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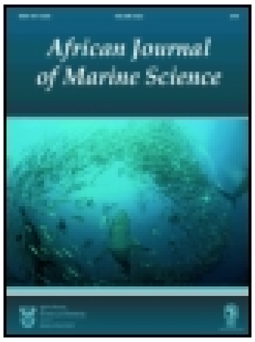

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RELATIONSHIP BETWEEN MEASUREMENTS OF HAKE BIOMASS AND SEA SURFACE TEMPERATURE OFF SOUTHERN NAMIBIA

E. MACPHERSON, M. MASÓ*, M. BARANGE*† and A. GORDOA**

A good relationship between the variability in measurements of Cape hake *Merluccius capensis* biomass during winter and summer swept-area research surveys and sea surface temperature off southern Namibia for the years 1983–1990 is presented. The results call into question the hypothesis that hake density is related to biomass and imply that abnormally warm summers could support higher catches, regardless of the state of the stock. A hypothesis that anomalous warm conditions could induce hake to concentrate closer to the sea bed, making them more susceptible to bottom trawling, is presented.

'n Goeie verband word aangetoon vir die jare 1983 tot 1990 tussen die wisselbaarheid in die winter en die somer van metings van die biomassa van Kaapse stokvis *Merluccius capensis* deur navorsingsopnames (met inagneming van die area gedek deur die treil en die area van die ondersoekgebied) en seeoppervlaktemperatuur teenoor suidelike Namibia. Die resultate bevraagteken die hipotese dat stokvisdigtheid in verband staan met biomassa en suggereer dat abnormaal warm somers hoër vangste kan dra, ongeag die stand van die stapel. 'n Hipotese word aangehaal, nl. dat afwykend warm toestande stokvis kan dwing om nader aan die seebodem saam te drom, en hul so kwesbaarder maak vir bodemtreil.

The waters off southern Namibia (23–29°S) form part of the northern Benguela upwelling system. They support an important demersal (bottom-trawl) fishery at depths of 200–400 m, to which shallow-water Cape hake *Merluccius capensis* contributes some 70–75 per cent of the annual landings of 300–600 thousand tons (Crawford *et al.* 1987).

The Benguela is one of four major eastern boundary current systems worldwide, all of which are characterized by coastal upwelling and large biomasses of hakes *Merluccius* spp. (Parrish *et al.* 1983, Shannon 1985). Variations in sea surface temperature (SST) in the region are related to mesoscale processes, e.g. upwelling, and such seasonal features as the presence of advected water masses and variable solar heating (Boyd and Agenbag 1985, Shelton *et al.* 1985, Boyd *et al.* 1987). The main features of hydrographical spatial heterogeneity in the area are the presence offshore north of Lüderitz of cold water resulting from the permanent activity of the Lüderitz upwelling cell (Lutjeharms and Stockton 1987) and a narrowing of the band of cold water south of Lüderitz as a result of the presence of a possibly semi-permanent eddy at that latitude (Shannon op. cit.). SSTs are at their lowest in winter (July–September) and at their highest in summer (January–March), and the main seasonal change is a contraction of the band of upwelled waters in summer. Together with the occurrence of warmer water offshore, this gives rise to stronger offshore temperature gradients in that season (Boyd and Agenbag op. cit.).

METHODS

Hake biomass between 23 and 29°S and at depths of 100–450 m was estimated from five bottom-trawl surveys in winter (July, August or September) and five in summer (January, February). The cruises took place from 1983 to 1990 (Table I) and all were designed on a swept-area method (Macpherson *et al.* 1985). The sampling area encompassed the coast between Walvis Bay (23°S) and the mouth of the Orange River (29°S), thereby covering the main distribution area of the Cape hake between those latitudes (Gordoa and Macpherson 1989). During each survey, over 70 trawl stations were occupied. However, only fish aged two years and more were used in the analysis, because younger ages were not fully recruited to the fishing grounds.

SST data were obtained from independently calibrated satellite images (NOAA 9, Channel 5) for the periods during which the hake biomass surveys were undertaken (Table I). However, images were not available for the periods of the first two cruises, and direct measurements of SST during the hake surveys had to be used instead. The temperature maps largely reflected

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both seasonal and inter-annual variability in the values of sea surface temperature. For the purpose of this paper, the location of the 18°C isotherm relative to the coastline was considered. The 18°C isotherm was selected as a relative estimate of the position in the area of the oceanic front, the dynamic boundary between oceanic and coastal water masses (Waldron 1985).

RESULTS

In winter, the 18°C isotherm was located between 60 miles offshore south of Lüderitz and more than 120 miles offshore at 24°S (Fig. 1a), the situation being reasonably consistent throughout the period considered. However, there were strong inter-annual fluctuations in SST during summer. In the summers of 1984, 1989 and 1990, the coastal waters attained sea surface temperatures >18°C, except off Lüderitz (Fig. 1b). In contrast, during 1986 and 1988 the 18°C isotherm was located during the surveys between 40 and 90 miles offshore practically throughout the region, except south of Lüderitz (Fig. 1c). Variability tended to be highest in the area between 23 and 25°S, where hake abundance is usually highest (Macpherson *et al.* 1985, Gordoa and Macpherson 1989).

The overall distribution of hake within the study area was not significantly affected by these temperature variations (Gordoa and Macpherson 1989 and references therein). This is in direct contrast to observations on the distribution of pelagic fish species in the same area (Shannon *et al.* 1988) and hake species in other areas during anomalous warm conditions (*Merluccius productus*, Mysak 1986; *M. gayi*, Barber and Chávez 1986). Nevertheless, although there is, as yet, no documentation of a clear seasonal migration of hake in the area (Crawford *et al.* 1987), displacements of hake from outside the sampling grid cannot be fully dismissed at this stage.

Although hake distribution was not seemingly affected by variability in surface temperature, the biomass of *M. capensis* definitely was. During relatively cool summers (January/February 1986 and 1988), when the 18°C isotherm was located some distance offshore, the estimated biomass approximated or was less than that six months earlier. However, during warmer summers (January/February 1984, 1989 and 1990), when the 18°C isotherm had shifted closer inshore, the biomass was more than twice the estimate made the preceding winter (Fig. 2). Most age groups were affected similarly (Table I), suggesting that the response was not age-dependent. It must be stressed that the observed changes in biomass between winter and summer cannot be related to seasonal variations in fishing effort, because fishing was uniformly high during the period considered (ICSEAF 1985–1989).

DISCUSSION

The close relationship between sea surface temperature and *Merluccius capensis* biomass estimates could have important implications for fishing-fleet strategies, calling into question the hypothesis that density (and therefore catch rate) is directly related to biomass. Therefore, if feasible, stock assessments for this important fishery should take into account the inherent variability in environmental parameters in order not to introduce substantial bias into projections.

Table I: Estimated biomass at age during the different cruises (*SE* <10% in all cases). Growth rate has been considered constant during the whole period for the biomass estimation (see Macpherson *et al.* 1985 for growth parameters)

Cruise	Biomass ('000 tons) at age							
	2	3	4	5	6	7	8	9+
Jul./Aug. 1983	286	129	32	32	25	18	9	11
Jan./Feb. 1984	825	150	31	42	45	38	22	18
Jul./Aug. 1985	520	546	33	30	31	28	14	7
Jan./Feb. 1986	673	108	21	29	30	18	5	4
Jul./Aug. 1987	261	39	13	13	16	10	9	4
Jan./Feb. 1988	245	76	8	12	20	16	3	4
Sep. 1988	130	116	11	8	6	5	3	–
Jan./Feb. 1989	501	293	20	22	17	16	8	4
Jul./Aug. 1989	91	7	16	15	6	2	3	–
Jan./Feb. 1990	905	209	45	53	31	14	3	4

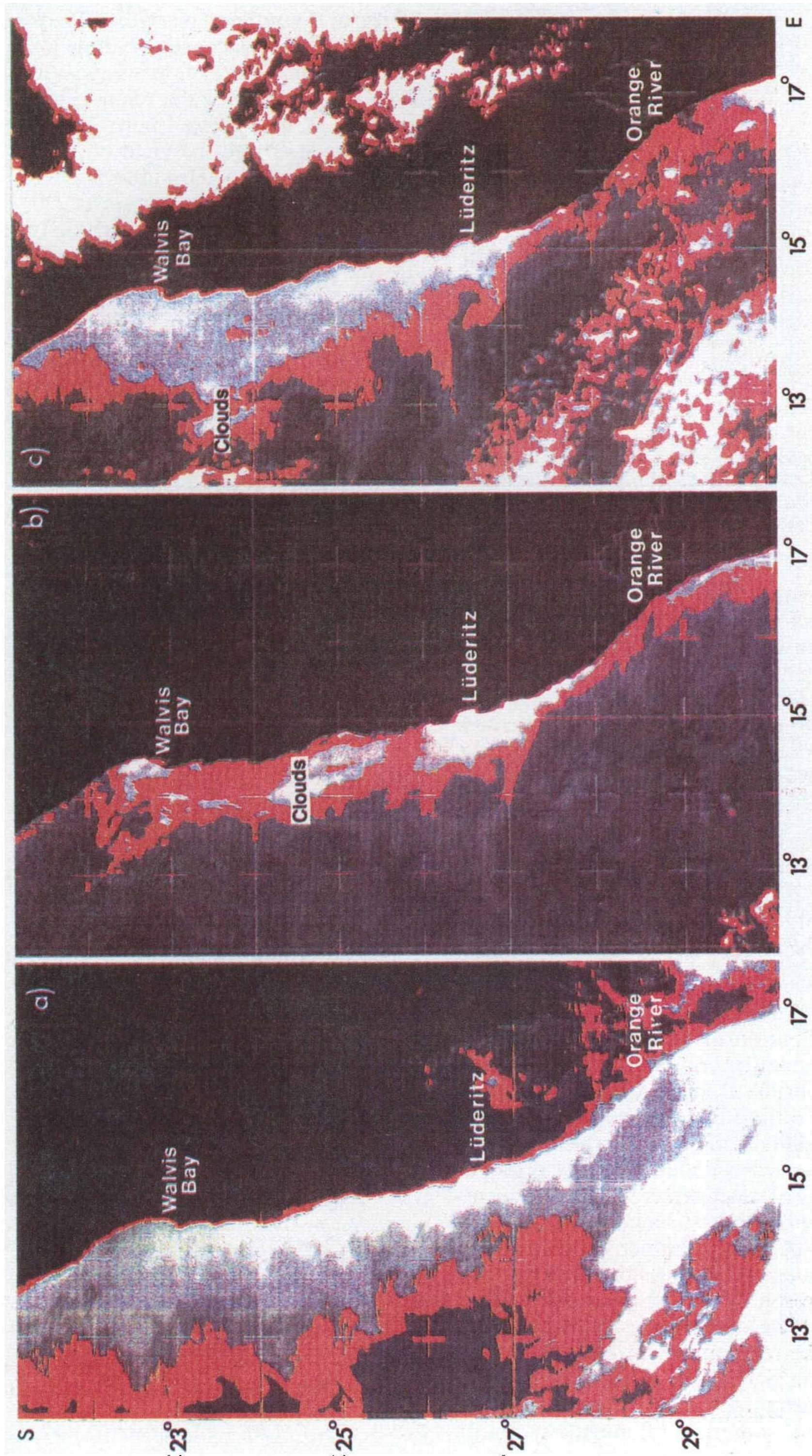

Fig. 1: Satellite images from NOAA Channel 5 for (a) winter (July) 1987, (b) summer (January) 1989, (c) summer (January) 1986. The area in which SST values were between 18 and 19,5°C appears in red

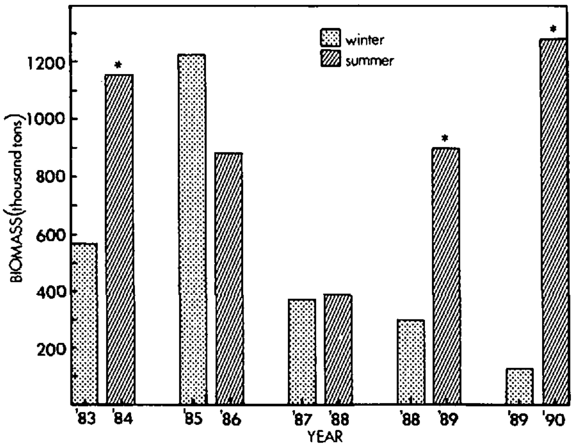

Fig. 2: Biomass estimated for the different seasons and years considered (*SE* < 10% in all cases). Warmer summers, when the 18°C isotherm was located close inshore, as depicted in Figure 1b, are indicated by the symbol *

The observed increase in estimated biomass of hake during warmer periods can only be related to displacements of the population along the inshore-offshore, north-south and/or vertical axes. During such periods, the oceanic front is found nearer the coast and Shannon *et al.* (1988) postulated that the effect could lead to increasing densities of hake on the fishing grounds. Nevertheless, horizontal displacements are unlikely to be the only factors involved because:

(i) the design of the biomass survey was such as to include the whole distribution of *M. capensis* between 23 and 29°S;
(ii) the already mentioned lack of clear north-south migration into the sampling area.

As an alternative, the present authors suggest that there may be a physiologically induced response related to the vertical distribution of the population during warmer periods. Shannon *et al.* (1988) concluded that groundfish species in the Benguela benefitted from cooler conditions. Following that hypothesis, abnormally warm conditions could induce hake to concentrate closer to the sea bed (reducing the distance between individual fish). Such effect would, of course, make the populations more susceptible to bottom trawling. Taking the possibility further, environmental forcing of hake populations during abnormally warm seasons could also result in poor recruitment for that year, thus explaining the observations of Shannon *et al.* (op. cit.) that hake recruitment off Namibia correlates negatively with SST. Roel and Bailey (1987) analysed the relationship between SST and the distribution of *Merluccius capensis* off northern South Africa and southern Namibia. They observed that, although there was negative correlation with hake age-classes 0 and 1, correlation was positive for ages 4 and older, suggesting that the relationship could be more complex than suggested here. In particular, several studies have related the yield of a fishery to hypoxic bottom levels (e.g. Brandhorst 1959, Leming and Stuntz 1984). Mas Riera *et al.* (1990) observed that low-oxygen water affects the distribution of the demersal fish community off Namibia, and similar specific studies in the Benguela may, in future, offer new light into the subject.

The distribution and density of several pelagic fish species has been related to SST (Fiedler and Bernard 1987, Herron *et al.* 1989). The fact that a relationship between a demersal fishery and SST has been obtained here suggests that surface conditions are good estimates of near-bottom conditions in the area and that variability in hake catches can be predicted to a certain extent by carefully monitoring environmental conditions. In view of the high inter-annual variability in summer SSTs, the ability to detect such variations by means of satellite-imaging has important economic consequences. Perhaps, estimates of hake biomass based on direct trawling surveys should be performed under the most constant environmental conditions (e.g. winter in the northern Benguela) in order to preclude unnecessary bias in the projections. Clearly, however, further research is needed to explain the ultimate causes underlying the interesting phenomenon recorded here.

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