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Flemish Cap cod year-class strength and environmental variables

by

S. A. Akenhead
Research and Resource Services
Department of Fisheries and Oceans
P. O. Box 5667
St. John's, Newfoundland A1C 5X1

INTRODUCTION

Flemish Cap is a roughly 100 km radius fishing bank at 47°N 45°W, with depths between 125 and 400 m. It is an isolated bank, with the 1100 m deep Flemish Pass separating it from the Grand Bank. The cod stock there (3M) is considered to be a discrete stock (Templeman 1977; Lear et al. 1980) and the area was selected as an arena for studying recruitment variations (Akenhead 1978). A review of the biological suitability of the area for such a project was completed by Templeman (1978), complementing review of the physical oceanography of the area by Hayes et al. (1978). In the last decade, the fishing pressure on Flemish Cap has become devastating, partly due to the displacement of fishing effort by the international fleets from a Canadian 200 mile limit since 1975. The 1981 spawning stock size is perhaps only 5% of levels observed in the 1960's. A reduction in stock size like this would be expected to jeopardize future recruitment if there were a stock-recruitment relationship. The implications of this for research were discussed by Anderson (1982).

MATERIALS

Year-class strength (YCS) estimates are for 3-yr-olds from the virtual population analyses of 3M cod by Wells (1973) and Gavaris (1981). Confidence in these VPA estimates is perhaps not as good as for other cod stocks in the Northwest Atlantic, due to relatively poor biological sampling by the international fleet. There is almost no data at all for the period 1969-72, leaving a gap in the YCS estimates for 1966-1968. While evidence from 4-yr-olds does suggest that the 1968 year-class was large, it is perhaps interesting to see if this conclusion can be reached from observing environmental correlates to recruitment. YCS estimates for 1965 and 1977, the initial point for the VPA's, were dropped, giving 16 points to work with.

Using a fixed weight-at-age the authors of the VPA's calculated the stock biomass at different ages. For this paper, the spawning stock is considered to be five years and older fish. This assumption is robust, since the correlation of 5+ and 6+ biomass has a coefficient of 0.96.

Temperature and salinity data from Akenhead (1981) were used, these are surface (0-20 m) monthly mean values, largely from the U.S. Coast Guard Ice Patrol surveys and from the Northwest Atlantic Fisheries Centre, formerly the Fisheries Research Board of Canada Biological Station, St. John's.

Winds data were provided by the Atmosphere and Environment Service, D.O.E., Canada. The data used in the report by Swail and Saulesleja (1981) were generously provided by Mr. Saulesleja. These winds are calculated by a geostrophic model from air pressure fields, giving direction and intensity for 6 h intervals on a 25 point grid. No station actually occurs on Flemish Cap, however AES-14 is at 46.8N 48.2W, the eastern edge of the Grand Bank. Since the centre of Flemish Cap bank is about 140 nmi due east (half a grid interval), this was felt to be a reasonable indicator of Flemish Cap winds, especially since the approach was based on 2 week averaged data. The data from this model extends to 1978. A second reason for using this station is that there is now an oil field on the eastern Grand Bank (Hibernia), and if historical winds from this area are valuable fisheries correlates, more recent wind estimates will be available for predictions.

RESULTS

Stock Size And Year-Class Strength

No relationship between stock and year-class strength is obvious from the data for 3M cod. Akenhead (1982) and Larkin (1973) comment that any dome shaped curve being forced through such a scatter as that of the 3M cod stock-recruitment plot (Fig. 1), is likely to be an artifact.

The only conclusion appears to be that if there is a relationship, it is masked by the environment. The correlation of stock and YCS is not significant ($r^2 = .05$) although a declining trend can be noted. Current theory holds that variable carrying capacity of the ichthyoplankton environment accounts for this observed YCS variability (Akenhead 1982; Sharp 1981).

In order to determine the existence of spawning stock size effects on 3M cod YCS, an address to the environmental variability, as it is reflected in YCS, is a prerequisite to future research. In fact, this concept has underlain the Canadian research efforts on ichthyoplankton ecology on Flemish Cap.

Temperature, Salinity and Year-Class Strength

Only April till August have sufficient coverage address to water properties on Flemish Cap. Correlation of the temperature and salinity signals from the series compiled by Akenhead (1981) require some lumping before use, since missing cells must be filled with monthly means in order to generate annual signals.

The result for sea-surface salinity (April to August combined) was not significant ($r^2 = .008$). Temperature of the euphotic zone (0-20 m) was postively correlated to YCS for both April-May ($r^2 = 0.20$) and April-August ($r^2 = 0.15$) indices. Missing data for both data sets in this correlation meant that only 13 points were able to be considered, and these correlation coefficients are not significant ($\alpha = .05$).

April-August temperature and salinity are significantly correlated ($r^2 = .36$), as are the April-May temperature and salinity ($r^2 = .46$). Using both T and S for April-May gives a significant YCS correlation ($R^2 = .64$) that is negative for salinity and positive for temperature. Adding the 5+ spawning biomass increases the correlation only marginally ($R^2 = .66$). Spawning stock size is a negative effect on year-class strength in this analysis, but not a significant one.

For the 13 points in common for spawning stock and the temperature and salinity, the trend is for warm fresh spring water to produce larger year-classes. This explains 64 percent of the YCS over those years, and spawning stock has no further explanatory power for this series.

But will this 13 point environmental effects result hold for the 17 points available by including years for which there is no matching spawning stock estimates? Unfortunately, these 4 extra points degrade the correlation to only 15% of the variance (the $\alpha = .05$ level is 35%). Using the summer temperatures and salinities as well does not give a significant correlation.

Thus, spawning stock has no power beyond surface temperature and salinity and none on its own, in explaining cod year-class strength fluctuations in Flemish Cap. The significant temperature and salinity trends for the data series where spawning stock estimates exist is not significant for the larger series using all possible points for an environmental correlate. The conclusion is that neither the sea-surface temperature nor salinity, nor their combination, nor spawning stock, nor spawning stock combined with sea-surface temperature and salinity are factors significantly explaining Flemish Cap cod year-class strength. However, there is a suggestion that relatively warm fresh spring surface conditions may be favourable to cod.

Wind Frequency and Year-Class Strength

A data matrix from the fortnightly frequencies of 8 wind directions was generated for the spring, March to May. Each yearly vector was correlated to the 16 estimates of YCS described. This gave 48 correlations, from which about 2 might be expected to be significant at $\alpha = .05$ if the data were random numbers. In fact, the chance of spurious correlations may be slightly higher because the 8 winds are not independent. This exercise resulted in the correlations presented in Table 1. Two groups of correlations are noted. Three significant negative correlations ($\alpha = .05$) are found with the south wind in early March and late April. A significant positive correlation with the north wind in early March occurs in a group with other non-significant but indicative correlations ($\alpha = .20$). The clustering of indicative correlations with the same sign yields credibility to those results.

The YCS of cod may be tentatively concluded to be accounted for by a particular wind direction, and it can at least be concluded that wind is significantly involved in year-class strength formation. The best correlation, -.79, was with the south wind in late March and was further examined. Figure 2 is the plot of YCS against this wind frequency. The two initial VPA points, 1965 and 1977, are not in agreement with this correlation. If it is real, they should be larger year-class strengths, especially 1965. The question of YCS for the missing years of the VPA is examined by the time-series plots of YCS and the late March south wind frequency presented in Fig. 3.

This plot suggests that the 1968 YCS should have been high, which is borne out by the 4-yr-old recruits figures used by Anderson (1982). The major outlier is the low 1970 YCS, a point discussed later.

How will the correlations be affected by lumping some time-direction cells of the wind data matrix? Spurious correlations should disappear after this treatment. This question led to adding together the south winds for all of March and April. This gave a significant negative correlation that explained 35% of the YCS. The scattergram for this suggested that the 5 good year-classes of the 14 considered were all years of infrequent March-April south winds. This lumped index seems effective only at predicting when large-classes will not appear, but does not effectively predict when large year-classes will appear, since small and large yearclass strengths appear at relatively low March-April south wind frequencies.

This exercise was repeated for the four positive correlations in the upper left hand of Table 1, all of which are significant at $\alpha = .20$, and one of which accounts for 26% of the variance in YCS. The result explains only 22% of the variance and is not significant ($P = .066$). Linear combination of these two indices is not an impressive increase in explanatory power, the result of both variables is only 46% of the variance in YCS.

The next approach was the application of multivariate exploratory techniques. Multiple linear regression was employed, but with some reservations. The reservation is due to the likelihood of spurious correlations when using 49 independent variables. A 3 factor model can be expected to yield $\alpha(49 \times 48 \times 47) = 1100$ significant correlations at $\alpha = .01$. Results are thus to be taken only as indicative of potential mechanisms and as corroboration of other results.

Simple correlation of 3M cod YCS and one wind cell gave a best result of 63% explanation. Incorporating two cells gave an increase of 16% in this, to 74%. The increase is due to incorporating the early March north wind with a positive effect. It is pleasing to discover that, at this level of environmental correction to the stock-recruit relation, stock-size becomes a significant effect. This best 3 variable model incorporates 5-plus biomass as a negative effect. The equations are presented as Table 4. This winds and stock-size model explains 87% of the 3M cod YCS.

DISCUSSION

March winds account for 63 to 74% of the variance in 3M cod YCS, independent of spawning stock. Spawning stock accounted for about 13% of the variance, as determined by increase of the multiple correlation coefficient.

March is the spawning month for 3M cod, as evidenced by the spawning curve presented by Anderson (1982). Spawning appears to be completed before April, and cod are not fully matured in early February (R. Wells, pers. comm.). The observed March winds effects lead to considerations of the effect of winds on cod eggs and early larvae. At 4°C, few eggs would be expected to have hatched during March, so direct effects (i.e. advection) are limited to eggs.

The hypotheses for mechanisms of negative south wind effects therefore include: a) egg transport off the Cap, and b) alterations to the production cycle that provide increased carrying capacity for early larvae. A positive correlation with north winds in early March, that is not present in April, supports the existence of some very early annual production cycle or egg transport effect. This is substantiated by the 2 variable regression result, with the best model being all March winds.

Transport

The transport of water out of the Flemish Cap clockwise gyre has been studied by means of drifting satellite tracked buoys (Akenhead 1978, Ross 1980). One characteristic noted is their tendency to exit from the Flemish Cap waters in the same region, towards the southeast.

South winds impart a net eastward movement to near-surface waters, perhaps acting to move newly spawned eggs from the southwest to the exit region of the Cap gyre. Whether such wind stress is sufficient to move eggs the required distance from cod spawning areas, and to overcome temporarily the forces that cause the gyre is not determinable yet. If in fact the southeastward departure of the buoys is as important as it appears to be, the negative south wind effect will have to be tied to egg and larvae departures from there in order to have egg transport an acceptable mechanism of year-class strength variation.

North and northeast winds in March are positive effects, and must prevent egg losses from the Flemish Cap gyre. The related westward Ekman transport of the near-surface water counters the gyre in northern Flemish Cap, and re-inforces it in the south. Both of these effects could be interpreted as preventing egg losses from the southeast. In the same way, south winds might move eggs in northern Flemish Cap eastward, allowing them to be lost in the southeast.

Tentatively, egg transport seems a possible mechanism by which March meridional winds could have an effect. The lack of a diagnostic model of the circulation of Flemish Cap prevents a more rigorous examination of this hypothesis. As well, the location of cod spawning is not clearly identified.

Countering the argument for egg transport and perhaps thereby supporting the argument for production cycle changes, the famous correlation of North Sea haddock and wind (Carruthers et al. 1951) was experimentally examined by Rae (1957), who determined that in fact the supposed wind-induced egg drift was negligible. In the case of cod, initial egg liberation occurs well below the surface (250 m in the Gulf of Georgia, J. Mason, D.F.O. Nanaimo, pers. comm.), making surface drift from wind unlikely to have an effect. The vertical distribution of cod eggs on Flemish Cap is not yet determined.

Production Cycle Changes

The alternative effect is an alteration of the spring and summer production cycle, with south winds somehow hampering one type of production cycle that favours cod year-class strength. The south wind does not appear to be a weak wind. While it is less frequent than the southwest, west and northwest winds (Table 2), it has a long-term mean velocity similar to the north and west winds (Table 3). This tends to preclude the idea that periods of calm allow the early development of spring stratification and hence an early bloom. There may be future support to supposing that more sunshine accompanies the south wind, as is observed at St. John's. This increased sunshine could allow an early spring bloom to be linked to more cod survival, however this data is not yet examined.

Spring stratification does not occur in the ocean climate data from Stn. 27 (47°33'N, 52°35'W, off St. John's) until late April, as revealed by inspection of sigma-t profiles. This station is in the Labrador current and might be thought to be slightly delayed in spring stratification compared to Flemish Cap. Anderson (1980) presents late April-early May chlorophyll data for Flemish Cap, suggesting that spring bloom was well underway by April 22, with surface nutrients declining through this period. Grimm et al. (1980) show little evidence for stratification of the central part of Flemish Cap from a section during April 18-20 1978, however the periphery of the bank was stratified. This agrees with Anderson (1980) who reports diminished chlorophyll in the center of the Cap in late April. From this it concluded that spring bloom on Flemish Cap begins in the second half of April, similar to stratification at Stn. 27. The relevance of this observation is that it does not agree with the hypothesis that the significant March winds are acting to delay or advance the timing of spring bloom, in accordance with the match-mismatch theory of variable year-class strengths. The winds correlated to cod year-class strength appear to be a month or more before spring bloom.

Upstream Effects

There are two remaining speculations. One is that the positive effect of north winds and negative effect of south winds may be related to the Labrador Current's outer branch volume and speed. This outer branch gives rise to the Flemish Cap branch of this current, which probably drives the Flemish Cap gyre. The stronger the gyre, the better the cod year-class, perhaps. This is contrary to the correlated wind stresses, however, since the required eastward Ekman transport from the south wind is contradicted by the sign of the correlations (negative).

The remaining speculation is that meridional March winds reflect the intensity of winter cooling and hence turnover of the surface waters with resultant nutrient replenishment. This could be an important component to productivity on Labrador Sea fishing banks. O.W.S. Bravo data indicated the period 1969-71 to be an anomalous accumulation of low salinity water in the Labrador Sea, preventing winter turnover to depths exceeding 200 meters (Lazier 1981). This lack of nutrient replenishment for the surface waters may account for these 3 years being poor cod year-class strengths in Labrador and Flemish Cap. 1969-71 were very poor year-classes for Labrador (Wells 1981). Sutcliffe et al. (1982) discuss a nutrient hypothesis to account for changes in growth and year-class strength of Labrador cod, suggesting that the tidal injection of sub-surface Labrador sea water into the Labrador Current in Hudson Strait accounts for variations in the productivity of the Newfoundland continental shelf. 1970 is a low outlier in the late March south wind correlation for Flemish Cap cod, giving some corroboration for this concept. To argue against this, 3M and 2J3KL cod are not very well correlated for those 10 reliably estimated year classes in common during 1958 to 1971. The correlation coefficient is .582, with a probability of 0.078. In particular, the large 1958 and 1973 cod year classes on Flemish Cap are not large in Labrador.

Conclusion

We are left with an enticing correlation of winds to YCS, for which no mechanisms are readily available. This is not an unusual situation in fisheries science. Hopefully, recent intensive biological oceanography collections on Flemish Cap will allow the generation of a model that will explain the mode of action of the destructive south wind. The concept of egg loss from the southeast part of the Cap is proposed, but appears to be best supported by the shortcomings of other mechanisms considered.

Kudlo and Boytsov (1979) generated a coefficient of multiple correlation of 0.867 (r^2 = 0.75) between cod year-class strength as 2-yr-olds from USSR trawl surveys of Flemish Cap, and

> "the intensity of the horizontal and vertical water circulation over the central part of Flemish Cap during the period of development of cod eggs and larvae".

This regression is dominated by the 1973 year-class (350 2-yr-olds per hour trawling) compared to a average of 30 for the other 10 years used. Their YCS estimates disagree with this paper, in particular their 1962 and 1963 YCS values are very low.

Hayes et al. (1978) explored ocean climate data in relation to cod YCS on Flemish Cap as well, and determined a multiple regression equation using 4 parameters that explained 83% of the YCS of 4-yr-olds for a 9 year series. For 4 degrees of freedom and 4 independent variables, Table Y of Rohlf and Sokal (1969) gave an critical correlation value for α = .05 of 0.93. Thus 87% of the variation must be explained, and their regression is not significant.

Konstantinov (1981) reported that the large 1973 3M cod year-class was associated with cold water on USSR oceanographic section 4A. This section is on the eastern Grand Bank between 45° and 46°N. Its applicability to Flemish Cap is questionable, and the 1 and 2-yr-old cod data from the USSR trawl surveys gives 1968 as a relatively weak year-class, whereas it apparently was quite strong.

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Table 1. Wind frequency correlations with 3M YCS, by direction and fortnight.

	FORTNIGHT						
	5	6	7	8	9	10	Wind
1	+	+	.	.	.	.	N
2	+.51	+	.	.	.	.	NE
3	.	.	+	.	.	.	E
4	.	.	.	.	.	.	SE
5	-.54	-.79	.	-.50	.	.	S
6	-	.	.	.	+	.	SW
7	-	.	.	.	-	.	W
8	.	.	.	.	-	.	NW

r = .47 for α = .05
r = .59 for α = .01
sign only for α = .20

Table 2. Mean (1957-1978) wind frequency by direction and fortnight (hours per fortnight).

	FORTNIGHT						
	5	6	7	8	9	10	Wind
1	44	39	30	31	38	30	N
2	24	36	18	26	53	21	NE
3	23	24	19	20	17	25	E
4	30	29	31	34	29	31	SE
5	34	41	50	40	51	64	S
6	48	59	72	65	64	82	SW
7	78	80	72	72	75	77	W
8	76	73	66	80	67	69	NW

Table 3. Mean (1946-78) spring wind speeds by direction and fortnight.

	FORTNIGHT						
	5	6	7	8	9	10	
1	136	124	110	120	121	95	N
2	136	115	114	128	86	79	NE
3	119	114	100	83	70	80	E
4	132	117	119	97	98	77	SE
5	130	131	117	116	97	89	S
6	129	126	120	110	105	96	SW
7	125	127	103	105	98	94	W
8	137	138	112	114	109	95	NW

Table 4. Multiple regression results for winds and stock size in predictions of 3M cod YCS.

Model	Coefficients	R^2 obs.	$R^2\alpha$ = 0.1
1) late March south wind	114.8, - 8.83	0.636	0.437
2) late March south wind, and early March north wind	92.3, -8.42, +2.29	0.733	0.567
3) late March south wind, early March north wind, and 5-plus stock biomass.	100.7, -8.71, +4.01, -0.23	0.866	0.663

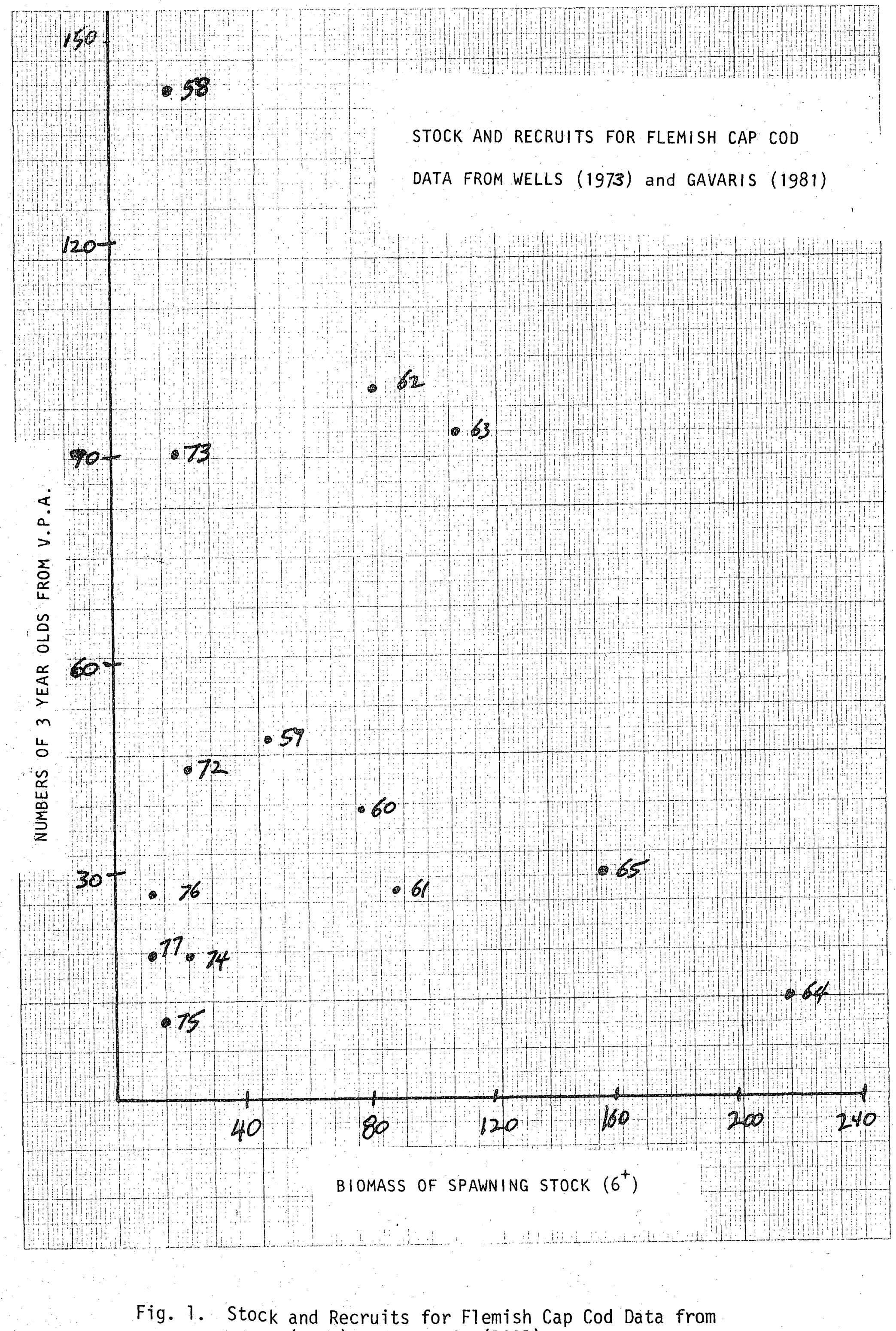

Fig. 1. Stock and Recruits for Flemish Cap Cod Data from Wells (1973) and Gavaris (1981).

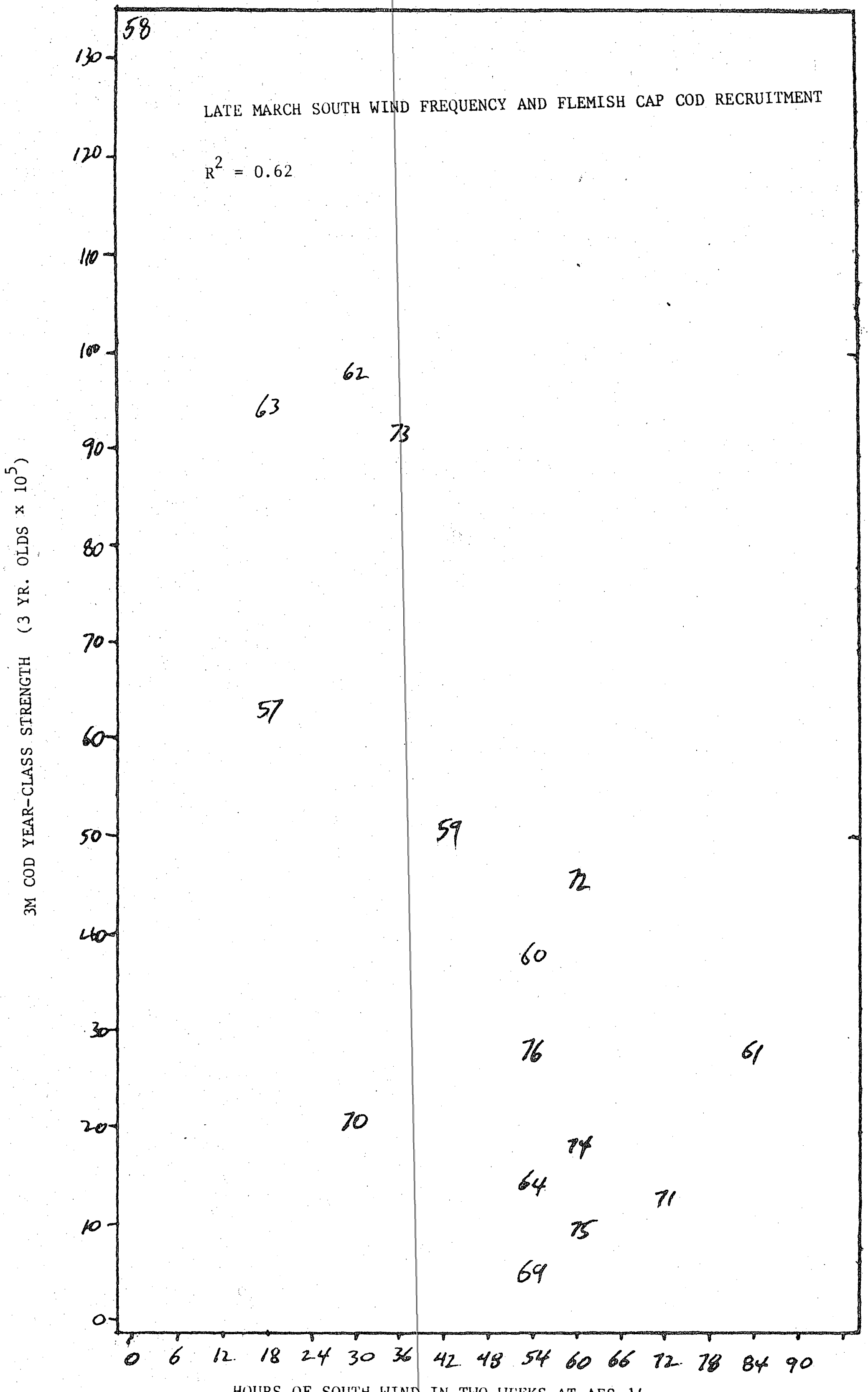

Fig. 2. Late March South Wind Frequency and Flemish Cap Cod Recruitment.

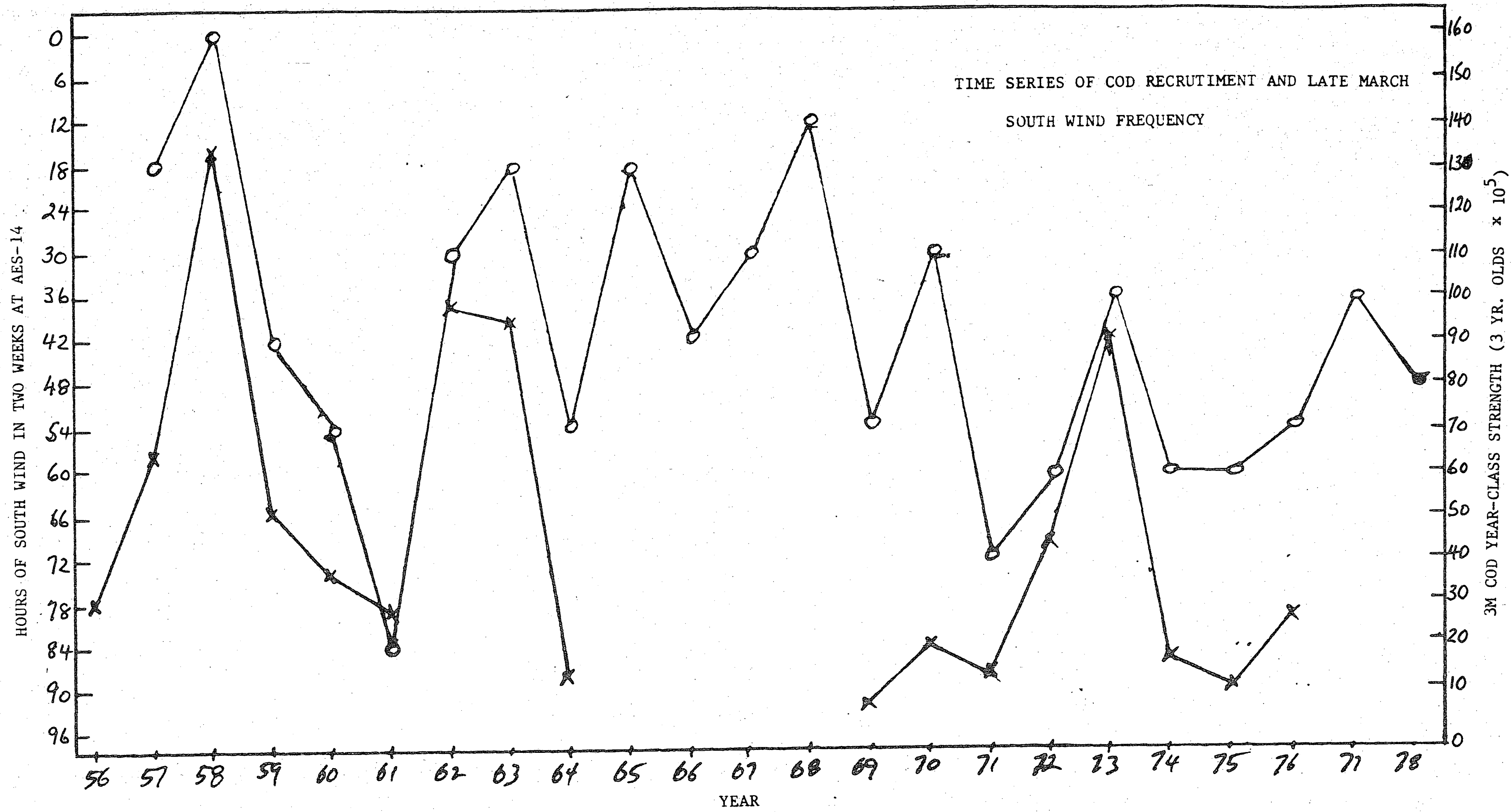

Fig. 3. Time Series of Cod Recruitment and Late March South Wind Frequency.