Northwest Atlantic Fisheries Organization

Serial No. N1698

NAFO SCR Doc. 89/96

(Revised)

SCIENTIFIC COUNCIL - 1989

WORKING GROUP ON SHRIMP AGEING - OCTOBER 1989

The Stock Size of Pandalus borealis in Ísafjaroardjúp, Estimated by VPA and Area Swept

by

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Abstract

The area is usually surveyed tvice annually with standard stations. An indication of the stock size is obtained by the area swept for every survey for the winters 1979/80 to 1988/89. In the same period all the samples obtained from the fishery and from the february survey are used to get basic figures for the virtual population analysis. The samples are compiled for every month in three groups , i.e. that of males, transitionals and primary females and females without spines in the months January to April. In the months October to December the shrimp is usually only divided into three categories, namely ovigerous females green heads and the rest. The method of MacDonald and Pitcher is applied to the half mm length frequency distribution of the afore mentioned categories for each month. Having estimated the proportions, the mean length at age, the total catch of the given month is then used to calculate the number of every year-class caught that month and subsequently the whole winter.

The size of *Pandalus* stock, either all the year-classes or a proportion of them is put in regressions with the corresponding estimates from the area swept method. There is a significant agreement between those two methods. Moreover the results for the biomass estimates of 1-3 year olds can be used to predict a value for the area swept index the following winter.

Introduction

Pandalus borealis has been investigated in Iceland since 1960 when Sigurdsson and Hallgrimsson (1965) introduced catch and effort reports to be filled in by the fishermen. Collection of samples was started in 1961 in Ísafjardardjúp and Arnarjördur. Very soon they started to estimate age by using the Petersen method. They also carried out accurate determination of the several sexual stages as done by Berkley (1930) and Rasmussen (1953). They estimated that *P.borealis* spawns as female mostly at the age of 3 years but some might spawn at the age of 2 and a few at the age of 4 for the first time. The means of assessing the variation in size of stock was meagre, only catch-rate in the first years. In 1973 were started the biannual surveys of the fjords. The number of stations was smaller in the first years but have in later years
increased. The increase has been mainly to make the stations more dense but the total area investigated has not changed much.

The present paper deals with a comparison of methods where the modal analysis of monthly LFDs of Ísafjardardjúp using the method of MacDonald and Pitcher has been carried out as a basis for the VPA which results are then compared to estimates of the surveys, using area Swept.

Material and Methods

Age estimation

The age estimation is carried out on commercial (unsorted) samples in the months October-January and March. The February samples come almost all from the late winter survey. The shrimp is measured fresh to the nearest 0.5 mm in the years from 1983 onwards. Before that all shrimps were measured to the nearest 1 mm CL. Sometimes November and December samples were combined as there were few samples taken in the latter, because of the Christmas holiday (3 weeks). All the samples within a month are compiled straight, whereupon an overall promille length frequency distribution LFD is calculated. The various classes like males, primaparous females and mature females (usually females without sternal spines) have LFDs which when summed, all add up to to the aforementioned overall promille LFD. The respective LFDs are run through the modal analysis of MacDonald and Pitcher. When possible, males and primaparous females were run through combined. Very rarely the males and primaparous females had to be separated. The classification of shrimp having sternal spines or not (MaCrary, 1971) was only used from 1985 onwards. In the year 1986 this method was used throughout the whole year. In order to see what difference there was between the old classification and the new, it was calculated from the afore mentioned samples that in the old, the specimens with no eggs corresponded very closely to the group of specimens with sternal spines, i.e. only 0.8% was misclassified in the months January-March in 1986. In the period October -December the misclassification was down to 0.5%. About half of the misclassified ones were parasitised small females without sternal spines , the rest was normal females without sternal spines with no eggs. So in the first 7 winters the classification of ovigerous (spawning is in September) and nonovigerous individuals was used. After the sternal spine classification was introduced that method was allways used in the months January to April, but the old simple method is often used in October- December. The term with and without sternal spines as used for the sake of simplicity in the tables and text hereafter are therefore approximations at times.

The number of components (age-groups) was decided both from the modes in the LFD and by the deviation method (Sund 1930, Skúladóttir 1981). Whenever possible the program was allowed to run without a constraint on the standard deviation (SD) and a starting value of length L at age which was estimated visually from the LFD and the deviation method. Quite often the modal analysis would be difficult with no constraint on the SD especially in the case of very small year-classes which usually have a smaller SD. In the cases where the program would not run freely the average SD at age calculated in the period 1978-1985 was used and thus fixed to get L´s and proportions of the age-groups in the LFD of males and primaparous females combined.

The estimation of the various parameters for the females without sternal spines was more difficult as the program would never run without a constraint. As deduced from the deviation method in the period 1984-1986 there seemed to be both four and five year olds present (fig.3). It was therefore decided allways to attempt to evaluate as many as 3 components at first with the constraint that all SD´s should be equal. If 3 components could not be fitted then usually two components could be fitted with this method.

<u>The virtual population analysis (VPA)</u>

After having calculated the L at age and respective proportions an extensive weight analysis of fresh shrimp was carried out associated with the measurements of the shrimp samples. The weighing was carried out in the two groups Pandalus with spines and Pandalus without spines. All the specimens of every 0.5 mm length group were weighed together and the number stated. Only unbroken specimens were used. This was carried out on all samples from November1987 to April 1988 in Ísafjarðardjúp. The regression was carried out on the average weight at length-class in all months where there were 5 specimens or more. In this manner there were often 6 weight values for each length-class. At first it was thought possible that the length weight relationship should change during the winter due to gradual loss of eggs. As there did not seem to be any significant change in the weight of the females without sternal spines as winter proceeded it was decided to use the same relationship for the months October -April for the females without sternal spines. The following are the two weight-length relationships used:

With sternal spines No. measured 10083	$W = 0.000887 \cdot L^{2.95911}$
Without sternal spines No. measured 3343	$W = 0.0009335 \cdot L^{2.87476}$

After calculating the weight at age (expressed in g) from L at age from table 3, using the appropriate formula shown above, the number of every age-class was first calculated from the proportions in table 4 as number per 100000. The 3 yr olds were then combined. After taking the same proportions out of the month´s catch a total number of individuals by age per month was calculated and then the whole winter was summed and presented in table 6. Now the overall weight at age had to be calculated again as the weihgted mean for the whole winter. These are presented in table 5. Other inputs are needed for the VPA, namely natural mortality which was chosen to be 0.5, the same all through. The maturity at age was estimated from the proportion in each age-class by months that had changed sex to a mature female, i. e. without sternal spines when that classification was used, in other cases ovigerous females. The figures in table 7 are weighted averages of these by the monthly catch.

The VPA was carried out using a program package from Lowestoft adapted and modified for use at the Marine Research Institute in Reykjavík. The package consists of various tuning models, separable VPA and a tradiditional VPA. The procedure we used is the one reccommended by ACFM of ICES. The estimation consists of three steps. The first one is the tuning, where effort data from the commerciel fleet and/or CPUE data from research surveys are used to estimate a terminal fishing mortality (F). In this step it is possible to choose among various tuning methods. Pope and Sheppherd (1985) test these methods and give detailed descriptions of those. In this paper the tuning was carried out using the effort from the shrimpers (table 8). The second step is the separable VPA. This step should be omitted if the conditions for separability are not fulfilled if e.g. selectivity has been changing. The last step is in any case the traditional VPA.

Area swept (SA)

The fjord Ísafjardardjúp is sureyed tvice annually. In the surveys standard trawlstations are taken in every survey. The fjord is divided into 14 strata of various sizes. The trawl stations have been chosen according to the experience of the shrimp fishermen. An effort has been made to cover all possible shrimp banks, even strata 12 and 13 where shrimp is quite often absent. Every haul is towed with the speed of 2 knots, lasting for one hour. The trawl used is of the design a conventional four panel wing trawl with the circumference of 1010 meshes (measured according to the working rules of ICES). The mesh size is 36 mm open mesh diamond shape the same as that of the fishing fleet except for the 1988/1989 season where a square mesh (same mesh size) in the codend was made compulsary in the fishery. The distance between the wings was 14.9 m. Thus the coverage of an hour´s haul was:

$$0.0149 * 2 * 1.852 = 0.0551896 \text{ km}^2$$

1.852 being the conversion factor for changing nautical miles into km. For calculating the index for the Pandalus population size in Ísafjardardjúp termed SA index, the catch per hour trawling is first calculated per haul, then an arithmetic mean kg/hr, or CPUE is calculated for the whole stratum where 0.0551896 km^2 is covered in the average haul, hence

$$\text{SA index} = \sum_{1}^{14} \text{CPUE} * \text{Area of Stratum} / 0.0551896$$

Thus all the indices of the 14 strata are summed to form an overall SA index for every survey.

Results and Discussion

The modal analysis was usually running quite easily on the LFD with sternal spines, termed PS+. On the whole there were small variations in length at age L . The age-groups 0-3 were allways growing throughout the winter. There is more variation in the proportions increasing slightly throughout the winter for the younger age-group as the selection of these is increased with growth. There should be no growth of females without sternal spines as these are practically all ovigerous. But there is a steady decrease in the proportions of the 4 and 5 year olds. There were certain inconsistencies in the results when looking at the L at age (table 3). Instead of growing steadily the L swings between months, especially in the age-classes older than 2 years. Worst of all are the 5 year olds. Presumably sampling error would affect those most as there are usually very few individuals in that age-class left (table 4). In the first 5 winters it was impossible to detect 5 year old shrimp at all. There had to be values for catch numbers so the small value of 1 was used. After this 5 year olds could usually be detected in October-December. It is possible that the "old shrimp" know some refugia, but sometimes there has been a sudden rise in the L of the 4-group (table 3) in the months March to April suggesting an influx of a few 5 year olds into the fishing area. In April 1981 there was a sudden rise of more than one mm in the L of 4 year olds. The same was true for the March-values of 1987 and April 1988.

P. borealis changes sex in Ísafjardardjúp at different sizes and ages throughout the 13 year period studied here. The period can be divided into three phases. In the first seven winters about half of the females spawn at the age of 3 and the rest spawns at the age of 4 for the first time (table 7). Then comes the second phase of three winters where all shrimp spawn for the first time at the age 4. In the third phase all females spawn for the first time when 3 years. It can be debated whether the estimation of age is correct. Indeed there were difficulties at times as mentioned earlier when the modal analysis could not run without a constraint. The method of MacDonald and Pitcher appears to be very sensitive to the size of SD of an age-group resulting in great changes of the proportions when the SD changes slightly. According to McNew and Summerfelt(1978), who studied the accuracy of the maximum-likelihood estimation method of Hasselblad (1966) on fish which could be aged from scales, the same applied there concerning the sensitivity to the SD. The great variation in SD was accompanied by a great variation in proportions of the age-groups. In our study of *Pandalus* in fact a small increase in the SD could sometimes double the proportion of a given age-group. Therefore it was considered more fortunate to keep the SD´s within a historic level. It was decided to use the average SD of the period 1978-1985 as a fixed value whenever there were difficulties in using the modal analysis in the length frequency distribution on shrimp with sternal spines.

In the years 1986-1989 the SD's were generally larger associated with faster growth and it would probably be more correct to use the average of 1986-89 for the SD's during that period, but as soon as there are some 3 year olds present the 78-85 mean SD will be needed. It was often neccessary to look at ajoining months and/or previous year's proportions when it came to decide whether the components detected as youngest among the females without sternal spines(FS-) were of age 3 or 4 e.g. in the years 1976-1985. The L's are usually considerably higher as 2 or 3 year olds when without spines than the same ages with spines. If we look at the winter 1980/81 the difference in the 3-group is about 2 mm in October and November. At first glance the proportions about 20 % (an average for the whole winter) is not so bad for 3 year olds in PS+ nor 18 % approximately for 3 year old in FS-. But if one looks at the proportion of 2-group/1-group in the previous winter where there is a strong 2-group one wonders how fast it diminished. However giving that could be true then the proportions of the 3-group FS- in season 80/81 should be called 4-group instead and woud be what is left of the 3-group of PS+ in 79/80 where the proportions are about 14 %. Now these will then have increased to the afore mentioned 18 % as 4 year olds and that we find unlikely given the assumption that the population is well defined and well sampled. In the years 1976-1980 there are the same difficulties and one could be temted to decide that all 3 year olds without sternal spines are indeed 4 year olds but again the proportions would then be all wrong. In later years when the McCrarie's method is used for the detection of sternal spines, the evaluation of the group that will spawn the following winter is of great importance in the estimation of age at sexchange and possible proportions of each age-class changing sex. Thus it was e.g. neccessary to run the primaparous females through modal analysis separately, during the winter 1985/86. Not only were there two distinct peaks in the LFD of primaparous females but there was also fusion of the 82- and 83- year-classes. In the months February-April 1986 the mean length at age for the primaparous females was first calculated with no constraint, then the calculated L's for 2 an d 3 year olds were supposed to be true for the males as well and subsequently fixed for use in the Male LFD. In the growth curves shown in fig. 4 for year-classes '82 and '83, ages 3 and 2 respectively are therefore expected to be slightly overestimated. In this case the use of a growth curve would probably be justified. The change of age at sex change (table 7) from age 4 to age 3 in winter 1986/87 was also verified by this bimodality of primaparous females in early 1986. The bimodality of primaparous females was absent in early 1985 ,1987,1988 but in 1989 there is some bimodality again in the primaparous females suggesting some spawning of 2 year olds in the winter 1989/90.

Looking at the various ages at which northern shrimp spawns for the first time as a female one would expect to find a difference in growth rate related to the afore mentioned changes in age at spawning. An early maturity would involve a faster growth. This can be seen in the year-classes 1983, 1984, 1985 and 1986 as compared to all earlier year-classes, namely 1977-1982 (fig. 4). On the other hand there does not seem to be a slower growth of the year-classes of the 1979,1980 and 1981, which are all 4 years old when spawning as females for the first time (in the winters 83/84, 84/85 and 85/86 respectively),than of the year-classes of 1977 and 1978. The change of age at maturity could be related to the catastroph of the year 1984 when the stock was reduced to about half of what it had been as well as the spawning stock biomass (Spbio table 13) which was reduced to 825 tons in winter 85/86 and then 672 tons in 86/87. At present there is not enough known about the variation in temperature of this 13 year period to exclude the effect of temperature. In the years 1969-1983 (most of the data are from the period 1970-1973) the mean bottom temperature of 3 stations of the depths about 70, 110 and 125 m respectively gave an approximate value of 4.4°C for the whole year. These depths are considered to be normal depths for *P.borealis* in Ísafjardardjúp.

Tables 9 to 13 show the results of the VPA. The application of VPA using the Laurec Shepherd starts by the tuning of the data with the total effort (table 8) so as to get plausible F's. In table 10 are the results of the separable analysis using the mean value of 1.17 of ages 2-4 in 1989 from table 9 for terminal F for age 3. The selection is put at 1 for age 3. The matrix of residuals shows reasonably good results the overall being only -3.071(table 10).

The tuning of the VPA shows some unrealistically high F's on ages 4 and 5 in the first few winters (table 9). The reason why is that the age proportions for 5 year olds in those winters are most probably wrong. A second VPA was run using only data from the period 81/82-88/89. The F values in these two runs for the various age-groups were very similar to those shown in table 9 up to age 4. The greatest differences were found in age-groups 4 and 5. Consequently they were the main reason for different F's for 2-4 year olds and those estimated by the second run of 81/82-88/89. This can be explained by noisy data for the oldest age-groups, a common problem in VP analysis. Age groups 0-3 are the main proportion of the catch each year (table 6). Since the tuning gives such similar F's in both VPA runs described in the former paragraph, the stock estimates will also be similar. The greatest difference in stock biomass is found in the season 82/83, 2.4 % and the lowest in 88/89, 0.4%. The difference in spawning stock biomass is greatest in 88/89, 12.4 %. The winters of 82/83 and 83/84 show a difference of 6.9 % and 7.5 % respectively. Other winters ly between 2.1-5.1 %. Bear in mind that these estimates are based on the noisiest age material.

Turning to the results of area swept. In table 13 the strata are listed and the respective areas in km^2. On the whole there is some variation between survey indices. Most prominent are the values of the first two wintes when the SA index falls to half in the late winter survey. This is probably bad sampling. In 84/85 there is also great reduction during the winter which is considered to be due to the great squid and cod concentrations. Strata 10 and 12 have fewest stations per km^2 and are therefore most subject to error. The shrimp is usually absent from stratum 12 in the autumn survey. September 1980 is an exception from this and note the very high estimate of 3013 (tables 14 and 15) as compared to the late winter survey of 1499 (1981). Both are probably bad estimates. But in the late winter surveys there was allways shrimp in stratum 12 in the first 5 winters. After 1984 there was first no shrimp but in 1987, 88 and 1989 the shrimp is spreading to this area again to some degree early in the year, but much less than in the first winters.

The correlation of the VPA analysis and SA indices are shown in tables 15 and 16, figures 5 and 6. It seems that the autumn survey indices and VPA biomass estimates give the best fits. This is not surprising, since the autumn indices are based on surveys made before the fishery starts and represents a stock estimate which coincides with the stock as estimated by the VPA, namely at the beginning of winter. Moreover as mentioned before, when shrimp is confined to the areas where stations are more dense the estimate of the stock index would be expected to be more accurate.

The value of 88/89 in fig. 5 is unusually high and is due to the exceptionally big 1987- yearclass. The biomass value of 1-3 year olds is in better agreement and can be used to forecast the survey values for the following winter. There is of course one snag here concerning the values for the winter 88/89 in the uptake of the afore mentioned square mesh which allows the escape of more than half of the one year-olds. In fig. 6 the forecast for SA index of designated 90 is about 1700 for the winter 89/90 if the gear is unchanged. From the experiments with square mesh versus diamond mesh it appeared that less than half of the one year olds was retained in the gear in the winter 88/89 and therefore the biomass should be increased to about 10 thous. tons see 90? in fig. 6.

The population of *P. borealis* has been rather variable in the thirteen year period. In the early eighties the population was at its peak. Recruitment was very good in the late seventies and early eighties. Total allowable catch was very high, usually higher than proposed by the Marine Research Institute. During the year 1984 and early 1985 there was a tremendous increase in the number of predators especially squid which is not usually in the area. Fishable cod was also very numerous in 1984. Moreover the 1984 year-class of cod which was very big in Ísafjarðardjúp stayed in the area all the year of 1985. The 1984 year-class of Pandalus which had been a prominent one (see deviation marked 1 in Sep. Nov. and Feb in the winter 1985/86 in fig. 3) and all other year-classes were greatly affected.

Conclusion

About half of the age-group 3 spawns as females for the first time during the first 7 winters. The rest spawns at the age of 4. In the period 83/84-85/86 all females spawn later or all at the age of 4 for the first time. In the last period 86/87-88/89 the age at first spawning as females was found to be at the age 3 for all of them. As yet differences in sea temperatures have not been studied close enough. It is possible that there are some differences in the temperature from both land and the Irminger current which allways flows into Ísafjardardjúp, that could explain the change of age at maturity. At present we find it more likely that the scarcity of 4 and 5 year old animals, i.e. mature females cause this response within the population, accompanied by the increase in food availability when the stock is cut down by half causing increased growth.

Although the age estimation was at times difficult, the results from the VPA are encouraging. Comparison of two VPA runs , using data from different periods give approximately the same results for the age-groups 0-3 year olds in the period 81/82-88/89. Both runs converged rapidly. Some discrepancies were found for 4 and 5 year old shrimp.

In spite of the few year-groups used for the VPA, the linear regression between the values of biomass and survey indices is highly significant. Both correlations from the autumn survey, SA index versus biomass of 1-3 year olds and 2-4 year olds respectively are significant.

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Table 1. The Standard Deviations of the age-classes 0-3 of Pandalus with sternal spines that could be fitted without any constraint in the period 1978-1985 in the top section and that of age-classes 0-2 in the period 1986-1989 in the rest of the table.

Age-cl	Sep-78	Jan-79	Mar-79	Sep-80	Mar-83	Okt-83	Jan-84	Feb-84	Okt-84	Nov-84	Jan-85	Feb-85	Mar-85	78-85 Mean
0								0.5610			0.3602	0.3119	0.4210	0.4135
1	0.9989	0.9946	0.9030	0.8420	0.5380	0.7980	0.6990	0.8740	0.8155	0.8110	0.7587	0.8270	0.7689	0.8176
2	0.7852	0.8684	0.8119	0.7050	1.0840	0.5580	0.7570	0.6140	0.8820	0.8560	0.8584	1.0610	1.0686	0.8392
3	1.1105	0.9258	0.8213	1.0490	0.8530	1.2365	1.1990	1.2690	0.8639	1.0750	1.0790	0.9830	1.1154	1.0446

Age-cl	Nov-86	Dec-86	Jan-87	Feb-87	Mar-87	Oct-87	Nov-87	Dec-87	Jan-88	Feb-88	Mar-88	Apr-88
0					0.5925	0.4489	0.6399	0.4654	0.6305	0.7952	1.0064	1.1140
1	0.9302	0.8258	0.8962	0.9075	1.1181	0.8763	0.8091	0.8428	0.8502	0.9420	0.8674	0.9498
2	0.9220	0.9201	1.0940	1.0606		1.0120	1.0127	1.0250	1.0500	1.1600	0.9663	1.2788

Age-cl	Nov-88	Des-88	Jan-89	Feb-89	Mar-89	86-89 Mean
0		0.2035				0.6551
1	0.8875	0.8968	1.0004	1.1497	1.1659	0.9950
2	1.1169	1.2166	1.3916	1.2432	1.1628	1.2270

Table 2. The Standard Deviation of the age-classes 3-5 of Pandalus without sternal spines fitted with equal SD for all age-classes.

Age-cl	Sep-79	Oct-80	Nov-79	Jan-80	Feb-80	Mar-80	Sep-80	Oct-80	Nov-80	Jan-81	Feb-81	Apr-81	Sep-81
3	1.0730	1.1470	1.2330	1.2240	1.0460	0.9330	1.1598	0.9651	1.1003	1.1387	0.9990	1.1380	1.2620
4	1.0730	1.1470	1.2330	1.2240	1.0460	0.9330	1.1598	0.9651	1.1003	1.1387	0.9990	1.1380	1.2620
5													

Age-cl	Nov-81	Dec-81	Jan-82	Feb-82	Mar-82	Sep-82	Nov-82	Dec-82	Jan-83	Mar-83	Sep-83	Oct-83	Nov-83
3	0.9240	0.9854	1.0430	1.2604	1.1358	1.0650	1.0080	0.9650	0.9720	0.9710	1.1740	1.0590	
4	0.9240	0.9854	1.0430	1.2604	1.1358	1.0650	1.0080	0.9650	0.9720	0.9710	1.1740	1.0590	1.0200
5	0.9240	0.9854				1.0650	1.0030	0.9650	0.9720		1.1740	1.0590	1.0200

Age-cl	Dec-83	Feb-84	Mar-84	Sep-84	Oct-84	Nov-84	Jan-85	Feb-85	Sep-85	Oct-85	Mar-85	Nov-86	Dec-86
3		1.1280	1.0280	0.9811	1.0020	0.9910	1.0540	1.0887			1.2290	1.0383	1.0632
4	1.0990	1.1280	1.0280	0.9811	1.0020	0.9910	1.0540	1.0887	1.2440	1.0350	1.2290	1.0383	1.0632
5	1.0990	1.1280	1.0280	0.9811	1.0020	0.9910	1.0540		1.2440	1.0350		1.0383	1.0632

Age-cl	Jan-87	Feb-87	Mar-87	Dec-87	Jan-88	Mar-88	Nov-88	Dec-88	Jan-89	Feb-89	79-89 Mean
3	1.5370	1.4038	1.2834	1.2310	1.1651	1.2642	0.9468	1.0480	1.0408	1.2172	1.1049
4	1.5370	1.4038	1.2834	1.2310	1.1651	1.2642	0.9468	1.0480	1.0408	1.2172	1.1045
5							0.9468				1.0373

Table 3. Length at age in the two categories, with sternal spines the top section and without sternal spines the lower section (bold letters). Primaparous females are occasionally run through modal analysis separately, that is why there are more than one value of 2 and 3 year olds at times.

Age-gr	1976			1977						1978		
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
0			7.00		7.60	8.13			7.00		7.50	7.75
1	12.74	12.21	12.50	12.33	13.00	13.01	11.69	12.22	12.14	12.81	12.48	12.69
2	14.89	14.98	15.39	14.89	15.17	16.05	15.58	15.78	15.93	15.98	16.01	15.93
3	17.40	17.29	17.70	17.67	17.77	18.46	18.24	17.61	17.96	17.64	18.06	17.70
3	**19.52**	**19.22**	**19.36**	**19.27**	**19.69**	**19.30**	**20.10**	**19.77**	**19.80**	**19.79**	**19.78**	**19.95**
4	**22.14**	**21.95**	**22.19**	**22.61**	**22.03**	**21.80**	**22.91**	**21.85**	**22.77**	**22.25**	**22.64**	**22.84**
No. samples	6	24	8	13	29	14	12	15	9	8	19	16

Age-gr	1979					1980				1981		
	Jan.	Feb.	Mar.	Oct.	Nov.	Jan.	Mar.	Oct.	Nov.	Jan.	Feb.	Mar.
0		6.80	6.39			6.82	7.26		7.20	7.00	7.55	7.04
1	11.98	12.26	12.20	10.62	11.13	11.29	12.39	11.96	12.07	11.60	12.38	12.61
2	15.57	15.92	15.99	14.47	14.84	15.09	15.73	14.60	14.78	14.78	14.37	15.86
3	17.58	17.84	17.56	16.63	17.01	17.37	17.60	17.15	16.78	17.11	17.38	18.09
3	**19.11**	**18.90**	**18.56**	**18.99**	**18.38**	**18.47**	**18.37**	**19.05**	**18.85**	**18.90**	**19.24**	**19.46**
4	**21.22**	**20.97**	**20.78**	**20.99**	**21.01**	**21.06**	**21.06**	**21.60**	**21.18**	**20.98**	**21.28**	**21.42**
No. samples	23	36	22	13	26	15	45	9	28	8	33	10

				1982					1983			
	Apr.	Nov.	Dec.	Jan.	Feb.	Mar.	Nov.	Dec.	Jan.	Feb.	Mar.	Oct.
0	7.00		8.20		6.67	7.56			7.25	7.25	7.56	
1	12.60	11.43	11.64	12.31	12.51	12.36	11.80	12.09	12.61	13.05	13.25	12.72
2	15.99	14.59	14.87	15.63	15.33	15.15	15.08	15.02	15.86	15.60	15.95	16.18
3	18.71	16.66	16.86	18.09	16.78	16.56	17.46	17.32	18.13	17.98	18.71	18.21
3	**19.56**	**18.17**	**18.06**	**18.77**	**18.55**	**18.25**	**18.46**	**18.37**	**18.90**	**18.91**	**19.29**	**18.47**
4	**22.60**	**20.50**	**20.50**	**20.81**	**20.82**	**20.87**	**20.19**	**20.35**	**20.91**	**21.21**	**22.28**	**20.97**
5		**22.70**	**23.68**				**22.40**	**23.59**	**23.06**	**23.88**		**23.77**
No. samples	7	28	9	8	50	21	27	4	14	49	3	9

			1984				1985					1986
	Nov.	Dec.	Jan.	Feb.	Mar.	Nov.	Jan.	Feb.	Mar.	Apr.	Nov.	Feb.
0		7.50		7.82	8.10		7.71	8.08	7.83	7.81	7.50	8.85
1	12.75	13.12	13.07	13.24	13.51	12.68	13.01	13.34	13.27	13.72	13.30	13.94
2	15.69	16.49	15.96	15.65	16.51	16.17	16.28	16.64	16.62	16.67	15.95	15.58
3	17.90	18.61	18.45	18.17	18.86	18.25	18.80	19.05	19.33	19.49	18.85	
3											18.63	19.02
3				**18.38**	**18.26**	**18.07**	**18.35**	**19.10**			**19.25**	**19.25**
4	**20.41**	**20.70**	**20.58**	**20.61**	**20.49**	**20.89**	**21.20**	**21.14**	**20.88**	**20.99**	**21.26**	**21.82**
5	**22.77**	**23.78**		**23.24**	**23.81**	**22.97**	**24.00**				**23.08**	
No. samples	21	41	14	39	22	3	29	35	12	11	35	36

	1986				1987						1988	
	Mar.	Apr.	Nov.	Dec.	Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	Jan.	Feb.
0	9.21	9.66	7.75	8.50	8.50	8.32	8.45	6.43	6.81	6.67	8.1	7.92
1	14.24	14.63	13.18	13.80	13.91	14.21	14.43	12.85	13.75	14.01	14.19	14.24
2	15.55	16.00	16.95	17.49	17.64	17.78	17.94	16.64	17.33	17.58	17.71	17.85
2											**16.36**	
3	19.33	19.82						20.88				
3	**19.25**	**19.25**	**18.94**	**19.47**	**19.42**	**19.08**	**19.13**	**20.31**	**20.32**	**20.50**	**20.57**	**20.06**
4	**22.04**	**21.88**	**21.59**	**21.89**	**21.89**	**21.71**	**22.46**	**22.30**	**22.27**	**23.45**	**23.74**	**22.71**
5			**23.80**	**23.85**				**24.21**	**24.04**			
No. samples	17	16	22	7	22	39	14	47	14	4	43	48

					1989		
	Mar.	Apr.	Nov.	Dec.	Jan.	Feb.	Mar.
0	8.57	8.57	8	8.03		8.50	8.37
1	14.17	14.59	12.74	12.58	12.98	12.56	13.04
2	16.84	18.03	18.26	18.32	18.20	18.33	18.59
2	18.33						
3	**20.35**	**20.68**	**20.71**	**20.63**	**20.79**	**20.71**	**20.24**
4	**23.63**	**24.03**	**23.10**	**23.48**	**23.12**	**23.30**	

Table 4. Proportion at age in the two categories, with sternal spines the top section and without sternal spines the lower section (bold letters). Primaparous females are occasionally run through modal analysis separately. That is why there are more than one value for 2 and 3 year olds at times.

Age-gr	1976 Oct.	Nov.	Dec.	1977 Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	1978 Jan.	Feb.	Mar.
0			0.5		0.5	0.8			0.1		0.2	0.8
1	10.3	10.2	17.3	11.8	16.2	18.8	19.1	13.1	11.9	14.7	16.6	21.7
2	15.7	21.4	20.6	28.9	22.3	27.3	28.7	24.2	19.2	23.3	30.0	23.9
3	19.4	23.5	18.0	22.7	32.3	21.9	8.4	17.8	15.3	20.4	19.3	28.4
3	**45.4**	**39.9**	**39.4**	**33.2**	**23.9**	**25.0**	**41.6**	**40.3**	**49.8**	**38.0**	**30.8**	**23.1**
4	**9.2**	**5.0**	**4.2**	**3.4**	**4.8**	**6.2**	**2.2**	**4.6**	**3.7**	**3.6**	**3.1**	**2.1**
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Age-gr	1979 Jan.	Feb.	Mar.	Oct.	Nov.	1980 Jan.	Mar.	Oct.	Nov.	1981 Jan.	Feb.	Mar.
0		0.5	1.3			3.3	4.4		1.0	0.2	2.9	2.4
1	20.9	38.7	42.9	12.6	7.0	17.3	22.5	26.1	31.6	26.8	43.3	35.7
2	22.5	34.2	33.2	46.3	46.8	49.1	29.1	28.4	21.9	27.0	24.8	29.1
3	14.1	4.4	4.4	7.9	11.9	11.8	23.9	18.4	24.1	22.6	19.4	18.7
3	**33.8**	**16.7**	**13.7**	**25.8**	**28.5**	**15.0**	**16.3**	**21.8**	**15.6**	**18.6**	**7.1**	**9.3**
4	**8.6**	**5.5**	**5.1**	**7.3**	**5.8**	**3.5**	**3.9**	**5.3**	**5.8**	**4.9**	**2.5**	**4.8**
Total	99.9	100	100.6	99.9	100.0	100.0	100.1	100.0	100.0	100.1	100.0	100.0

	Apr.	Nov.	Dec.	1982 Jan.	Feb.	Mar.	Nov.	Dec.	1983 Jan.	Feb.	Mar.	Oct.
0	0.5		1.5		0.3	0.9			0.4	0.5	1.3	
1	22.1	17.4	14.0	16.2	27.4	30.9	9.4	9.9	10.6	18.2	5.9	13.1
2	22.8	36.2	33.6	42.9	29.6	28.4	32.9	30.0	37.3	43.1	34.5	13.8
3	18.1	17.8	18.1	7.9	17.8	18.5	20.6	22.9	27.5	22.8	31.9	25.1
3	**34.9**	**17.3**	**20.5**	**23.3**	**19.1**	**13.7**	**23.8**	**26.7**	**16.0**	**12.5**	**22.8**	**1.5**
4	**1.7**	**10.0**	**11.6**	**9.8**	**5.9**	**7.6**	**10.7**	**9.5**	**6.5**	**2.8**	**3.6**	**43.9**
5		**1.3**	**0.7**				**2.7**	**1.0**	**1.8**	**0.2**		**2.6**
Total	100.1	100.0	100.0	100.1	100.1	100.0	100.1	100.0	100.1	100.1	100.0	100.0

	Nov.	Dec.	1984 Jan.	Feb.	Mar.	Nov.	1985 Jan.	Feb.	Mar.	Apr.	Nov.	1986 Feb.
0		0.5		1.6	0.1		2.8	0.6	3.4	13.4	0.3	5.5
1	17.0	17.4	22.8	38.5	24.8	15.9	13.4	14.1	13.9	12.1	30.6	49.7
2	15.0	11.1	15.3	14.6	17.3	36.3	39.7	40.3	39.8	40.1	10.5	6.3
2	44.4											4.0
3		23.7	33.3	29.9	30.0	23.2	19.3	13.7	15.7	19.4	18.8	7.0
3											3.5	12.0
3				**0.4**	**0.6**	**0.9**	**0.6**	**2.4**			**2.5**	**1.2**
4	**21.0**	**46.4**	**28.6**	**14.2**	**26.4**	**22.7**	**23.7**	**29.0**	**27.3**	**15.0**	**21.3**	**14.2**
5	**2.6**	**0.8**		**0.6**	**0.7**	**1.0**	**0.4**				**12.4**	
Total	100.0	99.9	100.0	99.8	99.9	100.0	99.9	100.1	100.1	100.0	99.9	99.9

	1986 Mar.	Apr.	Nov.	Dec.	1987 Jan.	Feb.	Mar.	Oct.	Nov.	Dec.	1988 Jan.	Feb.
0	5.8	2.8	0.2	0.1	0.1	1.1	4.0	0.3	4.2	1.7	13.1	17.5
1	25.8	18.9	48.7	47.7	39.9	58.2	56.2	17.5	17.2	15.5	22.2	23.3
2	4.3	3.1	31.1	28.5	34.2	29.0	28.7	50.3	50.0	51.0	42.4	37.8
2	8.3	5.3									0.5	
3	7.0	1.5						0.9				
3	23.2	26.6										
3	**4.6**	**2.1**	**7.3**	**8.2**	**10.9**	**4.1**	**7.1**	**23.4**	**23.4**	**28.5**	**19.6**	**16.9**
4	**21.0**	**39.6**	**9.5**	**12.7**	**14.9**	**7.6**	**4.0**	**5.7**	**4.1**	**3.3**	**2.3**	**4.4**
5			**3.2**	**2.7**				**2.0**	**1.2**			
Total	100.0	99.9	100.0	99.9	100.0	100.0	100.0	100.1	100.1	100.0	100.1	99.9

	Mar.	Apr.	Nov.	Dec.	1989 Jan.	Feb.	Mar.
0	15.9	24.0	0.3	0.4		0.5	1.1
1	16.1	22.6	61.3	59.9	67.8	77.1	80.2
2	20.8	34.7	17.1	20.1	15.9	11.9	11.2
2	22.8						
3	**22.4**	**18.2**	**18.0**	**18.8**	**14.2**	**10.0**	**7.5**
4	**2.0**	**0.5**	**3.0**	**0.9**	**2.1**	**0.6**	

Table 5. Weights at age (g).

Year / Age	76/77	77/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85	85/86
0	0.4	0.4	0.2	0.3	0.4	0.3	0.3	0.3	0.3	0.5
1	1.4	1.3	1.2	1.1	1.2	1.3	1.4	1.6	1.5	1.8
2	2.2	2.5	2.5	2.3	2.2	2.3	2.5	2.7	2.9	2.6
3	4.4	4.7	4.5	4.2	4.3	4.0	4.5	4.0	4.4	4.6
4	7.5	7.8	6.5	7.3	7.5	7.0	7.1	6.8	7.2	8.0
5	10.0	10.0	10.0	10.0	10.0	9.4	9.1	10.3	9.7	9.6

Year / Age	86/87	87/88	88/89
0	0.4	0.4	0.4
1	1.8	1.9	1.4
2	3.6	3.5	4.0
3	5.6	6.6	6.9
4	8.1	9.4	9.7
5	10.5	10.9	12.2

Table 6. Catch numbers at age (Numbers * 10^{-3}).

Year / Age	76/77	77/78	78/79	79/80	80/81	81/82	82/83	83/84
0	2084	2018	2993	25605	13450	5671	3628	3628
1	97300	122191	191860	172782	320983	258110	75627	178369
2	160520	184524	170900	403232	241782	333251	249208	101989
3	398643	398207	169213	337814	352172	351496	302483	213644
4	37306	23644	37098	45324	41994	84758	39561	161056
5	1	1	1	1	1	2705	7205	4349

Year / Age	84/85	85/86	86/87	87/88	88/89
0	15589	14206	3965	70118	2384
1	56993	133362	162559	109989	318712
2	157634	36206	95785	248711	60371
3	77177	83465	21954	120805	51935
4	95514	63970	28414	17337	4452
5	1335	9807	2390	1956	182

Table 7. Proportion mature at age.

Year / Age	76/77	77/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85	85/86
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.56	0.63	0.74	0.56	0.39	0.52	0.43	0.01	0.03	0.09
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Year / Age	86/87	87/88	88/89
0	0.00	0.00	0.00
1	0.00	0.00	0.00
2	0.00	0.00	0.00
3	1.00	1.00	1.00
4	1.00	1.00	1.00
5	1.00	1.00	1.00

Table 8. The nominal catch, effort (corrected by CPUE) and CPUE from the log data, where between 80 and 90% of the effort is reported.

Seasons	Effort, trawling hours	Nominal catch, tonnes	CPUE, kg/hr.
1976/77	16681	2528	151.5
1977/78	14423	2678	185.7
1978/79	7222	1653	228.9
1979/80	13673	2834	207.3
1980/81	13022	2750	209.3
1981/82	9984	3120	313.7
1982/83	8932.	2433	272.4
1983/84	11445	2578	225.2
1984/85	5917	1600	270.4
1985/86	9463	1330	140.5
1986/87	7281	1043	143.3
1987/88	12537	2100	167.5
1988/89	6736	1100	163.3

Table 9 Fishing mortalities from the tuning of VPA using Laurec/Shepherd method. Oldest age F = 1.000*average of 2 younger ages. Fleets combined by variance of predictions.

Year / Age	77/78	78/79	79/80	80/81	81/82	82/83	83/84
0	0.001	0.001	0.001	0.007	0.005	0.005	0.003
1	0.100	0.081	0.085	0.110	0.149	0.163	0.109
2	0.209	0.390	0.219	0.398	0.308	0.318	0.328
3	2.510	2.105	1.229	1.684	1.150	1.707	0.800
4	9.907	9.446	9.906	9.884	2.162	1.808	1.801
5	6.208	5.775	5.567	5.784	1.656	1.758	1.300
Wts	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Year / Age	84/85	85/85	86/87	87/88	88/89	89/90
0	0.009	0.016	0.011	0.004	0.013	0.003
1	0.257	0.263	0.246	0.223	0.208	0.098
2	0.293	0.548	0.377	0.399	0.949	0.235
3	0.774	0.545	0.983	0.604	2.769	0.795
4	3.858	1.775	2.560	2.274	3.801	2.472
5	2.316	1.160	1.772	1.439	3.285	1.633
Wts	1.000	1.000	1.000	1.000	1.000	1.000

Table 10. Results of the separable analysis 1980 - 1989 with terminal F of 1.170 on age 3 and terminal S of 1.000. Initial sum of squared residuals was 333.883 and final sum of squared residuals is 78.749 after 101 iterations.

Matrix of residuals

Years / Ages	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88
0/1	-0.060	-0.021	0.008	-0.697	0.060	0.427	0.100	0.183
1/2	-0.632	0.142	-0.125	0.114	0.090	0.179	0.055	0.178
2/3	-0.224	-0.266	-0.124	0.416	0.007	0.138	0.068	-0.015
3/4	0.972	0.807	1.230	0.031	-0.567	-1.429	-0.327	-0.719
4/5	6.734	-0.328	-1.222	-0.764	0.359	2.705	-1.265	-0.805
Sum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wts	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Matrix of residuals

Years / Ages	88/89	Sum	Wts
0/1	0.430	0.000	0.650
1/2	-0.413	0.000	0.744
2/3	0.210	0.000	1.000
3/4	0.349	0.000	0.245
4/5	-3.651	0.000	0.074
Sum	0.000	-3.071	
Wts	0.001		

Fishing mortalities (F)

Year	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87
F-values	0.9910	0.7460	0.9046	0.7771	1.2664	1.4256	1.2447	1.0281

Year	87/88	88/89
F-values	2.5214	1.1700

Selection at age (S)

Age	0	1	2	3	4	5
S-values	0.0068	0.1874	0.3844	1.0000	2.8599	1.0000

Table 11. Fishing mortalities from traditional VPA using terminal populations from weighted Separable populations.

Year / Age	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89
0	0.0067	0.0048	0.0047	0.0028	0.0090	0.0155	0.0109	0.0071	0.0183	0.0079
1	0.1085	0.1488	0.1637	0.1096	0.2561	0.2638	0.2456	0.2291	0.3873	0.1482
2	0.3955	0.3042	0.3183	0.3302	0.2952	0.5454	0.3779	0.3968	0.9943	0.5537
3	1.6074	1.1344	1.6554	0.7990	0.7831	0.5517	0.9741	0.6068	2.7108	0.8883
4	5.5837	1.6896	1.7125	1.5547	3.8313	1.8462	2.7055	2.1781	3.9319	2.0448
5	0.9421	0.0113	0.6684	1.0560	1.1603	1.1052	2.2265	2.0895	2.1918	2.3221
Fbar 2-4	2.5289	1.0427	1.2288	0.8946	1.6365	0.9811	1.3525	1.0606	2.5457	1.1623

Table 12. Stock numbers at age (start of vinter) from traditional VPA using terminal populations from weighted Separable populations. (Numbers* 10^{-3}).

Year / Age	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90
0	4867882	3573796	1526353	1641034	513946	1290105	1665443	711272	4907648	383378	0
1	2125874	2932794	2157254	921410	992541	308929	770480	999199	428354	2922637	230694
2	1543399	1156833	1532950	1110845	500838	465976	143924	365570	481932	176378	1528522
3	504177	630350	517627	676281	484284	226118	163821	59820	149100	108152	61492
4	49495	61283	122960	59968	184501	134232	78994	37513	19777	6013	26984
5	2	113	6862	13455	7684	2426	12850	3202	2577	235	472

Table 13. Stock biomass at age in tonnes (start of vinter) from traditional VPA using terminal populations from weighted Separable populations.

Year / Age	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89
0	1285	1390	495	496	177	443	849	300	1948	161
1	2400	3637	2714	1290	1551	474	1387	1844	804	4165
2	3496	2547	3544	2790	1363	1366	367	1300	1707	707
3	2134	2680	2069	3028	1956	991	752	333	989	744
4	359	462	860	425	1262	969	634	305	186	58
5	0	1	65	123	79	24	123	34	28	3
1-3	8030	8864	8327	7108	4870	2831	2506	3477	3500	5616
2-4	5989	5689	6473	6243	4581	3326	1753	1938	2882	1509
0-5	9674	10717	9747	8152	6388	4267	4112	4116	5662	5838
Spbio	1554	1508	2001	1849	1361	1022	825	672	1202	806

Table 14 The area of the various strata surveyed in Ísafjarđardjúp and number of trawling stations.

Strata no.	Area Sq.km	Number of trawl stations	Number of tr.st. per sq.km.
1	27.3	7	3.9
2	3.7	1	3.7
3	3.7	1	3.7
4	13.2	3	4.4
5	12.0	2	6.0
6	21.9	6	3.7
7	7.3	2	3.7
8	22.4	6	3.7
9	22.9	4	5.7
10	44.9	3	15.0
11	27.0	4	6.8
12	84.9	4	21.2
13	21.2	2	10.6
14	60.7	9	6.7
Total	373.1	54	6.9

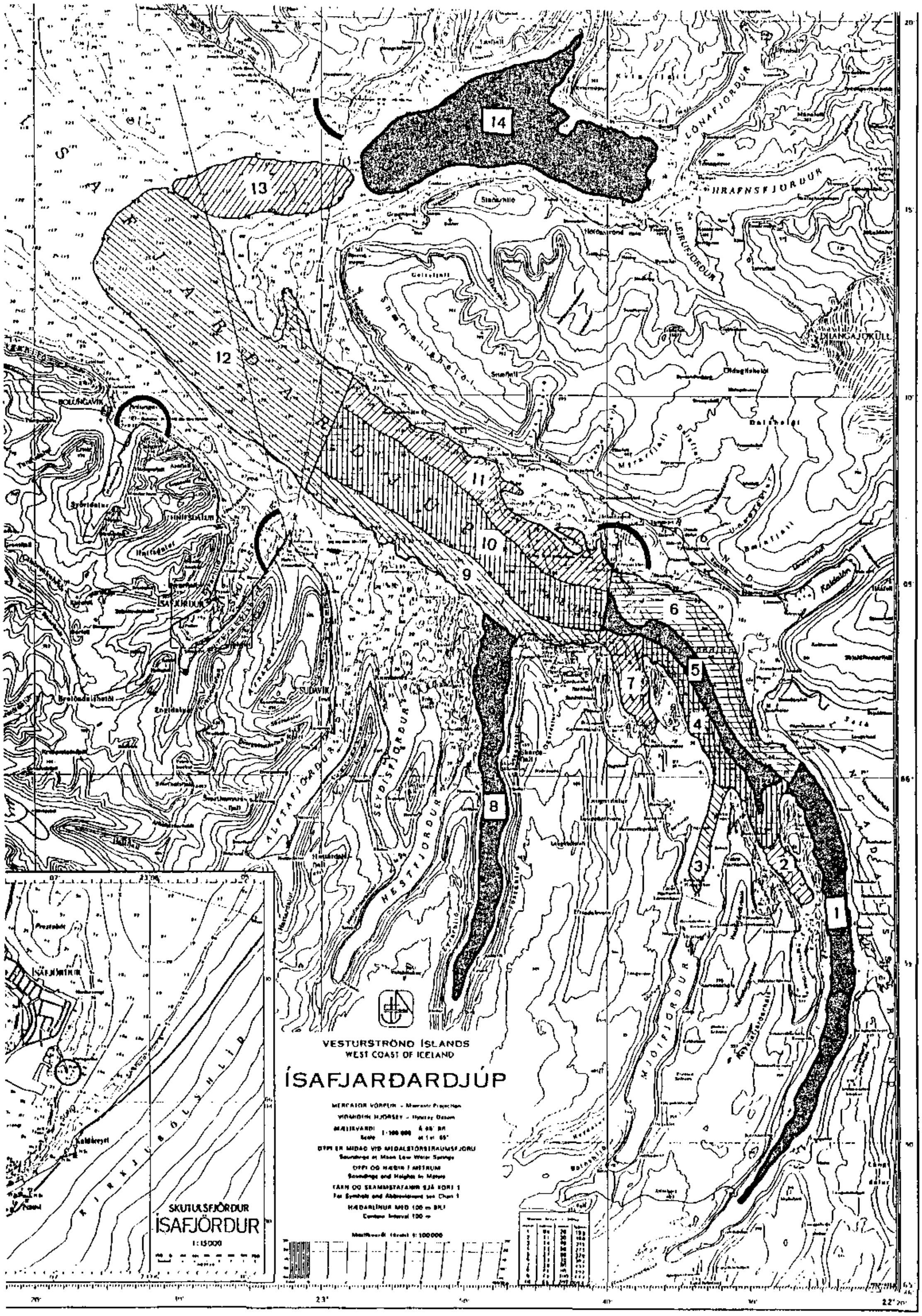
Table 15 Several stock estimates and the correlations, fitting a straight line between VPA biomass of 2-4 year olds and the respective index from the survey series.

Seasons	VPA biomass of 2-4 yr olds	SA Indices		
		Autumn survey	Late winter survey	Winter average SA indices
1979/80	5989	2196	1026	1611
1980/81	5689	3023	1503	2263
1981/82	6473	2501	2696	2599
1982/83	6243	2001	2000	2001
1983/84	4581	1887	1527	1707
1984/85	3326	1634	1322	1478
1985/86	1753	1424	679	1052
1986/87	1938	1110	1027	1069
1987/88	2882	2076	1756	1916
1988/89	1509	1543	1840	1692
The fit between VPA biomass of 2-4 yr olds and the SA index.		r=0.7792	r=0.4795	r=0.7312

Table 16 Several stock estimates and the correlations, fitting a straight line between VPA biomass of 1-3 year olds and the respective index from the survey series.

Seasons	VPA biomass of 1-3 yr olds	SA Indices		
		Autumn survey	Late winter survey	Winter average SA indices
1979/80	8030	2196	1026	1611
1980/81	8864	3023	1503	2263
1981/82	8327	2501	2696	2599
1982/83	7108	2001	2000	2001
1983/84	4870	1887	1527	1707
1984/85	2831	1634	1322	1478
1985/86	2506	1424	679	1052
1986/87	3477	1110	1027	1069
1987/88	3500	2076	1756	1916
1988/89	5616	1543	1840	1692
The fit between VPA biomass of 1-3 yr olds and the SA index.		r=0.7753	r=0.6685	r=0.8188

Figure 1. The shrimp grounds in Ísafjarðardjúp divided into 14 strata.



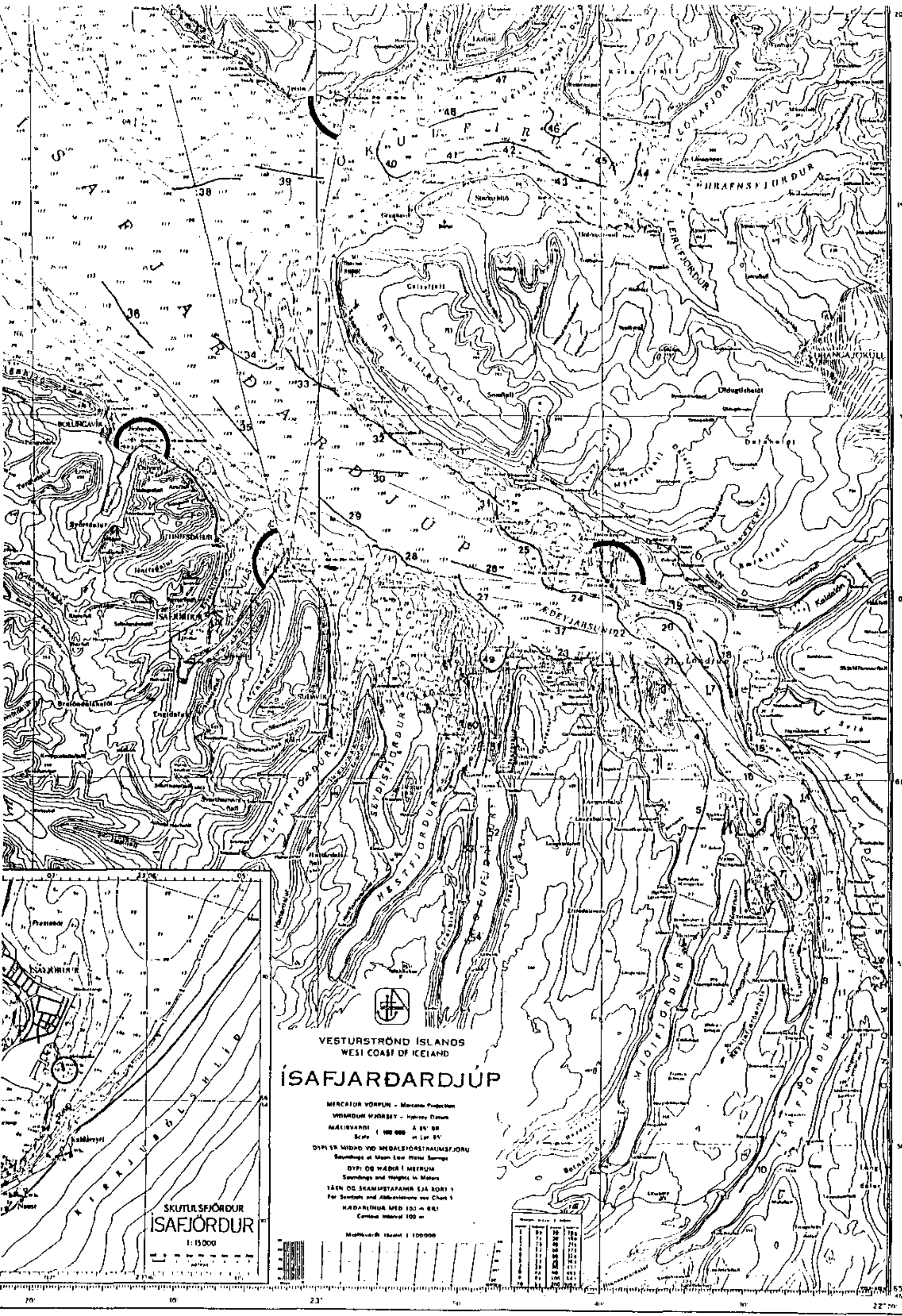


Figure 2. The 54 trawl stations taken in Ísafjarðardjúp in every survey.

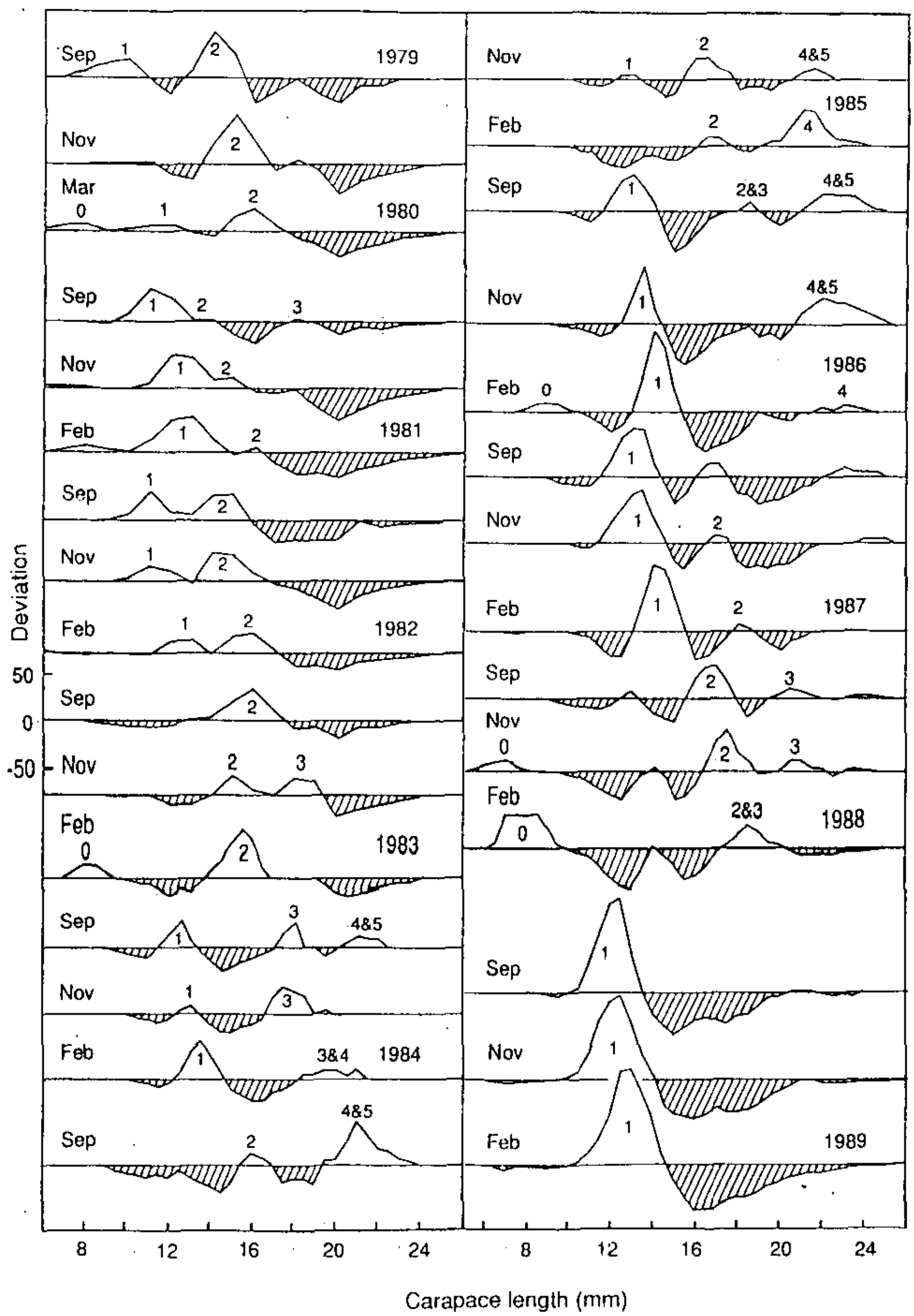


Fig. 3. Deviations of the monthly length frequencies of *P. borealis* of the biannual surveys and November each year.

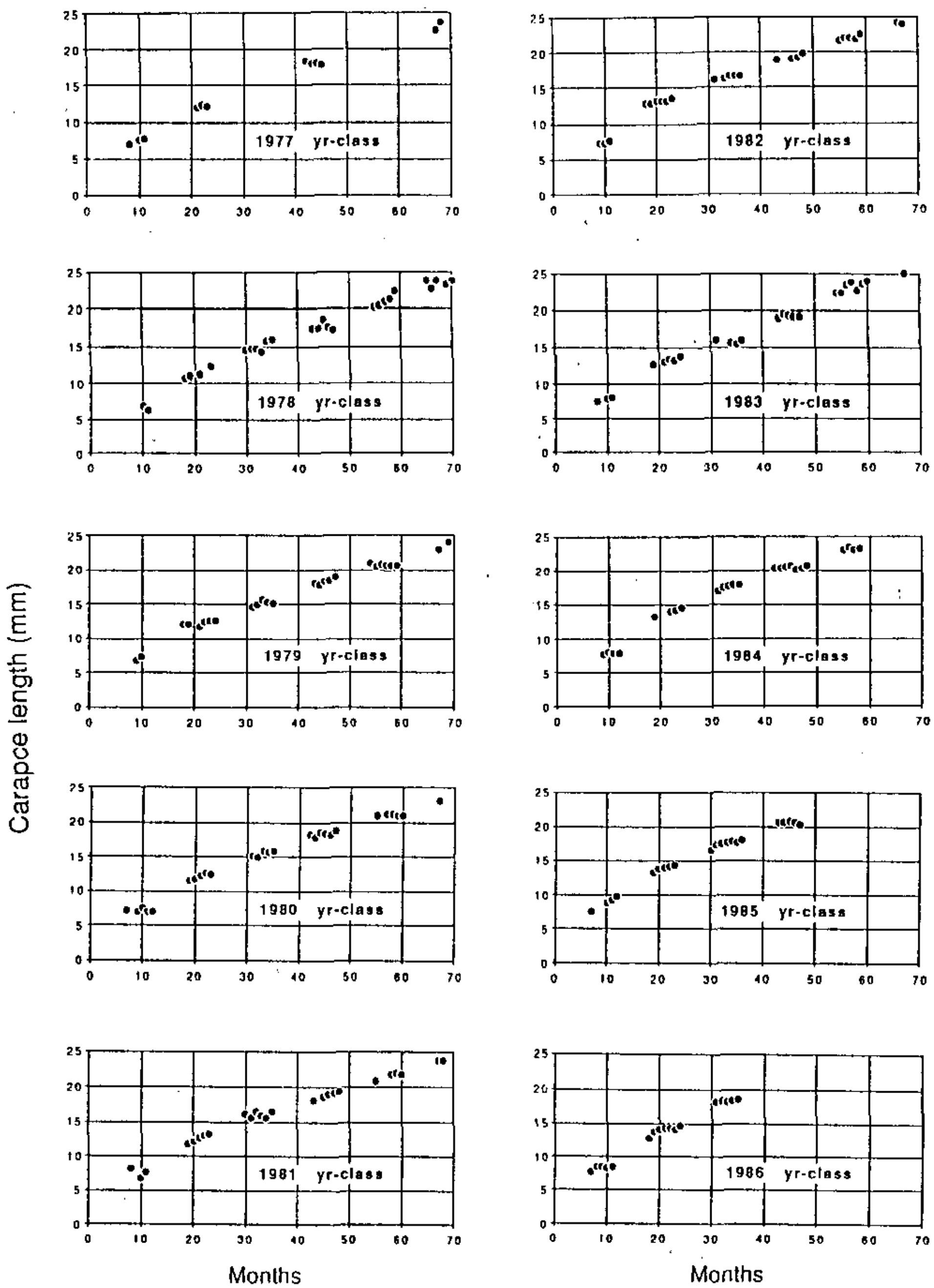


Fig. 4. The growth of the year-classes detected during the period 1977-1989.

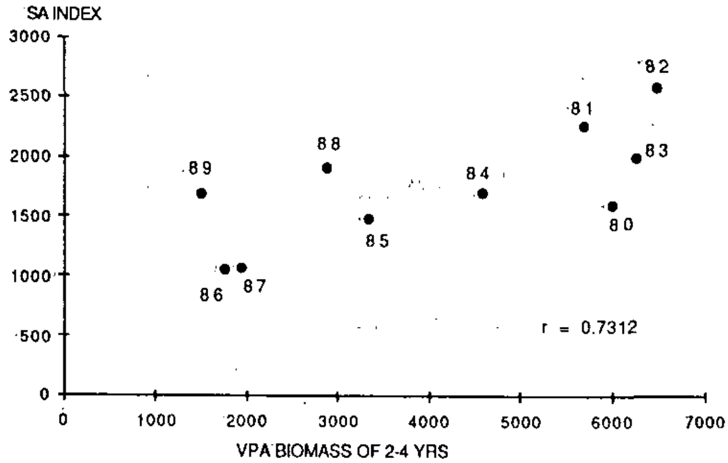


Figure 5. The SA index, the average of autmn and late winter survey, against the biomass of 2-4 year olds as estimated by the VPA, the same winter.

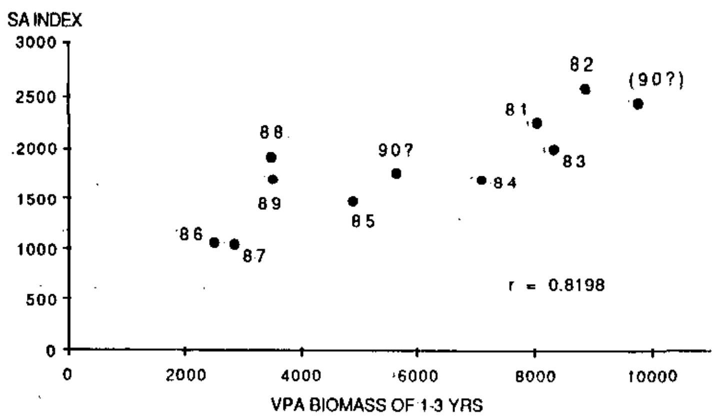


Figure 6. The biomass of 1-3 year olds as estimated by the VPA against the SA index the following winter (designated by the spring). The forecast for the index is about 1700 if the same gear is allways used. In brackets is the more reliable forecast for the winter 89/90 (designated 90)based on the change in selection of the square from the diamond, which was introduced in autumn 1988.