Benguela Dynamics
Pillar, S. C., Moloney, C. L., Payne, A. I. L. and F. A. Shillington (Eds). *S. Afr. J. mar. Sci. 19: 41–56*
1998

INTRUSION OF WARM SURFACE WATER ALONG THE ANGOLAN-NAMIBIAN COAST IN FEBRUARY–MARCH 1995: THE 1995 BENGUELA *NIÑO*

T. GAMMELSRØD, C. H. BARTHOLOMAE†, D. C. BOYER†, V. L. L. FILIPE‡ and M. J. O'TOOLE†*

The upper ocean temperatures in the Angolan-Namibian coastal waters were anomalously high during March 1995, with positive temperature anomalies of up to 8°C. Maximum temperature differences were 30–50 m deep, reflecting a deepening of the thermocline from normal depths of 10–30 m. The unusually warm water mass covered the Angolan coast from Cabinda (5°S), the northern limit of the survey area, to at least 24°S off central Namibia. Higher than normal temperatures were observed as far south as Lüderitz (27°S). Satellite-derived SST and direct observations indicated that the seaward distribution of warm water extended more than 300 km from the coast. Surface drogues released inshore along the central Namibian shelf suggested a maximum southward extension by 3 March 1995. The warm event was associated with observed mortalities in sardine *Sardinops sagax*, horse mackerel *Trachurus trachurus capensis* and kob *Argyrosomus inodorus* off the coast. It also caused a southward displacement of sardine stocks from Angola, resulting in an increased availability of pelagic fish in Namibian waters. Conditions have occasionally been anomalously warm in Angolan and Namibian waters in the past, with the last major event in 1984. These events are known as Benguela *Niños,* because of their resemblance to the well known Pacific *El Niño.* The 1995 Benguela *Niño* appeared to be associated with a positive subsurface salinity anomaly of 0.5×10^{-3} in Namibian waters and a negative (-4.0×10^{-3}) surface salinity anomaly in Angolan waters, thought to be derived from the freshwater input of the Congo River.

The well-known Pacific *El Niño* is manifest as an episodic warming of coastal waters off Peru. Warming of the equatorial Pacific is related to major shifts in the Walker circulation (Southern Oscillation) in the atmosphere, and is now called the *El Niño*-Southern Oscillation (ENSO, Bjerknes 1969). The ENSO caused marked changes in precipitation and wind patterns in the South-East Atlantic (Bakun 1996, Shannon and Nelson 1996).

It is less known that the Pacific *El Niño* has a counterpart in the South-East Atlantic (Shannon *et al.* 1986). So-called Benguela *Niño*s are less frequent and intense than the Pacific events. They are generally observed as intrusions of warm, saline surface waters on the Namibian shelf (Boyd *et al*. 1987). Shannon *et al.* (1986) discussed the Benguela *Niño* in detail, and concluded that it occurs about once every 10 years. There have been major, well-documented Benguela *Niño*s in 1934, 1949, 1963 and 1984, in addition to less intense or poorly documented events around 1910, the mid-1920s and early 1970s (Shannon and Taunton-Clark 1989).

The annual southward migration of the Angola-Benguela front, usually located between 14 and 16°S (Meeuwis and Lutjeharms 1990), introduces warm, saline Angolan water into Namibian coastal water. This seasonal migration is associated with the relaxation of the equatorward, upwelling-favourable wind-stress (Boyd *et al.* 1987). In contrast, the southward penetration of warm, saline water observed during a Benguela *Niño* does not seem to be associated with local winds (Stander and De Decker 1969). In fact, during the Benguela *Niño* in 1984, the equatorward wind-stress was twice as strong as usual (Shannon *et al.* 1986). Rather than being triggered by variation in local wind-stress, the Benguela *Niño* is believed to be associated with large-scale remote changes in the wind patterns. A sudden relaxation of the trade winds in the western equatorial Atlantic is followed by an east-propagating equatorial Kelvin wave. This wave is deviated polewards in both hemispheres on approaching the African continent. Shannon *et al.* (1986) found that the Benguela *Niño* was associated with low, westward wind-stress off Brazil. Model

* Institute of Marine Research, P.O. Box 1870, N-5024 Bergen, Norway; now Geophysical Institute, Allégaten 70, N–5007 Bergen Norway. Email: torg@gfi.uib.no
† National Marine Information and Research Centre, P.O. Box 912, Swakopmund, Namibia.
‡ Instituto de Investigação Pesqueira, Ilha de Luanda, C.P. 2601, Angola.

Manuscript received: December 1996

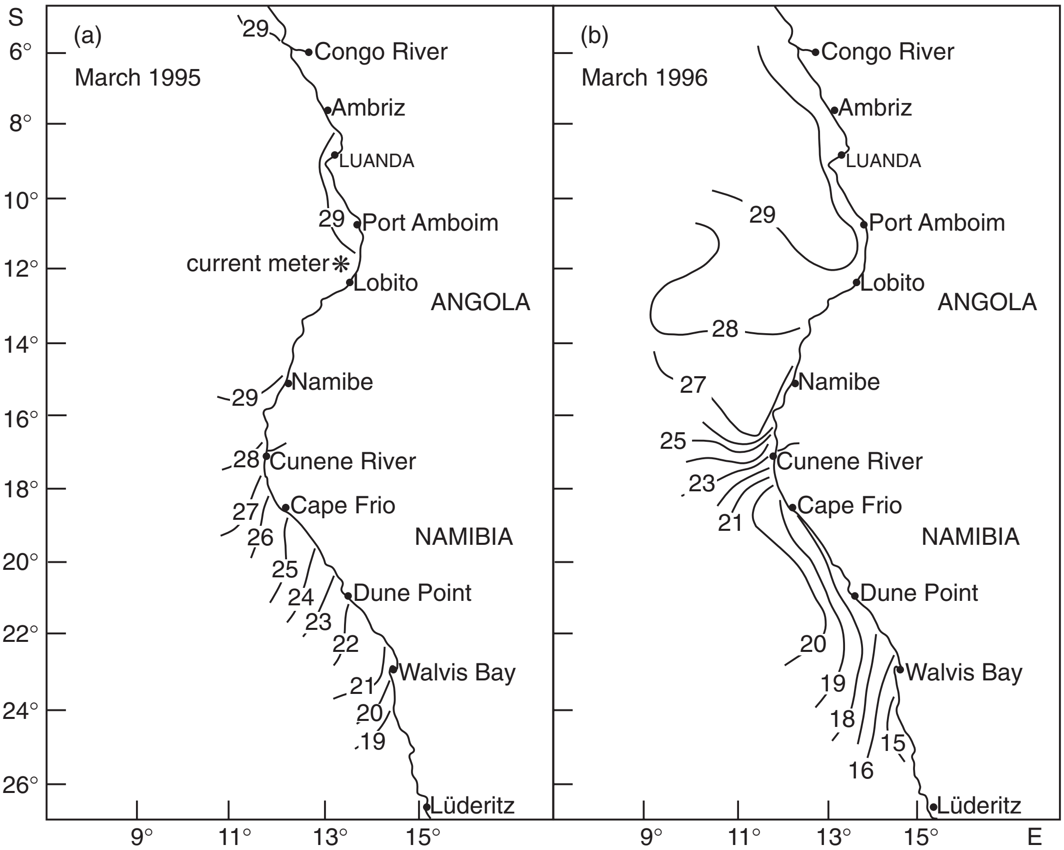

Fig. 1: Sea surface temperature (°C) distributions from ship measurements in (a) March 1995 and (b) March 1996 in Namibian and Angolan waters. The position of the current meter deployed in 1995 is shown

simulations (Carton and Huang 1994) indicate that the Benguela *Niño* in 1984 was associated with a relaxation of the stronger than normal trade winds. Horel *et al.* (1986) suggested that sudden changes in the wind patterns are more important than absolute values.

The Benguela *Niño* is known to have major impacts on the biota off the Namibian coast. During the 1963 Benguela *Niño*, the fishing industry reported consistently low oil yields for sardine *Sardinops sagax* (Schülein *et al.* 1995) which, under normal conditions, peak in June (Stander and De Decker 1969). Analysis of sardine samples showed greatly reduced gonad development and, during the main winter-spring spawning season of 1963, practically no eggs were collected on the known spawning grounds. Changes in the distribution and abundance of plankton were noted, with an increase in deep-water planktonic organisms farther south and abnormally high plankton volumes offshore (Stander and De Decker 1969). Unusual fish species of tropical origin were also caught by fishing vessels off Walvis Bay (Smith 1965).

The impact of the 1984 Benguela *Niño* on a number of fish stocks in Namibian waters has been reported (Le Clus 1985). For example, there were major southward shifts of the sardine stocks, and, although there was increased availability to the fishing fleet, the absolute levels of abundance were low. In 1984, anchovy *Engraulis capensis* recruit biomass was the lowest on record, with a marked decline in their abundance off the Namibian coast. Only 13 000 tons of an allocated quota of 200 000 tons were landed, a result

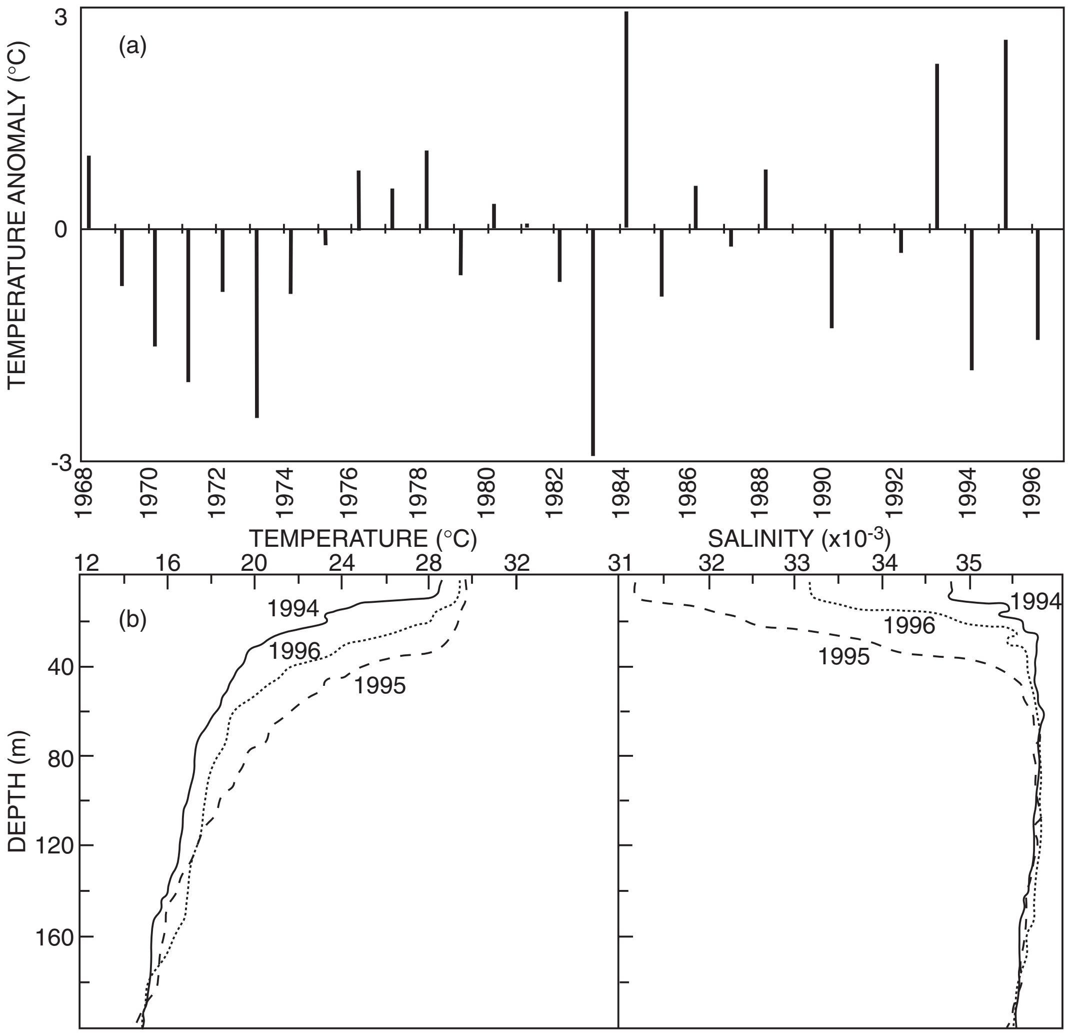

Fig. 2: (a) Mean March temperature anomalies observed at the Swakopmund Mole, Namibia; (b) comparisons of temperature and salinity profiles down to 200 m in central Angola, just south of Luanda (9°15′S) at approximately 400 m bottom depth in March 1994, 1995 and 1996

of poor spawning in anchovy, with egg production being 10% of that in 1982/83 (Boyd *et. al*. 1985). The egg production of the sardine for the 1983/84 spawning season declined by one-quarter relative to the previous two years.

In addition, the Angolan gilt sardine (sardinella) *Sardinella aurita,* a species characteristic of the warmer Angolan water, was found off the coast of northern Namibia, along with other tropical and equatorial fish species. Mortalities of young Cape horse mackerel *Trachurus trachurus capensis* and various coastal angling fish species, such as steenbras *Lithognathus aureti* and kob *Argyrosomus inodorus,* were recorded over 1–2 day periods at various locations along the Namibian coast between 19 and 23°S (Le Clus 1985). Kruger and Boyd (1984) found that

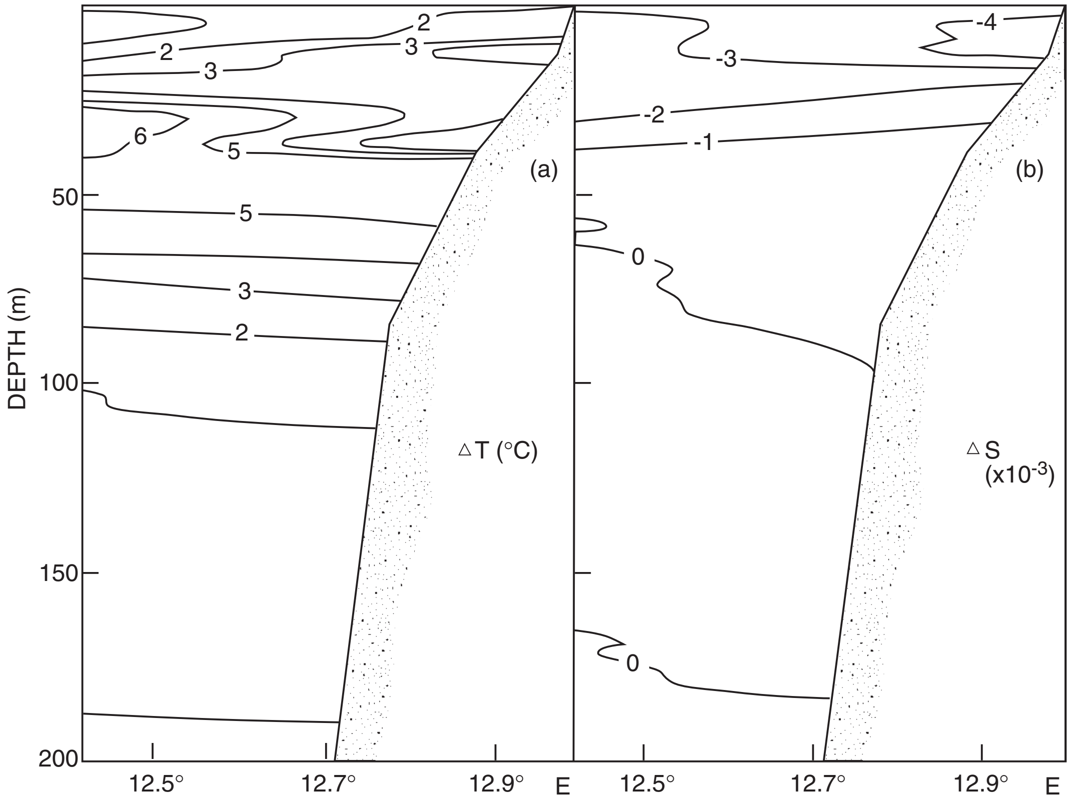

Fig. 3: Differences in the vertical distribution of (a) temperature (ΔT) and (b) salinity (ΔS) between March 1994 and March 1995 in a section perpendicular to the coast off central Angola, just south of Luanda

phytoplankton and zooplankton densities off Namibia were, on average, four times lower during the summer/autumn of 1984 than during the same period in 1982/83 and the previous two summers. In March 1984, phytoplankton abundance was 10 times less than in the previous years, the plankton being dominated by exotic species.

A warm anomaly was also observed in Namibian waters in 1986, which may have induced improved survival of egg and larvae for some pelagic species. This did not have the same amplitude as the 1984 perturbation (Boyd *et al*. 1987), which had a severe impact on recruitment of pelagic species (Le Clus 1986, 1991).

There was a cold period of $1\frac{1}{2}$ years, starting in mid-1991, in the northern Benguela and Angola, which was accompanied by pronounced upwelling. The South Atlantic remained cool until 1994, when the cold period was interrupted by a Benguela *Niño*. Between 1993 and 1994, there was a southward advection of oxygen-poor water on the shelf. The oxygen was further depleted by shelf processes, and in 1994 a number of intense sulphur erruptions were observed. The impacts of the 1995 Benguela *Niño* on fish resources were illustrated by the high starvation-induced mortalities of seal pups and adults.

The present study describes the environmental and associated biotic anomalies that occurred along the Namibian and Angolan coasts during what is considered to be the 1995 Benguela *Niño*.

MATERIAL AND METHODS

Various data sources were used in the present analysis.

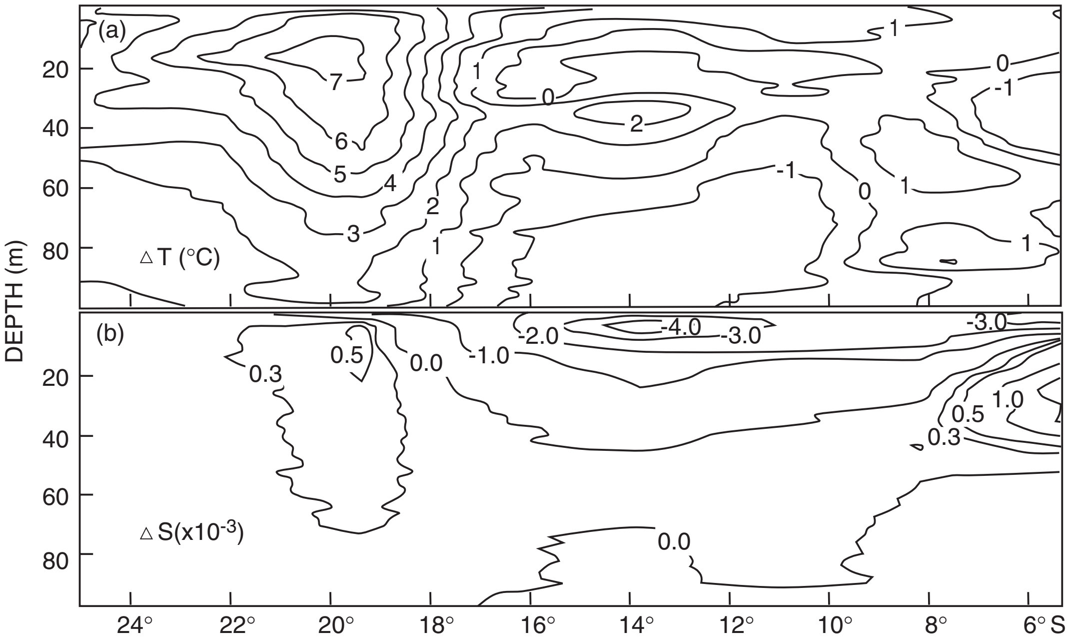

Fig. 4: Differences in the vertical distribution of (a) temperature (ΔT) and (b) salinity (ΔS) between March 1995 and March 1996 in a section parallel to the coast near the 100-m isobath

During late February and March 1995, the research vessels *Dr Fridtjof Nansen* and *Welwitchia* were conducting routine surveys of fish stocks in Angolan and Namibian waters respectively. As part of this monitoring work, environmental data were also collected, making it possible to detect and map anomalous hydrographic conditions during the cruises. The shelf area surveyed extended from 5 to 25°S (Fig. 1). The central part of Angola was surveyed twice, and therefore it was possible to study the evolution of the anomalous conditions for a period of up to two weeks.

Temperature, salinity and oxygen were obtained by means of a Seabird CTD. Salinity measurements were checked against water samples analysed on a Guildline Portasal salinometer on board *Dr Fridtjof Nansen*. For the 1995 cruise, 179 calibration points gave a standard error of about 0.03×10^{-3}. The salinity data collected by the *Welwitchia* were not calibrated during the cruise, but prior cruises indicated similar levels of accuracy. The temperature and pressure sensors of both vessels were calibrated in the laboratory prior to the cruises, and are accurate to factory standards of ±0.01°C and ±0.25% in pressure.

Several drifter buoys were released during the anomalous period to map surface currents. They were equipped with a cross-shape drogue with 1m^2 sails drifting 1 m deep. The drogue data were provided by the National Petroleum Corporation of Namibia (NAMCOR), from a number of commissioned surveys carried out by the South African Council for Scientific and Industrial Research (CSIR) on oil spill simulation experiments, which coincided with the period of the 1995 Benguela *Niño*. A mooring equipped with Aanderaa/RCM7 current meters (speed ±1 cm·s^{-1}; direction ± 5°) was deployed over a 24-h period. NOAA AVHRR high resolution sea surface temperature (SST) images were obtained from the receiving station at the National Marine Information and Research Centre in Swakopmond, Namibia.

The distribution of fish was monitored by hydroacoustics using Simrad EK500 echo-sounders with 38 kHz transducers. The surveys followed a systematic grid, with a maximum spacing of 20 miles between transects.

Changes in the horizontal fields are presented using an Underway Mapping System (Zauner 1995). For each cruise, the various parameters were averaged over 20′ × 20′ blocks. Changes were computed

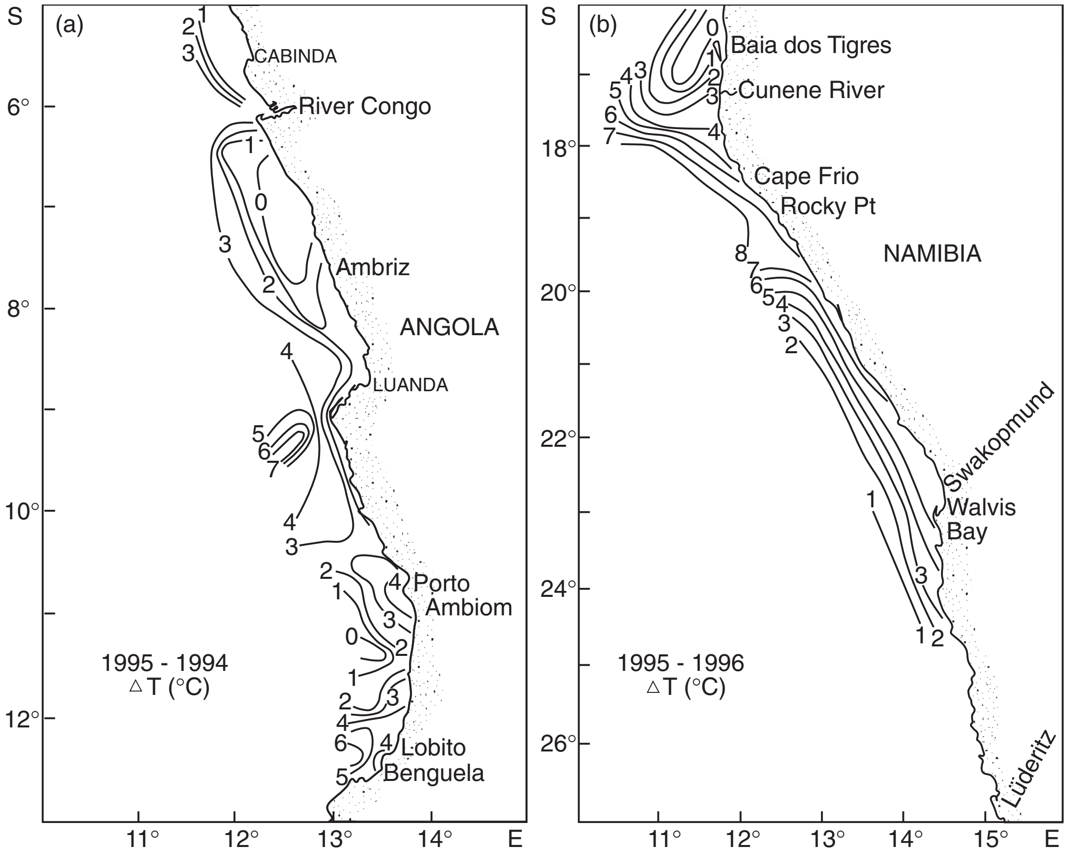

Fig. 5: Differences in the horizontal distribution of temperature 30 m deep off (a) Angola, 1995–1994 and (b) Namibia, 1995–1996

by subtracting overlapping fields from two different cruises.

RESULTS

The distributions of SST from ship measurements in March 1995 and March 1996 are shown in Figure 1. SST >28°C occurred as far south as 17°S in 1995, compared to 14°S in 1996. The Angola-Benguela front was located around 17°S in 1996, south of its more usual position of 14–16°S (Meeuwis and Lutjeharms 1990). In Namibia in 1996, the isotherms ran more or less parallel to the coast as a result of the temperature front created by upwelling (Cole and McGlade 1998). In contrast, during the 1995 Benguela *Niño* (Fig. 1a), the front was absent, and the orientation of the isotherms had changed from parallel to near normal to the coast, indicative of a poleward intrusion of warm Angolan water.

The mean March 1995 temperature measured at the Swakopmond Mole in Namibia was the warmest since the previous Benguela *Niño* in 1984 (Fig. 2a). Two comparative mean March temperatures in 1994 and 1996 were considerably colder than in 1995 (Fig. 2a). Farther north in Angola, CTD profiles taken in March just south of Luanda (Fig. 2b) showed that temperatures in 1996 were cooler and salinities were higher than the 1995 Benguela *Niño*, but respectively warmer and lower than in 1994.

A section perpendicular to the coast, obtained in

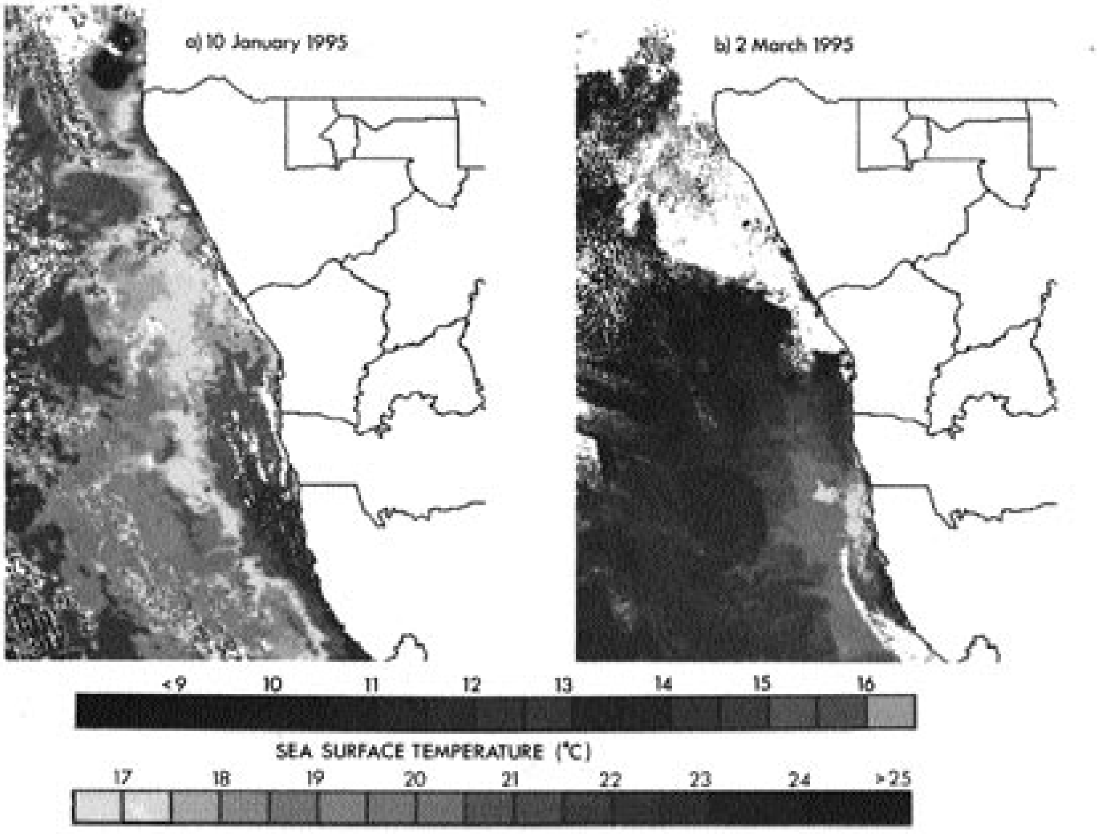

Fig. 6: NOAA satellite images showing the sea surface temperature off Namibia in (a) January 1995 and (b) March 1995

1994 and 1995 just south of Luanda, revealed the vertical structure of the anomalous conditions associated with the 1995 Benguela *Niño* (Fig. 3). The maximum temperature difference (>6°C) was between 20 and 40 m deep, outside the shelf break. The anomaly was limited to the upper 200 m. The negative salinity anomaly in central Angola (Fig. 3b) was restricted to around the upper 50 m. The maximum amplitude (-4.0×10^{-3}) was near the shore in the upper 20 m.

The longshore vertical structure of the 1995 Benguela *Niño* is shown in Figure 4 as the difference between the 1995 and 1996 temperature and salinity profiles in 100 m of water. In Angolan waters, the temperature differences between those years were small (Fig. 4a), because 1996 was a relatively warm year (see Fig. 2b). The maximum temperature difference (>7°C) was around 20 m deep at 20°S. A positive, subsurface salinity anomaly of $>0.5 \times 10^{-3}$ (Fig. 4b) was associated with the maximum temperature difference, in accord with previous Benguela *Niños*. In Angolan waters, there was a marked freshwater anomaly of about -4.0×10^{-3}. In the surface layer, a negative salinity anomaly of -1.0×10^{-3} was found as far south as 18°S.

To illustrate the horizontal distribution of the 1995 anomaly, the temperature at 30 m and the near-surface salinity at 4 m are compared with 1994 and 1996. The increase in temperature from 1994 to 1995 in Angolan waters is illustrated in Figure 5a. In Namibian waters, the 1996 data are used for comparison (Fig. 5b). The warming was substantial along the coast, with the maximum temperature difference (>8°C) at 18–19°S.

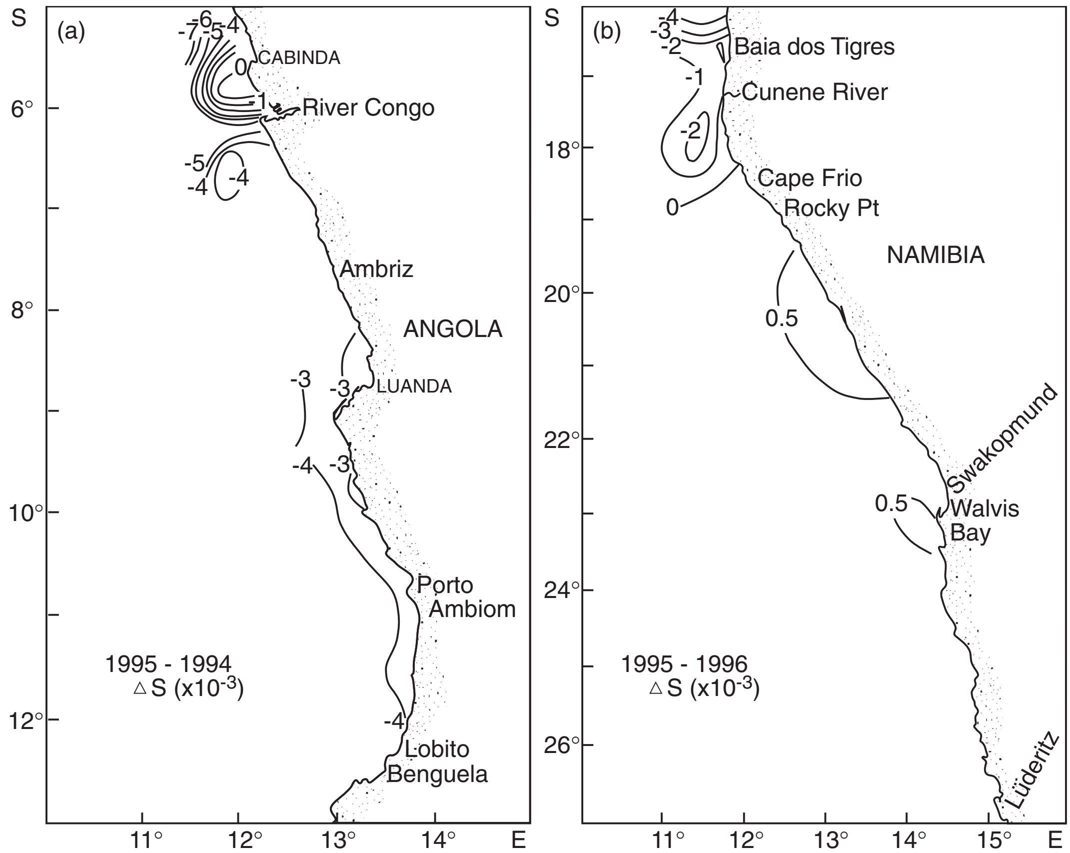

Fig. 7: Differences in the horizontal distribution of salinity (ΔS) 4 m deep off (a) Angola, 1995–1994 and (b) Namibia, 1995–1996

The patchy nature of the anomalies may be attributable to eddies, which occur in that region (Salat *et al*. 1992). Eddies can be identified in the NOAA 9 satellite image of SST in Namibian waters (Fig. 6). Comparing the SST distribution for January 1995 (Fig. 6a), the intrusion of the warm surface water in March is clearly demonstrated (Fig. 6b). The unusually warm conditions extended more than 300 km offshore.

The near-surface salinity differences between 1995 and 1994 (Angolan water) and 1995 and 1996 (Namibian waters) are shown in Figure 7. The freshwater anomaly in 1995 was between 3 and 5×10^{-3} in Angolan waters (Fig. 7a), but it was restricted to the area north of Cape Frio at 18°30′S (Fig. 7b). South of 19°S, the salinity was marginally higher at the surface in 1995 than in 1996, with the greatest anomaly at depth (Fig. 4b).

During the 1995 Benguela *Niño*, seven satellite-tracked surface drogues were deployed off the Namibian coast. Four were released at 22°40′S on 6 February and three at 28°30′S on 19 February. The drift paths of the three drogues tracked the longest are shown in Figure 8. The two drogues tracked north of Walvis Bay were those deployed the closest and the most distant from the shore. Although the distance between the two was only 15 miles at deployment on 6 February 1995, they had drifted some 80 miles apart by the end of the experiment on 8 March. However, the two drogues showed similarities; both initially drifted north-westwards, then southwards during most of the experiment, before changing to north-west again at the end of the experiment. In the south,

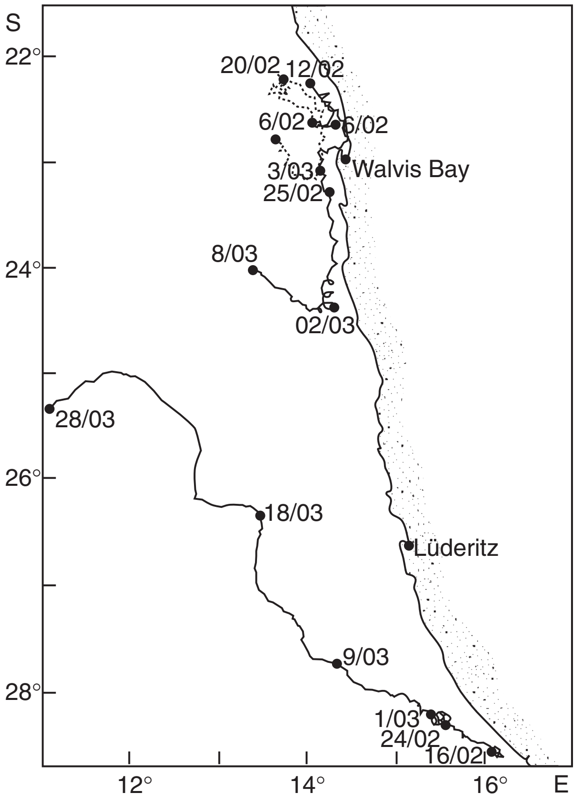

Fig. 8: Satellite-derived tracks of three surface drogues off Namibia for the period February–March 1995

all three drogues (the drift path of one is displayed in Fig. 8) showed similar drift patterns, with a prevailing north-westward drift, but with a very weak net current from 22 February to 3 March 1995.

Figure 9 shows the distribution of sardine based on acoustic surveys in December 1994, March 1995 and June 1995. In December 1994, most of the stock was north of 20°S, but by March 1995 it had migrated southwards. By June 1995, the stock had returned to its normal distribution off northern Namibia.

The biomass estimates of three commercially important pelagic species obtained during hydro-acoustic cruises in Angolan waters since 1985 (Fig. 10) show that low fish biomass is associated with the 1995 Benguela *Niño*. The biomass of sardine was near zero, the stock having probably migrated southwards into Namibian waters (see Fig. 9b). Sardinella and Cunene horse mackerel *Trachurus trecae* also showed marked declines in biomass and/or availability associated with the 1995 Benguela *Niño* (Fig. 10). However, caution should be used in interpreting these results, because the anomalous oceanographic conditions are likely to influence both their migration patterns and schooling behaviour. For example, sardinella concentrations seemed very scattered throughout the March 1995 survey in Angolan waters, making it difficult to distinguish them acoustically from other pelagic fish and plankton. As a result, the biomass of sardinella may have been underestimated.

DISCUSSION

Peak of the anomaly

The temperature differences 30 m deep in Namibian waters south of 19°S (Fig. 5b) reached a maximum close inshore. This may have been due to the absence of coastal upwelling in 1995 (Fig. 1) . It can also be interpreted as the southernmost penetration of warm Angolan water close inshore, indicative of a current with considerable horizontal shear, as observed from the drogue experiment (Fig. 8). The drogue closest inshore changed direction after about one week, whereas the drogue released 15 miles farther offshore continued northwards for another week before it changed to a south-south-east direction and parallel to the coast. This may be interpreted from the fact that the innermost drogue was transported by the south-moving disturbance first, but from about 20 February both drogues headed steadily southwards until 3 March. The innermost and outermost drogues had average speeds of 27 cm·s^{-1} and 18 cm·s^{-1} respectively. The drogues released farther south drifted north-westwards, but slowly, between 22 February and 3 March. On 3 March, all the drogues increased in speed and drifted in a "normal" north-westward direction (see Boyd and Agenbag 1985). It therefore appears that the near-shore, southernmost penetration at the surface of the 1995 Benguela *Niño* was around 3 March. As such, most of the hydrographic observations reported here were obtained while the surface disturbance was retreating.

The retreat of the 1995 Benguela *Niño* was also indicated by current measurements obtained from a 24-h mooring on 18–19 March at 11°44′S, 13°26′E in 80 m of water off Angola (Fig. 11). In this region the surface current (the Angolan Current) is usually southwards but, during the 24-h study, the surface (2 m) meridional current was unidirectional northwards

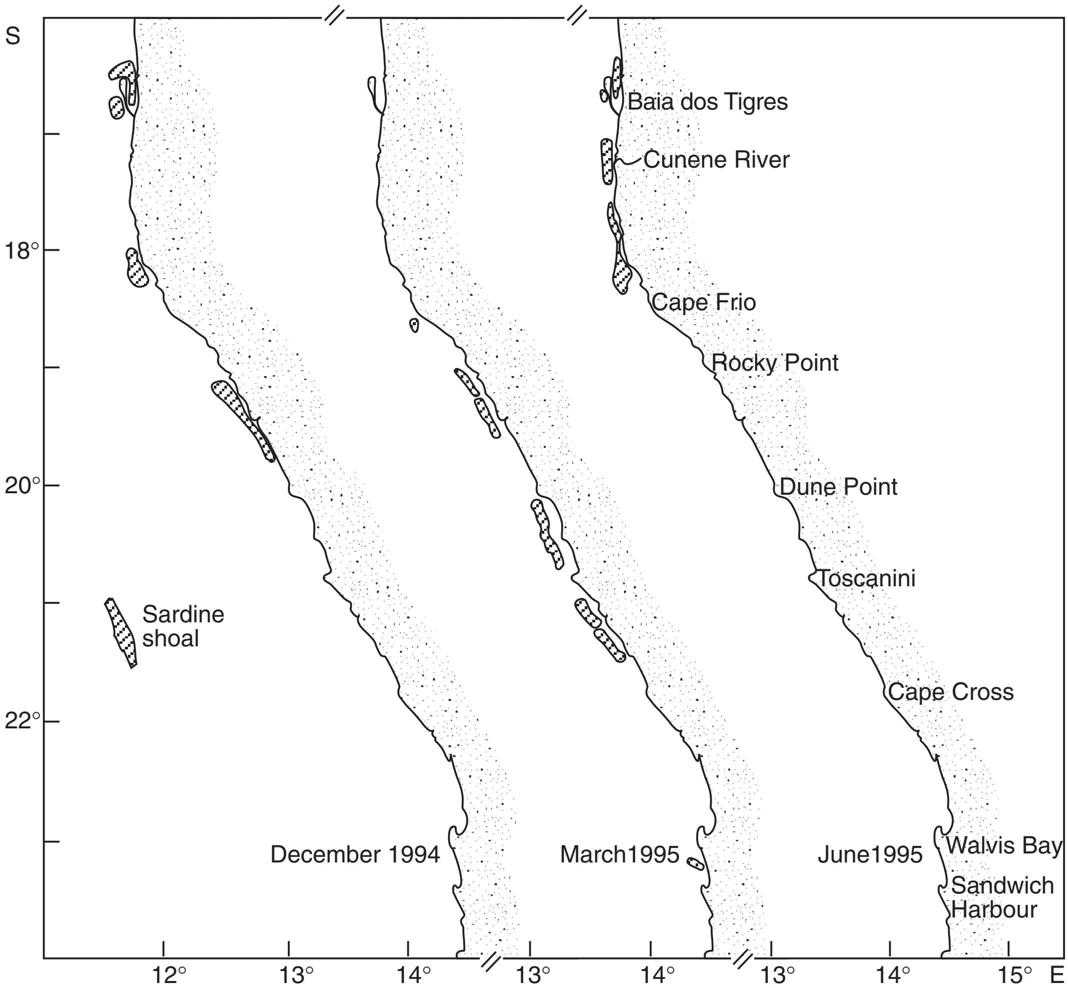

Fig. 9: Distribution of sardine in northern Namibia and southern Angola in December 1994, March 1995 and June 1995, based on acoustic surveys

(despite the strong tidal signal), with an average speed of about 30 cm·s^{-1}. The current at 38 m was mainly southwards, but much weaker, and the average speed at 65 m was close to zero. Therefore, the retreat of the surface disturbance was observed in Angolan waters two weeks after its southernmost penetration.

The retreat of the surface signal of the 1995 Benguela *Niño* around 3 March was probably related to the onset of south-westerly winds. As the wind friction takes time to penetrate the water column, a delay in the return of the disturbance with depth would be expected. This is demonstrated by changes in temperature and salinity anomaly profiles at a station 20 miles off Walvis Bay during 1995 (Fig. 12). The maximum anomalies for both temperature and salinity were more than 10 m deep in March, whereas in April the maximum for temperature and salinity was anomaly was 30 and 20 m deep respectively. In June, the effect of the *Niño* had disappeared at this location.

The surface drogues deployed farther south (Fig. 8) showed that the north-west current was weak and variable during the period when the drogues deployed

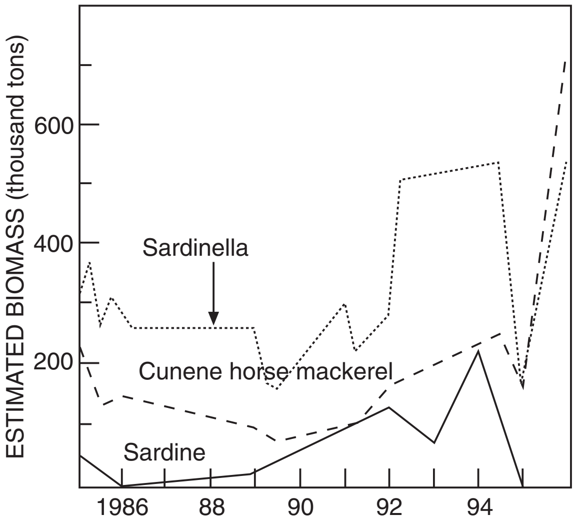

Fig. 10: Estimated biomass for three commercially important pelagic fish species in Angolan waters, 1985–1996 (updated from Luyeye 1995)

near Walvis Bay were heading south. Therefore, the effect of the 1995 Benguela *Niño* may have penetrated south of Lüderitz. The fact that the surface currents near Walvis Bay were directed south-eastwards during most of the study period, whereas the surface currents south of Lüderitz were weak or north-westwards, indicates the presence of a convergence in that area, which would probably cause a surface elevation. During the Benguela *Niños* in 1963 and 1984, the sea level at Walvis Bay was reported to be higher than normal (Shannon *et al.* 1986). Unfortunately, sea level data were not available for 1995.

Dynamics of the 1995 Benguela *Niño*

The temperature disturbance 30 m deep penetrated south, with maximum amplitude near the coast (Fig. 5b). This could be attributed to the effect of the Coriolis force pushing the southward current towards the coast. This concept is further supported by the indication of a horizontal current shear; the surface drogues show stronger southward currents close to the coast.

The vertical structure of the anomaly is demonstrated in Figure 13. In 1994, the characteristic upwelling structure is depicted in the temperature distribution, contrasting with the situation in 1995. The salinity distributions clearly show that the 1995 Benguela *Niño* was influenced by freshwater (river or rain) near the surface and water of higher than normal salinity below this, with salinities as high as 36.2×10^{-3} at 50 m. This suggests that, even with upwelling-favourable winds, the water available for upwelling during a Benguela *Niño* is not the nutrient-rich, deep water usually found on the Namibian shelf, but rather nutrient-poor water of Angolan or tropical Atlantic origin, capped by a warm layer of less-saline water.

The low salinity surface anomaly was about 25 km offshore. The profile shown in Figure 13b was for 5 March, two days after the southernmost penetration of the disturbance. Assuming that the northward turning of the surface drogues (Fig. 8) on 3 March was initiated by an onset of winds from the south, the offshore dislocation of the surface temperature maximum and salinity minimum may be explained by wind forcing, whereas 30 m deep the maximum temperature disturbance was still near the coast (Fig. 5b). Assuming that the surface maximum temperature and minimum salinity (Fig. 13b) were situated near the coast two days previously, a westward displacement speed of about 15 $cm \cdot s^{-1}$ is estimated. The average westward velocity components of the three surface drifters on 4 March were, from north to south, 15, 14 and 9 $cm \cdot s^{-1}$ respectively.

Near 18°S, the vertical distribution of dissolved oxygen concentration (Fig. 13) clearly demonstrated that, during the 1995 Benguela *Niño*, water in the upper 50 m of the water column was poorer in oxygen (by about 2 $ml \cdot \ell^{-1}$) than in 1994.

The salinity anomaly

A Benguela *Niño* is usually associated with a positive surface salinity anomaly (Shannon *et al.* 1986). However, previous studies of such *Niños* concentrated on the Namibian shelf, where the 1995 Benguela *Niño* also displayed a positive salinity anomaly. It is therefore possible that previous *Niños* had a low-salinity anomaly in Angolan surface waters. The data presented by Shannon *et al.* (1986) on the 1984 Benguela *Niño* indicated a low-salinity disturbance at the northern part of the Namibian shelf, similar to the situation in 1995 (see Figs 4b, 7b).

The Namibian inner shelf is usually dominated by upwelled water of low salinity ($34.9–35.2 \times 10^{-3}$, Boyd *et al.* 1987). The suppression of upwelling during the 1995 Benguela *Niño* and the subsequent onshore drift of the high saline ($35.2–35.5 \times 10^{-3}$) oceanic water may explain the positive salinity anomaly

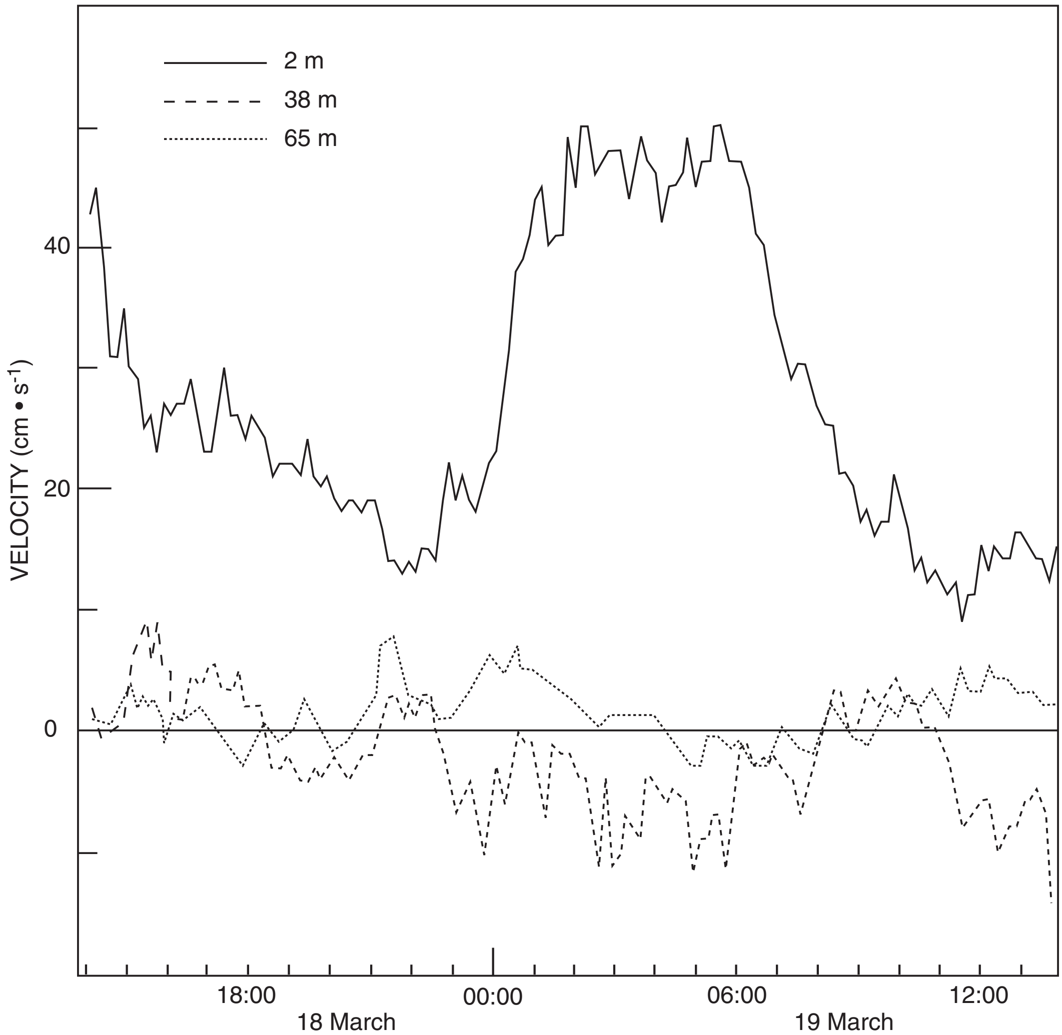

Fig. 11: North-South current component at three depths measured at 11°44′S, 13°26′E (see Fig. 1) on 18–19 March 1995

found at the surface on the central Namibian shelf (Fig. 6b). However, a seasonal intrusion of high saline Angolan Current water (>35.5 × 10^{-3}) is known to take place (Boyd *et al*. 1987). The vertical section at 18°S (Fig. 13b) indicates that, below the low-salinity anomaly, the high salinity Angolan water penetrated south at 100 m depth in inshore waters in 1995. Farther offshore, water with salinity as high as 36.2 × 10^{-3} was observed some 50 m deep (Fig. 13b). High saline water (>35.5 × 10^{-3}) was observed as far south as 24°S, and water with salinity >35.8 × 10^{-3} extended as far south as 20°S, indicating that the more-saline South Atlantic tropical water had penetrated from the north-west (Shannon and Nelson 1996).

In northern Namibian and Angolan waters, a low-salinity anomaly dominated the surface layers (Figs 4b, 7b). The most important freshwater source in the region is the Congo River, the second largest river (by volume) in the world. Water of low salinity is

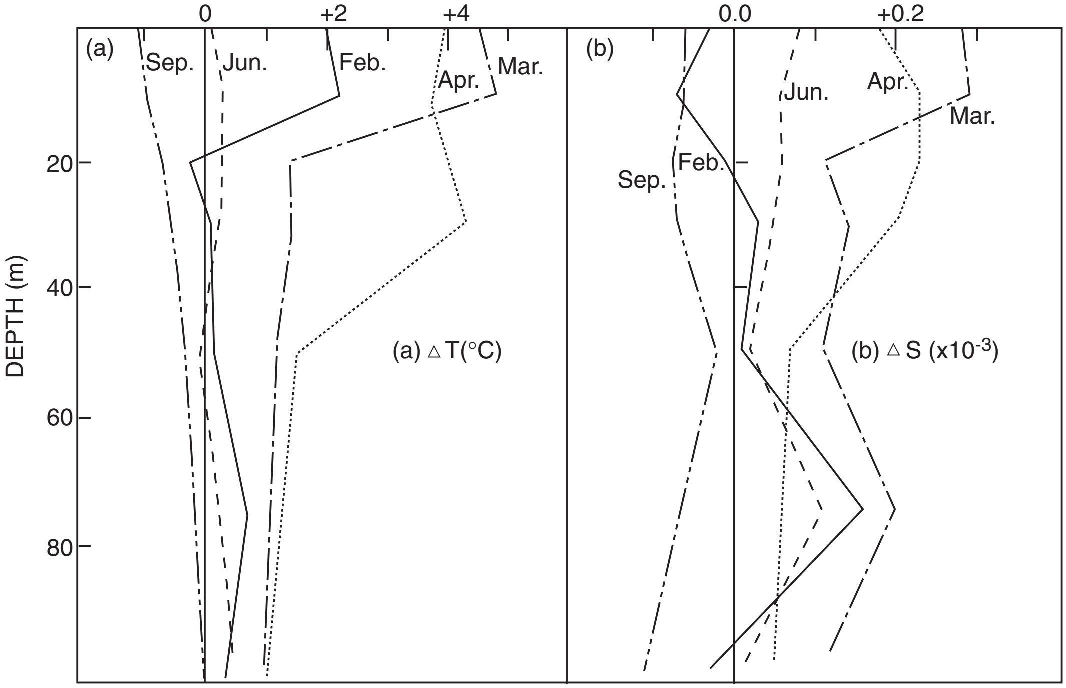

Fig. 12: Time development of the differences in the vertical distribution of (a) temperature (ΔT) and (b) salinity (ΔS) at a position 20 miles off Walvis Bay in 1995

usually found from the river mouth and northwards. The low-salinity anomaly may be explained by a southward displacement of this water mass. This is in agreement with the belief that the Benguela *Niño* is triggered remotely, creating large-scale disturbances that advect water masses over long distances. The large-scale nature of the phenomenon is illustrated by the fact that an anomalous equatorward current was measured as far north as central Angola during the retreat phase of the *Niño*.

Impact on the biota

The intrusion of water from Angola in summer 1995 resulted in a marked shift in the distribution of sardine, with increased availability of shoals to the fishing vessels farther south (Fig. 9). Widespread mortalities of fish were reported throughout southern Angolan and northern Namibia and there there was also a marked decline in the availability of sardinella, Cunene horse mackerel and sardine in Angolan waters (Fig. 10).

In early March 1995, dead or dying horse mackerel were found over a wide area of coastal waters off northern Namibia from 18°30′ to 20°45′S, extending some 20 km offshore. Mortalities were observed in other species of fish, such as kob. Most dead fish were found along the coast north of 19°S, near the Hoarusib River. Those fish mortalities may have been a result of respiratory stress associated with a combination of high seawater temperatures (>22.0°C at the bottom) and sediment loading from river discharge. However, the salinity from near the surface (4 m deep) to the bottom remained high ($>35.8 \times 10^{-3}$). Off southern Angola, there were mortalities of sardine at Baía dos Tigres. An estimated 25 tons of dead fish were found floating on the surface. Seals and scavenging seabirds were feeding heavily on these fish, suggesting that fish mortalities could have been much greater. The temperature in the bay was unusually high (>27°C) throughout the water column, suggesting that these fish may have been trapped in the bay by the intrusion of warm water.

Ichthyoplankton was not sampled during the 1995 Benguela *Niño*. It is likely that the intrusion of warm

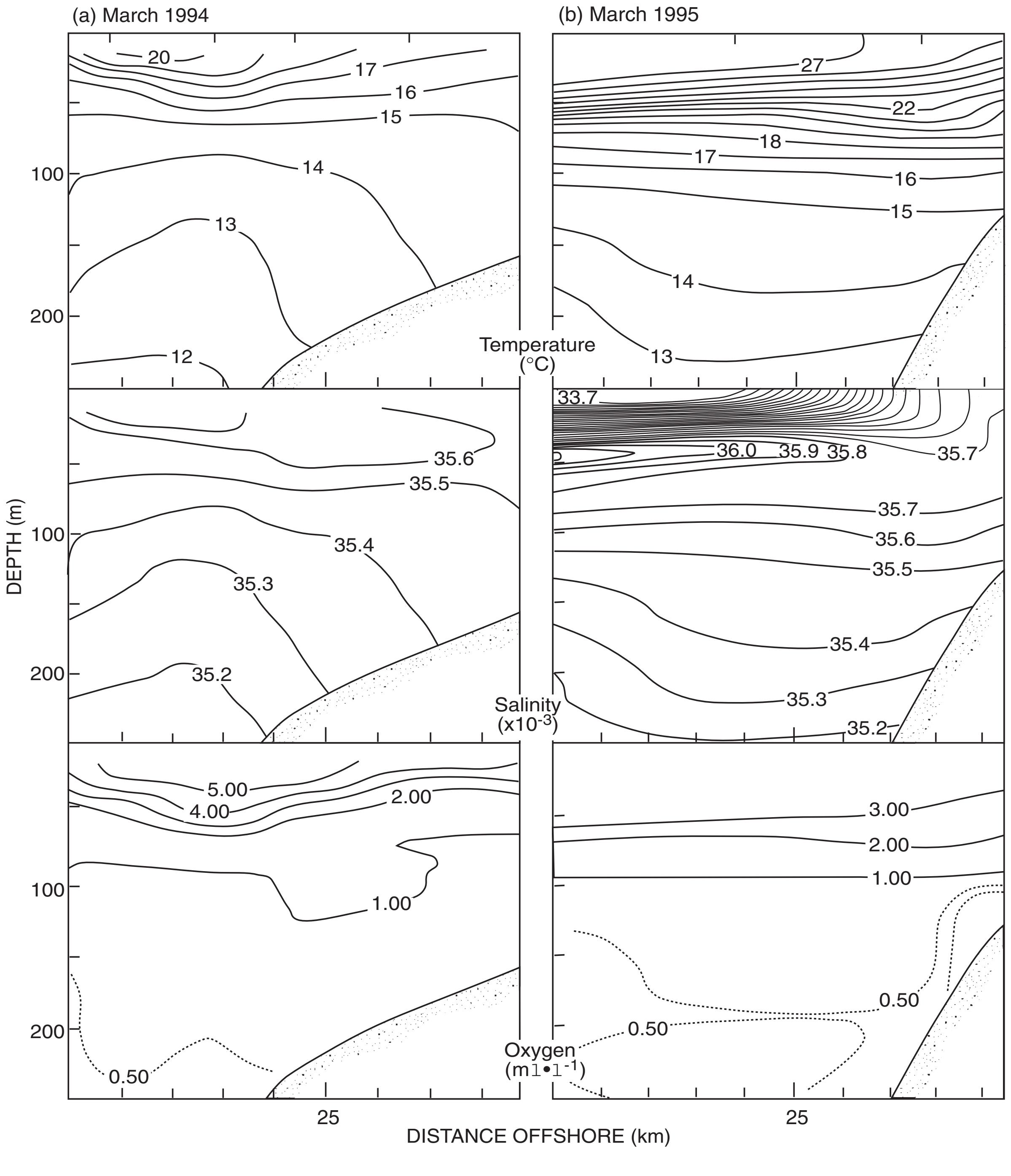

Fig. 13: Vertical profiles of temperature, salinity and oxygen near 18°S in (a) March 1994 and (b) March 1995

water had considerable impact on fish spawning and the development of eggs and larvae throughout the northern Benguela, as documented for the 1984 Benguela *Niño* (Boyd *et al.* 1985).

For Cape horse mackerel, which favour warmer water (O'Toole 1977), spawning may have been more widespread, with the distribution of eggs and larvae extending farther south along the coast of Namibia. Survival of horse mackerel larvae may therefore have been enhanced, favouring good recruitment for the following year. For pelagic species such as sardine and anchovy, impacts on spawning, larval survival and recruitment may have been less favourable. This was confirmed by the fact that virtually zero recruitment of both species was recorded and, at the end of 1995, both stocks were at the lowest biomass on record in Namibian waters (Boyer and Cloete 1996). In Angolan waters, the stocks of sardinella and Cunene horse mackerel seemed to have recovered by the end of 1996, whereas sardine stocks remained low (Fig. 10).

ACKNOWLEDGEMENTS

We thank Drs A. J. Boyd (Sea Fisheries [SF]) and L. V. Shannon (formerly SF) for critical and constructive comments on an earlier draft of this paper. We are most grateful to the National Petroleum Corporation of Namibia (NAMCOR) for permission to use the surfer drifter buoy data, and to the South African Council for Scientific and Industrial Research, Stellenbosch, who carried out the drift experiments and made the data available.

LITERATURE CITED

BAKUN, A. 1996 — *Patterns in the Ocean: Ocean Processes and Marine Population Dynamics*. University of California Sea Grant Program, San Diego, California, USA, in cooperation with Centro de Investigaciones Biológicas de Noroeste, La Paz, Mexico: 323 pp.

BJERKNES, J. 1969 — Atmospheric teleconnections from the Equatorial Pacific. *Mon. Weath. Rev.* **97**: 163–172.

BOYD, A. J. and J. J. AGENBAG 1985 — Seasonal trends in the longshore distribution of surface temperatures off southwestern Africa 18 – 34°S, and their relation to subsurface conditions and currents in the area 21 – 24°S. In *International Symposium on the Most Important Upwelling Areas off Western Africa (Cape Blanco and Benguela),*[*Barcelona, 1983*] **1**. Bas, C., Margalef, R. and P. Rubiés (Eds). Barcelona; Instituto de Investigaciones Pesqueras: 119–148.

BOYD, A. J., HEWITSON, J. D., KRUGER, I. and F. LE CLUS 1985 — Temperature and salinity trends off Namibia from August 1982 to August 1984, and their relation to plankton abundance and the reproductive success of pelagic fish. *Colln scient. Pap. int. Commn SE. Atl. Fish.* **12**(1): 53–60.

BOYD, A. J., SALAT, J. and M. MASÓ 1987 — The seasonal intrusion of relatively saline water on the shelf off northern and central Namibia. In *The Benguela and Comparable Ecosystems*. Payne, A. I. L., Gulland, J. A. and K. H. Brink (Eds). *S. Afr. J. mar. Sci.* **5**: 107–120.

BOYER, D. C. and R. C. CLOETE 1996 — Research and management of the northern Benguela pilchard. WOSAS-workshop on southern African Sardine: proceedings and recommendations. *Rep. Benguela Ecol. Progm. S. Afr.* **29**: 73–76.

CARTON, J. A. and B. HUANG 1994 — Warm events in the tropical Atlantic. *J. phys. Oceanogr.* **24**: 888–903.

COLE, J. and J. McGLADE 1998 — Temporal and spatial patterning of sea surface temperature in the northern Benguela: possible environmental indicators of clupoid production. In *Benguela Dynamics: Impacts of Variability on Shelf-Sea Environments and their Living Resouces*. Pillar, S. C., Moloney, C. L., Payne A. I. L. and F. A. Shillington (Eds). *S. Afr. J. mar. Sci.* **19**: 143–157.

HOREL, J. D., KOUSKY, V. E. and M. T. KAGANO 1986 — Atmospheric conditions in the Atlantic sector during 1983 and 1984. *Nature, Lond.* **322**(6076): 248–251.

KRUGER, I. and A. J. BOYD 1984 — Investigation into the hydrology and plankton of the surface waters off southwestern Africa in ICSEAF Divisions 1.3, 1.4 and 1.5 in 1982/83. *Colln scient. Pap. int. Commn SE. Atl. Fish.* **11**(1): 109–133.

LE CLUS, F. 1985 — Effects of a warm water intrusion on the anchovy fishery in Namibia. *Colln scient. Pap. int. Commn SE. Atl. Fish.* **12**(1): 99–106.

LE CLUS, F. 1986 — Aftermath of environmental perturbations off Namibia relative to the anchovy stock, and comparative pilchard spawning. *Colln scient. Pap. int. Commn SE. Atl. Fish.* **13**(2): 19–26.

LE CLUS, F. 1991 — Hydrographic features related to pilchard and anchovy spawning in the northern Benguela system, comparing three environmental regimes. *S. Afr. J. mar. Sci..* **10**: 103–124.

LUYEYE, N. 1995 — Distribution and abundance of small pelagic fish off the Angolan coast. *ICES Doc.* **C.M. 1995/H:32**: 16 pp. (mimeo).

MEEUWIS, J. M. and J. R. E. LUTJEHARMS 1990 — Surface thermal characteristics of the Angola-Benguela front. *S. Afr. J. mar. Sci.* **9**: 261–279.

O'TOOLE, M. J. 1977 — Investigations into some important fish larvae in the South East Atlantic in relation to the hydrological environment. Ph.D. thesis, University of Cape Town: pagination discontinuous, 8 sections + 7 supporting papers.

SALAT, J., MASÓ, M. and A. J. BOYD 1992 — Water mass distribution and geostrophic circulation off Namibia during April 1986. *Continent. Shelf Res.* **12**(2/3): 355–366.

SCHÜLEIN, F. H., BOYD, A. J. and L. G. UNDERHILL 1995 — Oil-to-meal ratios of pelagic fish taken from the northern and the southern Benguela systems: seasonal patterns and temporal trends, 1951–1993. *S. Afr. J. mar. Sci.* **15**: 61–82.

SHANNON, L. V., BOYD, A. J., BRUNDRIT, G. B. and J. TAUNTON-CLARK 1986 — On the existence of an *El Niño*-type phenomenon in the Benguela system. *J. mar. Res.* **44**(3): 495–520.

SHANNON, L. V. and G. NELSON 1996 — The Benguela: large scale features and processes and system variability. In *The South Atlantic: Present and Past Circulation*. Wefer, G., Berger, W. H., Siedler, G. and D. J. Webb (Eds). Berlin;

Springer: 163–210.
SHANNON, L. V. and J. TAUNTON-CLARK 1989 — Long-term environmental indices for the ICSEAF area. *Sel. Pap. int. Commn SE. Atl. Fish.* **1**: 5–15.
SMITH, J. L. B. 1965 — New records and descriptions of fishes from South-West Africa. *Occ. Pap. Dept. Ichthyol. Rhodes Univ.* **3**: 1–23.
STANDER, G. H. and A. H. B. DE DECKER 1969 — Some physical and biological aspects of an oceanographic anomaly off South West Africa in 1963. *Investl Rep. Div. Sea Fish. S. Afr.* **81**: 46 pp.
ZAUNER, C. 1995 — The Underway Mapping System. Users manual. Version 3.8., Cape Town; Sea Fisheries Research Institute: 53 pp.