
	3.10	56.92	4.66	178	136	53.36
	3.25	57.95	5.25	734	467	55.05
	3.80	63.33	4.93	109	79	61.00
	4.10	66.94	6.64	34	30	64.09
	4.25	66.50	5.89	459	269	65.59
	4.80	70.17	6.64	88	68	70.87
	5.10	75.33	6.26	15	13	73.60
	5.25	74.87	7.18	160	138	74.94
	5.80	78.73	8.71	22	22	79.62
	6.10	83.67	6.72	43	37	82.04
	6.25	79.78	7,87	91	75	83.22
	6.80	84.80	7.41	5	5	87.37
	7.10	95.40	7.91	5	5	89.52
	7.25	86.93	8.33	68	59	90.57
	7.80	100.33	6.02	3	2	94.25
	8.10	91.43	7.80	23	20	96.15
	8.25	93.20	7.98	45	41	97.08
	8.80	102.33	7.59	3	2	100.34
	9.10	98.05	8.77	20	20	102.04
	9.25	103.10	8.27	30	24	102.86
	9.80	102.50	2.50	2	1	105.75
	10.25	104.56	8.55	18	16	107.98
	11.25	117.29	5.01	7	7	112.52
	12.10	107.50	11.50	2	2	115.97
	12.25	122.14	5.91	7	6	116.55
	13.10	112.00	2.94	3	3	119.61
	14.10	123.50	6.50	2	2	122.83
	14.25	128.40	7.74	5	5	123.28
	15.25	131.50	4.50	2	2	126.09
Div. 5Y	1.30	14.94	3.62	70.	39	16.27
	1.85	23.12	4.92	412	113	24.32
	2.30	26.85	4.08	327	106	30.54
	2.85	37.21	7.17	222	159	37.71
	3.30	39.63	6.97	338	222	43.24
	3.85	54.53	8.55	101	84	49.63
	4.30	57.87	7.85	97	85	54.55
	4.85	68.10	7.83	69	60	60.24
	5.30	68.04	9.15	57	49	64.63
	5.85	70.35	11.14	52	46	69.69
	6.30	76.09	8.80	44	37	73.60
	6.85	78.89	7.94	36	31	78.11
	7.30	78.18	10.83	50	44	81.59
	7.85	83.32	13.07	34	32	85.60
	8.30	86.82	8.03	38	36	88.70
	8.85	93.57	9.61	21	19	92.27
	9.30	94.17	9.43	35	34	95.03
	9.85	97.29	9.24	14	14	98.22
	10.30	97.95	9.81	21	20	100.67
	10.85	100.43	10.94	7	7	103.51
	11.30	102.47	5.28	15	14	105.70
	11.85	101.33	7.36	3	3	108.22
	12.30	107.54	7.24	13	12	110.17
	12.85	119.00	1.00	2	2	112.42
	13.30	113.80	4.75	10	8	114.15
	14.30	119.50	1.12	4	3	117.70
	16.30	128.33	3.86	3	3	123.67
	17.30	127.00	3.00	2	2	126.17

TABLE 2. Mean lengths (cm) of cod for ages 1 to 3 from spring and autumn surveys in Subarea 5.

Area	Age 1 Spring	Age 1 Autumn	Age 2 Spring	Age 2 Autumn	Age 3 Spring	Age 3 Autumn
Georges Bank	22.4	35.0	44.1	52.0	57.9	63.3
South & Nauset	19.3	29.9	40.1	46.9	56.3	62.9
Gulf of Maine	14.9	23.1	26.8	37.2	39.6	54.5

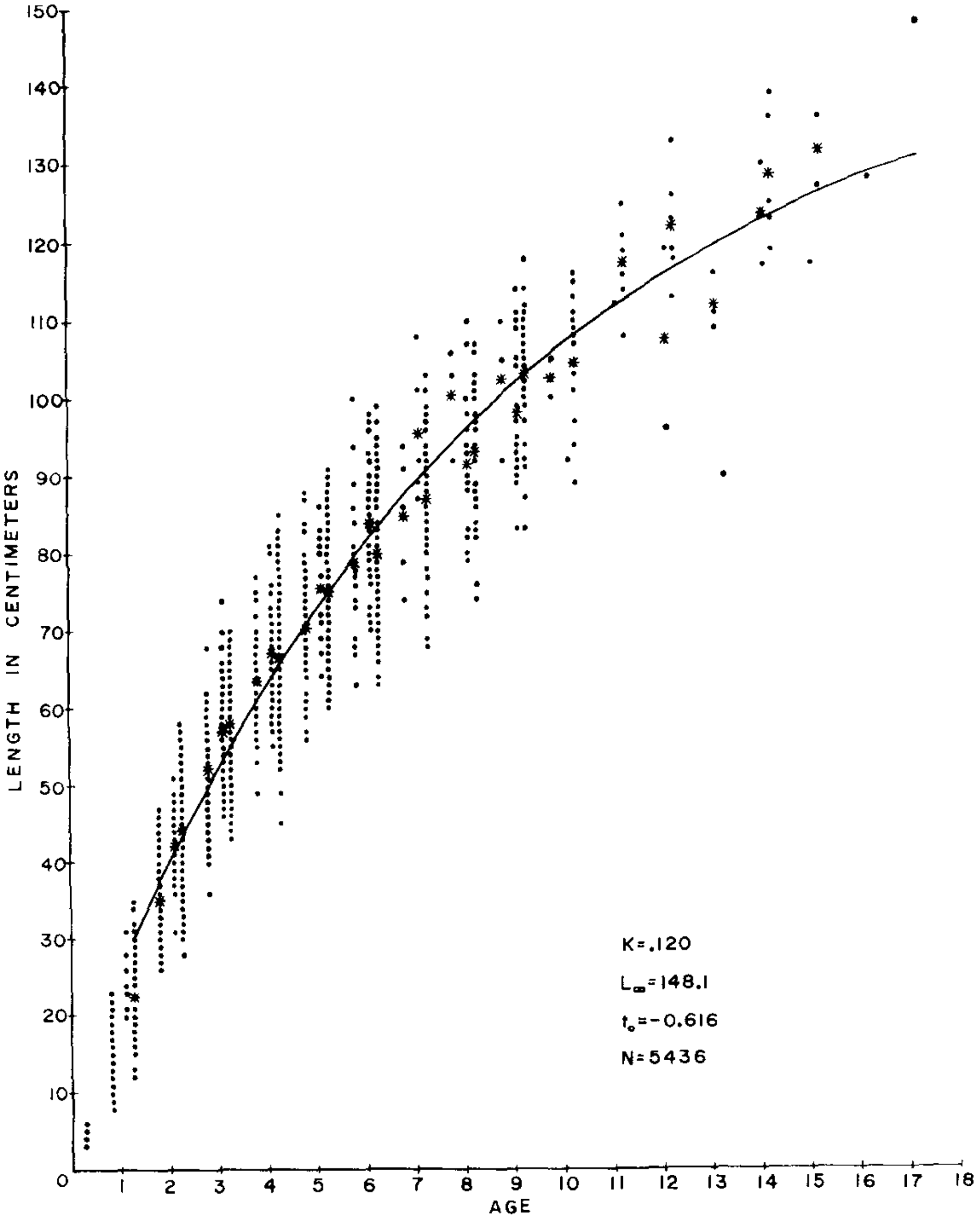

Fig. 2. Growth curve for cod from the Georges Bank area. See text for explanation.

with Georges Bank cod being consistently larger. An analysis of variance shows highly significant differences between the mean lengths at age for the three areas ($P < 0.001$). To test for individual differences, ranked mean lengths at age were compared using Duncan's new multiple range test (Steele and Torrie, 1960) modified for unequal sample sizes as proposed by Kramer (1956). This analysis showed highly significant differences between areas ($P < 1.0\%$), except for the age 3 autumn comparison between Georges Bank and the South and Nauset areas ($P > 5.0\%$). For age 4 and older cod the mean lengths at age from these two areas are very similar.

Growth rates

Von Bertalanffy growth curves were fitted by least squares, using Allen's method (1966), to the pooled mean length at age data for Georges Bank and Gulf of Maine separately (Table 1; Fig. 2 and 3). The asterisks show the

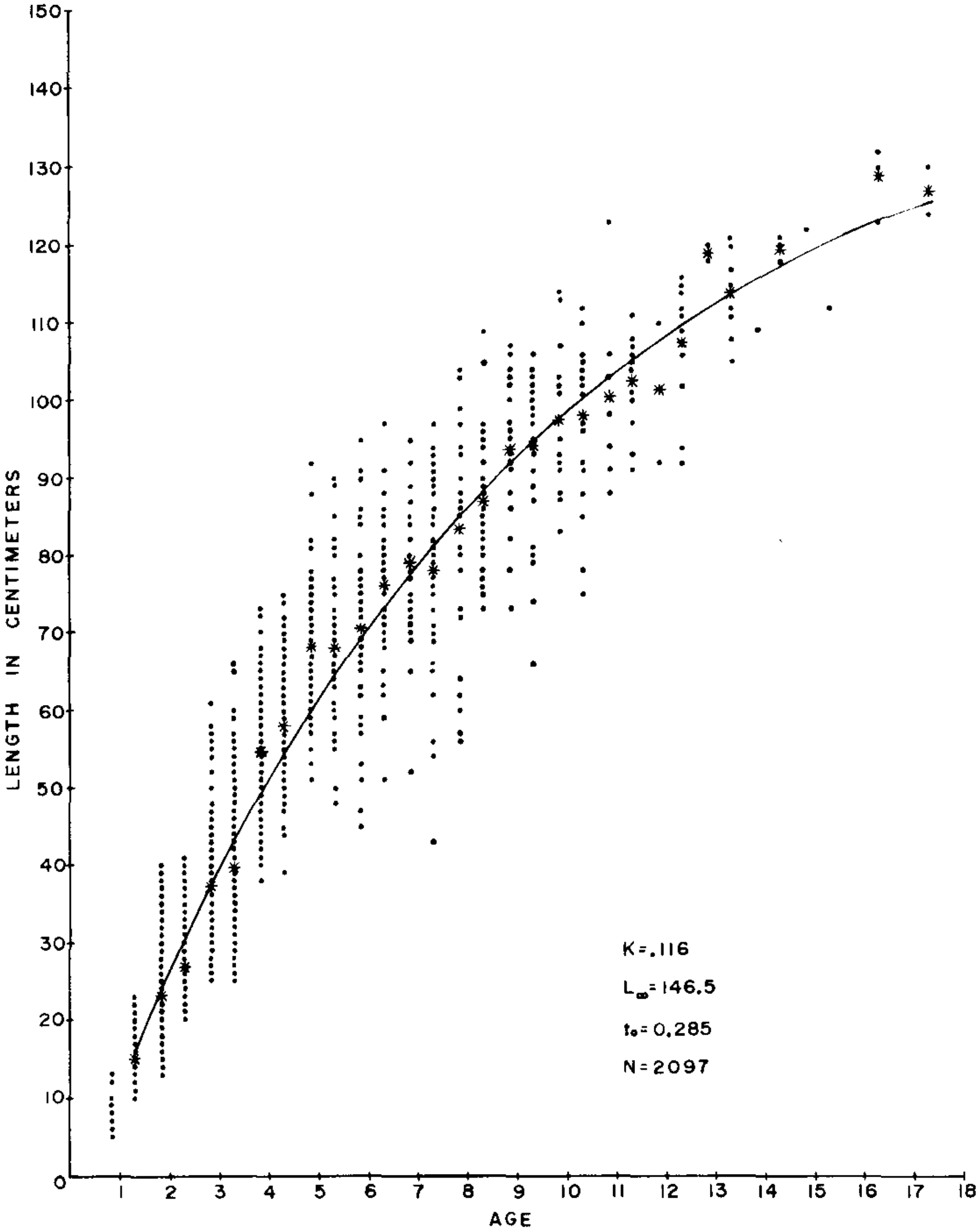

Fig. 3. Growth curve for cod from the Gulf of Maine area. See text for explanation.

mean lengths at age to which the growth curves were fitted, and the dots (each representing one or more fish) indicate the ranges of fish lengths about the mean lengths at age. The resultant parameters of the growth curves, together with their standard deviations, are as follows:

	Georges Bank		Gulf of Maine	
Parameter	Value	S.D.	Value	S.D.
K	0.120	0.015	0.116	0.011
L_∞	148.1	7.417	146.5	6.167
t_0	0.616	0.276	+0.285	0.187

The only other information available on growth rates of cod in these areas is Schroeder's (1930) data for the summer of 1923 from the Southern New England area. An analysis of his data by Allen's method gives estimates of K = 0.177 and L_∞ = 123.1. There are two factors which may account for the difference between the growth rates for Southern New England and Georges Bank. One is the lack of old fish in his samples and the other is that Schroeder's (1930) data are based on scales the age determination of which is very difficult for ages greater than 6 or 7.

Total mortality rates

Total mortality rates were calculated from declines in numbers of cod caught per tow (Tables 3 and 4) on spring surveys from 1970 to 1974 for both Div. 5Z and 5Y. Plots of the natural logarithms of the mean catch per tow of each year-class against age (Ricker, 1958) indicated that recruitment was essentially complete at age 3 for Georges

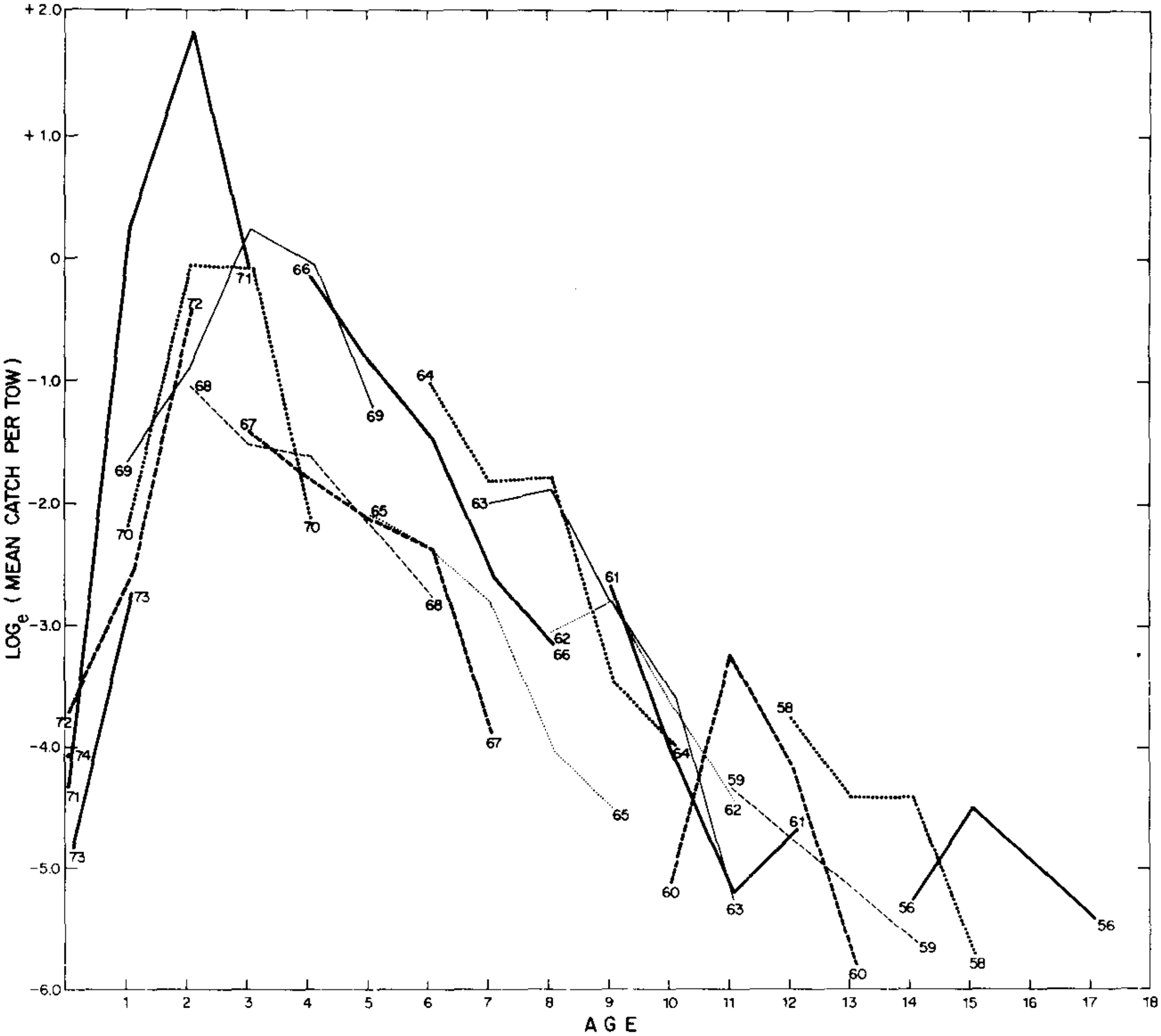

Fig. 4. Natural logarithm of mean catch/tow versus age for year-classes of cod from survey data for ICNAF Div. 5A.

TABLE 3. Estimated mean catch/tow per age-group for cod from ICNAF Div. 5Z (Spring cruises only).

Age-group	1970	1971	1972	1973	1974
0		0.013	0.024	0.008	0.017
1	0.190	0.111	1.321	0.078	0.064
2	0.353	0.409	0.942	6.275	0.658
3	0.243	0.219	1.265	0.920	0.912
4	0.852	0.166	0.198	0.942	0.118
5	0.122	0.423	0.117	0.110	0.295
6	0.364	0.093	0.233	0.092	0.062
7	0.135	0.161	0.060	0.075	0.021
8	0.048	0.151	0.169	0.017	0.043
9	0.068	0.060	0.058	0.031	0.011
10	0.006	0.018	0.025	0.028	0.019
11	0.013	0.039	0.006	0.012	0.005
12	0.023		0.016	0.009	
13		0.012		0.003	
14	0.005		0.012	0.004	
15		0.011		0.003	
16					
17				0.004	
Total	2.42	1.89	4.44	8.61	2.22

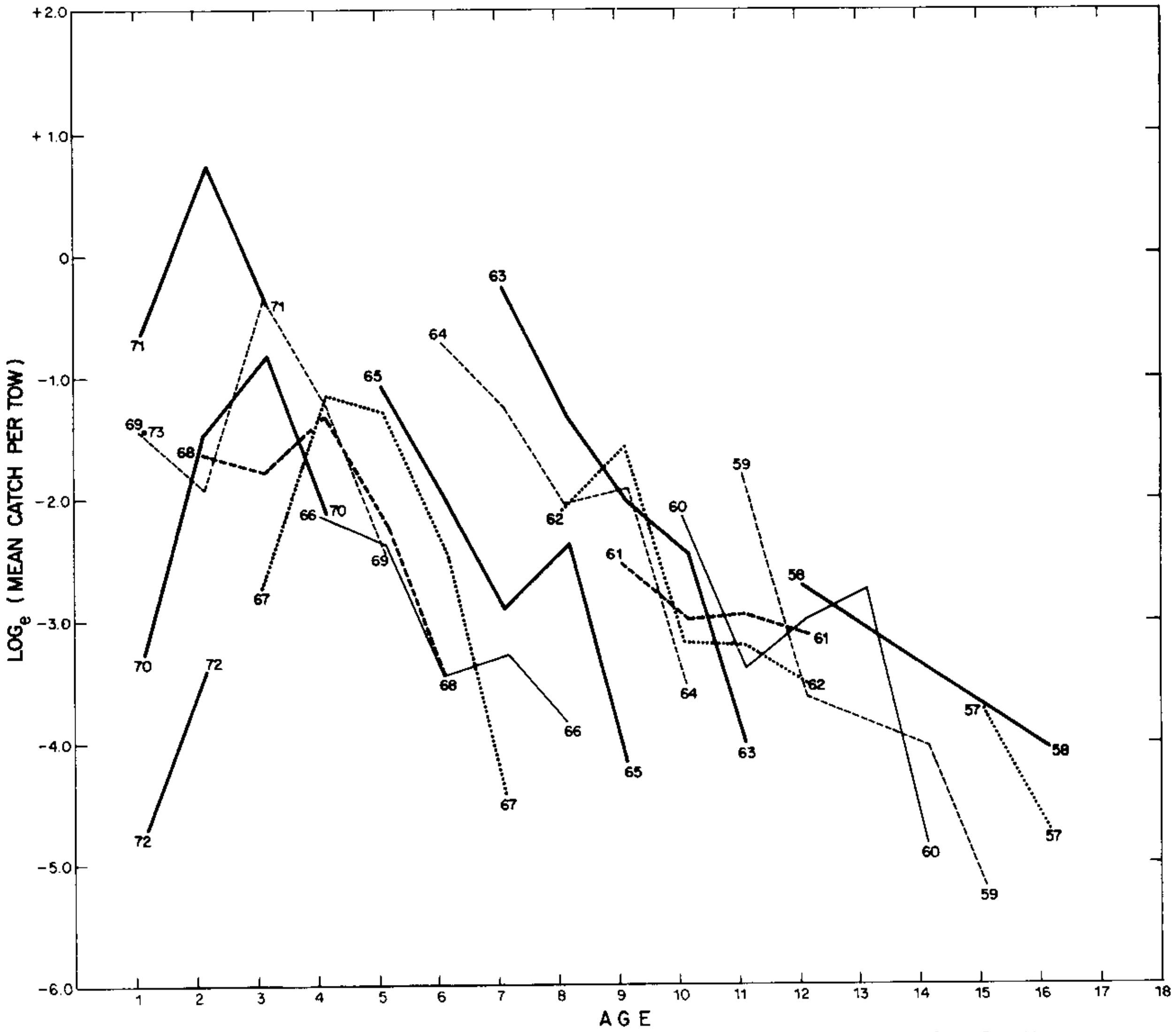

Fig. 5. Natural logarithm of mean catch/tow versus age for year-classes of cod from survey data for ICNAF Div. 5Y.

TABLE 4. Estimated mean catch/tow per age-group for cod from ICNAF Div. 5Y (Spring cruises only).

Age-group	1970	1971	1972	1973	1974
0					
1	0.237	0.038	0.525	0.009	0.231
2	0.197	0.147	0.227	2.128	0.033
3	0.066	0.169	0.714	0.441	0.641
4	0.117	0.313	0.264	0.279	0.121
5	0.340	0.092	0.277	0.108	0.086
6	0.492	0.132	0.032	0.084	0.031
7	0.773	0.282	0.055	0.038	0.012
8	0.121	0.269	0.127	0.093	0.021
9	0.078	0.206	0.135	0.146	0.015
10	0.117	0.049	0.041	0.085	0.030
11	0.162	0.033	0.052	0.040	0.017
12	0.067	0.026	0.050	0.043	0.029
13				0.063	
14				0.018	0.008
15			0.023		0.006
16				0.009	0.018
17				0.018	
Total	2.77	1.76	2.52	3.60	1.30

TABLE 5. Estimates of total instantaneous mortality rates (Z) for Div. 5Z and 5Y.

Area	Year-class	Ages of fish	Linear regression analysis Z	Linear regression analysis r[1]	Robson-Chapman method Z
Div. 5Z	1969	3-5	0.72	−0.94	0.62
	1968	3-6	0.43	−0.96	0.40
	1967	3-7	0.54	−0.92	0.44
	1966	4-8	0.76	−0.99	0.74
	1965	5-9	0.64	−0.97	0.55
	1964	6-9	0.71	−0.92	0.60
	1963	7-9	0.42	−0.81	0.34
	Average Z		0.60		0.53
Div. 5Y	1968	4-6	1.05	−0.99	1.01
	1967	4-7	1.09	−0.94	0.73
	1966	4-8	0.42	−0.94	0.44
	1965	5-9	0.64	−0.90	0.63
	1964	6-10	0.61	−0.94	0.56
	1963	7-10	0.71	−0.98	0.82
	1962	8-10	0.52	−0.64	0.33
	Average Z		0.72		0.65

[1] Correlation coefficient

Bank (Div. 5Z) cod and at age 4 for Gulf of Maine (Div. 5Y) fish (Fig. 4 and 5). The total instantaneous mortality coefficient (Z) for each area was calculated for each year-class (with at least three data points) by least squares regression of the points from age 3 to 9 for Div. 5Z and from age 4 to 10 for Div. 5Y (Table 5). Estimates of Z for each year-class were also calculated, using the Robson-Chapman (1961) analysis of a segment of the catch curve, for segments (with at least 3 years of data) based on ages 3 to 9 for Div. 5Z and ages 4 to 10 for Div. 5Y (Table 5).

The two methods of analysis gave average values of Z of 0.60 and 0.53 for Div. 5Z and of 0.72 and 0.65 for Div. 5Y. Averaging the two estimators for each area gives Z = 0.56 for Div. 5Z and Z = 0.68 for Div. 5Y.

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An Evaluation of the Northern Newfoundland-Labrador and Flemish Cap Redfish Fisheries

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Abstract

The status of northern Newfoundland-Labrador (Subarea 2 + Division 3K) and Flemish Cap (Division 3M) redfish is evaluated. Maximum sustainable yield (MSY) estimates of 40,000-47,000 metric tons for Subarea 2 + Div. 3K and 13,000-15,000 m tons for Division 3M redfish were derived from catch and effort data utilizing a general production model. Yield per nominal recruit curves for 3M redfish were essentially flat-topped. Estimated levels of F_{opt} ($F_{0.1}$) for 3M ranged from 0.1 to 0.3. Estimates of the instantaneous total mortality coefficient (Z) for 3M of 0.48 for males and 0.40 for females derived from 1972 USSR exploratory catch curves indicate that fishing mortality (F) was near or beyond the $F_{0.1}$ level for both sexes during 1963-72 when annual catches averaged 12,000 m tons, but must be viewed with caution in view of substantial differences in age reading among countries and difficulties of aging the older fish with precision. For both stocks the high catches of 1956-60 were far above any sustainable level. The Subarea 2 + Div. 3K stock is considered to be depressed. The 3M fishery was at a very low level during 1966-71 but increased dramatically in 1972 due to a diversion of fishing effort to that stock in response to improved catch per unit effort.

Introduction

The status of redfish in ICNAF Div. 3P, 3O and 3L-N was previously analyzed by Parsons and Parsons (MS 1973). This paper assesses the status of northern Newfoundland-Labrador (ICNAF Subarea 2 and Div. 3K) and Flemish Cap (ICNAF Div. 3M) redfish, utilizing a general production model to provide estimates of sustainable yield and also the Beverton and Holt yield per recruit model for Flemish Cap redfish.

Both *mentella*-type and *marinus*-type redfish occur on Flemish Cap and off northern Newfoundland-Labrador and significant catches of *marinus*-type redfish are occasionally obtained there. However, an examination of catches by the Canadian research vessel *A. T. Cameron* in these areas indicates that *marinus*-type redfish generally amounted to less than 10% by weight of the total redfish catch. No data are available on the relative proportion of *marinus*-type redfish in the commercial catches. However, it seems reasonable to conclude, because of the overwhelming predominance of *mentella*-type redfish in Canadian research catches and USSR research surveys (Yanulov 1960a and b; Chekhova MS 1973), that *mentella*-type redfish have comprised by far the major portion of the commercial catches.

In this paper *mentella*-type redfish includes both the European type *Sebastes mentella* (Travin) and the North American form of sharp-beaked redfish, *Sebastes fasciatus* (Storer). It has recently become apparent that these two species can be distinguished on the basis of the relative positioning of the extrinsic gasbladder muscles. These gasbladder muscles cross between the second and third ventral ribs in *Sebastes mentella* and between the third and fourth ventral ribs in *Sebastes fasciatus* as they pass posteriorly to attach to the vertebrae. There are external morphological differences as well (Barsukov 1968, 1972; Barsukov and Zakharov, 1972) but these are less clearly defined at present. No data are available on the relative proportions of these two species in the commercial redfish catches from Subarea 2 + Div. 3K and 3M.

For assessment purposes Mead and Sindermann (1961) considered the *mentella*-type redfish inhabiting the Flemish Cap area to be a separate stock. Yanulov (1960a and b), from a study of various morphological features and the degree of infestation with certain parasites, concluded that the *mentella*-type redfish on Flemish Cap constitute a self-contained stock. This is butressed by the occurrence in the vicinity of Flemish Cap of well-defined larval concentrations (Bainbridge and Cooper 1971), the bulk of which (> 90%) lack subcaudal melanophores.

The stock relationship of *mentella*-type redfish from Labrador to the eastern Grand Bank is less well-defined. Mead and Sindermann (1961) considered the redfish inhabiting Div. 3K and 3L and Subarea 2 to be a unit stock for assessment purposes. However, the exact relationship of redfish in Div. 3L (northern Grand Bank) to those of northern Newfoundland-Labrador is uncertain. These have been previously grouped for stock assessment purposes with redfish in Div. 3N (Parsons and Parsons MS 1973). In this paper the current ICNAF practice of

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treating redfish in Subarea 2 and Div. 3K as a unit stock is followed.

Materials and Methods

Since different countries have fished redfish in Subarea 2, Div. 3K and 3M in different years, it was impossible to standardize fishing effort on the basis of country. Instead, fishing effort was standardized on the basis of vessel tonnage category. For the Subarea 2 + Div. 3K stock, the procedure was as follows: catch per day fished of vessels in each of the 151-500, 501-900 and 901-1800 tonnage categories was plotted against catch per day fished of vessels in the > 1800 tonnage category, for months in which both categories of vessels fished for at least 15 days (Fig. 1). Straight lines passing through the origin were then fitted to the points for each tonnage category and the slopes of these lines used as conversion factors to convert the days fished in each tonnage category to equivalent days fished by vessels in the standard category > 1800 tons. The equivalent standard days fished in these tonnage categories were then summed to produce total number of standard days for the entire fleet. Adjustments were made in cases where some effort was missing from certain tonnage categories. The catch per standard day fished was then calculated from the total catch and the total standard effort (Fig. 2).

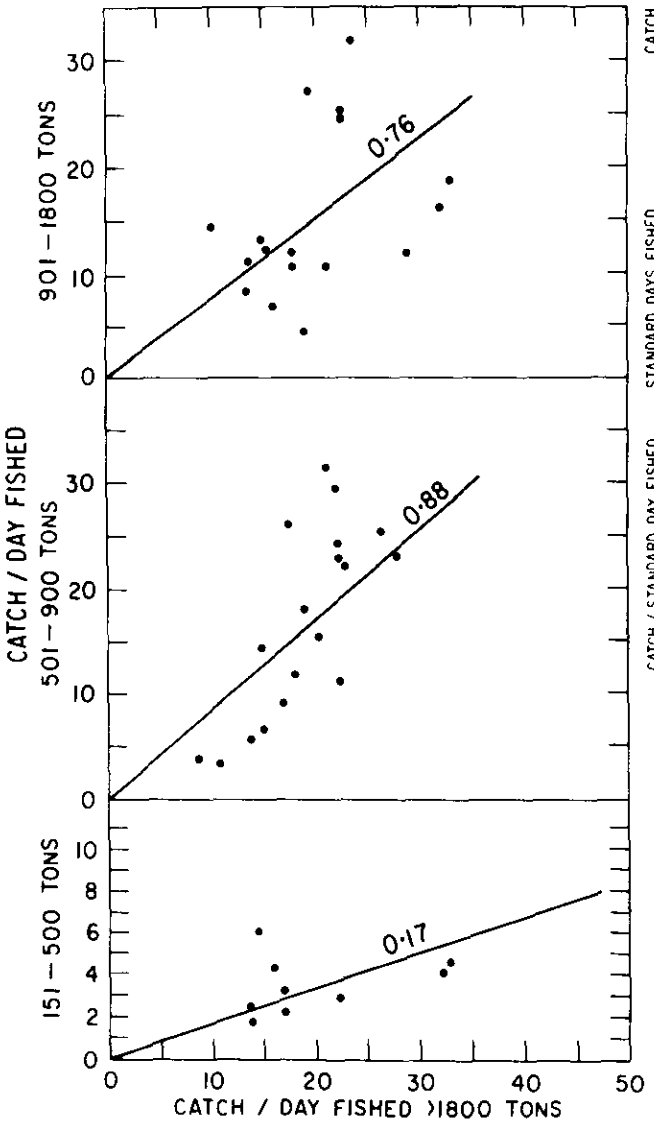

Fig. 1. Catch per day fished of various tonnage categories of vessels versus catch per day fished of vessels in tonnage category > 1800 tons, redfish, Subarea 2 + Div. 3K.

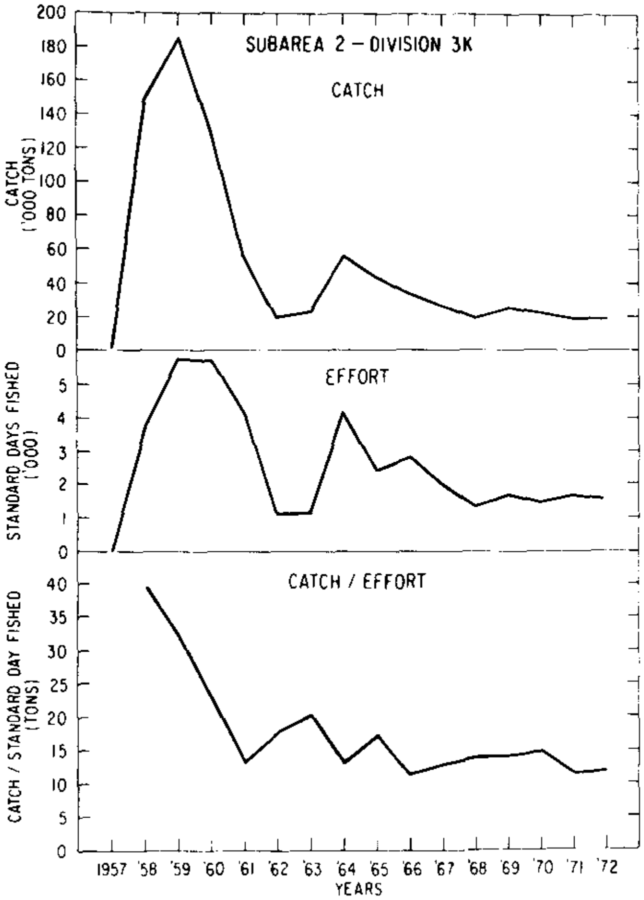

Fig. 2. Trends in redfish catch, effort and catch per unit effort, Subarea 2 + Div. 3K.

In Div. 3M, vessels of 151-500 tons fished most consistently during 1956-71; the catch per day of this tonnage category was selected as the standard unit of effort for this period, and in general the total number of standard days fished for the entire fleet was estimated by dividing the catch per day of this tonnage category into the total catch. Effort data were lacking for 1962 and 1967 and the catch per standard day for each of those years was derived by interpolation between immediately adjacent years (Fig. 3). The estimates of a low level of fishing effort thus derived are in agreement with the very small catches during those 2 years. The bulk of the catches in 1956,

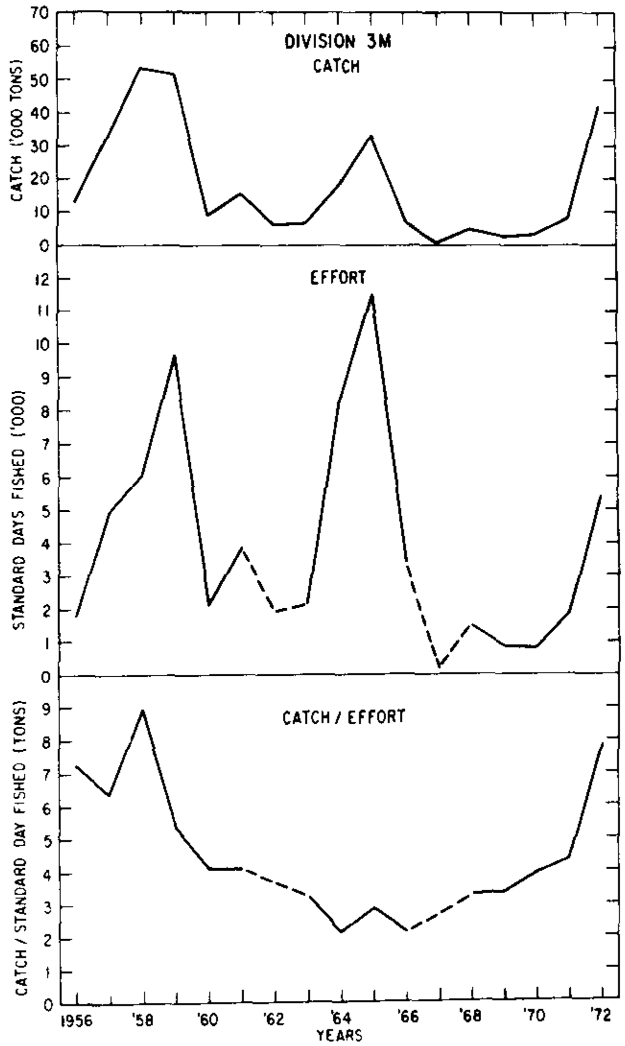

Fig. 3. Trends in redfish catch, effort and catch per unit effort in standard trawler units — vessels of 151-500 tons — for redfish in Div. 3M.

1957, 1958 and 1972 was taken by vessels of tonnage category > 1800 tons. The factor of 0.17 derived for vessels fishing in Subarea 2 + Div. 3K was originally applied to the Div. 3M data as well but this resulted in anomalous values for those years in which vessels of 151-500 tons and vessels of > 1800 tons both fished in Div. 3M. It was concluded that this factor of 0.17 was inappropriate for conversion of the catch per day of vessels > 1800 tons to that of the standard category for Div. 3M. An examination of those few years in which vessels of 151-500 tons and vessels of > 1800 tons both fished in Div. 3M suggested that a conversion factor of 0.33 was more appropriate and this was used instead to convert the catch per unit effort of vessels > 1800 tons to that of the standard category 151-500 tons. The total effort for each of those years was thus estimated in terms of days fished by the standard vessel tonnage category.

The Schaefer general production model (Schaefer 1954), as modified by Gulland (1961), was used to derive estimates of sustainable yields from these catch and fishing effort data. Running averages of fishing effort are used in the Gulland modification of the Schaefer general production model to better estimate the steady-state condition assumed in the fitting method used (Gulland 1961; Schaefer 1967). As pointed out by Fox (1975), Gulland's approach, which Fox terms the equilibrium approximation method, estimates the level of fishing effort which, if equilibrium obtained, would produce, on the average, the observed level of catch per unit effort in each year of the fishery. In this instance, periods of 6, 8 and 10 years were used to average the total effort over the mean number of years that a given year-class of redfish might contribute to commercial catches. The fishing effort in year i and 5 years prior to i (i.e. a 6-year period) was averaged and plotted against the catch per unit effort in

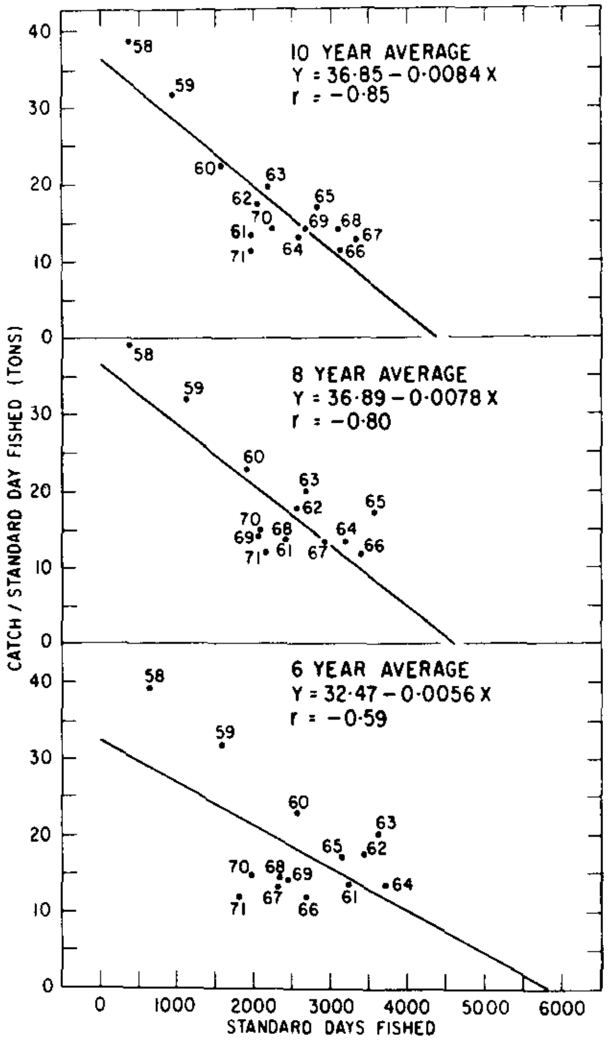

Fig. 4. Catch per standard day fished versus 6-year, 8-year and 10-year running averages of standard days fished, redfish, Subarea 2 + Div. 3K.

year i; similar calculations were performed for 8- and 10-year averaging periods. The same number of points could be obtained with any averaging period since the effort was zero in Subarea 2 — Div. 3K prior to 1958 and in Div. 3M prior to 1956. Least squares linear regressions relating catch per unit effort to mean effort were computed (Fig. 4 and 5). The parameters of the linear regressions for the 6-, 8- and 10-year averaging periods were then converted to those of the equilibrium yield versus effort parabolas depicted in Fig. 6 and 7.

The few commercial length frequencies for Flemish Cap (Div. 3M) available in the ICNAF Sampling Yearbooks for the years 1970 to 1972 and the length frequencies from USSR exploratory catches in 1972 (130 mm mesh) were also plotted for comparison with the size

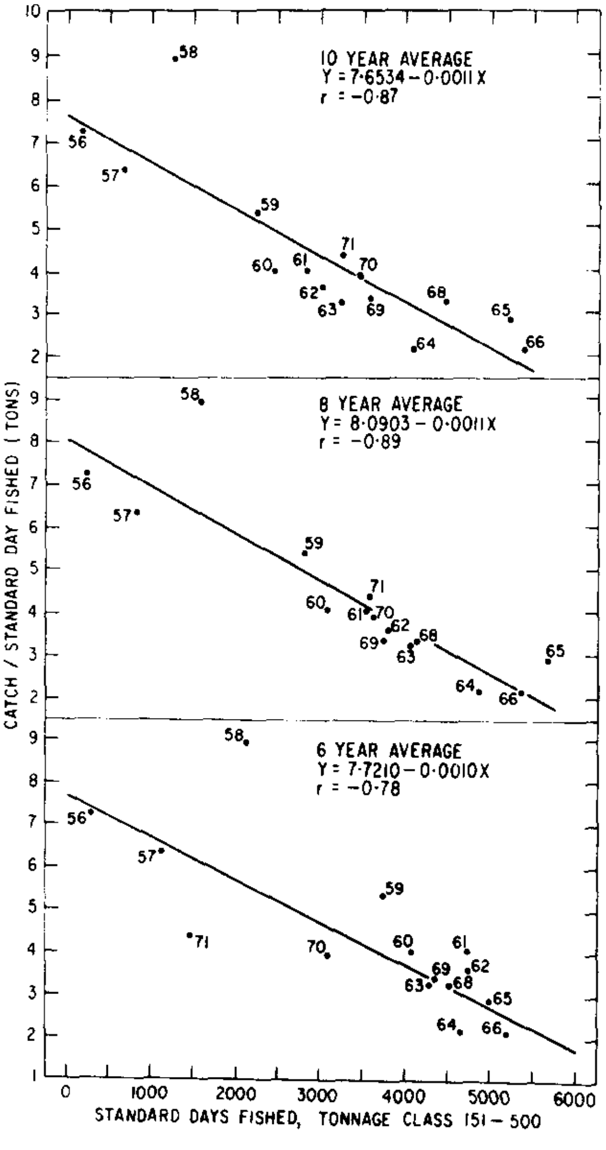

Fig. 5. Catch per standard day fished versus 6-year, 8-year and 10-year running averages of standard days fished, redfish, Div. 3M.

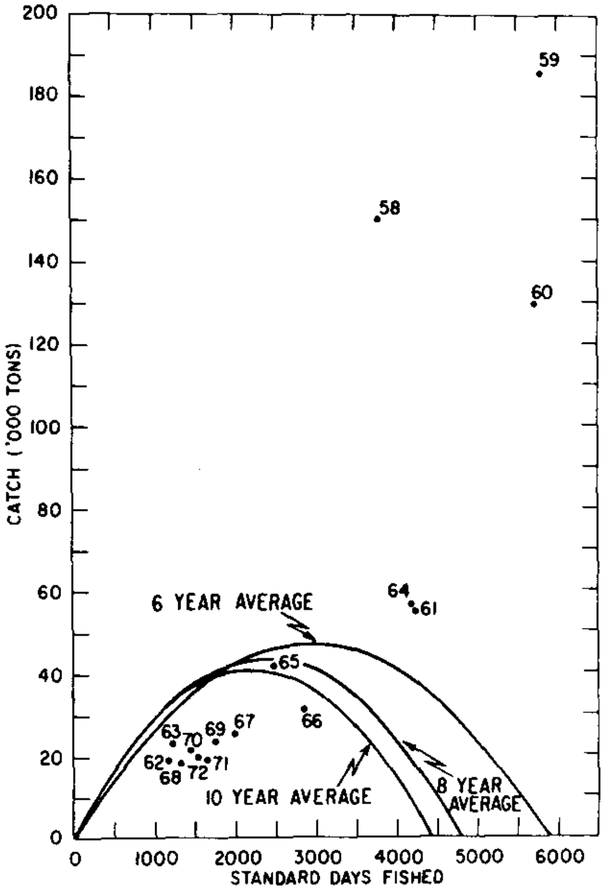

Fig. 6. Yield curves derived from the catch per unit effort/effort relation using 6-year, 8-year and 10-year running averages of standard days fished, redfish, Subarea 2 + Div. 3K.

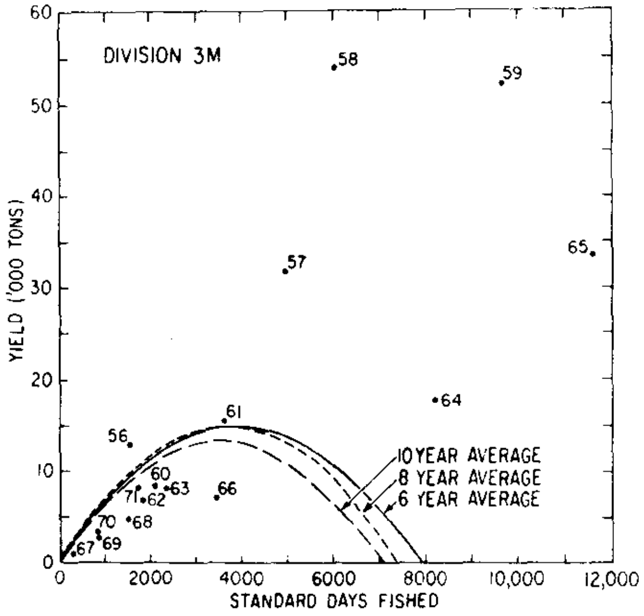

Fig. 7. Yield curves derived from the catch per unit effort/effort relation using 6-year, 8-year and 10-year running averages of standard days fished, redfish, Div. 3M.

distributions from a 1973 research survey by the Canadian vessel *Cape Farewell*. The *Cape Farewell* fished an Engels-Demone high-opening semi-pelagic trawl (lined by 29 mm mesh nylon liner) on the two survey lines across depth contours, to the north and east of Flemish Cap (Parsons and Parsons MS 1974).

Polish age composition data for a single sample from the 1972 Flemish Cap commercial catch and USSR age composition data for their 1972 exploratory catches were compared with the numbers caught per hour at each age during the 1973 *Cape Farewell* survey. The 1973 ages were determined by the authors from otoliths according to the method of Sandeman (1961, 1969). Age-length keys were derived from random samples of 225 males and 175 females taken from several depths and positions during July-August 1973 and these were used to estimate the numbers caught per hour at each age on the northern and eastern survey lines from the numbers caught per hour at each length interval.

Bertalanffy growth curves were fitted separately, using Allen's (1966) method, to the pooled length-at-age data for 225 male and 175 female redfish (ranging in age from 7 to 43) in the 1973 Flemish Cap research samples. These are compared with earlier growth curves for Flemish Cap redfish.

Beverton and Holt constant parameter yield-per-recruit curves were calculated for males and females separately, using parameters derived in this study and length-weight relationships from earlier Canadian research surveys in Div. 3M. We have no precise estimates of the natural mortality coefficient (M) for redfish. However, the natural mortality rate for slow-growing species such as redfish must be very low relative to faster-growing species such as cod. Sandeman (1973) considers the most likely value to lie somewhere between 0.1 and 0.05. The value of M for Pacific ocean perch has been estimated as 0.12 (Westrheim *et al* MS 1972). Values of M of 0.05, 0.1 and 0.15 were used here and yield-per-recruit values computed for fishing mortality (F) values up to 2.5.

Levels of $F_{0.1}$ (F_{opt}) — the level at which the change in yield-per-recruit with respect to changes in mortality rate is one-tenth of that of the fishery beginning on the virgin stock — were calculated according to the method of Gulland and Boerema (1973).

Results

Subarea 2 — Division 3K

Fishery trends

Reported catches of redfish in Subarea 2 and Div. 3K were nil prior to 1958. A directed fishery for redfish commenced in 1958 and catches reached 150,000 tons (Fig. 2). This increased to 187,000 tons in 1959 but decreased to 130,000 tons in 1960 and 55,000 tons in 1961. Catches were around 20,000 tons in 1962 and 1963 but increased to 56,000 tons in 1964. There was a steady decrease to 20,000 tons by 1968 and catches since then have remained stable at about this level. Trends in fishing effort were similar to catch trends. Catch per standard day fished (vessels of $>$ 1800 tons) was at a high level of 40 tons in 1958 when the fleet fished the accumulated stock of old redfish. However, there was a very sharp decline to 13 tons per day by 1961. Some increase was evident in 1962 and 1963 to 20 tons per day but the catch per unit of effort thereafter decreased and remained stable at 12-15 tons per day during 1966 to 1972.

Sustainable yields

Regressions of catch per unit effort on effort resulted in significant regression coefficients of 0.59 ($P < 0.05$), 0.80 ($P < 0.01$) and 0.85 ($P < 0.01$) for 6-, 8- and 10-year periods respectively (Fig. 4). Very little improvement was evident between the 8- and 10-year averaging periods.

Yield curves calculated from these regressions (Fig. 6) resulted in maximum sustainable yield estimates of 40,000 tons for the 10-year period, 44,000 tons for the 8-year period and 47,000 tons for the 6-year period.

Division 3M

Fishery trends

A directed fishery for redfish in Div. 3M commenced in 1956 when a catch of about 13,000 tons was reported. The catch increased to 54,000 tons in 1958, remained at 52,000 tons in 1959 but then declined sharply to 8,000 tons in 1971 (Fig. 3). Catches remained less than 16,000 tons during 1961-64, increased to 33,000 tons in 1965 and subsequently declined to a very low level from 1966 to 1971 averaging 4,400 tons during that latter period. The catch increased dramatically from 8,000 tons in 1971 to 42,000 tons in 1972. The 1973 catch was substantially lower at about 21,000 m tons.

Trends in fishing effort were somewhat similar to catch trends (Fig. 3). Peaks in fishing effort occurred at about 10,000 to 11,000 standard days fished (vessels of 151-500 tons) in 1959 and 1965. However, it should be noted that a large proportion of the 33,000 tons of redfish caught in 1965 was apparently taken as a by-catch of the cod fishery which peaked sharply at about 55,000 tons in 1965 (Wells MS 1973). Hence, the directed effort for redfish was probably considerably less than the 11,000 standard days fished shown in Fig. 3.

Catch per day fished for vessels of 151-500 tons was at a high level of 6.4-8.9 tons per day during 1956-58, subsequently declined to a low of 2.1 tons per day in 1964 and 1966 (Fig. 3). The fishery for redfish in Div. 3M was virtually non-existent in 1967 probably because of reduced abundance of fish. By 1968 the catch per day had recovered to 3.3 tons and subsequently showed a progressive increase to 4.4 tons in 1971 and a dramatic increase to 7.8 tons in 1972. The catch per day during 1972 was equivalent to those experienced during the initial years of exploitation. The greatly increased catch in 1972 was partly due to an increase in effort presumably in response to the improved redfish catch per unit effort resulting from increased recruitment; some of this effort may have been directed toward cod since the cod catch also increased dramatically in 1972.

Sustainable yields

Regressioins of catch per unit effort against mean effort during 1956-71 resulted in significant regression coefficients ($P < 0.01$) of 0.78, 0.89 and 0.87 for the 6-, 8- and 10-year averaging periods respectively (Fig. 5). Very little difference was evident between the 8- and 10-year averaging periods as was observed for Subarea 2 + Div. 3K redfish.

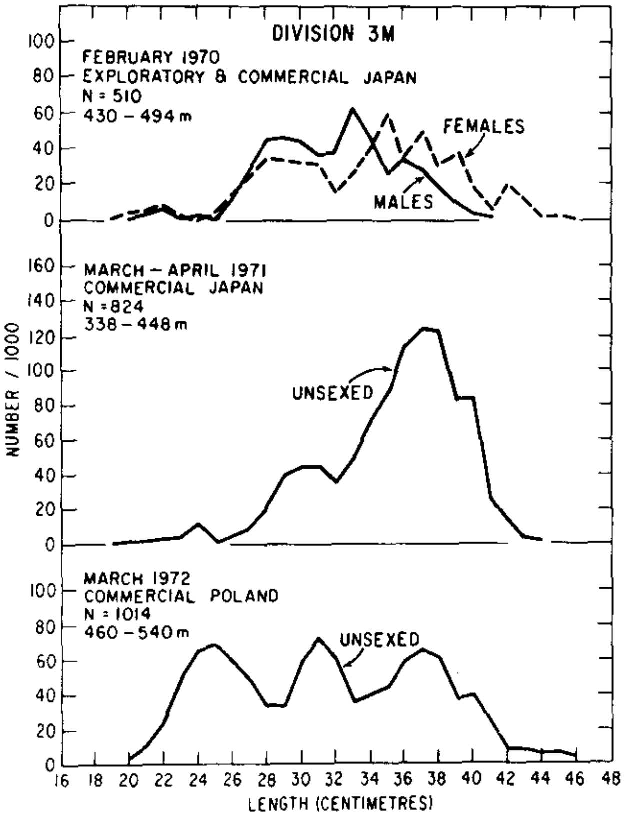

Fig. 8 Commercial otter trawl length frequencies for Div. 3M redfish, 1970-72.

Maximum sustainable yield estimates of 13,000 tons for the 10-year period, and 15,000 tons for the 8-year and 6-year periods were indicated by yield curves calculated from these regressions (Fig. 7).

Size and age

Cursory examination of the limited commercial length frequencies available for Flemish Cap for 1970, 1971 and 1972 reveals a broad size range in all 3 years (Fig. 8). In 1970 most of the fish were between 26 and 40 cm with three modes at 29, 33 and 36 cm for the males. The female size distribution exhibited more peaks. In 1971 the unsexed size distribution was trimodal with the dominant size group centered at 37 cm, a secondary peak at 30-31 cm and a few fish with a modal length of 24 cm. The bulk of the fish were between 32 and 41 cm. The single unsexed commercial frequency for 1972 indicates a trimodal size distribution with modes at 25, 31 and 37 cm. The size groups centered at these modal lengths appear to be of approximately equivalent abundance in terms of numbers. An influx of relatively small young fish into the fishery in 1972 is apparent.

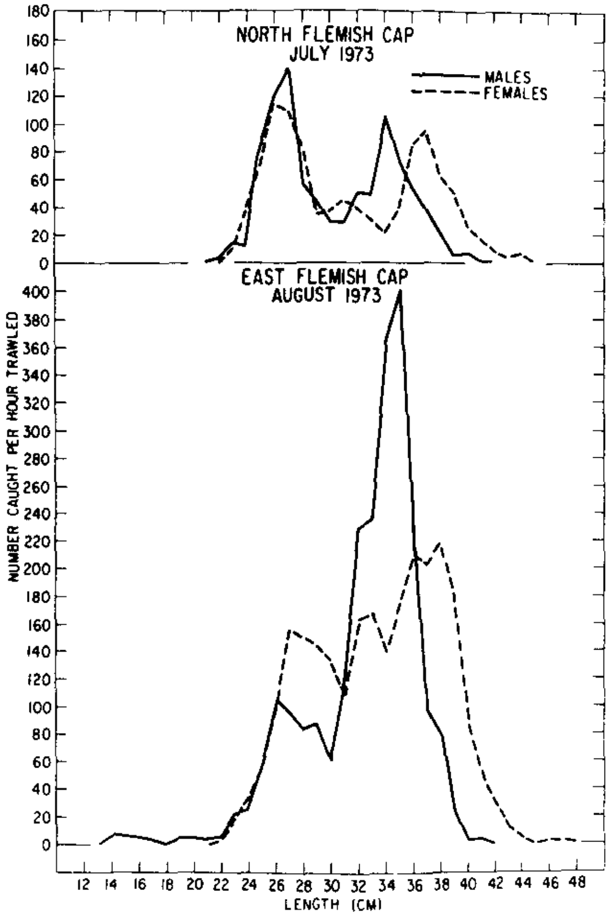

Fig. 9. Length distributions of *mentella* redfish taken by the *Cape Farewell* (June-August 1973) from the northern and eastern Flemish Cap.

In 1973 Canadian research survey catches on a survey line to the north of Flemish Cap the size distribution of the males was bimodal with peaks at 27 and 34 cm; the females were basically trimodal with prominent modes at 26 and 37 cm and a less prominent mode at 31 cm (Fig. 9). On the eastern survey line the males had peaks at 26 cm and 35 cm; the females approximated trimodality with peaks at 27 cm, 32-33 cm and 38 cm. Fish larger than 31 cm were markedly predominant among the males but less so among the females which were almost equally abundant over the broad size range of 26 to 40 cm. This contrasted with the predominance of the smaller size group (26-27 cm) to the north. Overall, substantial numbers of fish less than 30 cm were taken in the research catches.

The two 1972 USSR exploratory length frequencies (Fig. 10) are somewhat dissimilar. In March the dominant size groups had modal lengths of 35 cm for males and 37 cm for females. However, a substantial number of 22-33 cm fish were also present. In July 1972 larger fish were dominant in the exploratory catches with modal lengths of 37 cm for males and 40 cm for females. Apparently only negligible quantities of fish less than 32 cm were caught. USSR age readings indicate that males of ages 12-14 and females of ages 13-16 were dominant in their March exploratory samples (Fig. 11).

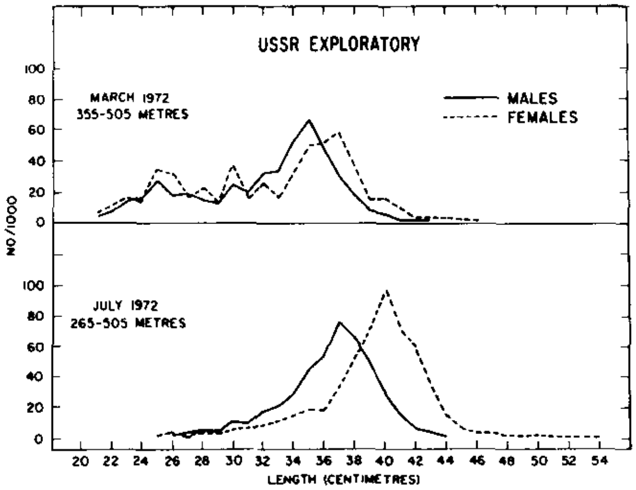

Fig. 10. Length distributions of *mentella* redfish taken in exploratory fishing by the USSR in Div. 3M, 1972.

The Polish age composition data for the March 1972 commercial sample indicate that 6- and 11-year-old fish were dominant among the males and 6-, 8- and 17-year-old fish among the females (Fig. 11).

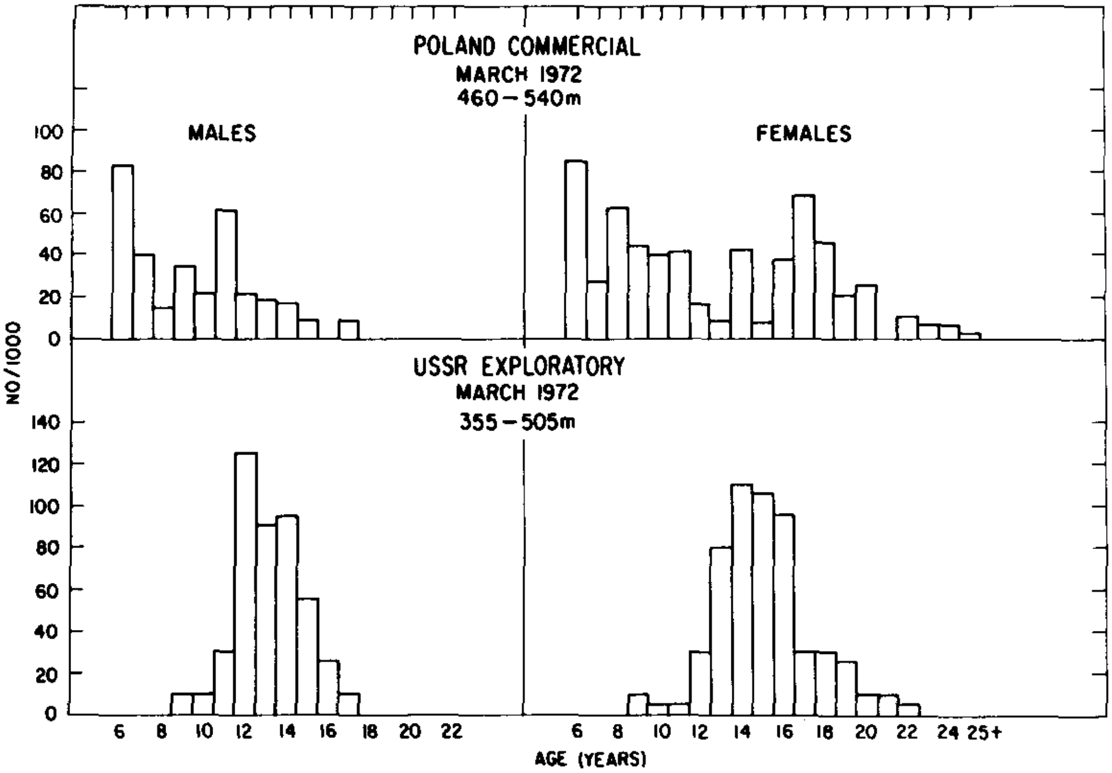

Fig. 11. Age distributions of 1972 Polish commercial and USSR exploratory redfish catches in Div. 3M.

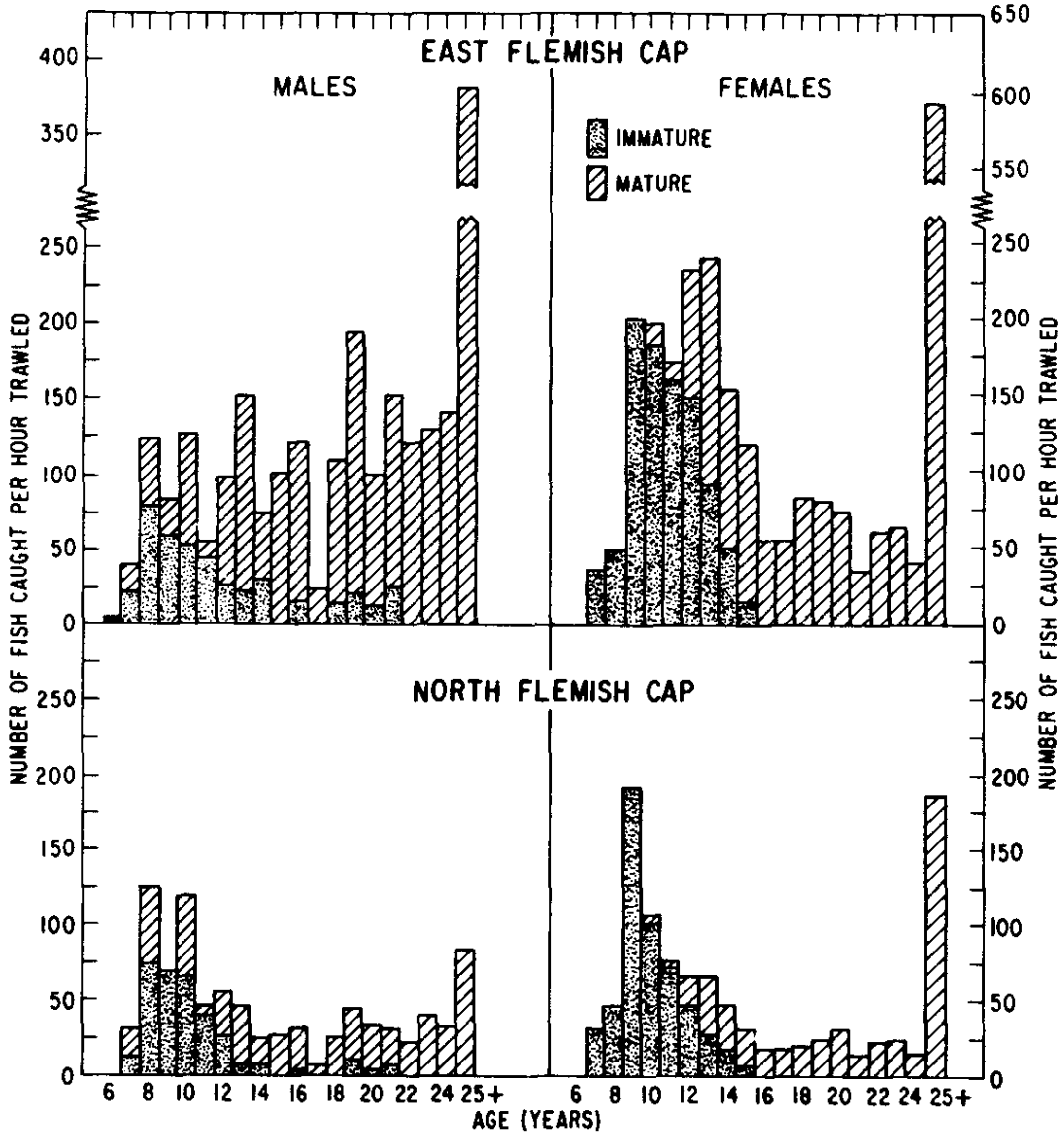

Fig. 12. Age distribution of 1973 Canadian research catches of *mentella* redfish in Div. 3M.

Age distributions of fish caught in the 1973 Canadian research survey (Fig. 12) were substantially different from those reported for the 1972 Polish commercial and USSR exploratory samples, both in terms of dominant age groups and range of ages present. There appeared to be a much greater proportion of older fish in the 1973 Canadian research catches than was evident from the ages reported for the Polish and USSR samples. These discrepancies probably stemmed from fundamental differences in redfish age reading by scientists in these three countries.

In our catch per hour data 8- to 10-year-old males were dominant on the northern survey line but there was little evidence of year-class dominance among males to the east of Flemish Cap. There was a greater proportion of older fish than to the north. Nine-year-olds were dominant among females on the northern line as compared with 9- to 13-year-olds on the eastern line. Overall, there were greater proportions of old fish (25 years and older) to the east of Flemish Cap than to the north, as suggested by the length distributions.

Approximately 40% of the females and 20% of the males caught in the 1973 research survey were immature. The males obviously attain maturity at an age several years younger than the females (Fig. 12). About 50% of the males were mature by age 10 whereas the bulk of the females were immature as late as age 12. Sandeman (1969) found that in Hermitage Bay, Newfoundland, on the average males mature at about 20 cm or 6 years old whereas females mature at about 30 cm or 10-12 years of age. This difference in the age at maturity is probably primarily responsible for the different growth rates of males and females (Fig. 13).

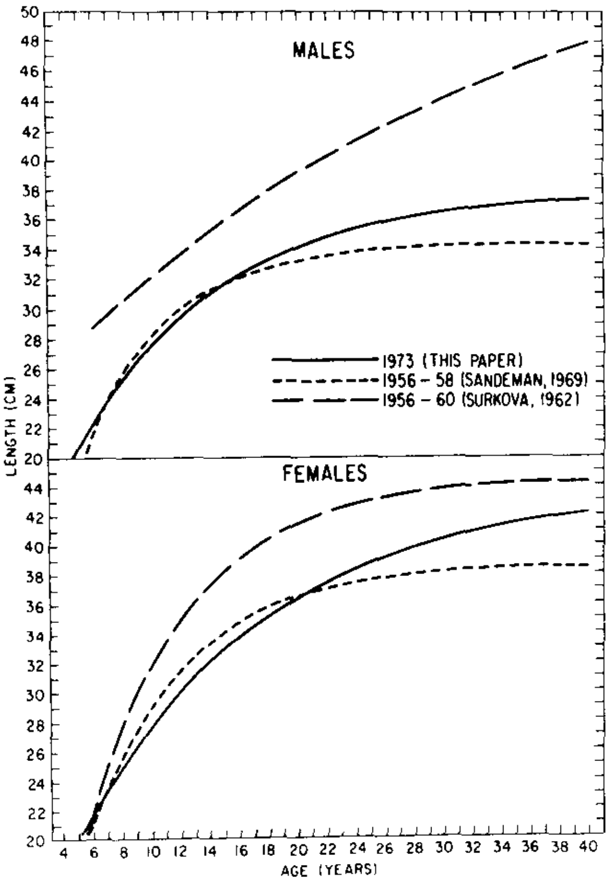

Fig. 13. Growth curves of male and female *mentella* redfish from Flemish Cap.

Growth

The parameters for the von Bertalanffy growth curves fitted to the 1973 research data and their standard errors are as follows:

	Males	Females
K	0.10 ± 0.01	0.08 ± 0.01
t_0	– 2.79 ± 1.10	– 2.83 ± 1.13
L_∞	37.92 ± 0.75	43.71 ± 1.24

These curves are shown in Fig. 13 with Sandeman's (1969) growth curves for Flemish Cap, which were based on 1956 and 1958 data, and curves fitted to Surkova's (1962) data for the years 1956-60 combined and averaged over the five years. Some differences are apparent but there is reasonably good agreement between our curve and Sandeman's for the younger ages. Our growth curves are more similar to Sandeman's than Surkova's. Sandeman (1969) attributed the lack of agreement between his and Surkova's growth curves to the fact that he used otoliths and Surkova scales.

A comparison of the ages for the 1973 *Cape Farewell* catches and those of the USSR for 1973, for fish of generally similar sizes from approximately the same depths, indicates that ages estimated for older redfish from otoliths are considerably greater than those from scales. Eighteen percent of the redfish caught by the *Cape Farewell,* with ages read from otoliths, were 25 years and older and 40% 19 years and older. Some of these fish of 25 years and older were apparently close to 50 years of age. According to the USSR ages, no redfish were older than 22 years and only 5% 19 years and older. It is evident that ages of redfish of large commercial size, as determined from scales, are grouped over a much smaller range of ages than those from otolith readings.

In view of the 15-year interval between the period represented by Sandeman's data and that for our 1973 data, the differences between his curves and ours might represent a real difference in growth but the possibility that they may, to a large extent, be one of technique rather than of real growth differences cannot be discounted.

Yield per recruit

The Beverton and Holt yield-per-recruit model was applied to males and females separately, using the following parameters.

		Males	Females
W_∞	(asymptotic weight)	0.768	1.240
K	(from von Bertalanffy equation)	0.101	0.079
t_0	(growth correction factor)	– 2.794	– 2.831
t_ρ	(age at entry to exploited area)	8.0	8.0
t_ρ^1	(age at mean selection length)	12.0	11.5
t_λ	(last age of significant contribution to the fishery)	25.0	28.0

The yield curves were essentially flat-topped with F_{max} occurring at 0.3 for females with M = 0.05 (Fig. 14). For other values of M no maximum values were obtained up to F = 2.5. However, beyond fishing mortality values of 0.4 the increments in yield-per-recruit were exceedingly small. Estimated levels of F_{opt} ($F_{0.1}$) (Gulland and Boerema 1973) for the males were 0.16, 0.27 and 0.34

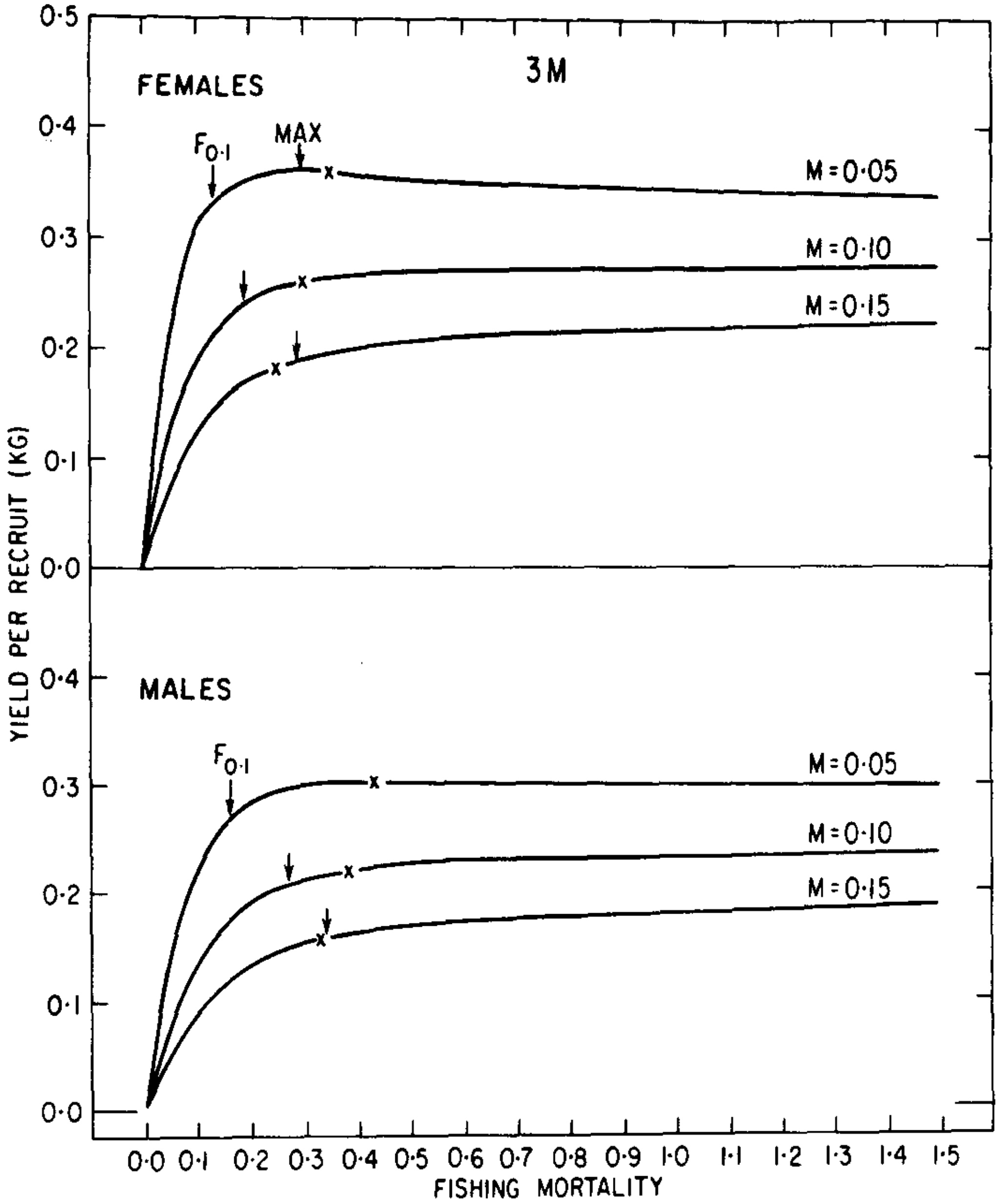

Fig. 14. Yield per recruit curves for male and female *mentella* redfish from Flemish Cap. Points on curves indicate fishing mortality estimates from 1972 USSR exploratory catches (X).

and for the females 0.13, 0.19 and 0.29 with M = 0.05, 0.10 and 0.15 respectively.

Estimates of total mortality (Z) of 0.48 for males and 0.40 for females were derived from 1972 USSR exploratory catch curves (Fig. 15). These values are beyond $F_{0.1}$ for both males and females with M = 0.05 and 0.1, and at or slightly less than $F_{0.1}$ for males and females with M = 0.15.

Because of the very substantial differences in proportional numbers at age on the two survey lines to the north and south of Flemish Cap, no consistent or reliable estimates of Z could be obtained from the 1973 Canadian research catch data. In view of the apparently substantial differences in age reading among countries and the known difficulty of ageing the older fish (> 20 years) with precision, estimates of total mortality Z obtained from catch curve data must be viewed with extreme scepticism.

Discussion

The equilibrium approximation method of fitting general production curves, first used by Gulland (1961),

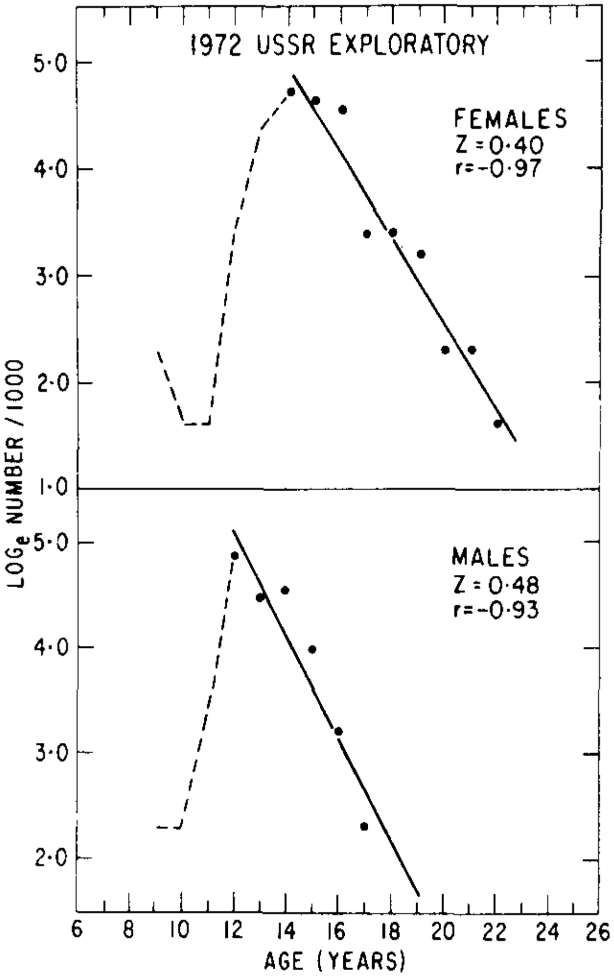

Fig. 15. Catch curves of redfish from 1972 USSR exploratory data.

only considers the effect of fishing on fish once recruited into the commercial stock but does not consider the longer-term effect fishing may have on recruitment, i.e. it does not adequately take account of a considerable time delay between spawning and recruitment such as that characteristic of redfish. Doubts have been expressed about the effectiveness of the "running average of effort" method in approximating a steady-state condition during the early years of a fishery. However, it is clear that the observed catch per unit of effort in the initial years of a fishery is greatly influenced by the accumulation of stock in the absence of a fishery. The high observed catch per unit of effort in year one of a fishery must reflect the fact that fishing effort has been nil for several years prior to the start-up year. Fox (1975) discusses the advantages and disadvantages of the transition state and equilibrim approximation approaches to fitting general production curves, with commentary on their underlying assumptions, and points out that the interpretation of results and the formulation of advice for managing a resource can be extraordinarily complicated by a variety of factors. He cautions that production model analysis is little more than a regression model yet very useful for making "first estimate" projections of the relationship between the level of exploitation and expected equilibrium yield. Cognizant of these uncertainties, we have followed the practice of many other authors in utilizing this technique merely as an attempt to derive some approximation, however crude, of the yields to be expected at various levels of exploitation. Our comments on the fisheries under consideration here should be interpreted in this light.

Our general production analyses indicate that the high catches of 1958-60 in Subarea 2 + Div. 3K were far above any sustainable level and that catches from 1966 to 1972 were below the equilibrium curve. Only the catches in 1965 and 1966 were close to the equilibrium curve. Catches in 1962 and 1963 were below the equilibrium curve and those in 1961 and 1964 were above. Fishing effort from 1967 to 1972 was relatively stable in the vicinity of 1,300-2,000 days fished but averaged approximately two-thirds of that required to produce the maximum sustainable yield under equilibrium conditions. The heavy fishing pressure in the early years of the fishery apparently reduced the stock to a level lower than required to produce equilibrium yield even though the fishing effort has been less in recent years. Although the stock, under maximum equilibrium conditions, can sustain catches of 40,000-45,000 tons, it appears to be in a depressed condition. Accordingly, the International Commission for the Northwest Atlantic Fisheries has restricted total allowable catches of redfish from Subarea 2 + Div. 3K for 1974 and 1975 to 30,000 tons to permit this stock to rebuild.

The high redfish catches of 1957-59 (32,000-54,000 tons) from Flemish Cap (Div. 3M) were also above any sustainable level. However, with the exception of a catch of 33,000 tons in 1965 (to some extent a by-catch of the cod fishery which peaked sharply at 55,000 tons in that year), catches during 1960-71 were generally below the sustainable yield level with the fishery at a very low level during 1966-71 (average yearly catch 4,400 tons and fishing effort only about one-third of that required to produce the maximum sustainable yield under equilibrium conditions). The dramatic increase in catch to 42,000 tons in 1972 was due to a diversion of fishing effort to that stock in response to greatly improved catch per unit effort. Fishing effort in 1972 was approximately half of the peak effort in 1959 and 1965, and was 35-40% in excess of that required to produce the equilibrium yield under stabilized conditions. The increase in catch per unit effort to a 1972 level considerably above that obtained in 1966 indicates a resurgence of this stock under relatively stabilized conditions of low fishing effort from 1967 to 1971. Templeman (MS 1975), from an analysis of commercial and research length frequency data for 1958-73, concluded that two good year-classes (those of 1959 and 1963) occurred on Flemish Cap following the initial period of removal of the accumulated stock. Although it is by no means certain that these are the specific year-classes involved, it is clear that the considerable improvement in catch per unit effort during 1968-72 and the upswing in the fishery in 1972-73 resulted from strong recruitment of relatively young fish.

The estimates of Z derived from the 1972 USSR exploratory catch curves for Div. 3M could conceivably represent the average level of total mortality during 1963-72 when catches averaged approximately 12,000 tons annually. These values are at or beyond $F_{0.1}$ for both males and females with one exception (females with $M = 0.15$). The 1972 catch of about 42,000 tons was almost five times as large as the average annual catch of 8,500 tons during 1963-71 and the estimated fishing effort in 1972 (5,400 standard days fished by vessels of 151-500 tons) was 60% in excess of the 1963-71 average annual fishing effort of 3,400 standard days fished. It seems likely that the 1972 value of F was considerably above the $F_{0.1}$ level.

The 1972 catch in Div. 3M was considerably above the sustainable yield level and was attained only by an increase in fishing effort beyond the level required to attain the maximum sustainable yield under equilibrium conditions. Catches of the magnitude of the 1974 total allowable catch of 40,000 tons cannot be sustained. The 1973 catch was substantially lower at about 22,000 tons. At its 1974 Annual Meeting, ICNAF agreed to restrict the 1975 total allowable catch of redfish from Div. 3M to 16,000 tons, a substantial decrease from the pre-emptive or precautionary catch ceiling of 40,000 tons which had been established previously for 1974. It would seem wise to limit catches at the estimated maximum sustainable yield level of 13,000-15,000 tons until such time as more rigorous assessments become available.

In the absence of adequate data on the size and age composition of the commercial catches from these redfish stocks, it will be impossible to adjust such catch quotas from year to year; rather catch restrictions should be set on a long-term basis until such time as adequate data become available to evaluate the effects of such catch restrictions upon the stocks.

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The Effect of Fishing on the Marine Finfish Biomass in the Northwest Atlantic from the Gulf of Maine to Cape Hatteras

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Abstract

Relationships between fishing effort, total finfish community biomass, and yield are determined using data on finfish biomass measured by research vessel trawl surveys and commercial catch and effort statistics. Combined individual species stock assessments and the Schaefer (1954) equilibrium yield model are utilized to estimate potential yields. The fishing effort of different gear types are combined to provide a standardized index of fishing effort in terms of days fished as reported to the International Commission for the Northwest Atlantic Fisheries (ICNAF). A multiplicative learning function is applied as a correction factor to reported days fished of newly developing fisheries, *i.e.* those deployed in areas and on stocks not previously fished. This correction factor adjusts data of fleets entering a fishery to the level of efficiency achieved by the third year in the fishery. These analyses demonstrate a six-fold increase in fishing intensity, and a 55% decline in finfish abundance during the period 1961-72. Plots of yield versus standardized fishing effort indicate that fishing mortality since 1968 has exceeded that which would result in sustaining a maximum yield from the stocks under equilibrium conditions. The projected maximum sustainable yield (MSY) from Schaefer yield curves is 900,000 tons[2], while the sum of the MSY's from individual assessment studies is 1,300,000 tons. It is suggested that because of species interactions summing the MSY's from individual assessments may be an overestimate of the total MSY.

Introduction

Historically, fisheries management has been stimulated by changes in the development of a fishery. New participants increase competition and may force changes in the distribution of the catches. New fisheries develop in areas and on species theretofore not fished; in the face of marked and rapid increases in fishing effort, serious doubts are often raised about the ability of the fish stocks to sustain their full potential productivity, especially when the catch per fishing unit begins to drop.

Such has been the case in the Northwest Atlantic fishery on the continental shelf off the northeast coast of the USA in ICNAF Subarea 5 and Statistical Area 6[3] (Fig. 1). Prior to 1960, almost all of the fishing in the area was carried out by USA vessels less than 300 GRT (gross registered tons), as the fishing grounds were close to the home ports where the landings were processed on shore. After 1960, the distant water fleets of USSR, Poland, Japan, FRG (Federal Republic of Germany), and other countries began fishing in the area. These fleets of large, highly mobile vessels steadily increased both in number and total tonnage (Table 1), and resulted in enlarging the scope of the total fishery with respect to species, area fished and intensity of fishing. While historically the USA fishery had concentrated on selected groundfish species (cod, haddock, redfish and flounders), greater catches of an increasing number of species (Table 2) have been reported since 1960 (ICNAF, 1962a-74a).

The Standing Committee on Research and Statistics of ICNAF (STACRES), which has been evaluating the effects of fishing on the resources in this area (ICNAF, 1961a, 1962b-74b), has on several occasions advised the Commission that the overall fishing intensity was fast approaching that which could not be supported by the stocks. This was emphasized at the 1961 Annual Meeting (ICNAF, 1961a). For certain species, concern that fishing mortality on the given stock was approaching a value greater than that which would maximize the long-term yield or yield per recruit was first expressed by the Subcommittee on Assessments in 1963 and 1968 (ICNAF, 1963b and 1968b), prior to severe overfishing (Hennemuth, 1969; Brown and Hennemuth, 1971). As a consequence, at the Annual Meeting in June 1972 the Commission extended quotas to many of the heavily fished species-stocks[4] (ICNAF, 1972c). Large reductions in the current catches were necessary in order to begin to rebuild those stocks which were severely reduced. STACRES also recognized that the rapid expansion of fishing activity precluded timely and complete assessments of the effects of fishing, particularly when a multitude of species-stocks was being harvested.

More importantly, STACRES began considering in the late 1960's the question of whether the goals of

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[2] All references to catches in tons refer to metric tons.

[3] Throughout the text the abbreviation SA is used when referring to Subareas and Statistical Areas, and Div. is used for Divisions.

[4] A species-stock refers to an ICNAF regulatory management unit; *i.e.* some regulations apply to a single population that is a self-contained component of the species considered to have uniform growth and mortality rates, other apply to convenient geographical groups of such stocks, while still others to even a combination of species.

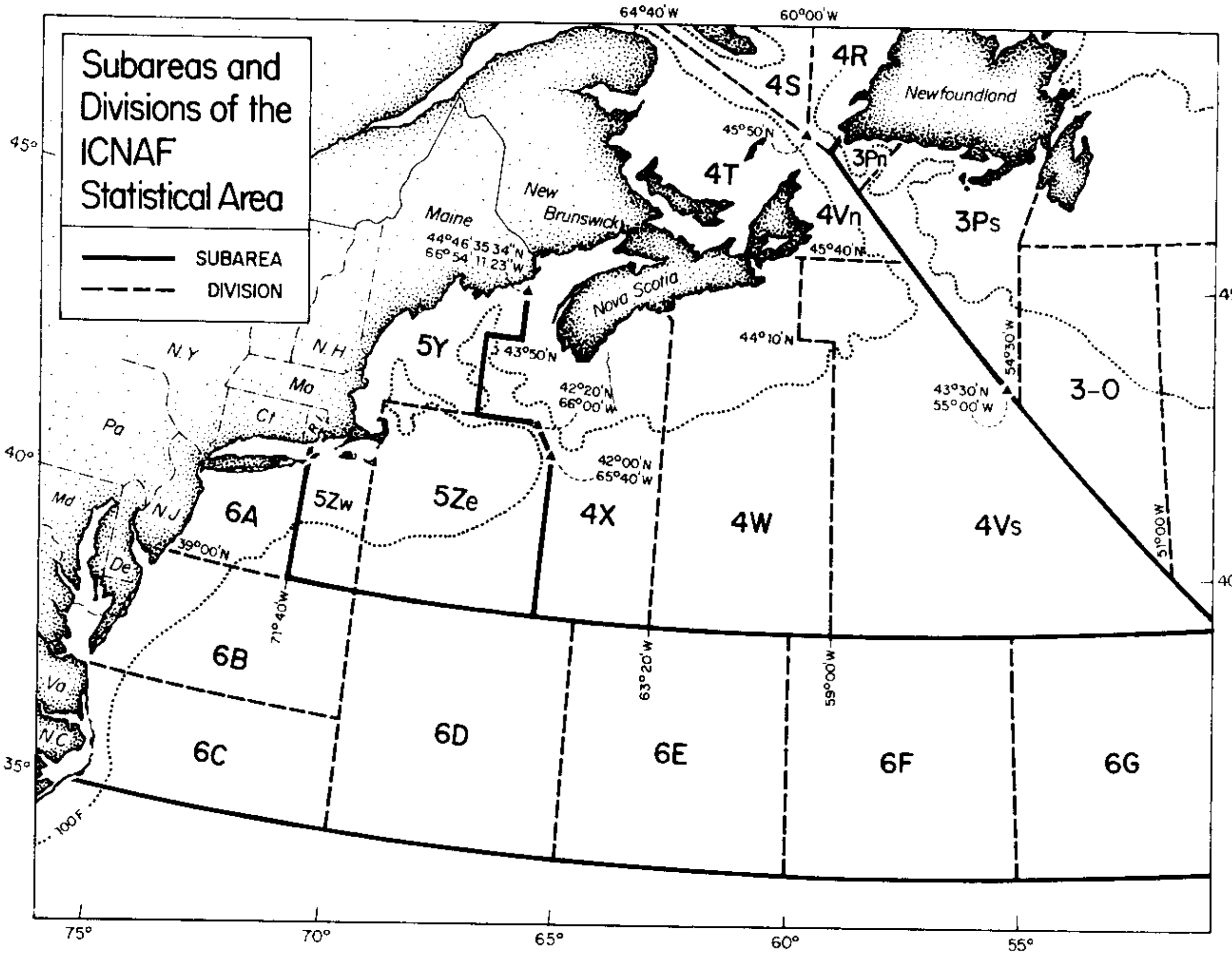

Fig. 1. Northwest Atlantic Ocean classified by ICNAF Divisions.

TABLE 1. Number of vessels (USA, Others) fishing in SA 5 + 6 during 1959, 1965, and 1971 by tonnage class (A = less than 901 GRT[a]; B = 901 GRT[a] and above).

		Number of vessels[b]												
		USA			Others				Total					
Year	Area	A		B	A		B		A		B		Total	
1959	SA 5	301		—	26		—		327		—		327	
1965	SA 5	323		—	244		110		567		110		677	
1971	SA 5	299	461	—	447	490	213	222	746	951	213	222	959	1173
1971[c]	SA 6	162		—	43		9		205		9		214	

[a] GRT — Gross registered tons.

[b] Data from ICNAF List of Fishing Vessels; ICNAF 1961b, 1967c, and 1973d.

[c] This includes only vessels which were listed for SA 6 and not for SA 5. SA 6 listings were not available for 1959 and 1965.

TABLE 2. Subarea 5 nominal catches as reported in ICNAF Statistical Bulletin Vol. 10 and 22 (ICNAF 1962a, Table 1; ICNAF 1974a, Table 3).

Species	1960	1972
Cod	14,430	31,357
Haddock	45,801	6,669
Redfish	11,375	19,095
Yellowtail flounder	13,581	29,620
Winter flounder	6,953	10,505
Witch flounder	1,255	5,454
Scup	3,779	1,229
Pollock	10,397	12,989
Silver hake	46,688	107,113
Red hake	3,410	60,062
White hake	2,483	3,084
Groundfish not stated	19,110[a]	1,239
Herring	69,046	220,964
Mackerel	1,011	200,518
Alewife	8,669	8,656
Atlantic Saury	—	3,429
Angler	8	4,332
Sculpins	—	4,862
Argentine	—	32,707
Sharks[b]	801	13,154
Skates	128	8,735
Other fish not stated	—	21,661
Squid	741	26,111

[a] 15,320 listed as industrial presumed to be mainly red and silver hake based on USA national statistical studies.

[b] Includes dogfishes.

management could be achieved based on individual stock assessments and regulations. The difficulty of achieving these goals stemmed primarily from the lack of resources allocated to collect the necessary data and to make the required assessments within the required time period. In addition, the severe mixed-species nature of the current fisheries in SA 5+6 led to the difficult but necessary consideration of the fishing mortality caused by the by-catch, *i.e.* the catch of species other than that which is the main target of the fishery (Brown *et al.*, 1973). The mixed-species catches resulted primarily from the extensive use of bottom tending otter trawls which are quite unselective.

In SA 5 + 6 numerous species make up significant portions of the fishable biomass (Fig. 2) and, hence, the otter trawl fishery catch. The species mixture is illustrated by the catches in the USA and USSR joint bottom trawl survey in 1971 in the area off Southern New England (Fig. 3, Strata 1-12), where the mean number of species caught per tow was 12 for the USA vessel and 11 for the USSR vessel (Grosslein, 1973). The inevitable incidental catches in species-directed fisheries may be great enough to harvest the total surplus production of some stocks, and this creates conflicts in objectives of conserving stocks which are at low abundance levels or maintaining an existing directed fishery without overfishing, *e.g.* haddock and yellowtail flounder (Brown *et al.*, 1973). The Assessment Subcommittee of ICNAF estimated that, in 1971, 33% of the total fishing mortality in SA 5 + 6 was generated as by-catch of the major species-directed fisheries (ICNAF, 1973b). Finally, the current generation of fishery-yield models does not include terms which describe the effects of species interactions on long-term biological productivity. The interrelationships among species are not well understood, and considerable research is needed on this subject. However, consideration of basic ecological concepts, such as prey-predator and competitive relationships, underscores the need to examine the yield of this total ecosystem as an integrated whole rather than as just the sum of the individual components (Steele, 1974). In this paper, the interspecific effects of the finfish component of the ecosystem are included implicitly in analysis of the total sustainable yield of the finfish biomass to the extent that they have been significant in affecting total yield as measured over the period 1962-72.

The description of the status of the finfish biomass in SA 5+6 is based on analyses of total finfish catch, fishing activity, research vessel surveys, and a preliminary evaluation of the status of the biomass reported in Grosslein, *et al.* (1972). The finfish biomass was defined as all species of finfish plus squids, except menhaden (which are captured close to shore primarily in a single-species fishery in the most southerly part of SA 6) and large pelagic species (swordfish, sharks other than dogfish, and tuna). The large pelagics contribute minimally to the total catch in a quantitative sense and hence would not affect the calculations significantly. This is not to say, however, that the interactions of other fish with this component are not important, but that the results presented are provisional with respect to them. Species assessments based on analysis of commercial catch and effort data are combined to give one estimate of overall maximum sustainable yield (MSY). A Schaefer yield model (Schaefer, 1954) for total finfish and squid, using commercial catch and effort data, is also used to estimate a total MSY. The relationship of current effort to that providing MSY is discussed.

Standardization of Fishing Effort

Those indices of fishing effort, which purport to be directly proportional to instantaneous fishing mortality (F), exerted on fishery resources over a period of time, have traditionally been used to determine the status of fisheries. For this study, because of the diversity of gear employed and the availability of comprehensive statistics reported to ICNAF for the SA 5 + 6 fisheries, the reported effort data of the different country-gear-tonnage classes were standardized in an attempt to have equivalent fishing mortality generated per unit activity. Catch and effort data from 1961 to 1972 were obtained from Table 4 of ICNAF Statistical Bulletin Vol. 11-21 (ICNAF, 1963a-73a) and Table 5 of ICNAF Statistical Bulletin Vol. 22 (ICNAF, 1974a). USA catch data for SA 6, 1961-62, was taken from national statistics.

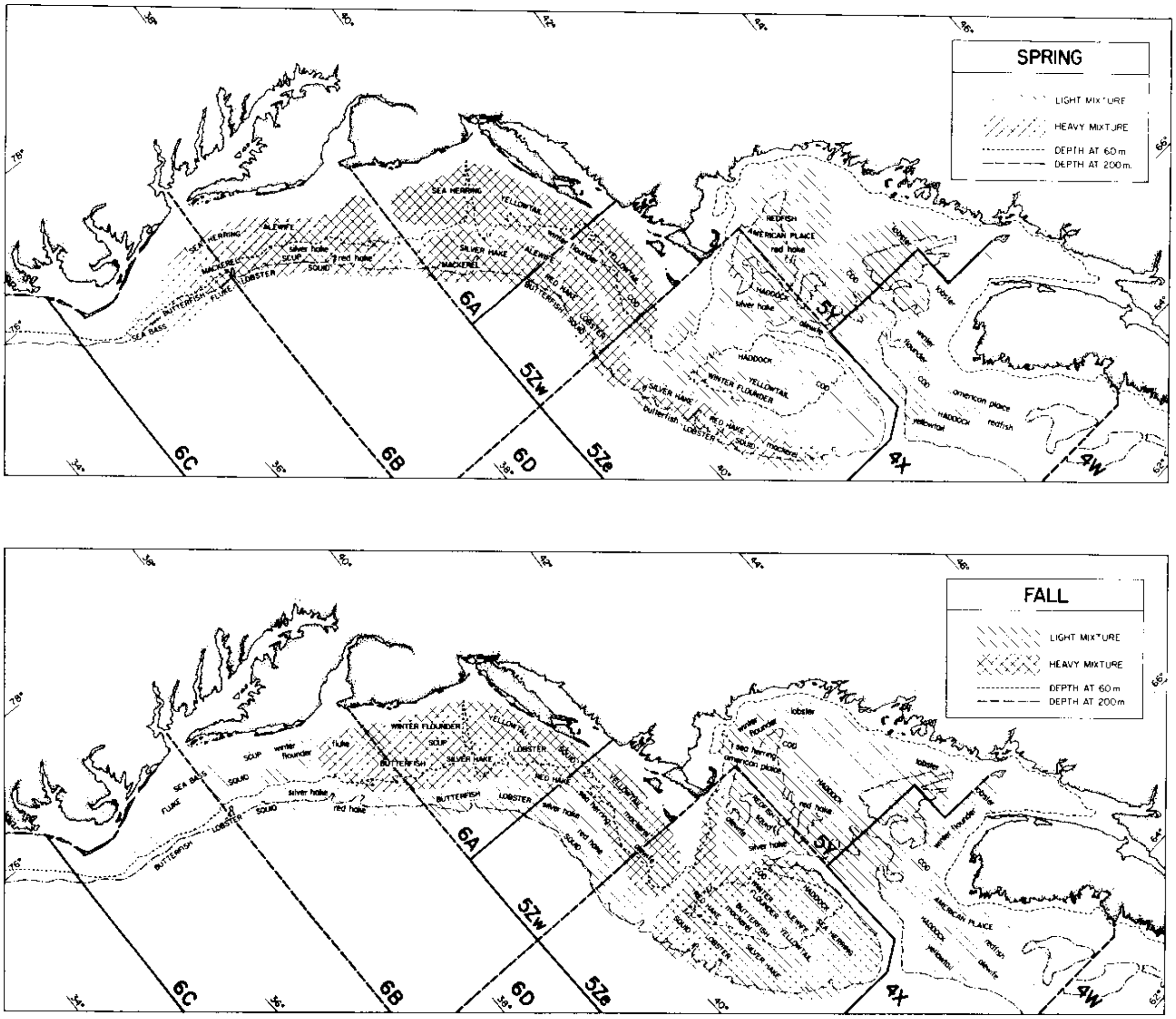

Fig. 2. Generalized pattern of species mixture of SA 5 + 6 (from Grosslein, M. D. and E. Bowman, Mixture of species in SA 5 + 6, *ICNAF Redbook 1973*, Part III, p. 169, fig. 6)

Numbers of days on grounds, days fished, hours fished and numbers of sets (trawl hauls or purse seine hauls) have all been reported with varying degrees of completeness to ICNAF. 'Hours fished' is probably the best of the effort units reported, in that it is likely to be more consistently proportional to F than 'days fished'. However, member countries have reported 'days fished' more often through the years than 'hours fished'. 'Days fished' was considered more closely related to fishing intensity than 'days on grounds' and it also appeared to be a more standard measure of fishing activity over all types of vessels and gears; for example, 'hours fished' definition may have differed greatly for purse seines depending on how searching time was recorded. Hence, 'days fished', as reported to ICNAF, was chosen as the basic unit of fishing effort for analysis.

In order to measure total fishing effort in standard units, catchability coefficients relative to an arbitrarily chosen standard class of vessel and gear were estimated for the various other classes, and used to convert the reported number of days fished for each respective category to the number in the standard equivalent. In all cases, the yearly total of catch and effort data for each class was the basic variable in the analysis.

Robson (1966) proposed a method for determining effort standardization coefficients using an analysis of variance model assuming no interaction. This model was selected for the present study and is defined as follows:

$$Y_{ijk} = m \times a_i \times b_j \times e_{ijk}$$

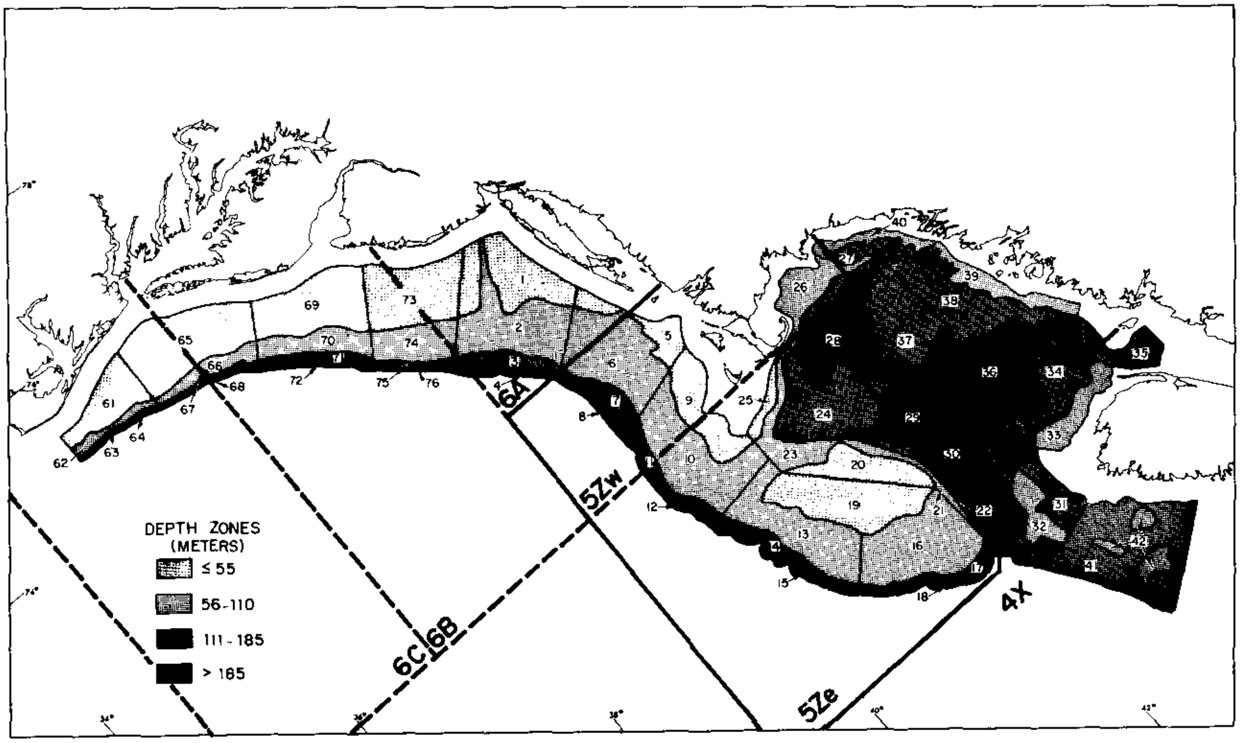

Fig. 3. Northwest Atlantic Ocean categorized by depth zone, sampling strata, and ICNAF Divisions. Southern New England area includes strata 1-12; Georges Bank area includes strata 13-25; Gulf of Maine area includes strata 26-30, 36-40; Mid-Atlantic area includes strata 61-76.

where Y_{ijk} = catch per effort of all fish for the i^{th} country, j^{th} gear-tonnage class, and k^{th} year, *i.e.* Σ catch/Σ days, where the sum is of the appropriate entries of Table 4 or 5 of the ICNAF Statistical Bulletins *(op. cit.)* entries over each month of the year and each area (SA 5 + 6),

m = the mean catch per effort over all categories,

a_i = the i^{th} country effect,

b_j = the j^{th} gear-tonnage class category effect, and

e_{ijk} = the error for testing significance and precision, if the k^{th} observation at the i-j level is such that $ln\ (e_{ijk})$ has a N $(0,\sigma^2)$ distribution.

The error term was measured by the year to year variations. A natural logarithmic transformation of the observations, Y_{ijk}, was performed so that the linear model analysis of variance procedures could be used. The cell coefficients (a_ib_j) were estimated using an analysis of variance procedure outlined by Snedecor and Cochran (1967) for a row × column design with unequal cell frequencies and missing observations. In order to express these coefficients in terms of a standard cell (gear tonnage class-country category), the value a_ib_j for the standard cell was subtracted from that of each of the remaining cells and the resultant sequence of numbers transformed by the exponential function. Since the a_ib_j values are all estimated from the row and column totals, it was immaterial which cell was selected as the standard. For this paper, the USA side trawler 0-50 GRT was used for the standard cell.

Fishing gear for which data were used in the analysis of variance included stern, side and pair trawls, purse seines, drift gillnets, long lines, and hand lines. These gears accounted for approximately 80% of the total catch of the species considered. The remaining 20% of the catch was taken by a variety of gears (mostly inshore) for which no effort data were recorded. The standardized effort associated with this catch for each year was estimated in the last stages of analysis by dividing this catch by the overall annual catch per standardized effort.

Adjustment for learning

It may be logically asserted that the development of new fisheries in areas and on stocks not previously fished involves learning: how to conduct and distribute the fishing fleet over the grounds, particularly in relation to seasonal changes; how to deploy the different kinds of gear in relation to depth or bottom types, current, and weather patterns; and how best to utilize spawning or feeding concentrations (time and space) and migratory patterns. All these factors affected the efficiency of operations (for further discussion see ICNAF Report of Special Meeting of Experts on Effort Limitation (ICNAF, 1973c)) and consequently involved a learning period. The magnitude of this learning was assumed to be reflected in the catch and effort statistics for the various countries but not clearly separated from other causes of variation in catch. There undoubtedly were many other components of success involved with the development of each fishery. In this study, no attempt was made to define the learning factors in terms of explicit causes. Rather, the problem was approached by assuming that learning could be expressed as a monotonically increasing function of catch per effort through a continuous time period, which was not caused by changes in stock abundance. In order to estimate the magnitude of learning, a multiplicative learning function was hypothesized for a given fleet in a fishery. The model for learning was defined as:

$$L_i = \frac{O_i}{P_i} \qquad (1)$$

where L_i = learning gained by a fleet in the i^{th} year in a fishery,

O_i = observed catch per effort by the fleet in the i^{th} year in the fishery,

P_i = predicted catch per effort for the fleet in the i^{th} year in the fishery assuming no learning,

P_1 = O_1

L_1 = *1*

and i = 1, 2, 3 ... The predicted catch per effort, P_i, was defined algebraically to be:

$$P_i = \left[\frac{(Z_i)}{(Z_{i-1})} \right] P_{i-1} \qquad (2)$$

where Z_i is an independent estimate of the abundance of the species in the i^{th} year in the fishery.

By recursion

$$P_i = \prod_{j\,=\,2}^{i} \left[\frac{(Z_j)}{(Z_{j-1})} \right] P_1 \qquad (3)$$

$$= \left[\frac{(Z_i)}{(Z_1)} \right] P_1$$

$$= \left[\frac{(Z_i)}{(Z_1)} \right] O_1$$

and $P_1 = O_1$.

The observed catch per effort in the first year in the fishery, O_1, was taken to be the predicted catch per effort, P_1. The first year of presence in a fishery was taken as that year in which a fleet first caught 20% of its total catch in a particular fishery, *i.e.* 20% of the total catch of a fleet was of the species by which the fishery is identified.

It was assumed that if the catch of a single species exceeded 80% of the total catch by the fleet in an area for a particular year, a "directed fishing" effort had taken place, and all days fished for the fleet during the year were assigned to the species. If the catch of the species was between 20 and 80% of the total catch, the directed effort was estimated as proportional to the species catch in the nominal landings. If less than 20% of the total catch consisted of a specific species, a directed fishery was assumed not to exist in that year.

Since the catch per effort for each species used to study the presence of a learning factor was based on the total catch of that species directed fishery divided by the total effort for that record, it seemed pertinent to examine whether or not any relationship existed between the learning factor and the percent of that species in the catch. Examination of these values (Table 3) showed no consistent relationship; for example, approximately the same learning value between the first and second year existed for herring for Div. 5Z Poland (1.00 and 2.16), SA6 Poland (1.00 and 2.80) and Div. 5Z Romania (1.00 and 2.80) despite differences in the percentage herring made up of the catch which were respectively (90, 86; 98, 66; and 80, 57).

A further assumption made in applying a learning function was that learning ceased when the ratio (L) decreased from year i to year $i + 1$, i.e. when $L_{i+1} < L_i$.

An independent measure of the abundance of a species was provided by the mean catch (pounds per tow) of the annual USA bottom trawl surveys.

Certain "sets" of data were incomplete and could not be used to estimate a learning factor, *e.g.* no fishing effort (in "days fished" units) was recorded by the USSR for 1962, although there was fishing before, during, and after 1962. For certain fisheries, *i.e.* squid and mackerel, there was no time series of commercial catch and effort data available at the time of analysis. Therefore, only complete sets of data could be used (Table 3). A learning function, derived from situations where statistics were available, could then be used to adjust reported units for other fisheries where the data were not available.

In most cases where L_i could be estimated for 4 or 5 successive years, L_i declined in the fourth year in the fishery (Table 3). It was concluded, therefore, that in general the learning process was completed by the end of the third year in the fishery.

An exponential curve was fitted to a fleet's data for the first three years in the fishery (see Fig. 4).

$$L_i = \frac{O_i}{P_i} = [\exp(a(i-1))]\, e_i, \text{ where} \qquad (4)$$

where $P_i = O_1 \times \frac{Z_i}{Z_1}$

O_i = the observed commercial catch per effort in the i^{th} year in the fishery after entrance, where i = 1, 2, 3 . . . .

Z_i = the stock abundance in the same year

e_i = the residual error, where *ln* (e_i) has a N (O, σ^2) distribution, and

a = constant

TABLE 3. Statistics used in development of learning model, by fleet, species, and area.

Data set	Year	Observed total catch per effort	% species in total catch	Research vessel abundance index[a]	Predicted catch per effort	i	L_i
Herring	1966	30.99	90	10.41	30.99	1	1.00
Div: 5Z	1967	20.98	86	3.26	9.70	2	2.16
Poland OTST	1968	28.13	60	1.36	4.05	3	6.94
> 1800 GRT	1969	22.96	42	1.14	3.39	4	6.77
	1970	27.21	45	.66	1.96	5	13.88
	1971	35.63	56	2.07	6.15	6	5.80
Cod	1964	6.00	82	7.62	6.00	1	1.00
Div: 5Z	1965	11.80	86	5.52	4.35	2	2.71
Spain	1966	19.25	88	4.84	3.81	3	5.05
P. trawl	1967	16.22	91	12.46	9.81	4	1.65
	1968	15.96	81	5.74	4.52	5	3.53
	1969	13.92	91	5.24	4.12	6	3.38
	1970	15.48	89	6.70	5.27	7	2.94
	1971	15.22	83	4.53	3.56	8	4.27
S. Hake	1963	6.13	33	9.90	6.13	1	1.00
Div: 5Z	1965	8.90	77	10.76	6.66	2	1.34
USSR OTSI	1966	10.56	53	5.84	3.62	3	2.92
151-500 GRT							
S. Hake	1964	8.65	73	8.16	8.65	1	1.00
Div: 5Z	1965	19.72	36	10.76	11.40	2	1.73
USSR OTSI	1966	16.03	28	5.84	6.19	3	2.59
501-900 GRT	1967	12.17	51	6.37	6.75	4	1.80
Herring	1968	12.20	98	17.40	17.40	1	1.00
SA 6	1969	10.23	66	6.40	4.49	2	2.28
Poland OTST	1970	12.02	65	1.20	.84	3	14.31
501-900 GRT	1971	8.71	54	3.70	2.59	4	3.36
Herring	1967	19.19	80	3.26	19.19	1	1.00
Div: 5Z	1968	22.42	57	1.36	8.01	2	2.80
Romania OTST	1969	12.03	54	1.14	6.71	3	1.79
> 1800 GRT	1970	13.95	25	.66	3.88	4	3.59
	1971	17.41	19	2.07	12.37	5	1.40

[a] *Pounds/tow index as recorded by USA Research Vessel Albatross IV bottom trawl surveys; all autumn surveys except for SA 6 where spring surveys were* used. Method used to calculate indexes is described by Grosslein (1971).

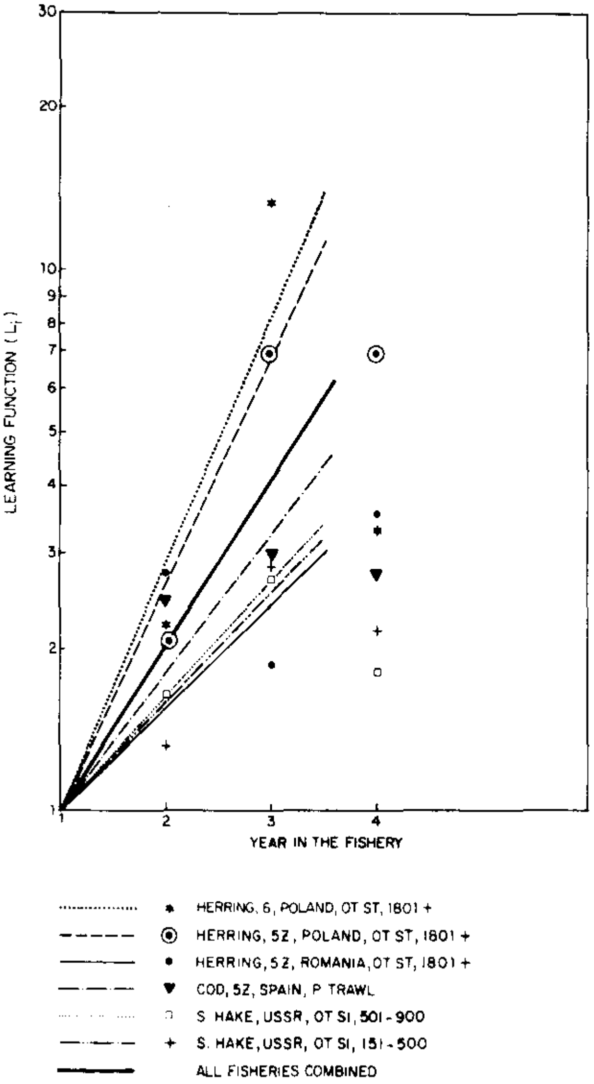

Fig. 4. Relationship of learning function (L_i) to year in the fishery (see text for explanation).

This curve was selected since the ideas underlying the model seemed to coincide with the underlying notion of learning: that the learning gained by time t_i was dependent on the learning gained by time t_{i-1} as well as the time interval t_i-t_{i-1}. Since the values of L_i did not appear to be grouped by country or tonnage class, pooled data were used to fit the curve. A least squares linear fit of ln (L_i) on i yielded the curve

$$L_i = 0.48 [\exp (0.735 i)], \text{ for } i = 1 \ldots 3$$

with a coefficient of determination of 0.82. From this equation, $L_1 = 1.00$, $L_2 = 2.09$, and $L_3 = 4.35$. This is approximately equivalent to halving and quartering the units of effort on that species during this learning period.

The effort data were adjusted so that a unit of effort in the first two years in a fishery was made equivalent to a unit of effort in later years. The adjustment involved was:

$$X_i = \frac{O_i}{L_i} \times L_3, \text{ for } i = 1 \ldots 3 \qquad (5)$$

where X_i = adjusted catch per effort for the i^{th} year in a fishery by a fleet, and O_i, L_i, and L_3 are as defined previously. The values of 1, 2 and 4 were used for L_1, L_2 and L_3 respectively. Adjusting data according to (5) essentially brought all entering fleets to the equivalent of the level of knowledge of the third year in the fishery. The data adjusted by (5) included data used in the development of the model (Table 3), as well as sets of data excluded because they were incomplete or where the abundance indices were not available. Table 4 lists these sets of data.

Application of Fishing Effort Standardization

Analysis of variance results

The assumptions of normality of errors and equality of error variances were investigated in both the original and logged catch per effort data. Both assumptions were more valid with the logged data. Due to the presence of many empty cells, tests for linearity on the logged data were not performed.

Standardization of effort was calculated with and without adjustments for learning. Both vessel class and country effects showed significance at the 0.01 probability level (Tables 5 and 6).

Inspection of the data to determine which levels of the two factors contributed most to the interaction sum of squares revealed that departures from main effect trends could be attributed mainly to USSR drift gillnet data. Considering the relatively minor contribution of this catetory to both total catch (0.08%) and effort (0.3%), the consequence of ignoring the interaction term was considered to be minimal. Relative catchability coefficients were calculated for the USA 0-50 GRT side trawler standard (Tables 7 and 8) which were present in the fishery during the years under consideration.

Estimation of total fishing intensity

Total fishing effort units in standard days fished (standardized effort) directed at finfish were estimated for 1961-72 for each country and gear combination, by multiplying the reported number of days fished by the relative catchability coefficients, with and without learning.

TABLE 4. Country gear-tonnage class categories where effort was adjusted for learning. Parenthesis indicates year in which greater than 20% of the total catch by gear-tonnage class-country was taken in the given species, but for which days fished data was unavailable. (OTSI = otter trawl side; OTST = otter trawl stern; PS = purse seine; PT = pair trawl; DGN = drift gillnet.)

	Area											
	Div. 5Y				Div. 5Z				SA 6			
Species	Country	Gear	GRT	Years adjusted	Country	Gear	GRT	Years adjusted	Country	Gear	GRT	Years adjusted
Herring	FRG	OTSI	901-1800	1969, 70	FRG	OTST	901-1800	1967, 68	Poland	OTSI	501-900	1968, 69
		OTST	1800 +	1969, 70		OTST	1801 +	1967, 68		OTST	1800 +	1968, 69
	USA	PS	51 +	1965, 66	GDR[a]	OTST	1801 +	(1965), 66	USSR	OTSI	151-500	1967, 68
					Poland	OTSI	501-900	1967, 68		OTSI	501-900	1969, 70
						OTST	901-1800	1967, 68				
						OTST	1801 +	1966, 67				
					Romania	OTST	1801 +	1967, 68				
					USSR	OTSI	151-500	(1962), 63				
						OTST	1801 +	1961, (62)				
						PS	51 +	1968, 69				
						DGN	All	1961, (62)				
	GDR[a]	OTST	501-900	1968, 69					GDR[a]	OTSI	501-900	1968, 69
		OTST	1801 +	1968, 69								
Cod	Spain	PT	151-500	1969, 70	Spain	PT	151-500	1964, 65				
Haddock					USSR	OTSI	501-900	1965, 66				
Silver hake					USSR	OTSI	151-900	1963, 65				
						OTSI	501-900	1964, 65				
						OTST	1801 +	(1962), 63				
Mackerel					Poland	OTSI	501-900	1969, 70	Poland	OTSI	501-900	1969, 70
						OTST	1801 +	1968, 69		OTST	1801 +	1970, 71
					Romania	OTST	1801 +	1969, 70	USSR	OTSI	151-500	1968, 69
					USSR	OTSI	151-500	1969, 70		OTSI	501-900	1969, 70
						OTSI	501-900	1969, 70		OTST	1801 +	1970, 71

[a] German Democratic Republic.

TABLE 5. Analysis of variance of ln (catch per effort) data for SA 5 + 6, adjusted for learning.

Source of variation	Sums of squares	Degrees of freedom	Mean square	F
Total	547.38	299	—	—
Country (unadjusted)	174.18	9	—	—
Gear-tonnage class (unadjusted)	477.53	18	—	—
Country (adjusted)	15.58	9	1.73	4.08[a]
Gear-tonnage class (adjusted)	257.96	18	14.33	33.80[a]
Interaction	45.39	26	1.75	—
Error	69.84	246	0.28	—
Interaction plus error	115.23	272	0.424	—

[a] *Significant at 0.01 level.*

TABLE 6. Analysis of variance of ln (catch per effort) data for SA 5 + 6 not adjusted for learning.

Source of variation	Sums of squares	Degrees of freedom	Mean square	F
Total	473.42	299	—	—
Country (unadjusted)	124.08	9	—	—
Gear-tonnage class (unadjusted)	421.65	18	—	—
Country (adjusted)	11.55	9	1.28	3.90[a]
Gear-tonnage class (adjusted)	260.21	18	14.46	44.09[a]
Interaction	37.35	26	1.44	—
Error	51.78	246	0.21	—
Interaction plus error	89.13	272	0.328	—

[a] *Significant at 0.01 level.*

TABLE 7. Estimates of fishing power factors for given country and gear-tonnage class combinations for SA 5 + 6 data without adjustments for learning, 1961-72. (OTSI = otter trawl side; OTST = otter trawl stern; PS = purse seine; PT = pair trawl; LT = line trawls; HL = hand lines; DGN = drift gillnet.)

Gear	Tonnage class (GRT)	USA	Canada	USSR	Spain	Poland	FRG	GDR	Romania	Japan	Bulgaria
OTSI	0-50	1.00	0.67	—	—	—	—	—	—	—	—
	51-150	1.30	0.87	—	—	—	—	—	—	—	—
	151-500	1.77	1.19	1.44	—	—	1.72	—	—	—	—
	501-900	—	1.63	1.98	—	1.64	2.35	1.32	—	—	—
	901-1800	—	—	3.16	—	2.62	3.76	2.11	—	—	—
OTST	0-50	3.33	2.24	—	—	—	—	—	—	—	—
	51-150	0.94	.63	—	—	—	—	—	—	—	—
	151-500	1.75	1.18	—	—	—	—	—	—	—	—
	501-900	2.67	1.79	2.18	—	—	2.59	1.45	—	—	—
	901-1800	—	—	5.54	4.38	4.59	6.59	3.70	—	—	—
	> 1801+	—	—	7.65	—	6.34	9.09	5.10	3.53	3.19	6.47
PS	> 50	7.35	4.93	5.99	—	—	—	—	—	—	—
	< 50	0.95	—	—	—	—	—	—	—	—	—
PT	All	4.36	—	3.56	2.81	—	—	—	—	—	—
LT	All	0.46	0.31	—	—	—	—	—	—	—	—
HL	All	0.14	—	—	—	—	—	—	—	—	—
DGN	All	0.11	—	0.09	—	—	—	—	—	—	—
OTSI (pelagic)	501-900	—	—	—	—	—	—	0.82	—	—	—
	901-1800	—	—	—	—	—	—	0.29	—	—	—

TABLE 8. Estimates of fishing power factors for given country and gear-tonnage class combinations for SA 5 + 6 data with adjustments for learning, 1961-72. (OTSI = otter trawl side; OTST = otter trawl stern; PS = purse seine; PT = pair trawl; LT = line trawls; HL = handlines; DGN = drift gillnet.)

Gear	Tonnage class (GRT)	USA	Canada	USSR	Spain	Poland	FRG	GDR	Romania	Japan	Bulgaria
OTSI	0-50	1.00	0.69	—	—	—	—	—	—	—	—
	51-150	1.29	0.89	—	—	—	—	—	—	—	—
	151-500	1.73	1.20	1.77	—	—	2.69	—	—	—	—
	501-900	—	1.58	2.34	—	2.28	3.55	1.40	—	—	—
	901-1800	—	—	3.73	—	3.63	5.65	2.23	—	—	—
OTST	0-50	3.34	2.31	—	—	—	—	—	—	—	—
	51-150	0.94	0.65	—	—	—	—	—	—	—	—
	151-500	1.74	1.21	—	—	—	—	—	—	—	—
	501-900	2.41	1.66	2.47	—	—	3.74	1.47	—	—	—
	901-1800	—	—	6.56	5.63	6.38	9.94	3.92	—	—	—
	> 1801+	—	—	9.09	—	8.84	13.77	5.43	5.04	3.22	6.54
PS	> 50 GRT	7.96	5.51	8.17	—	—	—	—	—	—	—
	< 50 GRT	0.96	—	—	—	—	—	—	—	—	—
PT	All	3.94	—	4.04	3.47	—	—	—	—	—	—
LT	All	0.46	0.32	—	—	—	—	—	—	—	—
HL	All	0.14	—	—	—	—	—	—	—	—	—
DGN	All	0.12	—	0.13	—	—	—	—	—	—	—
OTSI (pelagic)	601-900	—	—	—	—	—	—	0.83	—	—	—
	901-1800	—	—	—	—	—	—	0.30	—	—	—

Finfish catch per standardized effort was then estimated for each year by dividing the total annual catch of the categories associated with this effort by the standardized effort. Finally, the total annual finfish catch over all categories, including those catches from gear-country combinations which were excluded from the analysis of variance (Table 9), was divided by the yearly catch per standardized effort to obtain the total standardized effort in each year for SA 5 + 6.

Standardized effort for SA 6 prior to 1968 for countries other than the USA was estimated by dividing the catch in SA 6 by the corresponding SA 5 catch per standardized effort for that year. This policy was justified by the fact that these countries fished primarily on stocks which migrate between SA 6 and SA 5. Comparison of SA 5 + 6 catch per effort by country and vessel categories for 1968-72 supports this contention (Table 10). The effort for the USA fishery in SA 6 for 1961-67 was estimated by

TABLE 9. Subarea 5 + 6 catch data (tons) for which days fished was not reported.

	Year											
Country	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Canada	27	137	93	—	1,091	2,997	9,564	36,341	10,309	7,496	30,999	14,718
France	—	—	—	—	—	—	—	—	—	—	—	296
Iceland	—	—	—	—	—	—	—	292	12,786	—	—	—
Italy	—	—	—	—	—	—	—	—	—	—	—	4,000
Japan	—	—	—	—	—	—	331	7,212	16,251	28,795	27,673	—
Norway	—	—	—	—	—	—	—	—	1,224	—	—	—
Romania	—	—	—	—	1,982	3,433	—	—	—	—	—	—
Spain	—	—	—	—	—	—	—	—	—	—	4,197	7,546
USSR	—	201,224	7,960	22,393	34,464	—	—	—	—	—	—	75,704
USA	70,819	43,163	166,789	152,855	155,585	127,899	115,084	106,563	96,180	77,733	74,594	69,062
Others	—	—	2	10,213	5,722	—	202	263	6,516	8,998	108,180	2,381
Total (1)	70,819	244,524	174,844	185,461	198,844	134,329	125,181	150,671	143,266	123,022	245,643	173,707
Total catch[a] (2)	344,286	472,263	650,825	786,346	954,808	988,568	759,881	942,762	1,029,392	840,267	1,124,872	1,144,597
Percent[b] (1) (2)	21	52	27	24	21	14	16	16	14	15	22	15

[a] Total catch = catch of finfish (excluding sharks, billfishes, tunas, swordfish, menhaden), and squid.

[b] All years combined = 20%.

TABLE 10. Catch per effort (days fished) in tons for SA 5 + 6.

				Catch per effort	
Year	Country	Vessel class	GRT	SA 5	SA 6
1971	Poland	OTSI	501-900	7.3	8.5
	Poland	OTST	901-1800	32.6	35.4
	Poland	OTST	1801 +	35.6	42.3
	Romania	OTST	1801 +	17.0	25.4
	USSR	OTSI	151-500	6.2	5.8
	USSR	OTSI	501-900	8.2	8.5
	USSR	OTST	1801 +	33.6	38.1
1970	Poland	OTSI	501-900	7.9	12.0
	Poland	OTST	1801 +	27.2	40.9
	USSR	OTSI	151-500	5.9	7.2
	USSR	OTSI	501-900	8.7	9.2
	USSR	OTST	1801 +	34.2	47.6
1969	Poland	OTSI	501-900	7.9	10.2
	Poland	OTST	1801 +	23.0	26.2
	USSR	OTSI	151-500	5.6	6.9
	USSR	OTSI	501-900	27.5	9.1
	USSR	OTST	1801 +	41.3	31.5
1968	Poland	OTSI	501-900	11.4	12.5
	Poland	OTST	1801 +	25.6	21.6
	USSR	OTSI	151-500	6.8	8.1
	USSR	OTST	1801 +	42.9	50.1

TABLE 11. SA 5 + 6 total finfish plus squid catches, unadjusted effort, standardized effort with (without) learning, catch per effort and catch per standardized effort with (without learning) for the years 1961-72.

Year	Unadjusted effort	Total standardized effort	Standard effort with learning adjustment	Total catch	Catch per effort	Catch per standard effort	Catch per standard effort (learning)
1961	42,348	61,590	53,879	344,286	8.13	5.59	6.39
1962	60,780	110,342	108,816	472,263	7.77	4.28	4.34
1963	66,683	123,262	108,834	650,825	9.76	5.28	5.98
1964	71,812	150,353	165,896	786,346	10.95	5.23	4.74
1965	70,884	161,558	169,895	954,808	13.47	5.91	5.62
1966	68,698	175,278	191,583	988,568	14.39	5.64	5.16
1967	68,892	137,411	143,104	759,881	11.03	5.53	5.31
1968	84,100	171,723	180,260	942,762	11.21	5.49	5.23
1969	86,576	210,941	221,137	1,029,391	11.89	4.88	4.65
1970	75,905	171,834	182,667	840,267	11.07	4.89	4.60
1971	81,749	230,035	267,190	1,124,872	13.76	4.89	4.21
1972	91,203	263,126	315,316	1,144,597	12.55	4.35	3.63

dividing the yearly catches by the 1968-70 average USA catch per standardized effort for SA 6. The stocks fished primarily by the USA in this area, *e.g.* fluke, scup, black sea bass, etc., were different from those in the major fisheries in Div. 5Z. If these stocks had been decreasing over this period, an overestimate of effort would result. However, this bias would have a minor effect on overall results, because the USA yearly catches in SA 6 were always small (between 75,000 and 124,000 tons) relative to the total. Fishing by the distant water fleets in SA 6 with accompanying by-catch of species sought by the USA was minimal in the period 1963-65 (nominal catches less than 50,000 tons). The combined results of the above computations are presented in Table 11 and Fig. 5.

Relationships Between Fishing Intensity and Yield

The relationships between fishing intensity and yield were examined in three ways: (1) relative changes in finfish biomass measured by research vessel surveys were related to relative changes in total fishing intensity estimated in this paper, (2) data from individual species assessments (based on commercial catch and effort data and research vessel survey data) were combined to estimate the total potential yield, and (3) annual total catch and total standardized effort as estimated herein were used in an equilibrium yield to describe the equilibrium relationship between catch and standardized effort.

Changes in biomass as estimated from research vessel surveys

Estimates of relative changes in biomass of groundfish and flounder species for Gulf of Maine (Strata 26-30, 36-40), Georges Bank (Strata 13-25), and Southern New England (Strata 1-12) areas (Fig. 3) of SA 5 + 6 were calculated by comparing mean catch per tow in pounds (1 pound = 0.454 kg) for USA autumn bottom trawl surveys in 1963-1965 with the mean for 1970-72 (see Clark and Brown MS 1975, and Grosslein MS 1971, for detailed statistics). With few exceptions, there were substantial declines in abundance (Table 12).

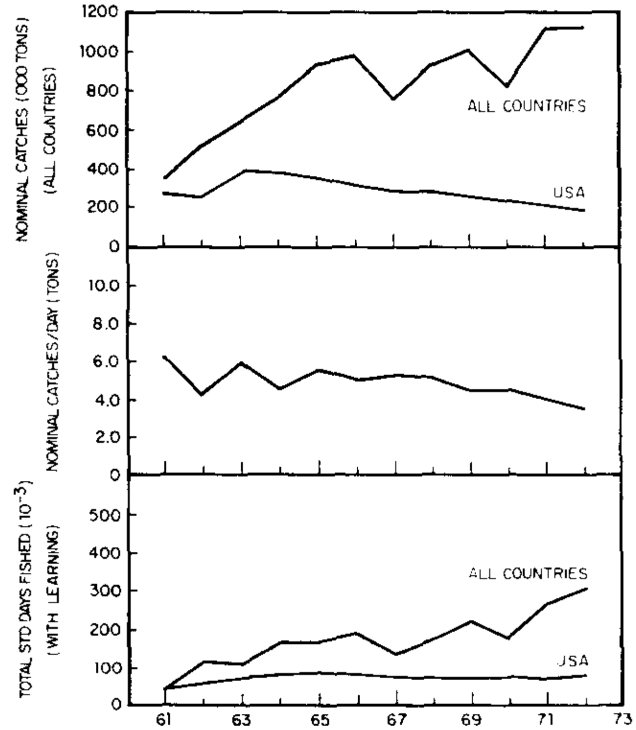

Fig. 5. Total commercial landings of finfish (excluding swordfish, tunas, billfishes, menhaden) plus squid, landings per day, and total standardized days fished (with learning) for SA 5 + 6 plotted against time.

An estimate of the relative change in biomass for all of SA 5 + 6 was made by pooling the survey results for all areas. This set of sampling strata covered almost all of SA 5 and Div. 6A. However, since the bulk of the major stocks

TABLE 12. Mean catch per haul (pounds) on USA *Albatross IV* autumn surveys for 1963-65 and 1970-72, and percent change from 1963-65 to 1970-72.[a]

	Southern New England[b]			Georges Bank[b]			Gulf of Maine[b]		
Species	1963-65	1970-72	% Change	1963-65	1970-72	% Change	1963-65	1970-72	% Change
Haddock	8.1	0.4	-95	134.1	14.2	-89	48.6	9.3	-81
Cod	3.8	2.1	-45	18.6	20.6	+11	23.9	20.9	-13
Redfish	—	—	—	4.4	7.6	+73	73.4	61.8	-16
Silver hake	13.6	8.2	-40	6.4	4.4	-31	30.7	8.6	-72
Red hake	13.3	10.2	-23	8.4	2.9	-65	4.9	2.3	-53
White hake	1.7	0.9	-47	1.9	4.9	+158	15.3	35.6	+133
Pollock	0.03	—	—	4.5	2.7	-40	14.7	12.8	-13
Yellowtail flounder	23.9	35.4	+48	16.3	7.9	-52	0.8	0.4	-50
Winter flounder	6.3	4.7	-25	4.3	5.3	+23	0.9	0.5	-44
All other flounders	8.3	4.5	-46	9.6	6.4	-33	17.9	12.1	-32
Sculpin	2.2	2.6	+18	6.2	4.4	-29	0.3	0.3	—
Ocean pout	1.0	0.3	-70	2.6	0.4	-85	—	0.2	—
Angler	12.0	10.3	-14	8.1	2.2	-73	5.2	6.3	+21
Other groundfish	3.5	2.1	-40	1.2	0.8	-33	4.1	5.7	+39
Skates	26.2	13.7	-48	50.0	29.4	-48	26.2	26.5	+1
Dogfish	263.5	83.4	-68	6.8	12.1	-78	59.3	34.9	-41
Squid	3.3	12.3	+273	1.5	3.1	+107	0.3	.7	+133

[a] Squid records were not adequately kept in the early years of the survey. Essentially none recorded in 1963, therefore the average for 1964-65 was used as a minimum estimate.

[b] See Fig. 3 for area description.

TABLE 13. Comparison of mean catch per two (pounds) on *Albatross IV* autumn surveys in Div. 5Z and Div. 6A for the two periods 1963-65 and 1970-72, the percentage change relative to the earlier period, and cumulative landings from 1962-72, for groundfish, skates, and herring.

	Mean catch per tow			
Species	1963-65[a]	1970-72[a]	% change	Cumulative landings for 1963'72 (000's tons)
Haddock	63.0	8.1	- 87	569
Cod	15.9	14.9	- 6	400
Redfish	28.9	25.3	- 12	121
Silver Hake	17.6	7.1	- 60	1,597
Red Hake	8.6	5.0	- 43	508
White Hake	6.8	14.8	+118	20
Pollock	7.0	5.6	- 20	98
Yellowtail Flounder	12.9	13.7	+ 6	387
Winter Flounder	3.7	3.3	- 11	135
Other Flounder'	12.3	7.9	- 36	123
Sculpin	2.8	2.3	18	47
Ocean Pout	1.1	0.3	- 73	82
Angler	8.2	6.2	- 24	17
All other groundfish	3.0	3.0	—	242[b]
Skates	33.7	23.4	- 31	49
Dogfish	106.7	42.8	- 60	62
Total groundfish, dogfish, skates, and flounders	332.2	183.7	- 45	4,457
Squid	1.6	5.1	+215	111
Herring	—		"-93"	2,478
Mackerel	—		"-37"	1,160
	Weighted mean[c] percentage change		- 55	8,206

[a] Calculated by pooling the means shown in Table 12 for Gulf of Maine, Georges Bank, and Southern New England into a single stratified mean representing Div. 5Y, 5Z, and 6A.

[b] For the "all other groundfish" category, the component of "groundfish NS" in each ICNAF Statistical Bulletin was averaged for the years 1967-72 and prorated for the period. That average of 8,300 tons contrasts with the average of 63,000 tons for 1963-67 before more detailed species breakdowns were available.

[c] Weights equivalent to cumulative landings in 1963-72.

are found east of Hudson Canyon (which is close to the boundary line between Div. 6A and Div. 6B (Fig. 1)) in the autumn, the data were considered adequate to represent changes in the whole of SA 6. The pooled mean catch per tow of all but four of the species or species groups declined from 6 to 90% (Table 13). The four exceptions are the catches of white hake (118% increase), yellowtail flounder (6% increase), other groundfish (no change), and squids (215% increase). The small increase in catch per tow of yellowtail is due to a large catch in the 1972 survey. This may be anomalous since it was not consistent with commercial yellowtail catches nor with previous and subsequent survey abundance indices of the year-classes involved (Parrack, MS 1974). Silver hake and dogfish declined 60%; red hake, skates, and miscellaneous flounders all declined between 30% and 40%; cod and winter flounder dropped about 10%; ocean pout showed a decline of 73%, and anglers and miscellaneous groundfish declined approximately by one third. The overall decline of all of these species pooled was 45%. The squid abundance indices show no evidence of a trend during this period; this is not surprising since directed fisheries for squid did not begin until 1970.

An estimate of the decline for herring was made using herring abundance indices from USA spring surveys which first began in 1968 (Fig. 6). The spring surveys begin in March when herring are concentrated south of Cape Cod. The abundance indices[5] shown in Fig. 6 represent sampling strata 1-12 and 61-76 combined (Nantucket to Cape Hatteras). The slope (estimated by least squares linear regression) of the line was −1.95 (ln scale) which gave a decline of about 93% in the period 1963-1972. This estimate corresponded closely to that based on other data (ICNAF, 1972b).

An estimate of the decline of mackerel was based on the USA spring surveys of 1967-74 as analyzed by Anderson (MS 1974a). A least squares linear regression through stratified means of ln (pounds + 1) (Fig. 7) eliminating the outlier value for 1969, gave a slope of −0.078 indicating a decline of 37% since 1967. There was no observed decline in the mackerel population until after 1967 (Anderson, MS 1974a).

The decline in total biomass of finfish in SA 5 and Div. 6A was calculated by weighting the percentage decline of groundfish, herring, squid, and mackerel (Table 13) in proportion to the total landings of those species groups in the 10-year period 1963-72. The resulting weighted change indicated about a 55% drop in total biomass of these species during the last decade (Table 13). The nominal catches were considered the best available proportional measure of the contribution of such species in the biomass. The estimate of the overall decline thus derived could be less than the true decline because nominal catches of some miscellaneous groundfish

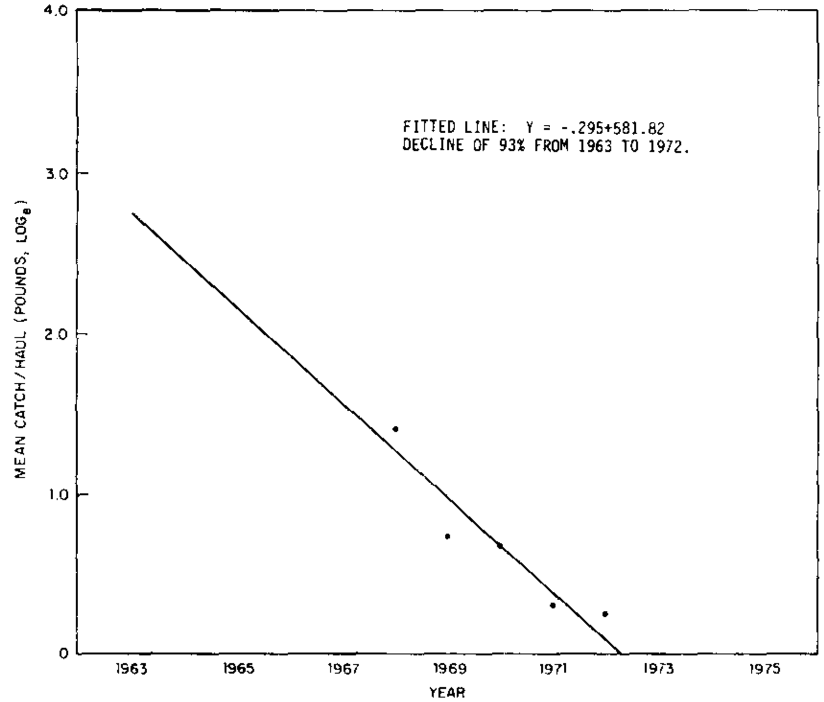

Fig. 6. Plot of herring abundance indices from USA *Albatross IV* spring bottom trawl surveys in strata 1-12 and 61-76 (Nantucket to Cape Hatteras).

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[5] Abundance indices for herring were calculated using a mean of the natural logarithm (number of fish + 1).

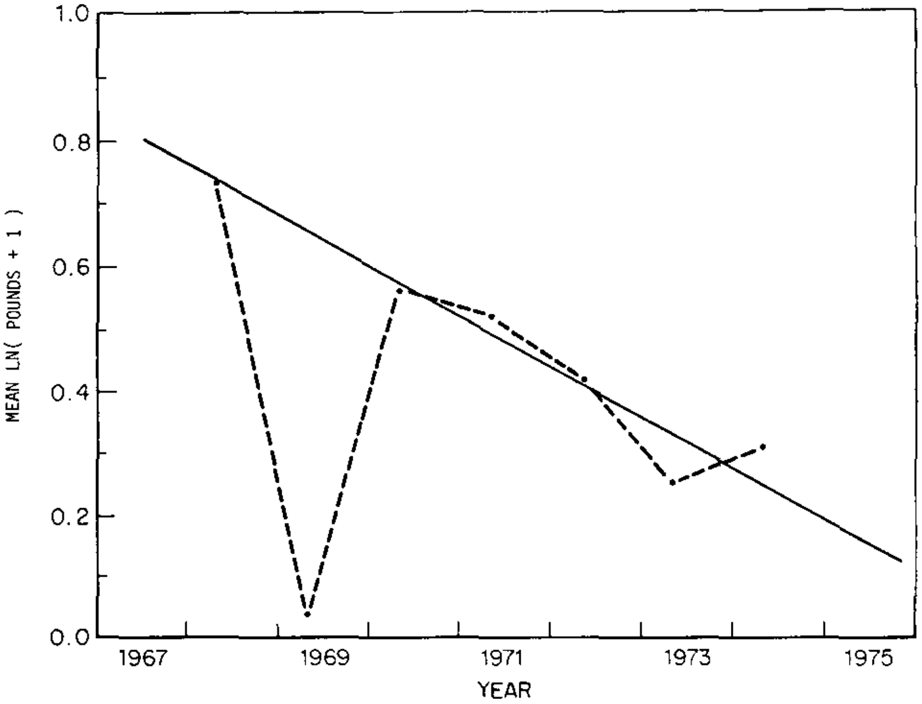

Fig. 7. Least squares regression fit (mackerel, SA 5 + 6) of mean 1n (pounds + 1) from USA bottom trawl spring surveys through time. Data for 1969 was excluded from the calculations (Anderson, 1974a).

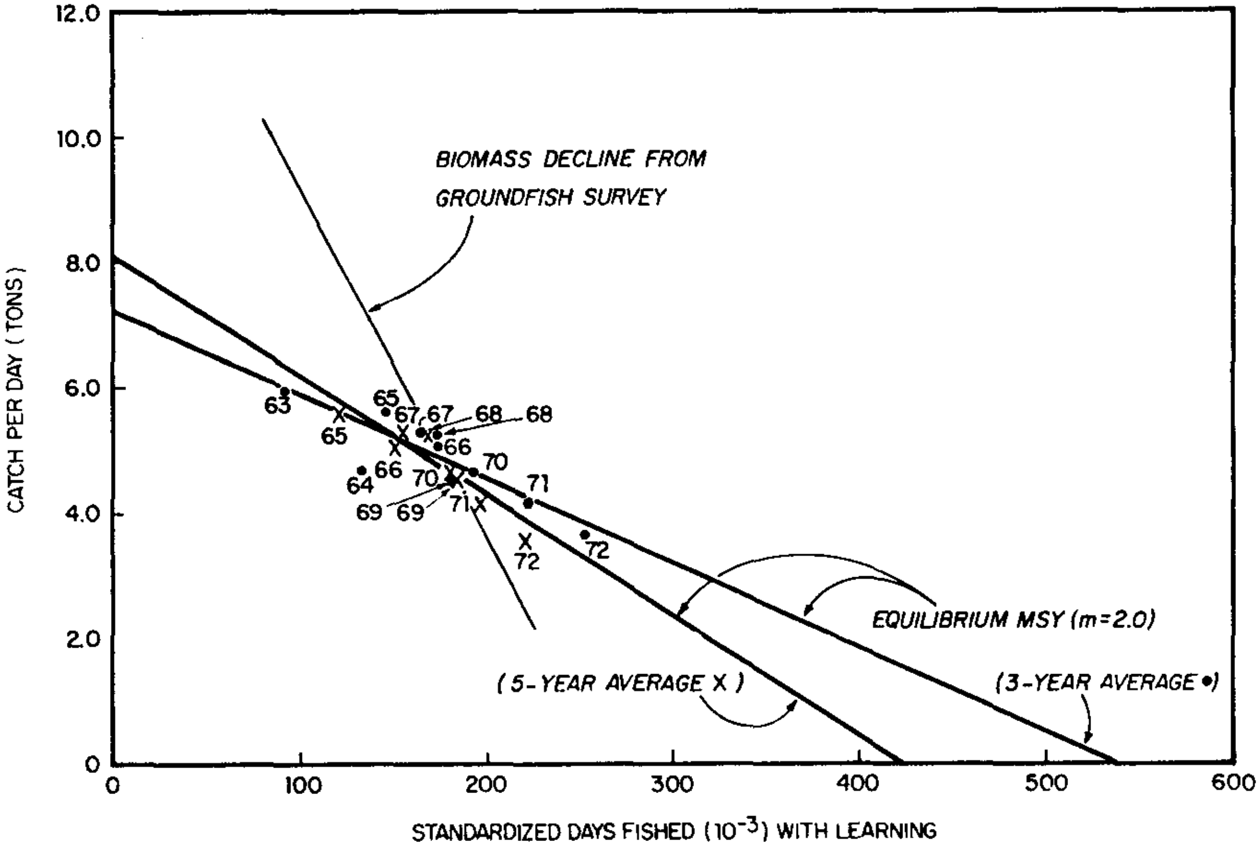

Fig. 8. Catch per standardized effort plotted against standardized days fished (with learning) for data from SA 5 + 6, 1961-72 (linear regression estimated using all years). Also, estimate of biomass decline of groundfish, skates, and herring from bottom trawl surveys (see Table 13).

species (particularly ocean pout, angler and skates) were not adequately reported in earlier years, either being included in categories such as other groundfish or other fish in Table 1 of the Statistical Bulletin Vol. 13 and 22 (ICNAF, 1965a and 1974a), or being unreported entirely (perhaps as discard), and these species showed major declines. The percentage declines were measured from an initial point of time (1963-1965) prior to which many of the stocks concerned had already been harvested in moderate to severe (say 25 to 100% of MSY) degrees. Thus, the overall decline from unfished abundance levels was greater than the 1963-72 decline.

It has been postulated, based on the Schaefer yield model, that MSY is obtained at a stock size about one-half the virgin stock size. The estimated decline of 55% since 1963, from research vessel surveys (Table 13), thus implied a significant degree of overfishing (Fig. 8). The average standardized effort estimates for 1963-65 and 1970-72 were used to position end points of the line with respect to the abscissa, and the line was fitted through the mean of commercial catch per standardized effort and standardized effort for the decade, to position it with respect to the ordinate. This implied a 65% decline in catch per effort between 1963 and 1972 concurrent with the increase in fishing intensity during the period.

An even greater rate of decline in biomass since 1967 was indicated by USSR autumn research surveys in the Southern New England area and by both USA and USSR autumn surveys since 1967 for the Mid-Atlantic area to the south (strata 61-76) (ICNAF 1973c) and provided further evidence of overfishing. USSR and USA autumn survey indices for all finifsh for SA 6 declined about 80% and 70% respectively in this later period of years.

Individual stock assessments and total yield

Results from individual species assessment studies and review of historic catches were used to estimate a composite MSY for the combined finfish stocks in SA 5 + 6 (Table 14). The ICNAF Assessments Subcommittee Reports for 1962-74 (ICNAF, 1962b-74b) provided the general source for the estimates, other than yellowtail catches in the last ten years (1963-72). The first silver hake assessment was presented by Anderson for 1972[6] followed in 1974 by further reports (Anderson, MS 1974b and Rikhter, MS 1974a and b). The MSY for silver hake was taken to be equal to the recommended total allowable catches (TAC's) for the Div. 5Z and SA 6 stocks in 1973 and 1974 (ICNAF, 1973b, 1974b) plus the estimate of MSY for the Gulf of Maine (Div. 5Y) stock given in the 1972 Assessment Report (ICNAF, 1972b). The MSY for red hake was taken as the TAC recommended for 1973 (ICNAF, 1973b). For pollock, cod (see also Brown and Heyerdahl, MS 1972) and redfish, estimates of MSY corresponded to the recommended TAC values for 1973 (ICNAF, 1973b). Estimates of MSY for haddock and yellowtail flounder were taken from the 1973 ICNAF Redbook (ICNAF, 1973b). The ICNAF Assessments Subcommittee provided a preliminary assessment of squid *(Loligo)* in 1972 and estimated an MSY of 50,000-80,000 tons. In order to include the yield of *Illex* squid, a value of 80,000 tons for the two genera combined was assumed (ICNAF 1973b). Individual assessments for herring in Div. 5Z and SA 6 (Schumacher and Anthony, MS 1972) and mackerel in Div. 5Z + SA 6 (Anderson, MS 1973) indicated MSYs of 285,000 and 310,000 tons respectively. The herring stock in Div. 5Y was estimated to have an MSY value of 50,000 tons (ICNAF, 1973b). (See also Anthony and Brown, MS 1972). Combining all MSY estimates for the entire species complement gave a total of 1,352,000 tons as a projected MSY value for the total finfish biomass.

TABLE 14. Individual stock assessments for finfish stocks in SA 5 + 6.

Species	Estimate of MSY (000's tons)
Herring	335
Mackerel	310
Silver Hake	200
Squid	80
Red Hake	70
Haddock	50
Cod	45
Yellowtail Flounder	37
Redfish	30
Pollock	20[a]
Other Flounder	25
Other Finfish	150
Sum of species assessments	1,352

[a] MSY estimated to be 50,000 tons including Div. 4VWX (ICNAF, 1972b), 20,000 tons based on catch ratios assigned to SA5.

The MSY estimates probably are too high for many of the species in SA 5 + 6 which have been subjected to heavy fishing mortality only recently. A high proportion of the available data represented an expanding fishery which was harvesting accumulated biomass rather than only yearly productivity. In addition, these single species assessment models have not explicitly accounted for species interactions. (See Pope and Harris, MS 1975 for discussion of implications of competition between species on yield, based on data of Stander and Le Roux (1968)).

These principles were perhaps of greatest significance in terms of the total biomass of herring and mackerel, for which the assessed MSY values were estimated during a time period when there were two

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[6] Anderson, E. A. 1972. Mimeograph Report on file at National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Massachusetts, USA 02543.

extremely good year-classes in the fisheries, and when a rapid monotonic increase in fishing effort occurred. Lett, *et al.* (MS 1975) have presented a model for the Gulf of St. Lawrence mackerel stock (at least some of the mackerel in SA 5 + 6 are spawned in the Gulf of St. Lawrence (Moores *et al.*, 1975) indicating that mackerel year-class strength may be density dependent on the combined abundance of herring and mackerel. Food studies indicate a possible high degree of competition between herring and mackerel (Maurer, MS 1975). Furthermore, herring and mackerel, at least in recent history, have not maintained a high biomass concurrently, but rather have fluctuated inversely, with the mackerel showing an increase in abundance while the herring have declined. The strong herring year-classes were 1960 and 1961, while those for mackerel were 1967 and 1968. Consequently, a more accurate description of the potential yield for the two species might be estimated by looking at their average combined catches. Table 15 presents the quantities of herring and mackerel landed by all countries over the period of the analysis. The average annual nominal catch for the two species combined (1961-72) is 336,000 tons. Substituting this combined figure for the individual assessment estimates resulted in reducing the projected MSY value for the total biomass to 1,043,000 tons.

TABLE 15. Total annual nominal catches (000's tons) from SA 5 + 6 for herring and mackerel, 1961-72.

Year	Herring	Mackerel	Total
1961	94	1	95
1962	224	1	225
1963	167	2	169
1964	159	2	161
1965	74	5	79
1966	172	9	181
1967	257	23	280
1968	436	60	496
1969	361	113	474
1970	303	210	513
1971	314	349	663
1972	237	387	624
Average	233	96	330

Surplus yield modeling

An estimate of MSY was calculated for the above selected finfish community as a whole in SA 5 and 6, using the generalized stock production model approach discussed by Schaefer (1954).

Fitted curves derived from this type of analysis were considered to represent the equilibrium, or long-term average, expected yields. However, as has been discussed earlier in this paper, a rather consistent and rapid increase in effort occurred in SA 5 + 6, particularly during the first part of the 1960's. When such large and consistent increases or decreases in fishing effort exist, the fitted curves will tend not to describe the true situation unless the population can react instantaneously in adjusting its productivity to the new density structure. If the population cannot do this, the effects of fishing effort in any given year will be dependent upon the cumulative effect of previous years' effort. Gulland (1961) suggested that, in order to account for this effect, an average of effort over previous years should be taken as the effort applicable to the final year, where the averaging occurs over the mean number of years that a year-class contributes significantly to the catch. The number of years to be averaged is, therefore, a function of the total mortality rate, age at maturity, and changes in growth rate.

For the SA 5 + 6 fish stocks in an equilibrium state which provided maximum yields, an average year-class contributes significantly to the catch over about a 3-year period. However, for the period covered in this study, some significant events should be considered. For herring, two very good year-classes were spawned in 1960 and 1961, and these fish carried a major share of the fishery for 5-6 years (Schumacher and Anthony, MS 1972; Anthony and Brown, MS 1972). Haddock have existed virtually without any significant recruitment since the 1962 and 1963 year-classes, and thus these year-classes contributed significantly over 7-8 years (Hennemuth, MS 1969; ICNAF, 1972b-74b). The mackerel fishery has been harvesting principally the same two year-classes, 1966 and 1967, since the fishery increased in 1968 through 1972 (ICNAF, 1974b). Silver hake, with a more stable distribution, showed a 3-4 year pattern of contribution (Anderson, MS 1972), as did yellowtail flounder (Brown and Hennemuth, MS 1971). Response to changes in biomass through fishing are reflected by recruitment and thus the age at maturity is important. Most of the major species mature between 3 and 4 years of age and contribute to the spawning stock for several years. Growth rate and age at maturity can also change in response to changes in stock abundance. No changes have been reported in these parameters that would alter the use of 3- to 5-year averaging periods. Consequently, running averages of total effort were made over 3-, 4-, and 5-year lag or delay-time periods to cover the possible range of this effect.

Solutions of the Schaefer model were obtained by computing least squares linear regressions of catch per standardized effort in year *i* on an averaged standardized effort as defined above (both with and without learning), terminating with year *i*. A series of linear regressions were calculated corresponding to data sets beginning with 1968-72 and successively adding earlier years' data back to 1961 (Tables 16 and 17 and Fig. 8). Each regression was then expressed as a yield *versus* effort parabola to obtain the equilibrium catches and corresponding effort in terms of the USA side trawler 0-50 GRT standard days fished (Tables 16 and 17 and Fig. 9). Coefficients of

TABLE 16. Estimate of optimum standardized effort, MSY, catch per standardized effort, and coefficient of determination for SA 5 + 6 catch and standardized effort data applied to the Schaefer model. Gulland's averaging method to determine effort in year i was used on the basic data.[a]

		3 Years	4 Years	5 Years
Optimum standardized effort	1963-72	271,857		
	1964-72	271,681	291,031	
	1965-72	224,375	216,987	213,740
	1966-72	225,709	217,342	202,690
	1967-72	227,835	212,405	194,369
	1968-72	235,535	220,108	193,089
	1969-72	257,552	241,430	209,264
MSY	1963-72	981,474		
	1964-72	980,942	996,064	
	1965-72	931,365	898,352	865,270
	1966-72	931,772	898,458	859,465
	1967-72	901,001	898,705	860,987
	1968-72	931,451	896,762	861,988
	1969-72	940,004	899,972	852,617
Catch per standardized effort	1963-72	3.61		
	1964-72	3.61	3.42	
	1965-72	4.15	4.14	4.05
	1966-72	4.13	4.13	4.24
	1967-72	4.09	4.23	4.43
	1968-72	3.95	4.07	4.46
	1969-72	3.65	3.73	4.07
Coefficient of determination	1963-72	0.77		
	1964-72	0.67	0.57	
	1965-72	0.96	0.95	0.94
	1966-72	0.94	0.93	0.94
	1967-72	0.94	0.93	0.96
	1968-72	0.93	0.93	0.94
	1969-72	0.97	0.99	0.99

[a] Data adjusted for learning.

TABLE 17. Estimate of optimum standardized effort, MSY, catch per standardized effort, and coefficient of determination for SA 5 + 6 catch and standardized effort data applied to the Schaefer model. Gulland's averaging method to determine effort in year i was used on the basic data. No learning.

		3 Years	4 Years	5 Years
Optimum standardized effort	1963-72	385,275		
	1964-72	270,246	302,939	
	1965-72	227,747	222,918	218,769
	1966-72	236,249	229,864	210,140
	1967-72	248,347	238,370	213,249
	1968-72	263,172	253,553	216,526
	1969-72	338,600	322,727	260,661
MSY	1963-72	1,274,828		
	1964-72	998,504	1,081,719	
	1965-72	964,367	939,613	910,024
	1966-72	974,312	947,857	899,647
	1967-72	986,631	957,489	902,401
	1968-72	1,007,138	976,682	905,414
	1969-72	1,117,381	1,088,310	959,131
Catch per standardized effort	1963-72	3.31		
	1964-72	3.69	3.57	
	1965-72	4.23	4.21	4.16
	1966-72	4.12	4.12	4.28
	1967-72	3.97	4.02	4.23
	1968-72	3.82	3.85	4.18
	1969-72	3.33	3.37	3.67
Coefficient of determination	1963-72	0.42		
	1964-72	0.65	0.56	
	1965-72	0.87	0.89	0.94
	1966-72	0.82	0.85	0.93
	1967-72	0.82	0.82	0.90
	1968-72	0.76	0.76	0.85
	1969-72	0.61	0.74	0.87

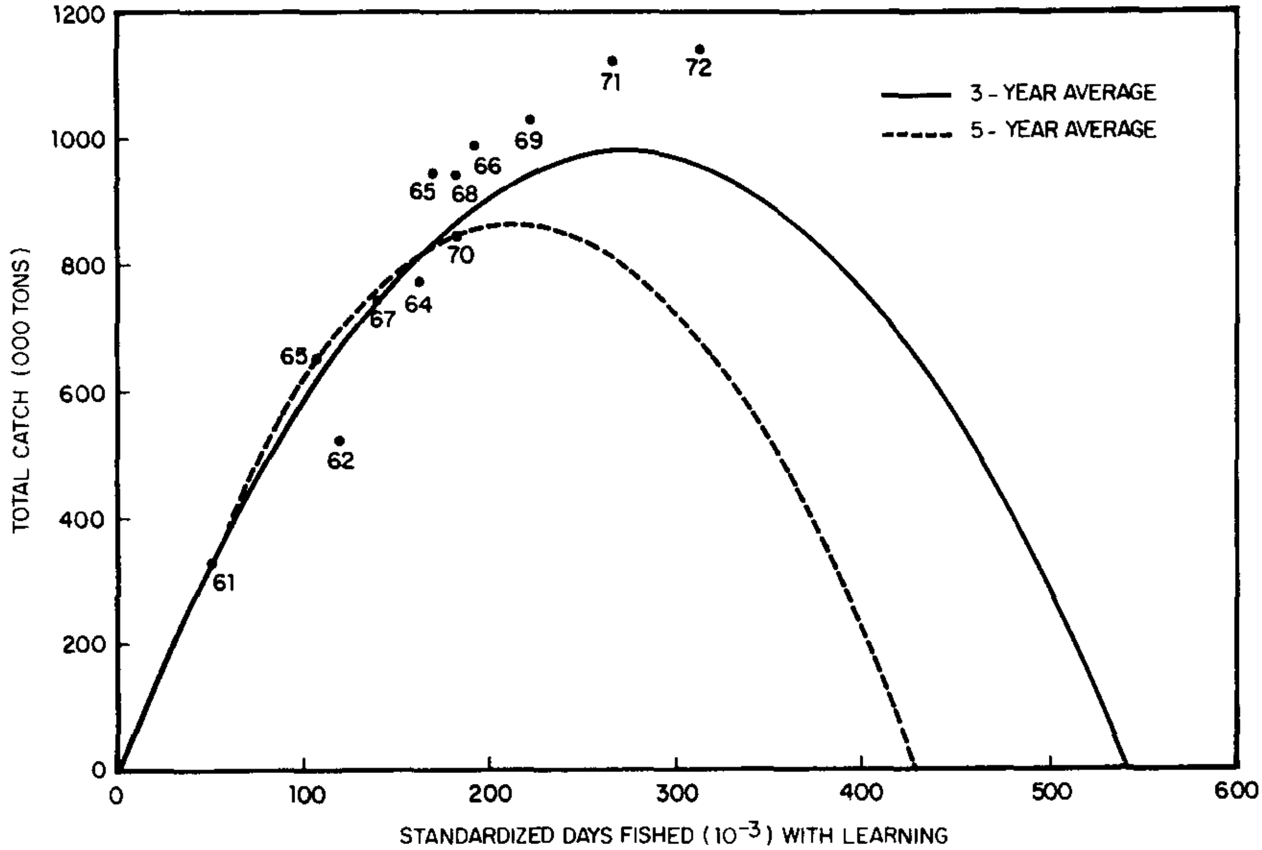

Fig. 9. Total catch (finfish plus squid) vs. standardized effort (with learning) for SA 5 + 6, 1961-72, using a 3-year average over standardized effort (days fished), and a 5-year average over standardized effort. Original data points (catch vs. standardized days fished) are plotted.

determination for all data sets, adjusted for learning, ranged from 0.57 to 0.99 with 15 of the 17 values being above 0.9; for data sets not adjusted for learning, the coefficients ranged from 0.42 to 0.97 with 3 values above 0.9 and 11 above 0.8. The range of parameter estimates derived from the yield *versus* standardized effort parabolas was less for data sets adjusted for learning than for those sets that had not been adjusted. However, this would be expected since learning accounted for a major source of variation or bias in estimating population size. For both data sets, *i.e.* with and without a learning adjustment, the best fit to the Schaefer model occurred when data for the years 1965-72 and later were used. The years prior to 1965 were those for which data were less complete, and for which the consequential changes associated with learning had their greatest effect. In addition, in those years effort was directed towards fewer species than in later years.

Discussion

Results of these analyses demonstrated a rapid and substantial increase in fishing intensity (a factor of 6, with data adjusted for learning), and a concurrent marked decline in abundance (about 55%) for the offshore finfish community in SA 5 + 6 during the period 1961-72. Yield *versus* standardized effort parabolas, estimated using the Schaefer approach, indicated that fishing mortality since 1968 had exceeded that level which would result in sustaining a maximum yield for the fishery under equilibrium conditions. The average MSY for the data sets for 1965-72, using 3-year, 4-year, and 5-year averaging methods for fishing effort, was 898,329 tons for data adjusted for learning and 938,000 tons for data without adjustment for learning (Tables 16 and 17).

The projected MSY value from the Schaefer model, approximately 900,000 tons, was somewhat lower than the composite MSY estimated earlier from single assessment summations of 1,300,000 tons, but, as discussed in that section, it may not be reasonable to assume that these individual assessments can be summed for the total biomass yield. It was similar to the 1,000,000 tons estimated from assessment summations after discounting for a hypothesized mackerel-herring interaction.

The estimated MSY values were for long-term equilibrium yields. Because the fishery had been subject to overfishing (as indicated in this case by the Schaefer model), the sustainable yield would be considerably less than the estimated MSY value.

The effort giving MSY was 218,367 standard days fished when adjusted for learning and 223,145 standard days fished without the learning adjustment. These are in the same order of magnitude as the respective efforts estimated for 1969, which were 221,137 and 210,914 standard days fished respectively (Table 11). The averages of catch and standardized effort for the years following 1968 (except for 1970) exceed the projected allowable values for maximum sustained yield of the fishery and hence indicated a condition of overfishing. For example, the percentage reductions in standardized effort from the 1972 observed levels required to reach the average MSY level resulting from the above fits to the Schaefer model ranged from 30.7% to 27.7% respectively for data with and without an adjustment for learning.

Using the survey cruise estimate of population decline of 8% per year for 1969-71 and assuming that the 1969 effort was equal to that giving the MSY, then the 1972 fishing effort was 22% in excess of that needed to take the total catch equivalent to the MSY.

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A Least Squares Approach to Analysing Catch at Age Data

W. G. Doubleday[1]

Abstract

Assuming a known, time and age independent, natural mortality rate and unknown, time independent, selection (partial recruitment) at age factors, a model is constructed to estimate recruitment, fishing mortalities and an effective effort multiplier from catch-at-age data. A computer program applying standard least squares technique to a series of linear approximations to catch equations is presented, together with a second program which may be used to provide initial estimates of the fishing mortalities. The new method is compared with the cohort analysis of Pope (1972) and applied to data on Greenland cod, previously analysed by Schumacher (1971).

Introduction

Virtual population methods (Fry 1949; Murphy 1964; Jones 1964; Gulland 1965; Pope 1972) have been developed to estimate fish stock sizes and fishing mortalities from catch at age data. These methods analyse the catches of a single year-class as a unit so that there are more parameters (population size and fishing mortalities) to be estimated than there are observations. Thus, each mortality estimate is supported by somewhat less than one observation. Mortalities for the same age and different year-classes are sometimes averaged to reduce their scatter, but this solution is not completely satisfactory since there are often considerable changes in fishing effort over a period of 2 or 3 years.

Recently, Pope (MS 1974) suggested a model where the instantaneous fishing mortality rate ${}_aF_n$ at age a in year n is the product of a year effect F_n (effort multiplier) and an age effect ${}_aS$ (gear selection or partial recruitment). Thus ${}_aF_n = {}_aSF_n$. He estimated these parameters by a modified steepest descent method applied to minimize the sum of squared differences of observed and predicted logarithms of catch ratios of the same year-class in successive years. Since the same ${}_aS$ and F_n are applied to several year-classes in this approach, the parameter estimates are supported by more than one observation each.

The model presented here arose out of an attempt to solve Pope's model by applying least squares methods to a series of linear approximations. This technique is called linearization and is discussed by Draper and Smith (1966). The reasons for linearizing are twofold. It was felt that linearization would contribute to understanding the structure of the model and that information concerning the reliability of parameter estimates obtainable from regression analysis would be of value.

This paper begins with an examination of the cohort analysis of Pope (1972) for bias and variance in estimation. The new model is then presented and applied to catches of West Greenland cod from 1956 to 1966.

Assumptions and Notation

Throughout this paper, natural mortality will be assumed to occur at a constant rate, independent of age and year and that all other removals from the population are contained in the catch data. More detailed knowledge about natural mortality could easily be incorporated into the following treatment, but catch-at-age data contains very little information about the rate of natural mortality so that such information must come from another source. Failure of these assumptions is not investigated. The standard catch equation of Beverton and Holt (1957) is used as a starting point but the adequacy of such an equation to describe a fishery is not investigated.

In what follows, subscripted prefixes refer to ages and subscripted suffixes to years. Carets (ˆ) are placed over parameter estimates. A catch-at-age matrix consisting of N rows (years) and A columns (ages) is the raw data.

M — instantaneous coefficient of natural mortality for age a and year n;
${}_aC_n$ — catch in numbers of age a fish in year n;
${}_as$ — logarithm to base e of availability at age a;

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f_n — logarithm of effective effort multiplier (fishing intensity) in year n;
${}_aF_n$ — $\exp({}_as+f_n)$;
${}_aP_n$ — stock size in numbers of age a fish in year n;
exp — exponential function;
ln — logarithm to base e;
rel-var — relative variance, Var(X/E(X)).

Cohort Analysis

We begin with a brief description of cohort analysis, as developed by Pope (1972), in our terminology. Cohort analysis was chosen for comparison because the consequences of sampling errors and choice of initial parameters are particularly clear and the method itself has acceptance, especially among the scientists who provide management advice to the International Commission for the Northwest Atlantic Fisheries (ICNAF).

The catch equation

$$ {}_aC_n = \frac{{}_aF_n (1 - \exp(-{}_aF_n - M)){}_aP_n}{{}_aF_n + M} \quad (1) $$

has an approximate solution for ${}_aP_n$ in terms of ${}_aC_n$, ${}_{a+1}C_{n+1}$, etc.:

$$ {}_a\hat{P}_n = {}_aC_n(\exp(M/2)) + {}_{a+1}C_{n+1}(\exp(3M/2)) + \ldots \quad (2) $$

Pope's approximation (2) is correct to the first power of M and fishing mortalities and would be exact if fishing took place during a short time interval of length Δt half way through the year with an instantaneous rate of fishing mortality F/Δt.

If the series is terminated before fishing is complete, the last term (for the final year N) is

$$ {}_{a+N-n}\hat{P}_N = \frac{{}_{a+N-n}C_n({}_{a+N-n}F_N + M)}{{}_{a+N-n}F_N(1 - \exp(-{}_{a+N-n}F_N - M))} \quad (3) $$

while, if fishing is complete at year N, and no fish form the year-class under consideration survive,

$$ {}_{a+N-n}\hat{P}_N = \frac{{}_{a+N-n}C_N({}_{a+N-n}F_N + M)}{{}_{a+N-n}F_N} \quad (4) $$

$$ {}_a\hat{F}_n = \ln({}_a\hat{P}_n/{}_{a+1}\hat{P}_{n+1}) - M $$
$$ = \ln\left(\frac{{}_aC_n(\exp(M/2)) + {}_{a+1}\hat{P}_{n+1}(\exp(M))}{{}_{a+1}\hat{P}_{n+1}}\right) - M \quad (5) $$

Ordinarily, the initial mortality estimate, ${}_{a+N-n}F_N$ is unknown and must be specified (usually arbitrarily) in order to use (3) or (4). As ${}_{a+N-n}F_N$ changes from 0.05 to 1, ${}_{a+n-n}\hat{P}_n$ changes by a factor of thirteen. This strong influence is steadily reduced in its effect on population estimates for younger ages. The size of the effect depends on M and on the catches as far back as the age of interest. If the contributions of all catches, discounted for natural mortality, were roughly equal, a choice of 0.01 instead of 1 for ${}_{a+N-n}F_N$ would change the population estimate 9 years earlier by a factor of two. Of course, small percentage changes in ${}_{a+N-n}F_N$ have very little effect a few years back. One could describe the influence of errors in ${}_{a+N-n}F_N$ as highly damped by the earlier catches. Also, the effect of changes in ${}_{a+N-n}F_N$ is diminished if the discounted earlier catches are much larger than the last as is often the case in practice. The simplest expedient is to repeat the analysis with different values for ${}_{a+N-n}F_N$ in order to ascertain the size of possible biases.

Over-estimation of ${}_{a+N-n}F_N$ results in over-estimation of all fishing mortalities. This effect also diminishes in back calculation similarly to the effect on population size estimates. The relative error in one is approximately the inverse of the relative error in the other.

Variance in ${}_aC_n$ due to sampling errors produces variance in ${}_a\hat{F}_n$. Equation (5) may be written as

$$ {}_a\hat{F}_n = \ln\left(1 + \frac{{}_aC_n(\exp(-M/2))}{{}_{a+1}\hat{P}_{n+1}}\right) \quad (6) $$

Thus, to a first order approximation, ${}_a\hat{F}_n$ has about the same coefficient of variation as a single observed catch.

The contribution of variance in ${}_aC_n$ to the rel-var of the estimate ${}_a\hat{P}_n$ depends on the sizes of the contributions of all component catches of ${}_a\hat{P}_n$. If all K components contribute equally, the contribution to rel-var due to ${}_aC_n$ is rel-var ${}_aC_n/K^2$, while if ${}_aC_n$ dominates, it contributes rel-var ${}_aC_n$. In practice, the effect lies somewhere between these extremes.

In conclusion, with a good choice of the final F value, for estimating mortalities, Pope's cohort analysis is about as good as the sampling error in a single observation, and, for estimating stock sizes, it is somewhat better. With a poor choice of the final F, serious errors can arise, especially with older fish.

Example: West Greenland Cod (from Schumacher, 1971).

Table 1 contains catch-at-age data and cohort analyses for one cohort of West Greenland cod. These data were analysed by Schumacher by a virtual population method other than cohort analysis, but Pope's cohort analysis is applied to them as an illustration for comparison with results from the new model. The value of 0.8 for ${}_{14}F$ was used by Schumacher. The extremes of the stock size estimates at age 5 differ by a factor of 1.43.

TABLE 1. Cohort analysis of a year-class of West Greenland cod (catch and population sizes in thousands of fish).

	Age (yr)									
	5	6	7	8	9	10	11	12	13	14
Catch:	4,996	9,362	7,501	3,881	2,743	2,333	1,709	1,156	321	34
F	.09	.24	.30	.25	.28	.42	.62	1.22	1.67	.8
${}_aP_n$	65,712	49,280	31,876	19,311	12,299	7,587	4,101	1,811	437	67
F	.08	.22	.28	.23	.26	.36	.49	.74	.47	.08
${}_aP_n$	68,253	51,360	33,579	20,705	13,440	8,522	4,866	2,438	950	487
F	.06	.15	.18	.13	.16	.16	.16	.16	.06	.008
${}_aP_n$	93,783	72,262	50,692	34,716	24,912	17,914	12,556	8,733	6,104	4,707

In the cohort analysis, catches at ages 6 and 7 each account for about 1/6 of the stock size estimate at age 5. Relative variance in these two catches is twice as important as in the remaining catches so far as estimation at age 5 is concerned. A 10% change in the catch at age 6 produces a two percent change in the estimated stock size at age 5. The stock size estimate at age 7 is dominated by the catch at age 7 (1/4 of total).

If the sampling variance associated with each catch were known, confidence intervals could be constructed for the stock size estimates, given a value for F at age 14.

The New Model

If the catch equations of Beverton and Holt

$${}_aC_n = \frac{{}_aF_n}{{}_aF_n + M}\left(1 - \exp(-{}_aF_n - M)\right){}_aP_n$$

and

$${}_{a+1}P_{N+1} = {}_aP_n\left(\exp(-{}_aF_n - M)\right)$$

were linear in P and F, least squares estimation by the general linear model of statistics (Seber 1966) would be appropriate. Unfortunately, the equations are non-linear in F, and terms in F are multiplied by terms in P. If the first equation is transformed by taking logarithms and expanding $\ln({}_aF_n)$ as ${}_as + f_n$:

$$\begin{aligned}\ln({}_aC_n) = {} & \ln({}_rP_{n-a+r}) - (a-r)M + ({}_aS + f_n) \\ & - \sum_{i=r}^{a-1} \exp({}_is + f_{n-a+i}) - \ln(\exp({}_as + f_n) + M) \\ & + \ln(1 - \exp(-\exp({}_as + f_n) - M)) + {}_a\epsilon_n \qquad (7)\end{aligned}$$

and a more nearly linear equation results.

Figure 1 illustrates the nearly linear relationship between $\ln({}_{a+N-n}P_N)$ and ${}_{a+N-n}F_N$ for various values of M and with fishing complete. Figures 2 and 3 show how the curved relationship between the logarithms of catch ratios $\ln({}_aC_n/{}_{a}{}_{1}C_{n\ 1})$ and the successive rates of fishing mortality becomes nearly linear in the scale of $\ln({}_aF_n) = {}_as+f_n$ and $\ln({}_{a+1}F_{n-1}) + {}_{a+1}s+f_{n-1}$ for fishing mortalities in the range normally encountered ($-5 \leq \ln(F) \leq 1$). Although not illustrated, the transformation has a similar effect of reducing curvature on $\ln({}_aC_n)$ as a function of s and f.

In equation (7) ${}_a\epsilon_n$ represents the sampling error in observing $\ln({}_aC_n)$ and is assumed to have zero mean and constant variance for all a and n and to be statistically independent for different catches; r is the age at which the year class of ${}_aC_n$ enters the table of catches.

The logarithmic transformation has an added benefit of stabilizing the sampling error variance since catch sampling aims at constant coefficient of variation in estimation of numbers caught at age.

In the main program, POPO, the non-linear terms in (7) are expanded in linear approximations by Taylor series

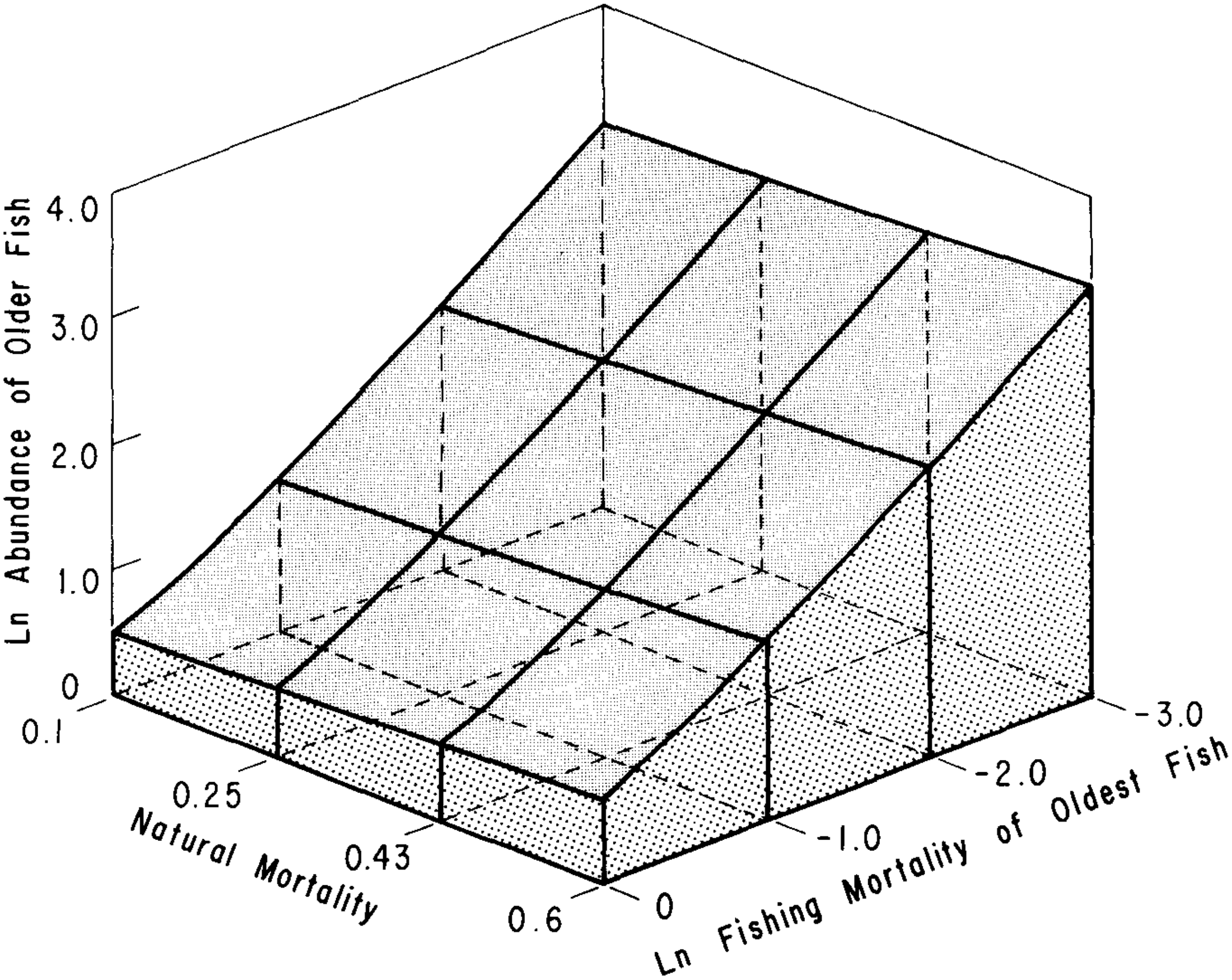

Fig. 1. Effect of final F and M on estimated population size of oldest fish.

at an initial set of estimates of ${}_as$ and f_n for all ages and years. Standard least squares procedures are applied to the linear approximations and the resulting estimates are, at the option of the operator, accepted or averaged with the previous estimates of ${}_as$ and f_n and ${}_rP_{n-a+r}$ to produce a revised set of estimates. This whole process of linear approximation and estimation is repeated until two successive estimates of all parameters differ by less than 10^{-2}. Since the contribution of ${}_rP_{n-a+r}$ is already linear, it does not enter into the Taylor series approximations.

This process of iterative linear approximation and estimation is called linearization and is one method of obtaining least squares estimates of the parameters of a non-linear response such as equation 7. For a discussion of the method, the reader is referred to Draper and Smith (1966, Chapt. 10).

Since ${}_as$ and f_n only affect the predicted catches through the sum $({}_as+f_n)$, there is an indeterminancy in the model. A constant could be added to all values of ${}_as$ and subtracted from all values of f_n without changing the predictions. In POPO, one of the ${}_as$ is held fixed, the choice of which is left to the user.

This model for ${}_aC_n$ is rather nonlinear in the terms expressing fishing mortality up to age a-1, i.e. mortality before the year under consideration, and this often leads to instability if the initial parameter estimates make the mortalities badly out of proportion. The option of averaging old and new estimates stabilizes the process to some extent, but not enough to allow arbitrary starting estimates.

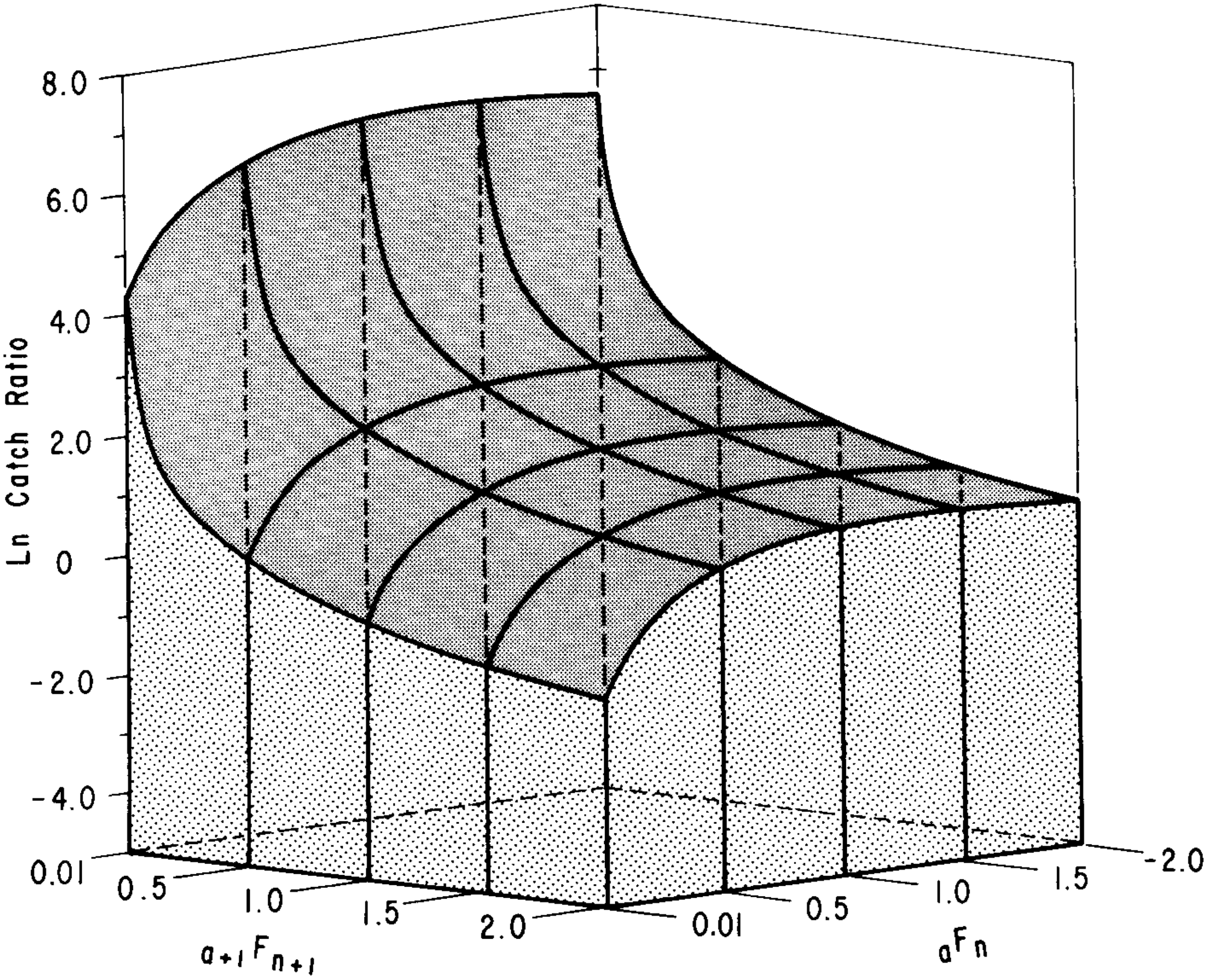

Fig. 2. Response of ln catch ratio to fishing mortalities at M = 0.2.

Therefore, a second computer program, POPI, is used to provide starting values. Here the logarithms of catch ratios are used.

$$\ln ({}_aC_n/{}_{a+1}C_{n+1}) = ({}_as + f_n) - \ln (+ \exp ({}_as + f_n) + M)$$

$$+ \ln (1 - \exp (- \exp ({}_as + f_n) - M)) + (\exp ({}_as + f_n) + M)$$

$$- ({}_{a+1}s + f_{n+1}) + \ln (+ \exp ({}_{a+1}s + f_{n+1}) + M)$$

$$- \ln (1 - \exp (- \exp ({}_{a+1}s + f_{n+1}) - M)) + {}_a\epsilon_n$$

This model is very nearly linear for fishing mortalities less than one (Fig. 3) and, if the values of f_n for the last year and ${}_as$ are specified and held fixed, convergence is rapid from arbitrary starting values.

The ratios of catches have a higher sampling variance than the catches themselves and successive catch ratios for the same year-class have negatively correlated sampling errors. For this reason, the method of POPO is to be preferred over that of POPI.

The advantages of the least squares approach over cohort analysis (or other virtual population methods) are as follows:

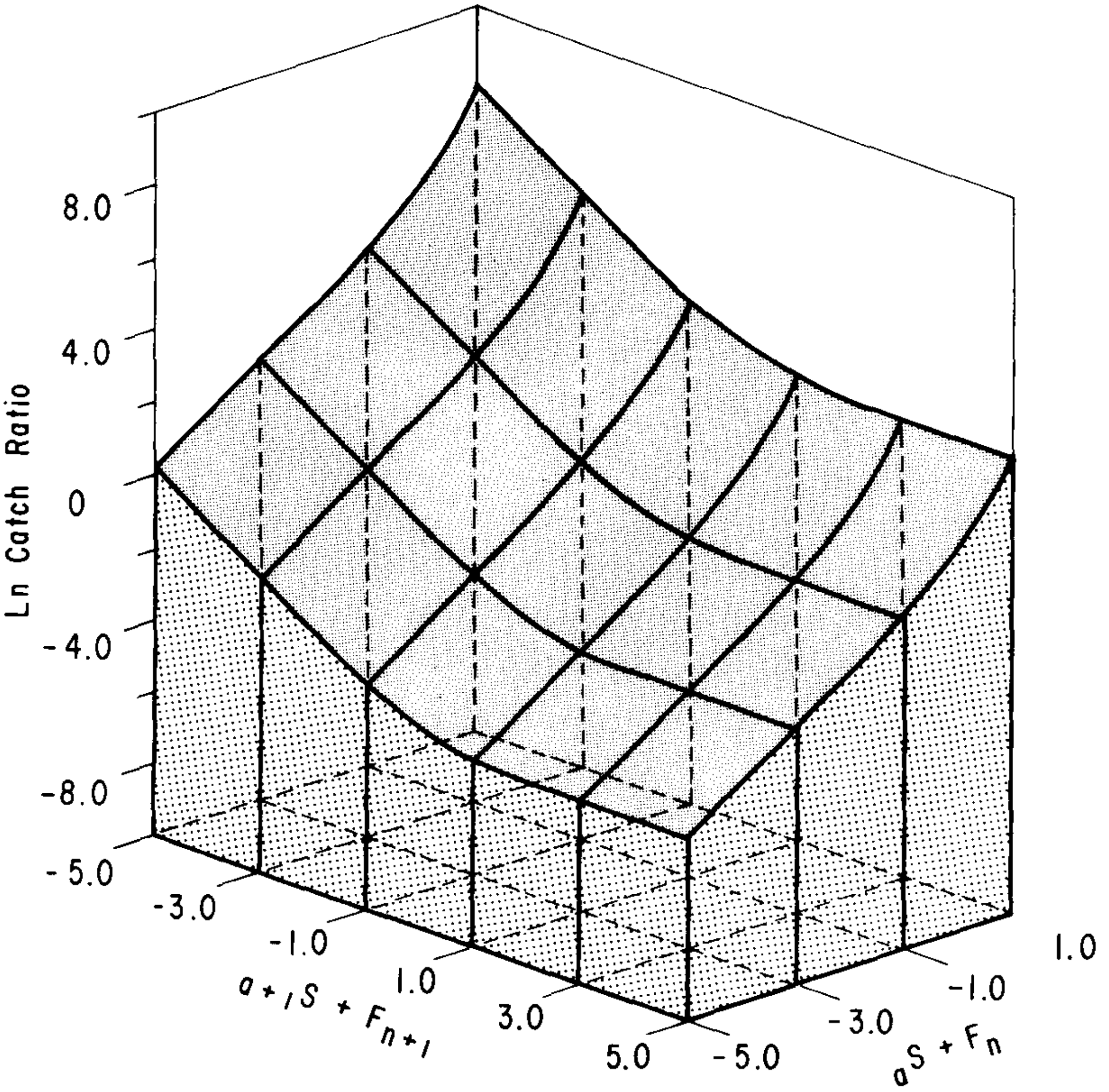

Fig. 3. Response of ln catch ratio to fishing mortalities at M = 0.2 (log scale).

1) There are fewer parameters than observations so that the arbitrary choice of the final rate of fishing mortality is removed and sampling errors have the opportunity to neutralize one another.

2) The residual mean square indicates how well the catches are explained.

3) Indication is given (variance estimates) of the reliability of parameter estimates.

4) There are residuals which may be examined to detect anomalies and indicate the appropriateness of the model to the data.

5) The amount of information contained in the catch data about stock sizes is indicated by the variance estimates associated with the stock size estimates.

The proposed model has, however, some serious imperfections.

1) There is no guarantee of a unique solution, as different starting values may produce different solutions, although discrepancies have been slight in test cases.

2) Long series of well sampled catches are required, but few fisheries retain the same age selection

characteristics for more than a few years. With A ages and N years there are $2(A+N)-1$ parameters to be estimated so that A and N must be large for good results. With 20 ages and 100 years, there would be eight observations per parameter, while with 9 ages and 11 years there are only two and one half. It follows that the analysis of variance table of the regression may mean little. The residual mean square often has a smaller component due to sampling (pure) error than due to systematic errors (lack of fit). Like cohort analysis, this model can explain most of the variation in almost any data.

3) Even when the catches are well explained, confidence intervals for the fishing mortalities can be wide. This is largely due to the lack of orthogonality between stock sizes and fishing mortalities as evinced in the negative correlations between their estimates. One may increase and the other decrease with little effect on catch.

Application: West Greenland cod 1956-66 (Schumacher, 1971)

Table 2 consists of catch-at-age data for West Greenland cod from 1956 to 1966. These data were thoroughly analysed by Schumacher (1971) and serve to illustrate the new method. Table 3 contains Schumacher's estimates of fishing mortalities. His choice of $M = 0.2$ was retained in the least squares analyses. The program POPI was run for ages 4 to 12 with the initial values of -1.8 for $_{12}S$ and zero for all remaining parameters. Nine ages were used due to the core restriction of POPO. POPI converged on eight iterations to give a residual mean square of 0.146. With the estimates from POPI as initial values, POPO converged in seven iterations. Repeating the estimation by POPO from different starting values resulted in agreement in parameter estimates to 0.001. $_2S$ was fixed in the analysis by POPO. The latter set of estimates is given in Table 4.

Numbers are assigned to year-classes by the following system: age 12 fish in 1956 are year-class one, age 11 fish in 1956 are year-class two, . . ., age 4 fish in 1956 are year-class nine, age 4 fish in 1957 are year-class ten, . . ., age 4 fish in 1966 are year-class nineteen.

The statistics which best describe the success of the solution are the residual mean square, called "Estimated SIGMA SQUARED" by POPO, and the variance of the ln catches. The usual analysis of variance is misleading

TABLE 2. West Greenland cod: number of fish landed per year and age-group (thousands of fish), 1956-66.

Age (yr)	Year 1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
2		544	488			24		296	8	2,752	88
3	209	1,177	348	578	435	2,946	869	7,612	8,655	14,718	1,294
4	1,758	19,353	1,772	2,866	6,186	22,958	11,423	6,589	27,181	58,619	7,738
5	4,996	12,493	15,136	5,464	5,168	19,756	70,311	19,301	11,407	53,331	59,987
6	17,901	9,362	6,751	27,411	4,652	8,055	29,344	48,418	18,264	8,994	40,726
7	6,622	17,367	7,501	6,622	20,250	6,980	7,816	22,517	30,864	9,152	5,791
8	6,400	3,967	17,177	3,881	4,492	23,126	5,050	3,973	11,355	15,125	4,403
9	24,418	4,061	3,181	5,996	2,743	4,359	13,772	1,708	2,543	2,595	6,667
10	2,345	8,893	3,652	1,124	5,363	2,333	2,433	6,768	1,027	539	1,166
11	4,106	1,271	12,981	1,477	805	4,724	1,709	1,104	4,138	472	276
12	1,014	1,899	1,691	4,327	1,438	528	2,599	1,156	591	1,864	122
13	1,363	485	2,168	999	5,195	1,138	720	2,325	321	73	981
14	2,893	436	725	836	741	5,052	1,219	189	933	34	137
14+	1,194	1,383	3,271	960	1,859	2,383	2,897	3,718	747	265	234

TABLE 3. West Greenland cod: fishing mortality, 1956-64 (Schumacher, 1971).

Age (yr)	Year									Mean F		
	1956	1957	1958	1959	1960	1961	1962	1963	1964	1956-61	1961-64	1956-64
3	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01
4	0.02	0.04	0.04	0.05	0.04	0.08	0.11	0.11	0.09	0.05	0.10	0.06
5	0.09	0.23	0.08	0.15	0.13	0.18	0.35	0.28	0.27	0.14	0.30	0.20
6	0.16	0.23	0.19	0.21	0.18	0.30	0.43	0.44	0.47	0.21	0.45	0.29
7	0.30	0.22	0.29	0.28	0.23	0.45	0.55	0.70	0.55	0.30	0.60	0.40
8	0.22	0.30	0.36	0.24	0.31	0.44	0.70	0.61	0.96	0.31	0.76	0.46
9	0.29	0.21	0.42	0.28	0.27	0.55	0.52	0.55	1.03	0.32	0.70	0.45
10	0.24	0.16	0.29	0.26	0.27	0.39	0.69	0.52	0.76	0.27	0.66	0.40
11	0.40	0.20	0.37	0.18	0.30	0.40	0.56	0.79	0.70	0.31	0.68	0.43
12	0.34	0.33	0.43	0.20	0.27	0.33	0.40	0.97	1.04	0.32	0.80	0.48
13		0.27	0.78	0.48	0.38	0.35	1.00	0.75	—	0.45	0.88	0.50

TABLE 4. West Greenland cod: parameter estimates from POPO.

Age (yr)	$_aS$	Year	f_n	Year-class	$\ln({}_rP_{n-a+r})$	Year-class	$\ln({}_rP_{n-a+r})$
4	−2.489	1956	−0.995	1	9.853	12	11.146
5	−1.501	1957	−0.802	2	10.776	13	12.107
6	−1.099	1958	−0.644	3	10.275	14	12.889
7	−0.864	1959	−0.791	4	12.151	15	11.804
8	−0.886	1960	−0.672	5	10.933	16	11.338
9	−1.090	1961	−0.230	6	10.539	17	12.936
10	−1.401	1962	0.099	7	12.071	18	13.580
11	−1.526	1963	0.081	8	11.335	19	12.040
12	−1.809	1964	0.119	9	11.471	—	—
—	—	1965	−0.146	10	12.757	—	—
—	—	1966	−0.473	11	11.002	—	—

since there is no grand mean to be removed and hence all sums of squares due to parameter estimation are inflated resulting in high F values even if the model fits badly. Table 5 presents the analysis of variance of the final regression. RSQ represents the proportion of the variance of ln catch explained by the regression. POPO succeeded in explaining 96% of the variation in the catch logarithms.

TABLE 5. West Greenland cod: analysis of variance of ln catches.

Source	Sum of squares	df	F
Parameters	11757.520	39	4896.414
Residual	3.694	60	—
Estimated Sigma squared	0.061570	—	—
Var of ln catch	1.591	—	—
RSQ	0.961	—	—

Table 6 contains the estimated rates of fishing mortality. Table 7 shows the estimated variances of the logarithms of the fishing mortalities. These are derived from the estimated dispersion matrix which is printed by POPO together with the corresponding correlation matrix. The variances shown are slight underestimates of the relative variances of the mortalities. While the estimates are in agreement with those of Schumacher (Table 3) for age 4, there is a steady tendency with increasing age for the least squares estimates to be less than those of Schumacher with the average mortality rate at age 12 less than one quarter of his estimate. The variance estimates

TABLE 6. West Greenland cod: estimated fishing mortalities, 1956-66.

	Age (yr)								
Year	4	5	6	7	8	9	10	11	12
1956	0.03	0.08	0.12	0.15	0.15	0.12	0.09	0.08	0.06
1957	0.03	0.09	0.14	0.18	0.18	0.15	0.11	0.09	0.07
1958	0.04	0.11	0.17	0.22	0.21	0.17	0.12	0.11	0.08
1959	0.03	0.10	0.15	0.19	0.18	0.15	0.11	0.09	0.07
1960	0.04	0.11	0.17	0.21	0.21	0.17	0.12	0.11	0.08
1961	0.06	0.17	0.26	0.33	0.32	0.26	0.19	0.17	0.12
1962	0.09	0.24	0.36	0.46	0.45	0.37	0.27	0.24	0.18
1963	0.08	0.24	0.36	0.45	0.44	0.36	0.26	0.23	0.17
1964	0.09	0.25	0.37	0.47	0.46	0.37	0.27	0.24	0.18
1965	0.07	0.19	0.28	0.36	0.35	0.29	0.21	0.18	0.14
1966	0.05	0.13	0.20	0.26	0.25	0.20	0.15	0.13	0.10

TABLE 7. West Greenland cod: estimated variances of logarithms of fishing mortalities, 1956-66.

	Age (yr)								
Year	4	5	6	7	8	9	10	11	12
1956	0.19	0.27	0.27	0.40	0.65	1.04	1.51	2.03	2.60
1957	0.15	0.27	0.21	0.33	0.56	0.92	1.36	1.86	2.41
1958	0.13	0.19	0.17	0.28	0.50	0.84	1.25	1.73	2.25
1959	0.11	0.16	0.14	0.23	0.43	0.75	1.15	1.60	2.10
1960	0.09	0.15	0.11	0.19	0.37	0.67	1.04	1.46	1.94
1961	0.11	0.15	0.11	0.19	0.36	0.65	1.00	1.41	1.87
1962	0.16	0.20	0.16	0.25	0.44	0.74	1.10	1.51	1.98
1963	0.30	0.33	0.30	0.40	0.62	0.95	1.34	1.77	2.24
1964	0.58	0.59	0.56	0.69	0.95	1.32	1.74	2.19	2.68
1965	1.02	1.01	0.99	1.14	1.44	1.86	2.30	2.77	3.26
1966	1.53	1.50	1.47	1.64	1.96	2.40	2.85	3.31	3.79

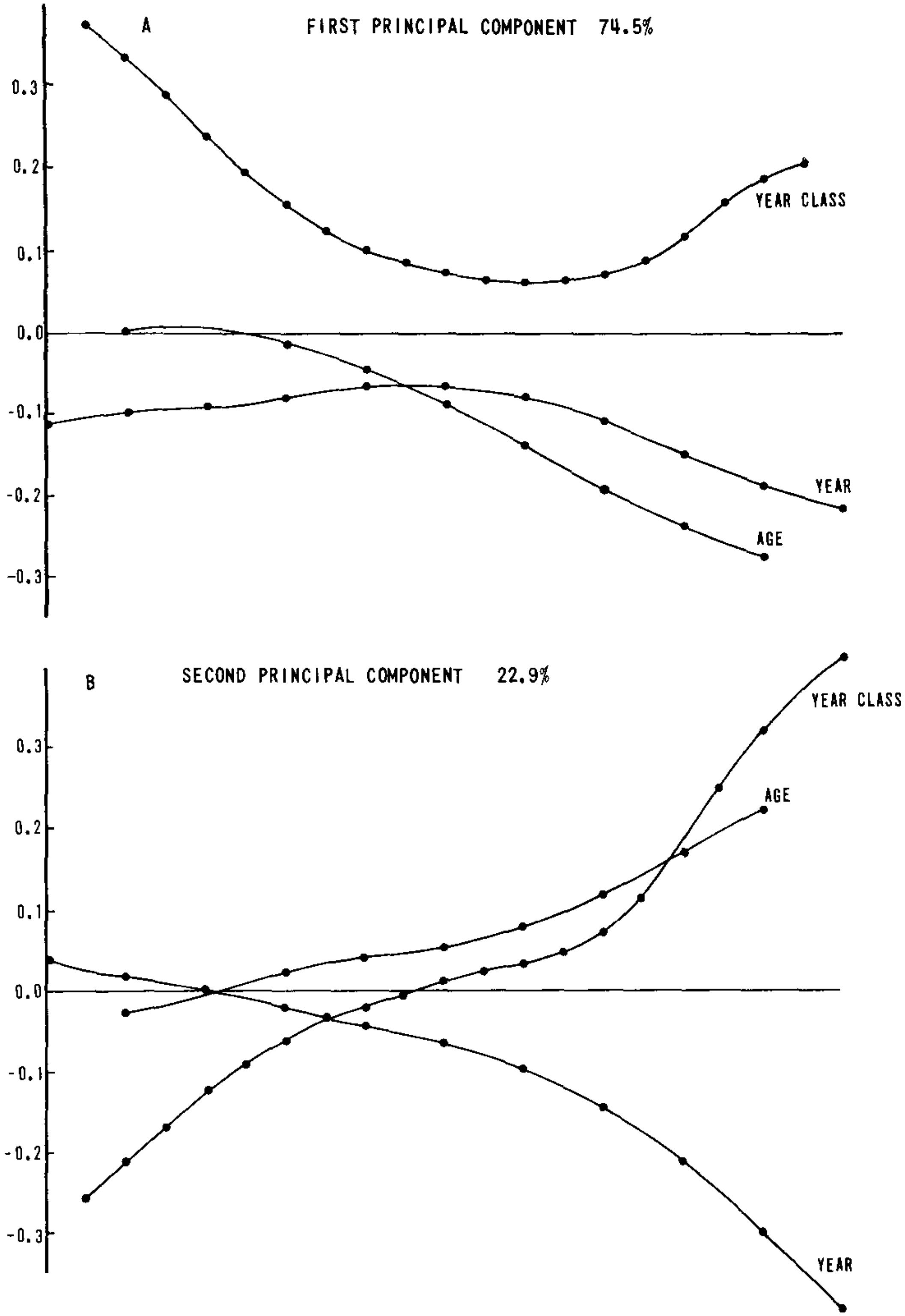

Fig. 4. Components of variance of parameter estimates.

near the middle of the table are acceptably small, while those for the final ages and years are very large.

As Table 7 indicates, the parameter estimates have large variances in spite of excellent explanation of the catch data (RSQ = 0.96). This indicates that some distinct linear combinations of the design variables (year, age, year-class effects) are nearly identical in their predicted catches. Typically, parameter combinations giving nearly identical predictions are related in some fairly simple way. These relations are made clear by examining the dimensions of greatest variability of the parameter estimate vector. These dimensions arise from a principal components analysis of the covariance matrix of the parameter estimates. Two principal components accounted for 97.4% of the total variance of the parameter estimates. The first component, comprising 74.5% of the total variance, is illustrated in Fig. 4A. The coefficients of this component for all three sets of parameters are plotted on the same graph and show a clear pattern. The vertical scale is the component score (the sum of squared scores for each component is one). The horizontal scale for the year-class variable is the number of the year-class with the smallest number at the left. The horizontal scale for the year variable has 1956 on the left and 1966 on the right and the age variable has age 4 on the left and age 12 on the right. The coefficients for year-class size are all positive, while those for age and year mortality factors are negative. This indicates the possibility of increasing all the stock size estimates together with decreasing all mortality estimates with little effect on the predicted catch logarithms. Thus, this component corresponds to the freedom of choice of the final F in cohort analysis. Note that the magnitudes of the coefficients are greater for the first and last few year-classes and the last few ages and years. This is a quantitative expression of the fact that these estimates are supported by fewer catches than the remainder due to the corresponding year-classes being fished for fewer years. The second component, comprising 22.9% of the total variance, is shown in Fig. 4B. There, the coefficients of age and year cross, indicating that a trend may be introduced in the age coefficients, are compensated for by adjustment of the year and year-class coefficients. Again, it is the first and last year-class size estimates that are most effected. The choice of fixing $_{2}s$ minimizes the uncertainty due to this component on ages 4 to 6 and years 1956 to 1960. A. different choice of $_{a}s$ would improve mortality estimates for a different group of ages. This component does not arise in cohort analysis and is due to the fact that $_{a}s$ and f_n affect mortality only through their sum.

The examination of the principal components indicates the limitations of the catch-at-age matrix to provide information about absolute mortality rates. The following conclusions may be drawn:

1) Absolute mortality rates are poorly defined as are absolute estimates of year-class size, especially for the first and last few year-classes.

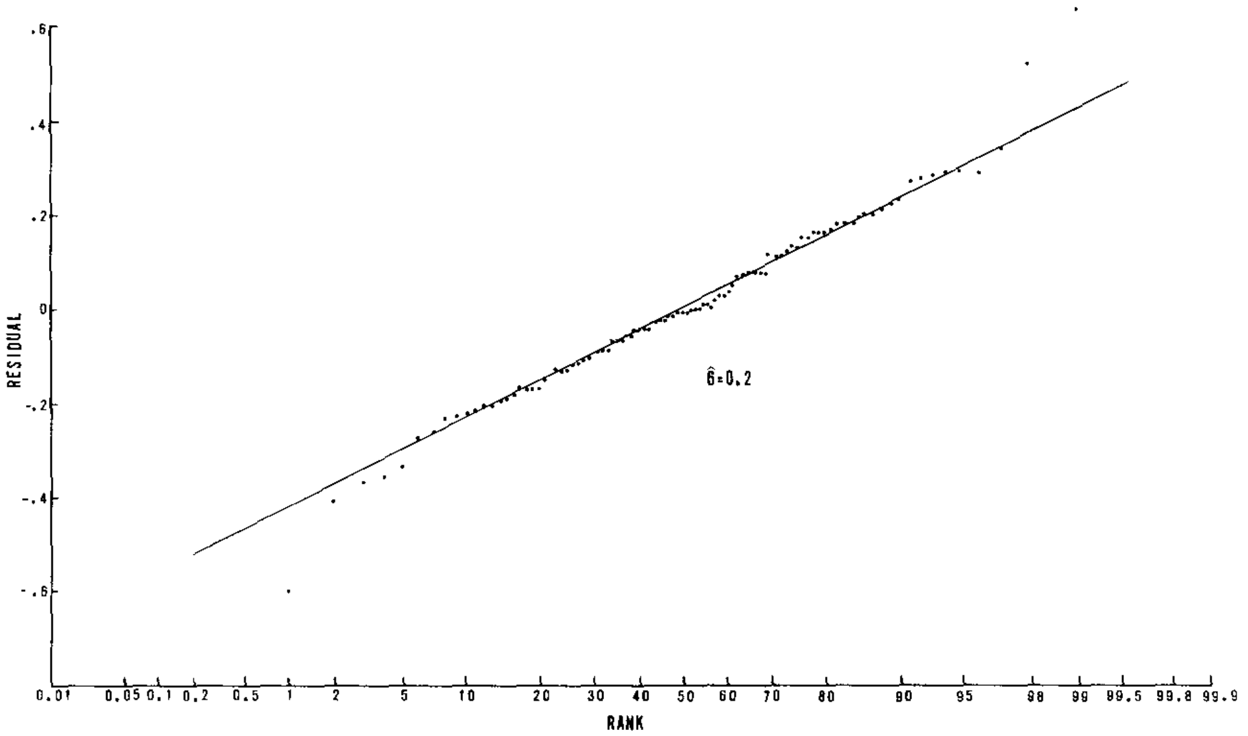

Fig. 5. Probability paper plot of residual $\log_e$ catch for Greenland cod.

2) All sets of estimates are subject to distortion by spurious linear trends.

3) Relative comparisons of mortality rates are more reliable than the co-variance matrix indicates, as are comparisons of nearby age and year factors.

4) Estimates of year-class sizes may contain a spurious long-term trend, but comparisons over short time periods are reliable.

The validity of the model discussed here depends not only on the catch equations of Beverton and Holt but also on the existence of age and year effects, which multiply together to give yearly fishing mortality at age. Since there are fewer parameters than data points, the predicted ln $({}_a\hat{C}_n)$ from the parameter estimates and the observed ln $({}_aC_n)$ differ. These differences are called residuals. It is through the examination of residuals for pattern that deviations from the model assumptions (called lack of fit) can be detected. For a discussion of residuals and their meaning see Draper and Smith (1966, Chapt. 3).

The analysis of residuals proceeded by plotting them on probability paper (Fig. 5). Most of the residuals resembled those from a normal distribution with an estimated standard deviation of 0.2, but there was one large negative and two large positive residuals. The probability paper plot suggests that as much as one-third of the residual mean square could be due to lack of fit. A projection of a three-dimensional graph of residuals against age and year was drawn (Fig. 6). It showed clearly that there was a serious lack of fit in 1957 and 1958, indicated by the sine waves in the residuals for these years and the large residuals for age 4 and 5. Examination of the catch-at-age matrix suggested that the cause was

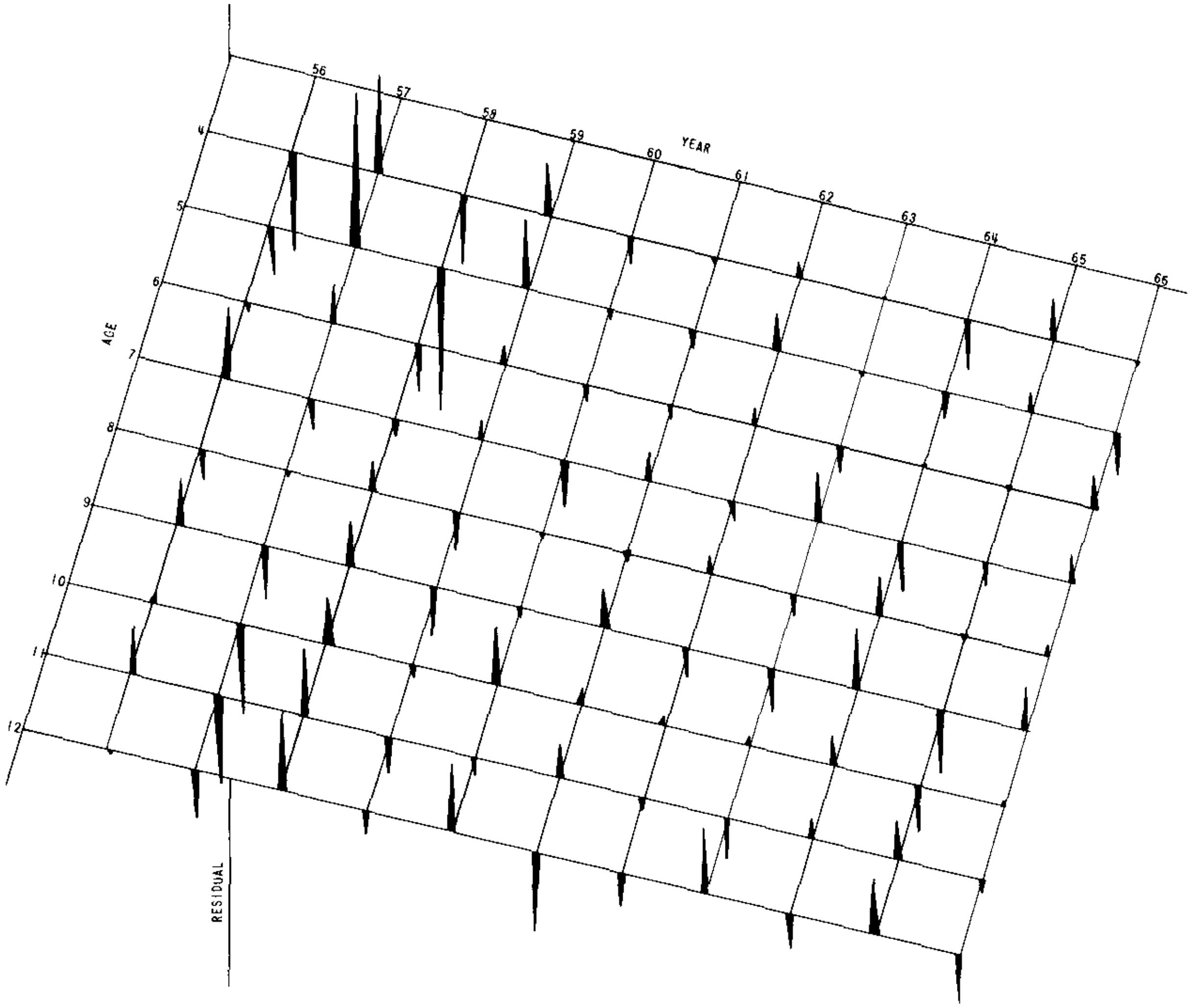

Fig. 6. Plot of residual $\log_e$ catch of Greenland cod vs age and year.

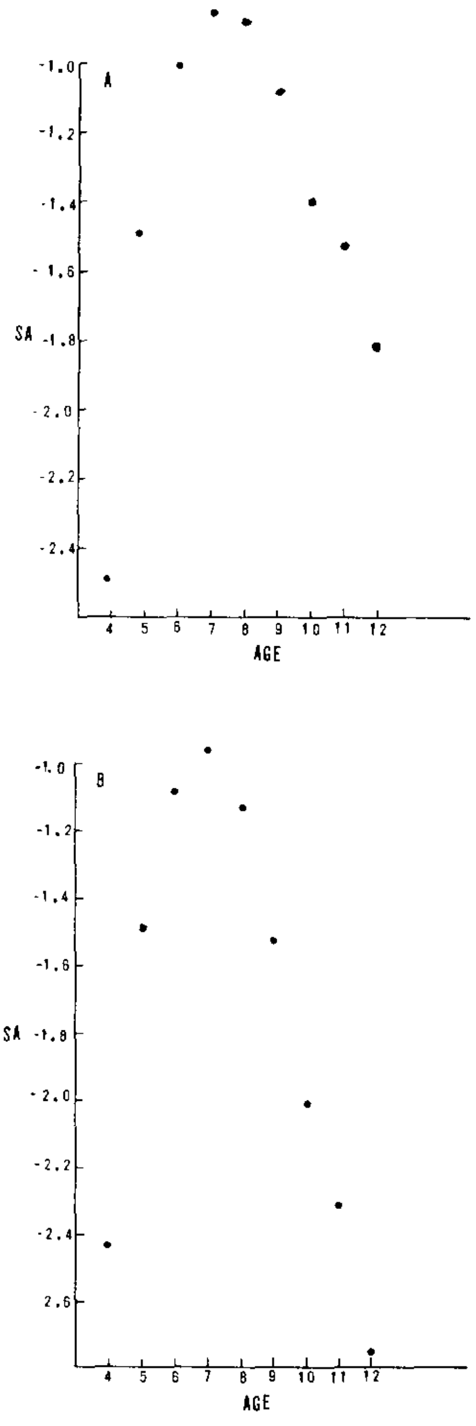

Fig. 7. Trends in selection at age.

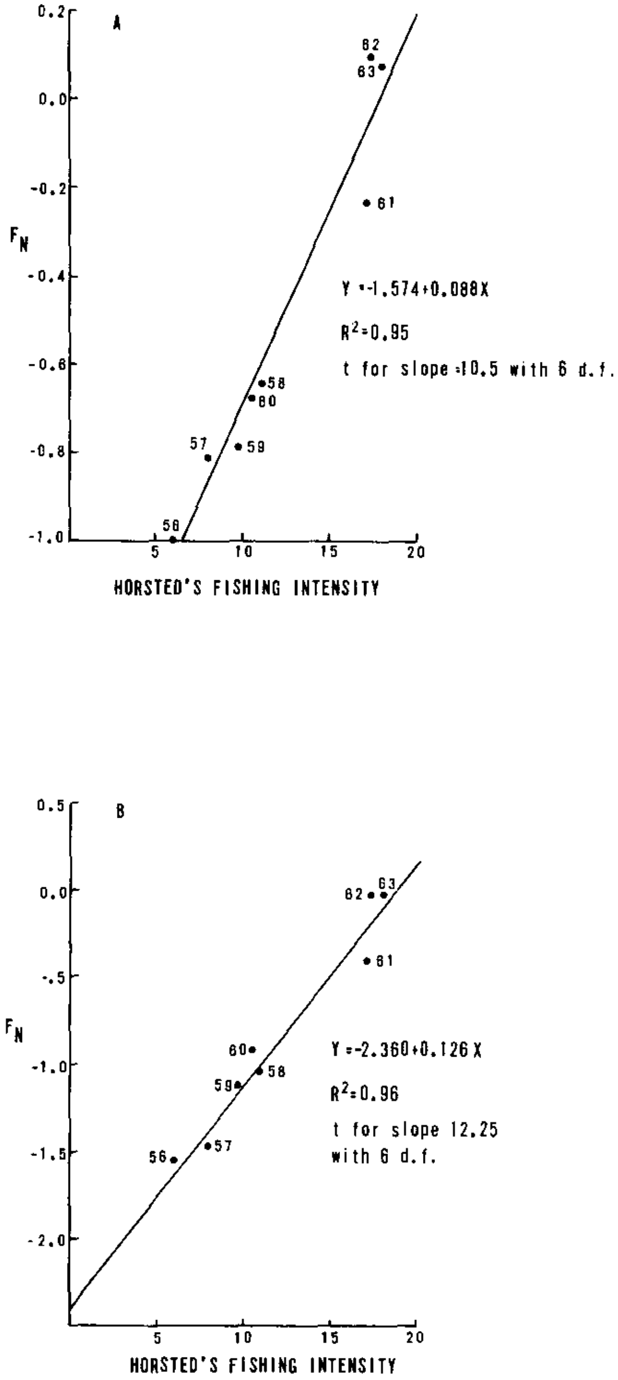

Fig. 8. Relationship between effective effort multipliers, f_n, and Horsted's fishing intensities.

TABLE 8. West Greenland cod: estimated fishing intensity (from Horsted, 1965).

Year	1956	1957	1958	1959	1960	1961	1962	1963
Intensity	5.94	7.99	11.01	9.79	10.50	16.95	17.31	18.04

the estimated catches of ages 4 and 5 fish in 1957. The analysis by POPO was repeated with catches of 7500 age 4 fish and 5000 of age 5 in 1957, resulting in a residual mean square of 0.042, a reduction of 32%. This improvement in fit casts doubt on these two catch estimates.

The effect of changing these estimated catches on estimates of age and year factors is illustrated in Fig. 7 and 8. In Fig. 7A, a quadratic trend in ${}_{a}s$, as cod enter the fishery, experience maximal selection and gradually leave the fishery, is apparent. This trend is clearer in Fig. 7B with the modified data. Dr Schumacher (personal communication) suggested that the older cod migrate out of this fishery. Horsted (1965) calculated an index of fishing intensity shown in Table 8. His definition of fishing intensity is the relative probability of capture of a tagged cod. In Fig. 8A and B, straight lines were fitted predicting f_n from Horsted's fishing intensity. The fit is very good (RSQ = 0.95 and 0.96) and is improved with the modified data. This linear relationship indicates that the estimates of f_n are not spurious but the relationship is insensitive to distortion of the f_n by trends due to the two principal components mentioned above. The fact that f_n is more linearly related to fishing intensity than is $\exp(f_n)$, as would be expected theoretically, indicates that some convex distortion of the f_n due to the first principal component is present.

Conclusion

A method of analysing catch at age by linearized least squares has been presented. The new method provides not only estimates of stock sizes and fishing mortalities, but also an indication of the reliability of these estimates. In particular, the inverse relationship between population size estimates and fishing mortality estimates is made explicit and the ability of a given matrix of catch data to resolve this antipathy is appraised.

The method requires a long history of well-sampled catches during which selection at age has not changed greatly. The new model satisfactorily explained most of the West Greenland cod data, but not the catches of 1957.

Even if the model is found lacking for a given fishery, examination of the residuals and of the variation is selection at age and fishing mortality may provide insight into changes in a fishery.

Note

Listings of the computer programs POPI and POPO and documentation of the programs are available on request as

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A Note on Yield Allocation in Multi-Species Fisheries

Yoshio Fukuda[1]

Abstract

Theoretically, an overall quota reduction, in addition to a system of species yield (strictly TAC, or total allowable catch) allocation, is of prime necessity for effective conservation of stocks concerned in the international multi-species fisheries under the prevailing circumstances, *i.e.* incomplete gear selectivity coupled with a variety of fishing strategies which may be freely utilized in the fisheries. The algorithms to calculate the necessary reductions have been developed step by step for the more general case to elucidate the intrinsic structure of yield allocation, that is, how interrelated such factors as conservation requirements, maximum utilization, technological constraints and their operation are to yield allocation. Generally, if the by-catch ratios (species composition in the mixed catch) are indeterminate within finite ranges, effective conservation of the stocks would require not only a reduction in the overall catch below the sum of the biological TACs but also reductions in the catches of the individual species below their TACs. The magnitude of the necessary reductions depend on the ranges within which the by-catch ratios are indeterminate, as well as on the given by-catch structure and on the biological TACs. Disregard of these features, especially of the constraints imposed by the by-catch structure, will result in optimistic allocations, increase in wasteful discarding of undesirable species, and eventual failure of the conservation program.

Introduction

A system of national yield allocations, with provision for possible new entries to the fisheries, has been established as one of the principal regulatory measures in the Northwest Atlantic. The system has been applied to the conservation of individual species stocks and, in some cases, to groups of species within a management area. However, it was soon realized that by-catches of certain species taken in directed fisheries for other species could not be neglected in considering the effective conservation of the stocks concerned.

This paper attempts to provide a better understanding of yield allocation in multi-species fisheries in relation to a recent proposal for effort limitation on the fisheries in Subarea 5 and Statistical Area 6. It progresses from simple numerical examples to a general formulation of the model and its algorithm for solution, indicating under what circumstances and how such an additional measure as reduction in the overall quota is needed for conservation of the stocks.

Progressive Formulation of the Model

For simplicity, let us start with the case where two species (S_1 and S_2) are exploited by two fisheries (G_1 and G_2), both with by-catches, and where the TACs (total allowable catches) for S_1 and S_2 are 5,000 tons and 7,000 tons respectively. Let us further assume that the by-catch ratios (column vectors) of G_1 and G_2 are as follows:

	G_1	G_2
S_1	0.90	0.15
S_2	0.10	0.85

We now proceed on the assumptions (a) that any yield allocation must meet the conservation requirement for each species, and (b) that the agreed objective is maximum utilization of these stocks, *i.e.* to maximize the resultant overall catch from the stocks.

If we denote the overall catches for the two fisheries by C_1 and C_2, then the conservation requirement is that the following inequalities must be satisfied:

$$0.90\,C_1 + 0.15\,C_2 \leqslant 5{,}000$$

$$0.10\,C_1 + 0.85\,C_2 \leqslant 7{,}000$$

Out of the infinite number of feasible sets (C_1, C_2) satisfying these inequalities with $C_1 \geqslant 0$ and $C_2 \geqslant 0$, the objective is to choose a set that will maximize $C = C_1 + C_2$. The solution, unique in this case, is as follows:

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[1] Far Seas Fisheries Research Laboratory, Shimizu, Japan.

	Overall Catch C_i	Breakdown by species	
		S_1	S_2
G_1	4,267	3,840	427
G_2	7,733	1,160	6,573
Total	12,000	5,000	7,000

The sum of the TACs may not always be attainable, although it was so in the above example. If we denote the by-catch matrix (column vectors) as

	G_1	G_2
S_1	0.90	0.45
S_2	0.10	0.55

then all members of the non-negative set (C_1, C_2), satisfying the conservation requirement for S_1, *i.e.* $0.90\ C_1 + 0.45\ C_2 \leq 5{,}000$, also meet the requirement in the inequality for S_2, and the feasible maximum overall catch of the two species amounts to only 11,111 tons. No catch quota would be left for the G_1 fishery, if the target of maximizing the combined catch of both species could not be modified. In other words, the allocation of a quota to the G_1 fishery would depend on the extent by which the feasible maximum overall catch could be reduced below 11,111 tons.

The reason for the difference in the two cases above, and its possible generalization to the case where *m* species are involved, may be more readily understood by reference to Fig. 1. The difference is whether or not the region between the two by-catch vectors includes the vector representing the set of TACs, hereinafter referred to as the TAC vector. Evidently a scalar product of the TAC vector can be found among the weighted combinations of the two by-catch vectors in Fig. 1A but not in Fig. 1B. This is also true in the case of *m* species, and the feasibility of having the sum of the TACs as a target depends upon where the by-catch vectors are located with reference to the TAC vector in the *m*-dimensional space. In the second example above, the conservation of S_2 is guaranteed by managing the fisheries so as to meet the conservation requirement for S_1; in other words, it is a single species case and S_2 will always be under-exploited.

Let us now consider the case where two species are exploited by more than two fisheries. It may happen, of course, that all of the by-catch vectors of the *n* fisheries will fall on one side of the TAC vector, as in Fig. 1B, but, if at least one of the by-catch vectors lies on the opposite side, the sum of the TACs can be attained as a target, as in the following by-catch matrix:

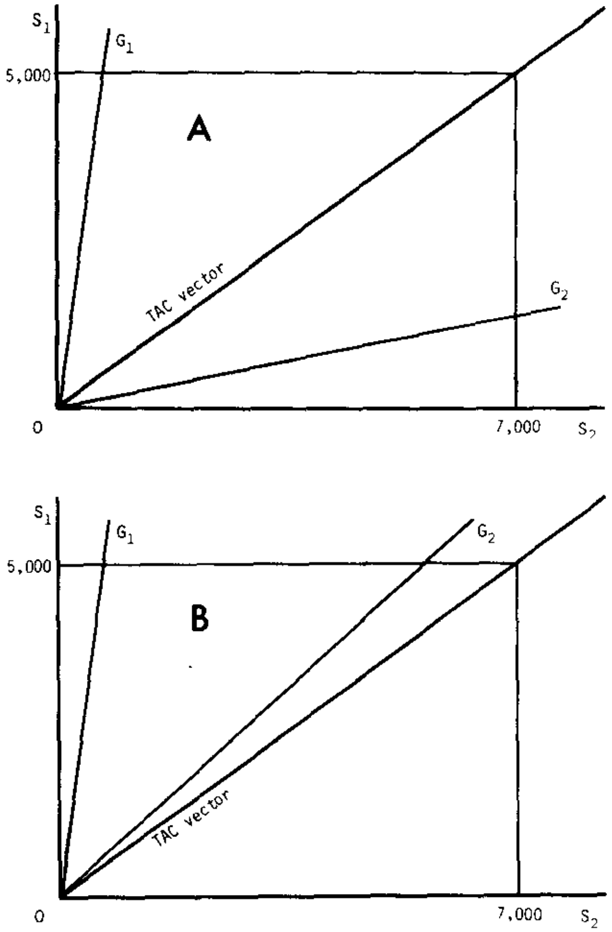

Fig. 1. Illustrations of by-catch structures for which (**A**) the sum of the biological TACs is attainable, and (**B**) the sum of the biological TACs is not attainable.

	G_1	G_2	G_3
S_1	0.90	0.45	0.15
S_2	0.10	0.55	0.85

since the by-catch vector for G_3 lies on the opposite side of the TAC vector from the other two.

If we denote the overall catches in the fisheries (G_i) by C_i as before, the problem is to find a solution (C_1, C_2, C_3) which maximizes the linear function $C = C_1 + C_2 + C_3$, out of the sets of solutions which meet the following conservation requirements, where $C_i \geq 0$:

$$0.90\ C_1 + 0.45\ C_2 + 0.15\ C_3 \leq 5{,}000$$

$$0.10\ C_1 + 0.55\ C_2 + 0.85\ C_3 \leq 7{,}000$$

A brief description of an algorithm may provide a better understanding of the underlying principles. Let us first introduce two "dummy" non-negative parameters, λ_1 and

λ_2, to allow for the replacement of the inequality signs by equality signs in the conservation requirements:

$$0.90\,C_1 + 0.45\,C_2 + 0.15\,C_3 = 5{,}000 + \lambda_1$$
$$0.10\,C_1 + 0.55\,C_2 + 0.85\,C_3 = 7{,}000 + \lambda_2$$

Solving these linear equations for two of the three variables (say, C_1 and C_2) results in the following functions:

$$C_1 = -889 + 0.667\,C_3 - 1.222\,\lambda_1 + \lambda_2$$
$$C_2 = 12889 - 1.667\,C_3 + 0.222\,\lambda_1 - 2\lambda_2$$

Adding the two equations,

$$C = C_1 + C_2 + C_3 = 12000 - \lambda_1 - 2\lambda_2$$

The target of maximizing C suggests that $\lambda_1 = \lambda_2 = 0$, and hence

$$C_1 = -889 + 0.667\,C_3$$
$$C_2 = 12889 - 1.667\,C_3$$

Thus, any set of non-negative C_1, C_2 and C_3, which satisfies these two linear relations, is one of the solutions; in other words, quota allocation is indeterminate in so far as it satisfies these two linear constraints. To obtain a unique solution, another linear relation can be introduced, but this does not imply that any linear relation would result in a solution without some modification of the attainable target. If a reduction in the attainable target can be accepted, then a solution satisfying an additional linear constraint may be obtained such that the "dummy" parameters (λ_1 and λ_2, both positive) will represent the amounts of reduction imposed by the additional constraint.

More generally, in the case of *n* fisheries, a set of feasible solutions satisfying the conservation requirements could be defined in the same way. Thus a 2 by *n* matrix determines the two linear independent relations among the *n* variables, $C_1, C_2, \ldots, C_n$. In the case of *m* species, the *m* by *n* matrix determines *m* linear independent relations among the overall catches (C_i) of the *n* fisheries ($m \leqslant n$). Theoretically, then, *n-m* additional linear relationships can be introduced in order to obtain a unique solution. Thus, while the number of management options would appear to be greater than in the case of managing single fisheries, the advantage might not be as great as expected, since the options available will depend on the intrinsic structure of the by-catch matrix.

In summary, for the case of *m* species and *n* fisheries, the *n* by-catch vectors (assumed as fixed for each fishery) forms a pyramid in the *m*-dimensional space, whose apex is at the origin, although some vectors may be buried in it. If the TAC vector is contained within the pyramid, the sum of the TACs can be attained as a target; otherwise, the sum of the TACs is not attainable. In the latter case, however, if some species are removed from consideration, the sum of the remaining TACs would be attainable as a target, and there would be no harm to the species that were removed, as is evident in the second numerical example above. In practice, therefore, if the conservation requirements are reasonably framed, the sum of the TACs is always attainable, although some species may remain under-exploited.

If the number of fisheries (*n*) is equal to the number of species (*m*), there exists a unique solution of yield allocation to attain the sum of the TACs, depending on the given by-catch matrix. If *n* is greater than *m*, there exists a set of solutions to attain the sum of the TACs, *i.e.* the yield allocation is indeterminate under the *m* linear constraints. Theoretically, *n-m* additional constraints can be introduced on some arbitrary basis to arrive at a unique solution, but, practically, the number of options would be very limited, unless appreciable reduction in quota for some species can be accepted, because the *m* by *n* by-catch matrix has imposed *m* linear independent constraints to be satisfied. When *n* is less than *m*, a satisfactory solution could be obtained through the appropriate exclusion of some species from the framework.

A More Generalized Model and its Algorithm

The by-catch ratios in the above examples were rather unrealistically assumed to be fixed for each fishery, but this is seldom the case in practice, as many factors are involved in determining the by-catch ratios: stock abundance, distribution and migration, coupled with gear selectivity, technical innovations to fishing vessels and gear, and variations in the overall year-round fishing strategy. The underlying complexities will be considerably amplified as the fisheries expand to involve more and more species stocks. However, the historical performances of the various fisheries indicate that, while the by-catch ratios may vary from year to year, sometimes considerably, they fluctuate within some definitive ranges, some of which are much larger than others. While there are some unpredictable, natural and operational factors involved, many others are undoubtedly controllable within finite ranges, and a satisfactory solution to the problems inherent in managing multi-species fisheries depends on the extent to which these factors can be controlled in practice.

Theoretically, in the two-species case, a by-catch ratio for either species determines the other as the complement. In the three-species case, a by-catch ratio for one species will leave the ratios for the other two species indeterminate, because there remains one degree of freedom for determination. Thus, more generally in the m-species case, there remain m-1 degrees of freedom, so that much of the underlying complexities could well be incorporated into this kind of linear formulation. Assuming that the by-catch ratios vary within finite ranges, their vectors form a pyramid in the m-dimensional space (more generally, a convex cone, if continuity is assumed, with no change in algorithm). If n fisheries are involved, there exist n such pyramids in the space, one for each fishery. Even though the model may appear to be very complicated, a key point is that it is not the detailed configuration of these pyramids nor all of their edge vectors that matter, but rather that some of the components of the edge vectors and their configurations play an important role in solving the problem, as will be shown below.

First, let us consider the case of two species stocks exploited by two fisheries, whose by-catch ratios are indeterminate with finite ranges as follows:

	G_1		G_2	
S_1	0.95	0.80	0.35	0.10
S_2	0.05	0.20	0.65	0.90

In Fig. 2[2], the actual catch of G_1 is represented by the region between the two rays $OG_1(U)$ and $OG_1(L)$ and that of G_2 between the rays $OG_2(U)$ and $OG_2(L)$. If we denote the overall catches of G_1 and G_2 by C_1 and C_2, then the actual catches of G_1 and G_2 will vary on the line segments A_1A_2 and B_1B_2 respectively.

Let us now consider the four combinations of two vectors, one for each of the two groups, (OA_1, OA_2) and (OB_1, OB_2). The sums of the two vectors in the four combinations will be represented by the four vectors (OX_{11}, OX_{21}, OX_{12}, OX_{22}), whose end-points are on the line segment $X_{11}X_{22}$, because they are all equal to $C_1 + C_2$. It is evident therefore that, wherever the actual catches of G_1 and G_2 may fall on the line segments A_1A_2 and B_1B_2, the point representing their sum is on the line segment $X_{11}X_{22}$. To satisfy the conservation requirements, this line segment must lie within the rectangle OM_1MM_2, so that the S_1 coordinate of the end-point X_{11} does not exceed the TAC for S_1 of 5,000 tons and the S_2 coordinate of the end-point X_{22} does not exceed the TAC for S_2 of 7,000 tons, that is,

$0.95\,C_1 + 0.35\,C_2 < 5{,}000$, for S_1 coordinate of X_{11},
and
$0.20\,C_1 + 0.90\,C_2 < 7{,}000$, for S_2 coordinate of X_{22}.

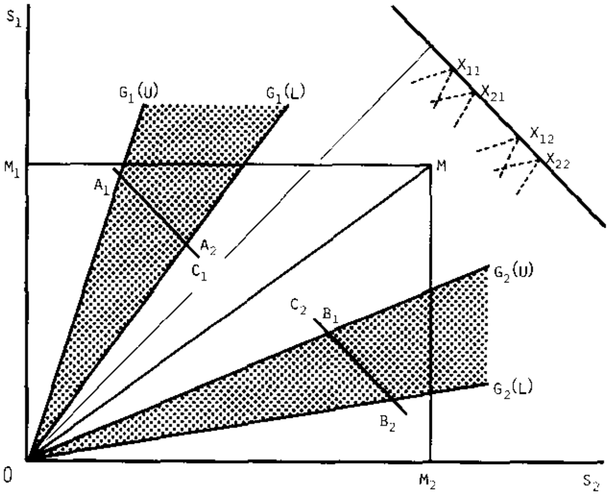

Fig. 2. Illustration of a more general by-catch structure in which the by-catch ratios are indeterminate but vary within finite limits.

Solving a set of these inequalities so as to maximize $C = C_1 + C_2$, we obtain $C_1 = 2{,}611$ tons and $C_2 = 6{,}478$ tons, and the yield allocations (tons) may be summarized as follows:

	G_1	G_2	Total
S_1	⩽ 2,480	⩽ 2,267	⩽ 4,747
S_2	⩽ 522	⩽ 5,830	⩽ 6,352
Overall Quota	2,611	6,478	9,089

The following observations may therefore be noted:

a) The overall quotas for G_1 and G_2 are uniquely determined, but the species allocations are indeterminate with possible maximum allowable catches, thus permitting options of species quotas which are constrained by the fixed overall quotas.

b) The total overall quota (9,089 tons) is appreciably less than the sum of the TACs, which has been shown to be attainable if the by-catch ratios are fixed on both sides of the TAC vector. Such a reduction in overall quota depends on the ranges within which the by-catch ratios are indeterminate.

c) The sum of the possible maximum species catches for S_1 (4,747 tons) and for S_2 (6,352 tons) are both less than their TACs of 5,000 and 7,000 tons respectively. This is because the target is assumed to be the maximum combined catch of both species. For example, if the catch S_1 is increased to the TAC level of 5,000 tons, the resultant decrease in the catch of S_2 will reduce the total overall quota below 9,089 tons.

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[2] Same as in Appendix 1 of Fukuda (1973) where it is applied to somewhat different situations.

The algorithm can be readily extended to the more general case of m species fished by n fisheries, in which the by-catch vectors, as noted earlier, form a pyramid in the m-dimensional space for each of the n fisheries. The edge vectors of each pyramid can be arranged in a matrix, as in the 2 × 2 matrix of the above example. The conservation requirements can be expressed in the form of inequalities for S_i ($i = 1, 2, ..., m$) by selecting the largest component on the ith row in the by-catch matrix for each of the n fisheries, in addition to the biological TACs for S_i. Having constructed a set of inequalities in this way, the solution can be determined as described above. A feature of the matrix, made up of the coefficients in the left side of the inequalities, is worthwhile to note, because the ranges, within which the by-catch ratio is indeterminate for each fishery, are indicative of how much the sum of the column components exceed unity. Evidently, any set of solutions will retain all of the features so far discussed.

Summary

Yield allocation problems, in the case where m species are exploited by n fisheries, have been rather theoretically considered in relation to conservation requirements, maximum utilization of resources and given by-catch structures with finite ranges, and the conclusions may be summarized as follows:

1) In the case of multi-species fisheries, some species may be of lesser significance and their conservation can be assured by reasonably regulating the fisheries on the others, although they may be left under-exploited. These could be better considered separately.

2) If such species are excluded, the sum of the TACs can generally be attainable as a target, if the by-catch ratios are assumed to be fixed for each fishery. On the other hand, if the by-catch ratios are indeterminate but fall within finite ranges, the sum of the TACs cannot be taken as a reasonable target if the stocks are to be effectively conserved, as it will be necessary both for the species quotas to be less than their TACs and for the overall quota to be less than the sum of the TACs. The required reductions, different for each species and with provision for fishery options, will depend on the ranges within which the by-catch ratios are indeterminate, as well as on the by-catch structure and the biological TACs.

3) In either case, the overall yield allocation among the n fisheries in uniquely determined when n is equal to m, or, more generally, is indeterminate under m linear constraints imposed, when m is greater than n, by the given by-catch structure. Theoretically, n-m additional linear constraints can be introduced on the basis of other considerations to arrive at a unique allocation, but, in practice, the actual freedom of options would be very limited, in comparison with the single species case, unless appreciable reduction in the otherwise attainable target yields can be agreed upon.

4) Disregard of these considerations, especially of constraints imposed by the given by-catch structure, will probably result in much too optimistic yield allocations, increase in wasteful discarding, and eventual failure of conservation attempts. In this sense, therefore, the present system of allocation, as applied to stocks individually, needs to be critically reviewed and reconsidered.

Reference

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Review Papers

Introductory Remarks

At the 1974 Annual Meeting of ICNAF, the Standing Committee on Research and Statistics endorsed the recommendation of the Environmental Subcommittee that a working group be established "to suggest a proposal aimed at determining the factors involved in the production of good and poor year-classes in some of the major fisheries of the ICNAF Area". The first meeting of the Environmental Working Group was held at Charlottenlund, Denmark, during 23-25 September 1974, during which proposals were made for the study of herring stocks in the Gulf of Maine-Georges Bank area and of cod on Flemish Cap, and review papers on the status of available information for these areas were invited for presentation to a later meeting of the Group.

The second meeting of the Working Group was held at Aberdeen, Scotland, during 21-31 May 1975 to further consider the proposals and to review a number of relevant papers presented to this meeting. In particular, the Working Group welcomed the valuable contributions of Dr D. F. Dumpus and Dr W. Templeman, whose great wealth of knowledge about the Gulf of Maine-Georges Bank area on the one hand and the Flemish Cap on the other are reviewed in the following papers.

The Editor

Biological and Oceanographic Background of Flemish Cap as an Area for Research on the Reasons for Year-Class Success and Failure in Cod and Redfish

Wilfred Templeman[1]

Abstract

Variability in year-class success of Atlantic cod and redfish, together with information on plankton and hydrography, was examined to form part of the background for a decision on the wisdom of carrying out a research program on Flemish Cap (ICNAF Division 3M), designed to determine the major reasons for year-class success and failure of these species. The main factors in the water circulation are a clockwise movement around the Cap and a northeastward flow away from the southeastern part of the bank. Water temperatures are typically those of the warmer seaward part of the Labrador Current, but in some recent years the colder water of the Labrador Current reached the bank.

The stocks of both cod and redfish on Flemish Cap are relatively isolated from those of the adjacent Grand Bank. There is a small stock of *Sebastes marinus* on the Cap, but the main population of redfish consists of the sharp-beaked variety, very likely a mixture of *S. fasciatus* and *S. mentella*, adults of the former being in the shallower areas and those of the latter, probably forming the major part of the redfish stock, being mainly in deeper water. Cod spawning usually occurs mainly in March with some in February and in April-May. Redfish spawning extends from March to July or even August, the earliest spawning occurring in the deeper water. The propagation of *Calanus finmarchicus* begins as early as March and a second generation begins in July. The occurrence of recently-extruded redfish larvae north of the Cap coincides with the first peak of copepod abundance in the area. Young redfish and young cod form a large part of the food of older cod, and smaller but significant amounts of young redfish are also eaten by the larger redfish.

There is considerable variation in the strength of year-classes of cod on Flemish Cap, but little indication of significant variation in the year-class strength of redfish prior to 1972 is evident on the basis of age reading of adults from commercial catches. However, length frequency data show that from 1958 to 1974 only two very successful year-classes (or year-class groups) of sharp-beaked redfish appeared on Flemish Cap, nominally those of 1959 and 1963. There are indications that there had not been a highly successful year-class for at least 17 years prior to 1959. The two very successful year-class groups appeared only after the development of a redfish fishery beginning in 1956 and reaching its peak in 1958 and 1959.

In order to evaluate the relative strength of year-classes for cod, and especially for redfish, age reading of commercial catch samples should be supplemented by length frequency data from research surveys using small-meshed trawls, codend liners or preferably small-meshed covers, and by studies on the size and abundance of young cod and redfish in cod stomachs. It is concluded that the size and isolation of the stocks, variability in year-class success and in environmental influences, and other factors are favourable to the use of the Flemish Cap as an area for research on year-class success and failure of cod and redfish.

Introduction

The ICNAF Environmental Working Group, which met at Charlottenlund, Denmark, 23-25 September 1974 (Mr E. J. Sandeman, Chairman), considered the feasibility of a research program designed to identify the parameters of greatest importance to the production of good and poor year-classes of some of the major groundfishes of the ICNAF area (ICNAF, MS 1975). The Working Group considered the possibility that Flemish Cap might be a suitable area to begin such a study and, as a preliminary to a decision, the author was asked to prepare a paper on the oceanographic and biological features of the Flemish Cap ecosystem. This paper was presented at the meeting of the Working Group in Aberdeen, Scotland, 27-31 May 1975.

The major populations of commercial fish on Flemish Cap (ICNAF Div. 3M) are Atlantic cod (*Gadus morhua* Linnaeus) and redfish of several species to be considered later. In this paper, I shall review some of the biological and oceanographic material available for the area, pertinent to the problem of variability in year-class success of cod and redfish. There is no attempt to review all fisheries, biological, and oceanographic research for the Flemish Cap area. The paper deals especially with data reported to ICNAF and with such other data as were readily available. There must be a great deal of additional data reported in the many languages of Commission countries or in the files of the various research organizations, which could not be obtained or dealt with in the time available.

Although the earlier information on cod landings from Flemish Cap is not available, this bank has evidently been fished for cod for a long time. Collins and Rathbun (1887), referring to US fishermen, said that Flemish Cap was visited in spring and summer and the only vessels fishing the Cap have been engaged in the salt halibut and cod fisheries. They said that, according to the statements of

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fishermen most familiar with these grounds, no trouble (apart from the area being a difficult one to fish) was ever observed in obtaining large quantities of medium-sized cod, below the standard size required in the United States markets. Larger fish were less common, although occasionally very successful trips for large cod have been made. Du Baty (1926) reported that the isolated plateau of Flemish Cap was an excellent fishing place and was one of the best fishing grounds off Newfoundland. He said that some French captains (but apparently not many) regularly visited the Cap and that cod were generally abundant there at all seasons.

Nominal catches of fish from the ICNAF area were first separated by division in 1953. Cod catches from Flemish Cap (Div. 3M) reached a peak of 54,000 tons in 1965 and 57,000 in 1972, and after 1965 were at their lowest at 18,000 tons in 1970. Catches from 1961 to 1974 averaged 31,000 tons. The USSR took most of the cod from Div. 3M (66%) from 1956 to 1965, but the largest amount (39%) was taken by Portugal from 1966 to 1974 (Fig. 1). Nominal catches of redfish from Div. 3M reached their highest levels of 55,000 tons in 1958 and 52,000 in 1959. After 1959, catches were generally at low levels until 1972 when they rose again to 42,000 tons. The

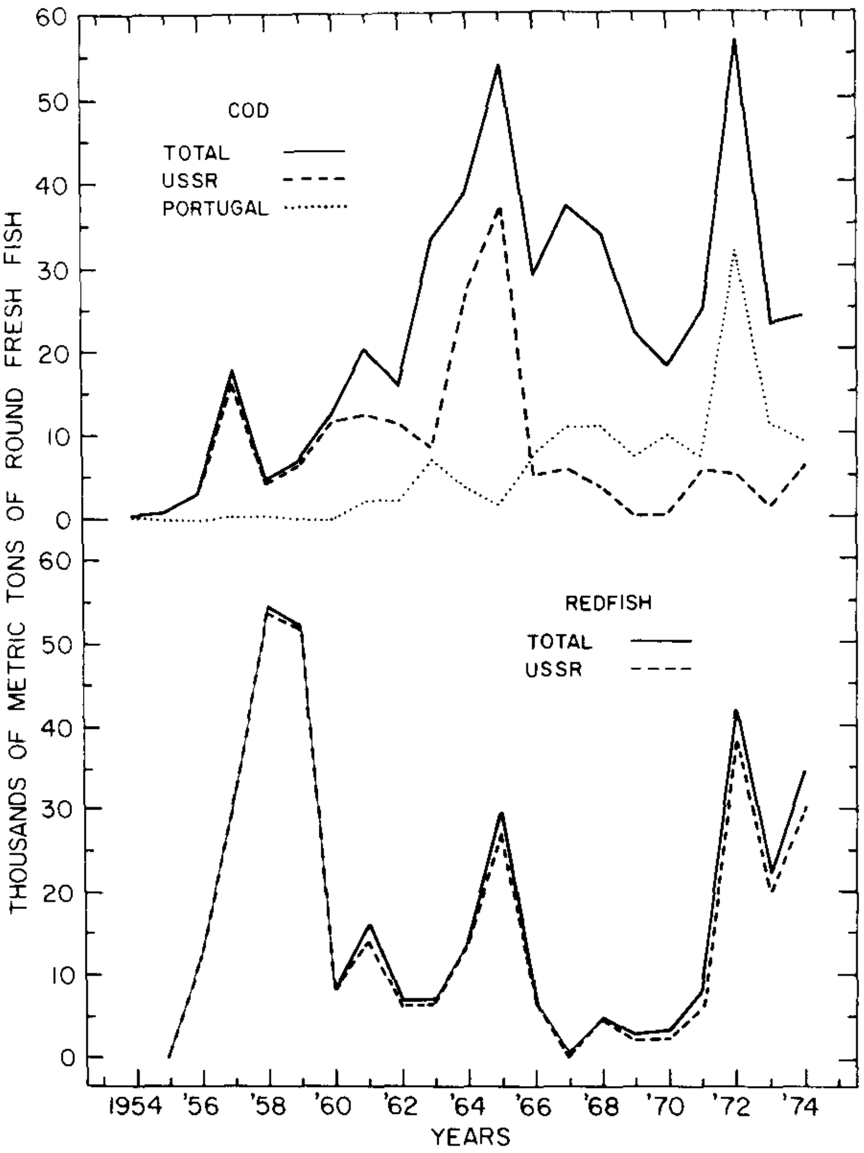

Fig. 1. Nominal catches of cod and redfish from Flemish Cap (Div. 3M), 1954-74.

average catch for 1956-74 was 19,000 tons, 94% taken by the USSR.

Of the total catches of all species from Div. 3M of 48,075 and 63,635 tons in 1973 and 1974, cod and redfish totalled 45,252 and 58,658 tons respectively. The next highest catches by species for the years 1973 and 1974 were (in tons): American plaice, 504 and 1,928; capelin, 317 and 0; wolffishes 254 and 306; witch flounder 248 and 50; and Greenland halibut 0 and 407. It is unusual for capelin to be reported from the Cap but in 1973 the water near the Cap was unusually cold.

It is evident that there are sizable populations of cod and redfish on Flemish Cap, sufficient to produce enough eggs and larvae to provide a basis for studies of year-class variability. Also, the populations of cod and redfish varied considerably when the influence of fishing was added to their normal variability in numbers and year-class structure.

Flemish Cap — Description, Name and Location

Flemish Cap is a small bank east of the northern Grand Bank from which it is separated by the Flemish Channel, over 1,000 m deep (Fig. 2). The part of the bank included within the 200 m isobath is about 52 nautical miles long from north to south and 42 nautical miles wide from east to west. The shallowest part of the bank at 140

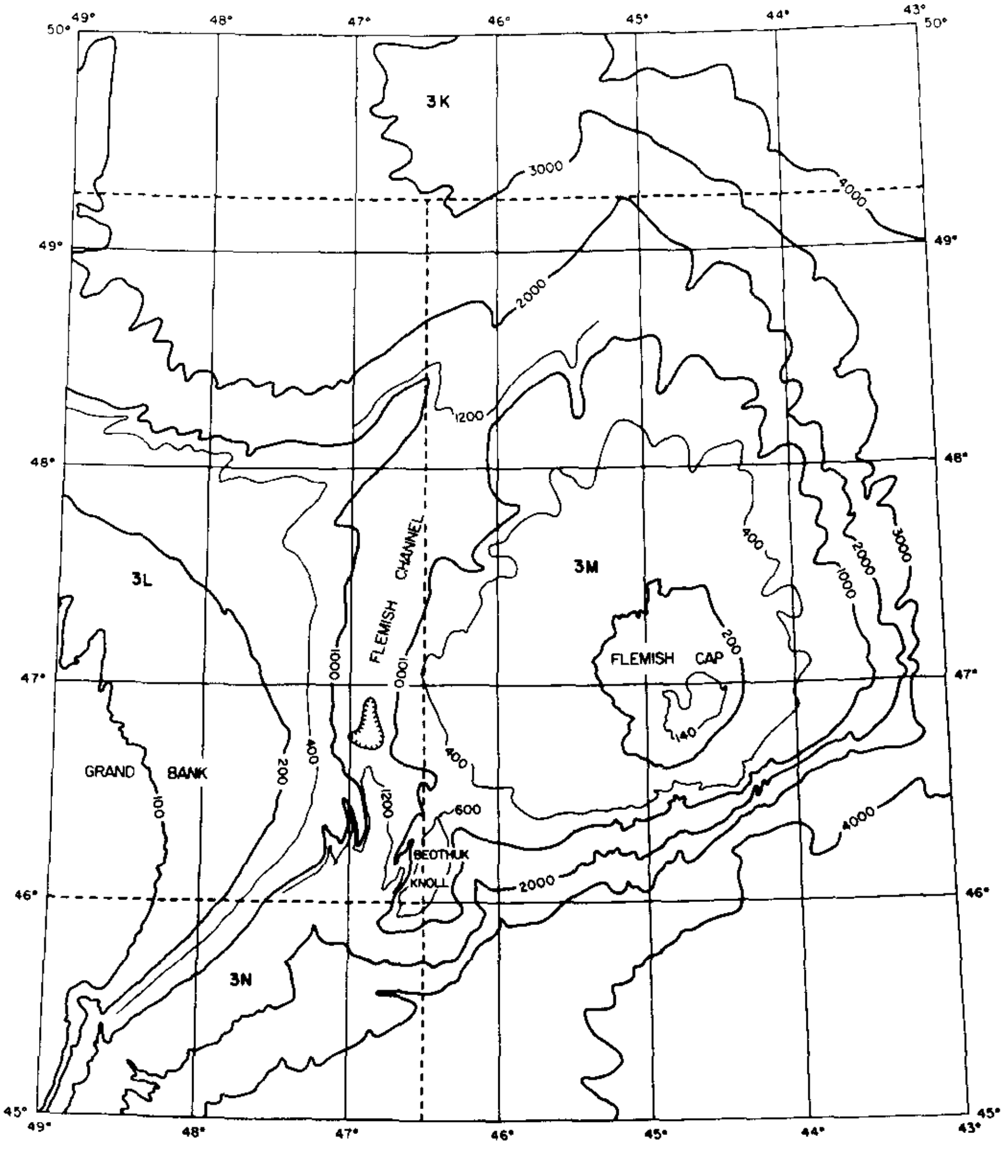

Fig. 2. Isobaths (metres) for Flemish Cap and adjacent ICNAF divisions and bank areas.

m and less lies to the southeast. The slopes with fishable limits to 800-1,000 m extend the bank considerably, particularly toward the north and west. The slopes to the south are precipitous with the isobaths close together.

On a chart of the banks of Newfoundland, dated at London, 25 March 1775 (Eaton and Macnab, 1975), Flemish Cap is called Outer Bank or False Bank and in smaller print, Flemish Cap. "Le Bonnet Flamand" was used as a name for Flemish Cap in the Manuscript Atlas of New France, 1782 (Public Archives of Canada) (Smith, MS 1970). It is most likely that the earliest form of the name Flemish Cap was Le Bonnet Flamand, although it is uncertain whether or not this was the earliest name for the bank.

Collins and Rathbun (1887) said that the bottom of Flemish Cap is composed of mud, sand, gravel, pebbles and rocks, distributed in patches of variable extent and character. In the localities (the shallower surface of the bank) at that time resorted to by vessels from the USA, the prevailing bottom is often a slaty rock, apparently *in situ,* and forming a smooth surface, on which the anchor often fails to take a firm hold. The hard central core of granite of the Flemish Cap itself, which is smooth and almost devoid of soft sediments, is surrounded by much younger sedimentary beds that slope outward from the Cap (Loncarevic and Ruffman, 1972). The geological origin of the Cap is discussed by Grant (1972) and the characteristics of the bottom at and surrounding the Cap by Litvin and Rvachev (1962).

It is apparent also from Fig. 2 that the dividing line, 46°30′W longitude, between Flemish Cap (Div. 3M) and Div. 3L and 3N is incorrect in that by using this line, Div. 3L and 3N include a considerable portion of the western slope of Flemish Cap as shallow in places as 400 m and including a good share of Beothuk Knoll with central depths shallower than 600 m. The error affects especially redfish and possibly also cod in the spawning season because Flemish Cap cod spawn mainly on the southwestern slopes of the Cap. The correct dividing line between Div. 3M and Div. 3L and 3N should be through the middle of the deepest water (over 1,000 m) of Flemish Channel.

Hydrography of Flemish Cap

Water circulation

For the surface circulation, Smith *et al.* (1937) noted that, from the northern edge of the Grand Bank to the tail of the Bank, parts of the Labrador Current are turned back to the northward. The northernmost of these returned branches forms a closed whorl between the trunk of the Labrador Current, Flemish Cap and the mixed waters of the border of the Atlantic Current. Buzdalin and Elizarov (1962a) reported that a relatively warm stream, the Flemish Cap Current separates from the Labrador Current near 48°N and moves generally eastward toward the northern slope of Flemish Cap. Most of this current flows southward on the eastern slope of Flemish Cap. Near the southern slopes of the bank it meets a northward flowing current of mixed water which parallels the southern slope of the Cap and then shifts northeastward taking with it the waters of the Flemish Cap Current. In the central area of Flemish Cap, the waters move slowly forming cyclonic and anticyclonic whirlpools.

In 1970-71 the main pattern of water circulation was similar to the usual pattern. The Labrador Current and its branch moved clockwise around Flemish Cap and clockwise on the central part of Flemish Cap. Although waters move mainly in a clockwise direction, on the southern part of the Cap secondary eddies with an anticlockwise movement were observed (Kudlo and Burmakin, 1972). Hill *et al.* (MS 1973), from work carried out in April and May 1972, concluded that their researches provided support for the view of Kudlo and Burmakin (1972) that normally there is a clockwise gyre around the Flemish Cap itself.

Temperatures and Salinities, St. John's Station 1951-74 Series

Yearly temperatures and salinities for a Flemish Cap section 1954-73 are available in Templeman (1955-74) for the St. John's — Flemish Cap line of stations at 47°N, between 20 July and 1 August. Similar information for the years 1951-53 and 1974 are also available at the Biological Station, St. John's. Newfoundland. A summary of highest, lowest and average temperatures at this time of year for 1951-71 and comparisons with 1972 and 1973 are available in Templeman (1975). Unfortunately, in the ICNAF group of publications there do not appear to be similar yearly Flemish Cap hydrographic sections in March to June when eggs and larvae of cod and redfish are abundant in the area, but I have noted some and others must be available in various countries' publications or files or in ICNAF or other publications that I have failed to note.

The Flemish Cap temperatures are normally those of the outer warmer part of the Labrador Current, and the colder waters of the eastern branch of the Current rarely reach it. In the 20 July-1 August sections (Templeman, 1975) at Station 41 immediately above the top of the Cap in 157 m, the bottom temperature range in 1951-73 was 2.43° to 4.84°C and the lowest temperature from surface to bottom was 2.42°C from 1951 to 1972 but in 1973 it was 1.01°C. Surface temperatures at this station in 1951-73 ranged from 9.2° to 15.8°C. At Station 42 in 503 m on the eastern slope of the Cap, the lowest temperature in 1951-71 was 1.33°C at 50 m, where the average temperature was 4.49° and the highest 7.54°C, but in 1972 some isolated cold water from the Labrador Current reached this station and the lowest temperature (again at 50 m) was −1.16°C. In 1973, also, this was the case and the lowest temperature was 0.22°C. There is, therefore, some variability in temperatures and their accompanying salinities on the Cap, and in cold years some of the colder water of the eastern branch of the Labrador Current can reach the Cap. At Station 41 in 157 m for the period 1950-73, the coldest years and lowest temperatures were: 1973 (1.01°C, 75 m); 1971 (2.42°C, 75 m); 1972 (2.43°C, 150 m); 1959 (2.85°C, 100 m); 1950 (taken on July 10, 2.94°C, 155m); 1957 (3.01°C, 152 m); 1953 (3.02°C, 153 m). In other years of the 1950-73 period, all temperatures were 3.25° or higher. In the warmest years, the lowest temperatures at this station were: 1968 (4.69°C, 75 m); 1966 (4.41°C, 150 m); 1967 (4.11°C, 150 m); 1962 (4.05°C, 155 m).

At Station 42 on the eastern slope of the Cap in 503 m, the lowest temperatures from 1950 to 1973 were: 1972 (−1.16°C, 50 m); 1973 (0.22°C, 50 m); 1971 (1.33°C, 50 m); 1950 (taken on July 10, 1.74°C, 50 m); 1968 (2.47°C, 75 m); 1951 (2.64°C, 100 m); 1969 (2.74°C: 75 m); 1959 (2.76°C, 75 m). In the warmest years, the lowest temperatures at this station were: 1952 (3.68°C, 100 m); 1961 (3.68°C, 400 m); 1965 (3.61°C, 500 m); 1962 (3.57°C, 500 m); probably 1966 judging from Station 41 but Station 42 not taken in 1966; 1967 (3.50°C, 75 m).

Comparisons of March-April and July temperatures in the same year

Deepwater temperatures in March 1961 on the eastern slope and at the top of Flemish Cap were very close to those of 22-25 July 1961, but on the western slope of the Cap temperatures between 200 and 300 m were approximately a degree higher and at 400-500 m a half degree higher in March than in July. Surface temperatures on the Cap in March were 3.8° to 5.7°C and in July 12.0° to 12.2°C (Templeman, 1962, fig. 4, standard St. John's-Flemish Cap section, 47°N line, 25-27 March 1961).

Temperatures immediately over and around the Cap in April 1958 sections (Movchan, 1967; Dietrich, 1960) were essentially similar to those on 27-30 July 1958 (Templeman, 1959a). Surface temperatures above the Cap were about 4° or 5° to 7°C in April and 9.8° to 10.8°C in July. Dietrich provides temperature, salinity and oxygen sections through the Flemish Cap area for April and August-September 1958.

In a St. John's Station cruise to Flemish Cap, 29 February-6 March 1968, the standard St. John's-Flemish Cap section on the 47°N line was occupied, (unpublished data). At Station 40, on the western slope of the Cap on 5 March, temperatures ranged from 3.6°C at the surface to 4.4°C near the bottom in 326 m. Lowest temperatures were at the surface and the highest (4.7°C) at 150 m. At Station 41 at the crest of the Cap on 5 March, temperatures were almost uniform from 4.5°C at the surface to 4.4°C at the bottom, and at Station 42 on the eastern slope of Flemish Cap on 6 March temperatures were 5.0°C at the surface (highest) and 3.8°C (lowest) near bottom at 500 m. Apart from temperatures above 50 m (surface temperatures 8.7° to 9.2°C at these stations in July), these March temperatures were not very different from those at the same stations during 25-27 July 1968 (Templeman, 1969b).

The eastern Grand Bank — western Flemish Cap temperature section of Hill *et al.* (MS1973) for 1972, apparently late April, showed surface temperatures of about 3°C on the western slope of Flemish Cap, compared with 10.8° to 12.4°C in late July 1972 (Templeman, 1973a). Bottom temperatures on the western slope between about 170 and 250 m were higher at about 3° to 4°C in April compared with late July temperatures of about 1.3° to 3°C. The colder part of the Labrador Current extended farther eastward toward the Cap in July.

It is apparent, therefore, that temperatures over the Cap in March-April are usually approximately similar to those in late July, and consequently the St. John's Station Flemish Cap sections for 1951-73, referred to above, are probably useful indicators of temperature conditions in the March-June spawning and early larval period. However, in cold years the cold part of the Labrador Current may extend farther eastward after April, producing lower mid-water and bottom temperatures in July, especially on the western slope of the Cap.

Although I have considered here mainly the readily available hydrographic sections that have been reported to ICNAF, the US Coastguard Oceanographic Reports contain immense amounts of hydrographic data, obtained mainly in April-June for Flemish Cap, which would require great effort, time and space to review adequately. A brief consideration of these reports for recent years indicates that the conclusions reached above are valid.

Other sections

Other sections or partial hydrographic sections of Flemish Cap noted were: temperature section at 46°45′N through Grand Bank and Flemish Cap, 12-16 June, 1925 (Du Baty, 1926); temperature sections SW and NE slopes of Flemish Cap, July 1959 (Magnusson, 1960); temperature and salinity sections, standard section on 47°N line through Flemish Cap, 10-11 July 1959, and northern slope of Flemish Cap, 7-9 July 1959 (Elizarov, 1960); standard temperature section Grand Bank-Flemish Cap on 47°N line, 21-24 August 1961 (Buzdalin and Elizarov, 1962b); temperature and salinity sections, 47°N line St. John's Station standard section, 4-6 December 1962 (Ramster, 1964).

Isolation of Flemish Cap Stocks of Cod and Redfish

Cod

Konstantinov (1970) reported 15 recaptures on Flemish Cap from cod tagging in the area during 1961-66, and no recoveries outside Div. 3M. Also, there were no records of tagged cod migrating to Flemish Cap from 35,000 cod tagged by USSR in Subareas 2 and 3 during 1960-66 (971 recaptures up to 1 March 1967; Konstantinov, MS 1967). Also from Canadian cod tagging in 1954-55 (Templeman, 1974), mainly in Newfoundland coastal areas, no recaptures were reported from Flemish Cap. However, there was relatively little cod fishing on Flemish Cap in the period 1954-59 when most of the recaptures were made.

From more recent Canadian results (unpublished data) of cod tagged on Flemish Cap in May-June 1962 and July 1964, 1 in 98 recaptures during the tagging year and 6 of 40 recaptures after the tagging year were reported from areas other than the Cap. Four cod tagged in Div. 3L and 2J (of 15,350 recaptures from tagging in all areas except Flemish Cap) were reported as recaptured on Flemish Cap. It has not been possible to authenticate these recaptures but occasional cod apparently cross oceanic depths and travel great distances (Thompson, 1943; Hansen, 1949; Postolaky, 1966; Tåning, 1934, 1937; Gulland and Williamson, 1962; Templeman, 1974). Thus, it would be very surprising if some cod did not leave Flemish Cap and also be recruited to it from adjacent areas. If the reported recaptures are assumed to be authentic, they indicate a greater tendency for cod to move from the Cap than to it, and in any case the migration of cod to the Cap is relatively small.

Other evidence for the relative isolation of the Flemish Cap cod stock is the lack of the cod nematode *Terranova (=Porrocaecum) decipiens* in the fillets of cod from Flemish Cap (Templeman *et al.*, 1957), the distinctly earlier cod spawning on Flemish Cap than on the neighboring eastern Grand Bank (Templeman, 1962), and lack of infection of Flemish Cap cod by *Lernaeocera branchialis* (Templeman and Fleming, 1963). The first and third of these would be mainly affected by the migration of cod to rather than away from Flemish Cap. Additionally, Jamieson (1975) showed highly significant differences in transferrin allele frequencies in blood sera between cod of Flemish Cap and of the adjacent northeastern Grand Bank.

Redfish

Studies of the incidence of its copepod parasite, *Sphyrion lumpi*, by Templeman and Squires (1960), indicated that *S. mentella* of the western Atlantic migrate relatively little. No *S. lumpi* infection was found in Flemish Cap redfish but some was found in the Grand Bank redfish southwest of the Cap. Also no redfish on Flemish Cap were found bearing "old heads" (dead cephalothoraces) of *S. lumpi* in their fillets, whereas some of these were present in the fillets of redfish of the adjacent Grand Bank slope.

In the study of parasites of *S. marinus* and *S. mentella* in the western Atlantic by Yanulov (1962a), no *S. lumpi* were found on Flemish Cap *S. mentella*, although small percentages of *S. mentella* on the eastern slope of the Grand Bank were infected by this parasite. Yanulov, however, found 0.2% of *S. mentella* on Flemish Cap to have dead cephalothoraces of *S. lumpi* compared with 0.7% and 1.3% in the adjacent Div. 3L and 3N. Similarly for the copepod, *Chondracanthopsis nodosus*, a gill parasite, the infection rate of *S. mentella* was 1.9% on Flemish Cap (Div. 3M) compared with 7.6% and 8.8% in the adjacent Div. 3L and 3N. Thus, the redfish stocks on Flemish Cap, at least of the sharp-beaked forms, are relatively but not necessarily completely isolated from those on the slopes of the adjacent Grand Bank. What relationship there may be with the oceanic stock of *S. mentella* is unknown. There is very likely at least some relationship with the Flemish Cap redfish through larval recruitment from both the oceanic and the Grand Bank stocks.

In view of the demonstration by Barsukov and Zakharov (1972) of the differences in meristic characters between *S. marinus*, *S. mentella* and *S. fasciatus*, it is not worthwhile to try to assess the degree of isolation of Flemish Cap as shown by the vertebral counts of Templeman and Pitt (1961) whose material was gathered in 1947-54 and thus had no separation by species. Similarly in the meristic material of Yanulov (1962b), the sharp-beaked redfish were all called *S. mentella*. In Barsukov and Zakharov (1972), although they separated the three species, because of the small numbers of redfish examined from Flemish Cap they did not separate the redfish meristics for Div. 3M from those of adjacent divisions. Also the state of the art of separating *S. mentella* and *S. fasciatus* and the smaller *S. marinus* at the present time may not always be accurate enough for precise comparisons.

Redfish Species on Flemish Cap

Sebastes marinus and *Sebastes mentella*

Traditionally, *Sebastes marinus* (Linnaeus) and *Sebastes mentella* Travin (or *Sebastes mentella*, North American type) have been reported from Flemish Cap. Because in almost all the literature, the sharp-beaked redfish of the Cap were referred to as *S. mentella*, I shall review most of the occurrences of redfish on the Cap in terms of *S. marinus* and *S. mentella* (the latter for the North American region being understood in this discussion to be a collective term for the true *Sebastes mentella* and the American form of sharp-beaked redfish, which Tåning (in Kelly *et al.*, 1961), Barsukov (1968, 1972), and Barsukov and Zakharov (1972) referred to as *Sebastes fasciatus* Storer.

Templeman and Sandeman (1957) described *S. marinus* and *S. mentella* occurrence on Flemish Cap, using material obtained from a cruise of the *Investigator II* in July 1956 (Templeman, 1957b). At 275 m, where relatively small numbers of redfish were caught, both species were present at all sizes and *S. marinus* were more abundant. At 365 m, most of the redfish were *S. mentella* but a few large redfish were *S. marinus*. Below this depth, at 460 m, where good redfish catches were obtained, and also at 550 and 640 m, only *S. mentella* were found. Flemish Cap *S. marinus* and *S. mentella* were also figured in Templeman (1959b).

TABLE 1. Average catches (kg) of *S. marinus* and *S. mentella* by the *A. T. Cameron* per 30-minute bottom trawling (No. 41 otter trawl with 24.1 m headline and 29-mm codend liner) on Flemish Cap, 1961-68. (Average weight of fish (kg) in parentheses.)

		Average catches (kg) at various depth ranges							
Year	Fishing period	145-200 m	220-295 m	310-375 m	365-695 m	435-460 m	520-560 m	610-640 m	Number of 30-min sets
				S. marinus					
1961	20-23 Mar.	0	1(0.68)	47(1.31)	0	2(1.53)	0	0	15
1964	8-22 Sept.	0	41(1.06)	3(1.06)	1(1.82)[a]	0	0	0	22
1968	28 July-6 Aug.	—	18(0.79)	1(1.82)	—	0	0	0	15
				S. mentella					
1961	20-23 Mar.	0.1(0.12)	1(0.35)	74(0.31)	810(0.69)[b]	736(0.56)	1,544(0.49)	1,024(0.53)	15
1964	8-22 Sept.	0	35(0.47)	204(0.26)	406(0.30)[a]	1,119(0.32)	1,630(0.53)	675(0.65)	22
1968	28 July-6 Aug.	—	557(0.42)	272(0.25)	—	394(0.45)	734(0.67)	15(0.82)	15

[a] 440-695 m.
[b] 365-440 m.

Three bottom-trawling cruises of the *A.T. Cameron* to Flemish Cap, on each of which either Sandeman or Templeman, both experienced in separating *S. marinus* from sharp-beaked redfish, was present and a range of depths from 220 to 620 or 730 m was fished, resulted in catches of *S. marinus* and *S. mentella* (about 2% and 98% respectively (Table 1). The best catches of *S. marinus* were at 220-295 m in July-September and at 310-375 m in March. Only one *S. marinus* was taken below 375 m in July-September and none below 460 m in March. Large catches of *S. mentella* were taken at 435-640 m in September and March. An exceptionally large catch of *S. mentella* was made at 275 m in July. The size of both *S. marinus* and *S. mentella* increased with depth. (This was noted by many scientists especially for *S. mentella:* Templeman, 1957b, 1959b; Chekhova, 1972, MS 1973; Nikolskaya, 1937.) There was an anomaly in the sharp-beaked redfish sizes, in that sizes at 220-295 m were greater than at 310-375 m. Similarly in Postolaky (MS 1972) and Chekhova (MS 1973), in a number of Subarea 3 divisions, including Flemish Cap, the sharp-beaked redfish at 201-300 m were on the average larger than those at 301-400 m. Many of those at the lesser depth may have been adult *S. fasciatus*, at the greater depth young *S. mentella* and adult *S. fasciatus*, and at still greater depths beyond 400 m increasingly adult *S. mentella*. Chekhova (MS 1973) reported the following average numbers of redfish caught per hour's trawling (average length in centimetres in parentheses) in a bottom-trawling survey of Flemish Cap during 4-7 April, 1972:

	100-200 m	201-300 m	301-400 m	401-500 m
Sebastes marinus	18(21)	856(36)	26(25)	0
Sebastes mentella	0	30(32)	1750(28)	3612(33)

S. marinus redfish were more numerous than in the *A. T. Cameron* catches, but at the time of Chekhova's trawling the largest catches of *S. mentella* should have been below 500 m (at 520-640 m in the *A. T. Cameron* catches in late March).

Redfish larvae

Tåning (1949) (See also Hansen and Andersen, 1961, and Tåning and Bertelsen, 1961, for the detailed picture) found large quantities of fry of the common redfish, *S. marinus,* in late June-early July 1947 in the area between the south of Iceland and Greenland and a little north of Flemish Cap. He states that in this area north of Flemish Cap he also found the young of the "American" redfish which he considered to have been carried out by currents from Flemish Cap or from neighboring areas of the Newfoundland banks. In this area, the young of *S. marinus* and those of the American redfish could be obtained in the same haul. Tåning and Bertelsen (1961) described the difference between these types as the possession of a melanophore in the cleft between the two large hypural plates in the American form (in which the larvae resembled those of *S. viviparus*) and the absence of the melanophore in the larvae of *S. marinus. Sebastes mentella* Travin, 1951 was not described at the time of Tåning's (1949) paper. The larvae caught by Tåning were older and larger than those subsequently described by Templeman and Sandeman (1959) and the subcaudal chromatophore system somewhat different. Templeman and Sandeman (1959), using well-developed larvae taken from parent females, described differences between the larvae of *S. marinus* and *S. mentella* females from the western Atlantic. A subcaudal melanophore or a group of 2 to 4 subcaudal melanophores was present in 98% of the larvae of *S. mentella* female parents and in only 24% of the larvae from *S. marinus* females.

Subsequent examination of unextruded but well-developed larvae from parent *S. mentella* females in the eastern and north-central Atlantic (Kotthaus, MS 1961; Henderson, 1964; Henderson and Jones, 1964; Raitt, 1964; Templeman, 1967c; Jones, 1968) showed that the larvae from these females did not possess the subcaudal melanophores. Kotthaus (MS 1961) found no subcaudal melanophores in unextruded larvae of *S. marinus* from trawl catches off Iceland, but Raitt (1964), in 2 females of *S. marinus* from off the south coast of Iceland, found one with 1% and the other with 12% of the larvae possessing subcaudal melanophores.

It was demonstrated by Henderson and Jones (1964) and Jones (1969) for southwest of Iceland, by Zakharov (1964) for southwest of Greenland to southwest of Iceland, and by Templeman (1967c) for the mouth of the Labrador Sea, that the oceanic redfish were *S. mentella* and that their larvae for the area southwest of Iceland and probably those of the Labrador Sea did not possess subcaudal melanophores. Consequently the oceanic larvae from the area north of Flemish Cap without subcaudal melanophores, taken by Tåning (1949) and subsequently by Henderson (1961, 1965a, 1965b, 1968 etc.), were from European type *S. mentella*.

Bainbridge and Cooper (1971) (summarizing previous work on redfish larvae with the Continuous Plankton Recorder for all areas sampled three or more times in the period April-August 1960-67) reported that along the North American Shelf, the first redfish larvae were extruded in April around Flemish Cap. They also recorded that the patch of larvae in the vicinity of Flemish Cap consisted almost entirely of non-pigmented individuals, and that larvae with subcaudal pigmentation were found in only two rectangles of this region where they constituted less than 10% of the total.

North American form or species of sharp-beaked redfish

When the absence of larvae with subcaudal melanophores in European *S. mentella* became known, it was immediately apparent that the North American form of beaked redfish, the American *S. mentella,* was at least different in this respect and might be a different species. The American form had been described briefly as a separate species, *Sebastes fasciatus,* by Storer (1856) at a time when little was known about the North Atlantic species of redfish.

Tåning (in Kelly *et al.,* 1961, and by implication in 1949) tentatively used the name *Sebastes fasciatus* for the American form of sharp-beaked redfish. Barsukov (1968, 1972) and Barsukov and Zakharov (1972) came to the conclusion that the American form of sharp-beaked redfish is enough different from *S. marinus* and *S. mentella* in form, distribution and biology to be given the species name *S. fasciatus*. These authors also ascribe *S. mentella* to the North American area, especially plentiful toward the north and less plentiful toward the south. Hallacher (1974, in an addendum) reported that William Eschmeyer has examined specimens of the four species of North Atlantic *Sebastes* and found that the gasbladder muscles pass between ventral ribs 2 and 3 in *S. marinus and S. mentella* and between ventral ribs 3 and 4 in *S. fasciatus* and *S. viviparus*. Litvinenko (1974) distinguished between *S. fasciatus* and *S. mentella,* 5-9 cm long, from the western Grand Bank, Div. 3O, on the basis of coloration. Subsequent examination of various morphometric and meristic characters in these juvenile specimens showed overlapping differences between the species.

It has often been customary to recognize that the North American form could be or was different and it has thus often been called the western or northwestern or

North American *mentella* (e.g. Templeman and Sandeman 1959; Sandeman 1961, 1969; Templeman, 1967c, 1973b) as compared with the oceanic eastern Atlantic form of *S. mentella* in the Labrador Sea and south of Iceland and Greenland. It was also realized (Templeman, 1973b) that the western fringes of pelagic *S. mentella* must ground on the Labrador and Northeast Newfoundland shelves. I have also noted on *A. T. Cameron* cruises from 1960 to 1964 in Div. 2J, 3K and 3L that the form of sharp-beaked redfish at the shallower depths was different in many respects and superficially more like *S. marinus* than those from the deeper levels which had the true *S. mentella* appearance.

Barsukov (1968) and Barsukov and Zakharov (1972) conclude that, although no one character separates *S. fasciatus* and *S. mentella, S. fasciatus* can often be recognized by eye from its general appearance (as we now distinguish between *S. marinus* and *S. mentella*), that the species *S. fasciatus* should be recognized, and that the recognition of a name for the species or form will lead to the necessary research which will further distinguish it from *S. mentella*. It must be recognized that the material now available for this paper treats the sharp-beaked redfish as one species, *S. mentella*. For most of the biological data gathered up to the present time, only depth information is available to help relate the data to the two forms of sharp-beaked redfish. All 12 sharp-beaked female redfish from Flemish Cap in Templeman and Sandeman (1959) possessed larvae with subcaudal melanophores (an average of 118.5 larvae with these melanophores in 120 larvae per fish). These parent redfish were therefore *S. fasciatus*. They were late-spawning redfish collected 25-30 June from 275 to 375 m (10 of them from 270 to 310 m)).

From their figure 1, Barsukov and Zakharov (1972) studied 7 specimens of *S. fasciatus* and 21 specimens of *S. marinus* from Flemish Cap, but, from their table 12, apparently 20 *S. mentella* from Div. 3M were studied also. How the *S. fasciatus* were selected is not stated but presumably they were called *S. fasciatus* as being sharp-beaked redfish and different in general appearance from the *S. mentella* of the eastern Atlantic. In their table 12, Barsukov and Zakharov separate *S. fasciatus* and *S. mentella* from Flemish Cap (Div. 3M) on the basis of vertebral numbers, with *S. fasciatus* at 275-370 m and *S. mentella* at 335-490 m.

The small percentages ($<$ 10%) of *Sebastes* larvae with subcaudal melanophores, reported by Bainbridge and Cooper (1971) from the vicinity of Flemish Cap, indicate a relatively small population of *S. fasciatus* on Flemish Cap compared with *S. mentella* and *S. marinus* which produce larvae without and mainly without subcaudal melanophores. It is, however, indicated that the population of *S. marinus* on the Cap is also relatively small.

Spawning of Cod and Redfish on Flemish Cap

Cod

In a cruise of the *A. T. Cameron* to Flemish Cap, 20-23 March 1961, the author checked maturities in 163 mature female cod and found 84% spent (of the year), 3.7% partly spent, 4.9% with more than 50% of the eggs clear, 3.7% with some clear eggs, and 3.7% developing, with opaque eggs. Most of the females had apparently spawned in March and some probably as early as February. Most of the unspawned females with clear eggs should have spawned in April while those with opaque eggs and none clear presumably would not spawn before May. Most of the mature spawning cod were to the south of Flemish Cap rather than to the north and the best catches of cod, using a No. 41 otter-trawl (24.1-m headline), were 445, 370, 385 and 865 kg per 30 minutes towing on bottom in 185, 240, 280 and 400 m respectively on the southeastern slope of Flemish Cap. (Only the northern and southeastern slopes and the top of the Cap were fished.)

Travin (1959) said that the spawning of cod on Flemish Cap occurs in March. Mankevich and Prokhorov (1962) stated that the Flemish Cap cod spawn most intensively in March and at the beginning of April, mainly on the southwestern slope of the Cap and that cod also spawn, but not in large concentrations, on the other slopes of Flemish Cap. The spring fishery for cod on Flemish Cap is therefore efficient only on the southwestern slope. Sexually mature fish move to considerable depths during spawning, leaving mainly immature fish at the shallower depths of 350 m and less. Noskov *et al.* (1963) noted that mature cod formed dense and stable concentrations in spring of 1962 on the spawning grounds of the southwestern slope of the Cap, while the immature fish were spread over the bank. The spawning season extended from the latter part of February to early April, reaching a peak in mid-March, the older fish being the first to spawn.

According to Serebryakov (1965) cod eggs were observed in the Flemish Cap area in March and April, 90% in the first stages of development in March and some in these stages in April. Cod larvae were noted in April over the central part of the bank. In May, only a small number (5) of cod eggs in the first stages of development were observed in the area. Even in July-August, individual cod eggs were found in the central part and on the slopes of Flemish Cap. Serebryakov (1965) concludes that the drift of cod eggs on the Cap was directed from the south and southwest slopes. Direction of drift is determined by the circular currents or rather their branches flowing from the slopes to the central part of the Cap (Buzdalin and Elizarov, 1962a).

Dias (1969) reported 46% of female cod spawning, 49% developing and none post-spawning from catches on Flemish Cap in 400-410 m during 6-10 March 1968. Templeman (1969a) said that about 35% of the mature females were spent in catches by *A. T. Cameron* on the Cap during 6-8 March 1968.

Redfish

In the *A. T. Cameron* cruise to Flemish Cap in March 1961 on the northern slope of the bank, *S. mentella* females with the best-developed larvae in their ovaries and oviducts were found in deep water at 455 and 530 m (21-22 March). A high proportion of the larvae was hatched, 5-10% of the females had larvae all hatched, fully developed and ready for extrusion and a few females were already spent. At 275, 320 and 365 m (22 March) there were very few mature *S. mentella* females in the catch and both *S. mentella* and *S. marinus* (encountered in moderate numbers at 320 m) were generally at least several weeks later in development than the *S. mentella* at 455-530 m. Instead of a large proportion of fish with 50-100% of the larvae hatched as at 455-530 m, most of the females at the shallower depths had larvae 2-10% hatched (Templeman, 1962).

Pechenik and Noskov (1962) say for Div. 3L and 3M that redfish pre-larvae occur in the catches from April to August. The maximum spawning apparently takes place in April-May. Bainbridge and Cooper (1971) indicate that the first larvae were extruded in April around Flemish Cap. Templeman and Sandeman (1959) show that some spawning occurs in July, as some *S. mentella* females with well-developed unextruded larvae were taken in 270-375 m during 25-30 June 1958.

Plankton in Relation to Larval Survival and Year-Class Strength of Cod and Redfish on Flemish Cap

Many of the factors affecting larval survival and year-class success of marine fishes were discussed by Hempel (1963, 1965), Cushing (1966, 1969a, 1973), and Templeman (1972b). Among these factors, food size, abundance and quality must affect growth and hence mortality of the fish larvae through greater predation on smaller, weaker and slower-moving larvae (Jones, 1973). Marshall and Orr (1964) showed that egg production by *Calanus* was related to the supply of phytoplankton. Cushing (1967) related the spawning and early larvae feeding times of autumn-, winter-, and spring-spawning herring of the Northeast Atlantic to three phytoplankton blooms in the same areas. The relatively fixed spawning dates of a number of northern fish stocks (Cushing, 1969b) allow the best chance of hitting a somewhat fluctuating production cycle at its appropriate peak.

Cod

The smallest stages of cod larvae in the North Sea (Goodchild, 1925), in Lofoten and other Norwegian coastal waters (Wiborg, 1948), and in the Gulf of Maine and on Georges Bank (Marak, 1960), feed mainly on copepod nauplii. Larger larvae feed on available food of the correct size, especially *Evadne,* copepodite stages of copepods, and lamellibranch larvae.

The food of cod larvae, 3 to 8 mm in length from off West Greenland in June, was almost entirely nauplii of *Calanus finmarchicus.* In Faxa Bay, Iceland, in May, the nauplii of the copepods *Temora* and *Calanus* were the most important food for cod larvae 3 to 6 mm in length, and copepodites and nauplii of these copepods, euphausiid nauplii and *Evadne* for 7 to 10 mm cod larvae. The relative lack of food in the stomachs of cod larvae at West Greenland compared with those of the same size in Faxa Bay, Iceland, was probably due to differences in the availability of plankton food (Bainbridge and McKay, 1968).

Redfish

Einarsson (1960) noted the food of the young stages of *S. marinus* (including also *S. mentella)* in Icelandic and adjacent areas. For larvae from 8 to 14 mm in length, 6 out of 30 stomachs were empty, only 3 were filled with food and the remainder had moderate quantities of food. The main bulk of the food was gastropod larvae *(Spiratella* sp.). Other food items were copepod eggs and nauplii and an early stage of *Calanus.* For fry of 15-25 mm in length, all stomachs examined were filled with food consisting entirely of copepod eggs. For 25-35 mm fry, all stomachs were full of food, the smaller specimens containing copepod eggs exclusively. Some of the 30-35 mm specimens had copepod eggs but others had only copepodite stages of *Calanus.* In fry of 35-45 mm, the main food items were small copepods *(Pseudocalanus)* and copepodite stages of *Calanus.*

During April and May, recently extruded redfish larvae in the Barents Sea were feeding principally on *Calanus* eggs (Bainbridge, 1965; Bainbridge and McKay, 1968). In June and July, the recently extruded and older larvae taken in the Irminger Sea and off West Greenland were mainly eating nauplii of *C. finmarchicus.*

Plankton over Flemish Cap and vicinity

Pavshtiks *et al.* (1962) said that the spring plankton development in 1960 and 1961 began much earlier in the warm Atlantic waters, such as off Flemish Cap, than in the colder Labrador current waters. The propagation of *Calanus finmarchicus* in the warmer water east of the Grand Bank and on the Flemish Cap occurred as early as March, whereas in the colder Labrador current water the mass spawning of *Calanus* was recorded only in June.

Semenova (1962) found the greatest concentration of *C. finmarchicus* at a station east of Flemish Cap, the greatest number of eggs and nauplii occurring in the mixing zone of the Labrador and Atlantic currents between Flemish Cap and the Grand Bank. On Flemish Cap, zooplankton organisms of the cold-water complex were rare and those of the warm-water complex more plentiful and often frequent. Konstantinov and Noskov (1966) noted that, at Flemish Cap, the second generation of copepods was observed with a great number of copepod eggs and nauplii in the July samples. In contrast to Labrador waters, mass development of diatoms was not observed in Atlantic waters, in which peridinians prevailed in the phytoplankton.

Movchan (1967) investigated the phytoplankton in April and November 1958 on the northern Grand Bank and northeast, east and southeast of the Grand Bank. Mass development of phytoplankton was noted in April, consisting mostly of diatoms, with peridinians being considerably less in quantity. The maximum development of phytoplankton in April was on the northeastern Grand Bank in polar and bank waters and southeast of the Grand Bank in slope water. The minimum development of phytoplankton in April was in the temperate water near Flemish Cap and in the warm water of the North Atlantic Current. The waters off the Newfoundland coast and north of Flemish Cap were richest in phytoplankton in November. Fedosov (1962), however, showed Flemish Cap as the area of more intensive phytoplankton growth (data for April, May-August 1958-59).

The occurrence of small recently-extruded redfish larvae north of Flemish Cap coincides with the first peak of copepod abundance in the area, for larval extrusion from April to August with a peak in June (Bainbridge and Cooper, 1971, fig. 6). There is a second period of copepod abundance in this area, peaking in September-October, which is important for the growth of young cod and redfish.

Robinson *et al.* (MS 1973), for the period 1961-71, showed considerable and different variations in abundance of *Sebastes* larvae from year to year in ICNAF Subareas 1-5, but material for the Flemish Cap area alone was not presented. Similarly Colebrook (1972) discussed the variability in the distribution and abundance of zooplankton in the North Atlantic. The area E8 (Colebrook's fig. 2), which includes Flemish Cap, is one of the areas for which material is available for 7 years but was not one for which the annual fluctuations in abundance of zooplankton was figured. The temperature and circulation regimes for Flemish Cap are so different from those of the adjacent Grand Bank that separate summaries of fish larvae and zooplankton abundance for the two areas are undoubtedly necessary.

Cod and Redfish as Predators on Their Young on Flemish Cap

Cod

The stomach contents of cod were examined during a research cruise to Flemish Cap in late March 1961 (Templeman, 1962) (Table 2). In some cases the volume of all food was measured and in others, for lack of time, close estimates were made of the contents, usually of full stomachs. The mature cod had mainly completed spawning and were feeding heavily. No capelin or launce, the favoured food of the cod over most of the Newfoundland area, were present in the stomachs. Adult cod were feeding heavily on young cod in the shallower parts of the bank and on young redfish in the deeper areas. The young cod were abundant on the southern part

TABLE 2. Stomach contents of cod from Flemish Cap in *A. T. Cameron* cruise, 22-23 March 1961.

Depth (m)	Cod catch: Weight (kg)	Cod catch: Number of fish	Number of cod stomachs examined	Stomach contents by volume (%): Redfish	Stomach contents by volume (%): Cod	Total food (cc)	Location re center of Cap
145	80	198	59	4	29	86	South on Cap
175-190	445	249	70	[a]	*ca.* 80[b]	—	Southeast slope
230-235	7	17	12	79	0	40	North slope
230-245	370	541	30[c]	*ca.* 5	*ca.* 85	—	Southeast slope
275-295	387	397	30[d]	*ca.* 95	*ca.* 2	—	Southeast slope
315-320	231	355	72	83	0	1.892	North slope
365-440	866	618	30[d]	*ca.* 98	0	—	Southeast slope

[a] Occasional little redfish.

[b] Young cod in stomachs were mainly 10-15 cm long, but stomachs of the largest cod contained young cod of 20-25 cm.

[c] Full stomachs.

[d] Full stomachs of cod 50 cm and over in fork length.

of the Cap and its slopes. The adult cod were also more plentiful on the southern slopes where they spawn.

The young cod in the stomachs were mainly 1 and 2 year-olds, 10-25 cm in length, the size taken being related to that of the adult predator. They were especially numerous in the stomachs of the medium and larger-sized cod. The redfish in cod stomachs were usually small, 7.5-12.0 cm in length. On the northern slope at 230-235 m the young redfish were mainly 7.5-8.0 cm in length and at 315-320 m most of the stomach contents consisted of young redfish usually about 7.5-10.0 cm long, there being large numbers of 8-9 cm fish. At 280 m and 400 m on the southeast slope, where young redfish were almost the only stomach contents of cod, most of the young redfish were about 10-12 cm in length. In some hauls, the occurrence of 9-15 small redfish in a single cod stomach was not uncommon. The young redfish were sharp-beaked (not *S. marinus*) and were darkish coloured (not red). Occasionally in a larger cod there was a larger redfish.

In the *A. T. Cameron* cruise of 11-19 September 1964, cod taken in 145 to 455 m (with greatest catches at 275-365 m) were observed to be feeding heavily on small (*ca.* 18 cm) redfish. At that time there were two size groups of redfish on Flemish Cap, one with a modal length of 18 cm and the other with modal lengths of 33 cm for males and 35-36 for females (Fig. 6E).

Popova (1962), who investigated stomach contents of cod taken in July-August 1959-60 on Flemish Cap, did not find capelin and launce among the cod food and also did not mention young cod and redfish as a significant part of the food on the bank itself or on the southern and southeastern slopes. However, he said that cod on the western part of Flemish Cap characteristically feed on larvae in June and on redfish fry in August. The consumption of redfish was especially significant in 1960 (32%). Also, Kashintsev (1962) found the cod food, at 300-400 m on Flemish Cap, 1-20 December 1960, to consist of 23% young sharp-beaked redfish (also 3% launce).

Redfish

Kashintsev (1962), for the southeastern slope of Flemish Cap, 1-20 December 1960, reported young redfish as 11% of the *S. mentella* stomach contents. Yanulov (1962c) did not include redfish in his list of 16 fish species found in the food of beaked redfish from Subareas 2 to 4, including Flemish Cap (1956-60), although he included them (in his fig. 9) as less than 2% of the food of cod and much less than 1% of the food of beaked redfish on the northeastern slope of Div. 3L. Yanulov said that capelin were completely absent in the diet of redfish from Flemish Cap. However, Noskov *et al.* (1963) reported that the redfish (in summer 1962) on the Cap were feeding heavily on capelin.

Evidences of Year-Class Success and Failure for Cod and Redfish on Flemish Cap

Cod is the most important fish on which information on the reasons for year-class success or failure is desired for Subareas 2 and 3 and the northern part of Subarea 4. Granting that the cod stock on Flemish Cap is relatively isolated from those in adjacent areas, in order for Flemish Cap to be considered a suitable area for research on year-class success and failure, there must be distinct evidence of successful and unsuccessful year-classes of cod in the area. The more extreme the success and failure, the more likely it is that satisfactory conclusions can be reached by such a study. Also, there is considerable advantage in studying redfish year-class success at the same time, if fluctuations in year-class strength are evident.

The strengths of year-classes must be capable of being measured with a fair degree of accuracy. The main methods available for assessing year-class success are by conducting surveys of numbers and sizes of young taken by small-meshed trawls or trawls with codends lined with small mesh netting, or preferably using codend covers of small mesh, in the late autumn-early spring of their first, second and third years of life, and by collecting material for age reading from research and commercial catches. Virtual population analyses and similar studies can integrate the results of age reading over the life of the fish, the accuracy of determining year-class success from such studies being dependent on that of age reading.

Cod

Age composition. The year-class success indices for cod (Table 3) provide moderately good overlapping information, from ages read for material collected during 1957-66 and 1968-72, for year-classes of 1953-63 and 1972. Of the year-classes for which enough overlapping or other relatively suitable information is available, the following appear to have been the most successful: 1953, 1954, 1957, 1958, 1962. Most of the others have indications of moderate to good success but they cannot be correctly judged because of the lack or inadequacy of available age readings in 1951-56, 1967, 1969-71 and from several countries in most of the other years. The 1955 and very likely the 1952 and 1964 year-classes were probably relatively unsuccessful, but it is difficult to be at all certain regarding other unsuccessful year-classes because of the inadequacies mentioned above. On the basis of the available age composition data, year-class production does not appear to have been highly variable in the period examined.

TABLE 3. Relative year-class success of cod on Flemish Cap from age-readings of otoliths collected in 1950-72. Where there was an age frequency from the same country in more than 1 month of the same year, the greatest monthly index for each year-class was selected. (The age frequencies, except for those with author references and those designated by footnotes [a] and [b], are from the ICNAF Sampling Yearbooks. The tabled indices correspond with the following per mille age frequencies in parentheses: < 1(0-50); 1(51-100); 2(101-150); 3(151-200); 4(201-250); etc.)

Year-	Fleming (1960) July	Konstantinov (1970)		Jónsson (1960) July	USSR Sept.	USSR Mar. and July	USSR Mar., Oct.	May & Williamson (MS 1962)	USSR Mar., Dec.	Konstantinov (1970)	Poland Mar.	St. John's Station[a]	St. John's Station[b]	Poland Apr., June	Portugal Mar., Apr.	Portugal Mar.	USSR Mar.	St. John's Station[b]	Spain Feb., Mar.	UK June-Sept.
class	1950	1957	1958	1959	1959	1960	1961	1961	1962	1963	1963	1964	1964	1965	1966	1968	1968	1968	1972	1972
1969	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
1968	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	11
1967	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	6
1966	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	3
1965	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	4	1
1964	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	<1	1
1963	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	3	5	2	—
1962	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	9	10	3	—	—
1961	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	2	3	—	—	—
1960	—	—	—	—	—	—	—	—	1	—	—	3	3	2	4	1	1	—	—	—
1959	—	—	—	—	—	—	—	—	1	1	—	2	1	3	5	<1	—	—	—	—
1958	—	—	—	—	—	—	1	4	1	9	6	7	5	7	6	1	—	—	—	—
1957	—	—	—	—	—	2	6	5	7	3	5	2	3	1	1	—	—	—	—	—
1956	—	—	—	—	—	<1	4	4	3	1	2	<1	—	—	<1	—	—	—	—	—
1955	—	—	—	—	3	<1	1	<1	1	1	1	<1	—	—	1	—	—	—	—	—
1954	—	—	3	8	11	9	6	1	4	1	2	1	—	—	—	—	—	—	—	—
1953	—	—	3	8	3	4	5	1	3	—	—	—	—	—	—	—	—	—	—	—
1952	—	—	1	1	—	<1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1951	—	3	2	1	—	<1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1950	—	4	3	1	—	<1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1949	—	5	1	1	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1948	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1947	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1946	8	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1945	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1944	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1943	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
No. aged	234	—	—	—	298	676	1,057	596	963	—	534	137	336	278	452	300	299	626	58	144
No. meas.	234	—	—	—	402	3,369	—	2,576	—	—	4,041	—	—	468	1,050	750	12,119	—	863	2,373

[a] *Investigator II*, July; random sample with 114-mm mesh codend and no liner.

[b] *A.T. Cameron*, September 1964 and March 1968; random sample with 29-mm mesh liner codend.

The Flemish Cap cod stock has been the subject of a virtual population assessment by Wells (MS 1973), in which the number of cod at each age present at the beginning of the year was estimated. This information (from table 3 of Wells) was transformed to year-class abundance in Fig. 3. For the period under examination, there appeared to be no complete failures of year-classes (those of 1952-64 and 1949-51 were not represented by the earlier ages for which relative numbers could be judged). The 1958 and 1962 year-classes were the most successful. Other relatively successful year-classes were those of 1954, 1957, 1959 and 1963. The 1964, 1952 and 1951 year-classes were probably quite unsuccessful, but their success cannot be judged completely from the evidence available.

Special trawling for young cod. Cod year-class success, as judged from the average catches per hour trawling of cod up to 40 cm long from USSR research surveys in Div. 3M (Bulatova, MS 1973, table 1), is

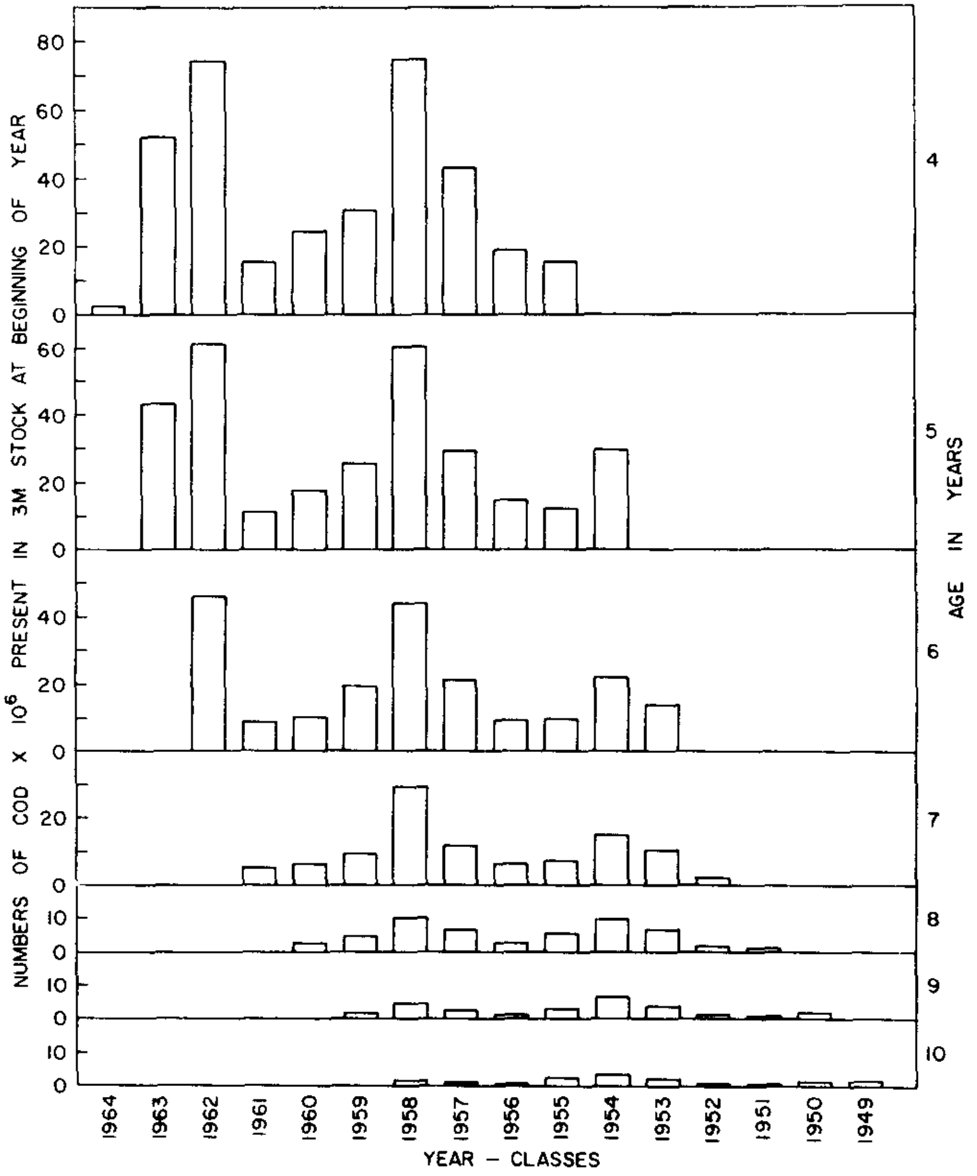

Fig. 3. Abundance of the 1964-49 year-classes of cod on Flemish Cap (from virtual population assessment of Wells, MS 1973).

shown in Fig. 4. A bottom trawl was used, having the codend lined with a fine-meshed capron net (8-mm bar). From the information on available year-classes, age 3 fish probably provide the best basis for comparison of year-class success, with supplementary information especially for ages 1 and 2. The earlier ages are presumably not usually so available to bottom trawls and are more likely to be lost through the large meshes at the front of the trawl than the 3-year-olds. The larger fish of age 4, greater than 40 cm in length, are not included. From these USSR data, the 1962 year-class was a successful one and the 1968 year-class can be classed as having been very successful. From the comparative catches of 1-year-old fish, the 1971 year-class was as successful as, or more successful than, that of 1968. Apparently the 1969 year-class was a very poor one and probably also that of 1970. Konstantinov and Noskov (MS 1975) provide recent information on Soviet young fish trawling, indicating that the 1972 year-class of cod in Div 3M was only moderately successful but that the 1973 year-class is extremely large. The catch of 1-year-old cod of the 1973 year-class per hour's trawling was 219 fish, about 20 times as many as for the very successful 1968 year-class as 1-year-olds. However, the 1971 year-class, with catches per hour trawling of 16 age 1 and 62 age 2 fish, indicated only two age 3 fish per hour's trawling, so the actual comparative success of the 1973 year-class will be estimated better from surveys in 1975 and especially in 1976.

Length frequencies. Length frequencies of cod from Flemish Cap, showing Petersen curves indicative of

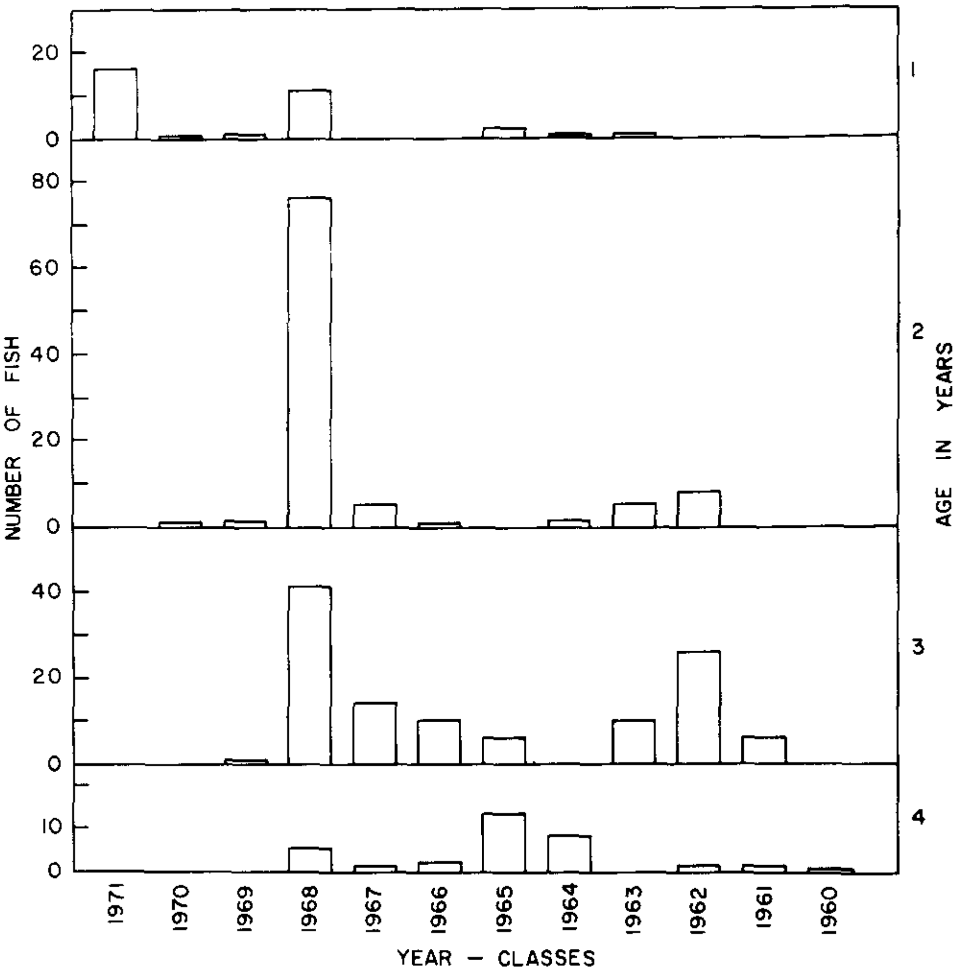

Fig. 4. Average numbers per trawling hour of young cod (up to 40 cm long) of the 1971-60 year-classes on Flemish Cap. (From Bulatova, MS 1973. Trawling carried out in 1963-66 and 1968-71 with codend lined with 8-mm (bar) netting.)

year-classes, are available from research cruises (Fig. 5). There is relatively little possibility of error for the first 2 or 3 age-groups. The modes indicated in Fig. 5B for the 1958 and 1957 year-classes were checked by May and Williamson (MS 1962) as containing fish mainly of these year-classes. The 1960 year-class of Fig. 5C was checked by Messtorff as 2 years of age. From these frequencies it is apparent that the 1957, 1958, 1960 and 1962 year-classes were relatively successful and that the 1959 and 1961 year-classes were smaller.

The relative numbers of small and large cod in the frequencies (as in Fig. 5) depend on the depths fished. In the *A. T. Cameron* cruise of November 1958, young cod of age-groups 0, 1 and 2 were prevalent at 205-278 m whereas the smallest fish taken at 366-457 m was 39 cm in length. In the *A. T. Cameron* cruise of March 1961, the 1-year-old cod and most of the 2-year-olds were taken at 146-243 m; the smallest cod taken at 274-320 m was 25 cm long and at 366-457 m was 37 cm. In the *A. T. Cameron* cruise of September 1964, the 1-year-olds and

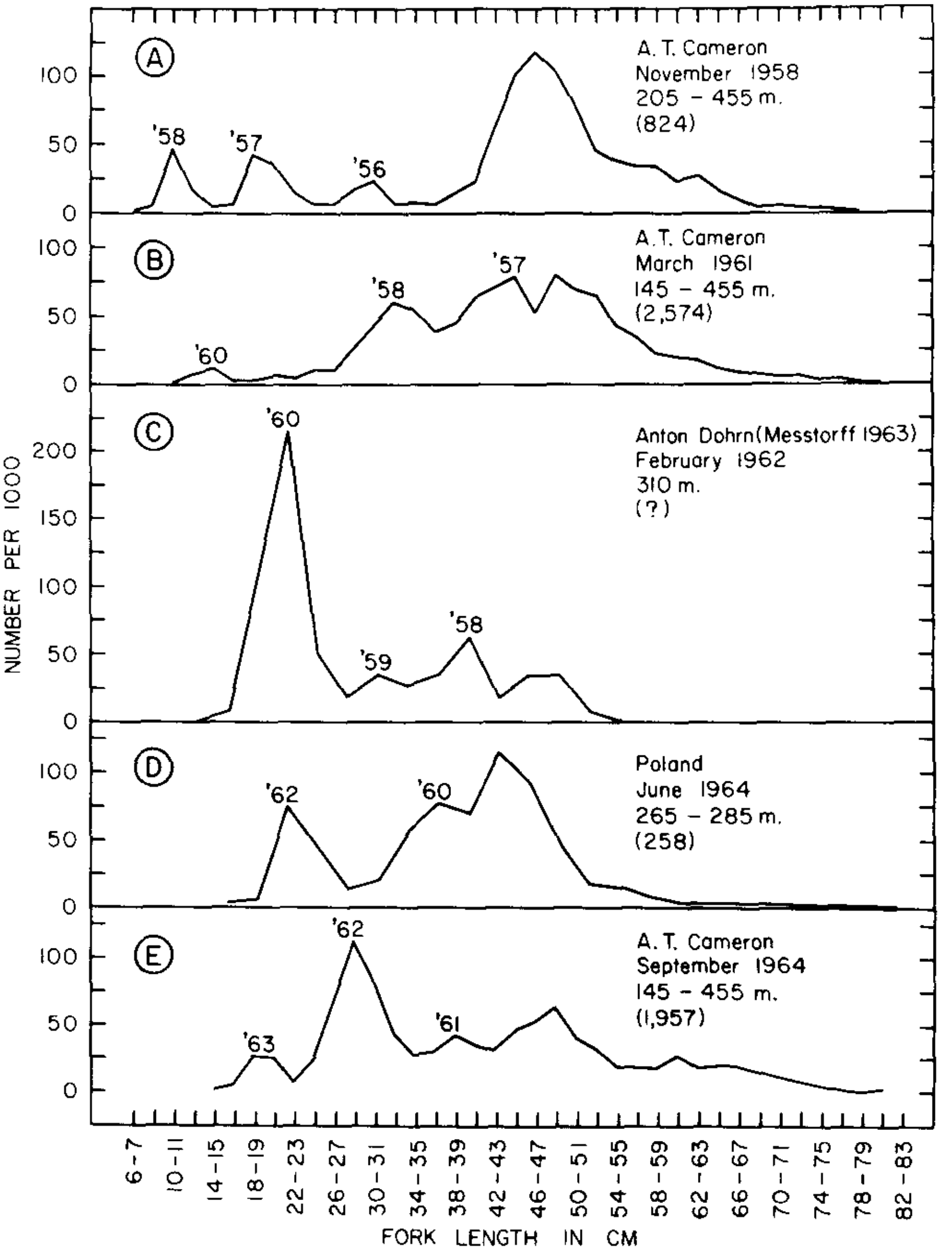

Fig. 5. Cod length frequencies from bottom trawl catches in research cruises to Flemish Cap, 1958-64. (Small-meshed codend liners were used for all except 100 mm for D.)

most of the 2-year-olds were at 146-238 m; the smallest cod taken at 274-357 m was 25 cm long and the smallest at 366-457 m was 37 cm in length.

Redfish

From the available information on Flemish Cap in ICNAF Sampling Yearbooks, redfish are chiefly identified as *mentella*-type or beaked redfish, *marinus*-type redfish, or redfish in which the species are not separated. The only worthwhile evidence for assessment of year-class strength is for the *mentella*-type redfish which makes up almost all of the commercial catch, and only this type (presumably or mainly *mentella*) will be considered.

Age compositions. The relative strengths of successful year-classes of redfish within each age frequency reported in the ICNAF Sampling Yearbooks (1958-75) are shown in Table 4. In any one of the age frequencies, for commercial redfish samples whose peak ages were 10 years or more, there is usually a peak age with the frequency declining towards the younger and the older age-groups. The peaks occur toward the central part of the age frequencies, and thus a number of successive frequencies with information on the age distribution over their central parts are required for comparison of year-class success. Only for the age composition data of 1958 to 1962 are there enough age frequencies for good comparisons of year-class strength. From Table 4, for all the year-classes for which the central parts of the age frequencies were available and also for some others, all year-classes from 1943 to 1953 appear to be successful in their turn. From the appearance of the other age frequencies, it seems that, if more age frequencies were available so that the central parts of the frequencies could be assessed, the 1954 to 1960 year-classes would show similar evidence of success. In the age frequencies from Poland for 1972 and USSR for 1973 (Table 4), a second peak appears at younger ages, showing evidence of new year-classes but again usually without great variation in year-class strength in the region of the peak. In the age data of Parsons *et al.* (MS 1975) for 1973, with ages determined by otoliths, the frequency is spread over about twice as many ages as those derived from scale reading,

TABLE 4. Relative year-class success of redfish on Flemish Cap from age-readings of redfish material collected in 1957-73. Where there was an age frequency from the same country in more than 1 month of the same year, the greatest monthly index for each year-class was selected. (Age frequencies, except those indicated by [a] and [b], are from Sampling Yearbooks; the tabled abundance indices correspond to the per mille frequencies in parentheses as follows: < 1(0-50); 1(51-100); 2(101-150); 3(151-200); etc.)

Year-class	USSR Jan.- June 1957[c]	USSR[a] Mar.- Sep. 1958[d]	USSR Mar.- Dec. 1959[d]	USSR Mar.- Oct. 1960[d]	USSR Mar.- Dec. 1961[d]	USSR Jan.- Aug. 1962[e]	USSR Feb., June 1965[d]	USSR Jan. 1967[d]	USSR Mar. 1972[c]	Poland Mar. 1972[d]	USSR Feb.- Apr. 1973[c]	Canada[b] July- Aug. 1973[d]
1967	—	—	—	—	—	—	—	—	—	—	1	—
1966	—	—	—	—	—	—	—	—	—	3	3	—
1965	—	—	—	—	—	—	—	—	—	1	3	1
1964	—	—	—	—	—	—	—	—	—	1	2	1
1963	—	—	—	—	—	—	—	—	—	1	2	1
1962	—	—	—	—	—	—	—	—	—	1	1	1
1961	—	—	—	—	—	—	—	—	—	2	2	1
1960	—	—	—	—	—	—	—	—	3	<1	2	1
1959	—	—	—	—	—	—	1	—	3	<1	2	—
1958	—	—	—	—	—	—	1	—	4	1	2	—
1957	—	—	—	—	—	—	1	—	3	1	3	—
1956	—	—	—	—	—	—	1	1	2	<1	1	—
1955	—	—	—	—	—	—	<1	3	—	1	—	—
1954	—	—	—	—	—	—	1	3	—	—	—	—
1953	—	—	—	—	—	1	3	3	—	—	—	—
1952	—	—	—	—	—	1	3	2	—	—	—	—
1951	—	1	—	1	2	2	3	2	—	—	—	—
1950	—	4	—	4	5	4	4	1	—	—	—	—
1949	—	4	2	4	4	6	2	—	—	—	—	—
1948	—	4	3	4	3	4	—	—	—	—	—	—
1947	—	4	3	4	3	4	—	—	—	—	—	—
1946	1	3	4	3	3	1	—	—	—	—	—	—
1945	2	2	4	2	2	<1	—	—	—	—	—	—
1944	3	3	3	1	2	1	—	—	—	—	—	—
1943	3	1	2	1	1	—	—	—	—	—	—	—
1942	2	1	2	—	1	—	—	—	—	—	—	—
1941	2	1	2	—	1	—	—	—	—	—	—	—
1940	1	—	1	—	—	—	—	—	—	—	—	—
No. aged	1,184	809	1,813	1,321	1,624	2,455	520	539	200	1,014	536	390

[a] Travin (1959).

[b] Parsons *et al.* (MS 1975).

[c] Reported as "redfish".

[d] *Sebastes mentella*.

[e] *S. mentella* and *S. marinus*.

the per mille numbers being 21, 54, 91, 84, 51, 66, 72, 41 and 39 for the year-classes of 1966 to 1958. Thus the 1964, 1963 and 1960 appear to have been the most successful but not exceptionally large. There is therefore little evidence, from redfish age reading of the mainly adult redfish in commercial catches, of the variation in year-class strength necessary for Flemish Cap to be considered a good area for research on year-class success.

Apart from the age readings of Parsons *et al.* for 1973, those indicated in Table 4 were apparently based on scales. By analogy with results from age reading for fishes such as cod and haddock, scale reading probably underestimates considerably the ages of old fish. Sandeman's (1969) table 2, showing only 9% agreement in age estimates from otoliths of the same 445 redfish (*S. mentella*) by two age readers in the same laboratory, also leaves little hope that relative year-class strengths of redfish of commercial size could be found by otolith reading at even a much higher level of accuracy. Strangely, the growth curves for *S. mentella* from Flemish Cap derived from otolith reading by Sandeman (1969), appear to be relatively correct compared with those derived from scale reading. There appears to be no reason why age reading from scales should not be equally as accurate as that from otoliths for the younger ages, but these younger fish are rarely taken in quantity by the commercial fishery.

It is evident that ages estimated for older redfish from otoliths are considerably greater than those from scales. The redfish length frequencies from the *Cape Farewell* for 1973 (Fig. 6M) and those of USSR for 1973 (Fig. 6L) came from approximately the same depths and were generally similar, with the USSR samples having more fish at the larger sizes. In the *Cape Farewell* frequencies, 19.5% of the redfish were 37-47 cm long, whereas 28% of the fish were 37-48 cm long in the USSR frequencies. The earlier date of the USSR samples (March-April), with the possibility of some growth before the July-August date of the *Cape Farewell* frequencies, and the greater abundance of larger fish in the USSR frequencies will tend to compensate for the difference between the total-length measurements of the USSR frequencies and the shorter fork-length measurements in the *Cape Farewell* frequencies. For these *Cape Farewell* samples of 1973, 25% of the redfish, with ages read from otoliths, were 23 years and older and 40% were 19 years and older (Parsons *et al.*, MS 1975). Some of these fish of 23 years and older were read at ages in the high forties. In the USSR samples for 1973 from ICNAF Sampling Yearbook, ages were apparently determined from scales and no redfish were shown to be older than 22 years and only 5% were 19 years and older. Thus, the ages of the redfish of large commercial size are grouped over a much smaller range of ages from scale reading than those from otolith reading, and the indices of year-class strength, as shown in Table 4, are considerably increased. The growth rates from such ageing differ correspondingly, with those from otoliths being much slower than those from scales. Also, mortality rates based on ageing by the two methods are very different, being much lower when calculated from a catch curve based on otolith readings than on scale readings.

In the redfish age frequencies available for Div. 3M, almost all from ageing of the older commercial-sized fish by scale reading, males and females rarely show comparable year-class strengths in the same year. The most successful year-classes for males appear at earlier years than those for females. It is to be expected that the scale-reading technique, when used for the older fish, is likely to give fewer fish for males than for the larger females of the same age.

Age and growth of young redfish. To establish the probable year of origin of the successful year-classes of Flemish Cap redfish, as indicated by the length frequencies (Fig. 6), it is necessary to know the approximate rate of growth of young redfish, preferably independently of age estimations from scales or otoliths, or with Petersen curves to validate these age estimations. The most pertinent available data are probably those listed in Table 5 from Sandeman (1961, 1969), Hansen (1961) and Surkova (1961).

Sandeman (1961) followed the growth of a single year-class (1953) of *S. mentella* in Hermitage Bay, Newfoundland, isolated by very poor year-classes in earlier and especially in later adjacent years. The specimens were taken by trawl with the codend lined or covered with 10-13 mm mesh netting. For specimens taken during the first winter of capture, the first hyaline ring in the otoliths and the first zone of narrow circuli on the scales were laid down, so that presumably these fish were 1 year old in January 1954 when they were 6-8 cm long. Selection in at least the front part of the net would ensure the capture of the largest of the year-class so that the sizes, especially for the younger ages, are probably too large. The lengths at age of Sandeman's 1953 year-class, from age reading of otoliths and scales and from the modes of his length frequencies (Table 5A, B), are quite similar. Sandeman (1969) also calculated von Bertalanffy growth curves for Flemish Cap *S. mentella* from otolith age reading of 53 males and 62 females, using length data at ages 4-30 years for males and at 6-40 years for females. Data for younger ages were lacking but Sandeman's t_0 for the von Bertalanffy growth curve is 0.1 ± 1.2 for the males and 0.6 ± 2.5 for females; the calculated lengths at ages 1 to 6 for males are given in Table 5C. These Flemish Cap samples were taken in July 1956 and November 1958. Some of the annual growth would have occurred by July and almost all of the growth

TABLE 5. Redfish lengths (cm) for ages 1 to 6 fish from various sources.

		Ages in years					
Row	Source of data	1	2	3	4	5	6
A.	Sandeman (1961)[a]	7.1	9.0	11.4	14.0	(17)	20.0
B.	Sandeman (1961)[b]	7.3	9.3	11.3	13.8	—	—
C.	Sandeman (1969)[c]	4.9	9.5	13.4	16.7	19.5	21.8
D.	Hansen (1961)[d]	—	9.0(5)	12.1(5)	15.2(5)	18.3(4)	20.8(4)
E.	Hansen (1958-64)[e]	6.0(1)	9.4(7)	12.4(6)	14.8(3)	17.6(3)	20.4(1)
F.	Surkova (1961)[f]	5.0	8.6	12.3	15.4	18.3	21.2

[a] As of 1 January, from 1953 year-class *S. mentella* (North American type) from Hermitage Bay, Newfoundland; ages 1-4 from both otoliths and scales, and 5-6 from otoliths only, Sandeman's fig. 6; data are lacking from June of year 4 to August of year 5, and 17 cm is considered a more likely length for age 5 than the 18 cm indicated by Sandeman.

[b] Lengths at modes (by the author) from Sandeman's (1961) length frequencies of the 1953 year-class of *S. mentella* from Hermitage Bay; modes for November to February were equated with lengths at 1 January.

[c] By the author from Sandeman's (1969) von Bertalanffy growth parameters for *S. mentella* from Flemish Cap; ages from otoliths; lengths at age as of July and November and for males only.

[d] Calculated by the author from Hansen (1961, fig. 2); lengths as of 1 January (number of observations in parentheses).

[e] Calculated by the author directly from modes in Hansen's redfish length frequencies from Sampling Yearbooks, Vol. 1-7 (1958-64), for 1954-62, December-April; in any year, the earliest month with adequate length-frequency data was used; and modal lengths were equated where necessary to 1 January; numbers of observations are given in parentheses.

[f] Back-calculated (from scales) growth rate of *S. mentella* on Kopytov Bank off Norway.

would have occurred by November, so that these calculated lengths at age (Table 5C) are more related to the beginning of the following year than to the year in which they are ascribed.

Hansen (1961) calculated length at age directly from length frequencies of year-classes of redfish captured at one location in Godthaab Fjord (Table 5D). In addition, redfish length frequencies for Godthaab Fjord, reported by Hansen in ICNAF Sampling Yearbooks 1958-64, were used by the author to estimate lengths at age for young redfish (Table 5E). These estimates are very similar to those calculated directly by Hansen (Table 5D). Surkova (1961) back-calculated the length at age of *S. mentella* from Kopytov Bank off northwestern Norway, and the lengths at age up to 6 years (Table 5F) are similar to those listed for the Northwest Atlantic (Table 5F).

Sandeman's lengths are fork lengths to the nearest centimetre. Hansen's are total lengths to the centimetre below and this method should result in lengths close to those from Sandeman's method of measuring. Surkova's measurements are presumably total lengths to the nearest centimetre, as indicated in the ICNAF Sampling Yearbook for 1967, and these would thus be slightly greater than those from Sandeman's method.

Hansen used the inclusive name of *Sebastes marinus* for his small redfish, but examination by the author of redfish in Hansen's fishing area of Godthaab Fjord (Templeman, 1966) indicated that they were *S. mentella* (not distinguished from *S. fasciatus*). They were probably, however, true *S. mentella*. Sandeman's Hermitage Bay "*S. mentella*" were taken at 220-330 m and were probably at least mainly *S. fasciatus*, and his Flemish Cap "*S. mentella*" from 275-550 m could have been a mixture of *S. mentella* and *S. fasciatus*. Surkova's Kopytov Bank fish were *S. mentella*. Despite the possible species differences, the age-length data listed in Table 5 are quite similar for fish up to 6 years of age.

Evidences of successful year-classes and their age and growth from length frequencies. Contrary to the evidence from age reading, there were occasional successful year-classes of *mentella*-redfish on Flemish Cap, with sometimes many years of relatively poor and very poor survival between them. In the following account, when redfish is mentioned it is understood to be nominally *mentella*-redfish (sharp-beaked redfish, without distinction between *S. mentella* and *S. fasciatus*).

Of the length frequencies shown in Fig. 6, all the redfish in the research cruises of the *A. T. Cameron, Investigator II*, and *Cape Farewell*, working for the St. John's Biological Station, were caught by otter trawl with the codend lined by 29-mm nylon mesh. Occasional 6-8 cm redfish were taken by this mesh, which is much too large for sampling young redfish, but typically the smallest sizes caught in numbers sufficient to indicate a year-class were about 12-16 cm in length. Data for countries other than Canada were taken from ICNAF Sampling Yearbooks and include all *mentella* or "redfish" length frequencies of small as well as adult fish. The samples were taken mainly by commercial otter trawl with codend mesh sizes usually reported as 110 mm or in recent years 130 mm. The smaller sizes of redfish were only occasionally taken by trawls with these large meshes. Most of the commercial frequencies reported were from 1965 to 1974, when the redfish of new successful year-classes were becoming large enough to be taken in numbers by the large-meshed trawls.

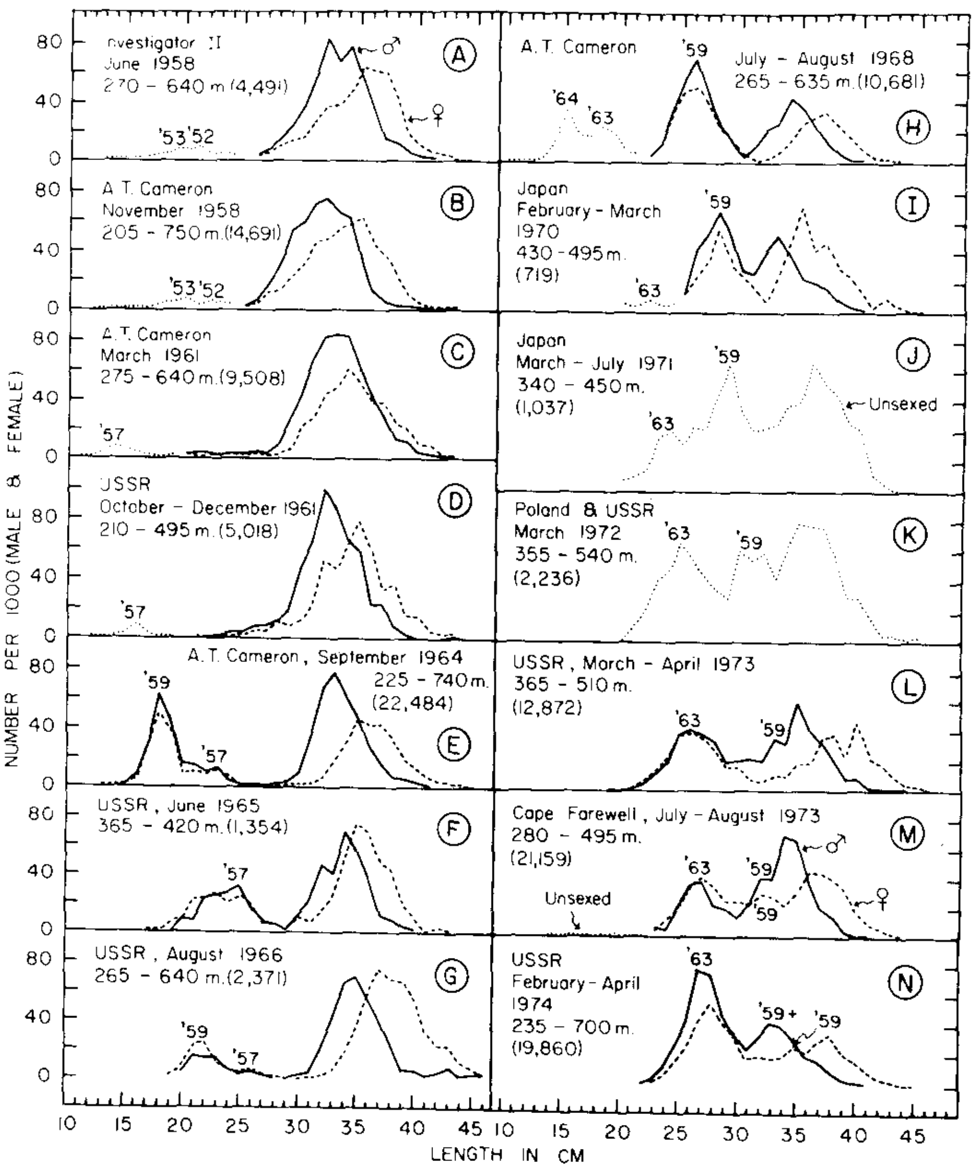

Fig. 6. Redfish length frequencies from Flemish Cap, 1958-74. (A-F, H, K, M, N are indicated as *S. mentella* and G, I, J, L as "redfish". The numbers in parentheses are numbers of fish in the entire catches for *Investigator II*, *A. T. Cameron* and *Cape Farewell* and numbers measured for the others. Depth ranges indicated are bottom depths. Frequencies shown for more than one month in the same year are averages of the monthly per mille frequencies from the Sampling Yearbooks. Canadian and Japanese measurements are fork lengths, and those for Poland and USSR are total lengths, all to the nearest centimetre.)

Year-class designations were assigned to the modes of the frequencies in Fig. 6 on the basis of the information provided in Table 5, with due allowance for the months of capture. Consideration was also given to the whole picture of Fig. 6 in relation to the probable number of years between the year-classes as judged from the location of the modes. The length frequencies shown in Fig. 6 represent a mixture of results from trawls with small-meshed codend liners for Canadian research vessels, 110-130 mm mesh commercial type codends used by other countries, as well as different methods of measuring the fish and the different months of capture. Thus, with the selectivity and other differences, the possible species differences, the possibility of different growth rates in different years and the overlapping combination of year-classes from adjacent years, it would not be expected that all of the results will fall exactly in line, but the agreement is reasonably good. Observations by the author on the very small sizes of redfish on Flemish Cap in March 1961 indicated that both the 1959 and 1960 year-classes were abundant, but later observations indicate that only one apparent large year-class, or year-class group resulted (*e.g.* Fig. 6E). Also, it should be noted that the length of the nominally designated 1959 year-class in Fig. 6G is probably better suited to that of the 1960 year-class. Although, for purposes of discussion, nominal year-classes have been assigned, the year-classes have usually been first recognized in their fourth or fifth year, and consequently an error of a year is possible. Following Hansen and Surkova of Table 5 for ages 4 and 5, instead of Sandeman, the ages corresponding with the first appearance of the 1959, 1963 and 1964 year-classes in the catches could be a year younger than the ages assigned and consequently the year-classes would be a year later. Also, the larger designated year-classes may include other smaller year-classes not indicated in length frequencies by separate modes. However, none of these errors or inclusions will interfere with the main purpose of the argument, which is the demonstration of year-class variability.

In 1958, one year after a major redifsh fishery began on Flemish Cap, the frequencies (Fig. 6A, B) showed a large group of nearly fully grown redfish representing an accumulation of year-classes, and also probably two small year-classes, those of 1953 and 1952, at about 17-23 cm. The modal lengths of these two year-classes in 1958 were at 19 and 21 cm in June and at 20 and 22 cm in November. (In these frequencies for the small fish not divided by sex, the frequency height is twice what it would be if the frequencies were divided by sex.) In the following years up to 1961 (Fig. 6C, D) these year-classes had essentially merged with the left-hand limb of the frequency representing the major group of earlier year-classes. By 1964, and especially in 1966, the modal group of commercial-sized fish had moved to the right so that practically all of the males were greater than 31 cm and the females greater than 33 cm, in contrast to considerably smaller sizes in 1958. For males, the mode of this major group of year-classes moved from 32 cm to 33 cm between 1958 and 1964 and to about 35 cm in 1973. For females, the mode increased from 34 to 36 cm between 1958 and 1964 and to about 37 cm in the summer of 1973, although the USSR frequency in the spring of 1973 indicates a mode at 40 cm. These latter samples were probably taken at greater depths than usual, where larger sizes of redfish prevail, and thus do not reflect the normal growth pattern indicated by the other length frequencies.

In 1961, a small year-class (presumably that of 1957) was taken, with modal lengths of 14 cm in March and 16 cm in October-December (Fig. 6C, D). The modal lengths of this year-class were 23 cm in 1964, 25 cm in 1965, and 26 cm in 1966. By 1968 (Fig. 6H), this year-class had merged with the right side of the larger 1959 year-class group.

In September 1964, when most of the year's growth should have been completed, a new year-class (nominally that of 1959, but could be mainly that of 1960 or in any case includes the 1960 year-class) was evident (Fig. 6E). This 1959 year-class group was much greater than the 1957, 1953 and 1952 year-classes and had a modal length for both sexes of 18 cm in September 1964, 22 cm in August 1966, 26 cm in July-August 1968, 28 cm in February-March 1970, 29 cm in March-April 1971, 31 cm in March 1972 and apparently 32-33 cm at 14+ years of age in July-August 1973 (Fig. 6M). By 1970 (Fig. 6I) the right side of the frequency of the 1959 year-class group had joined the left side of the adult frequency to a large degree for males but considerably less for females, whose adult frequency peak was at a larger size. In the 1971 and 1972 frequencies, with sexes combined (Fig. 6J, K), the amalgamation of the 1959 year-class group with the adult group was more advanced. In 1973, the 1959 year-class group was represented by a small peak on the left side of the adult male frequency at 33 cm for the USSR frequency in March-April (Fig. 6L), and at 32 cm in July-August for the Canadian *Cape Farewell* frequency (Fig. 6M). The slightly greater modal size in the USSR frequency is probably due to the total length measurements by the USSR compared with the shorter fork-length Canadian measurements. By 1974 (Fig. 6N), the 1959 year-class group was absorbed completely in the adult male frequency. The peak of the adult male frequency, under the influence of the entering of the 1959 year-class group and probably from an increasing tendency to fish at depths where the 1959 year-class group was abundant, was reduced from 35 cm in 1973 (Fig. 6L) to 33-34 cm in 1974 (Fig. 6N), which size also represents approximately the peak of the 1959 year-class group. By July-August 1973, the peak of the 1959 year-class group in the female frequency was at 32-33 cm (Fig. 6M) and by February-April 1974 it is shown at 35 cm (Fig. 6N). The apparent fast growth between 1973 and 1974 may be in part due to the different measuring techniques used by Canada and USSR. By 1974, it was evident that the 1959 year-class group would soon be completely merged with the adult female group. Although this year-class group has been nominally assigned to the year 1959 (Fig. 6E), based on growth data, it is possible that the year-class might be that of 1960. Tokareva (MS 1965), from special towing for young fish in January-April 1964, using an otter-trawl with a small-meshed liner in the codend, provided a length frequency from Flemish Cap which indicated a successful year-class of small *S. mentella* centered at about 16.5 cm, and he attributed it to the 1960 year-class.

In July-August 1968 (Fig. 6H), two new year-classes were present, peaking at 15 and 18 cm, probably the 1964 and 1963 year-classes (but they could be the 1965 and 1964 year-classes). In 1968, these two year-classes were combined at their bases but distinct at the modes, but in the following years the two year-classes were not distinct. The peaks of this year-class group at 22 and 24 cm in 1970 and 1971 (Fig. 6I, J) appear to be more related to the

1963 than to the 1964 year-class. Consequently the 1963 year-class was nominally assigned to this group. It appears that the commercial gear (Fig. 6I, J) took mainly the older (1963) year-class of this group. It is not until 1972 (Fig. 6K) that the "1963" year-class, peaking at 25 cm, appears to have a wide-enough base for the inclusion of the 1964 year-class in significant numbers. The peaks of this "1963" year-class group were at 27 cm in July-August 1973, and at 27-28 cm for males and 28 cm for females in February-April 1974.

From 1958 to 1973, there were evident in the length frequencies (Fig. 6) only two very successful year-class groups, nominally those of 1959 and 1963, each numerous enough to have a considerable effect on the commercial fishery. Several other and much smaller year-classes appeared at pre-commercial sizes but at larger sizes showed no evidence of adding significantly to the main adult group.

The length frequency of an age-class of young redfish is a relatively normal curve, and, in discussing the number of years between successful year-classes, it is assumed that the peak lengths are closely related to length at age. The growth increments from peak to peak of the length frequencies up to ages 14 and 11 for the successful year-class groups of 1959 and 1963 are closely related to those of Sandeman (1969), based on a small number of age readings of 1956 and 1958 material. At 11 years of age, fork lengths from length frequency modes were 28 cm (February-March) for the 1959 year-class group and 27.5 cm for males and 28 cm for females (February-April) for the 1963 year-class group (Fig. 6I, N). At age 14 (in July-August, when much of the growth for the year should have been completed), the modal lengths were 28 cm for males and 32.5 cm for females of the 1959 year-class group (Fig. 6M). Comparable lengths from Sandeman's (1969) von Bertalanffy growth curves for age 10 in July and November (when much of the growth equivalent to 11 years in February-April was completed), were 28.0 cm for males and 29.1 cm for females, and at 14 years of age they were 31.2 cm for males and 33.3 cm for females. Sandeman's growth rates were therefore used, where necessary, for estimating periods between year-classes when the older fish are considered.

Assuming that the peaks of the adult frequencies in November 1958 at 32 cm for males and 35 cm for females (Fig. 6B) approximately represent the peaks of the last highly successful year-class or group of smaller year-classes, these correspond to age 16 for males and ages 16-17 for females from Sandeman's (1969) *S. mentella* growth curves for Flemish Cap. This would indicate that by 1959 there had not been a highly successful year-class or group of year-classes for at least 17-18 years. In 1964, when the 1959 year-class group (age 5 with a modal length at 18 cm) first became very evident in the frequencies, the peaks of the adult frequencies were 33 cm for males and 36 cm for females. These latter peaks correspond with 19 years for each sex in Sandeman's (1969) growth curves. Thus, there were at least 14 years without a highly successful year-class on Flemish Cap.

Surkovas's (1962) growth curves for Flemish Cap *S. mentella* show a considerably faster growth rate than Sandeman's and this would result in a shorter period between the 1959 year-class and the earlier successful ones. One apparent reason for seemingly higher growth at the younger ages is the use by Surkova (1962) of commercial catch data, with no fish less than age 7 and few less than age 8, which usually results from net selection of the fastest-growing fish of the younger age-groups. Another reason is that Surkova apparently used scales for age determination and this, compared with ageing from otoliths, results in underestimation of the ages and consequent overestimation of the growth rate. Also, Surkova's lengths were presumably total lengths whereas Sandeman's were the shorter fork lengths. The difference is about 1.0-1.5 cm for redfish of 30-40 cm in length (Templeman, 1959b).

The growth curves of Parsons *et al.* (MS 1975) were derived from otolith readings of samples of *S. mentella* from the 1973 *Cape Farewell* catches. Their curves are slightly lower than those of Sandeman (1969) for ages 8-14 males and ages 8-20 females but are considerably above Sandeman's curves at greater ages. These growth curves of Parsons *et al.*, in relation to density-dependent growth, agree with the relative abundance of young redfish since 1959 and the relative scarcity of older fish.

Decline of the virgin stock of redfish and the effect of new successful year-classes on fishing success. Catch per unit effort for redfish on Flemish Cap was described by Parsons and Parsons (MS 1974) and revised in Parsons *et al.* (MS 1975). From a catch per effort in 1957 of over 6 tons per standard day for 151-500 ton vessels, the catch rate fell to about 2 tons per day in 1964-66, but rose steadily, at least from 1968, to about 4.5 tons per day in 1971 and declined slightly to 4 tons per day in 1972.

Murphy (1968) showed by competitive and genetic models that, under conditions of uncertain survival of pre-reproductives and relatively stable survival of reproductives, there was a clear competitive advantage in iteroparity (Cole, 1954). This means that there is an evolutionary tendency under these conditions toward an increase in the number of spawnings. In its unfished state, the redfish satisfies these requirements by its long spawning life of more than 30 years in females, by the location of most of its spawning areas on the continental slopes and a consequent high likelihood of loss of larvae (even with the compensating factor of viviparity), the large amount of predation on the slow-growing young by cod, redfish and other fishes, and by the relatively small number of enemies of the adult fish. The large number of spawnings and the viviparity compensate for the rarely successful year-classes, and the long life of the individual ensures that, in the virgin population state, the population of adult fish is large and stable and that, consequently, highly successful year-classes are rare. Under conditions of intensive fishing, the numbers and age of the adults and consequently the number of spawnings and the number of larvae produced are severely reduced. Also, however, much of the predation pressure on the younger fish is removed by the reduction in the numbers and size of the major predators.

Explained in terms of the length frequency and year-class picture in Fig. 6, the early good catches (over 50,000 tons in 1958-59, Fig. 1) and catch per effort were on the virgin stock of adult redfish accumulated over about forty years of growth. In the historical period of greatest accumulation, there is no evidence of very successful year-classes approaching or entering the adult frequencies (fig. 6). When the adult population had been reduced by heavy fishing, such that the catch per effort had decreased by one-fifth, the successful 1959 year-class appeared. In 1963, when the population had fallen still further with the catch per effort reduced to one-half of that on the virgin stock, the 1963 year-class was successful. Mainly, on account of the presence of these two year-classes (and possibly of an adjacent year-class in each case), the stock began to recover its numbers and mass and no new successful year-classes appeared up to 1974. By 1967-68, the fish of the 1959 year-class group were large enough to influence the commercial fishery and catch per effort increased. By 1972, the 1959 year-class group was at a good commercial size for the area (29 cm or larger) and the 1963 year-class group was entering the commercial fishery. It was at this time that redfish catches increased again to 42,000 tons, with the average for 1972-74 being 33,000 tons. Some of the apparent success of the new successful year-class groups of 1959 and 1963, relative to the adult part of the stock, is due to the decreasing numbers of adult fish under the effect of the large catches in 1957-59.

As discussed in detail under "cod food", when cod are in deep water after spawning, young redfish up to at least 5 years of age can be their principal diet. The adult redfish apparently eat considerably smaller quantities of young redfish. Over a period of years, a large stock of cod could greatly reduce a year-class of redfish, especially a small or medium-sized one, so that few of them are left to join the adult stock. Recorded catches of cod (Fig. 1) from Div. 3M were insignificant before 1957 but ranged between 29,000 and 54,000 tons during 1963-68. When good year-classes of redfish appeared, the reduction in the numbers of large cod and also large redfish in these years was favourable to much larger numbers of the year-classes surviving to reach the adult sizes, but the favourable effect of the reduction in cod numbers was much greater for the 1963 than for the 1959 year-class group of redfish.

Sandeman (MS 1973) described the course of the redfish fishery in the Gulf of St. Lawrence, a similar area where the virgin stock was quickly reduced and followed by the appearance of the very successful 1956 year-class which at age 7 began to enter the fishery in numbers in 1963. In the years following, this year-class, together with other subsequent successful year-classes, formed the basis of a much greater fishery than that provided by the virgin stock. The contributions of the two successful year-classes (or year-class groups) to the Flemish Cap stock were relatively considerably less.

Conclusions

1. Cod and redfish have moderately large populations on Flemish Cap and these have varied significantly in numbers since intensive fishing began. These are the only large populations of commercial fish known to be present there.

2. The circulation pattern on the Cap is mainly clockwise but there is also a loss of water in a northeasterly direction from the southeastern slope. There is a possibility, therefore, of periodic variations in retention and loss of fish larvae.

3. Flemish Cap temperatures are normally those of the seaward warmer part of the Labrador Current but the colder water of the eastern branch of the Labrador Current may reach the Cap in cold years. Thus, there is a moderate amount of temperature variability.

4. The cod stock of Flemish Cap is relatively isolated from that of the adjacent Grand Bank.

5. Redfish stocks of Flemish Cap are to some degree isolated from those of the Grand Bank. The relationships between the stocks on the Cap and the oceanic stocks of *S. mentella* are unknown.

6. Three species of redfish occur on the Cap. From experimental fishing, the *S. marinus* population on the Cap is believed to be relatively small. From larval studies, the *S. fasciatus* stock is believed to be much smaller than the total of *S. mentella* and *S. marinus*. However, the relative quantities of *S fasciatus* and *S. mentella* on the Cap need to be much better established.

7. Cod spawning on Flemish Cap usually occurs mainly in March with some in February and in April-May.

8. Redfish spawning extends from March or April to July. The earliest spawning is apparently from the deeper water, inhabited, according to Barsukov and Zakharov (1972), by *S. mentella*. *S. marinus* and *S. fasciatus,* which prevail at shallower depths, spawn later. From the latest evidence of spawning in shallower water (in July), almost all the larvae (Templeman and Sandeman, 1959) possessed subcaudal melanophores, so that the parents were *S. fasciatus*.

9. The propagation of *Calanus finmarchicus* in the Flemish Cap area, beginning in March, agrees with the timing of the main production of cod larvae. There are two periods of copepod abundance at Flemish Cap important to fish larvae and fry, the first, and most important, peaking in June and the second in September-October. In the general area including Flemish Cap, there is considerable variability in the production and abundance of zooplankton.

10. In the absence or relative absence of capelin and launce from Flemish Cap, cod are heavy predators on young redfish and secondarily on young cod. When cod are plentiful, this predation may seriously reduce the survival of at least the redfish year-classes. The study of numbers and sizes of young redfish and young cod in cod stomachs from suitable depths, locations and times should provide early comparisons of year-class strenghts.

11. The reduction in the standing stock and sizes of cod on Flemish Cap since 1956 should have been favourable to the survival of the two good year-class groups of redfish that have appeared and also to the survival of year-classes of cod. The reduction in large redfish must have also been a factor. Cod can prey significantly on young redfish for many years, whereas the main effect of redfish feeding is on the younger redfish.

12. There is considerable variation in the success of year-classes of cod at Flemish Cap. Flemish Cap is a very good area for the use of Petersen-type frequency curves in studies of year-class numbers of cod. The short spawning period, the fairly uniform temperatures, the relative isolation of the cod stock from other stocks with different lengths at sexual maturity and different growth rates, the regular growth from the first to the fourth years of about 10 cm per year (May *et al*., 1965, and Fig. 5) and the rapid cropping of the older year-classes as they join the spawning schools, allow the development of separate frequency peaks for the earlier year-classes, usually up to 3 or 4 years of age.

13. In the unfished population, the appearance of large year-classes of young redfish was apparently highly unusual. After the fishery had reduced the standing stock of old fish, several large year-classes appeared. Because of their isolation from other year-classes and from the adult population, and because of their slow growth, these large year-classes or year-class groups could be followed up to 14 or 15 years of age before they merged with the adult population and thus offer a useful check on growth rates over these ages.

14. The new redfish year-classes as they reached commercial size produced a considerable increase in the redfish catches which for 12 years previously had been at comparatively low levels.

15. The general picture is one of relatively large stocks of cod and redfish in relation to a limited area with enough isolation and variability of stocks, year-classes, and environmental factors to make Flemish Cap an interesting area of study in a program designed to identify the parameters of greatest importance in the production of successful and unsuccessful year-classes. However, it is not so certain that the important factors at Flemish Cap would be exactly the same as those, for example, for the stock providing the most important fishery in ICNAF Subareas 2 and 3, the Labrador-Newfoundland cod stock, which exists over a much larger area and in colder water.

Acknowledgements

I am grateful to Mr L. S. Parsons and Mr R. Wells for the provision of St. John's Station data on redfish and cod, and to Mr S. H. Lee for much assistance.

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Review of the Physical Oceanography of Georges Bank[1]

Dean F. Bumpus[2]

Abstract

Previously published information on the bathymetry, rotating tidal currents, temperature-salinity distribution and general circulation of the Gulf of Maine and Georges Bank are discussed. New information on surface temperature fronts in relation to monthly Ekman transport vectors is presented. Data on the distribution of herring larvae during successive periods during the autumns of 1972, 1973, and 1974 are used as evidence of dispersion and advection. Feasible approaches toward development of a circulation model are mentioned.

Introduction

Thirty-seven and a half years ago as a young biologist I cut my oceanographic eyeteeth as we commenced a study of the distribution of certain planktonic species on Georges Bank. It became obvious over the next several years of the study that the key to the problem lay in an understanding of the circulation of the area. World War II interrupted the study, and, in spite of intermittent attempts by numerous people and agencies over the intervening years, we still have only an approximate understanding of the circulation over Georges Bank, and many other continental shelf areas for that matter. We shall have to acquire a much better understanding of the dynamics if we are to evaluate the role of circulation in controlling dispersal of planktonic forms and organic production in general.

Hope springs eternal, even in the breast of one soon to retire from this field of endeavor. New techniques for making Eulerian and Lagrangian measurements are now at hand, and bright young minds are available to develop theoretical models to be compared with the real world measurements. It would appear that the chances for successfully defining the circulation scheme are now good, if we are willing to make a serious attempt to elucidate it.

As background for developing a plan of attack on the problem, I shall briefly review the major known features of the physical oceanography of Georges Bank and the Gulf of Maine and then attempt to relate these features to what is known about the movement and dispersion of herring larvae. Finally I shall comment on what seem to be feasible approaches toward development of a circulation model.

Bathymetry

Uchupi's (1965) chart (Fig. 1) handsomely illustrates the bathymetry of the Gulf of Maine, characterized by its rocky laybrinthine coastline and bottom topography on the north, its smoother coastline and bottom topography on the west, its deep basins interrupted by ridges and swells enclosed by the offshore banks, Browns and Georges which are intersected by the deep Northeast Channel and the shallow Great South Channel. The south side of Georges Bank is deeply penetrated by canyons, as the continental margin slopes away to the deep ocean basin.

Rotary Tidal Currents

One of the distinctive features of Georges Bank is the strong semi-diurnal rotary tidal currents with speeds ranging from a fraction of a knot to greater than 2 knots. Progressive vector diagrams for surface current measurements (the upper 4.5 m) as reported in Haight (1942) and Anonymous (1973) are shown to scale in Fig. 2. Those over Georges Bank appear for the most part as elipses, with the long axes oriented NNW-SSE ranging from 4 to 8 miles in length. The short axes are 2 to 4.5 miles. Rotation is clockwise. Those over the northern edge of the bank and over the deeper parts of the south side are somewhat irregular. Those to the west of Georges, i.e., in Great South Channel and over Nantucket Shoals, have various orientations, the westernmost over the Nantucket Shoal and another east of Chatham having a NNE-SSW orientation. One directly east of Nantucket has a counterclockwise rotation. The number alongside each tidal elipse represents the sum of the hourly speeds over a 12 hr period, an approximation of the distance traveled by a parcel of water during that time. These range

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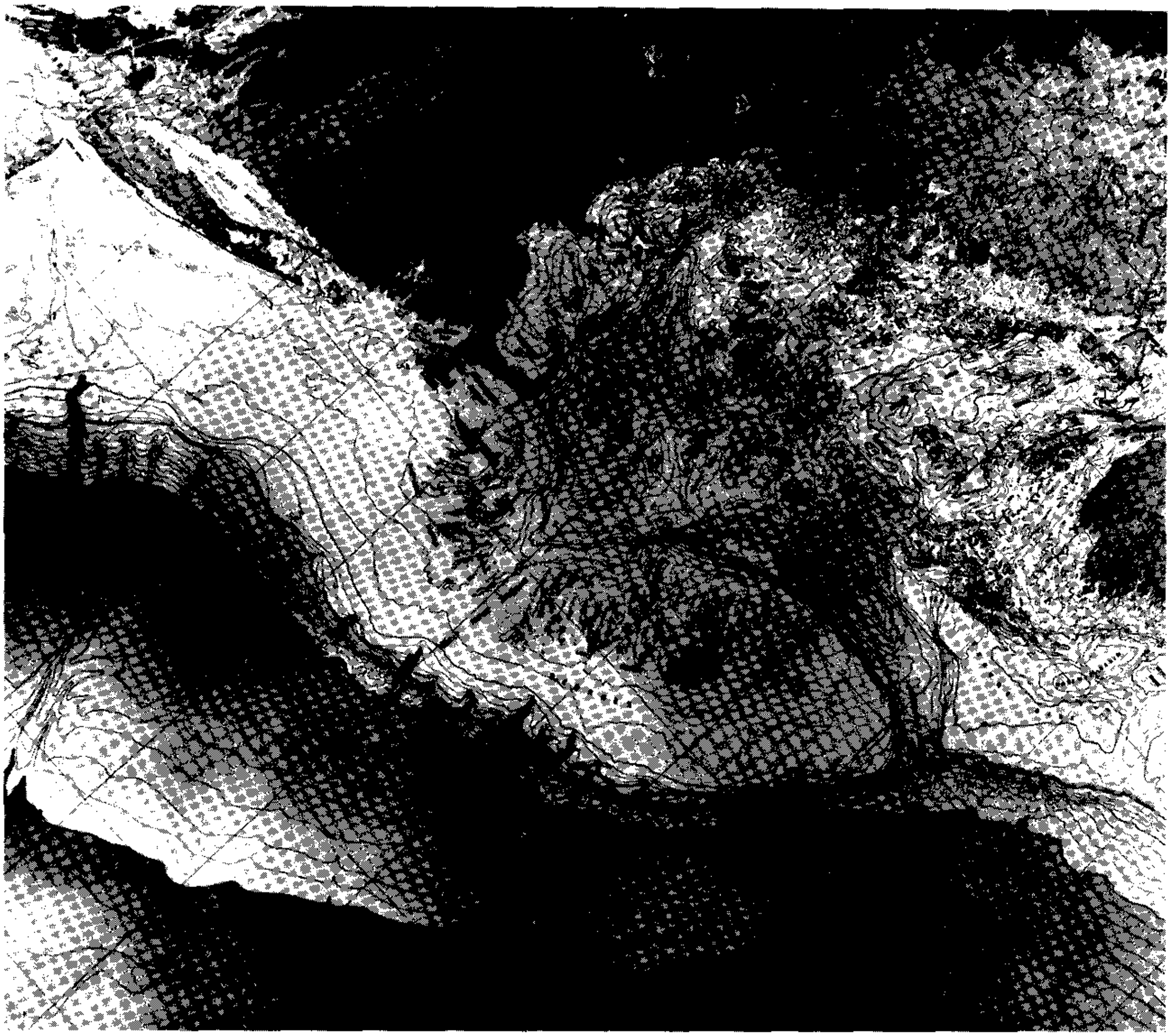

Fig. 1. Bathymetry of the Gulf of Maine (Uchupi, 1965).

from 10.7 to 19.9 miles over the shallower parts of Georges Bank, as little as 6.5 miles near the southern edge and 5.5 miles off the northern edge and 8.8 to 19.4 miles off Nantucket. One thus might think of the tidal oscillation over Georges Bank as being like a semi-solid irrotational eliptical motion with a circumference of the order of 20 nautical miles over the shallow parts of the bank, grading off to 5-6 nautical miles over the deeper parts.

Temperature and Salinity Distribution

The profiles of Colton *et al.* (1968), along the 67°30′ meridian from the northern shore of the Gulf of Maine across Georges Bank to the slope water on the south, provide a reasonably good characterization of the temperature/salinity depth distribution. Profiles for mid-December 1964 and 1965 are shown in Fig. 3. Note that the deepest parts of the Gulf of Maine are slightly warmer and saltier than the waters above, the total range in temperature of the Gulf being 1° to 2° C and the total range in salinity from 2 to 2.5°/oo. The water over the bank is mixed vertically. An oceanographic front occurs well off the bank in December 1964, but lies above the 100 m contour in December 1965.

In Fig. 4 we see profiles for March 1965 and 1966. The temperature increases with depth everywhere throughout the Gulf of Maine. Over the bank the water is

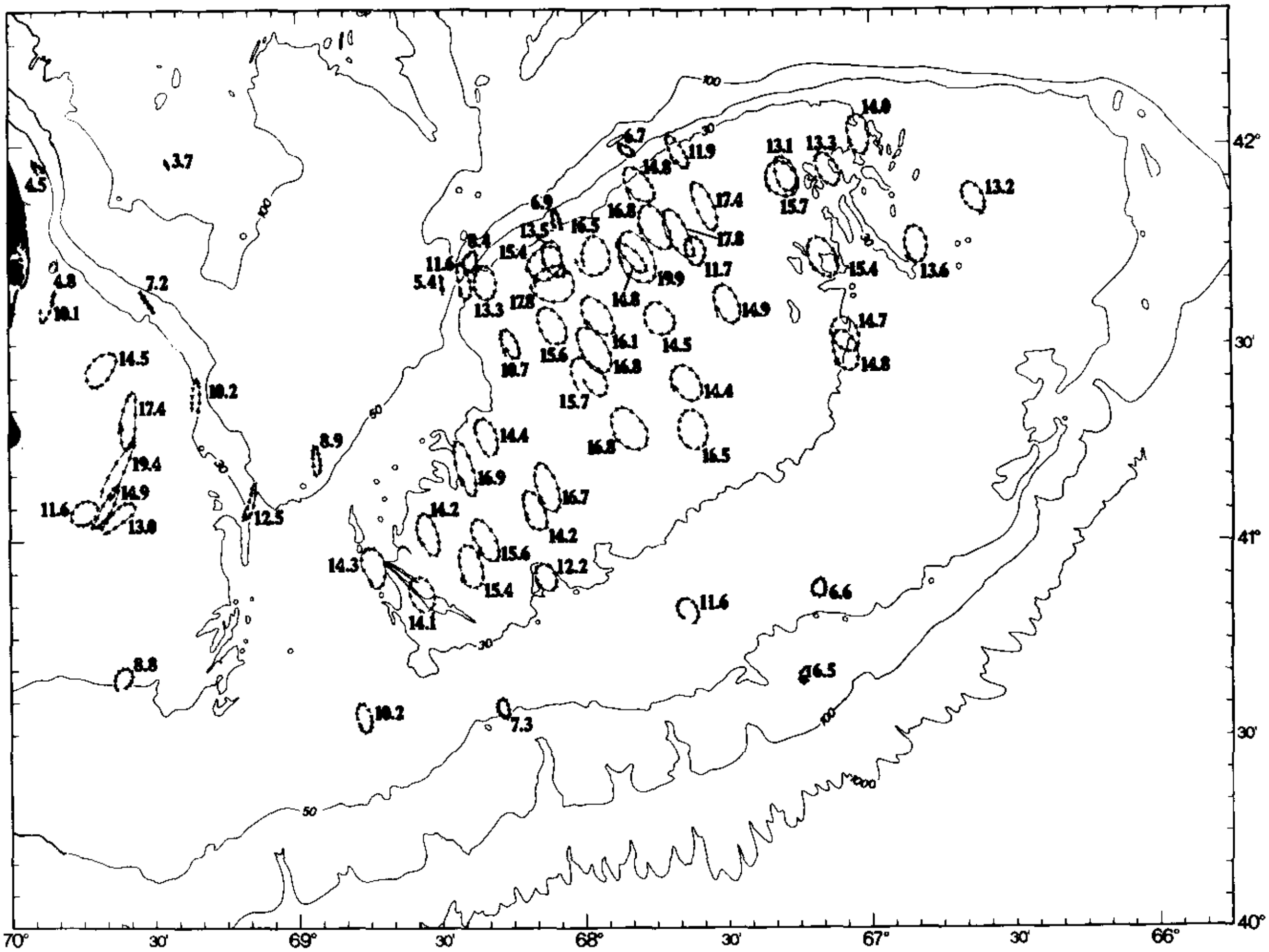

Fig. 2. Progressive vector diagrams of tidal oscillations on Georges Bank drawn to chart scale.

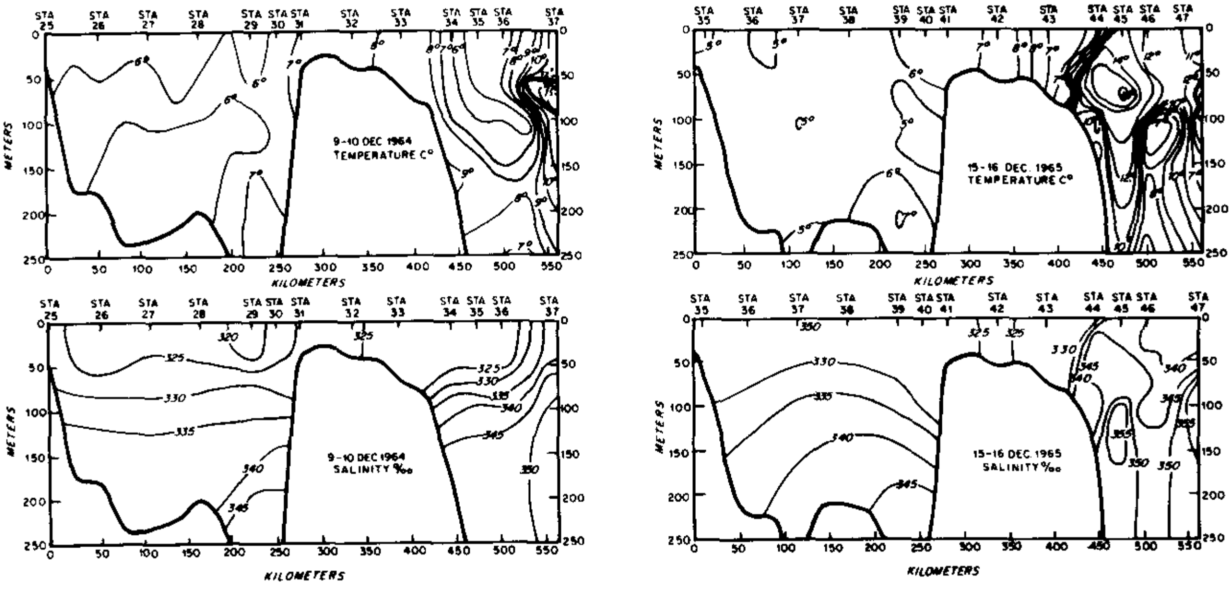

Fig. 3. Temperature, salinity profiles along 67°30′W across Gulf of Maine for December 1964 and 1965 (Colton *et al.*, 1968).

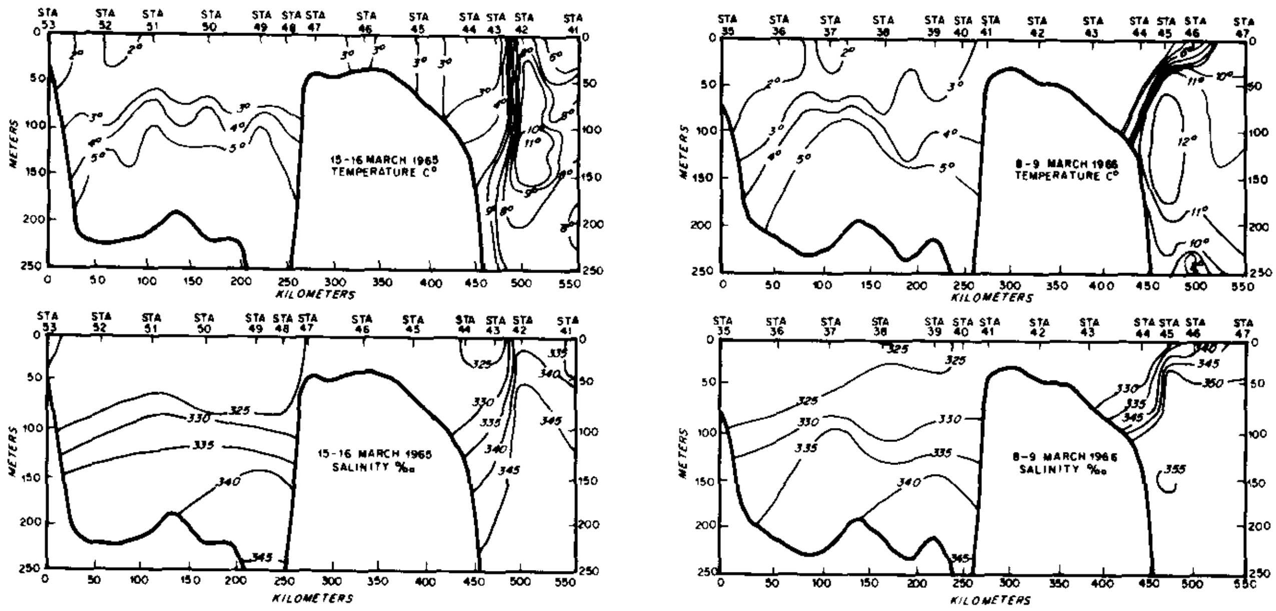

Fig. 4. Temperature, salinity profiles along 67°30′W across Gulf of Maine for March 1965 and 1966 (Colton *et al.*, 1968).

isothermal with a front along the southern edge, somewhat diffuse in 1965, very sharp in 1966. The salinity distribution on these occasions is markedly similar with increasing salinity with depth in the Gulf, isohaline conditions over the Bank and a salinity gradient between the southern edge of the Bank and the slope water.

Figure 5 represents the distributions in May 1965 and 1966. By this time a seasonal thermocline has begun to develop over the Gulf in the upper 50 m below which the temperature increases with depth. Although warmer than in March, the water is isothermal over the shallow (< 50 m) parts of the bank with a slight thermocline beginning to develop over the deeper southern part producing an isolated cold core of "winter water" next to the bottom, which extends all the way westerly along the outer edge of the continental margin as far as about 38° N latitude, nicely illustrated in Whitcomb (1970). A bulge of this cold core extends out over the edge of the bank in the 1965 section. The temperature front between the shelf and slope water lies beyond this bulge in 1965, whereas it is close in over the edge of the shelf in 1966. The salinity distribution for May is almost identical with that for March.

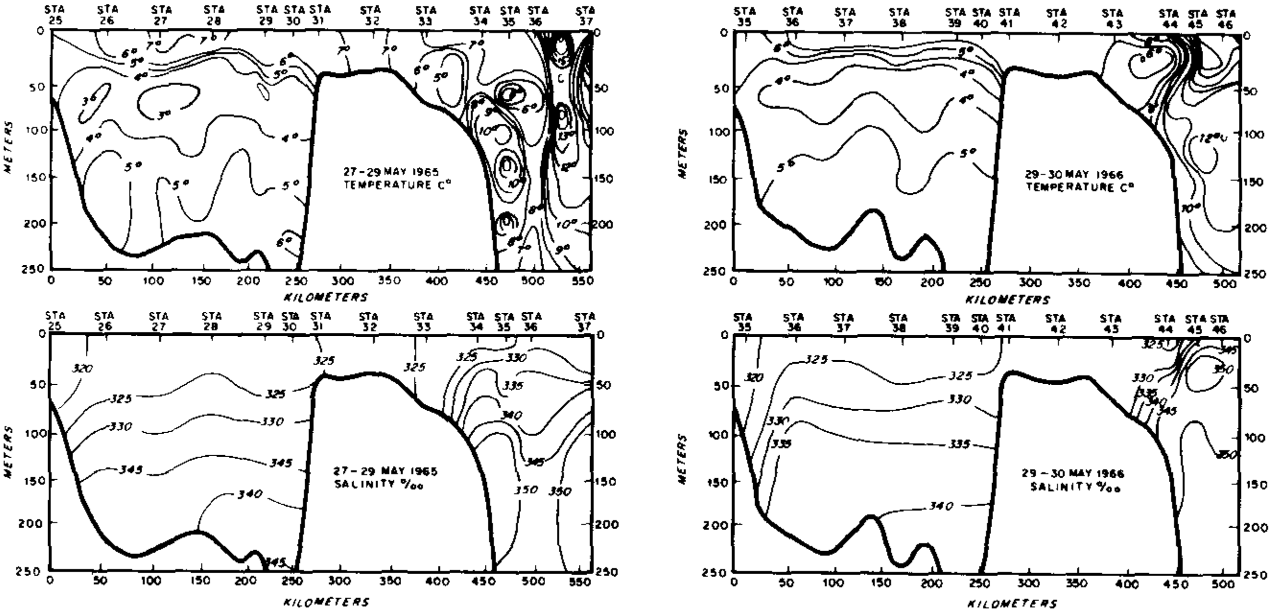

Fig. 5. Temperature, salinity profiles along 67°30′W across Gulf of Maine for May 1965 and 1966 (Colton *et al.*, 1968).

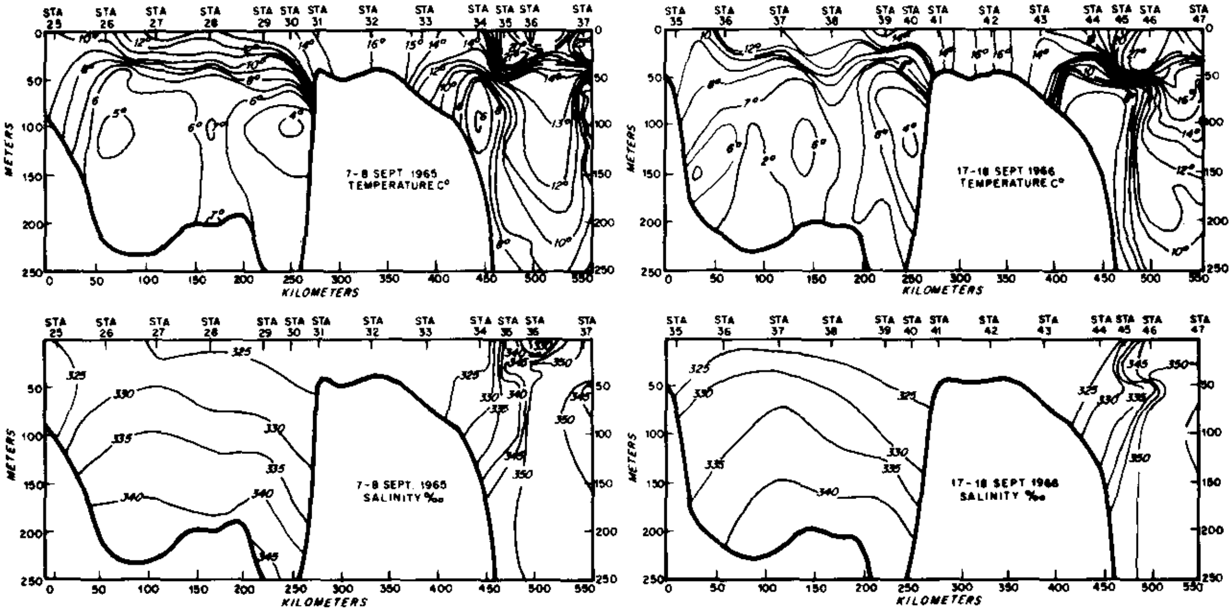

Fig. 6. Temperature, salinity profiles along 67°30′W across Gulf of Maine for September 1965 and 1966 (Colton *et al.*, 1968).

In Fig. 6 we can see the distribution for September 1965 and 1966. The strong thermocline which has developed over the central Gulf of Maine to a depth of 50 m has begun to weaken. The coldest water appears at mid-depth with slightly warmer below. A temperature front appears at depth along the northern edge of Georges Bank occasioned by the colder vertically-mixed water over the bank. The cold core of winter water persists over the southern side of the bank and the sharp thermal front in the upper 50 m lies just off the southern edge. The salinity distribution is little changed from that seen in May.

In discussing the general hydrographical conditions pertaining to Georges Bank, Clarke, Pierce and Bumpus (1943) wrote in part:

"The depth of the major portion of Georges Bank lies between 40 m and 100 m, although areas of less than 25 m occur in the north central position, and shoals themselves are covered by only 5 to 15 m of water. Along the northern edge of the Bank the bottom drops rapidly from about 40 m to more than 200 m as the deep basin of the Gulf of Maine is approached. Along the southern edge the depth changes somewhat more gradually from 100 m to 200 m. Beyond 200 m it increases rapidly to about 2000 m.

"Georges Bank is therefore roughly speaking, a submerged, flat-topped plateau and it presents a sufficiently large obstacle to water movement to produce a profound effect on the ocean currents of this region. —

"The turbulence produced by the tidal currents and by the wind in the relatively shallow water overlying Georges Bank causes a vertical mixing of the water which results in a nearly uniform distribution of temperature and salinity from top to bottom at all seasons of the year, particularly in the central part of the bank. The bank water thus contrasts sharply with the surrounding water masses, which are typically stratified during all expect the winter months. Since the temperatures and salinity values on the Bank are generally intermediate between those of the surface and deeper strata on the Gulf of Maine but usually much lower than those of the water lying to the south, we know that the bank water is originally derived, in a large part at least, from the Gulf. That portion of the Bank over which vertically uniform water was found is termed the *Mixed Area,* and all stations at which the salinity does not vary by more than 0.2 part per mille from surface to bottom are considered to lie within it. The limits of the Mixed Area are ordinarily rather sharp . . . ."

A review of the profiles presented in Colton *et al.* (1968) reveals that the mixed area covers all of Georges Bank shallower than 50 m in December, deepening to 80 m in March and returning to an area of less than 50 m in depth during the remainder of the year.

General Circulation of the Gulf of Maine

The development of our concepts of the circulation in the Gulf of Maine, including Georges Bank, have been documented in Bumpus (1973). It is not necessary to repeat that here, but we shall review the circulation as described by Bumpus and Lauzier (1965) on the basis of drift bottle data, and Bumpus (1973) on the basis of drift bottle and sea-bed drifter data. There have also been a few experiments with drifting buoys which help to confirm or amplify the inferences made from the drift bottle data.

To quote from Bumpus and Lauzier (1965) relative to surface drift:

"Gulf of Maine —

"The indraft from off Cape Sable, from across Browns Bank and the eastern Gulf of Maine into the Bay of Fundy, is the chief characteristic during the winter season. A southerly flow develops along the western side of the Gulf of Maine and continues past Cape Cod through Great South Channel. Between the indraft in the Bay and the southerly flow along the western side of the Gulf several irregular eddies develop by February. An area of divergence north of Georges Bank is well developed by February.

"The Gulf of Maine eddy develops rapidly during the Spring months so that one large cyclonic gyre encompasses the whole of the Gulf of Maine by the end of May. There is an indraft on the eastern side of this gyre from the Scotian Shelf and Browns Bank. Abreast of Lurcher Shoals the drift may continue on northward into the Bay of Fundy or it may turn westward toward the coast of southern Maine, continue south and across Massachusetts Bay where it may divert into Cape Cod Bay or turn toward the east, north of Georges Bank.

"The Maine eddy, which reached its climax in May, begins to slow down in June. By autumn and winter the

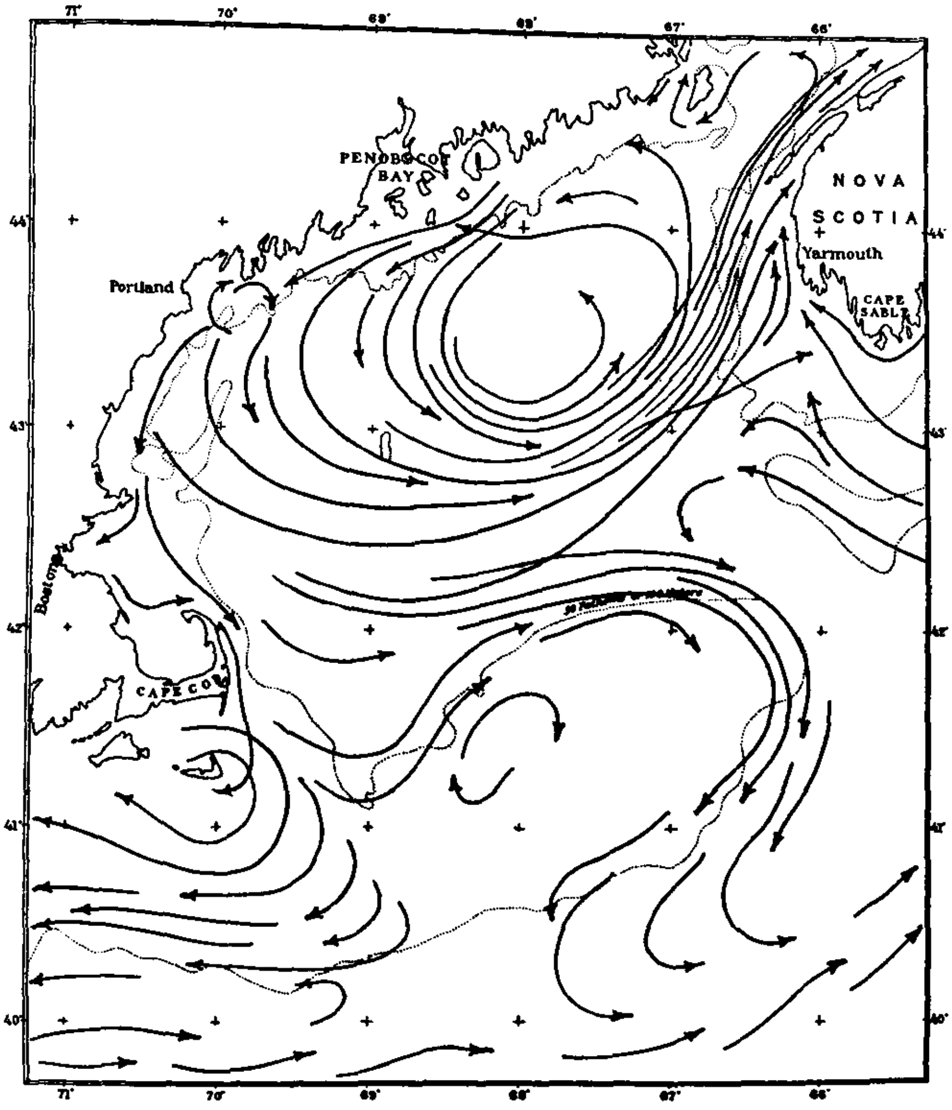

Fig. 7 Schematic representation of the dominant non-tidal circulation of the Gulf of Maine, July to August (Bigelow, 1927).

southern side breaks down into a drift across Georges Bank.

"Georges Bank —

"The few returned drift bottles from winter releases on Georges Bank suggest a southerly flow across this area during the winter months, with a westerly component across Great South Channel. During the Spring months an anti-cyclonic eddy develops over Georges Bank. The northern side of this Georges eddy is common with the southern side of the Maine eddy; an area of divergence continues along the northern edge of Georges Bank. A persistent westerly drift along the southern side of the Bank continues across Great South Channel.

"During the summer the eastern side of the Georges eddy veers southerly and off-shore. With the onset of autumn the west side of the Georges eddy breaks down into a westerly and southerly drift."

Bumpus (1973) points out that the limited drift bottle data for the 1960-1970 period in the Gulf of Maine and over Georges Bank add very little to our previous understanding of the circulations in that area.

One may note, however, that the diagrams in Bumpus and Lauzier (1965) indicate the speeds of residual drift range from 1 to 8 nautical miles per day, the greater speeds restricted to the approaches of the Bay of Fundy or the western side of the Gulf of Maine, where the circulation is significantly influenced by river runoff. The drifts over Georges Bank are frequently on the order of 2 to 3 nautical miles per day, although greater speeds have occasionally been inferred. The classic diagram of Bigelow (1927) illustrates as well as any the general circulation pattern (Fig. 7).

Thus to return to our "semi-solid irrotational eliptical motion" induced by the tide over Georges Bank, we might now add a clockwise rotation of 2-3 miles per day. We might liken this surface circulation over Georges Bank to a very slowly clockwise turning record in a record player estimated at one rotation per 100 days (3.6 rotations/year) on a spindle with a large (8 mile by 4 mile) eliptical eccentricity.

As for the bottom drift, Bumpus (1973) in reporting on the sea-bed drifter results states: "A persistent and continuous bottom drift of 0.5 ± 0.2 nautical mile/day extends toward the southern tip of Nova Scotia and the eastern side of the Bay of Fundy from Browns and LeHave Banks east of the Northeast Channel. This is in agreement with Lauzier's (1967) findings. Along the western side of the Gulf of Maine the drifts next to the coast tend to flow directly ashore, whereas farther offshore the drift is more nearly parallel with the coast in a westerly direction. Fewer than 10% of the drifters are recovered from the deeper parts of the Gulf of Maine and from Georges Bank whereas returns are substantially greater from the periphery of the Gulf of Maine and from the Continental Shelf west of Nantucket Shoals. The drifts in the deep parts ($>$ 100 m) are less than 0.1 nautical mile/day whereas those from Georges Bank are on the order of 1 nautical mile/day. A line of divergence occurs at Northeast Channel with northerly drifts north and east of the channel and westerly drifts south of it. In general, the drifts over Georges Bank follow a clockwise rotation around the shoals with a net drift to the west and across Great South Channel."

Because there are so few returns of drift bottles and sea-bed drifters from Georges Bank, one cannot help but suspect that a great number are carried offshore, rather than drifting to the west to strand, in the case of drift bottles, or be recovered by fishermen's trawls, in the case of sea-bed drifters.

Certainly when one views the results of some drogued drifting buoy experiments conducted jointly by the U.S. Fish and Wildlife Service and the Woods Hole Oceanographic Institution in 1957, one obtains the feeling that there are ample opportunities for exchanges between Georges Bank water and slope water. Buoys equipped with on-demand radio signals were located via ship or air-borne radio direction finders. They drifted with the top 5 m of the water column.

One experiment (Fig. 8) was conducted between Northeast Peak and central Georges Bank during the period 15 April to 10 June 1957. Buoys set out at the Northeast Peak (*Mike* and *India*) moved rapidly, more than 5 miles per day, and southerly into deep water. Buoys launched in the shallower areas exhibited a slower net movement, between 1 and 4 miles per day, in a clockwise rotation. Buoy *Hotel,* after a slow southwesterly movement (81 miles in 55 days), suddenly increased speed and moved 128 miles to the WSW in 12 days. Buoy *November,* which failed to respond after 21 April, was reported on 20 June just east of Hudson Canyon on the 1,000-fathom contour, possibly having run parallel to the track of *Hotel. November* was subsequently sighted 500 miles to the eastward (38° 42'N, 60°30'W) on 31 July, obviously drawn into the Gulf Stream.

Another experiment with four drift buoys was conducted during 9-17 October 1957 in the South Channel area (Fig. 9). An easterly drift along the northern edge of the bank, between 6 and 13 miles per day was indicated, with a slower, less definite drift in the center of the channel, and a southerly set of about 5 miles per day on the western side of the channel.

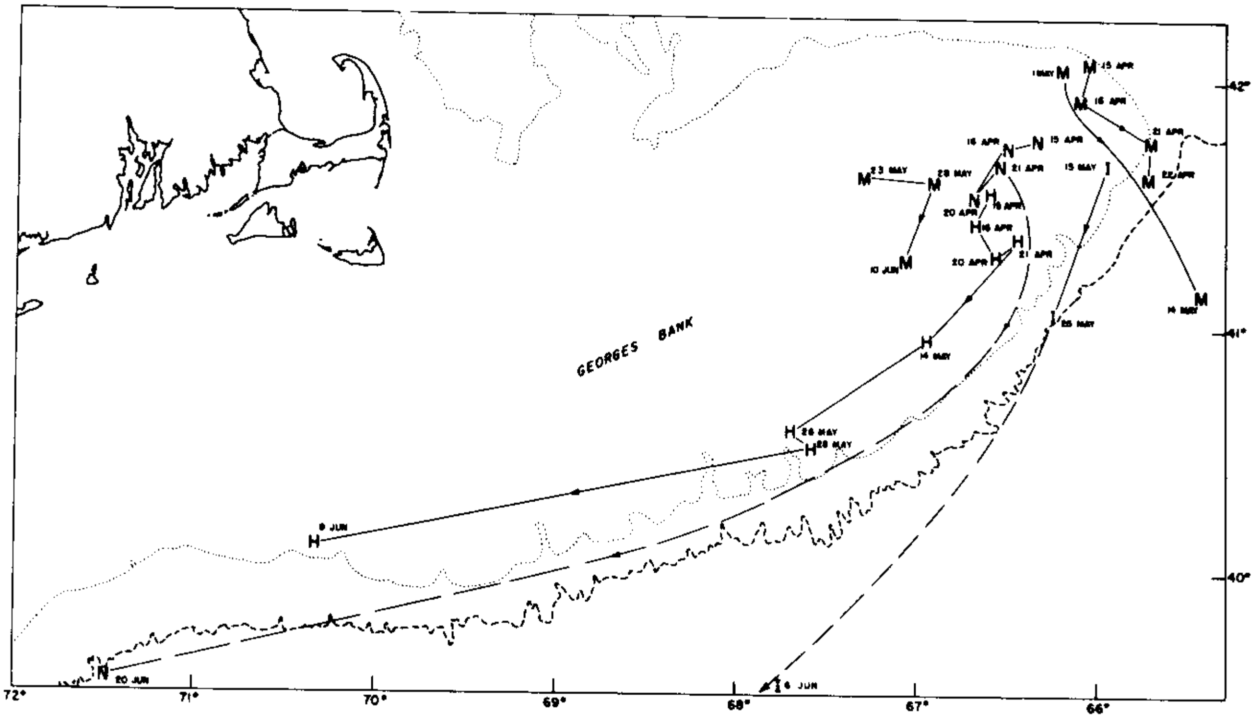

Fig. 8 Drift buoy trajectories, 15 April to 10 June 1957.

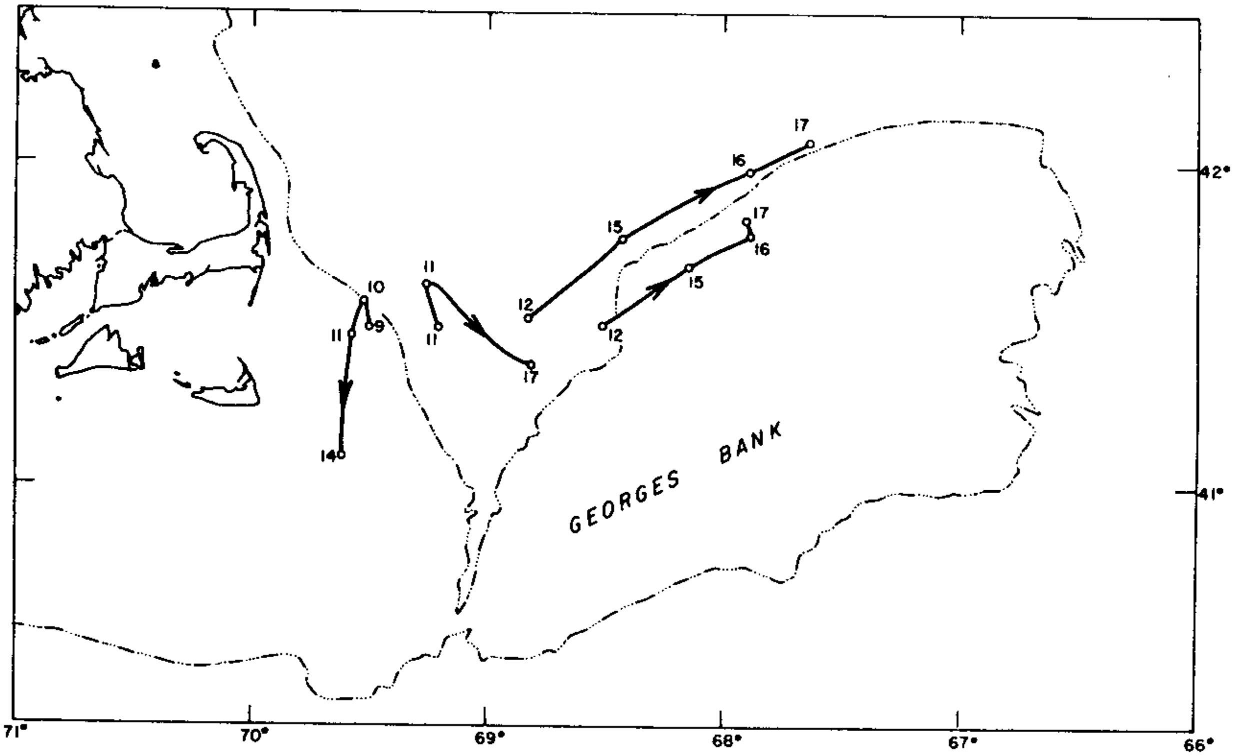

Fig. 9. Drift buoy trajectories, 9-17 October 1957.

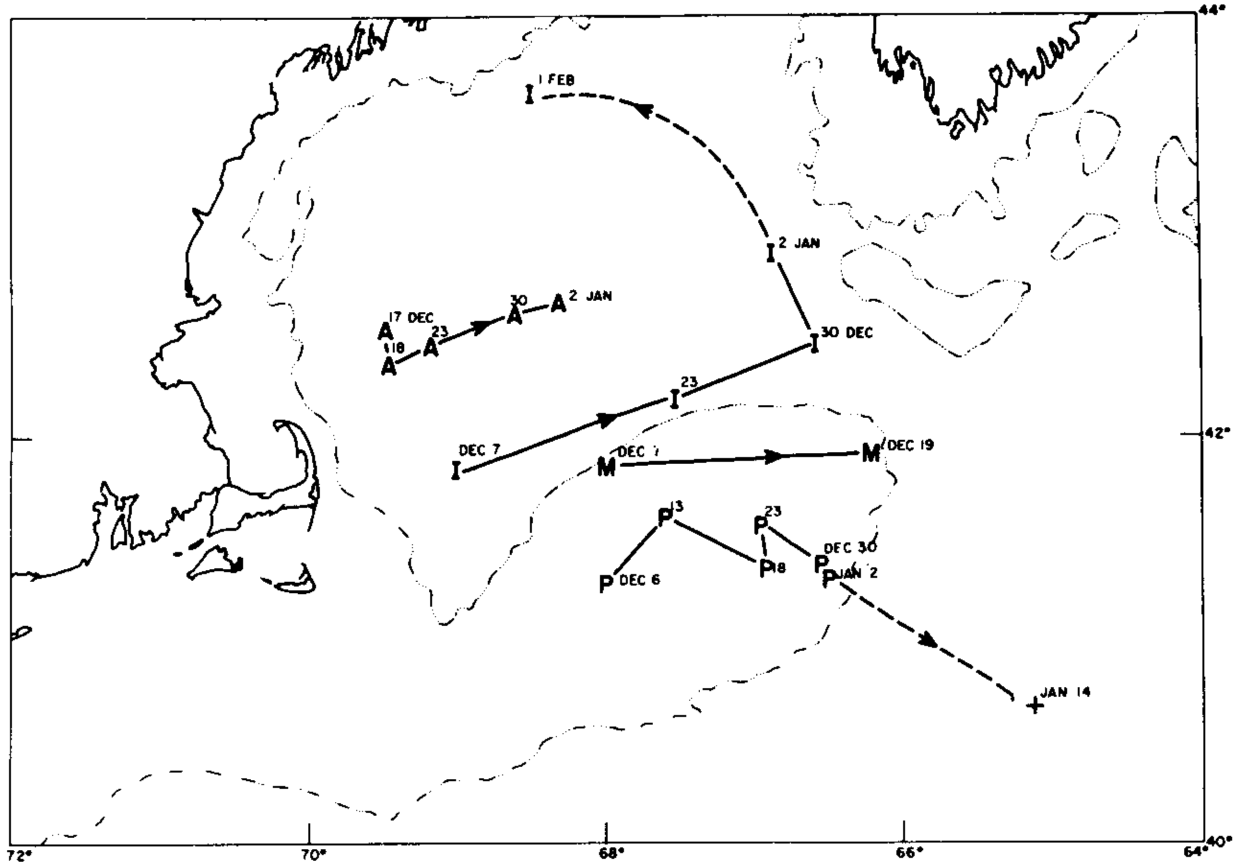

Fig. 10. Drift buoy trajectories, December 1957.

Five more buoys were set out on December 6, 7 and 17, 1957 (Fig. 10). *Hotel,* launched on the southeastern part of the bank subsequently failed to function and is not shown in the figure. It was recovered about 500 miles to the SE 8 months later. *Mike* was picked up and replaced by a fisherman, but was apparently damaged as it ceased to respond to radio calls. It had moved 50 miles eastward in 12 days. The remainder were repeatedly located during December. This experiment yields evidence of an easterly set on Georges Bank in December 1957 on the order of > 1 to > 4 miles per day as indicated by *Papa* and *Mike. Papa* eventually drifted off into deep water southeast of the bank where it was sighted. *India* moved at a similar rate but skirted the northern edge of Georges, then turned northerly before reaching Browns Bank, being ultimately recovered by a fisherman 21 miles SE of Matinicus Rock. This buoy was obviously in the Gulf eddy. *Alpha,* following the innerpart of the Gulf eddy, moved more slowly, at > 5 miles per day.

This experiment perhaps explains why so few drift bottles set out on Georges during the autumn and winter have been recovered. The Georges eddy has given way to an easterly drift. Bigelow (1927, p. 864-865) examined the current measurements made by the U.S. Coast and Geodetic Survey during 1911 and 1912 at *Nantucket* Lightship. This analysis showed "a dominant drift toward the north and west during the spring, summer, and early autumn, averaging about 3.4 miles per day; but about as strong a southeasterly set (3 miles daily) during the late autumn, winter, and early spring, averaging about S.50°E (SE × E) in direction." Bigelow credited the presence of the strong northwest winds of the season with the reversal in drift. During our December experiment the winds were predominantely from the southwest, with strong easterlies on a few occasions. Whatever the reason, the surface drift across Georges Bank during the autumn and winter is different and apparently contrary to the drift of other seasons. It is quite probable, at this stage of our information, that the net circulation on Georges Bank is not readily predictable. It is reasonable to expect that the water movements on the bank, especially during those seasons where the water is well mixed, respond to the short-term wind effects as postulated by Chase (1955) for Georges Bank in regard to haddock larvae and as reported by Howe (1962) in the Middle Atlantic Bight and more recently Beardsley and Butman (1974). The latter authors, with measurements south of New England,

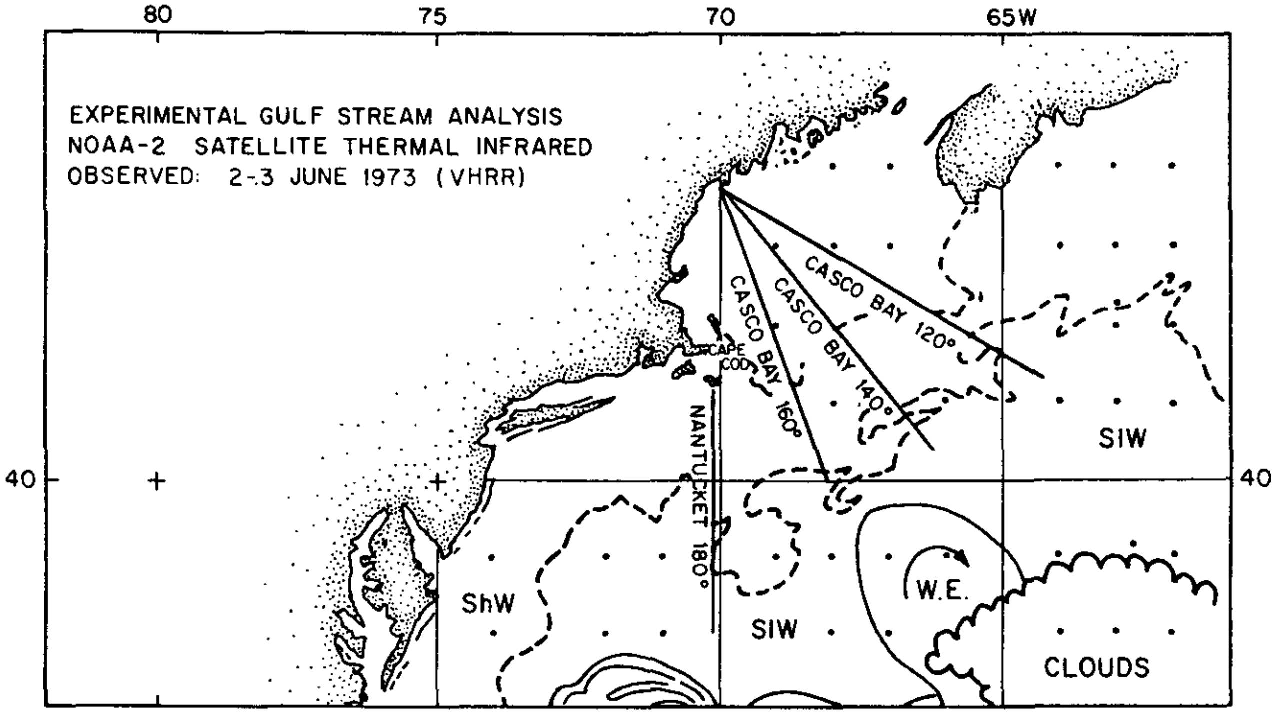

Fig. 11. Example of weekly frontal chart, produced by National Environmental Satellite Service, NOAA, with standard lines along which fronts were measured superimposed.

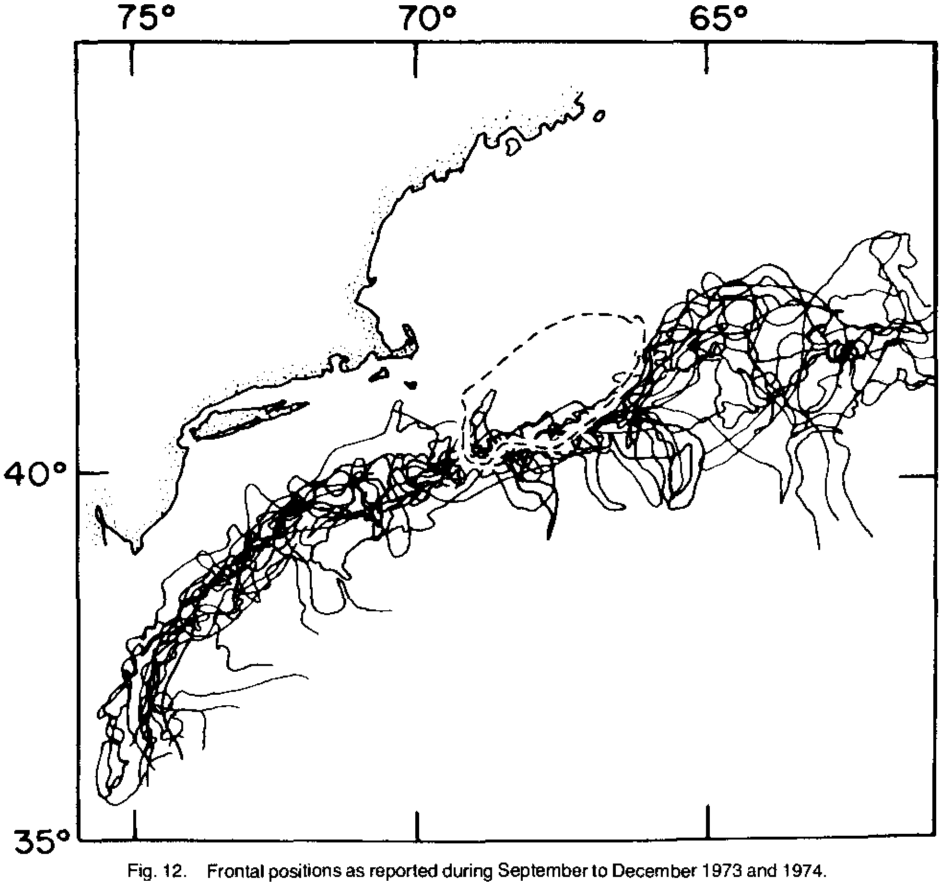

Fig. 12. Frontal positions as reported during September to December 1973 and 1974.

demonstrated that short intense wind events dominate the circulation over the shelf in winter and account for most of the observed net flow. Their observations show that large westward mass transports along the shelf were produced by strong easterly winds and the sea level rise at the coast (see Miller, 1957), while westerly winds produced little along-shore flow. However, the storm producing the westerly winds was much weaker than the one with the easterly winds. It may be that we cannot extrapolate the southern New England Shelf response to Georges Bank because the geography is quite different. However, it is quite possible that when an intense low pressure cell moves south of Georges causing easterly winds over the bank and an increase in sea level over the shoals, there will be a strong net westerly flow over the south side of the bank. Contrarywise, an intense low passing north of Georges could similarly create strong easterly flows along the north side of the bank, with weaker flows south of the shoals.

Sea Surface Temperature Fronts

As we have seen from Colton's profiles, the interface between the colder, less saline shelf water and warmer, more saline slope water appears at the sea surface as a thermal front. This front can be observed by satellite-borne infra-red radiometers. The National Environmental Satellite Service prepares charts of the sea surface temperature fronts off the east coast of the USA on a weekly basis. Ingham and co-workers at the NMFS Atlantic Environmental Group have used these charts to monitor and analyze the position of the shelf water front from June 1973 through December 1974 (Fig. 11, for example). Figure 12 is a composite of the frontal positions during September-December 1973 and 1974. The dashed line represents the shelf edge as defined by the 100-fathom contour.

In the course of the analysis the temporal variation of the Shelf Water front was established along certain standard lines (Fig. 11). The results of the first four, Casco Bay 120°, 140°, 160°, and Nantucket 180° are shown in Fig. 13. The location of the front is plotted as the distance from the shelf edge to the front.

The mean position of the front during the 18-month period is shown in Table 1. The variability of the front's position, as indicated by the standard deviation, is large

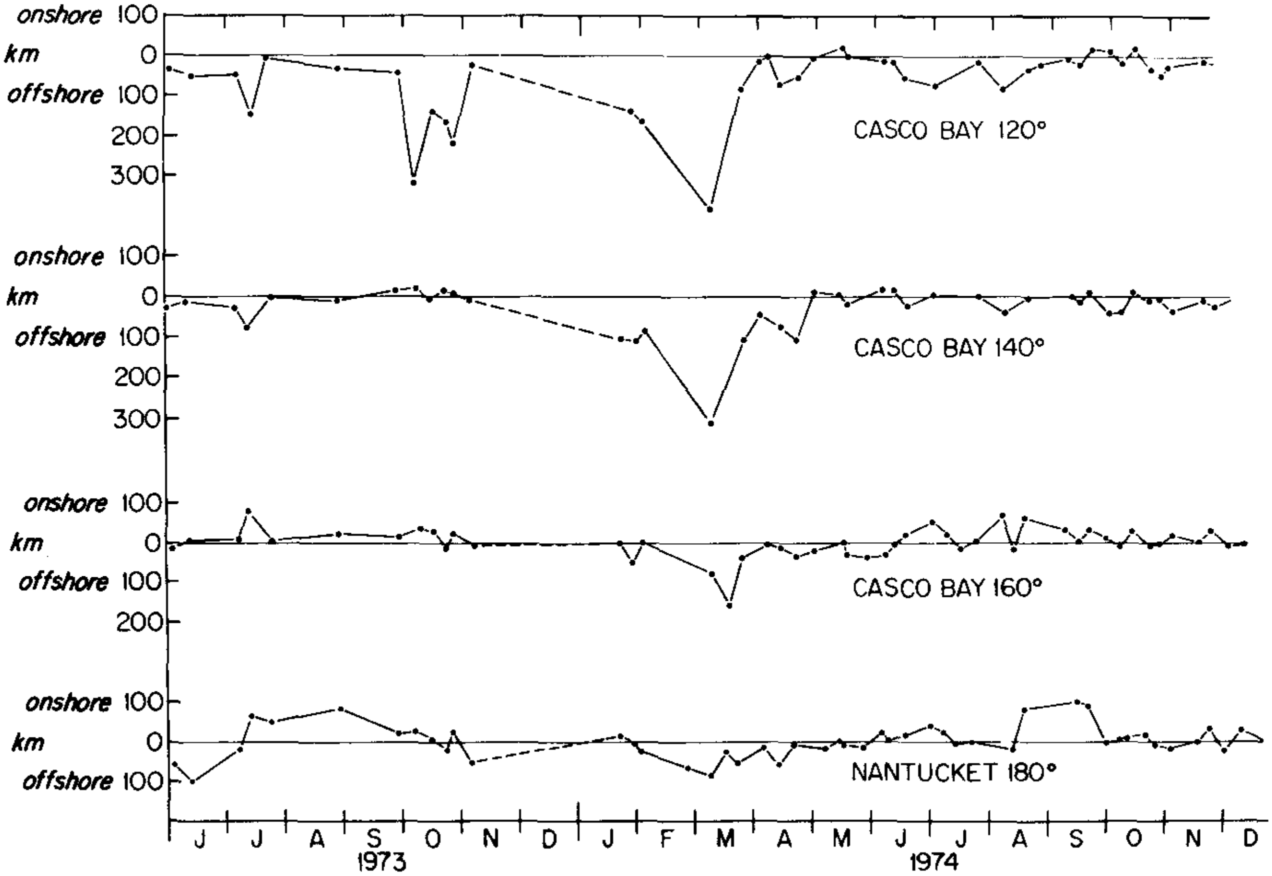

Fig. 13. Temporal variation of the position of the shelf water front relative to the edge of the continental shelf along the indicated azimuths. Positive values are shoreward from the shelf edge.

on all azimuths, being largest at the eastern corner of Georges Bank and least south of Nantucket.

Major offshore excursions occurred on the Casco 120° line in July and October 1973 and during the winter of 1974; on Casco 140° line in July 1973 and during the winter and early spring of 1974; on Casco 160° line during March of 1974 and on the Nantucket 180° line during June and November 1973 and winter of 1974. Intrusions of slope water appear greater on the Casco 160° and Nantucket 180° lines than over the eastern parts of Georges. On Casco 160° the intrusions occurred during June 1973 and during the summer of 1974 whereas they were fairly extensive on the Nantucket 180° line during the summers of 1973 and 1974. Ingham (1976) estimates 14% of Georges was invaded by slope water in late August 1974, increasing to 18% coverage by early September, then decreasing to about 4% by the end of the month. He states: "At no time during the year did the invasion of the Bank by Slope Water exceed 18% and the average coverage for the year was 3.5%, with a standard deviation of 4.8% based on a sample of 30 observations."

TABLE 1. Mean position of the shelf water front during the period from June 1973 through December 1974.

Bearing line		Sample size	Distance from shelf edge (km)[a]	Standard deviation
Casco Bay	120	30	—45.5	70.9
	140	31	—35.4	64.0
	160	36	— 6.1	39.3
Nantucket	180	37	+ 0.6	38.5

[a] + = Shoreward; — = Seaward.

Wright (1975) has carefully examined the position of the shelf water-slope water boundary between 69° and 72°W longitude, an area which slightly overlaps our area of interest. His study shows that this interface, identified by the 10° isotherm, intersects the bottom within 16 km of the 100-m contour about 80% of the time, with a seasonal progression from south in the winter to north in the autumn. The sea surface boundary position is much more variable, averaging 45 km seaward of the 100-m contour in winter and 75 km seaward in late summer. This boundary is much more nearly horizontal than vertical. He also finds detached parcels of shelf water in the slope water at all seasons of the year.

Estimates of Wind-Driven Ekman Transports

The Pacific Environmental Group of the N.M.F.S. provides estimates of monthly wind-driven Ekman transports computed from the monthly average atmospheric pressure charts after the method of Fofonoff (1962) as described by Bakun (1973). Figure 14 shows the estimated monthly Ekman transport at 40°N70°W for 1972, 1973, and 1974. It is quite obvious from this figure that the direction and intensity of the transport is extremely variable from month to month and from year to year. One is not at all assured either that the water movements are going to be in the direction of the computed Ekman transports, in the shallow waters of Georges Bank and Nantucket Shoals. They may indeed be more directly downwind, i.e., 90° to the left of these Ekman transport vectors. What these vectors mean to me

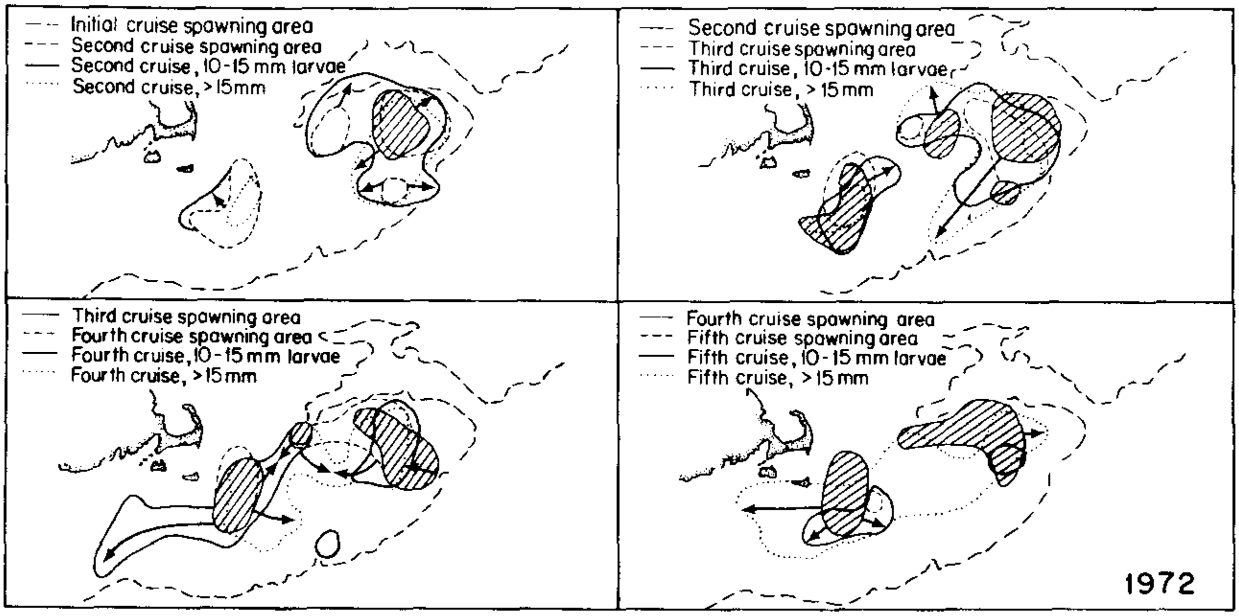

Fig. 15. Locations of various length herring larvae relative to previous cruises in 1972.

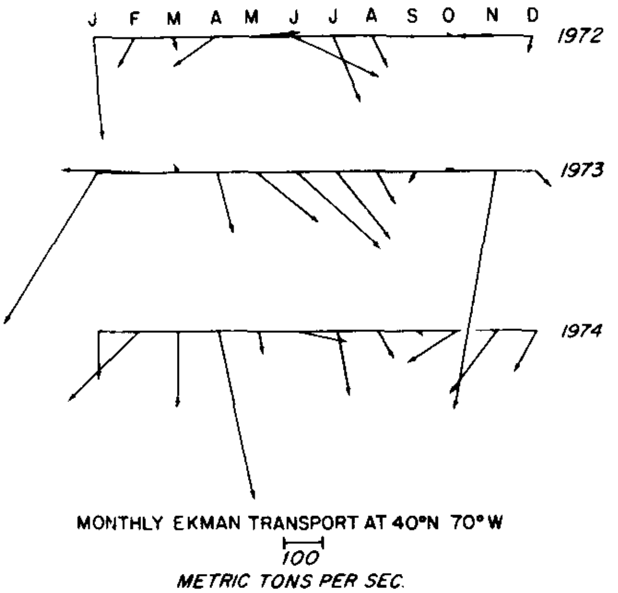

Fig. 14. Monthly Ekman transport at 40°N70°W for 1972-1974.

is that there are periods of intense forcing which may indeed induce extreme wind-stressed flows as well as periods of minimal forcing.

We have compared the data for 40°N70°W with data for 39°N69°W, 39°N66°W, 42°N60°W, and 42°N66°W, for 1974 and found 40°N70°W representative of the area. However, the position of the fronts relative to the edge of the bank in the last half of 1973 and all of 1974 do not appear to correlate well with the monthly Ekman transport vectors. It is very possible that the development of eddies north of the Gulf Stream have a significant impact on the location of the shelf water-slope water front.

Evidence from the Distribution of Herring Larvae

We have inspected the information presented by Schnack and Stobo (MS 1973) and Schnack (MS 1974) summarizing the results of the 1972 and 1973 joint herring larval surveys and the several separate reports on the 1974 cruises. These cruises took place as follows:

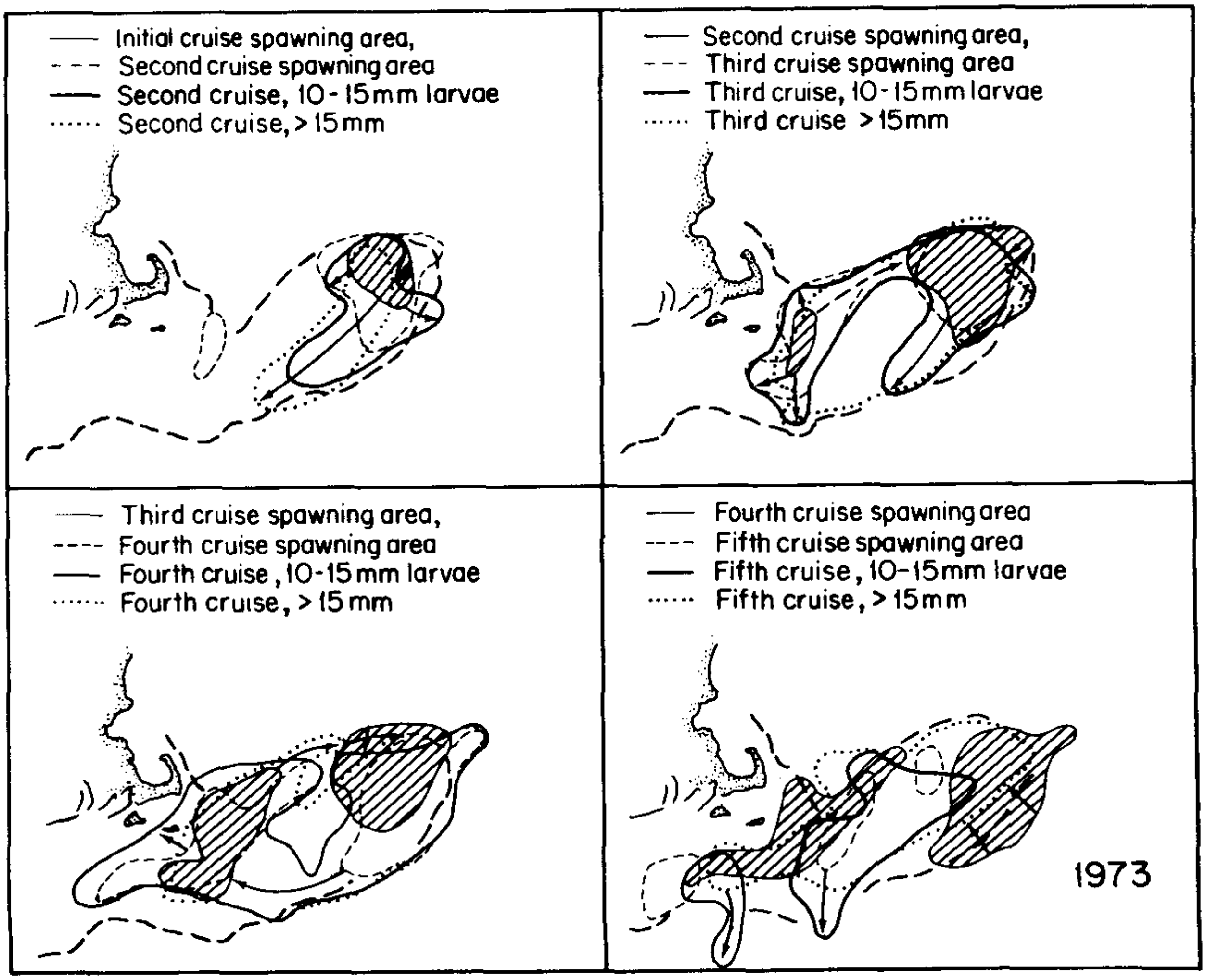

Fig. 16. Locations of various length herring larvae relative to previous cruises in 1973.

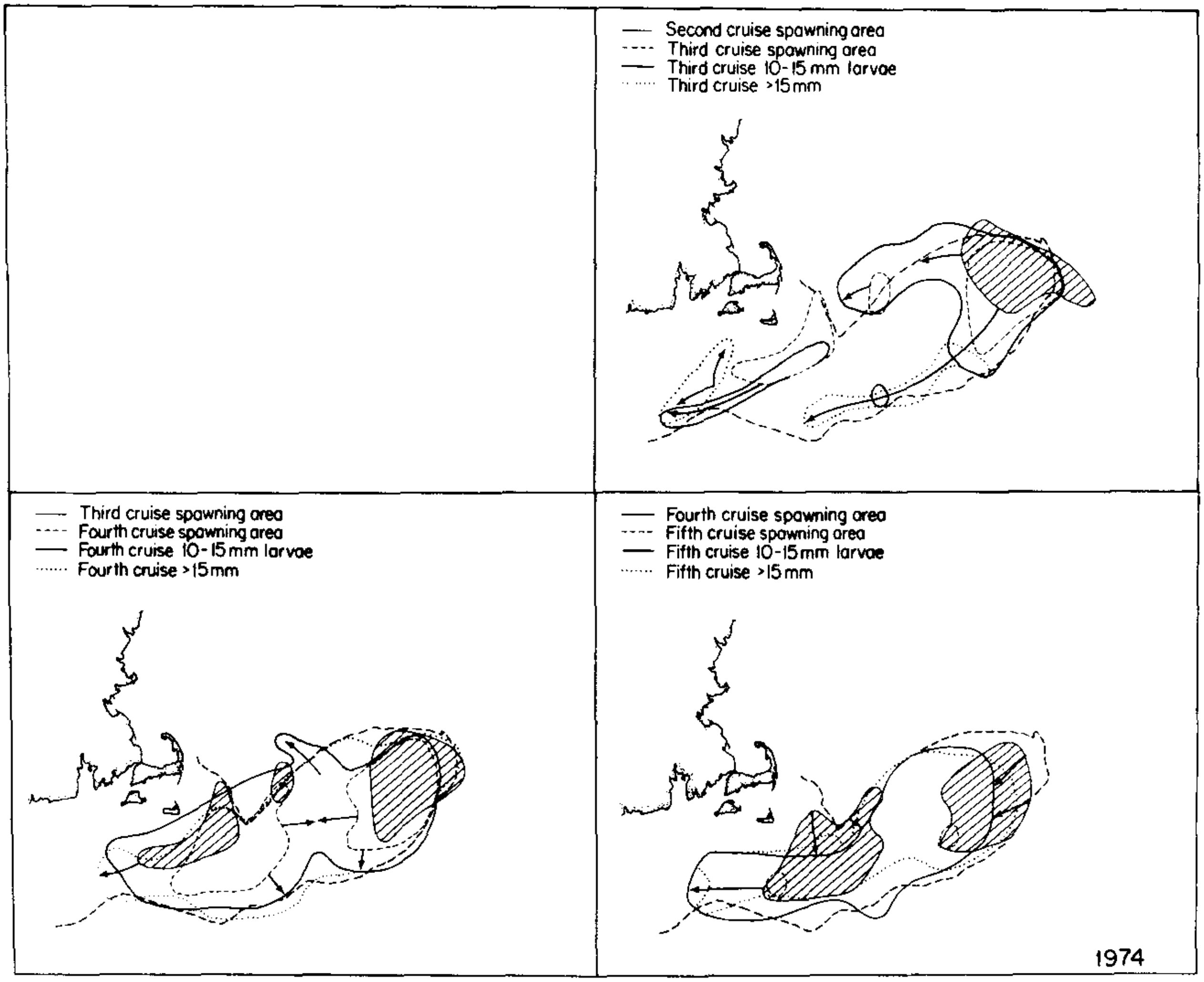

Fig. 17. Locations of various length herring larvae relative to previous cruises in 1974.

1972	1973	1974
22-30 Sep	16-28 Sep	6-24 Sep
2-28 Oct	29 Sep-20 Oct	27 Sep-18 Oct
12-28 Oct	15 Oct-1 Nov	18-30 Oct
31 Oct-12 Nov	28 Oct-8 Nov	16-23 Nov
28 Nov-15 Dec	4-20 Dec	4-19 Dec

We have delineated the areas where 10 or more herring larvae per 10 m^2 were caught (Fig. 15, 16, and 17) and made some inferences from the distributions of the various size categories. We have inferred that the area occupied by herring larvae $<$ 10 mm in length to be the spawning area and have outlined it and the spawning area for the preceding cruise. We have then outlined the area occupied by the 10-15 mm larvae and the $>$ 15 mm larvae and drawn arrows representing the inferred spread of the larval distribution of the larger size categories from the spawning areas. It is quite apparent that advection and dispersion have occurred.

The spread from the "spawning area" between the first and second cruises in 1972 appears to be on the order of one mile per day and due to dispersion by the tidal oscillation. Between the second and third cruises an advective spread of $>$ 10 miles per day southwestward occurred with a lesser northerly drift north of Georges Shoal and northeasterly drift from Nantucket Shoals. Between the third and fourth cruises mixed movements of 1-2 miles per day occurred over Georges Bank, but a four-mile-per-day spread occurred westward from Nantucket Shoals spawning area. By the fifth cruise herring larvae are well spread over the whole area, the major drift having been westward from Nantucket Shoals at about two miles per day. It would appear that there had been no drifts away from the shallow waters except for a small tongue of 10-15 mm larvae over the edge of SE Georges on the second cruise. An anticyclonic eddy was drifting westward just south of Georges Bank during this period (U.S. Naval Oceanographic Office, 1972).

During the interval between the first and second cruises of 1973, there was a southwestward advection from the Georges spawning area of about five miles per day and a weak southeasterly drift. Between the second and third cruise the southwestward drift continued, coupled with a general expansion from the Nantucket Shoals spawning area and possibly a northeastward drift along the NW side of Georges. The westward drift continued between the third and fourth cruises and a weak southerly drift was apparent between the fourth and fifth cruises. The larval population was larger in 1973 than in 1972 and tended to move closer to the southern edge of Georges Bank or even beyond the 100-m contour during 1973. There were no anti-cyclonic Gulf Stream eddies in the vicinity during this period (U.S. Naval Oceanographic Office, 1973).

Spawning was late in 1974, so that no herring larvae were caught during the first cruise. Between the second and third cruises there appear to be westward advections from the spawning areas at speeds of 3 to 8 miles per day. Between the third and fourth cruises there appeared a general dispersion from the spawning areas. Between the fourth and fifth cruises the overall tendency was for the area occupied by larval herring to compress slightly latitudinally, with a slight westward drift of the whole at between 1 and 2 miles per day. As in 1973, the larval herring population tended to extend beyond the limits of the 100-m contour. The computed monthly Ekman transports during this period were moderate toward the SW, being somewhat stronger in October than for the 10-year mean for October, which is usually weak. It is interesting to note that an anticyclonic eddy drifted during November from the vicinity of the Gulf Stream to the southern edge of Georges Bank and continued westward along the edge during December (U.S. Naval Oceanographic Office, 1974).

TABLE 2. Change in total number of herring larvae and area occupied from cruise to cruise.

	Δ Total number of herring larvae			Δ Area		
	1972	1973	1974	1972	1973	1974
From 1st to 2nd cruise	3.8[a]	24	—	4.7	5.0	—
From 2nd to 3rd cruise	1.5	2.5	1.3	1.2	1.6	1.3
From 3rd to 4th cruise	.42	.64	1.4	1.1	1.3	3.0
From 4th to 5th cruise	.34	.16	.47	.73	.80	.82

[a] Georges Bank only.

Table 2 provides us with an idea of how the total population of herring larvae changes from cruise to cruise in relation to the change in area occupied. It is apparent from this information that the herring population tends to increase at a greater rate than the area it occupies through the end of October (the third cruise) but somewhat later in 1974, and then begins to decrease due to the various exigencies which cause a decrease in the population, while the area occupied by the population continues to increase through the fourth cruise (prior to the first of December), following which the area decreases slightly.

The evidence from the Joint Herring Larvae Surveys appears to suggest that the larvae are retained within the shelf water. The area they occupy expands with time due to the vigorous tidal stirring and advection. The advection appears to be principally toward the west. There are some indications of a northeasterly drift north of Georges Shoal, i.e. a continuation of a clockwise gyre around the shoal part of the bank. We do not have adequate data to evaluate the effect of the passage of storms through the area.

It is possible that some larvae may drift off the southeast edge of Georges Bank. This is the location where the thermal fronts, as observed by satellite, appear to have their maximum excursion. It is also possible that the anticyclonic eddies drifting away from the Gulf Stream along the southern edge of the bank may entrain shelf water along their perimeter. The sampling pattern for larval herring may not extend far enough off the bank in this vicinity. It is also fairly obvious that we do not know how far the larvae drift west of Nantucket Shoals in November and December, inasmuch as the sampling is not adequate west of 71°W long.

Summary and Research Proposals

In summary, we are dealing with an area which has the temperature and salinity characteristics of the continental shelf bordering on slope water to the south. The front between the shelf and slope water ranges from diffuse to very sharp, and it frequently wanders large distances (several hundreds of kilometers) at the surface, probably much shorter distances (tens of kilometers) at the bottom. Anticyclonic eddies from the Gulf Stream drift close to the southern edge of the bank, impringing directly against it as they move westward. The energetic tidal oscillations over the bank are predictable whereas the net drifts are much less well understood. There appears to be a clockwise rotation around the bank during the seasons when the thermocline is developing. At other seasons it would appear that the winds may be the mechanism for providing advective forces of the sea surface.

A concerted effort should be made to understand the advective processes above and around Georges Bank and the physical forces which regulate them. In order to determine how the circulation is conditioned by the wind systems, a drogued buoy program should be conducted with initial buoy plantings in the spawning areas. The movements of these buoys should be related to the daily, or better still 6 hourly, components of the wind stress. Equipping the drogues with recording thermistors or conductivity meters would provide some clues as to how well the buoys stay within the shelf water. The presence of the winter water, as seen in Fig. 6, is engimatic. Does this water move at all? Is there a shear zone above it? Drogues should be placed in it and above it to determine this.

The forcing by the wind and an evaluation of the Ekman transport needs also to be determined by judicious employment of current meter arrays at the northern and southern edges of the bank, with at least one array over a shallower part of the bank. Equipping these current meter arrays with conductivity cells would permit an estimate of the flux of salt across the bank and its boundaries.

Both Lagrangian and Eulerian current measurement studies should be accompanied by concurrent synoptic temperature and salinity profiles in order to gain a clear understanding of the characteristics of the water being advected. Sampling for nutrients along these profiles would also make it possible to estimate nutrient fluxes across isobaths so necessary in the evaluation of primary production.

As learning proceeds, the locations of fixed and drifting elements of the experiments should be modified to develop time and space scales of the transport processes. Assistance from oceanographers skilled in the technical and theoretical aspects of this research should be enlisted.

Acknowledgements

The preparation of this report has been funded through National Marine Fisheries Service Contract No. 03-5-043-327 and the National Sea Grant Program Grant No. 04-5-158-8. The author gratefully acknowledges the generous assistance of Marvin D. Grosslein, Merton C. Ingham, and R. Gregory Lough, all of the National Marine Fisheries Service, in providing data and wise counsel.

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NOTE

Length-Weight Relationship in Witch Flounder, *Glyptocephalus cynoglossus*, in the Newfoundland Area

W. R. Bowering[1]

Introduction

During recent years, the witch flounder, *Glyptocephalus cynoglossus*, has become an important commercial species in the Northwest Atlantic, particularly in ICNAF Subareas 2 and 3, where the nominal catches had reached a total of 35,000 tons in 1973. International catch quotas were imposed in 1973 and all stocks are now under international regulation. An important parameter for stock assessment is the relationship between length and weight and this paper documents this parameter. Since witch flounder are always landed whole, one equation for length versus whole weight was deemed sufficient.

Materials and Methods

The length-weight equation was computed using lengths and weights of 3,325 specimens taken in research vessel catches from the Newfoundland area of the Northwest Atlantic. The fish were measured to the nearest centimetre from the tip of the snout to the end of the longest caudal fin ray. The lengths ranged from 9 to 70 cm (Fig. 1). Whole weights were taken to the nearest gram.

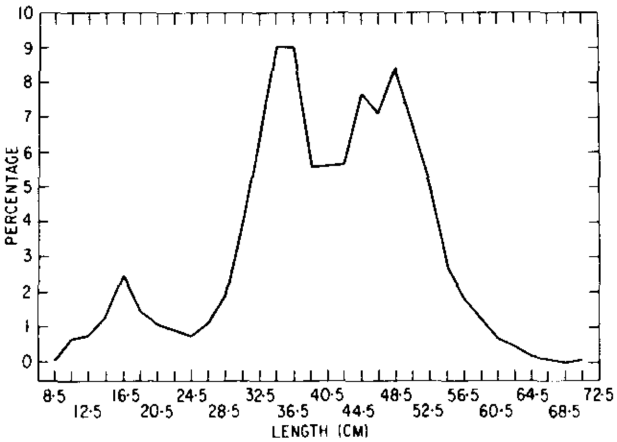

Fig. 1. Length distribution of fish used in computing length-weight curve.

The length-weight curve was obtained by the equation $W = cL^b$, where W = weight, L = length, and c and b are constants. The least squares regression of the logarithmic transformation was used, where Y = log W; and X = log L.

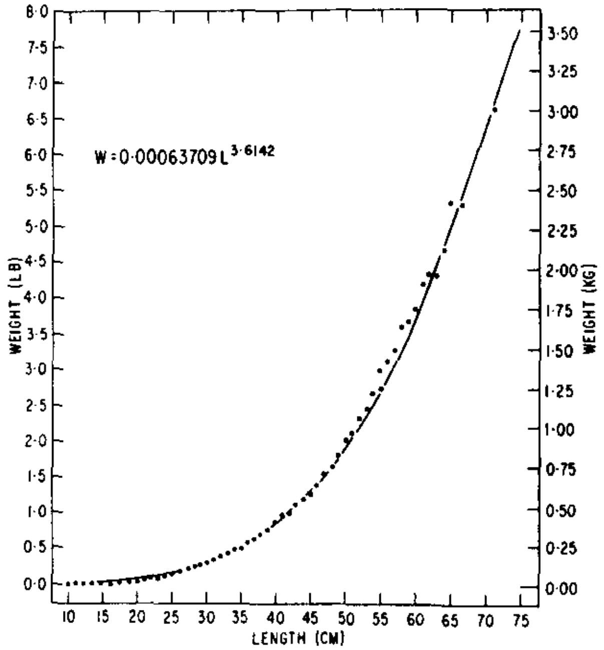

Fig. 2. Length-whole weight curve of witch.

Results

The calculated equation derived from the logarithmic transformation for length versus whole weight is

$$W = 0.00063709L^{3.6142}$$

and the length-weight curve is presented in Fig. 2.

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International Commission for the Northwest Atlantic Fisheries

The Commission in Brief

Under the terms of a Convention signed in 1949, the International Commission for the Northwest Atlantic Fisheries (ICNAF) is responsible for promoting and co-ordinating scientific studies on the stocks of the species of fish which support international fisheries in the Northwest Atlantic. Based on these researches, the Commission recommends measures to keep these stocks at a level permitting the maximum substained catch.

The governments sharing these conservation interests are Bulgaria, Canada, Cuba, Denmark, France, Federal Republic of Germany, German Democratic Republic, Iceland, Italy, Japan, Norway, Poland, Portugal, Romania, Spain, Union of Soviet Socialist Republics, United Kingdom, and United States of America.

Research Bulletin of ICNAF

The International Commission for the Northwest Atlantic Fisheries invites contributions to its serial publication, "The Research Bulletin of ICNAF".

There will be one or more issues each year depending on the number of papers received and accepted for publication.

Purpose. The main purpose of the Research Bulletin is to publish the results of research carried out in the ICNAF area. It is expected that most papers published in the Research Bulletin will be selected from papers presented at Annual Meetings of the Commission, but other papers, either concerning the ICNAF area or outside it, will be accepted if their contents are of importance to the work of the Commission.

Submission of Manuscripts. Manuscripts for publication should be submitted to the Commission's Secretariat on or before 1 October each year. This provides authors with sufficient time to revise or extend papers submitted or solicited at the previous Annual Meeting of the Commission which is held in early June each year. The arrangement also provides the possibility that the Bulletin can be issued before the next Annual Meeting of the Commission.

Editing. The Editor of the Research Bulletin will be the Executive Secretary of the Commission. He will be assisted on matters of editorial policy by the Chairman of the Commission's Standing Committee on Research and Statistics and the members of the Steering and Publications Subcommittee.

Refereeing. To maintain a high standard of publication each contribution will be submitted by the Editor to one or more referees from a panel of experts appointed for that purpose. On the advice of the referee(s), the Editor will request the author to make such amendments to his manuscript as will help to avoid error or misunderstanding and add strength to his presentation or will reject the manuscript. Referees will remain anonymous and will treat all Manuscripts as confidental.

Preparation of Manuscripts. To achieve maximum conformity of presentation by authors and to minimize typing and other editorial work, the Commission's Secretariat has prepared the following aid.

Instructions to Authors for the Preparation of Manuscripts Intended for Publication in the Research Bulletin of ICNAF

Text

a) Manuscript should be type-written, *double-spaced*, and on one side only of good quality white bond quarto paper, size 8½ × 11 inches (220 × 280mm).

b) Leave all margins 1 inch (25mm) to 1½ inches (38mm) for editorial marks and queries.

c) Prepare and submit the original and two carbon copies of the text and at least two sets of illustrations.

d) Number all pages of the manuscript consecutively with Arabic numerals in the centre of the top margin space.

e) Start a new page for each of the following sections with appropriate headings and sub-headings: (1) title, name and address of author, list of contents (if applicable); (2) abstract of the paper; (3) text; (4) references to literature; (5) tables; (6) legends for figures and (7) figures.

f) Please *double-space everything* — Text, quotations, footnotes, tables and table headings, legends, references to literature, and use even greater spacing where helpful (particularly around equations and formulate).

g) Wherever practical the text should be subheaded into Introduction, Materials and Methods, Results, and Discussion. Authors must provide a Summary which lists one by one the principal facts and conclusions of the paper. Acknowledgements should be placed immediately after the Summary.

h) All measurements, linear, weight, and time, should be given in numerals (not words) in the metric system. The Celsius scale should be used as a standard. When other units of measure are preferred, authors should include equivalents in metric units.

i) Footnotes should be avoided as far as possible, but if necessary they must be numbered consecutively in the text and type under a horizontal line at the foot of the page concerned.

j) Only those words to be printed in italics should be underlined.

(This page is perforated. TEAR OUT and file for future use)

Abstract

Each Manuscript should have an abstract not to exceed 3% of the length of the text or 200 words whichever is the smaller. For position of the abstract in the manuscript see (e) above. The abstract should summarize the contents and conclusions of the paper, point to new information in the paper and indicate the relevance of the work.

Tables

a) Tables should be carefully constructed so that the data presented may be easily understood.

b) Tables should be set out on separate sheets following the references.

c) Position of the tables in the text should be indicated clearly.

d) Each table should be provided with a descriptive heading which, together with the column headings, makes the table intelligble without reference to the text.

e) Tables should be numbered consecutively with Arabic numerals, e.g. Table 1, 2, 3, etc.

Figures

a) All illustrations, whether black-and-white drawings, graphs, photographs, or tone drawings, are to be considered as figures.

b) Each figure should be mentioned and described in the text.

c) A legend should be provided for each figure; the legends should all be typed together on a separate sheet or sheets attached to the manuscript following the tables.

d) Figures should be numbered consecutively with Arabic numerals, as Fig. 1, 2, 3, etc.

e) Figures should be set out on sheets preferably the same size as the text pages and in any case should not require a printer's reduction to less than one-third. Small Figures can be arranged in groups on sheets the same size as the text pages.

f) For guidance in preparing figures, the size of the printed area of the *Research Bulletin* page is 21 × 17 cm. The *Bulletin* will have a two-column format, each column 8 cm. wide.

g) Photographs presented as figures should be high contrast, glossy prints, about 5 × 7 inches (125 × 175 mm) in size and should be shipped flat protected by stout cardboard.

h) Each illustration should be identified by markings on the back lightly in soft pencil on the margin the figure number and the author's name.

Bibliographic Style

a) References to literature in the text should be by the author-date system, for example

> It was reported that (Collins, 1960) the ...;
> In examining the situation, Rossini (1959) felt that ...

Where more than one paper by the same author(s) have appeared in one year, reference should be given as follows:

> Osborne and Mendel (1914a); Osborne and Mendal (1914b)

or Oxborne and Mendel (1914a and b); (Barnet and Robinson, 1942; King and Pierce 1943a, 1954)

Reference to material not yet submitted for publication should be written into the text e.g. "Harvey, in an unpublished manuscript,..." or "Harvey, in a letter,..."

b) All references cited by the author-name system in the text should be listed alphabetically by the surname of the first *author* at the end of the paper. *Year* of publication follows the authorship. Then give the full *title* of the paper. This should be followed by the abbreviated name of the *periodical* with the *volume* and *pages* in Arabic numbers (e.g.:2: 120 - 136). For abbreviations of periodicals follow the "Word List of Scientific Periodicals". An issue, number supplement or other part within a volume is shown in parentheses only when paged independently (e.g.: 2(4) :1 - 56; 34 (Suppl. 2) :1 - 26). Any special Series (Ser 3, III, cr C) precedes the volume number. In *book citations* after the title, there appears the edition, the publisher's name, place of publication, and the number of pages if one volume, but the number of volumes if more. Reference to material submitted but not yet published should be referred to in the list of references as "in press" or "Submitted for publication" followed by the date of submission.

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