Growth and Mortality Estimates of Rockfishes (Scorpaenidae) from B.C. Coastal Waters, 1977-1979

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GROWTH AND MORTALITY ESTIMATES OF ROCKFISHES (SCORPAENIDAE) FROM B.C. COASTAL WATERS, 1977-1979

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ABSTRACT

Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1048: iv + 57 p.

Estimated parameters of total and natural instantaneous mortality, as well as von Bertalanffy growth parameters are presented for 10 species of rockfish (genus Sebastes) from British Columbia coastal waters. These estimates were derived from analysis of ageing data obtained through the application of new ageing techniques. The estimated longevity of species in this genus increased considerably (up to 80+y) as a result of this work. Concomitantly, estimates of instantaneous mortality were reduced substantially (_50%) from previously published estimates. For unexploited or lightly exploited stocks estimates of Z ranged from 0.01-0.07, while for heavily exploited stocks the corresponding estimates ranged 0.09-0.18.

Estimated parameters of growth changed relatively little from published values, largely because increased longevity occurs after major inflections in linear growth. Von Bertalanffy growth parameters presented here do not describe growth throughout life due to the lack of younger fish in the data set. The extension of age compositions past the point of major decreases in linear growth implies that the use of age-length keys for rockfishes, in British Columbia waters at least, is invalid.

Key words: Rockfishes, growth, mortality, British Columbia, longevity.

RÉSUMÉ

Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1048: iv + 57 p.

On présente les estimations des taux instantanés de mortalité naturelle et totale ainsi que les paramètres de croissance de Von Bertalanffy pour dix espèces de scorpènes (du genre Sebastes) provenant des eaux côtières de la Colombie-Britannique. Ces estimations ont été tirées de l'analyse des données sur l'âge obtenues grâce à la mise en application de nouvelles techniques de détermination de l'âge. Ce travail a eu, entre autres, pour résultat d'augmenter considérablement (jusqu'à 80+y) l'évaluation de la longévité des espèces de ce genre. Les évaluations du taux instantané de mortalité ont été réduites en même temps de façon substantielle ($\geq$50 %) par rapport aux estimations déjà connues. Pour les stocks légèrement ou pas exploités, les estimations de Z variaient de 0,01 à 0,07; pour les stocks fortement exploités, les estimations correspondantes variaient de 0,09 à 0,18.

Les estimations des paramètres de croissance ont relativement peu changé par rapport aux valeurs connues, ce qui est dû en grande partie à une augmentation de la longévité suite à d'importantes déviations dans la croissance linéaire. Étant donné l'absence d'individus plus jeunes dans la série des données, les paramètres de croissance de Von Bertalanffy présentés ici ne retracent pas la croissance au cours de tout le cycle vital. Le fait qu'il y ait une répartition des âges après d'importantes diminutions dans la croissance linéaire signifie que l'utilisation des clés âge-longueur pour les scorpénes, du moins dans les eaux de la Colombie-Britannique, n'est pas valable.

Mots-clés: scorpènes, croissance, mortalité, Colombie-Britannique,
longévité.

INTRODUCTION

Pacific coast rockfishes (genus *Sebastes*) are one of the major groups of fish landed by the British Columbia commercial trawl fleet. Until quite recently, Pacific ocean perch (*S. alutus*) was the most important species in the rockfish group. Commercial landings of *S. alutus* during 1968-70 comprised 8% of the total Canadian groundfish landings, twice as much as the landings of all other rockfish species combined. With the decline in *S. alutus* stocks, due primarily to intensive exploitation by foreign trawlers in the 1960s (Ketchen 1981), commercial interest in other rockfish species increased dramatically. By 1977-79, other rockfish species comprised 16-21% of the domestic groundfish landings, more than a four-fold increase since the beginning of the decade.

Effective management of these newly-exploited rockfish species is hampered by the general lack of biological information on them, with the notable exception of preliminary work done by Phillips (1964), Westrheim (1975), and Westrheim and Harling (1975). It is the purpose of this report to partially rectify this situation by presenting and analyzing length-at-age and age composition data collected for a number of rockfish species from B.C. coastal waters, during 1977-79. This information was used to estimate growth and mortality rates. The species examined in this report are listed with their common names in Table 1.

MATERIALS AND METHODS

DATA COLLECTION

The raw length-at-age and age composition data on which this report is based are presented by Shaw and Archibald (1981). The data were collected from both port sampling of commercial catches and sampling aboard research cruises during the period 1977-79. Minimum sample size in all cases was 100 fish; fork lengths were measured to the nearest centimeter and double otoliths were taken for age determination. For further information on methods of data collection, see Shaw and Archibald (1981).

In the past, ages have been determined from surface readings of fish otoliths. In this procedure, the whole otolith was viewed under a dissecting microscope and each annulus, as seen on the surface, was counted (Westrheim 1973). This method has recently been found to underestimate the age of rockfish when compared with the ages interpreted from either broken-and-burnt otoliths or cross sections of otoliths from the same fish (Beamish 1979). Although ages obtained by both latter procedures have yet to be validated by tagging, they are judged to be the most accurate ages available for rockfishes (D. E. Chilton, Head of Ageing Unit, Pacific Biological Station, pers. comm.) and they are supported by the movement of strong cohorts over time in age frequency distributions. All ages presented in this report were obtained either by sectioning or breaking and burning the otoliths. For further discussion of these data, see Shaw and Archibald (1981).

ESTIMATION OF MORTALITY RATES

Total instantaneous mortality rates (Z) were estimated by calculating the slope of the right-hand descending limb of the natural log of the age frequency distribution (catch curve) using simple linear regression (Ricker 1975). The majority of the catch curves did not show a smoothly descending right-hand limb. This could be attributed to highly variable recruitment and possibly to variable fishing effort over time. Since these two factors violate the method's assumptions of constant recruitment and constant mortality over time, the resulting slope estimate can only be viewed as a rough approximation to average total mortality. The influence of particularly large or small year-classes on the estimation of mortality was diluted, in most cases, by the fact that rockfishes have so many age-groups present in the catch. With such extreme variability in the descending limb of the catch curves, the standard errors associated with the slopes were very large (0.4-0.7), about an order of magnitude greater than the values for slope.

With catch curves of this sort, the choice of the first age at full recruitment (the starting point for slope calculation) was rather subjective since little independent information was available for these species. In general, age at full recruitment was chosen to be the first major peak in the age distribution and this was usually between 15 and 20 years of age. If there was any doubt in choosing one of two peaks, the peak at the older age was chosen to ensure that only fully recruited ages were used for mortality estimation. Samples consisting entirely of very young (partially recruited) fish were not included. The end of the catch curve for purposes of slope calculation was taken to be the last age represented in the catch before a large break (>5 y) in the age distribution. The few fish in the sample that were older than this represented a very small percentage of the total number. This ensured that the mortality was estimated over ages which were reasonably well represented in the catch.

It should be emphasized that the mortality estimates thus derived represent the mortality rate only for those ages over which the slope was calculated. While abundance of very old fish decreases markedly with age, there is often a considerable extension of the catch curve for lightly exploited stocks. Fish were not abundant enough in such segments of the catch curve to allow estimation of mortality, as we have noted, but such data suggest that a decrease in mortality may in fact occur for older fish, prior to the onset of major senescent mortality. An additional feature of *Sebastes* stocks is that age distribution is correlated with depth, such that older fish are more abundant in deeper water. Exploration into deeper waters may be required in order to improve mortality estimates for older fish.

For each species, age composition data were kept separate according to year, major statistical area (Fig. 1), and whether they represented commercial or research samples. The samples from a statistical area were grouped together to obtain the best estimate of the age composition for that particular area. In most cases there were not enough samples from an area to justify comparison among subareas.

ESTIMATION OF GROWTH PARAMETERS

To improve sample size for average length-at-age estimates, available data were combined across all years and all sample types (research and commercial) to produce one growth curve for each sex per species, per statistical area. There is a maximum of two years between samples that were grouped together and for such a slow-growing group as rockfishes it is unlikely there would be any significant difference in growth rate over this time frame. In cases where both research and commercial samples were large enough from one area to allow a comparison, there was no difference in average length-at-age.

Growth curves were compared between areas for each species and areas were grouped together when no difference in average length-at-age could be detected by eye. This grouping is not meant to imply that there is no difference between the areas grouped, but only that any differences that do exist could not be detected with the present sample size.

Once the final groupings were decided upon, von Bertalanffy growth curves were fitted to the resulting data using the method of Allen (1966). Since the program had difficulty converging to a solution when the curve was fitted to the raw data, the curves were fitted to the average length-at-age values with each value weighted according to the sample size comprising it. A few of the curves had extremely low t_0 values (-10.2 to -29.6), due in part to the paucity of data for young fish. Therefore, for all curves with an unconstrained t_0 value of less than -10.0 the von Bertalanffy fits were recalculated with a fixed value for t_0. The curves involved here were all for species with more than one curve presented for each sex, and the fixed value chosen for t_0 was the unconstrained t_0 estimate for the same sex in the other group of areas for the species. When a curve for combined sexes needed a constrained t_0 value, the average of t_0 values for males and females was chosen. The reader should note that the estimated von Bertalanffy parameters are intended for use in a general descriptive sense rather than for precise prediction, because of the relatively small amount of data comprising the growth curves.

RESULTS

GENERAL COMMENTS

To put the rockfish species into perspective with one another and with other well-known species, maximum recorded length is plotted against maximum recorded age in Fig. 2. Note particularly the great longevity of the rockfish species and the relatively small maximum lengths (low growth rates). There is an obvious correlation between maximum length and maximum age among the rockfish group.

MORTALITY

Fig. 3-8 present the age compositions for each species by sex, area, and year. The resulting mortality estimates from both commercial and research samples are summarized in Table 2. Mortality rates were not estimated from age compositions of very small samples (<50 fish).

Sebastes aleutianus

S. aleutianus had the greatest longevity of the rockfish species examined, with total annual instantaneous mortality (Z) estimated to be very low, 0.03-0.04 in most samples and even lower (0.01-0.02) in the 1979 commercial samples from Area 5E (Table 2). Males were more abundant than females in the samples taken (Fig. 3), but there was no difference in mortality rate between the sexes (Table 2).

Sebastes alutus

Mortality (Z) estimates for S. alutus were also low; 0.04-0.06 for most samples (Table 2). Two samples had Z estimates less than 0.02 (1979 research from Area 5E, 1979 commercial from Area 5D), while the 1979 commercial sample from Area 5B had the highest Z estimate of 0.08 for each sex. The sex ratio for S. alutus was variable with males far outnumbering females in some samples and the reverse in others (Fig. 4). There was no appreciable difference in the Z estimates between sexes. For S. alutus, the 1952 year-class was an exceptionally large one (Westrheim et al. 1972; Westrheim 1973) and this can be seen by the peaks around age 26 in 1978 and age 27 in 1979.

Of special interest is the age distribution of S. alutus in Area 5E in 1979 commercial samples. The presence of a substantial number of fish aged

11-15 y appears anomalous with other samples from this area. On closer examination of this group of samples however, it was discovered that this group of young fish was entirely taken from the Langara Spit area in northwest Dixon Entrance (Fig. 5). This area experienced extremely heavy fishing pressure between 1965-1967 when over 60,000 t of rockfish were removed, and this group of young fish may represent the last successful year-classes prior to this intensive fishery.

Sebastes brevispinis

Mortality estimates for S. brevispinis varied mainly between 0.03 and 0.05. The 1979 results from Area 5B were slightly different in that the research sample gave a lower Z estimate (0.01-0.02) than the commercial sample (0.06-0.07). However, in neither case was the sample size very large (<100 fish total in each sample). The sex ratio in the catch was generally variable, although in areas 5C and 5D males consistently outnumbered females (Fig. 6). Despite this, no consistent difference was detectable between male and female Z estimates.

Sebastes crameri and Sebastes entomelas

Little can be said about S. crameri and S. entomelas due to the small sample sizes. The 198 S. crameri sampled were almost all females (Fig. 3) and mortality was estimated to be about 0.07 (Table 2). The single S. entomelas sample was primarily males (Fig. 7), yielding a mortality estimate of about 0.05.

Sebastes flavidus

S. flavidus showed a striking difference in sex ratio with males consistently being two to three times as numerous as females in the catch samples (Fig. 7). There were very few older female fish and this resulted in higher Z estimates: 0.1-0.14 for females and 0.06-0.09 for males (Table 2). For both sexes, the Z estimate was highest in Area 3D.

Sebastes pinniger

S. pinniger was another species with the sex ratio shifted heavily in favour of males; very few females were found among the older fish (Fig. 8). The mortality estimates for male S. pinniger were generally between 0.03 and 0.04, although somewhat higher (0.07) in the 1978 commercial sample from Area 5B (Table 2). The low Z value of 0.01 in Area 5E was based on a very small number of fish. The estimated Z for females was 0.11-0.24, but since the sample sizes here were also very small the only real information provided by the female age distribution is that their mortality rate appears to be substantially higher than that for males.

Sebastes proriger and Sebastes zacentrus

S. proriger and S. zacentrus were represented by one sample each (Fig. 7). The Z estimate for female S. proriger was 0.09 (Table 2). For S. zacentrus, males were more abundant than females and the mortality estimate for both sexes was 0.05.

Sebastes reedi

S. reedi had an approximately even sex ratio in all samples (Fig. 9). Mortality estimates varied substantially among areas and years, ranging from 0.08-0.15 for males and 0.06-0.19 for females (Table 2). For samples taken in Area 5E there is a large secondary peak of abundance for fish between ages 26 and 29. This is comparable with S. alutus and is probably the result of strong year-classes in the early 1950s. Such secondary peaks make the estimation of mortality difficult, especially since S. reedi does not have as extensive an age range as some other rockfish species, to dampen the effect of an unusually large year-class. Generally, male and female mortality estimates were comparable. Although a few samples had higher Z estimates for females (notably 1977 and 1979 commercial samples from Area 5E), examination of the age distribution does not show a clear difference between the sexes. Again, additional data are required to clarify this point.

The age distributions of S. reedi in Area 5A illustrate the effects of gear selectivity and bathymetric segregation of age-groups. Both the 1977 commercial and 1979 research samples from Area 5A exhibit substantial numbers of fish in the 10-20 y range, when compared with the 1978 and 1979 samples illustrated (Fig. 9). The former samples were all obtained from midwater trawl catches, while the latter were taken from bottom trawl hauls. These data suggest that either younger fish are higher in the water column or that they are more vulnerable to midwater trawls.

GROWTH

Graphs of mean length versus age are shown in Fig. 10-16; the von Bertalanffy parameters of the best-fit curves are given in Table 3. An example of a von Bertalanffy fit to the data with confidence limits about the means is shown for S. flavidus in Fig. 14. The variances of mean lengths for S. aleutianus (Fig. 10) and S. entomelas (Fig. 13) were too great for convergence of the estimator for the von Bertalanffy parameters. The parameters for sexes combined were calculated only to permit comparison with other published work. They were not used for comparisons among areas or species since these parameters were highly dependent on the sex ratio of the samples. For such comparisons, parameters were compared within each sex.

For all species the average maximum length estimated (L_∞) was larger for females than males. This larger length-at-age for females was true over all ages examined, but of course was less pronounced for the younger ages. For species where differences in growth could be detected among areas, it was always the more northern area or group of areas that had the smaller lengths-at-age. This trend was slightly evident for S. brevispinis (Fig. 12) and S. pinniger (Fig. 15), more noticeable for S. alutus (Fig. 11) and pronounced for S. reedi (Fig. 16). S. reedi was the only species compared among single, ungrouped areas.

There are two other von Bertalanffy parameters besides L_∞: t_0, which is the theoretical length at age zero, assuming the fish grew according to the same von Bertalanffy curve since birth (which is almost certainly not true); and k, which is a measure of how quickly L_∞ is approached (low values of k correspond to flattened, gradual curves). The parameters presented here approximate growth only over the age range examined and make no pretense at describing growth throughout the fish's life. In particular, growth in early life is not well defined due to the paucity of data for younger ages. Also, fish undoubtedly change their growth pattern as they age and it is not surprising that some of the von Bertalanffy approximations using data from older ages have t_0 values quite different from zero. The range of k values obtained in this work is comparable to those obtained by other investigators (Table 4).

Note that for most species in most areas there is essentially no growth (increase in length) past age 25 y. S. brevispinis showed a small amount of growth past age 25 y and it had a correspondingly low k value (flattened growth curves). In most cases where a species' growth was separated by area, the more northern area had the higher k value, indicating a more rapid decrease in growth rate with age. The only exception to this was for female S. pinniger, however this is based on limited data (Fig. 15). There was no consistent trend in the values of k between males and females.

There was a vague inverse relationship between growth and mortality for these rockfish such that those species with shorter life spans tended to approach their maximum size more quickly (have higher k values) (Fig. 17). As a corollary of this, there was also a rough relationship between k and estimated natural mortality (Fig. 18). (Latter taken to be the minimum Z estimate for a species in an area--see below for additional discussion of natural mortality component of Z.) Both relationships were more pronounced for females, and were confounded by exploitation histories of the stocks involved.

DISCUSSION

The age distributions presented in this report were used to obtain estimates of total instantaneous mortality rates for rockfishes off the B.C. coast. The longest-lived rockfish species have life spans in excess of 70 years and have very low mortality estimates, between 0.03 and 0.06 (S. aleutianus, S. alutus, S. brevispinis, and male S. pinniger). The species with slightly shorter life spans, 40-60 y, had mortality estimates between 0.05 and 0.09 (female S. crameri, male S. entomelas, male S. flavidus, S. proriger, and S. zacentrus). Females of S. flavidus and S. pinniger appeared to have much shorter life spans than their male counterparts, and had correspondingly higher mortality estimates (0.10-0.14 and 0.11-0.24, respectively). Mortality estimates for S. reedi were quite varied, centering around 0.10 or slightly higher.

All of the above figures refer to total instantaneous mortality (Z) which is the sum of instantaneous natural mortality (M) and instantaneous fishing mortality (F). The slope of the descending right-hand limb of the catch curve represents total mortality experienced by the fish at the time they recruited to the fishery (Ricker 1975, p. 50). Thus for long-lived species like rockfishes, the mortality estimate is that averaged over the previous 20 years or more. Since many of these rockfish species have only undergone significant exploitation in recent years, the Z estimates are primarily estimates of M because F is essentially zero. The most obvious exception to this is S. alutus, particularly the stocks in Queen Charlotte Sound (Area 5B) which were very heavily fished by foreign trawl fleets from 1965-1969 (Westrheim et al. 1972; Ketchen 1980a). Mortality estimates for S. alutus in Area 5B were twice as high as in other areas, a clear reflection of the increased F component of Z. For S. flavidus, mortality estimates for both sexes were highest in Area 3D. This difference is harder to ascribe to increased fishing in Area 3D, but the intense Polish fishery in this area in 1975 and 1976 (Ketchen 1980b) may have been a contributing factor.

Since S. alutus has been of major commercial interest for quite some time, there are more data concerning it in the literature than for other species. From our work the value of natural mortality for S. alutus would appear to be 0.04-0.05, which is far lower than that estimated by previous investigators: 0.11-0.16 (Alverson, cited by Robinson 1972); 0.1-0.2 (Gunderson 1977); 0.2 (Robinson 1972); 0.12 (Westrheim et al. 1972). Since these other estimates were based on surface readings of otoliths, the high M values are probably a result of significant underageing of the type described by Beamish (1979). Such ageing errors also affect estimates of growth, making length appear to increase more rapidly with age than it actually does. This is clearly seen in Fig. 19 which compares the present growth results with Gunderson's (1977) surface-aged results for S. alutus from Queen Charlotte Sound. The ages estimated with the more reliable sectioning procedure result in a more gradual increase in length with age and a lower von Bertalanffy k parameter; 0.12 for males and 0.11 for females in Gunderson's data, and 0.097 for males and 0.078 for females in the present work.

Experiments designed to validate the ages estimated by the sectioning and breaking-and-burning technique are currently underway (Shaw et al. 1981), and partial verification of these ages can be obtained by following a dominant year-class over time. Such a year-class occurred in 1952 for S. reedi and S. alutus, and the progression of this year-class is clearly seen in the Area 5E commercial samples for S. reedi: the peak at 25 y in 1977 moves to 26 y in 1978 and 27 y in 1979 (Fig. 9).

Two species, S. flavidus and S. pinniger, were sampled quite extensively and yet showed a marked and consistent predominance of males. S. alutus has been shown to exhibit a seasonably variable sex ratio with males predominating on the fishing grounds in spring and the sex ratio balancing out later in summer as females move inshore from their deep-water wintering area (Gunderson 1971; Ketchen 1981). However, the predominance of males for S. flavidus and S. pinniger is not a seasonal phenomenon since samples for S. pinniger in Fig. 8 represent April through October plus January, and although the S. flavidus samples in Fig. 7 represent August and September only, commercial samples from the rest of the year all show the same skewed sex ratio (Venables 1978, 1979). Other investigators have noted a similar predominance of males for these two species in samples taken off the west coast of the United States (Boehlert 1980; Fraidenburg 1980). At present, insufficient information is available to determine whether the females of these species actually have higher mortality rates than males or whether the older females are unavailable to the gear on the traditional fishing grounds, possibly by staying in very deep water or higher in the water column.

Recently (Fraidenburg 1981), estimates of natural mortality for an unexploited stock of S. flavidus off Washington have been published (0.2-0.3). Since these estimates were based on surface readings of otoliths, their validity is questioned, particularly considering the consistency of results presented here for lightly exploited areas (∿.06).

For the most part, the von Bertalanffy curves fitted to the length-at-age data were biologically realistic. In the example shown in Fig. 14, female S. flavidus growth was described very well by the fitted von Bertalanffy curve while for male growth the fitted curve did not inflect as strongly as required by the data. For the comparative purposes used in this paper, such descriptions of rockfish growth were adequate; the estimation of more accurate, predictive growth curves must await further data collection, particularly for young fish.

The type of relationship noted here between natural mortality (M, approximated by minimum Z) and the rate of approach (k) to L_∞ has been found generally among fishes (Beverton and Holt 1960). Fig. 20 shows the relationship of the rockfish group to other fish groups in terms of M and k values. It is clear that rockfishes are exceptionally long-lived species (low M) which approach their maximum sizes very gradually (low k).

Westrheim and Ricker (1978) have noted that the use of an age-length key to estimate age-frequency distributions is usually biased for fish such as rockfishes, unless the keys are applied to samples taken at about the same time in the same year. Given the great longevity of many of these species and the fact that very little growth in length occurs after age 25, it would appear that age-length keys are useless for rockfishes since length alone cannot differentiate between fish in the 25-70y age range. The only way to properly establish the age composition of rockfish stocks is to age sufficient fish and, given the large number of age-groups involved, this number is a minimum of several hundred.

While complete validation of the ageing techniques used in this analysis, and hence the age compositions and mortality rates, must await the return of tagged and tetracycline-injected fish, the progression of dominant year-classes and the inflections of the catch curves associated with major effort changes lend strong support to these results. If these mortality rates are correct then they represent substantial changes from previous estimates and call for re-evaluation of present exploitation strategies for this group. Reports detailing the ecological and management implications of extended longevity in this and other genera are in preparation at this laboratory.

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Table 1. List of scientific and common names of the rockfish species examined in this report.

Scientific name	Common name
Sebastes aleutianus	Rougheye rockfish
Sebastes alutus	Pacific ocean perch
Sebastes brevispinis	Silvergray rockfish
Sebastes crameri	Darkblotched rockfish
Sebastes entomelas	Widow rockfish
Sebastes flavidus	Yellowtail rockfish or greenies
Sebastes pinniger	Canary rockfish
Sebastes proriger	Redstripe rockfish
Sebastes reedi	Yellowmouth rockfish
Sebastes zacentrus	Sharpchin rockfish

Table 2. Total instantaneous mortality rates (Z) by species, by major statistical area, and by sex for research and commercial rockfish (genus Sebastes) catches collected during 1977-1979. Sample sizes are shown in Fig. 3-9. Range represents age in years over which slope was calculated to estimate Z. Sex denoted by M (males), F (females), and T (sexes combined). Comm. = commercial sample; Res. = research sample.

Species	Area and sample type	Sex	1977		1978		1979	
			Range	Z	Range	Z	Range	Z
S. aleutianus	5E (comm.)	M	-	-	21-61	0.04	20-63	0.01
		F	-	-	21-58	0.03	-	-
		T	-	-	21-61	0.05	21-72	0.02
	5E (res.)	M	-	-	-	-	18-68	0.03
		F	-	-	-	-	21-61	0.04
		T	-	-	-	-	18-68	0.04
S. alutus	5B (comm.)	M	-	-	-	-	18-44	0.08
		F	-	-	-	-	17-47	0.08
		T	-	-	-	-	18-47	0.10
	5C (comm.)	M	-	-	-	-	18-55	0.05
		F	-	-	-	-	19-52	0.06
		T	-	-	-	-	18-55	0.06
	5D (comm.)	M	-	-	-	-	15-77	0.005
		F	-	-	-	-	-	-
		T	-	-	-	-	15-77	0.01
	5E (comm.)	M	-	-	16-53	0.04	15-71	0.04
		F	-	-	17-73	0.04	15-71	0.04
		T	-	-	16-73	0.05	15-71	0.05
	5E (res.)	M	-	-	-	-	18-68	0.03
		F	-	-	-	-	21-61	0.04
		T	-	-	-	-	18-68	0.04
S. brevispinis	3C (comm.)	M	-	-	-	-	-	-
		F	-	-	-	-	-	-
		T	-	-	20-51	0.04	-	-
	5A (comm.)	M	-	-	-	-	17-68	0.03
		F	-	-	-	-	18-63	0.04
		T	-	-	23-52	0.04	18-68	0.04
	5A (res.)	M	-	-	-	-	-	-
		F	-	-	-	-	15-43	0.04
		T	-	-	-	-	15-43	0.05
	5B (comm.)	M	20-68	0.03	16-67	0.03	19-45	0.06
		F	20-51	0.02	16-47	0.04	-	-
		T	20-68	0.05	16-67	0.04	20-45	0.07

Table 2 (cont'd)

Species	Area and sample type	Sex	1977		1978		1979	
			Range	Z	Range	Z	Range	Z
	5B (res.)	M	-	-	-	-	18-66	0.01
		F	-	-	-	-	19-66	0.03
		T	-	-	-	-	18-66	0.03
	5C (comm.)	M	-	-	17-57	0.04	16-43	0.04
		F	-	-	16-43	0.02	-	-
		T	-	-	17-57	0.05	14-43	0.06
	5D (comm.)	M	20-71	0.04	20-55	0.03	-	-
		F	20-51	0.05	-	-	-	-
		T	20-71	0.05	20-55	0.04	-	-
S. crameri	5E (res.)	M	-	-	-	-	-	-
		F	-	-	-	-	11-48	0.07
		T	-	-	-	-	11-48	0.07
S. entomelas	5B (res.)	M	-	-	-	-	23-59	0.05
		F	-	-	-	-	-	-
		T	-	-	-	-	23-59	0.05
S. flavidus	3D (res.)	M	-	-	16-44	0.09	-	-
		F	-	-	13-26	0.14	-	-
		T	-	-	16-44	0.10	-	-
	5B (comm.)	M	-	-	-	-	17-49	0.06
		F	-	-	-	-	12-30	0.14
		T	-	-	-	-	17-49	0.07
	5B (res.)	M	-	-	-	-	19-53	0.06
		F	-	-	-	-	10-32	0.10
		T	-	-	-	-	19-53	0.07
	5D (comm.)	M	-	-	-	-	18-39	0.06
		F	-	-	-	-	-	-
		T	-	-	-	-	18-39	0.06
S. pinniger	3D (comm.)	M	23-58	0.03	-	-	16-76	0.03
		F	-	-	-	-	-	-
		T	23-58	0.03	-	-	16-76	0.03
	5A (comm.)	M	-	-	16-48	0.04	-	-
		F	-	-	-	-	-	-
		T	-	-	16-48	0.04	-	-
	5B (comm.)	M	15-51	0.04	21-54	0.07	16-46	0.04
		F	-	-	17-31	0.17	-	-
		T	15-51	0.05	21-54	0.08	16-46	0.05

Table 2 (cont'd)

Species	Area and sample type	Sex	1977		1978		1979	
			Range	Z	Range	Z	Range	Z
	5C (comm.)	M	-	-	16-46	0.03	18-54	0.04
		F	-	-	16-24	0.24	-	-
		T	-	-	16-46	0.05	18-54	0.04
	5E (comm.)	M	-	-	21-57	0.01	-	-
		F	-	-	15-34	0.11	-	-
		T	-	-	21-57	0.02	-	-
S. proriger	5A (comm.)	M	-	-	-	-	-	-
		F	-	-	11-31	0.09	-	-
		T	-	-	11-32	0.10	-	-
S. reedi	5A (comm.)	M	17-41	0.11	-	-	-	-
		F	17-43	0.10	-	-	-	-
		T	17-43	0.13	-	-	-	-
	5A (res.)	M	-	-	21-48	0.09	-	-
		F	-	-	18-52	0.06	16-31	0.15
		T	-	-	18-52	0.08	16-31	0.18
	5B (comm.)	M	-	-	-	-	20-41	0.08
		F	-	-	-	-	20-34	0.11
		T	-	-	-	-	20-41	0.12
	5E (comm.)	M	16-30	0.12	17-33	0.10	19-34	0.14
		F	17-31	0.19	17-33	0.09	19-38	0.18
		T	16-31	0.19	17-33	0.11	19-38	0.21
	5E (res.)	M	-	-	-	-	18-33	0.08
		F	-	-	-	-	17-31	0.14
		T	-	-	-	-	17-33	0.12
S. zacentrus	5E (res.)	M	-	-	15-43	0.05	-	-
		F	-	-	16-46	0.05	-	-
		T	-	-	15-46	0.07	-	-

Table 3. Von Bertalanffy parameters for curves fitted to the mean length-at-age data presented in Fig. 10-16. All t_o values unconstrained except those noted by an asterisk (see text). Sex denoted by M (males), F (females), and T (sexes combined); L_∞ values given in cm.

Species	Area	Sex	Von Bertalanffy parameters		
			t_o	k	L_∞
S. alutus	5B+5C	M	-7.64	0.097	43.0
		F	-8.18	0.078	47.7
		T	-8.22	0.088	44.8
	5E	M	-3.50	0.172	39.7
		F	-3.53	0.132	43.9
		T	-5.22	0.126	42.6
S. brevispinis	3C+5A	M	-4.13	0.088	57.0
		F	-8.46*	0.068	60.6
		T	-6.30*	0.080	58.5
	5B+5C+5D+5E	M	-4.13*	0.101	54.9
		F	-8.46	0.069	60.1
		T	-6.30*	0.085	56.8
S. crameri	5E	F	-5.42	0.087	38.3
S. flavidus	3B+5A+5B+5D	M	-2.37	0.153	48.5
		F	-0.95	0.157	52.3
		T	-0.76	0.186	48.6
S. pinniger	3D+5A+5B	M	-3.98	0.114	54.1
		F	2.00	0.209	55.3
		T	-2.71	0.139	53.8
	5C+5D	M	-0.45	0.137	52.8
		F	-1.05	0.095	62.1
		T	-0.24	0.139	53.3
S. proriger	3C+5A+5E	M	-1.71	0.178	34.0
		F	-1.02	0.148	41.3
		T	-0.90	0.166	38.3
S. reedi	5A	M	-2.73	0.125	45.6
		F	-2.18*	0.124	47.2
		T	-2.45*	0.126	46.3
	5E	M	-3.09	0.132	43.9
		F	-2.18	0.133	44.8
		T	-3.33	0.125	44.5
S. zacentrus	5E	M	-5.30	0.100	30.4
		F	1.26	0.134	36.1
		T	-2.12	0.095	34.9

Table 4. Ranges obtained by various investigators for von Bertalanffy growth parameters of rockfishes, separated by sex and then for sexes combined.

			Von Bertalanffy parameters					
			♂			♀		
Source	Area studied	No. species examined	t_o	K	L_∞	t_o	K	L_∞
This study	B.C. coast	8	-7.64→0.45	0.088-0.18	30.4-57.0	8.46→2.0	0.068-0.21	36.1-62.1
Westrheim and Harling (1975)	NE Pacific	16	-9.3 →1.2	0.06 -0.66	27.4-73.5	-17.3→ 1.4	0.015-0.23	30.2-116.7
			Sexes combined					
			t_o	K	L_∞			
This study	B.C. coast	8	-8.22 0.24	0.08- 0.186	34.9-58.5			
Westrheim and Harling (1975)	NE Pacific	16	-9.14 0.9	0.05- 0.16	29.9-80.7			
Phillips (1964)	California	10	-0.7 -0.1	0.10- 0.28	31.5-81.3			
Chen (1971)	California	5	-3.0 -0.5	0.06- 0.17	16.2-39.2			

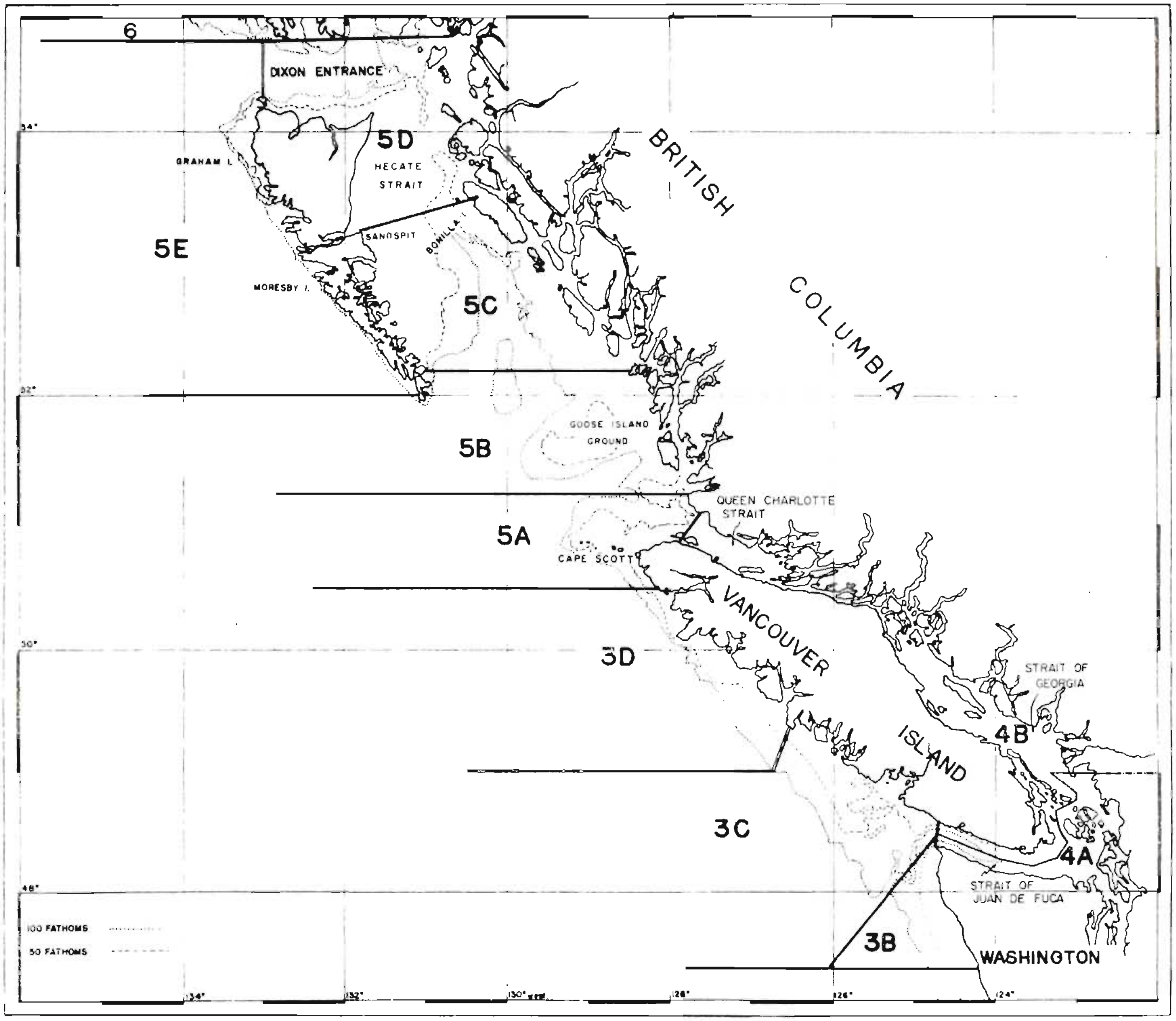

Fig. 1. International (Pacific Marine Fisheries Commission) Statistical Areas along the British Columbia coast.

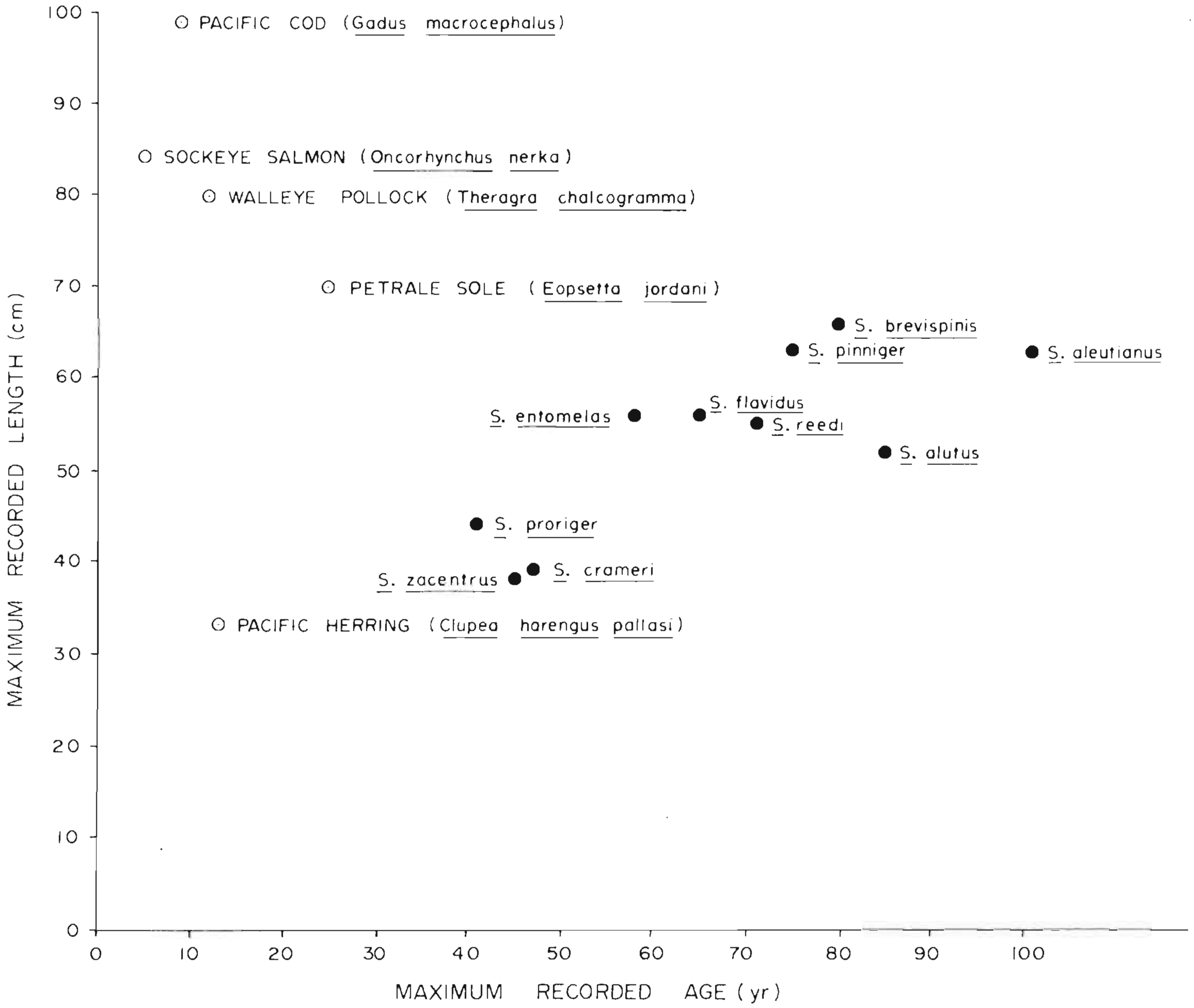

Fig. 2. Maximum recorded length and maximum recorded age for Sebastes spp., in comparison with other northeast Pacific fishes.

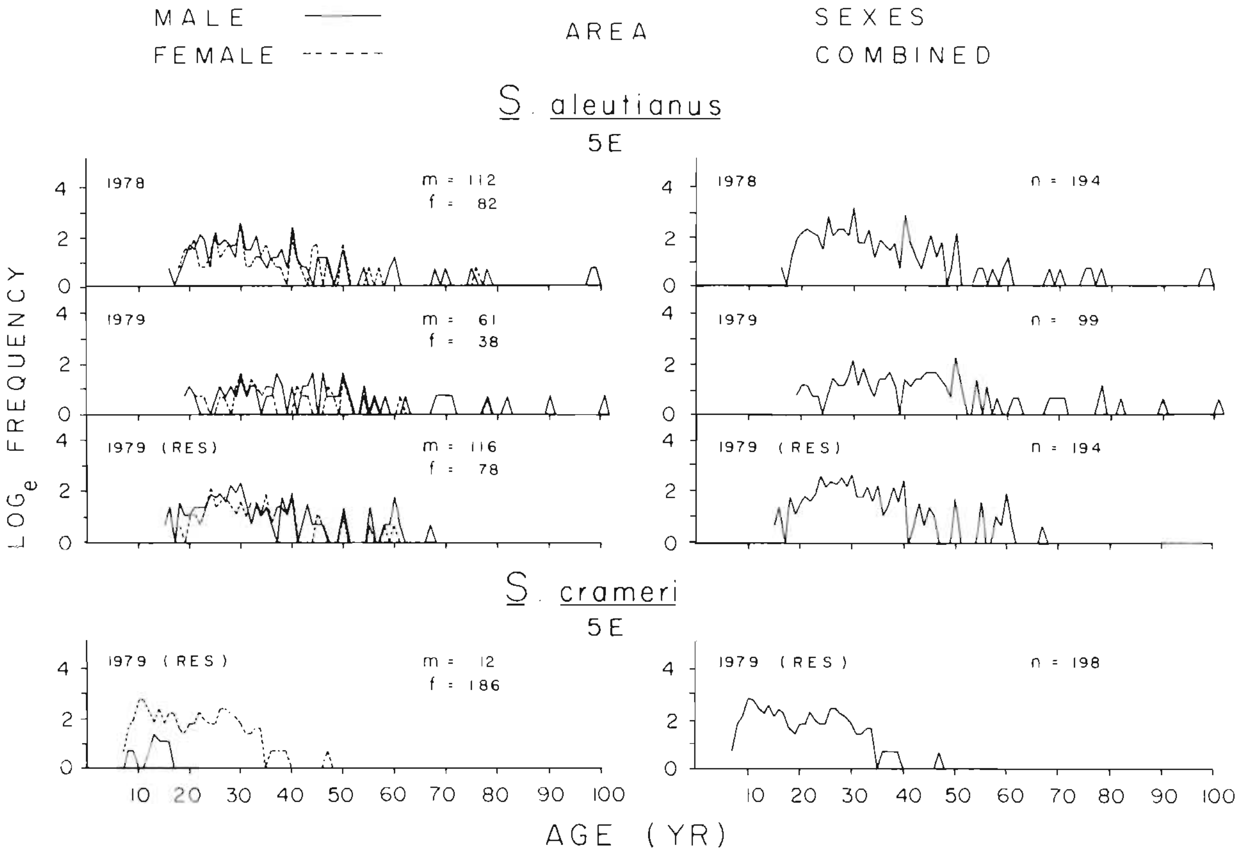

Fig. 3. Age compositions by year, sex, area and sample types for Sebastes aleutianus and S. crameri.

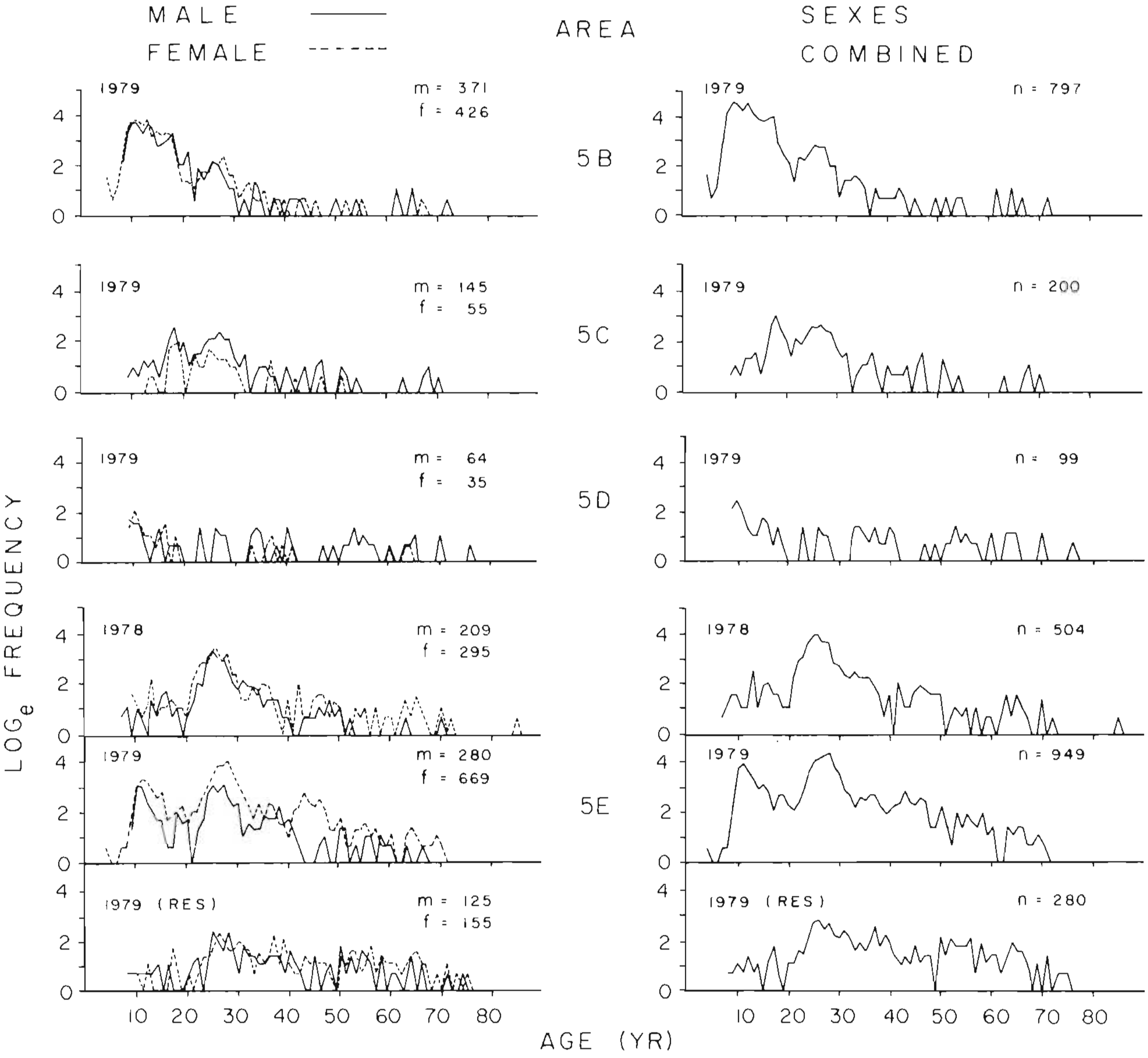

Fig. 4. Age compositions by year, sex, area and sample type for *Sebastes alutus*.

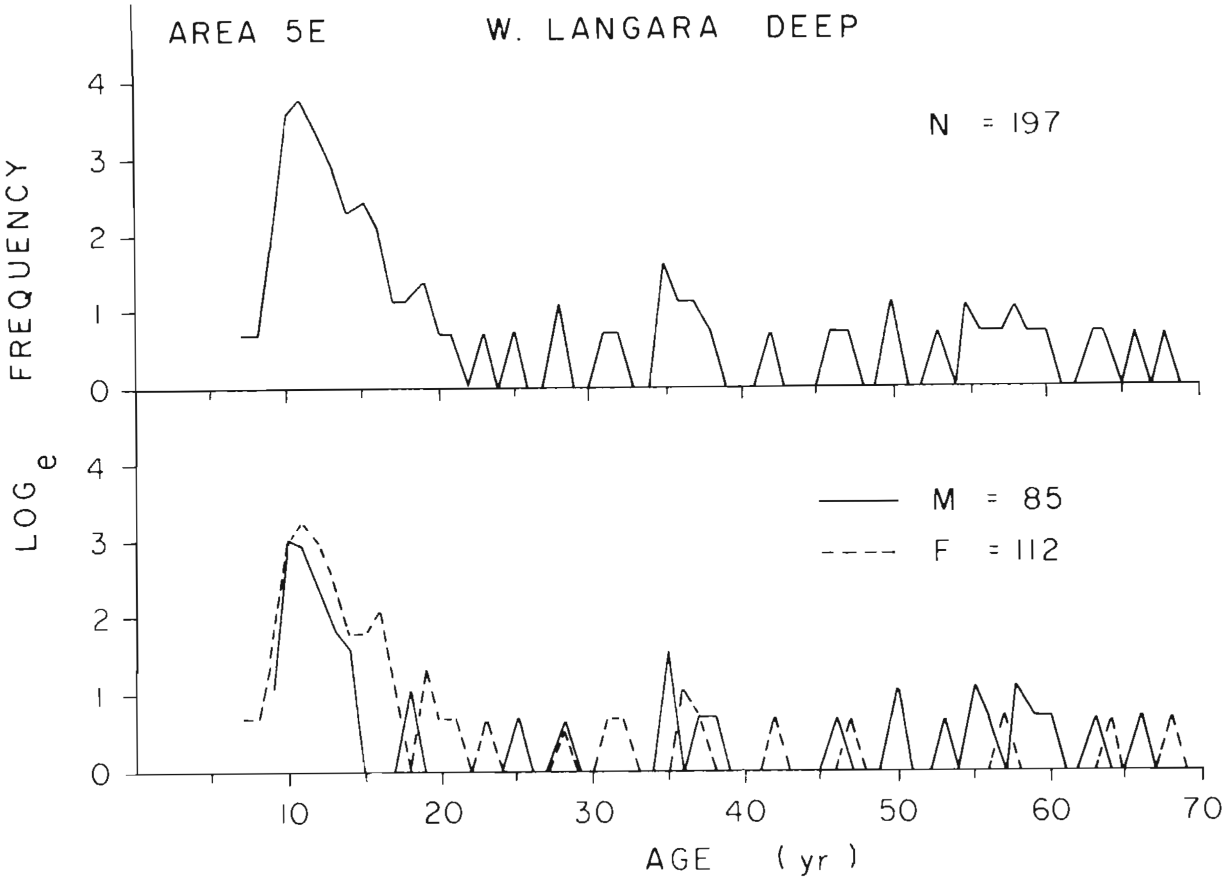

Fig. 5. Age composition of Sebastes alutus samples from 1979 research cruises in the Langara Spit area. Note the preponderance of fish <20 y.

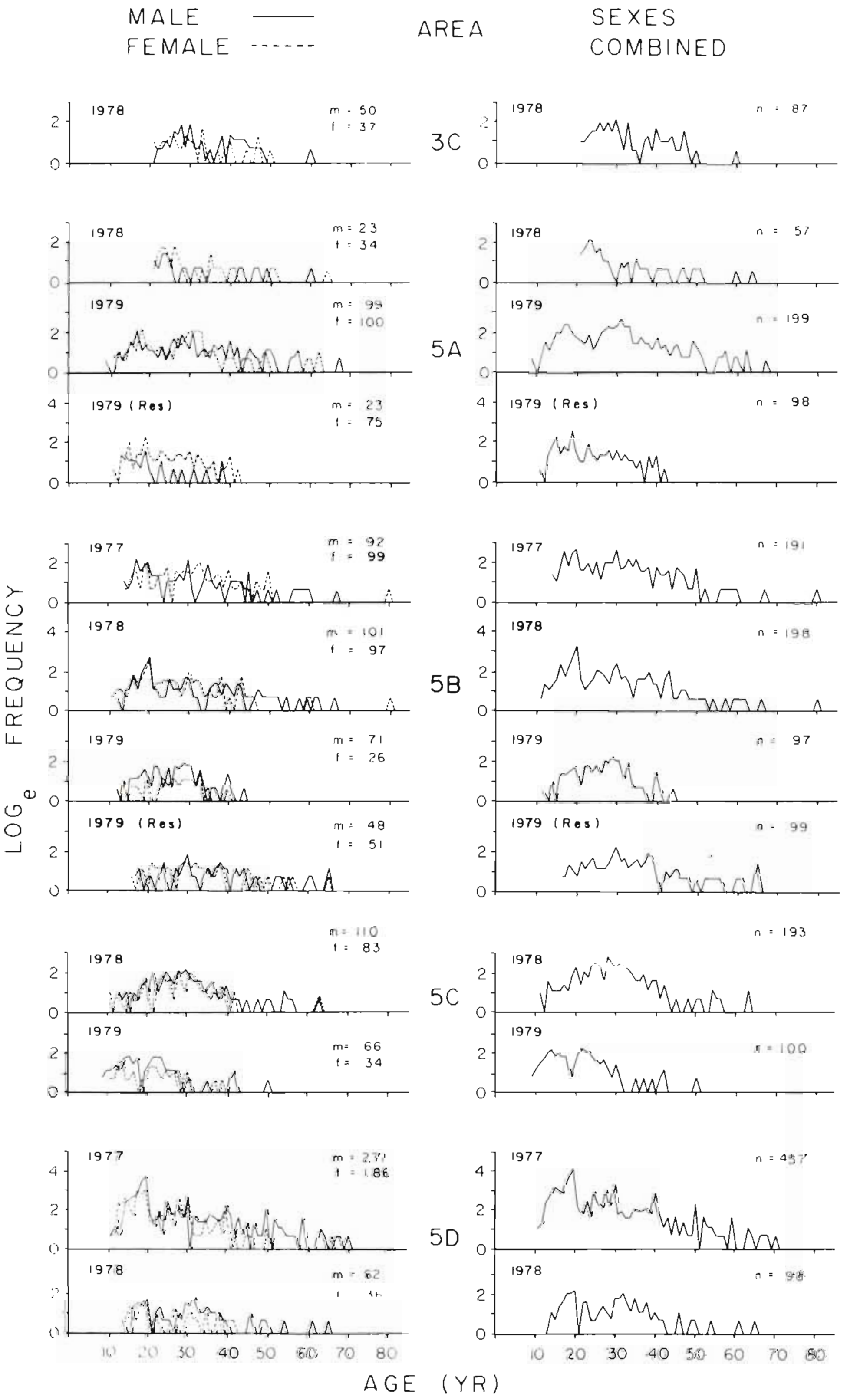

Fig. 6. Age compositions by year, sex, area and sample type for Sebastes brevispinis.

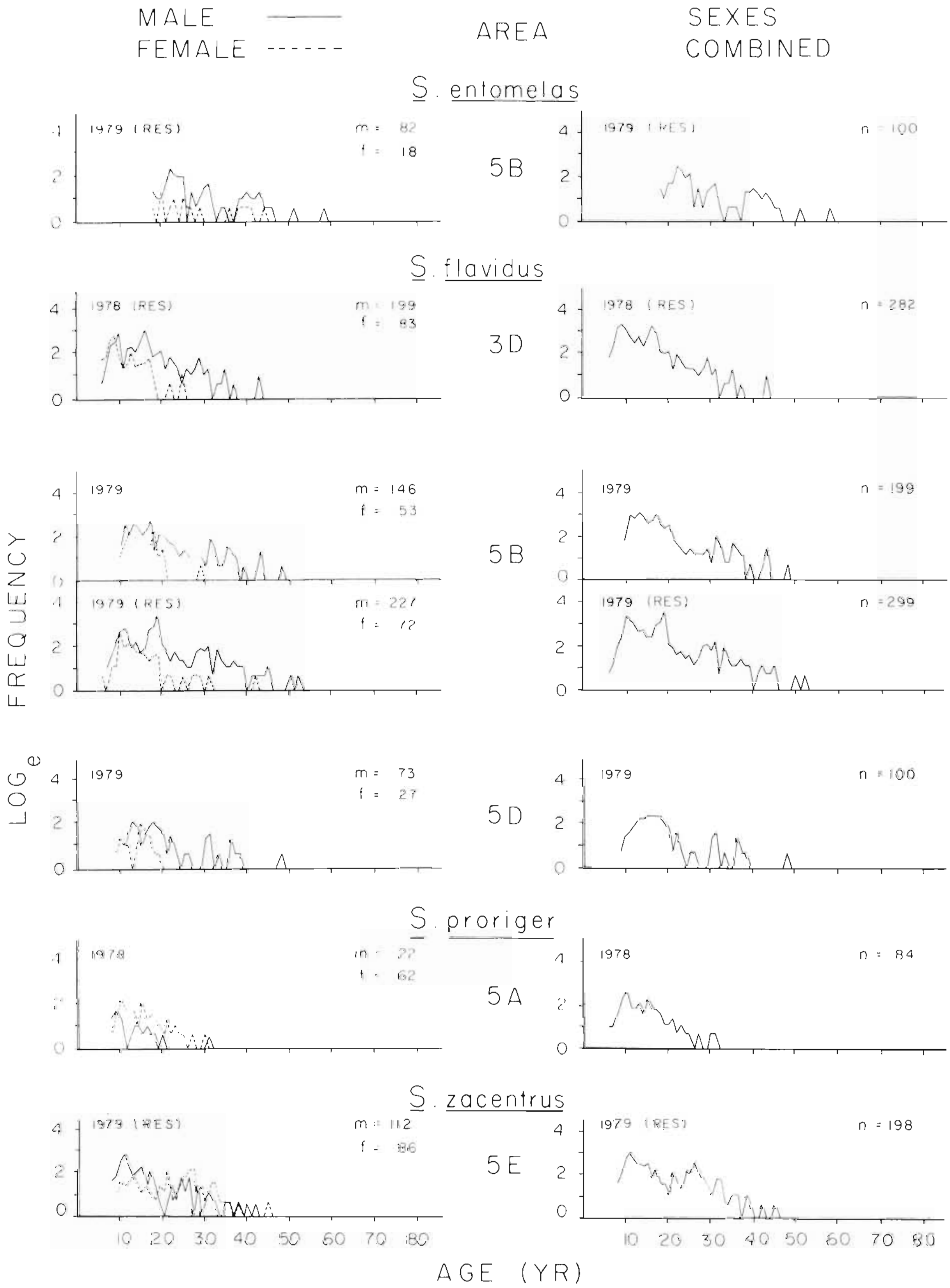

Fig. 7. Age compositions by year, sex, area and sample type for Sebastes entomelas, S. flavidus, S. proriger and S. zacentrus.

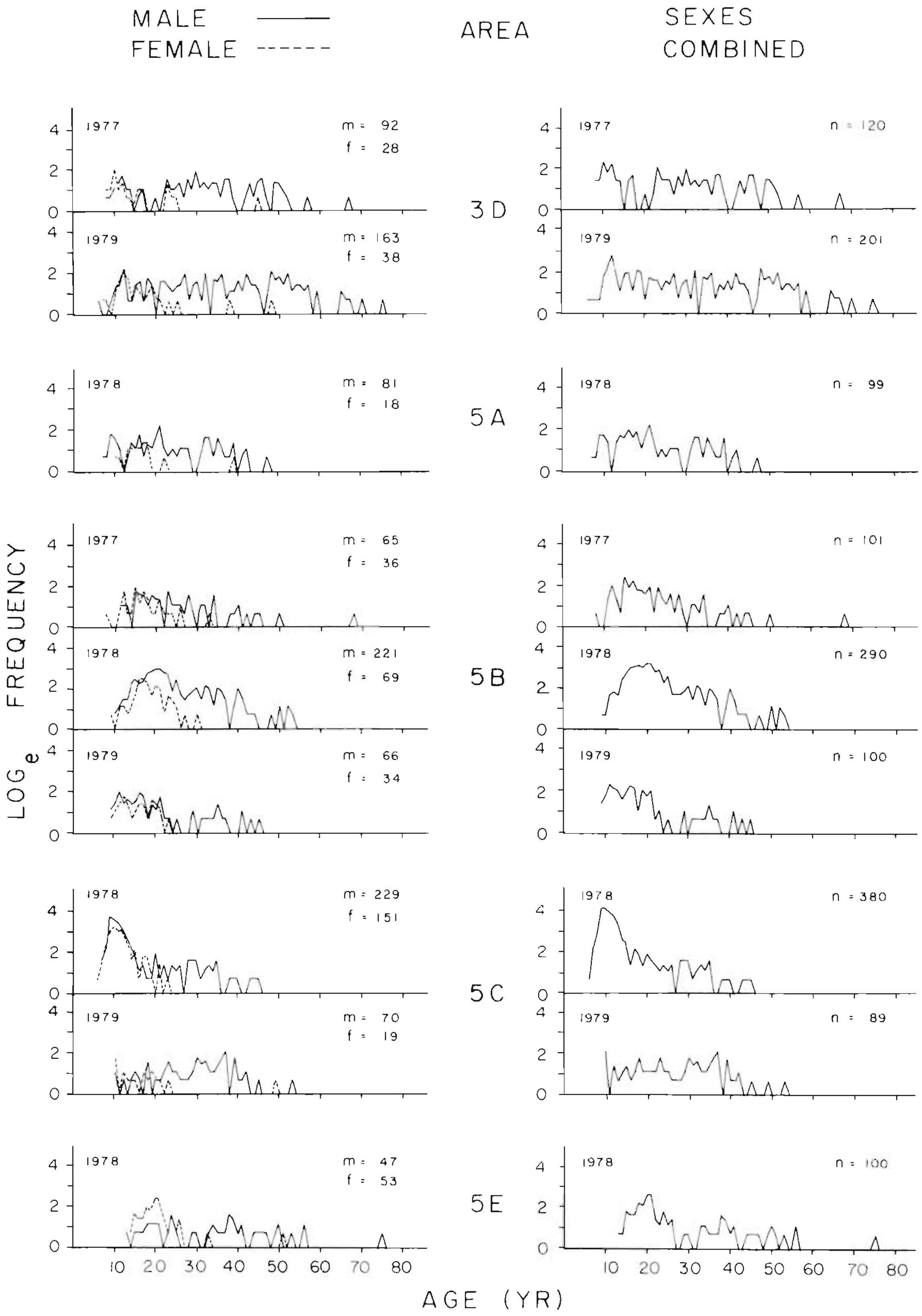

Fig. 8. Age compositions by year, sex, and area for Sebastes pinniger. All samples from commercial landings.

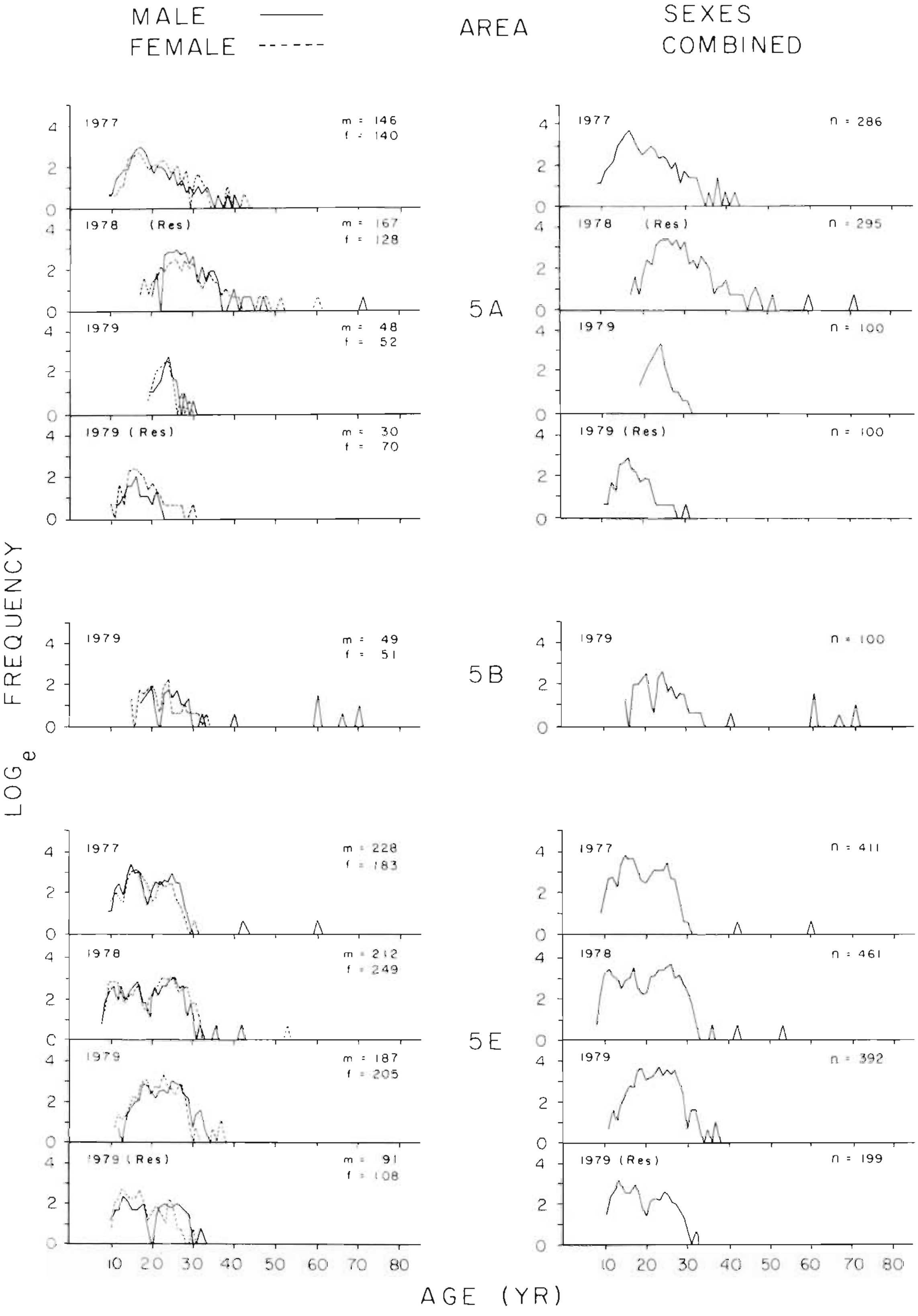

Fig. 9. Age compositions by year, sex, area and sample type for *Sebastes reedi*.

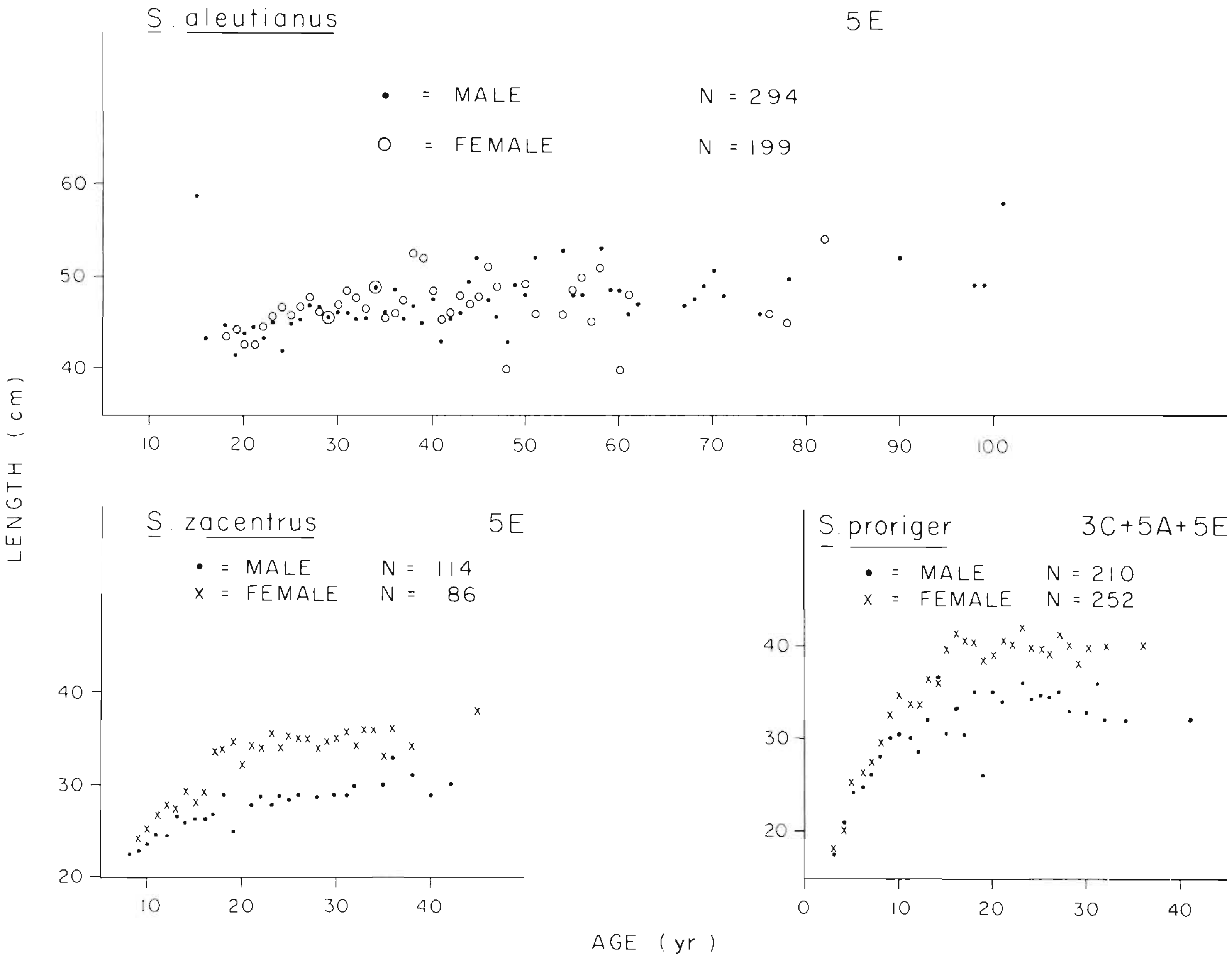

Fig. 10. Mean lengths at age for Sebastes aleutianus, S. zacentrus and S. proriger samples, 1977-79.

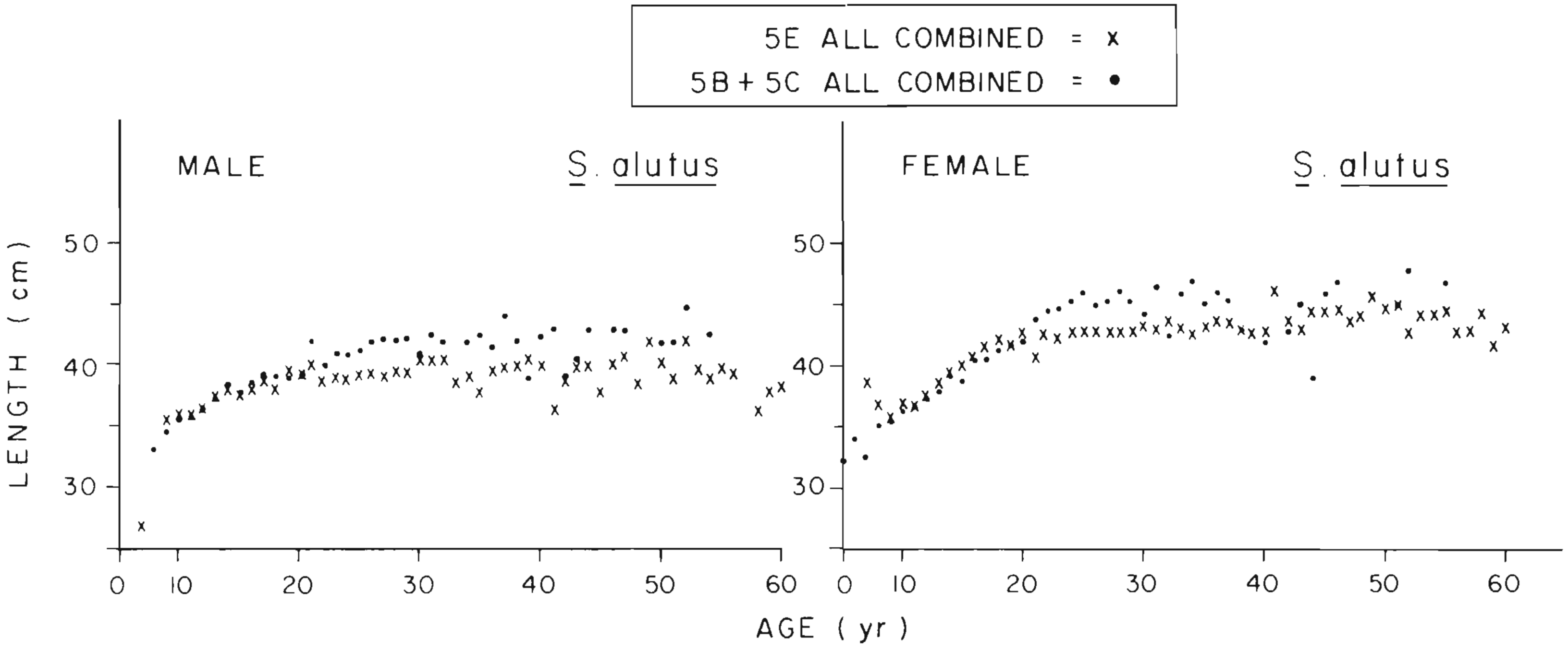

Fig. 11. Average lengths at age for Sebastes alutus from northern (x) and more southerly (.) areas, showing apparent latitudinal effects on growth.

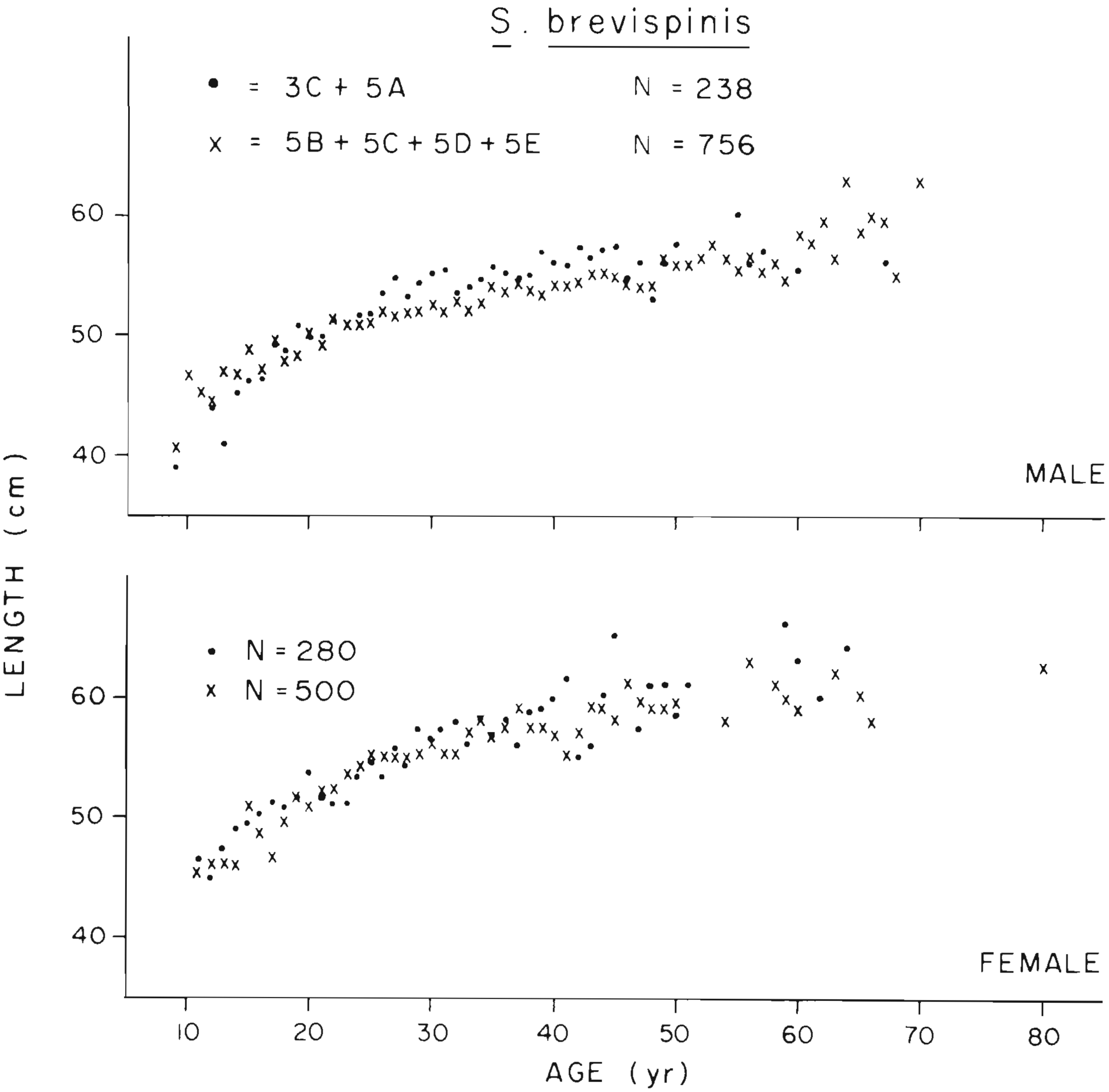

Fig. 12. Average lengths at age for Sebastes brevispinis, by broad geographic area. (. south, x north)

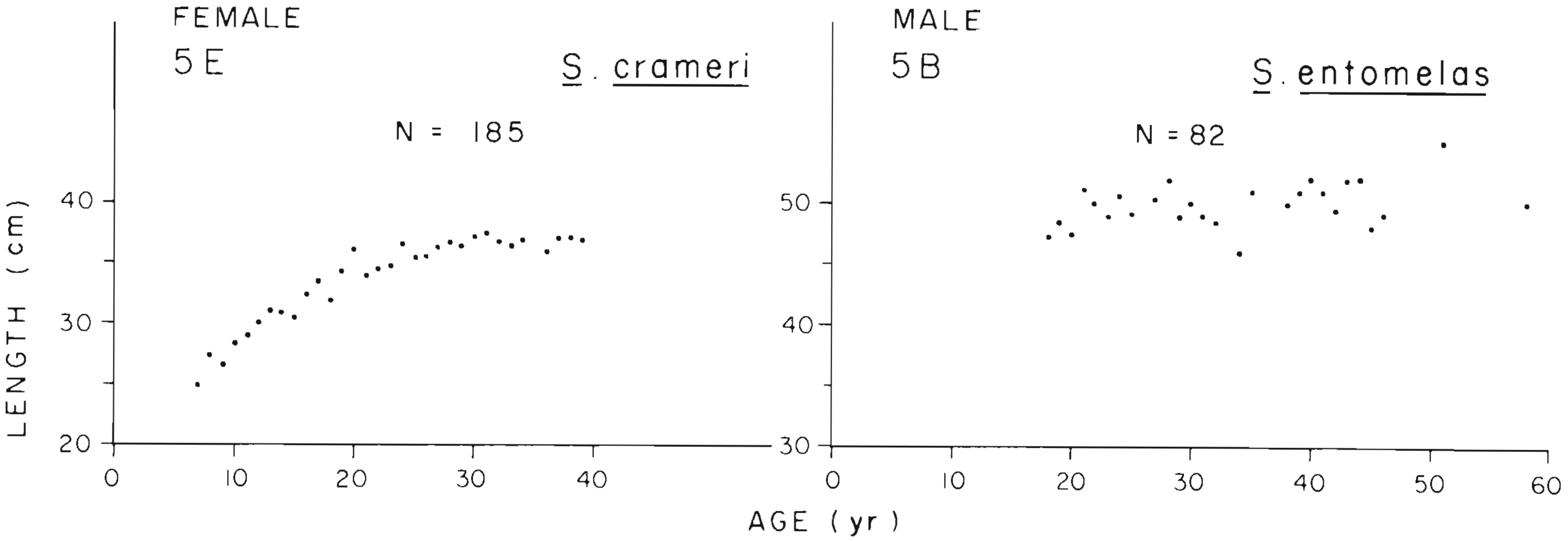

Fig. 13. Average lengths at age for Sebastes crameri and S. entomelas samples. Sample sizes too small for presentation by sex.

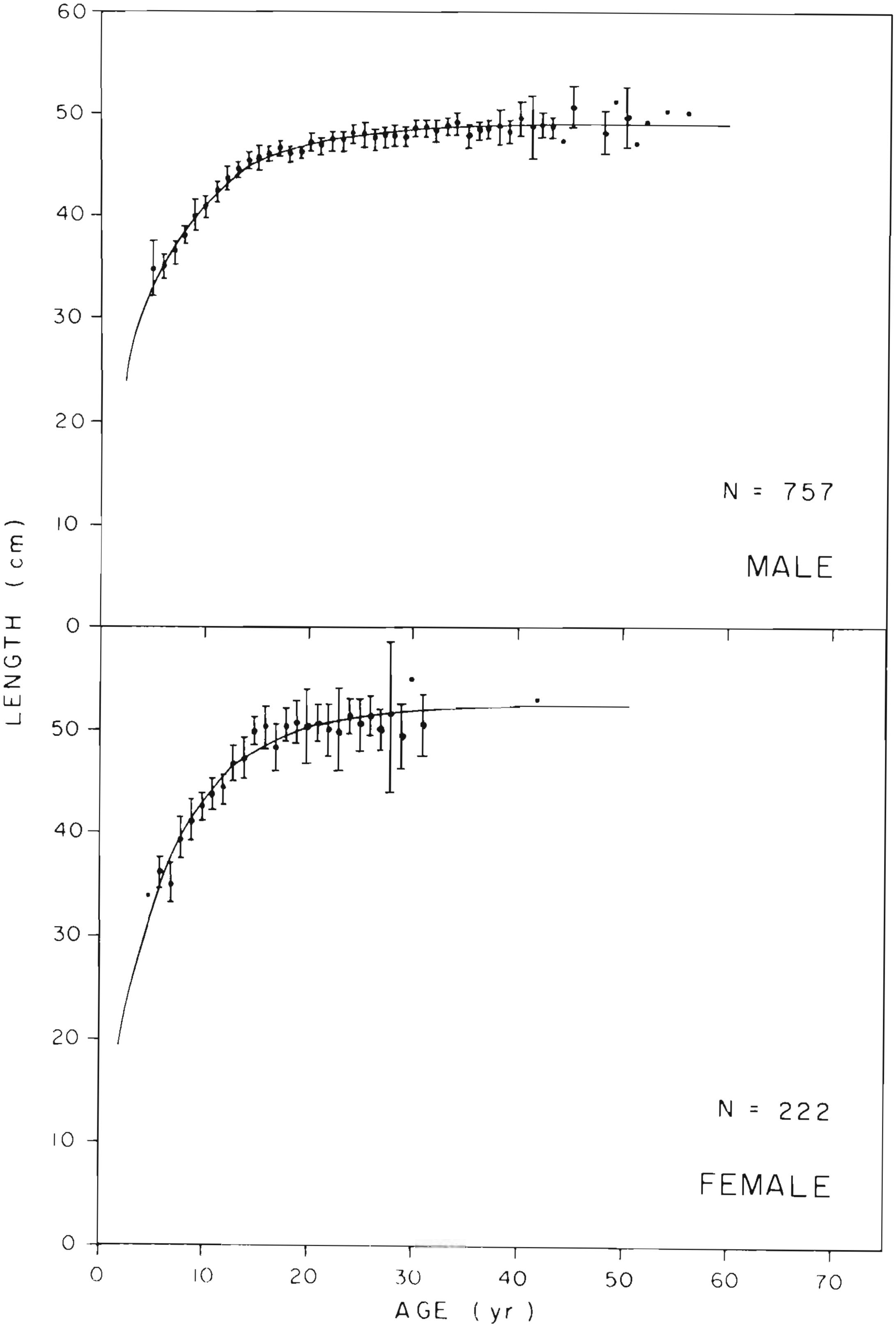

Fig. 14. Average lengths at age and 95% confidence limits for Sebastes flavidus, by sex. Data from areas 3B, 5A, 5B and 5D combined. Solid line represents best von Bertalanffy fit to the data.

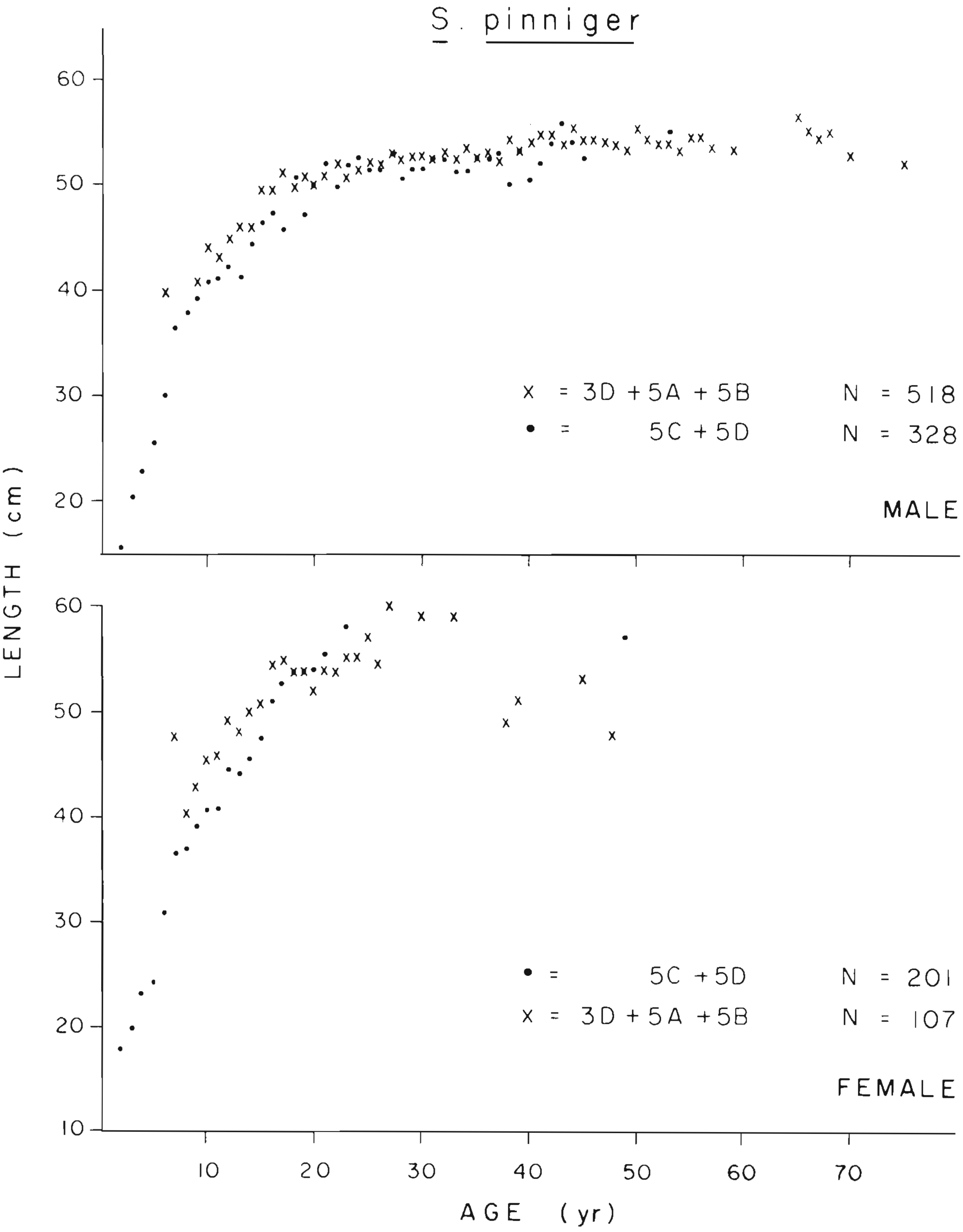

Fig. 15. Average lengths at age for Sebastes pinniger by broad geographic area (x south, . north).

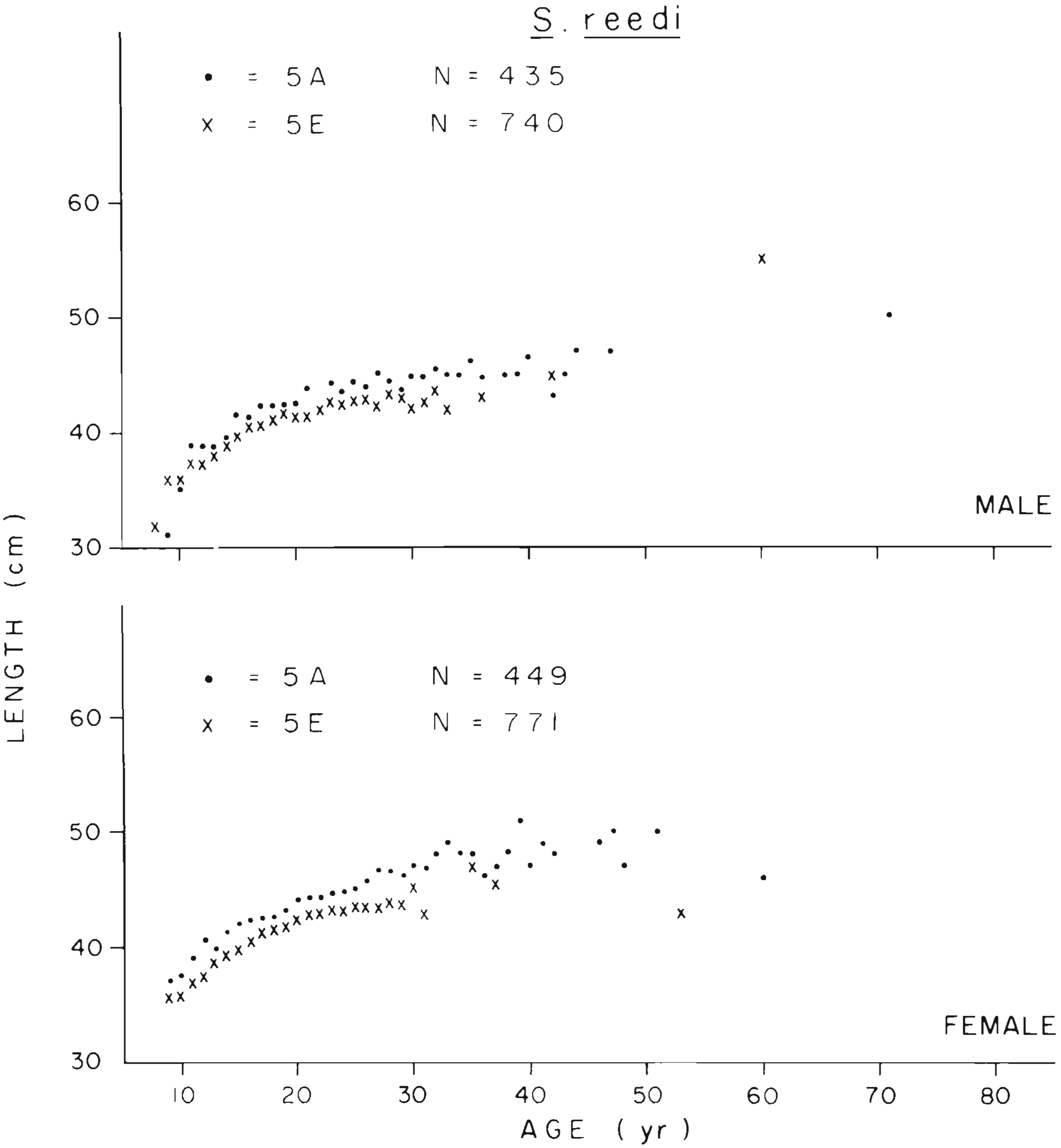

Fig. 16. Average lengths at age for Sebastes reedi from southern (.) and northern (x) areas, showing apparent latitudinal effects on growth.

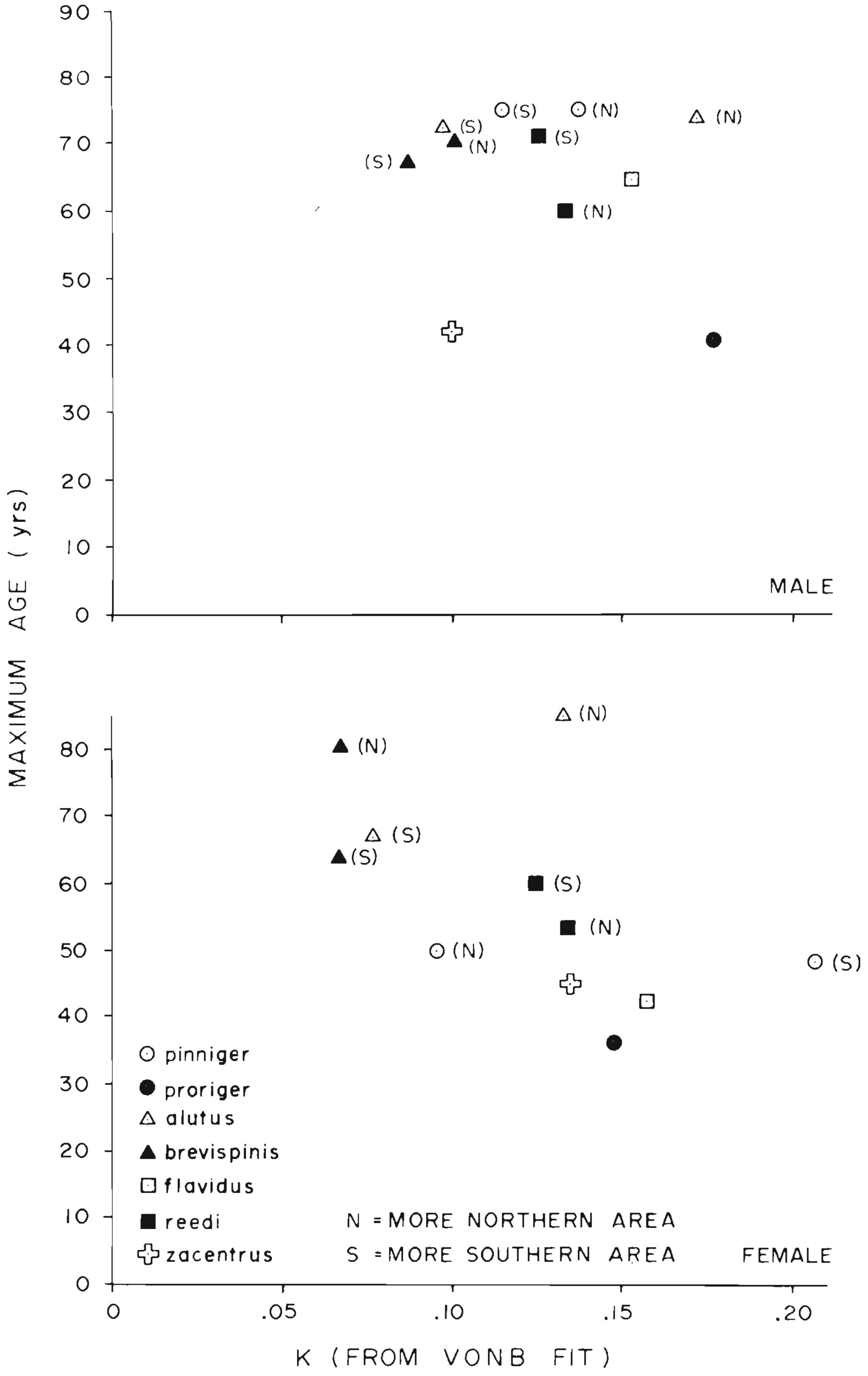

Fig. 17. Relationship between maximum age and rate of approach to asymptotic size (k), by broad geographic area, for the *Sebastes* spp. studied.

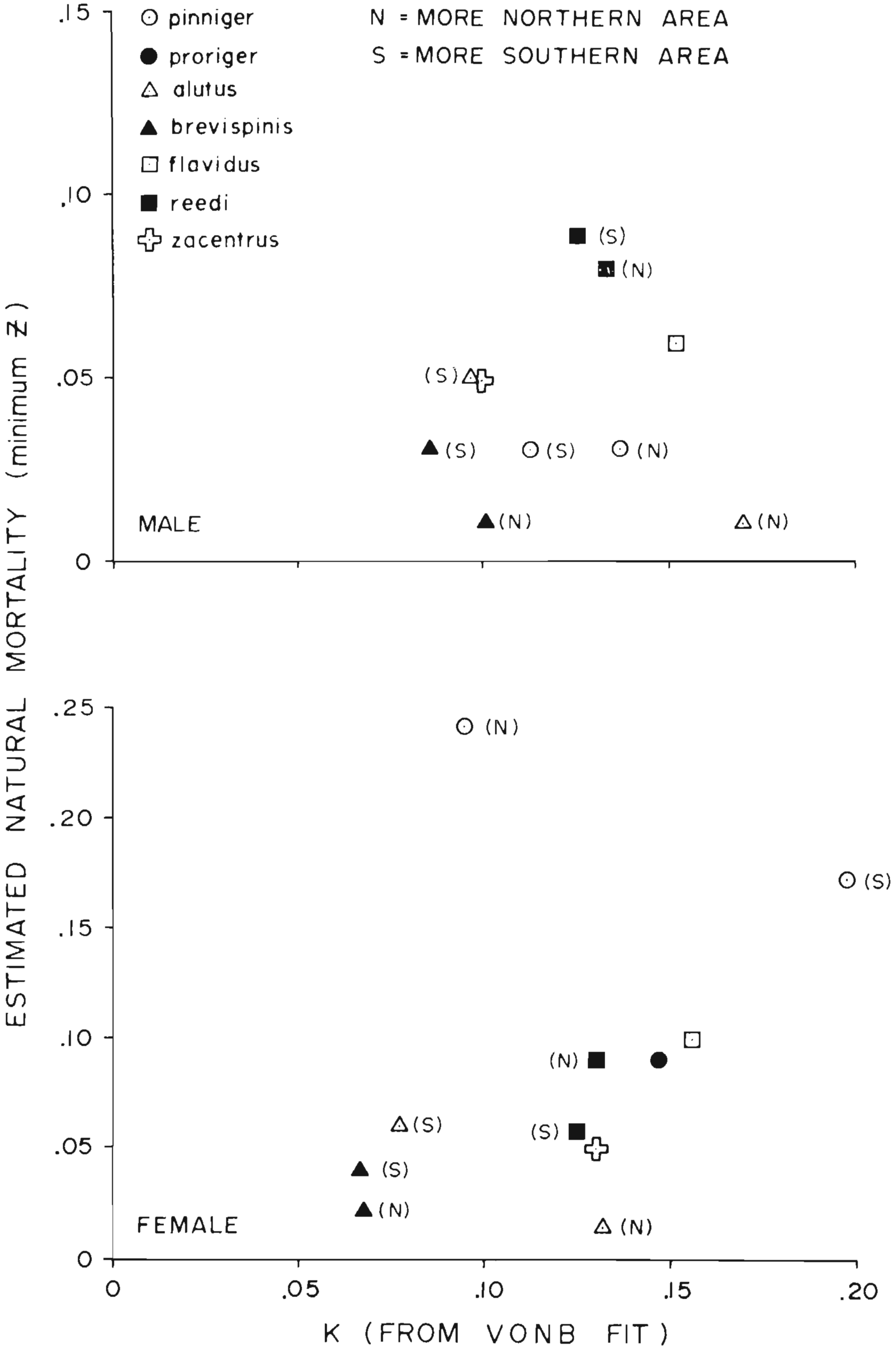

Fig. 18. Relationship between estimated natural mortality and rate of approach to asymptotic size (k), by broad geographic area, for the Sebastes spp. studied.

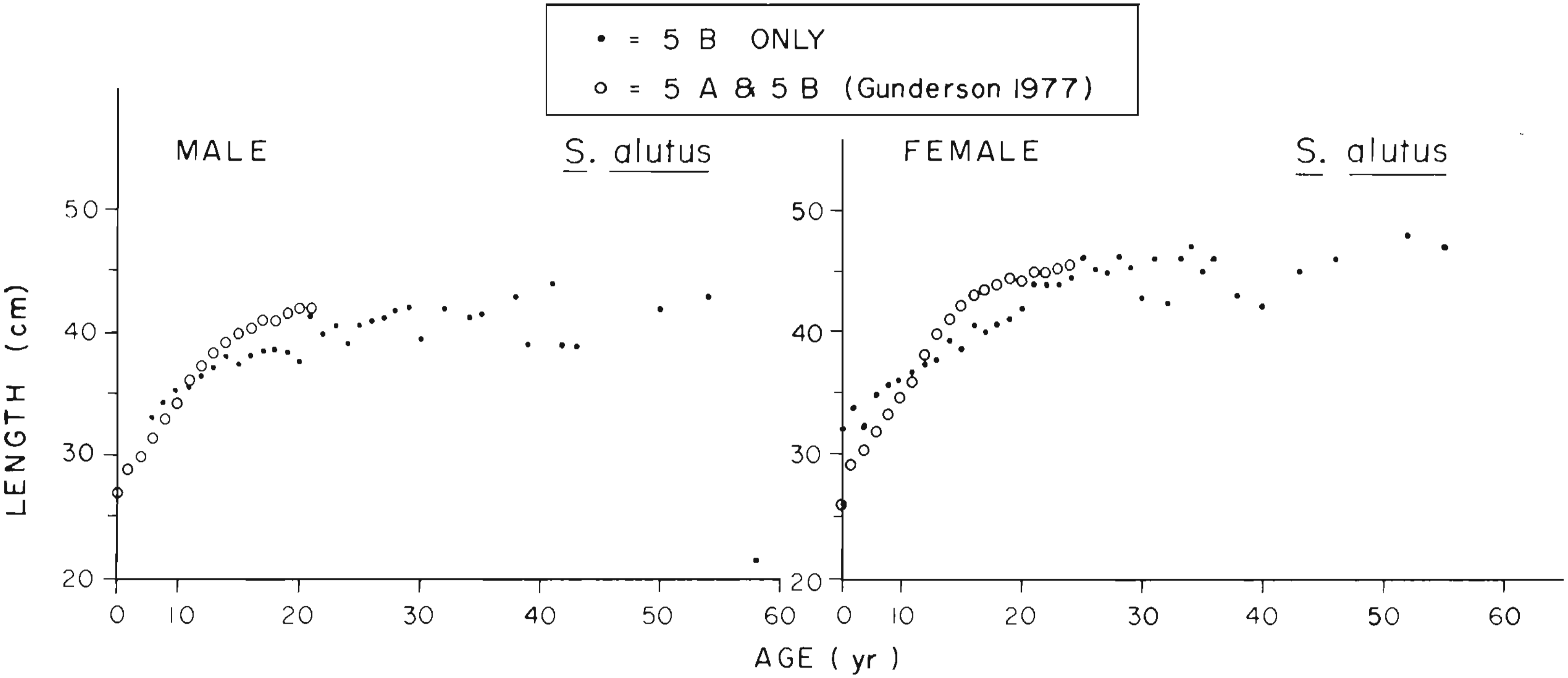

Fig. 19. Average lengths at age for Sebastes alutus estimated in this study (.) compared with those provided by Gunderson (1977) (o) for Queen Charlotte Sound.

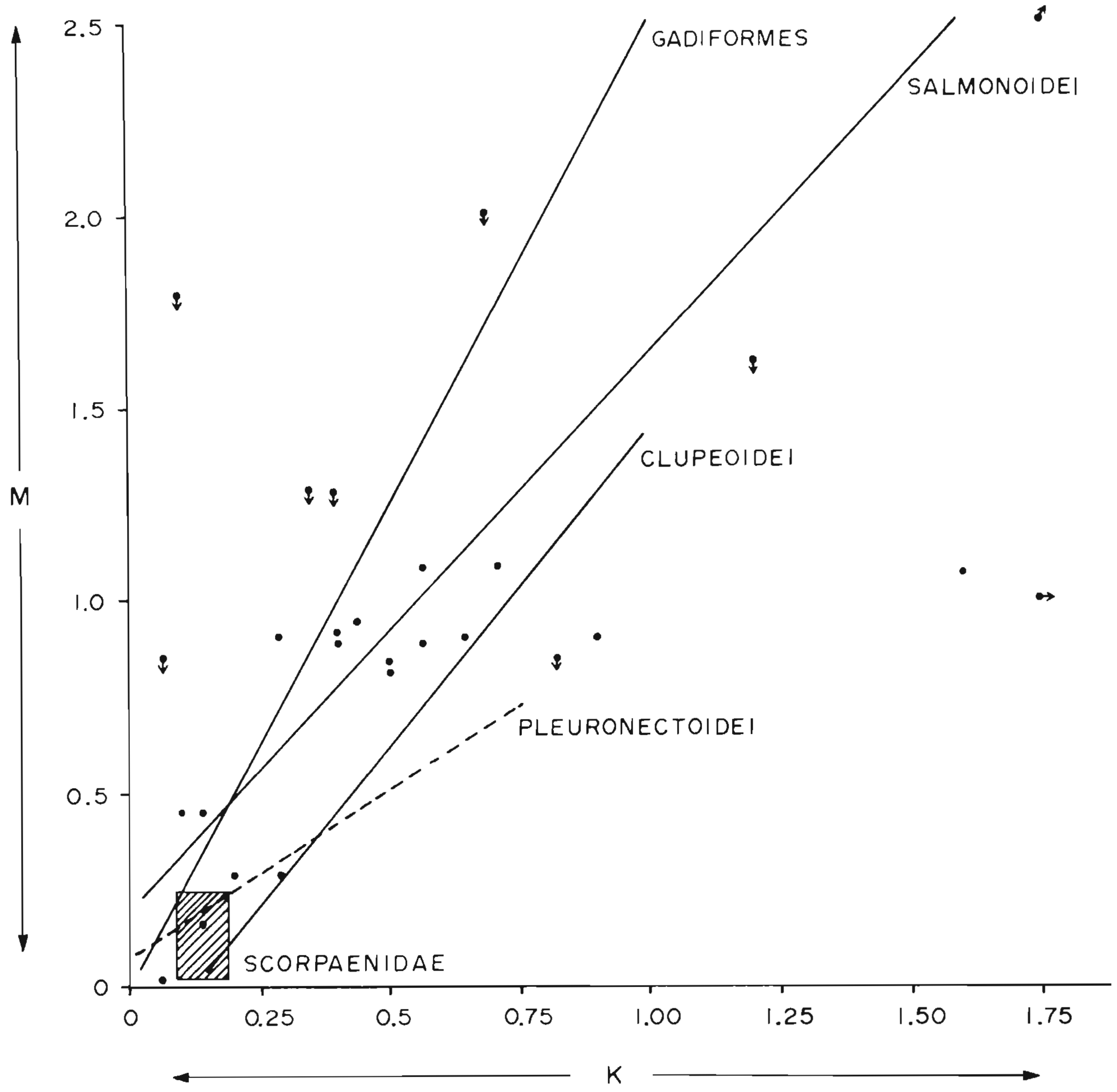

Fig. 20. Relation between instantaneous natural mortality rate (M) and rate of approach to asymptotic length (k) for some major groups of fishes (after Beverton and Holt 1960).