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Distribution, Age and Growth, and Sexual Maturity of American Plaice (*Hippoglossoides platessoides* (Fabricius)) on Flemish Cap (NAFO Division 3M)

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Abstract

American plaice (*Hippoglossoides platessoides*) distribution, age and growth, and sexual maturity on the Flemish Cap from 1978 to 1985 were determined. American plaice were distributed mainly in the shallower areas, generally in the central, southern and southwestern areas of Flemish Cap. Densities were much lower on average than in the adjacent Grand Bank area. There was no size selective distribution by depth or temperature.

Examination of otoliths revealed that females grew at a faster rate than males after age 3. The maximum age recorded was 15 years, which was considerably lower than the value for adjacent stocks of American plaice. In many years the population was dominated by one year-class, which comprised up to 68% of the catch numbers.

The M_{50} values for age and length for males were 3.8 years and 26.4 cm, respectively, and the corresponding values for females were 6.2 years and 39.7 cm. The lengths at M_{50} were similar to those for American plaice in other areas of the Northwest Atlantic, although the ages at M_{50} were considerably lower.

Key words: Age, American plaice, distribution, Flemish Cap, growth, maturation, temperature

Introduction

American plaice (*Hippoglossoides platessoides*) on Flemish Cap, NAFO Div. 3M (Fig. 1) are considered to be a discrete stock and bear little or no connection with the American plaice stock on the adjacent Newfoundland Grand Bank, NAFO Div. 3LNO (Pitt, 1963). Although under quota management since 1974, commercial exploitation of American plaice in this area has mainly been as a bycatch in the cod and redfish fisheries, primarily by the former USSR in earlier years and Spain in later years. Catches since 1960 have varied from as low as 62 tons in 1970 to a high of 5 600 tons in 1987, but have generally averaged 1 500 tons annually (Table 1). Increased catches in the late-1980s resulted from increased effort, particularly by newly introduced Spanish and Portuguese freezer trawlers. A total allowable catch (TAC) of 2 000 tons was placed upon this stock by the International Commission for the Northwest Atlantic Fisheries (ICNAF) in 1974, and with the exception of an increase to 4 000 tons in 1978, this TAC has been in place until the end of 1993. However, in 1993 the Scientific Council of NAFO advised that the TAC for 1994 should not exceed 1 000 tons (NAFO, 1993; Godinho and de Cardenas, MS 1993).

Very little has been published on American plaice from Flemish Cap other than references to incidental occurrences of this species in other studies (Pitt, 1963; 1966; 1967; Yanulov, 1962). This paper describes the distribution, age and growth, and sexual maturity of American plaice on Flemish Cap based upon a comprehensive data collection during Canadian research vessel surveys from 1978 to 1985.

Methods and Materials

All data analyzed in this paper were from surveys conducted on board the research vessel *Gadus Atlantica*. This vessel is 74 m in length, 2 351 gross tonnage, and fished with an Engels 145 bottom trawl containing a small (29 mm) mesh nylon liner in the codend to prevent the escapement of small fish. Surveys were conducted in January–February of each year from 1978 to 1985, inclusive, using a stratified random design, stratified by depth (Doubleday, 1981), with fishing tows, or sets, intended to be of 30 min. duration over a distance of 1.75 naut. miles. Only sets with minimal or no net damage were analyzed, and catches were adjusted to correspond to the standard tow distance of 1.75 naut. miles where necessary. Sets were conducted in bottom depths ranging from 124 to 728 m. The bottom temperature was measured to the nearest 0.1°C at the end of each set using an expendable bathythermograph (XBT). Allocation of sets to the 19 strata in each year was approximately propor-

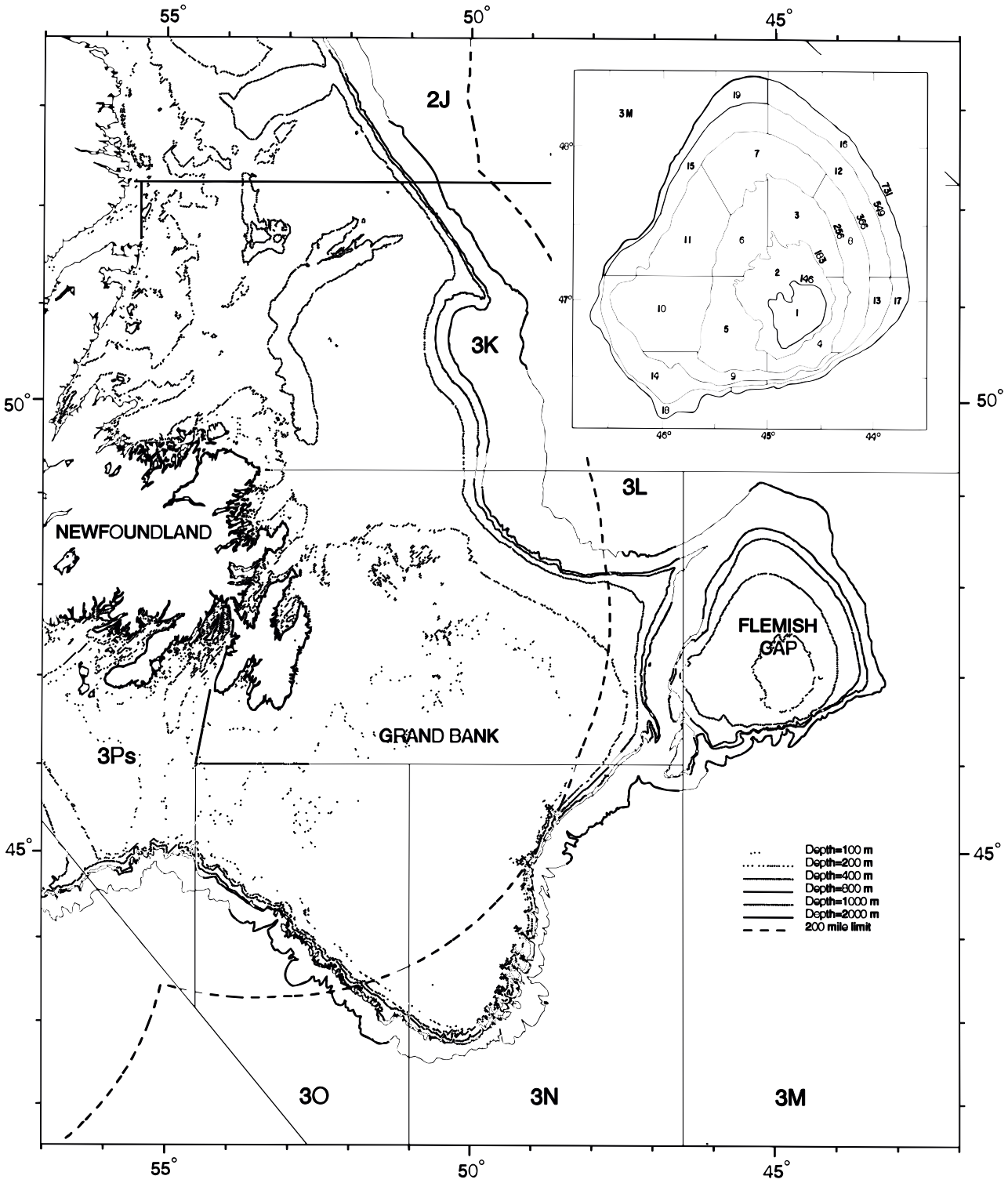

Fig. 1. Map showing location of Flemish Cap (NAFO Div. 3M) in the Northwest Atlantic. The insert is the depth stratification scheme (m) used in the Canadian research vessel surveys on Flemish Cap. Stratum numbers are referred to in the text as a 500 series, e.g. stratum 1 = stratum 501, etc.

TABLE 1. Nominal catches of American plaice from NAFO Division 3M, 1960–92.

Year	Country			Others	Total	TAC
	Canada	Poland	USSR			
1960	–	–	303	13	316	
1961	–	–	2 279	–	2 279	
1962	14	150	557	–	721	
1963	–	108	51	20	179	
1964	–	8	1 831	37	1 876	
1965	19	216	4 964	85	5 284	
1966	–	17	4 003	53	4 073	
1967	57	63	–	34	154	
1968	100	–	121	4	225	
1969	12	–	113	–	125	
1970	–	–	62	–	62	
1971	–	–	1 079	–	1 079	
1972	–	8	665	188	861	
1973	68	39	312	85	504	
1974	211	–	1 110	607	1 928	2 000
1975	140	522	958	88	1 708	2 000
1976	191	15	809	177	1 192	2 000
1977	30	7	987	594	1 618	2 000
1978	7	21	581	724	1 333	4 000
1979	–	2	457	327	796	2 000
1980	1	5	909	270	1 185	2 000
1981	–	–	309	323	632	2 000
1982	–	–	1 002	70	1 072	2 000
1983	–	–	1 238	651	1 889	2 000
1984	–	–	711	591	1 302	2 000
1985	–	–	971	749	1 720	2 000
1986	–	–	962	2 792	3 754	2 000
1987	–	–	501	5 106	5 607	2 000
1988	–	–	228	2 633	2 861	2 000
1989	–	–	88	3 806	3 894	2 000
1990	–	–	–	788[a]	788[a]	2 000
1991	–	–	5[a]	2 076[a]	2 081[a]	2 000
1992					800[a]	2 000

[a] Provisional.

tional to stratum size, and all strata were surveyed in each year with the exception of 1982. Data from 1 008 sets from 1978 to 1985 were analyzed, with yearly totals ranging from 95 to 142 sets, and stratum totals over the period ranging from 20 to 94 sets (Table 2).

Distribution

To examine the distribution of American plaice, average catch numbers and weights (kg) per tow were calculated for each stratum shown in Fig. 1, for all years combined. The spatial distribution was examined for each year by overlaying a representative sized symbol of each catch weight on a map of the survey area. Each symbol was plotted to correspond to the actual position of the catch, using ACON computer software (Black, MS 1993).

To determine if differences in distribution in relation to size existed, length frequency data (a total of 13 318 length measurements) collected from each catch were analyzed. To facilitate presentation of these results, data from the 19 strata were grouped into four depth zones: 101–200, 201–300, 301–400 and >400 m. As well, the mean weight (kg) per fish was calculated for each stratum as the quotient of the mean weight (kg) per tow and the mean number per tow.

Age and growth

Otolith samples for age interpretation were obtained from the research vessel catches discussed above. Aging was conducted using standard techniques with full otoliths, often ground on the convex surface (Pitt, 1974; Bowering, 1976). Powles (1965) and Pitt (1967) provide evidence on the validity of age determination from American plaice otoliths. Growth was expressed in terms of the von Bertalanffy function estimated using the Marquardt algorithm (Rivard, 1982). The growth curves were fitted to the mean length-at-age.

TABLE 2. Number of survey sets, by stratum, from Canadian surveys on Flemish Cap, 1978–85.

Strata	Depth range (m)	Year								Total
		1978	1979	1980	1981	1982	1983	1984	1985	
501	128–146	4	4	4	5	5	5	4	4	35
502	147–183	11	6	11	11	11	11	10	10	81
503	184–256	10	6	8	8	8	8	8	8	64
504	"	6	4	4	5	5	5	4	4	37
505	"	10	6	8	9	9	9	8	8	67
506	"	8	6	6	7	7	7	6	6	53
507	257–366	8	6	10	11	11	11	10	10	77
508	"	9	6	8	9	9	9	8	8	66
509	"	4	4	4	4	4	4	4	4	32
510	"	14	6	12	13	12	13	12	12	94
511	"	11	6	10	11	11	11	10	10	80
512	367–549	5	6	8	9	4	9	8	8	57
513	"	4	4	3	3	3	3	3	3	26
514	"	8	6	7	8	8	8	7	7	59
515	"	7	4	8	9		9	8	8	53
516	550–732	4	6	8	9		9	8	8	52
517	"	4	3	3	3		3	3	3	22
518	"	2	3	3	3		3	3	3	20
519	"	5	3	5	5		5	5	5	33
	Total	134	95	130	142	107	142	129	129	1 008

To determine the age structure of the population over time, the percentage-at-age in the survey catches was examined for each of the 8 years available. Percentages were chosen in favour of abundance indices because of the high interannual variability in abundance estimates. In this way, it was easier to follow good or poor year-classes without affecting annual population structure.

Sexual maturity

Data on sexual maturity were obtained from the same fish that were sampled for age. Maturity observations in the field were made using the five basic stages described in Pitt (1966): immature, resting, maturing, spent and spent/recovering. Percent maturity was calculated by probit analysis (Bowering, 1987) as the length and age at which 50% of the fish were mature. As was done for the age samples, the data were combined for all years, with sexes treated separately, since an analysis of covariance indicated no interannual differences ($p > 0.05$).

Results and Discussion

Distribution

On Flemish Cap, American plaice were highest in abundance in the shallower areas, generally between 200 and 400 m (Fig. 2). Catches were generally larger in the central, southern and southwestern areas, with few being found on the eastern and northern regions of the Cap. For the 8 years combined, stratum 504 (Fig. 1), which ranges in depth from 184 to 256 m, had by far the highest mean weight per tow (Fig. 3) and mean number per tow (Fig. 4) of the 19 strata surveyed. This stratum had the highest mean weight per tow in 5 of the 8 years as well as 4 of the 5 largest individual catches, the highest of which was 1 347 kg. Occasional large catches such as this are not uncommon, and have been reported from surveys of other areas around Newfoundland (Brodie, MS 1986; Walsh and Brodie, MS 1987). In a research vessel survey conducted by the European Economic Community on Flemish Cap in 1992, stratum 504 had the third largest mean weight of American plaice per tow of the 19 strata surveyed (Vazquez, MS 1993).

An examination of mean number and mean weight per tow by depth and temperature showed no categories of either variable which had a large mean number and small mean weight per tow, or *vice versa*. In most strata on Flemish Cap, the mean weight of an individual was between about 0.45 and 0.65 kg. A plot of these data showed some between-stratum differences (Fig. 5), indicating that strata 501 and 509 had the largest fish on average. There were no obvious similarities between these strata; they were not adjacent and they differed in both mean temperature (Fig. 6) and depth range (Table 2). There were no strata with significantly smaller fish than all others. Figure 7 also shows for most years that there were minimal differences in mean lengths in each of the four depth groupings, and in years where differences existed, they were not consistent. Overall it can be concluded that there was no consistent indication of depth preferences for groups of very small or very large fish on Flemish

Cap. This is in contrast to the adjacent Grand Bank area, where specific areas of high abundance of juvenile American plaice (i.e. nursery areas) have been identified (Walsh and Brodie, MS 1987; MS 1988; Walsh, MS 1990), although it should be noted that specialized trawl gear more suitable for catching juveniles was used in the Grand Bank studies.

The distribution by depth observed on Flemish Cap was similar to that observed for the adjacent stock on the Grand Bank (Wells *et al.*, MS 1988). Pitt (1967), in a paper on growth of American plaice, noted that large concentrations of this species existed along the northern and eastern slopes of the Grand Bank, in depths from 73 to 274 m. This has

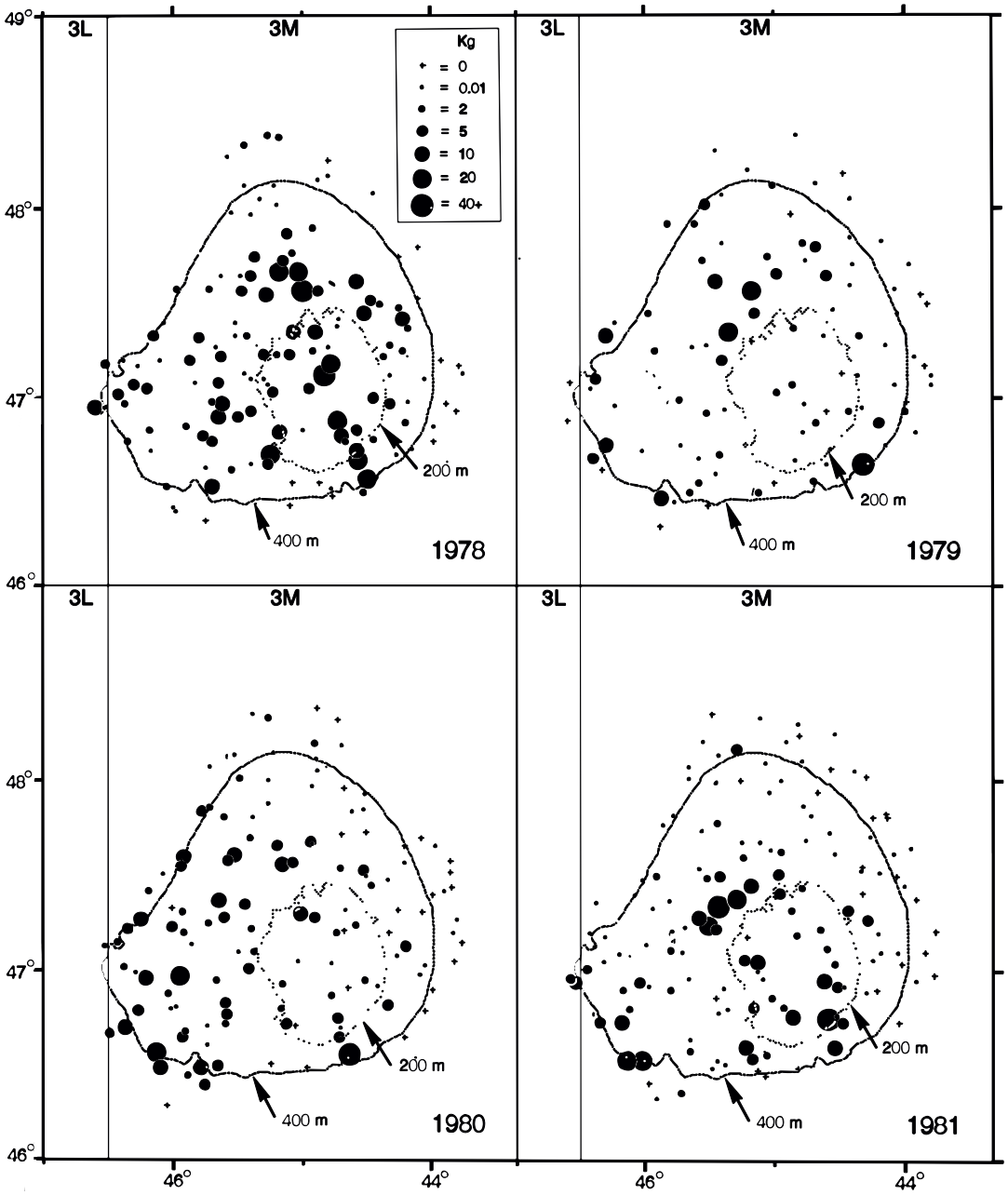

Fig. 2. Distribution of American plaice catches (kg per standard tow) from Canadian research vessel surveys on Flemish Cap from 1978 to 1981. The 200 and 400 m depth contours are shown.

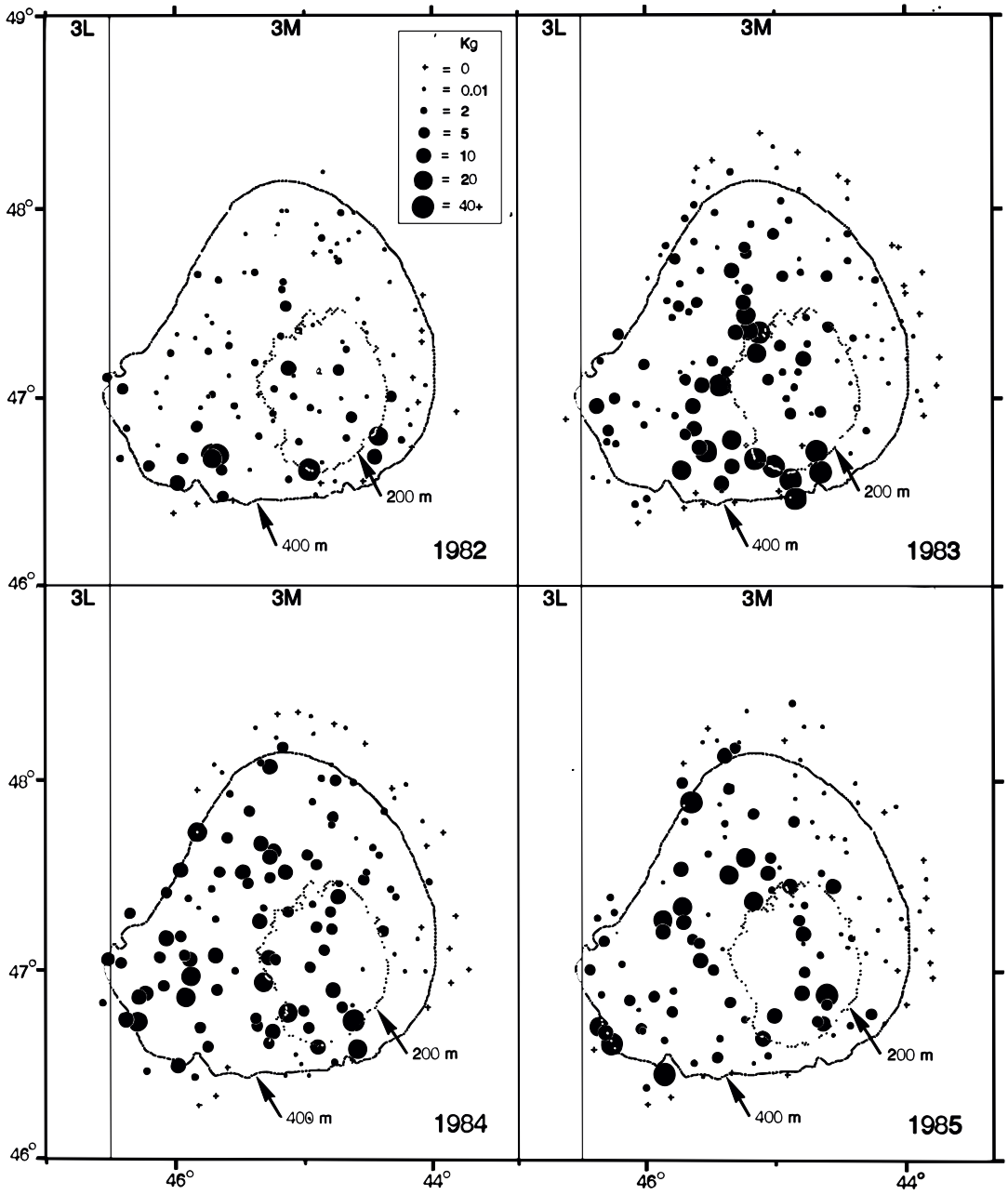

Fig. 2. (Continued). Distribution of American plaice catches (kg per standard tow) from Canadian research vessel surveys on Flemish Cap from 1982 to 1985. The 200 and 400 m depth contours are shown.

been verified in many subsequent surveys of the area (Brodie, 1988), and by the concentration of commercial fishing effort in many years. On Flemish Cap few were found in water deeper than 550 m (strata 516–519), although there were no sets in depths greater than 728 m. This is also in agreement with most information from other areas (Brodie, MS 1986; MS 1988), although Walsh and Brodie (MS 1987; MS 1988) provided some information on a few very large (>1000 kg/tow) catches taken in April 1986 and 1987 by the research vessel *Wilfred Templeman* in depths greater than 500 m on the northeastern Grand Bank.

The densities of American plaice observed in most years for Flemish Cap strata were consider-

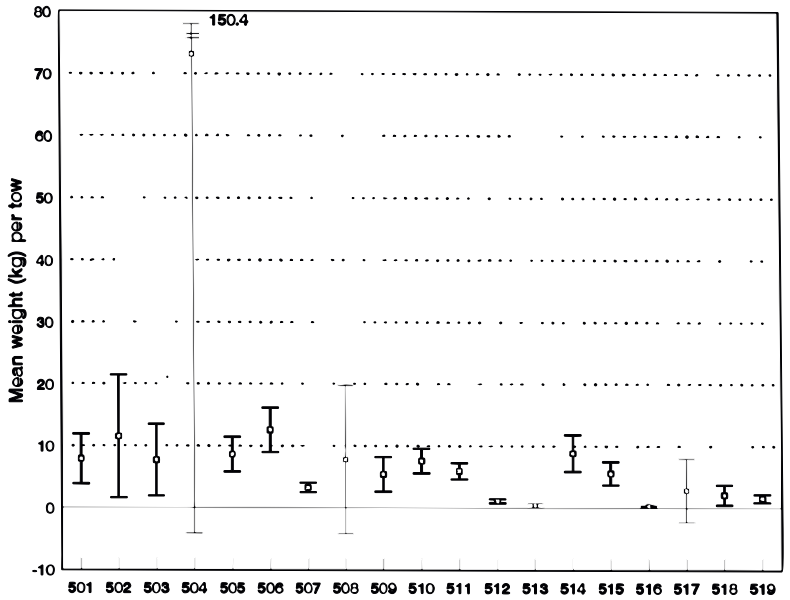

Fig. 3. Mean catch weight (kg) of American plaice per tow, by stratum, on Flemish Cap from 1978 to 1985. The upper and lower bounds around each point represent the 95% confidence interval around the mean.

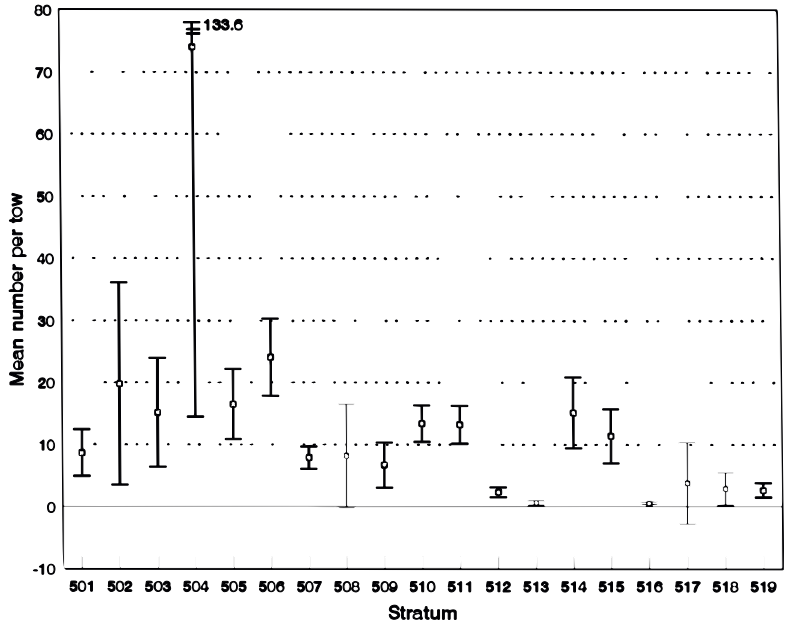

Fig. 4. Mean catch number of American plaice per tow, by stratum, on Flemish Cap from 1978 to 1985. The upper and lower bounds around each point represent the 95% confidence interval around the mean.

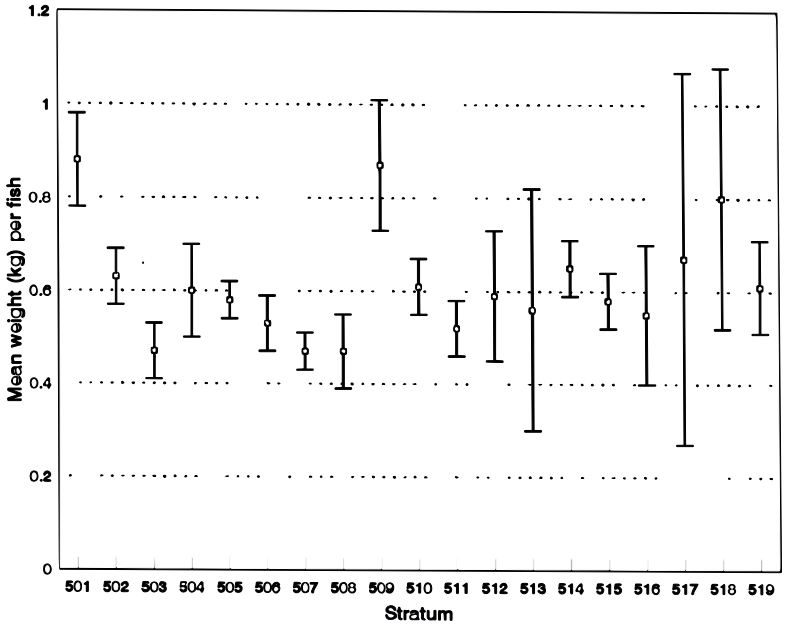

Fig. 5. Mean weight (kg) of individual American plaice, by stratum, on Flemish Cap from 1978 to 1985. The upper and lower bounds around each point represent the 95% confidence interval around the mean.

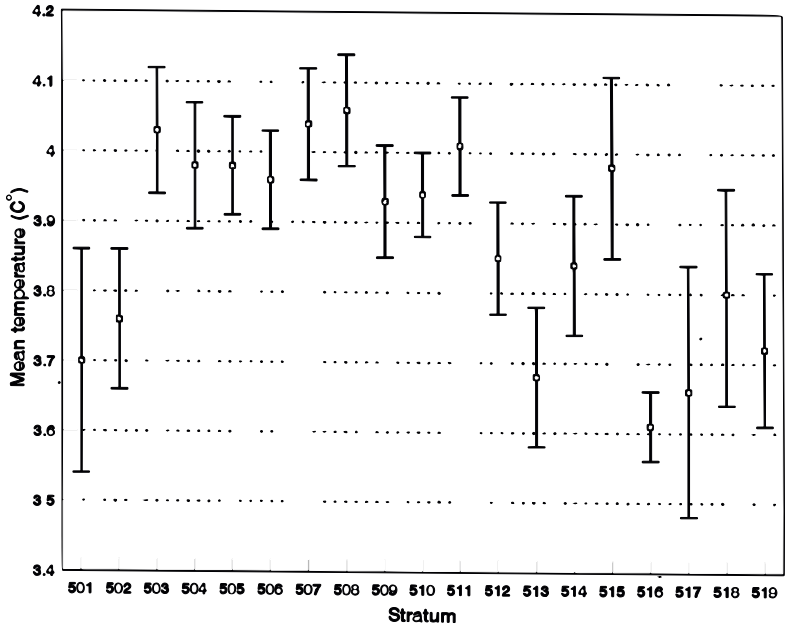

Fig. 6. Mean bottom temperature (˚C), by stratum, from Canadian research vessel surveys on Flemish Cap from 1978 to 1985. The upper and lower bounds around each point represent the 95% confidence interval around the mean.

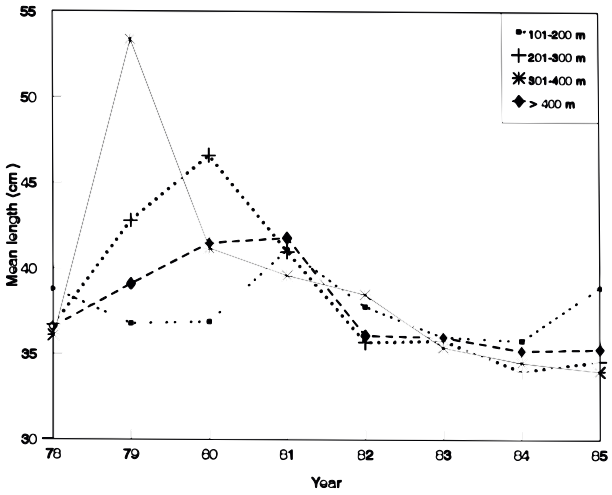

Fig. 7. Mean length of American plaice by depth range on Flemish Cap from 1978 to 1985.

ably lower than for the adjacent Grand Bank strata, where average catches were often greater than 100 kg/tow over wide areas during the 1970s and 1980s (Brodie, MS 1988). However, the bottom temperatures found on Flemish Cap were much higher than those found at similar depths on the Grand Bank during the same period (Wells *et al*., MS 1988; Morgan and Brodie, 1991). As stated earlier, there appeared to be no strong preference for certain depths by different sized American plaice in the January–February period on Flemish Cap. However, these observations were thought to be well before spawning time (Pitt, 1966), when aggregations of larger fish might be encountered more frequently in certain areas. While it is likely that American plaice undertake some seasonal migration (Powles 1965, Morgan and Brodie, 1991), this cannot be documented for the Flemish Cap stock as there is no record of any tagging studies of this species on the Flemish Cap, nor is there complete information on seasonal distribution from research vessel surveys. The data available are not sufficient to evaluate the effects of other factors such as feeding patterns and bottom sediment type on the distribution of American plaice on Flemish Cap.

A plot of bottom temperature by stratum (Fig. 6) shows the means within a range of 3.6˚ to less than 4.1˚C, with two-thirds of the actual observations occurring within this range. Ninety three percent of the observations were between 3.4˚ and 4.4˚C, with the lowest observed bottom temperature being 2.7˚C. The small range of bottom temperatures observed in this study and the relatively low annual variation found on Flemish Cap preclude any detailed analysis of distribution by temperature. A comparison of the scatterplot of mean weight per fish against mean stratum temperature (or a comparison of Fig. 5 and 6) was not conclusive, although it did give an indication that the smaller fish tended to be in strata with the highest temperatures.

Pitt (1967) and Templeman (1976) reported that the bottom temperatures on Flemish Cap are relatively high, generally above 3˚C. This is due to the influence of the warmer Gulf Stream currents and these temperatures differ substantially from those on the adjacent northern Grand Bank, which is affected by the colder Labrador Current. In that area of the Grand Bank, Pitt (1967) reported that American plaice were concentrated principally in the bottom depths where temperatures were generally between -0.5˚ and 1.0˚C. Wells *et al*. (MS 1988) reported that catches from research vessel surveys on the Grand Bank were generally small where bottom temperatures were greater than 1˚C, and that the largest catches were often found where temperatures were less than 0˚C, usually in depths from 50 to 200 m. Morgan and Brodie (1991) noted that, on the northern Grand Bank in all seasons during 1985, American plaice appeared to be most common at temperatures between -1.1˚ and -0.5˚C. Given the differences in bottom temperatures found at comparable depths on Flemish Cap, it was impossible to make any meaningful comparisons between the distribution of American plaice in this area and in adjacent areas in relation to temperature.

Age and growth

Because of known differences in growth between sexes of American plaice in other areas, males and females were treated separately. An analysis of variance of mean size-at-age for both sexes indicated no interannual differences for the time period ($p > 0.05$), therefore, samples were combined for all years (1978–85), totalling 1 289 males and 2 546 females. Age compositions of males and females are shown in Fig. 8 for the period 1978–85. Both sexes were generally observed in equal proportions up to about age 8, beyond which the relative percentage of females increased. Males occurred up to an age of 12 years, although there were very few older than age 8. Females were observed up to age 15, however, the numbers of females older than age 10 in most cases were negligible, while recognizing the occurrence of some large females of unknown age in the samples. This is in contrast to adjacent areas such as the Grand Bank where ages ranged up to 15 years for males and 20 years for females during the same time period (Brodie, MS 1988). Pitt (1975) examined age and growth patterns of the Grand Bank American plaice and indicated that at least up to 1972, females up to 24 years in age were present, which represents an additional nine age groups to those shown here for

Flemish Cap. On the other hand, Pitt (1967) showed that in samples taken from Flemish Cap in 1961 and 1963 (54 males and 94 females) males and females older than ages 11 and 14, respectively, were not present. This may suggest there has been no change in the age range on Flemish Cap since the early-1960s, although at that time commercial exploitation of American plaice in the area may have been relatively low. For other areas where this species has experienced long periods of exploitation, a reduced age range has often been observed, e.g. Pitt (1975) for Grand Bank and Powles (1965) for the southern Gulf of St. Lawrence. This pattern has also been shown to be very pronounced in stocks of another flatfish species, witch flounder, for the Gulf of St. Lawrence (Bowering and Brodie, 1984), southern Labrador and eastern Newfoundland (Bowering, 1987) and southern Newfoundland (Bowering, 1989). However, without detailed information on percentage-at-age composition during the earlier period, it is difficult to fully evaluate any effects of exploitation on the age structure of American plaice on Flemish Cap.

The population abundance of American plaice on Flemish Cap appeared highly dependent upon the year-class strength of as few as one age group (Fig. 8). The 1973 year-class dominated the population from 1978 through 1981 at about 56, 42, 28 and 28% of total abundance, respectively. The 1979 year-class dominated the population from 1982 through 1985 at about 22, 56, 68 and 40%, respectively. In 1985 the 1980 year-class also appeared strong and the 1979 and 1980 year-classes comprised more than 80% of the entire surveyed population in that year. Pitt (1967; 1975), while studying age and growth of American plaice in the Labrador and Newfoundland areas, did not note any dominant year-classes throughout the area and it was generally considered that recruitment in those areas were relatively stable. More recently, Brodie and Bowering (1991) observed that good catch rates on the Grand Bank in the late-1970s and early-1980s were partially attributable to stronger than average year-classes of 1968 to 1972. However, considering the large number of age groups comprising the resource, it was believed that a single stronger than average year-class may not have a pronounced effect on population size. Powles (1965), on the other hand, tracked the predominance of the 1950 and 1953 year-classes of American plaice in the southern Gulf of St. Lawrence despite the fact that there was a wide range of ages in the population. However, the highest contribution of a dominant year-class to population abundance in any one year was a little over 30% compared to the highest of 68% presented here.

The mean size-at-age and the respective growth curves for males and females on Flemish Cap are presented in Fig. 9. The growth rates were similar between the sexes up to age 3, however, beyond age 3, females grew faster. This divergence of growth pattern between the sexes is typical, however, such divergence at an early age is not typical of other American plaice stocks in the Northwest Atlantic. Pitt (1967) showed that for Newfoundland and Labrador stocks, the difference in growth patterns between the sexes was not apparent until at least 8 years of age for most areas. Powles (1965) observed differences at about age 5–6 years in the southern Gulf of St. Lawrence. The growth rates presented here for Flemish Cap are also faster than those presented for the Newfoundland-Labrador area by Pitt (1967; 1975) and the southern Gulf of St. Lawrence (Powles, 1965). Pitt (1967) observed, from 94 females examined from Flemish Cap in 1961 and 1963, that the initial growth rate was faster than all other areas, however, the overall growth rate was slower. By comparison, both the growth rate and the mean size-at-age are considerably higher for the data presented here (Fig. 9). Without adequate data, it can only be hypothesized as to what contributed to this change. It is unlikely that temperature conditions would have contributed in a significant way since bottom temperatures on Flemish Cap were consistent throughout the time period. A possible reduction in the stock size of American plaice due to increased exploitation may have provided a density-dependent effect while a considerable reduction in abundance of Atlantic cod (*Gadus morhua*) may also have contributed to this effect since they both occupy similar depths and they both eat similar prey (Pitt, MS 1975). The estimated biomass of cod on Flemish Cap in the 1960–65 period was 200 000 tons, compared to 30 000–35 000 tons during 1978–80,with a further reduction in more recent years (NAFO, 1988).

Sexual maturity

Sexual maturity ogives for males and females at length and age are presented in Fig. 10. The observed length and age at which mature males first occurred were 22 cm and 3 years. All were mature at a length of 39 cm and an age of 8 years. The length and age at which 50% were mature (M_{50}) from probit analysis were 26.4 cm and 3.8 years. Mature females first occurred at an observed length of 32 cm and an age of 4 years, and were all mature at 50 cm and 9 years. The length and age at M_{50} from probit analysis for females were 39.7 cm and 6.2 years. The mean sizes at M_{50} for both males and females were similar to those reported for other areas. Pitt (1975) observed for the Newfoundland Grand Bank area the size at M_{50} ranged from 25.3

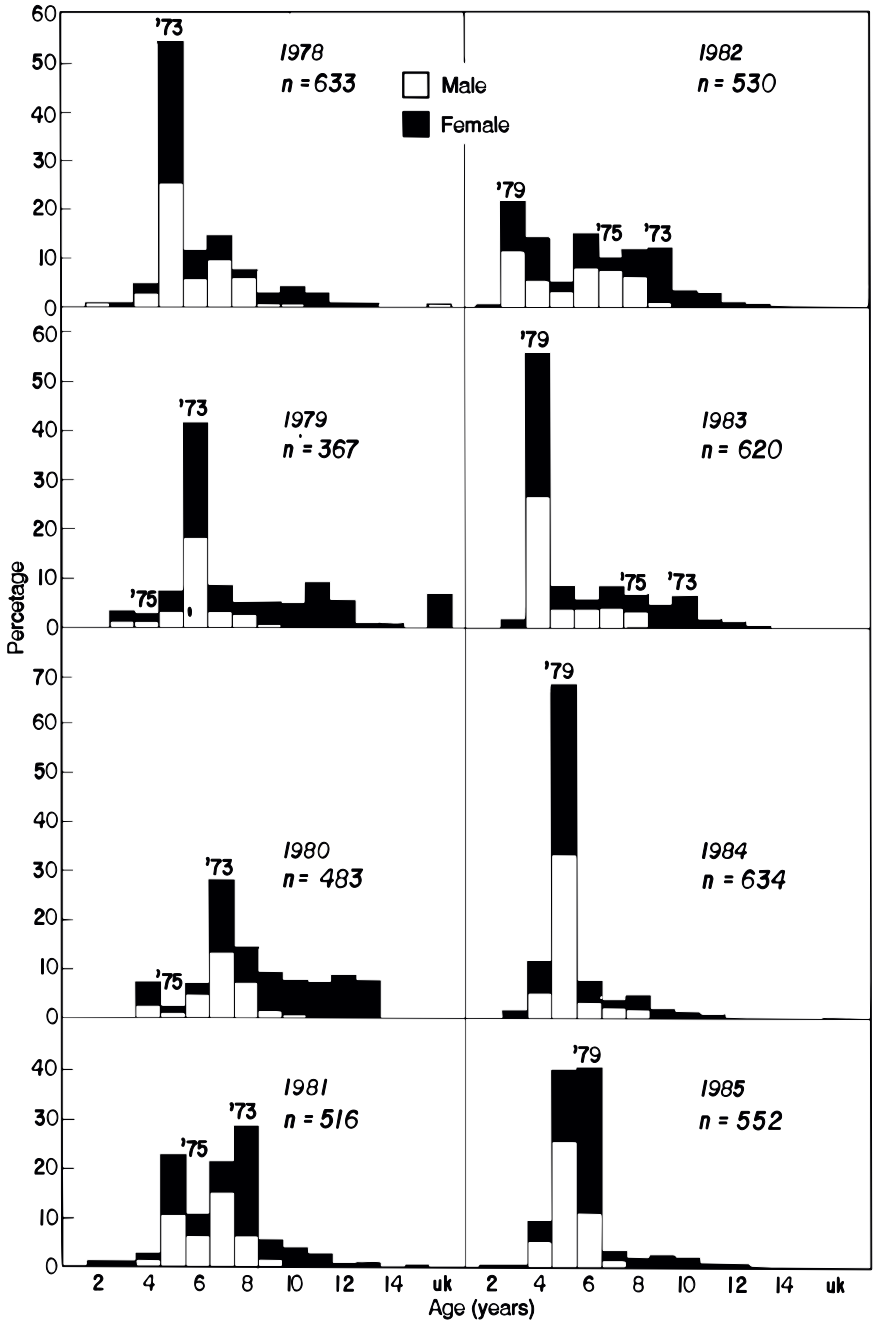

Fig. 8. Age composition of American plaice on Flemish Cap from 1978 to 1985.

to 26.0 cm for males and 41.5 to 43.7 cm for females. Powles (1965) reported that the length at M_{50} in the southern Gulf of St. Lawrence was 25 cm for males and 41 cm for females. Pitt (1966) also reported that the length at M_{50} for a small sample of females (50 fish) on Flemish Cap collected in 1961 was 41.3 cm, very similar to the present value. The ages at M_{50} for these areas, on the other hand, were considerably older than those shown here. For the Grand Bank areas investigated by Pitt (1975), the ages at M_{50} ranged from 4.7 to 7.6 years for males and 8.8 to 14.0 years for females, while Powles (1965) in his study observed the ages at M_{50} of 6 years for males and 10 years for females. Pitt's (1966) sample of females from Flemish Cap had an age at M_{50} of 7.8 years. It would appear, therefore, that the attainment of sexual maturity for American plaice may very well be more a function of body

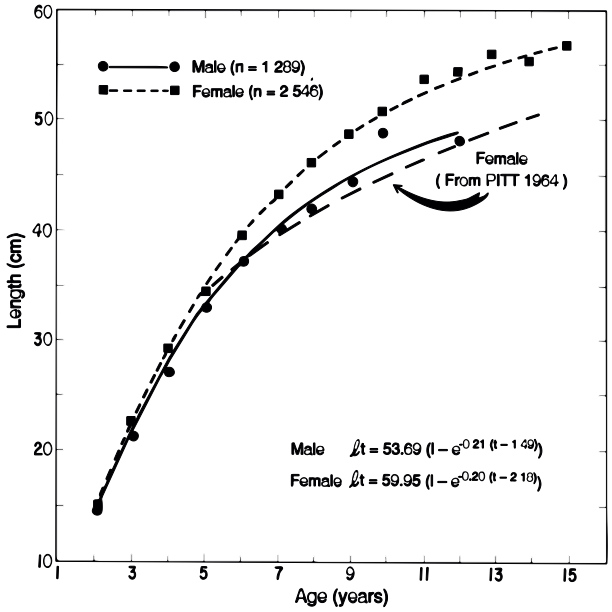

Fig. 9. Growth curves for male and female American plaice on Flemish Cap.

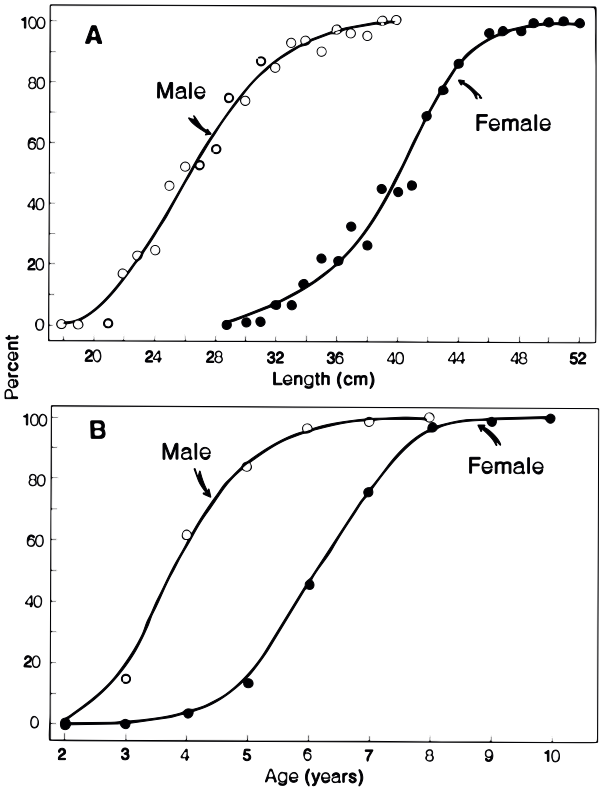

Fig. 10. Maturity ogives, by (**A**) length and (**B**) age, for American plaice on Flemish Cap.

size than age for the areas discussed, since the lengths at M_{50} were similar throughout these areas whereas the ages sometimes varied by several years. The relationship between size and age of fish and the development of sexual maturity has been, however, the subject of much debate. A comprehensive summary of literature and experimental work on the connection between maturity, size and age in fishes can be found in Alm (1959).

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