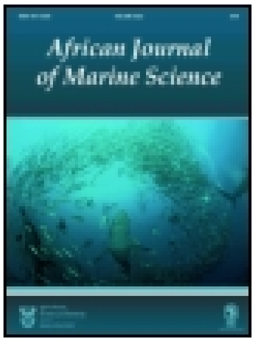

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STATISTICAL CORRELATIONS BETWEEN PURSE-SEINE CATCHES OF CHUB MACKEREL OFF SOUTH AFRICA AND SELECTED ENVIRONMENTAL PARAMETERS

C. A. VILLACASTIN-HERRERO, R. J. M. CRAWFORD† and J. G. FIELD**

Annual catches of chub mackerel made by South African purse-seiners have decreased markedly since the mid 1970s, in spite of the species continuing to be abundant in the northern part of the Benguela ecosystem and a powerful year-class having been formed in 1977. To investigate a possible influence of environmental conditions on availability of chub mackerel to purse-seiners, prewhitened residuals of catches were correlated with prewhitened residuals of sea surface temperature and wind for three areas off South Africa. Statistically significant correlations for the two southern areas were only marginally greater than the number that would have been expected to have arisen spuriously. However, catches appear to be significantly related to cool sea surface temperatures and north-westerly winds in the northern area. These responses may indicate the preferred habitat of the prey (cooler water temperatures) and/or availability of the resource to the fishing fleet (north-westerly winds push the upwelling front closer inshore). The best purse-seine catches of the older ages of chub mackerel have followed a south-westerly movement of these age-classes into the fishing grounds. If the extent of this movement is modulated by environmental conditions in the north, there may be benefit in purse-seiners extending their search for older chub mackerel northwards and offshore.

Die jaarlikse vangste van makriel deur Suid-Afrikaanse beursnetbote het aanmerklik sedert die middelsewentigerjare afgeneem, ofskoon die spesie steeds volop in die noordelike deel van die Benguela-ekostelsel gebly het en 'n sterk jaarklas in 1977 gevorm is. Om die moontlike invloed van omgewingstoestande op die beskikbaarheid van makriel aan beursnetbote te ondersoek, is residue met alle struktuur vooraf verwyder van vangste gekorreleer met dié van seeoppervlaktemperatuur en wind vir drie gebiede teenoor Suid-Afrika. Statisties beduidende korrelasies vir twee suidelike gebiede was slegs marginaal groter as die getal wat na verwagting toevallig sou kon ontstaan het. In die noordelike gebied was vangste egter beduidend gekorreleer met koel seeoppervlaktemperatuur en noordwestelike wind. Hierdie resultaat dui dus moontlik die voorkeurhabitat van die prooi aan (koeler watertemperatuur) en/of beskikbaarheid van die hulpbron aan die vissersvloot (noordwestelike wind stoot die opwelfront nader aan die kus). Die beste beursnetvangste van die ouer makriel het die suidweswaartse beweging van hierdie ouderdomklasse na die visvangronde gevolg. As die omvang van hierdie beweging deur omgewingstoestande in die noorde gemoduleer word, kan dit tot die voordeel van beursnetbote strek om hulle soektog na ouer makriel noordwaarts en aflandig uit te brei.

Chub mackerel *Scomber japonicus* constitute a valued catch in the South-East Atlantic Ocean (Baird 1975, Crawford 1981b). Over the past few decades catches have fluctuated widely, particularly those by the South African purse-seine fleet (Crawford 1981a, Crawford *et al.* 1987). This can be attributed partially to variable abundance of the species in the region. Some powerful year-classes have been formed (Crawford and De Villiers 1984) and fishing has probably also had an impact. However, changes in the availability of chub mackerel to fishing fleets may also have contributed to the variability of the catch. To investigate this possibility, the relationship between South Africa's purse-seine catch and information on sea surface temperature (SST) and wind speed and direction is examined. Selection of the environmental parameters was influenced by the existence of long-term, high-density records of environmental variables in the South-East Atlantic.

Table I: Recorded annual catches of chub mackerel *Scomber japonicus* by the South African purse-seine fishery, 1950–1985 (after Crawford *et al.* 1987)

Year	Catch ('000 tons)	Year	Catch ('000 tons)
1954	4,0	1970	77,9
1955	20,2	1971	54,2
1956	32,6	1972	56,7
1957	7,4	1973	58,8
1958	21,6	1974	30,7
1959	33,1	1975	69,3
1960	31,0	1976	0,5
1961	49,7	1977	21,3
1962	20,4	1978	2,4
1963	13,2	1979	2,7
1964	50,0	1980	0,2
1965	41,4	1981	0,3
1966	53,4	1982	2,7
1967	128,2	1983	3,8
1968	91,0	1984	0,7
1969	91,7	1985	0,1

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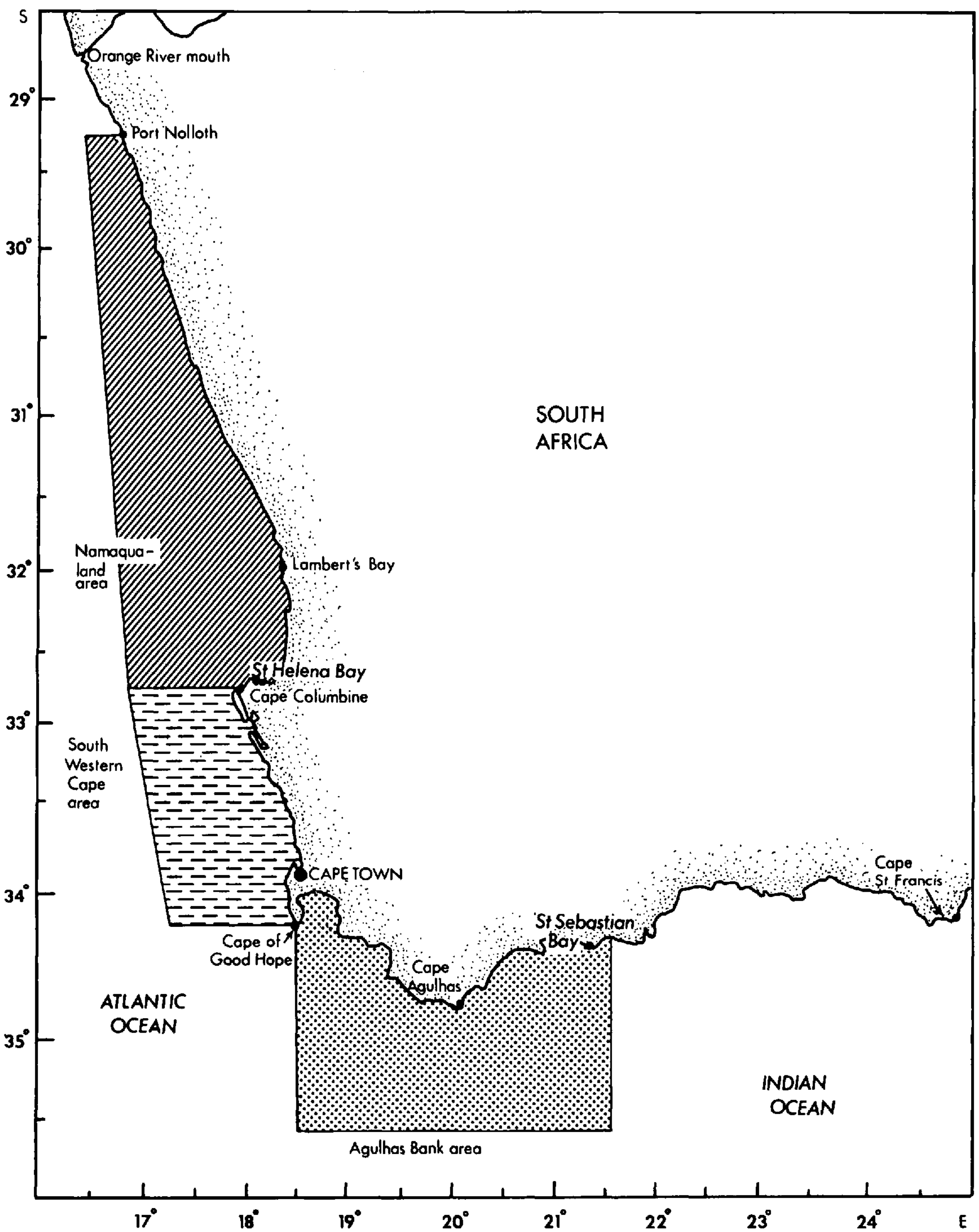

Fig. 1: Map of the South African coast showing the three areas used in the study

METHODS

Annual catches of chub mackerel by South Africa's purse-seine fleet have been documented by Crawford *et al.* (1987). The catches are listed in Table I. Information on the contribution of different ages to the catch is incomplete, so it was impossible to apportion the catch into age-classes. The species is highly migratory (Crawford and De Villiers 1984) and the catch was therefore also not apportioned to areas. The log-transformed catch data were then subjected to a first order autoregressive model followed by a first order moving-average model.

Information recorded by Voluntary Observing Ships (VOS) of SST, wind speed and wind direction were obtained for the period January 1940–September 1985 from the South African Data Centre for Oceanography's

Table II: Details of the auto-regressive (AR) and moving-average (MA) structure and residuals applied to the sea surface temperature records in the three areas. "Structure" indicates the percentage variation explained by the auto-regressive model and "Residual" the percentage residual variation

Data series	Sea surface temperature			North–south wind			West–east wind		
	Order of AR,MA	Structure (%)	Residual (%)	Order of AR,MA	Structure (%)	Residual (%)	Order of AR,MA	Structure (%)	Residual (%)
				Namaqualand					
January	1,1	37	63	2,0	9	91	0,0	–	100
February	0,1	5	95	2,0	3	87	1,2	23	77
March	1,0	7	93	2,1	3	87	0,0	–	100
April	0,0	–	100	1,0	8	92	0,0	–	100
May	0,0	–	100	2,0	8	92	0,2	12	88
June	0,1	8	92	0,0	–	100	0,2	11	89
July	0,1	12	88	0,0	–	100	0,0	–	100
August	0,0	–	100	0,0	–	100	0,0	–	100
September	0,0	–	100	1,1	8	82	0,1	24	76
October	0,0	–	100	1,0	9	91	0,0	–	100
November	1,0	21	79	1,0	4	86	0,0	–	100
December	1,0	46	54	1,0	8	82	0,0	–	100
				South-Western Cape					
January	0,1	17	83	0,0	–	100	0,0	–	100
February	0,1	4	96	0,0	–	100	0,1	10	90
March	0,0	–	100	0,0	–	100	0,0	–	100
April	1,0	18	82	0,0	–	100	0,0	–	100
May	1,0	16	84	0,4	11	89	0,0	–	100
June	1,0	11	89	1,0	13	87	0,0	–	100
July	1,0	27	73	0,2	14	86	0,0	–	100
August	1,0	10	90	2,0	14	86	2,0	12	88
September	1,0	6	94	0,0	–	100	0,0	–	100
October	0,0	–	100	0,0	–	100	0,2	13	87
November	0,0	–	100	0,0	–	100	0,2	10	90
December	0,1	16	84	0,0	–	100	1,0	17	83
				Agulhas Bank					
January	1,1	8	92	0,0	–	100	0,1	8	92
February	0,0	–	100	2,0	11	89	0,0	–	100
March	0,0	–	100	0,0	–	100	0,0	–	100
April	0,0	–	100	0,0	–	100	0,0	–	100
May	0,0	–	100	0,0	–	100	0,4	18	82
June	0,0	–	100	0,0	–	100	0,0	–	100
July	0,1	5	95	0,0	–	100	0,2	6	94
August	1,0	5	95	0,0	–	100	0,0	–	100
September	0,0	–	100	0,0	–	100	0,4	18	82
October	0,0	–	100	0,0	–	100	0,1	6	94
November	0,0	–	100	0,0	–	100	0,2	49	51
December	0,0	–	100	0,1	13	87	1,0	19	81

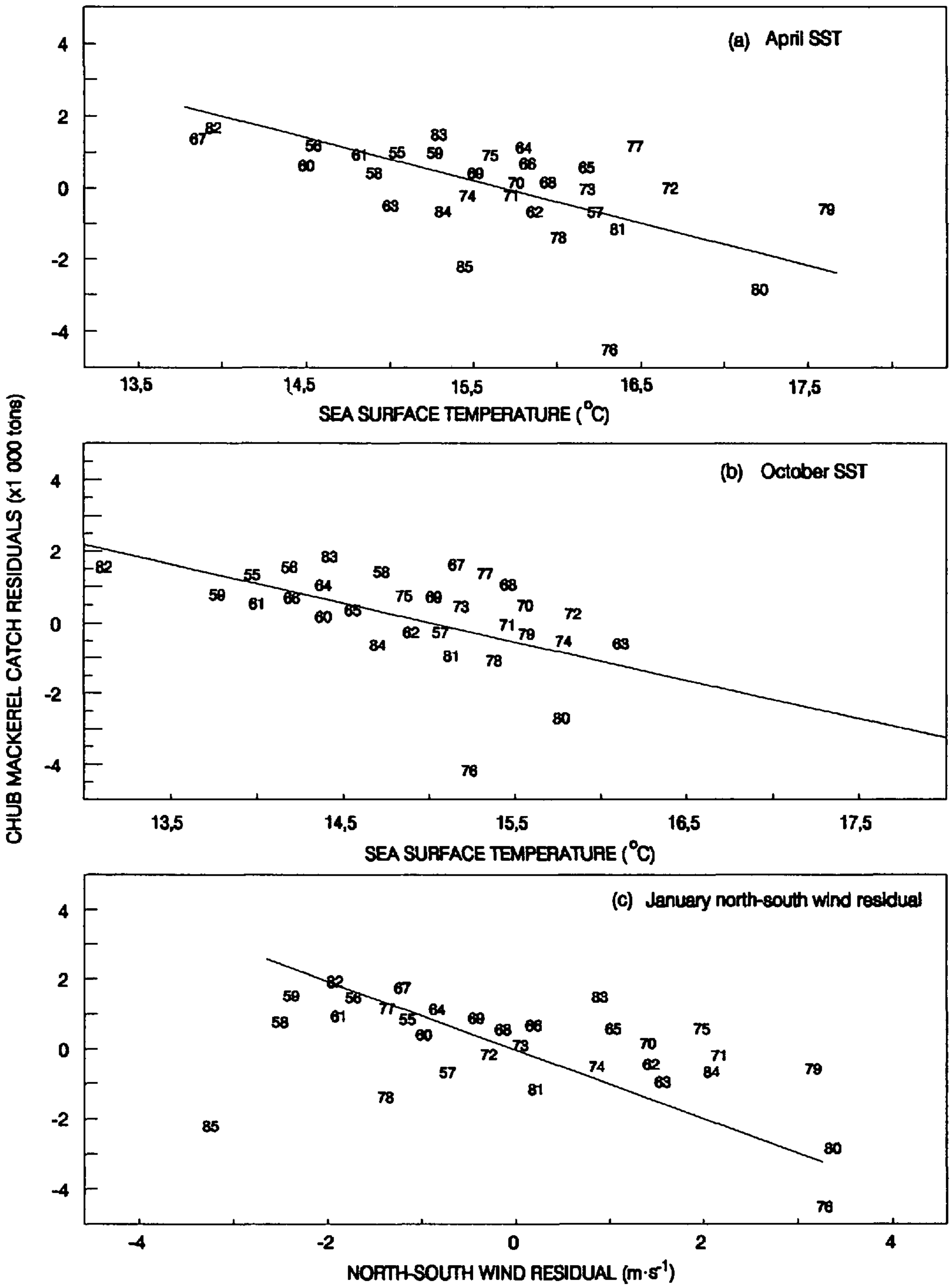

Fig. 2: Cross-correlations between annual chub mackerel catch residuals after removal of autocorrelation and (a) April sea surface temperature residuals, (b) October sea surface temperature residuals, (c) January north–south wind residuals in the Namaqualand area. A linear regression line is fitted to depict the trend. The numbers indicate years

Table III: Cross-correlation coefficients between annual chub mackerel catch residuals and residuals of sea surface temperature, north-south and west-east wind components for all months and for the first two lags in the Namaqualand area, 1954–1985

Month	Cross-correlation coefficients					
	Sea surface temperature		North–south wind component		West-east wind component	
	Lag 0	Lag 1	Lag 0	Lag 1	Lag 0	Lag 1
January	–0,1094	–0,2525	–0,6398[6]	–0,3444	–0,3779[1]	–0,3274
February	–0,2104	–0,3252	–0,3728[1]	–0,0018	–0,2504	–0,0460
March	–0,4498[3]	–0,2251	–0,1604	–0,3856[1]	–0,0831	–0,5577[6]
April	–0,5162[4]	–0,3486[1]	–0,3907[1]	0,2600	0,1329	0,2401
May	–0,4188[2]	–0,4889[4]	–0,2948	–0,0423	–0,3399	0,0761
June	–0,2603	–0,4994[4]	–0,1091	0,1991	0,0587	–0,1026
July	–0,3255	–0,4413[2]	–0,0392	–0,1220	–0,4749[3]	–0,1179
August	–0,1616	–0,4630[3]	–0,2359	–0,1432	–0,2157	0,1590
September	–0,4032[2]	–0,3109	–0,0692	–0,1040	–0,0820	0,0785
October	–0,5517[5]	–0,2204	–0,3669[1]	–0,2481	–0,3894[1]	0,0432
November	–0,3474[1]	–0,0978	–0,0594	–0,0549	0,4605[2]	–0,1705
December	–0,1482	0,0283	–0,2273	–0,4169[2]	–0,1519	–0,0123

[1] $p < 0{,}05$ [4] $p < 0{,}005$
[2] $p < 0{,}025$ [5] $p < 0{,}0025$
[3] $p < 0{,}01$ [6] $p < 0{,}001$

(SADCO) marine climatology database for the three areas off South Africa (Fig. 1). These three areas were:

(i) Namaqualand (Port Nolloth — Cape Columbine; 29°–32°40′S, 16°30′–18°30′E), a major nursery and spawning area for chub mackerel (Baird 1977);
(ii) South-Western Cape (Cape Columbine — Cape of Good Hope; 32°40′–34°15′S, 17°10′–18°30′E), an area where large chub mackerel are caught and also a spawning area (Baird op. cit.);
(iii) Agulhas Bank (Cape of Good Hope — St Sebastian Bay; 34°–35°30′S, 18°–21°15′E), where chub mackerel are caught near the sea bed by demersal trawlers (Crawford and De Villiers 1984).

The offshore boundaries of these three areas loosely follow the 200 m depth contour.

Normally there was at least one observation for each environmental parameter per day in each area. However, if fewer than five records were available for an area in any month, the information was not used.

Table IV: Cross-correlation coefficients between annual chub mackerel catch residuals and residuals of sea surface temperature, north-south and west–east wind components for all months and for the first two lags in the South-Western Cape area, 1954–1985

Month	Cross-correlation coefficients					
	Sea surface temperature		North–south wind component		West-east wind component	
	Lag 0	Lag 1	Lag 0	Lag 1	Lag 0	Lag 1
January	0,1185	–0,0946	–0,5861[6]	–0,3665[1]	–0,2130	0,0760
February	–0,0546	0,0557	–0,2951	0,0592	–0,0591	0,0804
March	–0,1056	0,1308	–0,1514	–0,3423	0,0294	–0,1962
April	–0,2066	–0,1882	0,1304	0,0519	0,1886	0,0723
May	–0,1138	–0,4616[3]	0,0286	0,0090	–0,2346	0,1939
June	–0,0501	–0,4567[3]	–0,1504	0,3062	–0,1148	0,0056
July	–0,0632	–0,3038	–0,0121	0,1510	0,0820	0,1223
August	0,0796	–0,2194	–0,0025	–0,2318	–0,2013	–0,1482
September	0,3019	–0,1355	0,1815	–0,4739[3]	–0,0626	–0,2543
October	0,1730	–0,2121	–0,3153	–0,3178	–0,0150	–0,3403
November	0,0372	0,1025	0,0985	–0,2429	0,2740	0,0072
December	–0,0892	0,3050	–0,0746	–0,2302	0,4137[2]	–0,0419

[1] $p < 0{,}05$ [6] $p < 0{,}001$
[2] $p < 0{,}025$
[3] $p < 0{,}01$

Daily information on wind speed and direction was decoded into north–south (positive indicating southerly winds, i.e. from the south) and west–east (positive indicating easterly winds) components. Monthly averages were calculated for these two components of wind speed and for SST.

Cross-correlation was used to investigate the relationship between South Africa's purse-seine catch of chub mackerel and environmental parameters for the three areas. Cross-correlations between two time-series, each having some autocorrelation structure, may yield spurious results. Therefore, in order to cross-correlate these series in a valid manner, the structure must be removed and "prewhitened residuals" must be obtained. All data series analysed here were modelled with the MicroTSP statistical package (MicroTSP 1990) on an MS-DOS PC with standard univariate techniques (Box and Jenkins 1976). As a check for the removal of systematic trends, the Q-statistic was computed,

$$Q = n \sum_{k=1}^{p} r_k^2 ,$$

where n is the number of observations and $r_1, r_2, \ldots, r_p$ are the autocorrelations at lags $1, 2, \ldots, p$. Large values of Q indicate autocorrelation at one or more of the first n lags. By subtracting model estimates from the original series, it was possible to obtain "prewhitened residuals". Cross-correlations were computed between series of prewhitened residuals for the same year and catch-lagged by one year. All correlations are reported, and those significant at different levels of significance are indicated.

RESULTS

Models

Models used to generate prewhitened residuals for time-series that were subject to cross-correlations are indicated in Table II.

Cross-correlations

NAMAQUALAND

Prewhitened residuals of annual catches of chub mackerel by the South African purse-seine fleet were significantly negatively related to SST of the Namaqualand area for April–August of the preceding year and for the periods March–May and September–November of the same year (Table III). Other cross-correlations were not significant, but all except that for the SST of the preceding December were negative.

All except two of the 24 correlations between catches and the north–south wind component were negative (Table III), i.e. the catch was positively related to northerly winds. Six of the correlations were significant, including that for the period December of the previous year through February of the same year, all being negative. In all, two-thirds of the 24 correlations between purse-seine catches and the west–east wind compared were negative (Table III), suggesting a positive influence of westerly winds on the catch. Four of the negative correlations and one of the positive correlations were significant.

Relationships between residuals of catches and SST for the Namaqualand area for April and October with no lag are shown in Figure 2. Clearly, much of the significance is attributable to certain years, such as 1976, 1979 and 1980 for SST in April and October. In 1982, in both instances, although cooler waters were in evidence, there was a large catch. In January 1976, 1979 and 1980 there is also a strong contribution to the negatively significant relationship between catch residuals and the north–south wind residuals.

SOUTH-WESTERN CAPE

Residuals of annual purse-seine catches of chub mackerel were significantly related in only two of the 24 correlations with SST off the South-Western Cape, those for May and June of the preceding year (Table IV). The majority (15) of the correlation coefficients were negative.

There were three significant relationships with the north–south wind component, but only one with the west–east wind component (Table IV). Again, northerly winds in January were positively related to catches. This relationship (Fig. 3) is also strongly influenced by the results of a few years, notably 1976, 1980 and 1985.

AGULHAS BANK

There were only four significant relationships between catches of chub mackerel and SST or wind over the Agulhas Bank (Table V). Most (22) of the correlations with SST are negative, whereas most (17) of those with the north–south wind component were positive, i.e. indicative of a positive influence of southerly winds on catches. Half the correlation coefficients

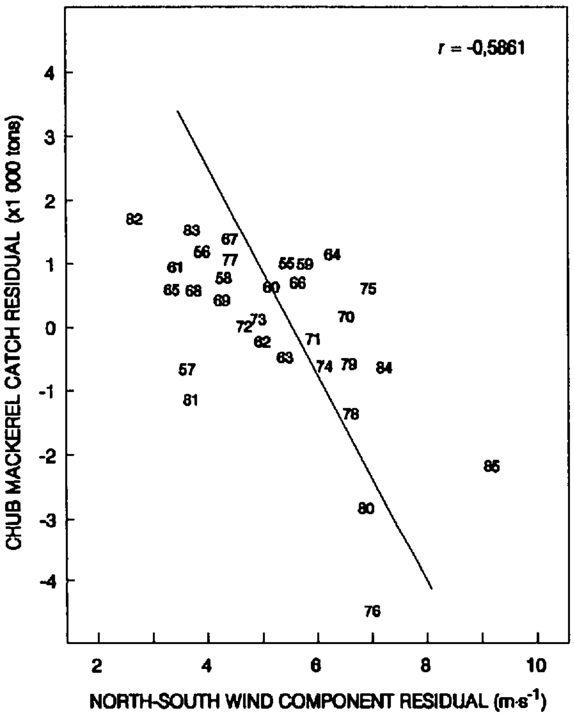

Fig. 3: Cross-correlations between annual chub mackerel catch residuals after removal of autocorrelation and January north–south wind component off the South-Western Cape. A linear regression line is fitted to depict the trend. The numbers indicate years

between catches and the west–east wind component were negative.

DISCUSSION

Colinearity among variables creates problems when interpreting the effects of individual explanatory variables on the response variable (Chatterjee and Price 1977). This problem is common to all regression analyses in which two or more of the explanatory variables are correlated (Rose *et al.* 1986). One or more of the assumptions of least-squares estimations may be violated by the inclusion of the response variable as an explanatory variable or by the presence of autocorrelated errors. Such violation of assumptions may result in biased and/or inconsistent estimates of the regression coefficients.

Sutcliffe *et al.* (1977) have advised caution with the use of correlations to relate environmental parameters to fluctuations in fish populations, because of the chance of spurious relationships. In order to assess such a possibility, the numbers of significant cross-correlations and the expected numbers of their occurrence by chance are presented in Table VI. Clearly, the numbers of significant correlations between catches and environmental parameters for both the South-Western Cape and the Agulhas Bank are only marginally greater than those that might be expected to occur by chance. Therefore, SST and wind in these areas

Table V: Cross-correlation coefficients between annual chub mackerel catch residuals and residuals of sea surface temperature, north–south and west–east wind components for all months and for the first two lags in the Agulhas Bank area, 1954–1985

Month	Cross-correlation coefficients					
	Sea surface temperature		North–south wind component		West-east wind component	
	Lag 0	Lag 1	Lag 0	Lag 1	Lag 0	Lag 1
January	–0,0860	–0,1925	–0,1976	0,0382	–0,6114[6]	0,0772
February	–0,1038	–0,0214	–0,0477	0,2979	–0,1445	0,0282
March	–0,1317	–0,1007	0,3077	–0,1112	0,2025	–0,1303
April	–0,1861	–0,2650	0,2530	0,3771[1]	0,1725	0,2321
May	–0,1799	–0,3453	0,1296	0,0610	–0,1611	0,4355[2]
June	–0,1017	–0,3514[1]	–0,0529	0,2592	0,1174	–0,0365
July	–0,0356	–0,3293	–0,1278	0,0096	–0,1325	0,0014
August	0,2527	–0,1933	0,1588	–0,0610	–0,3594[1]	0,0558
September	0,1977	–0,1741	0,3786[1]	–0,2344	–0,0693	–0,2211
October	0,1582	–0,3063	0,0330	0,2520	–0,0442	0,2791
November	0,0925	–0,2564	–0,2660	–0,2515	0,2624	–0,1993
December	–0,0406	–0,0740	–0,1494	0,0366	0,2996	–0,1654

[1] $p < 0{,}05$
[2] $p < 0{,}025$
[6] $p < 0{,}001$

Table VI: Numbers and estimated probabilities of significant relationships between fish catch and joined environmental variables in all areas

Area	Total number of comparisons between catches and environmental parameters	Likely number of spurious correlations at the $p < 0{,}05$ level (i.e. $0{,}05 \times 72$)	Actual number of correlations significant at the $p < 0{,}05$ or higher level
Namaqualand	72	3,6	21
South-Western Cape	72	3,6	6
Agulhas Bank	72	3,6	5

appear to have little influence on purse-seine catches. By contrast, a considerably greater proportion of correlations that may be expected by chance are significant for the Namaqualand area, some at a high level of significance (Table III).

Purse-seine catches of chub mackerel off South Africa peaked in the late 1960s (Table I), partially as a result of offshore exploitation of older age groups (Baird 1978a). This was facilitated by the charter of a Norwegian purse-seiner with crew experienced in deep-water herring fishing in the North Sea, and by aerial fish-spotting that was initiated in 1967 (Crawford 1981b). Older age-classes moved from the north-west towards fishing grounds in the vicinity of Cape Columbine (Baird 1978a, Crawford 1981b). Environmental conditions in the northern areas can be expected to have influenced this south-westerly movement, helping to explain the findings of statistically significant relationships between catches and both SST and wind in the northern Namaqualand area. Winds most favourable for catches were those that blew from the north-west, i.e. in the direction of the south-westerly migration, particularly winds from the north early in the year. Temperatures most favourable for catches were relatively cool in autumn and winter (April–August) of the preceding year and in autumn (March–May) and spring (September–November) of the same year. It is possible that cool conditions influence the vertical distribution of chub mackerel, which may in turn affect catches in the same year. Alternatively, chub mackerel are piscivorous and feed predominantly on fish that inhabit cooler inshore areas (Baird 1978b). Therefore, the effect of cooler waters on the catch may relate to the preferred habitat of the prey. One effect of the north-westerly winds is to move the upwelling front towards the coast, and this probably concentrates potential prey in an area accessible to the mackerel purse-seine fishery.

Purse-seine catches of chub mackerel off South Africa have decreased markedly since the early 1970s (Table I). This cannot be attributed to a collapse of the resource, because chub mackerel have remained abundant farther north and a powerful year-class was formed in 1977 (Crawford and De Villiers 1984). Whereas environmental conditions in the Namaqualand area in 1967 appear to have been particularly favourable for catches (Figs 2, 3), those in 1976 and 1980 were unfavourable. Therefore, it appears that environmental conditions in the Namaqualand area to the north of the main fishing grounds may influence availability of chub mackerel to South African purse-seiners. If the extent of the southward penetration of older age-classes is environmentally modulated, it may prove beneficial for purse-seiners to extend their search for chub mackerel farther north and to offshore waters.

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