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A Statistical Description of Recruitment in Eighteen Selected Fish Stocks

by

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ABSTRACT

For both predicting and understanding purposes, one is concerned with identifying suitable models and methods that are descriptive of the empirical and theoretical relationships that may exist between fish stock, environment, and recruitment. In this paper, we review recruitment in 18 stocks around the world by examining them empirically as to frequency distribution which subsume the total effect of all factors. The actual frequency distribution of individual fish stocks were plotted and each set of recruitment data was tested for goodness of fit to the normal and Log-normal distributions. Conclusions from the test were that most of the data sets could be described by a lognormal distribution function.

Plots of the recruitment data and accompanying catch over time (years) indicated that catch is primarily dependent on the strength of the existing year-classes of recruitment. Serial correlations run on the recruitment data indicate that in most cases recruitment in one year is correlated with the previous year.

INTRODUCTION

Worldwide fisheries developed to the point in the early 1970's of encompassing nearly all of the important fish stocks and productive ocean areas. Increases in fishing activity in the last decade have not resulted in increased catches. Many recently developed and traditional fisheries have suffered declines in yield, and the development of alternative fisheries has been limited. This state of affairs has led to concern about the future of fisheries and increasing proposals for and actual limitations on fishing.

The traditional habit of collecting fishery statistics expanded as fisheries became more important, and studies of population dynamics based on these statistics also expanded. The studies led more and more to the conclusion that fishing mortality had become a pervasive and primary cause of changes in stock abundance.

This in turn led to studies of the effect of changes in stock size on productivity, and also led to consideration of regulating fishing mortality as a means of controlling change in stock size. Because implementation of this type of management usually meant a cutback in catch, or at the very least no further increase, the validity of the concept became rather controversial.

The size of the exploited stock is, of course, primarily based on the annual amount of young fish that are produced by the process of spawning, hatching, growth, and survival--the process of recruitment. The effect of spawning-stock size on this process led to extensive investigation and formulation of stock-recruitment models. Unfortunately, fundamental studies of the process in the ecological setting were very few--in fact are just now getting started--and most research was empirical, based on observations from the fishery.

For both predictive and understanding purposes, one is concerned with identifying suitable models and methods that are descriptive of the empirical and theoretical relationships that may exist between stock, environment, and recruitment. Generally speaking, the models and the methods discussed in literature have attempted to express recruitment in terms of stock, allowing the parameters present to represent relevant factors governing the environment. Although some association between stock size and recruitment was demonstrated, it seems safe to say that most conclusions about cause-effect were foregone.

It is only natural that a comprehensive model for the study of recruitment should incorporate different factors involving the stock and the environment. It should incorporate time-dependent features also. In this paper we review recruitment in 18 stocks around the world by examining them empirically as to frequency distributions which subsume the total effect of all factors.

Recruitment as here defined involves a series of events and processes. These include spawning, survival and hatching of eggs, growth and survival of larvae, and growth and survival of juveniles through the pre-adult stage to the point of vulnerability to the fishery. The state of the spawning stock, magnitude and physiological, affects spawning and subsequent survival of eggs and larvae because of preconditioning and the density and distribution of eggs. Environmental conditions affect every stage, but probably exert most effect by modifying the time and place of spawning, the distribution of eggs and larvae, and production and distribution of larval food.

In the total ecological setting, competition and predation within the plankton populations, and predation by nekton are also important. The multiplicity of processes, the magnitude of the time-space continum, and the inefficiencies of sampling tools make it difficult to obtain adequate observations and construct appropriate models. The process seems much too variable to measure only one of the factors to determine its effect.

We can, however, begin the statistical analysis by examining the joint probability density function (pdf) of recruitment and total effect of all conditions that influence recruitment, e. g., spawning stock, environment, etc. The latter are most likely conditional and not independent, so that statistical inversion may not be possible. However, this approach can provide some insight into the possible form of marginal density distributions.

More important perhaps is the utility of this approach in demonstrating the shape of the recruitment function so that a realistic view of expectation can be generated without compounding this view by bringing in spawning stock size and the implied regulatory control of it. There is much information in the recruitment joint pdf, and some rather clear and useful advice can be based upon it. More specifically, we hypothesize a continuous function, which may be multimodal, but which is discontinuous at the origin. That is, there is either no finite probability of zero recruitment, or it is discontinuous with respect to recruitment greater than zero. There are many functions which could be used to express a pdf of this sort. As a first approach we have plotted the actual frequency function of a number of fish stocks, and examined some empirical goodness of fits.

MATERIALS AND METHODS

Eighteen stocks were examined for this paper (Table 1). They consisted of stocks where there was at least 10 years of recruitment estimated in quantitative sense, usually from virtual population analysis techniques (VPA) (Ricker, 1975). The species/stocks chosen were the Northeast Arctic, the North Sea, and Georges Bank cod (*Gadus morhua*); haddock (*Melanogrammus aeglifinus*) from the same three areas; North Sea saithe (*Pollachius virens*); North Sea whiting (*Gadus merlangus*); silver hake (*Merluccious bilinearis*) from Georges Bank; North Sea herring (*Clupea harengus*); Norwegian spring-spawning herring (*Clupea harengus*); Georges Bank herring (*Clupea harengus*); North Sea and Northwest Atlantic mackerel (*Scomber scombrus*); South African pilchard (*Sardinops ocellata*); anchovy (*Engraulus capensis*); and round herring (*Eutremus teres*); and Peruvian anchovy (*Engraulis ringens*).

Source documents for these stocks were the laboratory reference document series of the Northeast Fisheries Center, USA National Marine Fisheries Service, Woods Hole, Massachusetts; the 1979 International Commission for the Exploration of the Sea (ICES) Working Group Reports; and the ICES-ICNAF Symposium on the Biological Basis of Pelagic Fish Stock Management, July 1978. For the latter two sources, all data were used as presented in the documents. For the Northwest Atlantic stocks, the statistical analysis was limited to the 1972 and earlier year classes which would not be sensitive to starting F values used in the virtual population analyses. The estimates of year-class strength for the years since 1972, for these stocks, were examined after the statistical analysis had been performed on the earlier data to determine whether or not the more recent information contradicts or supports the patterns observed in the data tested.

RESULTS

The recruitment data, with the accompanying catches, are plotted on Figures 1 through 18. It can be seen from these that the catch is extremely dependent upon the strength of the entering year classes.

There also appear to be time-related trends in some of these data; for example the South African herring recruitment rose, fell, and then rose again, and Georges Bank herring increased for several years followed by several years of decreases. Therefore we examined the time-series aspects of these data as well as the probability density function.

In examining these graphs it becomes obvious that there are two distinct periods in the Georges Bank haddock time series (Figure 4): 1931-1965 and 1965 forward. Therefore, the recruitment data for this stock was examined not only for the total time series but for these two separate time series.

The Kolmogorov-Smirnov (K-S) one-sample, goodness-of-fit test was used to test the null hypothesis that the recruitment data for an individual species represents a sample of years drawn from a normally distributed population. The alternate hypothesis was that the sample was not drawn from a normally distributed population. The K-S test was chosen because it is a powerful test for goodness fit, especially for small sample sizes (Seigel, 1956). Each sample value was also logged ($Y = \ln X$) and tested to determine if the samples were drawn from a population with a lognormal distribution. Results are presented in Table 1. For the unlogged data, the null hypothesis would be rejected at the $\alpha = 0.05$ level for Georges Bank haddock for two periods, 1931-1973 and 1931-1965, for North Sea and Northeast Arctic haddock, Norwegian spring-spawning and North Sea herring, and North Sea and Georges Bank mackerel, North Sea saithe, South African pilchard, South Africa round herring and Georges Bank silver hake. The null hypothesis would not be rejected for the cod stocks, Georges Bank haddock for 1966 to 1973, Georges Bank herring, North Sea whiting, and South African and Peruvian anchovy. For the logged recruitment data, the null hypothesis was rejected at $\alpha = 0.05$ only for haddock on Georges Bank for the entire series, and P-values of 0.2 or above existed for Georges Bank, North Sea, and Northeast Arctic cod; Georges Bank (1966-1973), North Sea, and Northeast Arctic haddock; herring and mackerel in all areas; saithe; whiting; South African anchovy and round herring; and silver hake. It should be noted that a low P-value ($P \leq .05$) cast doubt upon the null hypothesis; conversely a high P-value tends to support the hypothesis. In only two cases (Georges Bank cod and Peruvian anchovy) were the test statistic for the unlogged data observably lower than those of the logged data, indicating that these two species would fit a normal better than a lognormal distribution. In all other cases where the null hypothesis was not rejected, the logged data gave a considerably better fit than the unlogged data.

It is reasonable to suspect that, for an individual species, the number in the recruiting year class in year i + k is related to the number in the recruiting year class in year i. Serial correlations are used to test for this dependency between observations of stock size in successive years. This serial correlation coefficient (r_k) is defined as:

$$r_k = \frac{\text{Cov }(X_i, X_{i+k})}{(\text{Var}(X_i)\text{Var}(X_{i+k}))^{\frac{1}{2}}}$$

where $r_0 = 1$, $r_{-k} = r_k$ (Yamane, 1967)

and k = lag time in years

x_i = number of fish at age in year i for an individual species.

The time series presented here are short ($n \leq 20$ years) in all but two cases and may have trends present; therefore, a noncircular definition of r_k is used here. Noncircular means that for each series it can be assumed that $x_1 \neq x_{n+1}$.

The results are presented in Table 2. Correlations were calculated with time lags (k) of 1 and 2 years, and where the 2-year correlation was significant at the $\alpha = 0.5$ probability level a time lag of 3 years was examined.

Test results indicate significant correlations of age 1 Georges Bank cod, Norwegian spring-spawning herring, South African pilchard, Northwest Atlantic mackerel, Georges Bank silver hake, and South African round herring for 1-year time lags. So the time series for these species are nonrandom if observations are only 1 year apart. With 2-year time lags, Georges Bank cod, South African pilchard, and Georges Bank silver hake were the only species to show significant correlation. None of these species had significant correlations for 3-year time lags.

DISCUSSION

The conclusion from the analyses of the above data on recruitment is that a lognormal distribution function describes the vast majority of the data sets.

A visual review of histrograms of the data (Figures 19-36) supports this conclusion. The interval width of these histograms was determined by dividing the mean by 5 and rounding. Georges Bank cod and Peruvian anchovy (Figures 19 and 35), however, appear more normally than lognormally distributed. Miltimodal distributions were not considered here, but Georges Bank haddock and Northeast Arctic haddock (Figures 22 and 24) showed indications of multimodality.

The generally more normal distribution of recruitment for cod than for other species may be indicative of the fact that cod yields and stock tend to be more stable and less subject to extreme fluctuations than many of the other species reviewed here.

Haddock on Georges Bank presents an intriguing problem--the entire series from 1931 to 1973 would not be described by either a normal or a lognormal distribution (Table 1). There would appear to be two different patterns in the distribution of recruitment numbers (Figure 4). Therefore it is pertinent to discuss the periods 1931-1965 and 1966-1973. The earlier period has data for which one cannot reject a fit to a lognormal distribution. Figure 37 illustrates the fit to the lognormal and can be seen to be quite acceptable. The period 1966-1973 fits both a normal and a lognormal distribution. Since 1973, recruitment was poor in 1974, 1975, 1977, 1978, and strong in 1976. It is obvious that the good 1975 year class would be more appropriate to a lognormal than a normal distribution. Interestingly enough, the probabilities of a year class as large as the preliminary estimates (200×10^6) for the 1975 year class occurring under the lognormal distribution fit to the values estimated for the period 1966-1973 would be only 0.83%, when in fact the observed frequency was 10 times that, or 8%. When comparing the lognormal distributions for the two time periods, it is obvious that the latter period has both a smaller mean and a larger variance. The value of the range of recruitment for the earlier period was 19:1, while that for the total series is about 2,700:1. For the latter period it was 92:1 not including the 1975 year class, and about 1,100:1 including it.

Herring stocks in all areas can be described by a lognormal distribution. For the Georges Bank stock a normal distribution could not be rejected. The shorter time series observed for Georges Bank as opposed to the other stocks, and a lesser observed range in stock sizes due to earlier cessation of fishing when stocks were rapidly declining, have resulted in a lesser range of stock sizes and may account for the observed fit to a normal. The range in year-class size for herring in all cases is less than for Georges Bank haddock and more resembles cod with the exception of the tremendous range (130:1) for Norwegian spring spawners. The lesser range, 5:1, for Georges Bank opposed to 10:1 in the North Sea may in part be due to Georges Bank being based on 2-year-old fish while that of the North Sea was based on age-0 fish.

Mackerel can be described very well by lognormal distributions. The Georges Bank fit moderately well to a normal at the α = .01 level. The better fit to normal distribution for cod, herring, and mackerel on Georges Bank compared to the Northeast Atlantic may indicate a more stable situation in the western area. The range in year-class size was 18:1 on Georges Bank about 41:1 in the North Sea. However, if the last two years of data (1977 and 1978) are eliminated, the ratio for the North Sea becomes 20:1, essentially the same as that for the Northwest Atlantic. It is possible that this may be related to the more rapid implementation of management restrictions in the Northwest Atlantic halting declines in stock sizes at proportionally larger sizes than in the North Sea.

Recruitment for the other two North Sea stocks examined, saithe and whiting, can also be described by lognormal distributions. The range in the whiting year-class size is 6.5:1 while that of saithe is 12:1. Interestingly, the saithe has approximately the same range as herring. The other Georges Bank stock examined, silver hake, fit slightly less well to a lognormal than many of the other stocks and has a range in year-class strength of approximately 10:1.

The Southern Hemispheric stocks examined present a rather interesting pattern. The lowest year-class size range observed, with the exception of cod on Georges Bank, was found in the South African anchovy

(2.7:1). Recruitment for this species can be described by both normal and lognormal distributions. Peruvian anchovy, round herring, and pilchard had ranges in year-class sizes of about 10:1. The recruitment of Peruvian anchovy was better described by a normal than lognormal distribution, while the reverse was true for the other two.

The serial correlation data indicate that the most frequently occurring correlation was with a 1-year time lag. Significant (α = 0.5) correlations occurred for several stocks on Georges Bank (mackerel, cod, and silver hake), and two in the Southern Hemisphere (pilchard and round herring). None were significant for stocks in the Northeast Atlantic. Two-year time lags occurred only for pilchard and Georges Bank cod. In no case were correlations with 3-year time lags significant. The implication of short time lag correlations in examining recruitment is that, in at least some instances, one needs not only to examine the probability distribution functions as if recruitment estimates were random variables, but also to consider the relationships of adjacent year classes. However, the relative infrequency of such significant correlations and the actual low numerical correlations in almost all cases (the only two above 0.8 were pilchard and Georges Bank silver hake) would mean that ignoring them would create only moderate problems in examining the probability distribution function of year classes as independent variables.

Short-term correlations would be expected when environmental conditions affecting egg and larval survival were similar in adjacent years. In addition, these correlations would be influenced by stock/recruitment relationships to the extent that spawning potentials in adjacent years might be expected to be similar.

This review of recruitment data, although preliminary, has some interesting implications. It is obvious from the data that a hard line cannot be drawn distinguishing pelagic and demersal stocks on the basis of recruitment variability or the presence of dominant year classes. Furthermore it is obvious that there are great similarities in the form of probability distribution functions of widely differing stocks. The approach of studying these functions, as more data are accumulated, may provide useful guidelines in understanding the influence of recruitment on fish populations and fisheries.

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REFERENCES

Anderson, E.D. 1977. Assessment of the Georges Bank silver hake stock. Natl. Mar. Fish. Ser., Northe. Fish. Ctr., Woods Hole, MA. Lab. Ref. No. 77-21. 24 p Mimeo.

Anderson, E.D. and A.L. Paciorkowski. In Press, 1980. A review of the Northwest Atlantic mackerel fishery. Rapp. P.V. Reun. Cons. Int. Explor. Mer. Vol. 177.

Anthony, V.C. and G. Waring. In press, 1980. Assessment and management of the Georges Bank herring fishery. Rapp. P.V. Reun. Const. Int. Explor. Mer. Vol. 177.

Clark, S.H. and W.J. Overholtz. 1979. Review and assessment of the Georges Bank and Gulf of Maine haddock fishery. Natl. Mar. Fish. Ser., Northe. Fish. Ctr., Woods Hole, MA. Lab. Ref. No. 79-05. 64 p Mimeo.

Csirke, J. In press, 1980. Recruitment in the Peruvian anchovy and its dependence on the adult population. Rapp. P.V. Reun. Const. Int. Explor. Mer. Vol. 177.

Dragesund, O., J. Homre, and O. Ulltang. In press, 1980. Biology and population dynamics of the Norweigian spring spawning herring. Rapp. P.V. Reun. Cons. Int. Explor. Mer. Vol. 177.

ICES C.M. 1979/G:6 Report of the saithe (coalfish) Working Group. Inter. Council Explor. Sea. Copenhagen, Denmark. 50 p Mimeo.

ICES C.M. 1979/G:7 Report of the North Sea roundfish Working Group. Inter. Council Explor. Sea. Copenhagen, Denmark. 92 p Mimeo.

ICES C.M. 1979/G:20 Report of the Arctic Fisheries Working Group. Inter. Council Explor. Sea. Copenhagen, Denmark. 85 p Mimeo.

ICES C.M. 1979/H:5 Report of the Mackerel Working Group. Inter. Council Explor. Sea. Copenhagen, Denmark. 39 p Mimeo.

Lilliefors, H.W. 1967. On the Kolmogorov-Smirnov test for normality with mean and variance unknown. Journal of the American Statistical Association. p 399-401.

Newman, G.G. and R.J.M. Crawford. In press, 1980. Population biology and management of mixed species pelagic stocks off South Africa. Rapp. P.V. Reun. Cons. Int. Explor. Mer. Vol. 177.

Ricker, W.E. 1975. Computations and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Canada, 191:283 p.

Saville, A. and R.S. Bailey. In press, 1980. The assessment and management of the herring stocks in the North Sea and to the west of Scotland. Rapp. P.V. Reun. Cons. Int. Explor. Mer. Vol. 177.

Serchuk, F.M., P. Wood, and B.E. Brown. 1978. Atlantic cod (Gadus morhua): Assessment and status of the Georges Bank and Gulf of Maine stocks. Natl. Mar. Fish. Ser., Northe. Fish. Ctr., Woods Hole, MA. Lab. Ref. No. 78-03. 18 p Mimeo.

Siegel, S. 1956. Nonparametric statistics for the Behavorial Sciences. McGraw-Hill Book Co., Inc., New York.

Yamane, T. 1967. Statistics; an Introductory Analysis. Harper and Row, Inc., New York, N.Y.

TABLE 1. Description of recruitment for 18 fish stocks.

					Unlogged recruitment estimates					Logged recruitment estimates			
Species	Area	Reference	Age	Year	Mean	S.D.	Ratio largest Smallest	C.V.	P-values	Mean	S.D.	C.V.	P-values
Cod	Geo. Bank	Serchuk et al. 1978	1	1960-73	24,766	6,302	2.5:1	0.25	P>.20	10.09	0.27	0.03	P>.20
	North Sea	ICES CM 1979/G:7	1	1963-77	232,937	146,880	5.5:1	0.63	P>.20	19.08	0.62	0.03	P>.20
	NE Arctic	ICES CM 1979/G:20	1	1962-77	1,011,370	774,546	16.2:1	0.77	.15<P<.20	13.55	0.80	0.06	P>.20
Haddock	Geo. Bank	Clark/Overholtz 1979	1	1931-73	72,231	73,039	2,700:1	1.01	P<.01	10.59	1.55	0.15	P<.01
				1931-65	88,611	73,358	19:1	0.83	P<.01	11.22	0.54	0.05	.05<P<.10
				1966-73	6,588	5,956	92:1	0.90	P>.20	7.94	1.78	0.22	P>.10
	North Sea	ICES CM 1979/G:7	1	1961-78	1,082,995	1,542,532	100:1	1.42	P<.01	13.13	1.31	0.10	P>.20
	NE Arctic	ICES CM 1979/G:20	1	1962-78	273,897	356,238	9:1	1.30	.01<P<.05	11.94	1.12	0.09	P>.20
Herring	Geo. Bank	Anthony/Waring, In press	2	1963-74	1,743,079	1,040,054	5.2:1	0.60	P>.20	14.22	0.58	0.03	P>.20
	North Sea	Saville/Bailey, In press	0	1957-74	7,771,000	4,753,970	10:1	0.61	.01<P<.05	15.71	0.59	0.04	P>.20
	Norwegian spring spawning	Dragesund 1978	1	1950-69	13,734,900	19,059,000	130:1	1.39	P<.01	15.64	1.38	0.09	P>.20
Mackerel	Geo. Bank	Anderson/Paciorkowski 1977	1	1962-73	2,107,308	2,070,906	18:1	0.78	.01<P<.05	14.19	0.90	0.06	P>.20
	North Sea	ICES CM 1979/H:5	1	1969-79	683,364	976,403	41:1	1.43	P>.01	5.87	1.18	0.20	P>.20
Saithe	North Sea	ICES CM 1979/G:6	1	1961-78	265,372	157,683	12:1	0.59	.01<P<.05	12.33	0.60	0.05	P>.20
Whiting	North Sea	ICES CM 1979/G:7	1	1963-78	1,333,274	651,530	6.5:1	0.49	P>.20	20.89	0.53	0.03	P>.20
Pilchard	S Africa	Newman/Crawford, In press	3(?)*	1950-75	13,673,500	10,354,600	9.6:1	0.76	.01<P<.05	16.18	0.73	0.05	.10<P<.15
Anchovy	S Africa	Newman/Crawford, In press	0(?)*	1964-76	56,030,770	15,411,700	2.7:1	0.28	.15<P<.20	17.80	0.27	0.02	P>.20
Round Herring	S Africa	Newman/Crawford, In press	(?)*	1964-76	2,830,770	2,233,600	10:1	0.79	.01 P>.05	14.57	0.80	0.05	P>.20
Peruvian Anchovy	Peru	Csirke, In press	(?)*	1961-76	307,563	145,626	11:1	0.47	P>.20	12.50	0.61	0.05	P>.20
Silver Hake	Geo. Bank	Anderson 1977	1	1955-73	1,207,453	874,699	9.6:1	0.72	.01<P<.05	13.80	0.69	0.05	P>.20

*Ages are not given in tables presented in the reference.
The ages are our judgment based on interpretation of the text.

[1] H_0: The recruitment data for an individual species represents a sample of years drawn from a population with a normal or log normal distribution.

TABLE 2. Serial correlations for recruitment estimates for 18 selected fish stocks.

Species	Area	Year	η	Correlations Lag 1yr	Lag 2yrs	Lag 3yrs
Cod	Georges Bank	1960-73	14	0.575*	0.359*	0.202
	North Sea	1963-77	15	-0.111	-0.354	-
	Northeast Arctic	1962-77	16	0.327	-0.273	-
Haddock	Georges Bank	1931-73	43	0.201	-0.054	-
		1931-65	35	-0.008	-0.254	-
		1966-73	8	0.207	-0.122	-
	North Sea	1961-78	18	-0.131	-0.342	-
	Northeast Arctic	1962-78	17	0.058	-0.143	-
Herring	Georges Bank	1963-74	12	-0.158	-	-
	North Sea	1957-74	18	-0.224	0.109	-
	Norwegian Spring Spawner	1950-69	20	0.335*	-0.052	-
Mackerel	Northwest Atlantic	1962-73	11	0.447	0.134	-
	North Sea	1969-78	11	0.235	0.315	-
Saithe	North Sea	1961-78	18	0.312	-0.013	-
Whiting	North Sea	1963-78	16	0.200	-0.004	-
Pilchard	South Africa	1950-75	26	0.830*	0.510*	0.200
Anchovy	South Africa	1964-76	13	-0.056	0.032	-
Round Herring	South Africa	1964-76	13	0.545*	0.124	-
Peruvian Anchovy	Peru	1961-76	16	0.194	-0.041	-
Silver Hake	Georges Bank	1955-73	19	0.835*	0.491*	0.101

*Significant at $\alpha = .05$

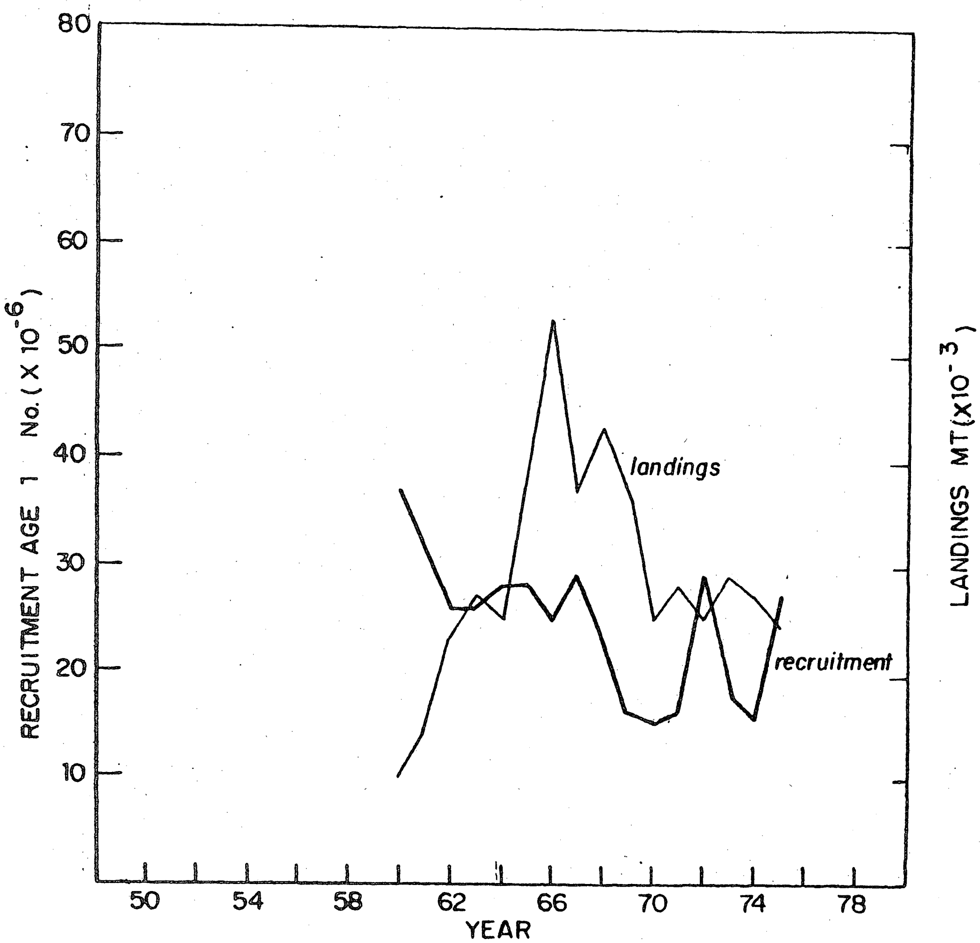

Figure 1. Nominal catch and recruitment for Georges Bank Cod from 1960 to 1975.

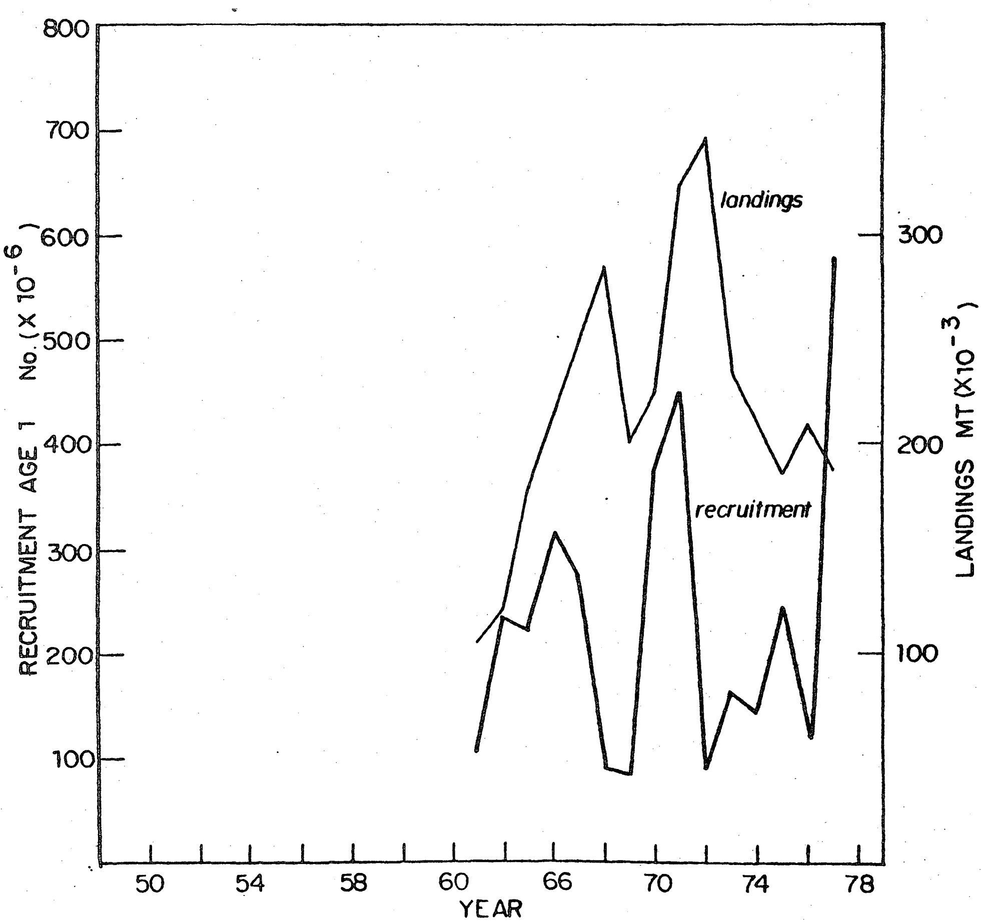

Figure 2. Nominal catch and recruitment for North Sea Cod from 1963 to 1977.

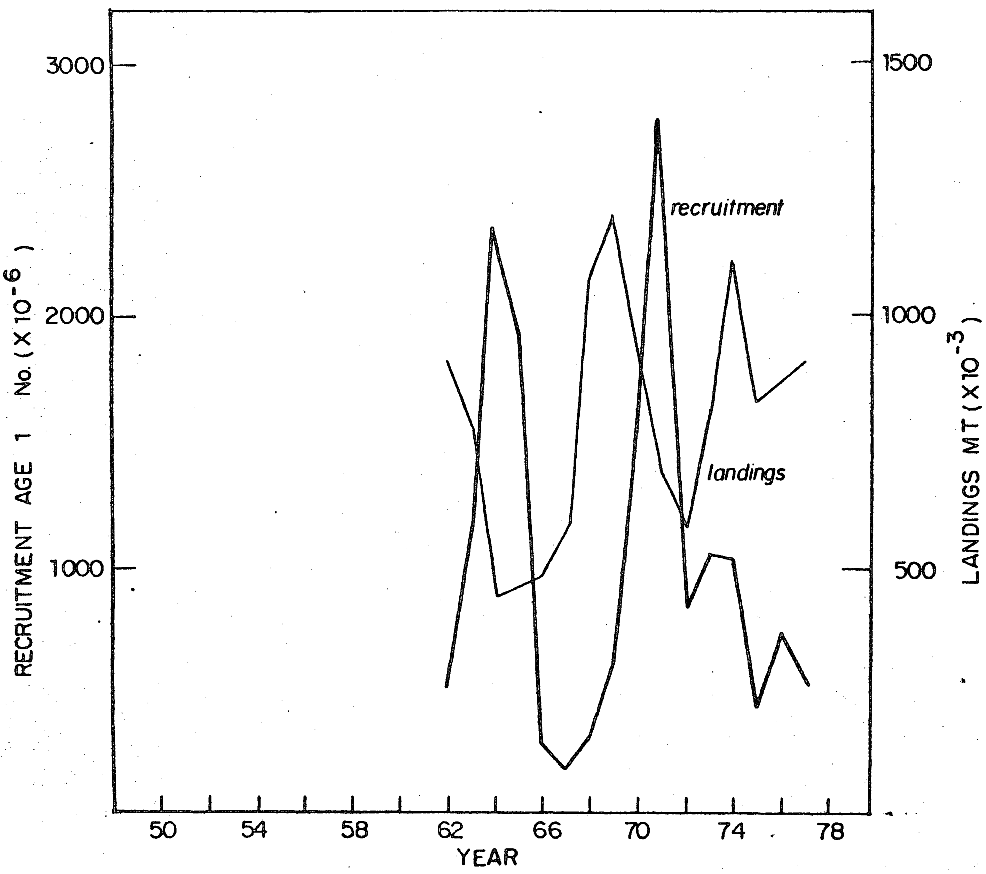

Figure 3. Nominal catch and recruitment for Northeast Arctic Cod from 1962 to 1977.

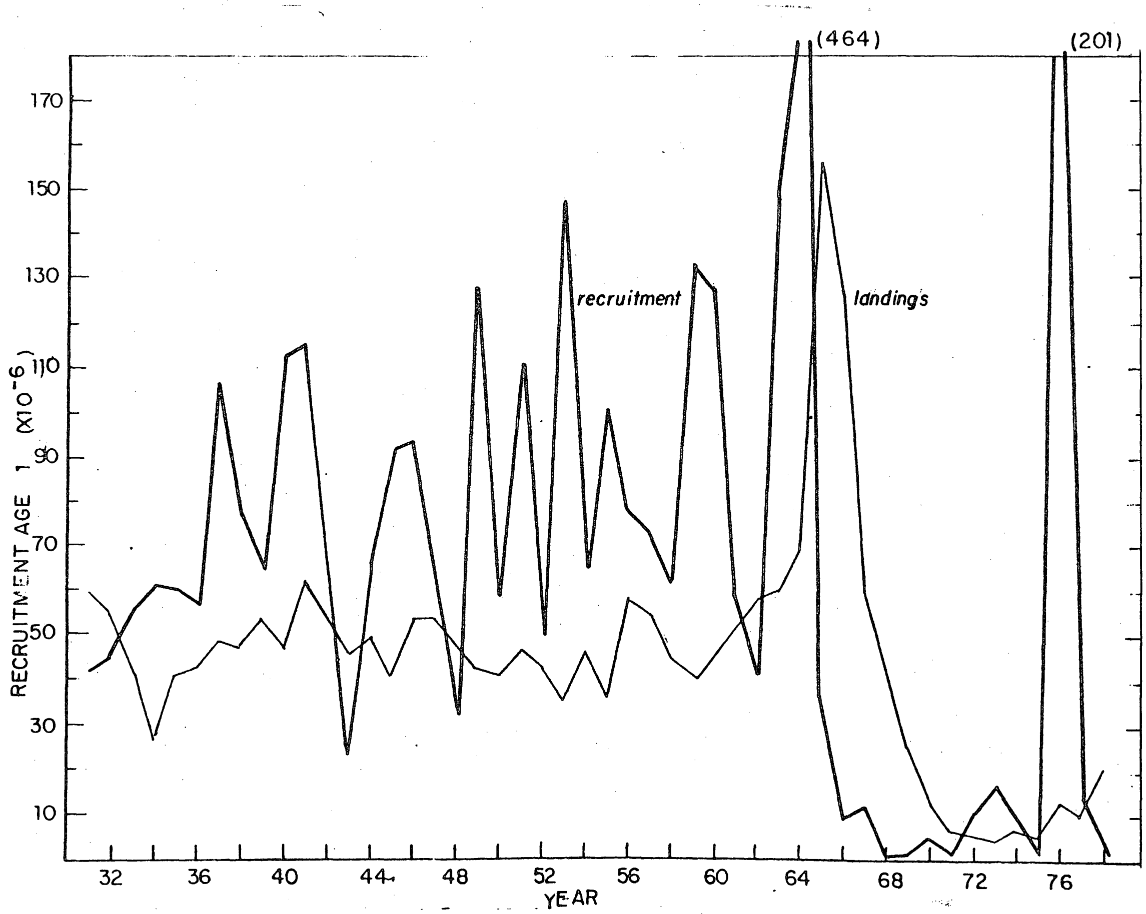

Figure 4. Nominal catch and recruitment for Georges Bank Haddock from 1931 to 1976.

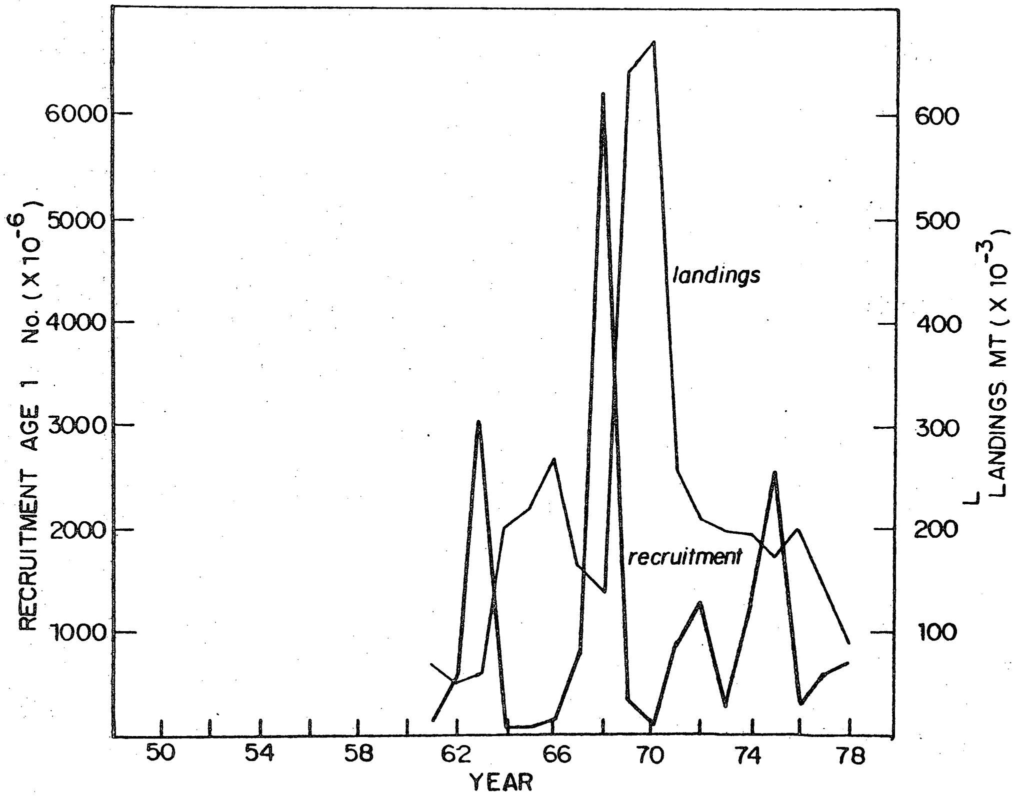

Figure 5. Nominal catch and recruitment for North Sea Haddock from 1961 to 1978.

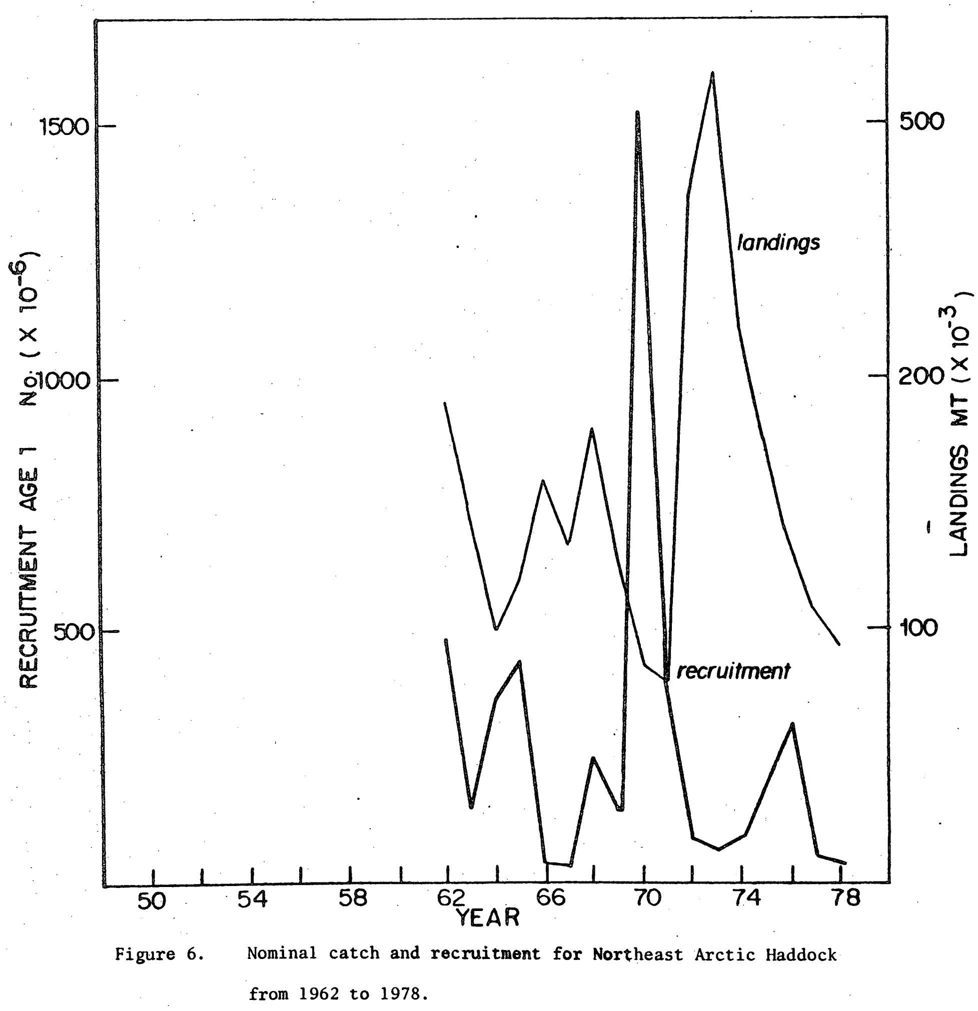

Figure 6. Nominal catch and recruitment for Northeast Arctic Haddock from 1962 to 1978.

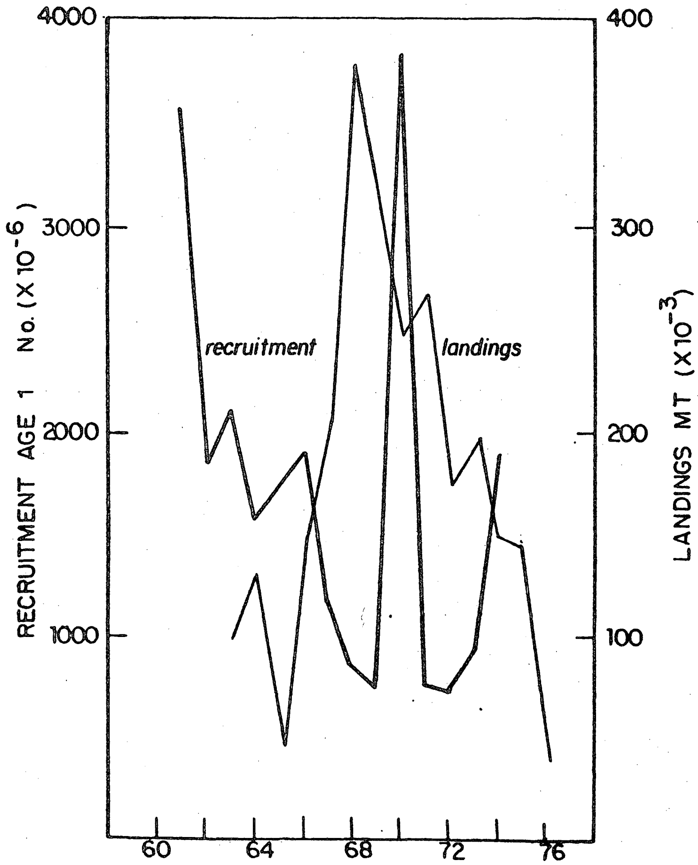

Figure 7. Nominal catch and recruitment for Georges Bank Herring from 1963 to 1976.

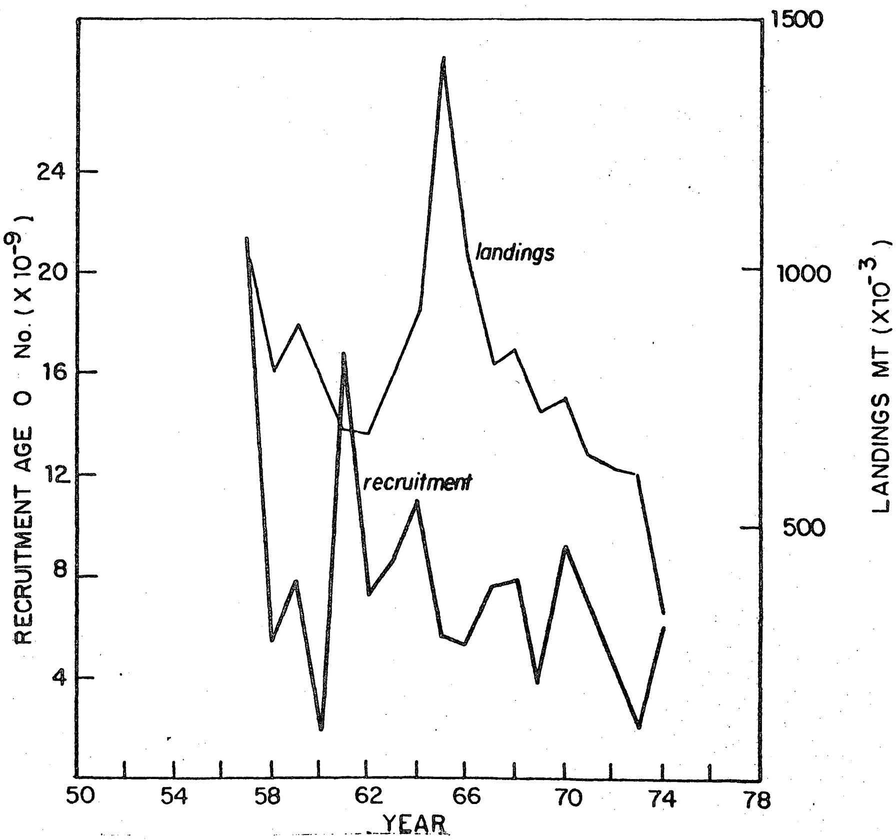

Figure 8. Nominal catch and recruitment for North Sea Herring from 1957 to 1974.

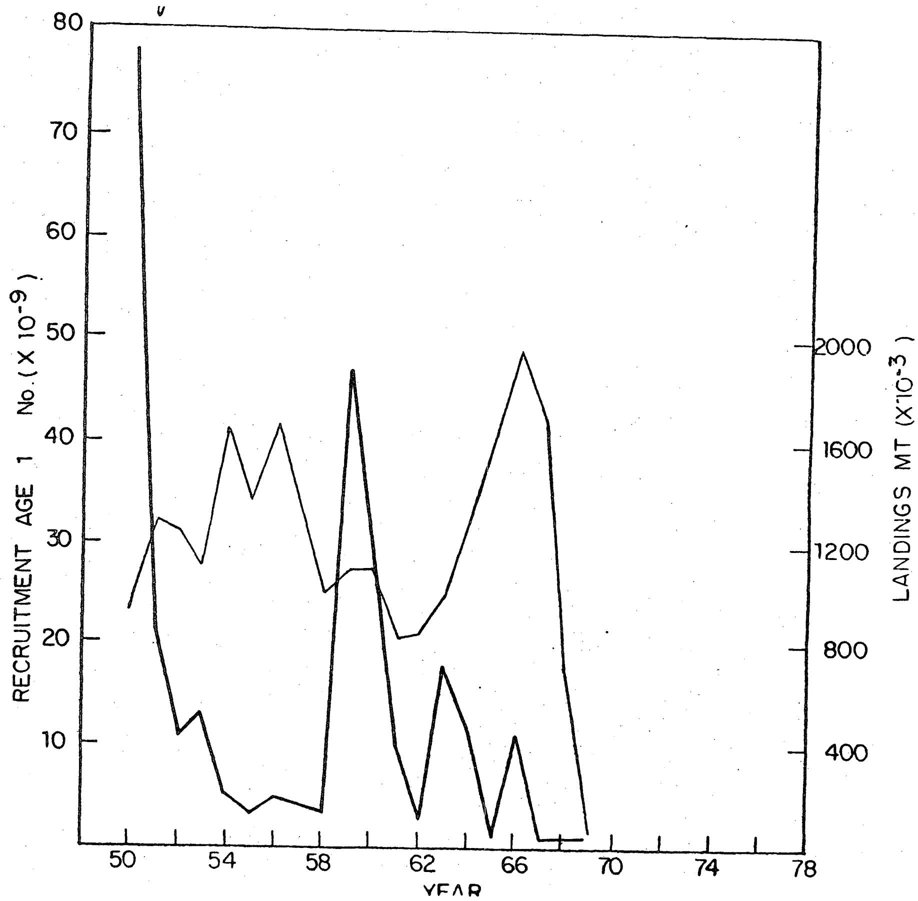

Figure 9. Nominal catch and recruitment for Norwegian Spring Spawning Herring from 1950 to 1969.

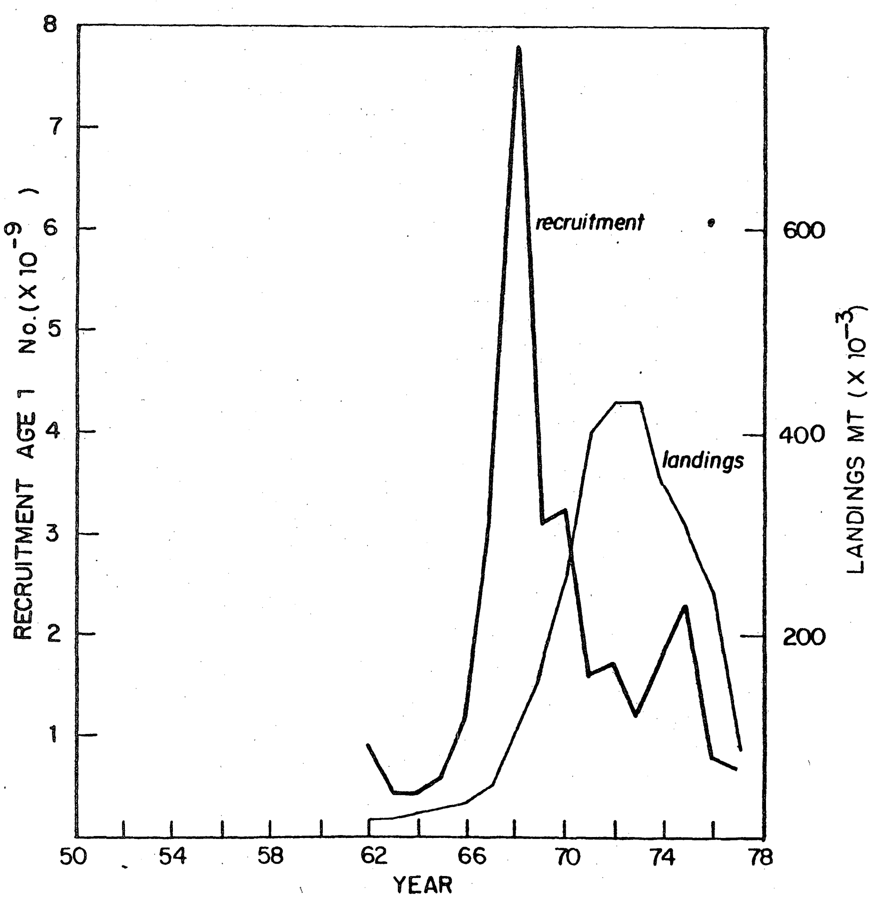

Figure 10. Nominal catch and recruitment for Northwest Atlantic Mackerel from 1962 to 1977.

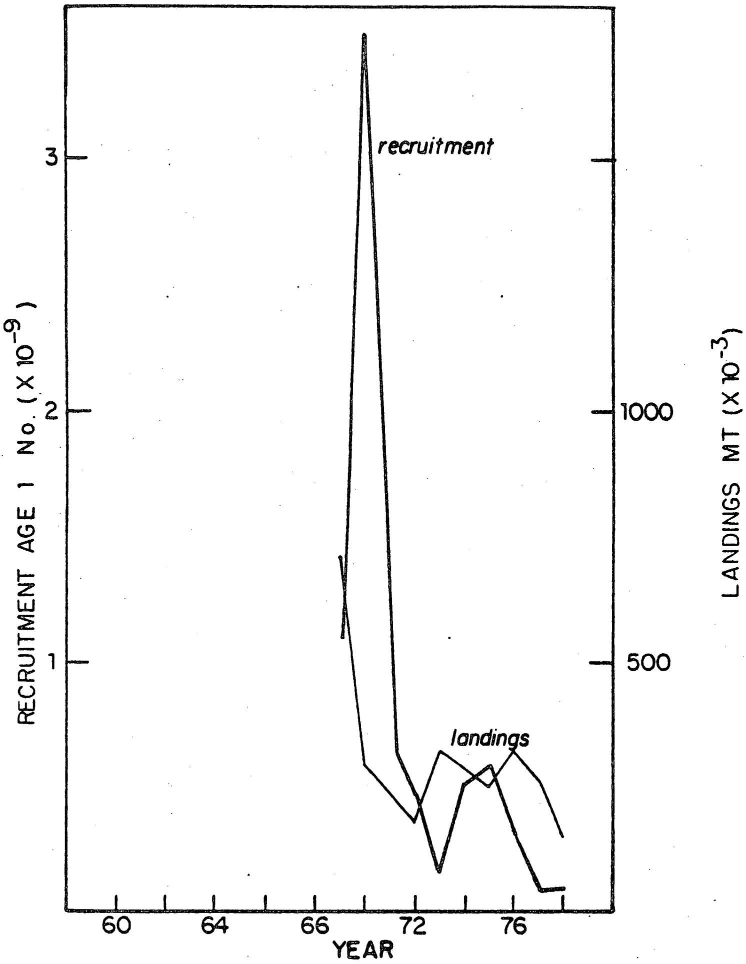

Figure 11. Nominal catch and recruitment for North Sea Mackerel from 1963 to 1978.

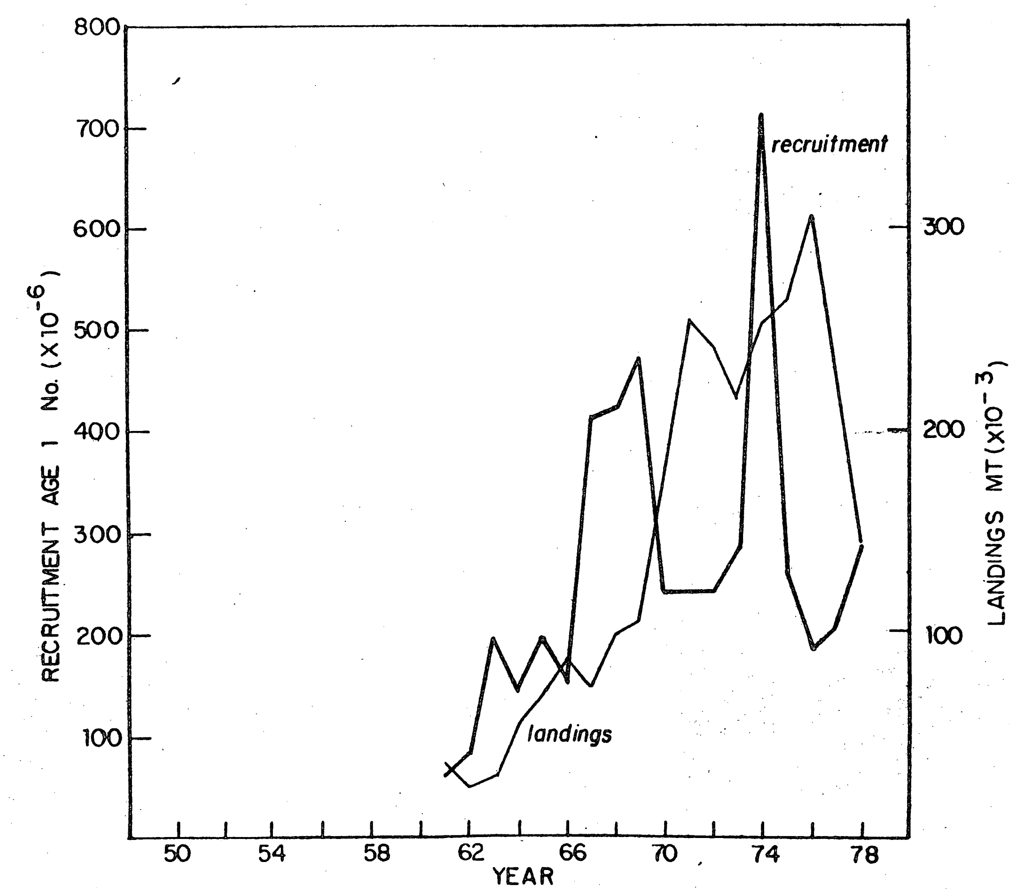

Figure 12. Nominal catch and recruitment for North Sea Saithe from 1961 to 1978.

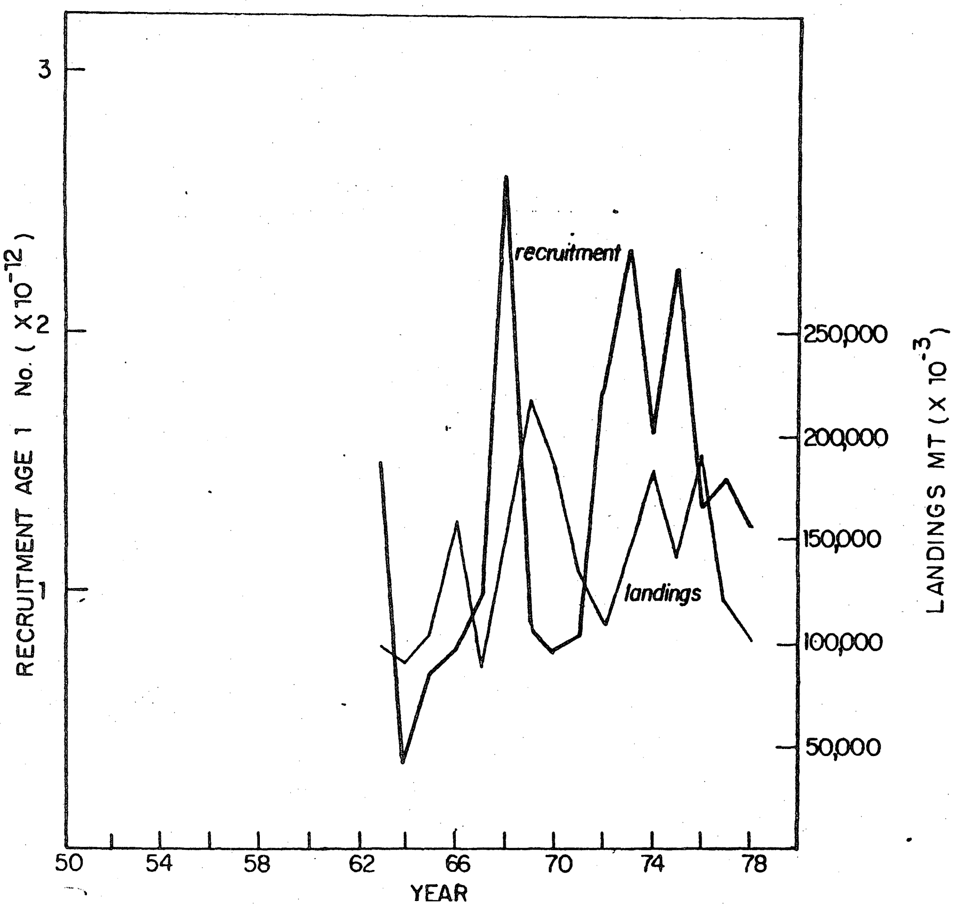

Figure 13. Nominal catch and recruitment for North Sea Whiting from 1963 to 1978.

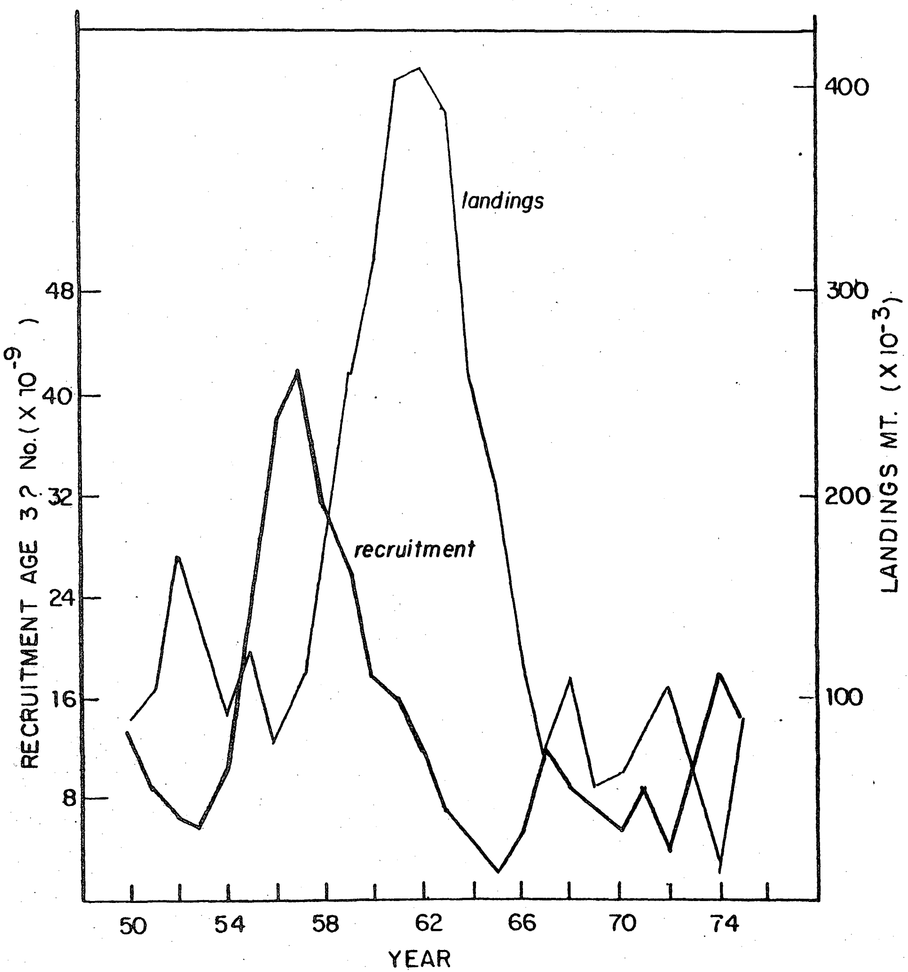

Figure 14. Nominal catch and recruitment for South Africa Pilchard from 1950 to 1975.

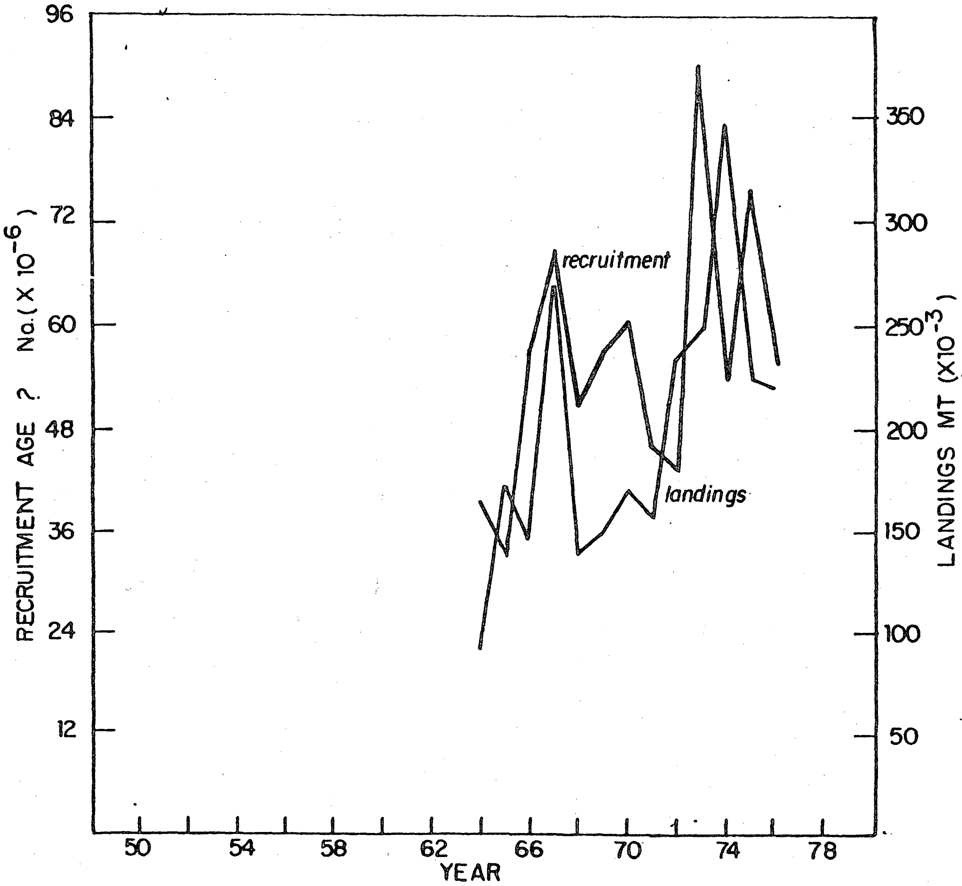

Figure 15. Nominal catch and recruitment for South Africa Anchovy from 1964 to 1976.

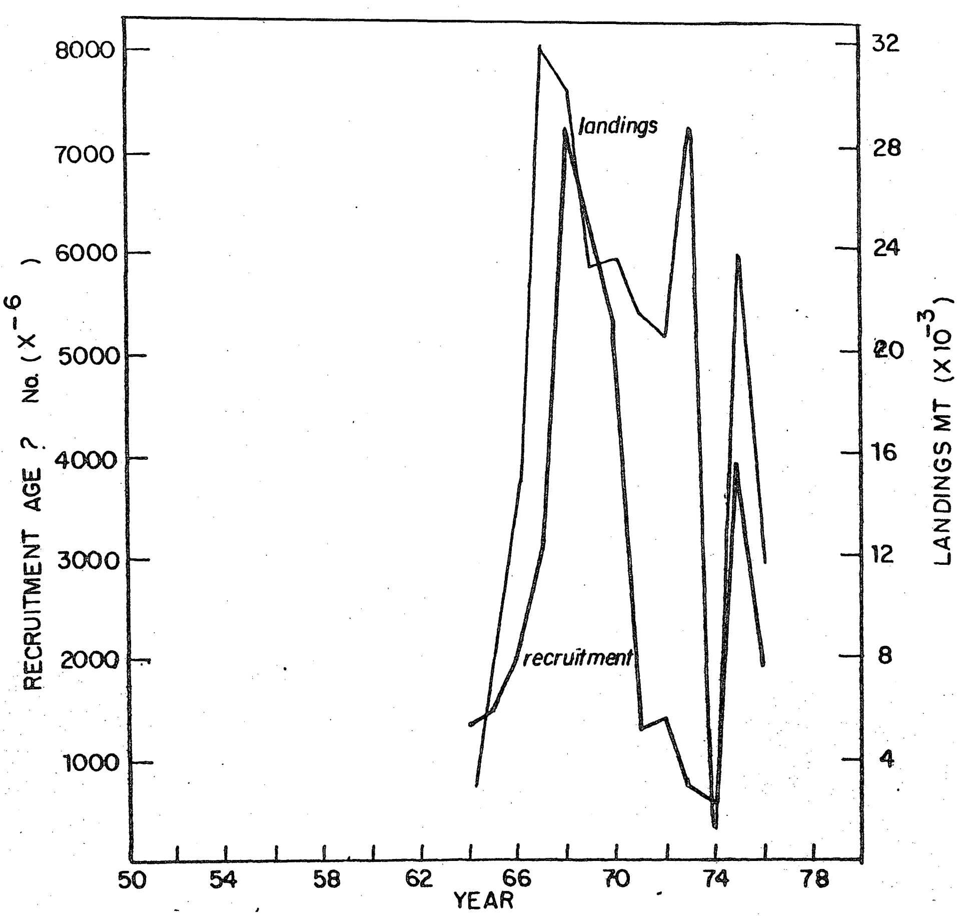

Figure 16. Nominal catch and recruitment for South Africa Round Herring from 1964 to 1976.

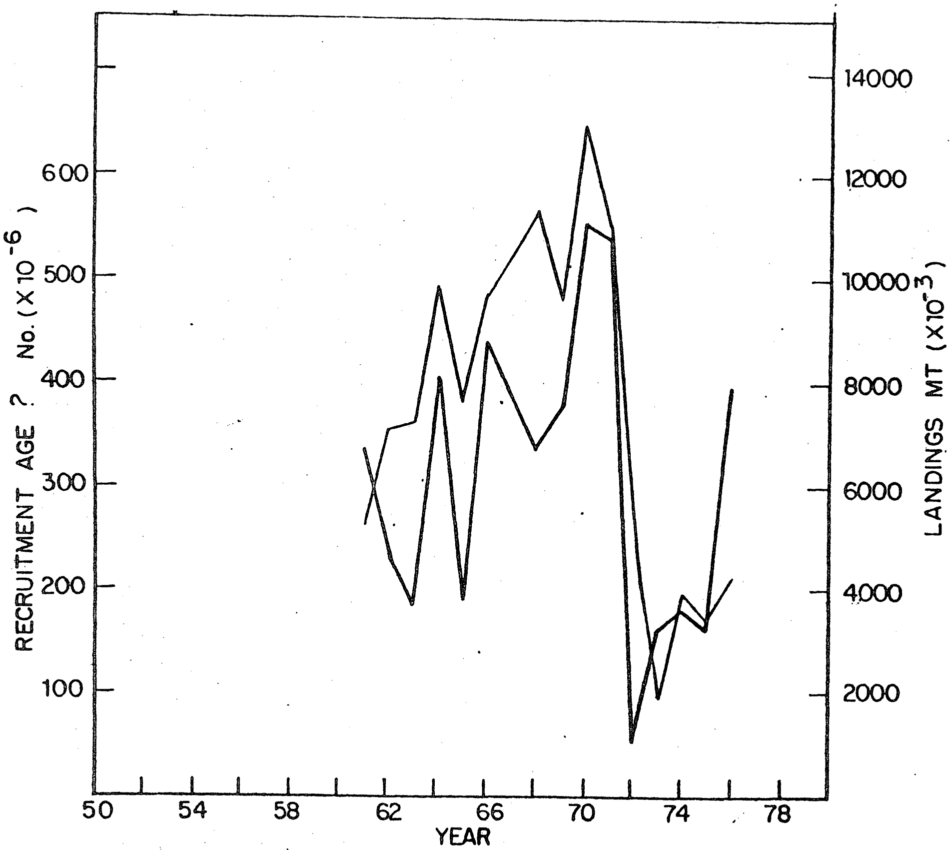

Figure 17. Nominal catch and recruitment for Peruvian Anchovy from 1961 to 1976.

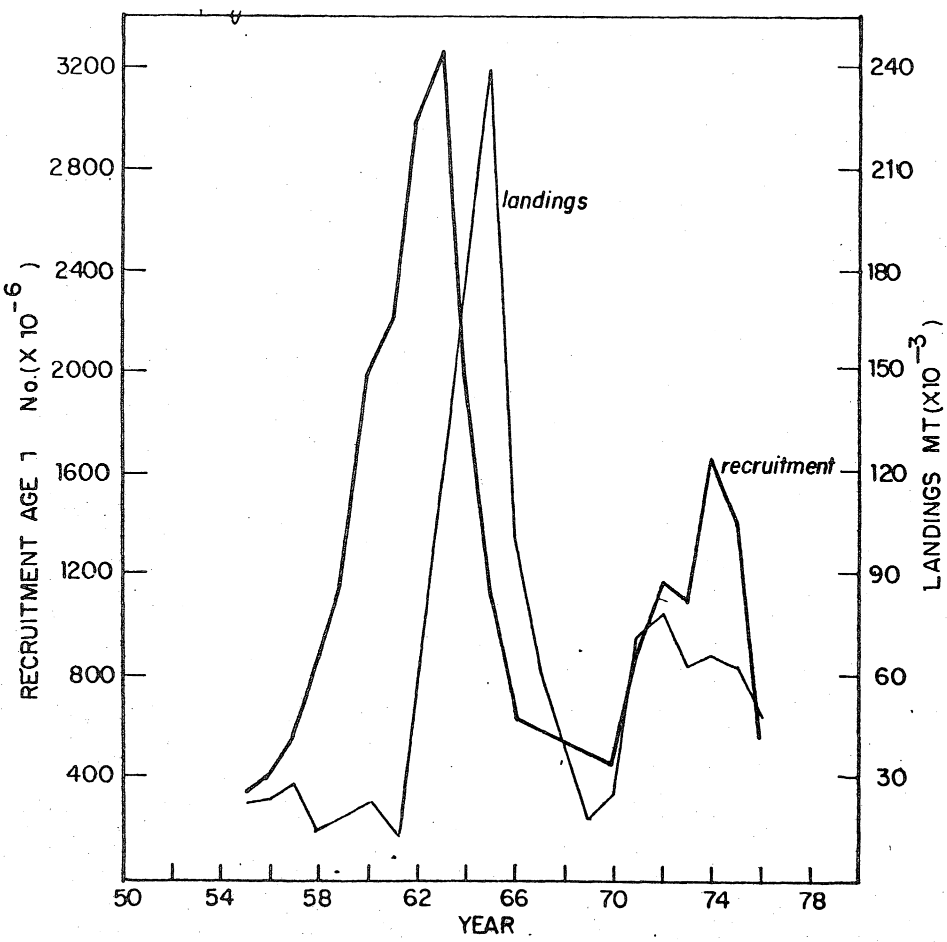

Figure 18. Nominal catch and recruitment for Georges Bank Silver Hake from 1955 to 1973.

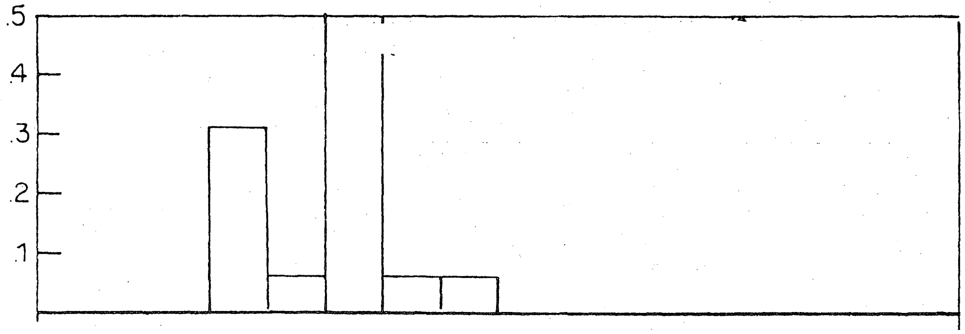

Figure 19. Frequency histograms of recruitment - Age 1 for Georges Bank Cod, 1960 to 1975. Interval width (X) is 5×10^6 and n = 16.

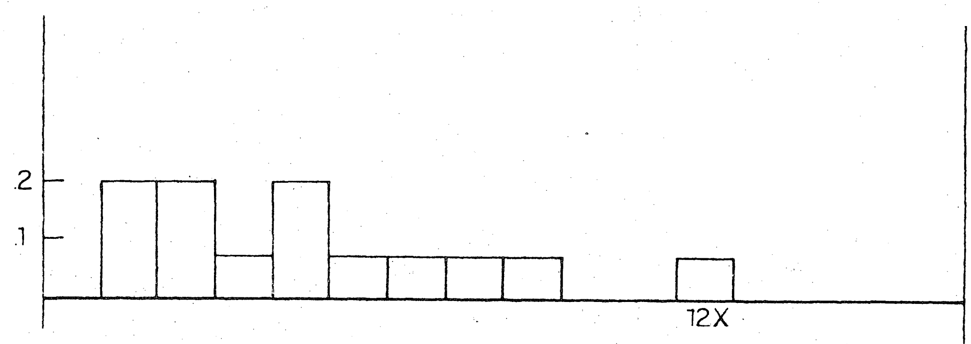

Figure 20. Frequency histograms of recruitment - Age 1 for North Sea Cod, 1963 to 1977. Interval width (X) is 50×10^6 and n = 15.

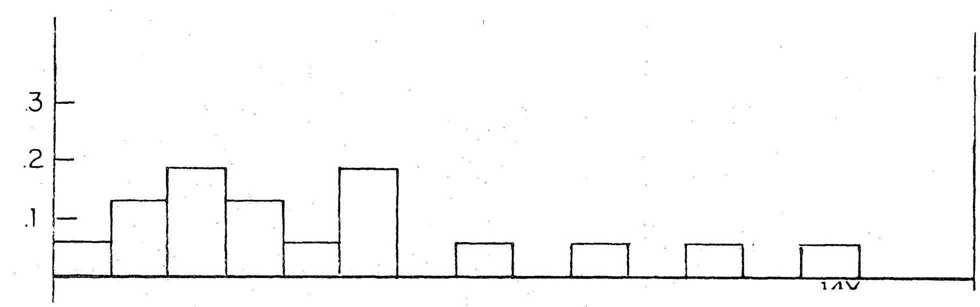

Figure 21. Frequency histograms of recruitment - Age 1 for Northeast Arctic Cod, 1962 to 1977. Interval width (X) is 200×10^6 and n = 16.

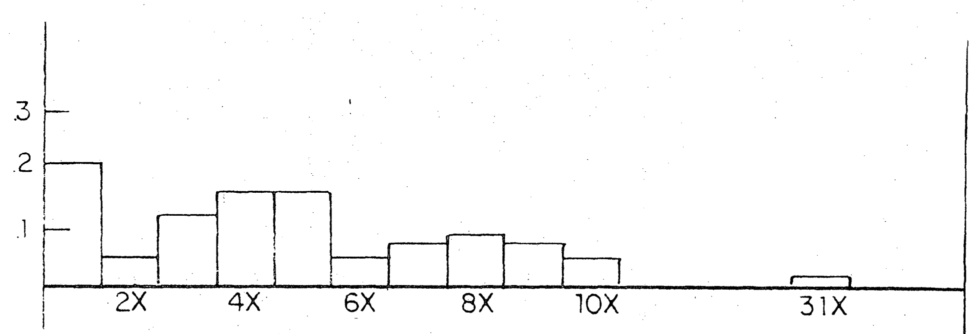

Figure 22. Frequency histograms of recruitment - Age 1 for Georges Bank Haddock, 1931 to 1973. Interval width is 15×10^6 and n = 43.

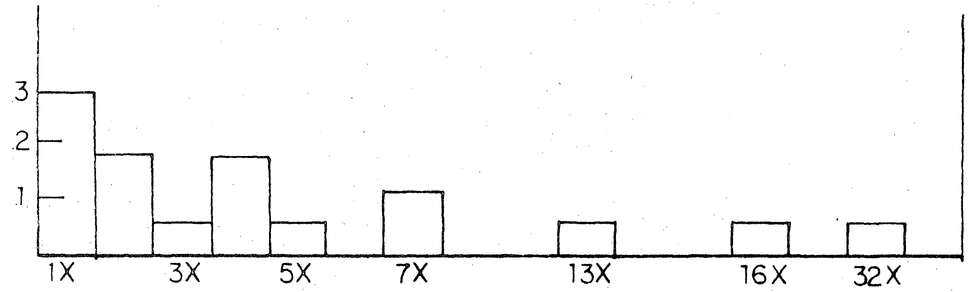

Figure 23. Frequency histograms of recruitment - Age 1 for North Sea Haddock, 1961 to 1978. Interval width is 200 x 10^6 and n = 18.

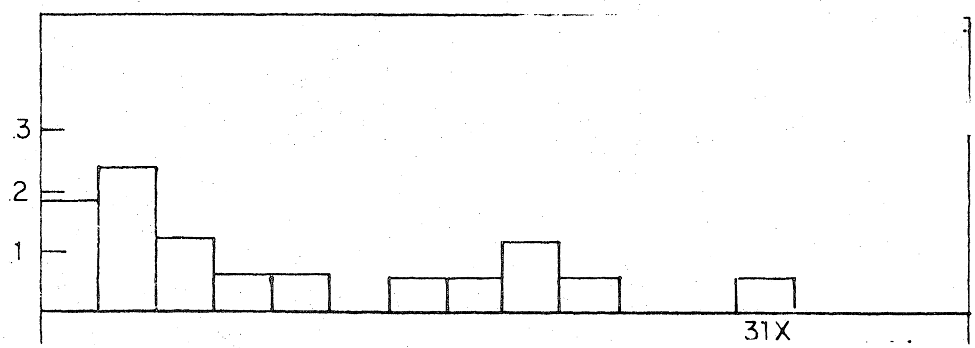

Figure 24. Frequency histograms of recruitment - Age 1 for Northeast Arctic Haddock, 1962 to 1978. Interval width is 50 x 10^6 and n = 17.

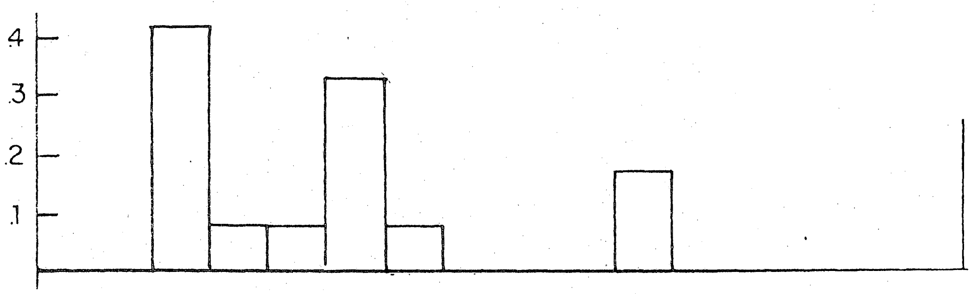

Figure 25. Frequency histograms of recruitment - Age 2 for Georges Bank Herring, 1963 to 1974. Interval width is 350 x 10^6 and n = 12.

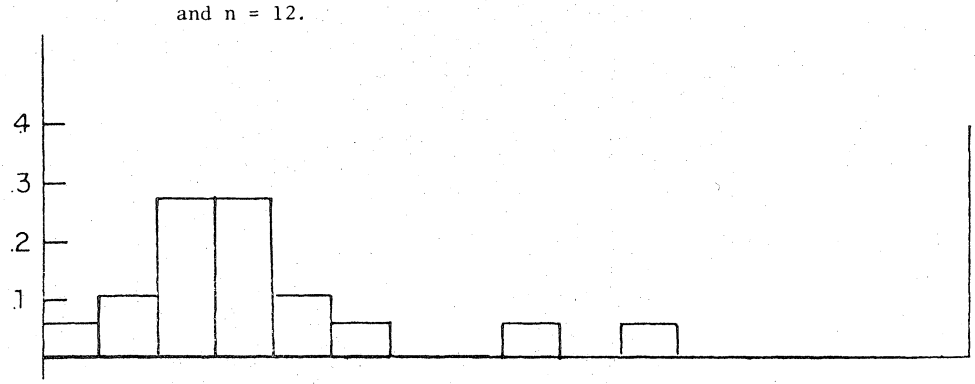

Figure 26. Frequency histograms of recruitment - Age 0 for North Sea Herring, 1957 to 1974. Interval width is 2 x 10^9 and n = 18.

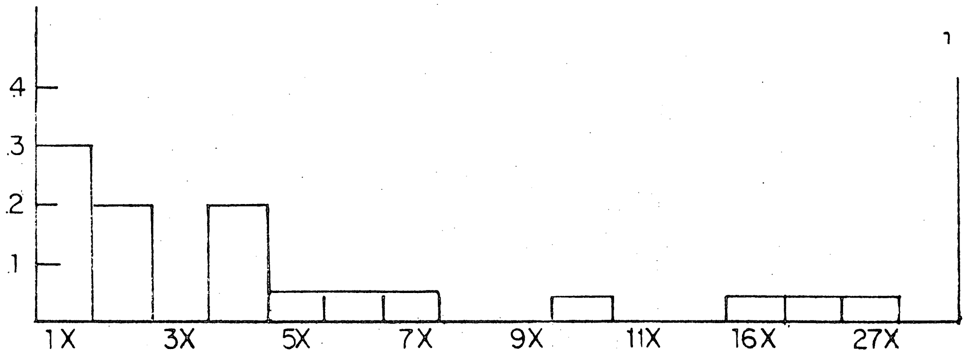

Figure 27. Frequency histograms of recruitment - Age 1 for Norwegian Spring Spawning Herring, 1950 to 1969. Interval width is 3 x 10^9 and n = 20.

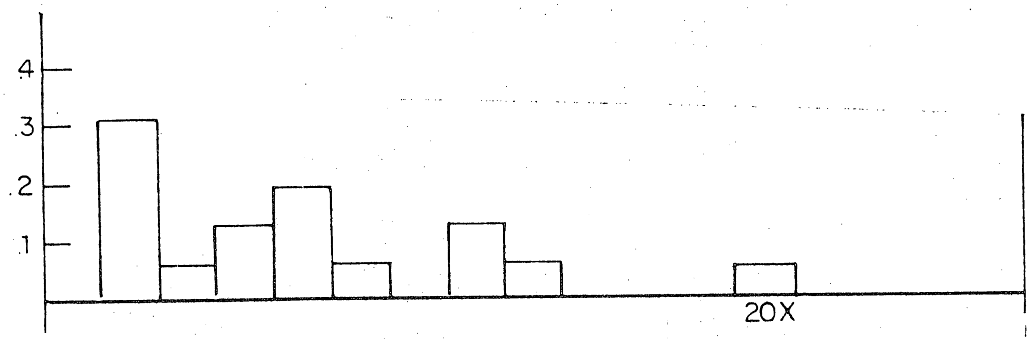

Figure 28. Frequency histograms of recruitment - Age 1 for Northwest Atlantic Mackerel, 1962 to 1977. Interval width is 400 x 10^6 and n = 16.

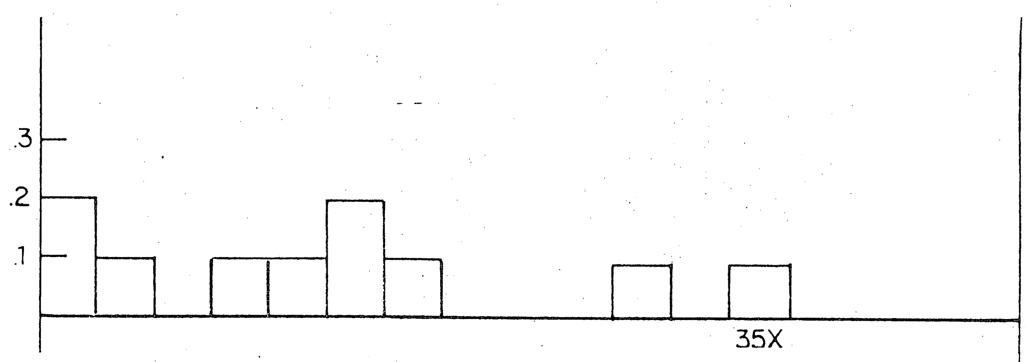

Figure 29. Frequency histograms of recruitment - Age 1 for North Sea Mackerel, 1969 to 1978. Interval width (X) is 100 x 10^6 and n = 10.

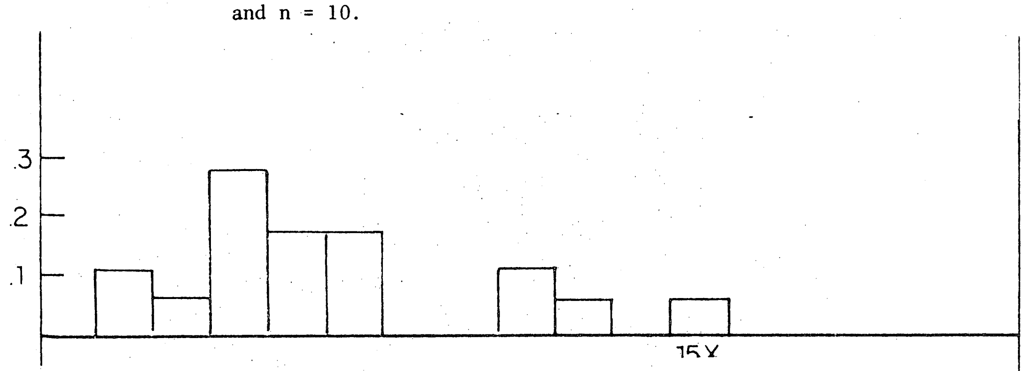

Figure 30. Frequency histograms of recruitment - Age 1 for North Sea Saithe, 1961 to 1978. Interval width (X) is 50 x 10^6 and n = 18.

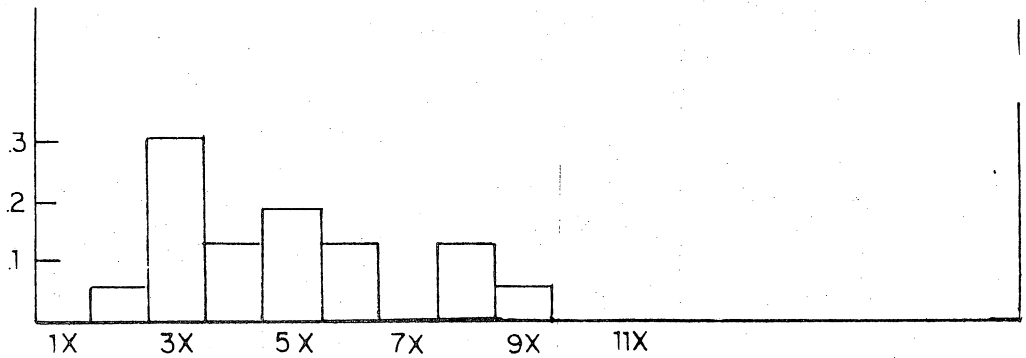

Figure 31. Frequency histograms of recruitment - Age 1 for North Sea Whiting, 1963 to 1978. Interval width (X) is 300 x 10^6 and n = 16.

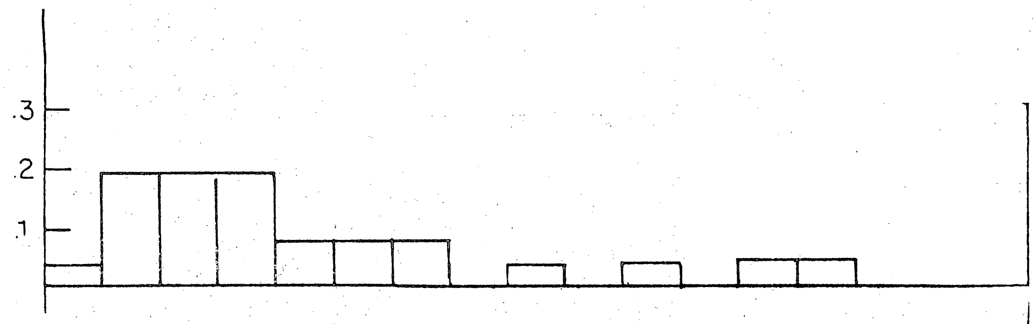

Figure 32. Frequency histograms of recruitment - Age 3 (?) for South African Pilchard, 1950 to 1975. Interval width (X) is 3 x 10^9 and n = 26.

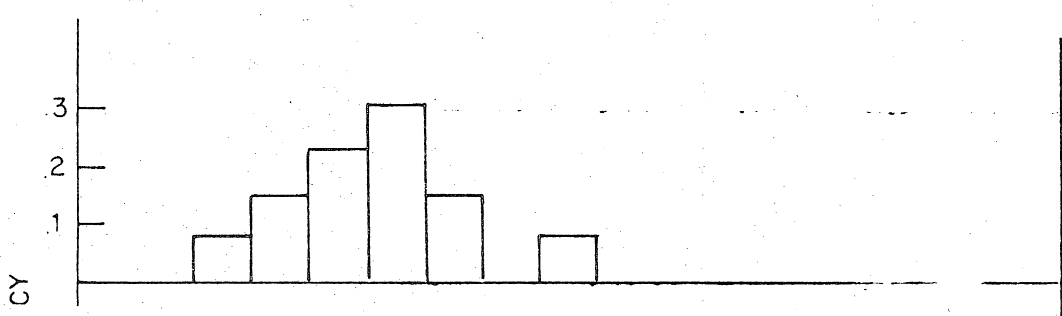

Figure 33. Frequency histograms of recruitment - Age 0 (?) for South African Anchovy, 1964 to 1976. Interval width (X) is 11 x 10^9 and n = 13.

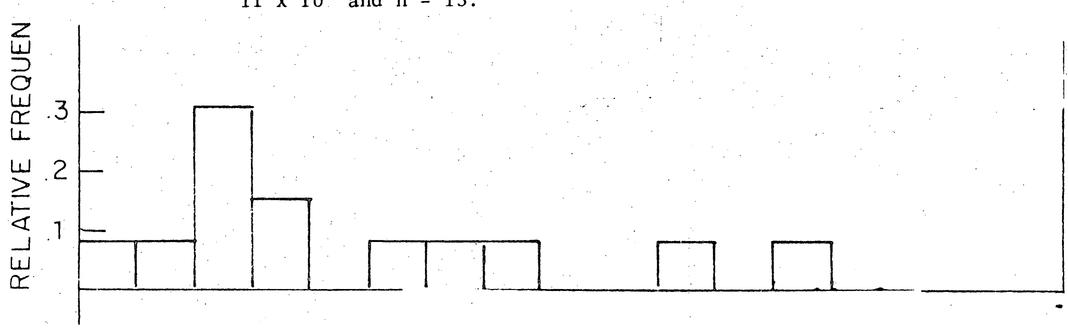

Figure 34. Frequency histograms of recruitment - Age (?) for South African Round Herring, 1964 to 1976. Interval width (X) is 600 x 10^6 and n = 13.

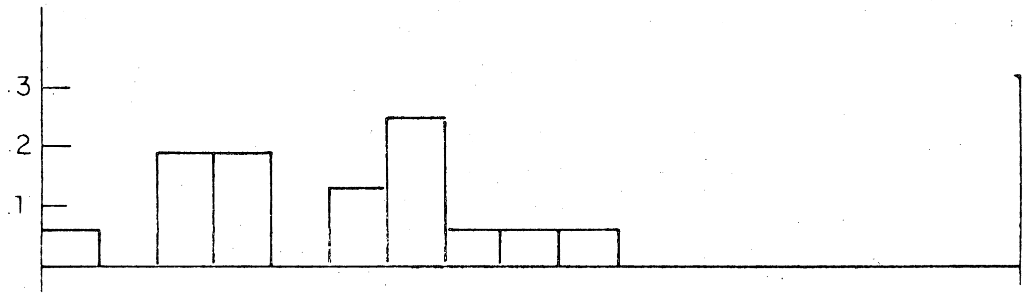

Figure 35. Frequency histograms of recruitment - Age (?) for Peruvian Anchovy, 1961 to 1976. Interval width (X) is 60 x 10^6 and n = 16.

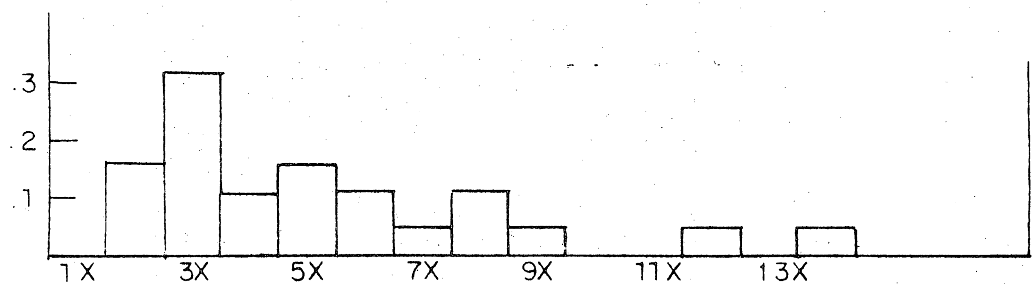

Figure 36. Frequency histograms of recruitment - Age 1 for Georges Bank Silver Hake, 1955 to 1973. Interval width (X) is 250 x 10^6 and n = 19.

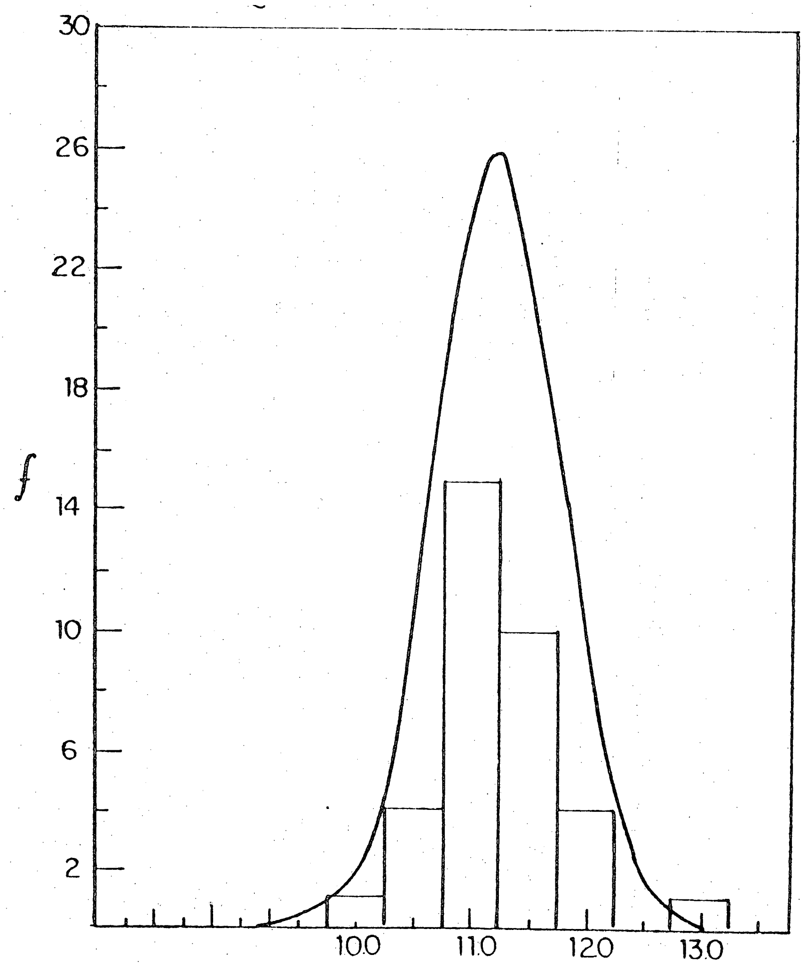

Figure 37. Fit of the normal curve to logged haddock recruitment estimates, 1931 to 1965.