Nutrients and Upwelling

By Anja Risser

Nutrients, as the basic building blocks of living matter, are a prerequisite for primary production. The principal chemical elements constituting organic material, such as phytoplankton, are oxygen, hydrogen, carbon, nitrogen and phosphorus. Of these, the first three are abundant and widely found in nature. These are the bio-unlimited elements. The elements nitrogen and phosphorus are not always available in the required suitable chemical form and so can become limiting factors for the growth of plants.

In the marine environment nitrogen, mainly in the form of nitrate, is often the biolimiting factor for phytoplankton production. Nitrogen and phosphorus are therefore regarded as the two most important biological nutrients. Another quantitatively important nutrient in seawater is silica. It forms part of the skeletal shells or outer casings of many planktonic organisms such as diatoms and radiolarians.

The Benguela upwelling system generates an abundance of marine life along the Namibian coast. Southerly winds blowing parallel to the coastline and the earth’s rotation or Coriolis force result in a westerly off-shore movement of coastal surface water. This water mass is replaced by the upwelling of cold, nutrient-rich water from deeper layers. In the presence of sunlight, phytoplankton flourishes on these dissolved nutrients brought to the surface from the seabed.

During phytoplankton blooms surface waters become depleted in nutrients as they are incorporated into organic or skeletal material. These blooms die when there are no more nutrients available. As the planktonic organisms sink to the bottom, they decompose, thus releasing the nutrients. Deep ocean water and the seabed are rich in nutrients in comparison to surface waters. The nutrients are recycled through the upwelling process where once again they reach surface waters and are available to the phytoplankton.

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The Benguela Niños

By Mick O’Toole and Chris Bartholomae

Unusual environment conditions prevailed off the coast of Namibia in 1994. Sea surface temperature patterns during 1994 were typical for those times of the year. Warm stratified surface layers of between 18° and 21°C typical of summer/autumn months (December – April) occurred over the continental shelf off northern Namibia. In the south, cooler water was more widespread and active upwelling was characteristic along much of the coast, especially around Lüderitz where cold 13°C water predominated.

Later in the year during spring (September – November), intense upwelling characterised by 11° to 14°C was found off the Lüderitz area whereas further north, around Walvis Bay warmer more stable waters prevailed.

Off northern and central Namibia low oxygenated bottom water is a seasonal feature of coastal oceanographic processes especially during summer and autumn months. At these times upwelling is reduced and the prevailing southwest winds slacken. The ocean becomes warmer and more stable and favourable for the production of high levels of phytoplankton and zooplankton. The organic decay of plankton leads to a build up of low levels of oxygen near the seabed. This area of anoxic (oxygen depleted) water usually concentrates in a coastal band downstream of the main upwelling cell off Lüderitz. It is particularly pronounced for most of the year from Conception Bay to Cape Cross within the 100 m isobath or depth contour. Traditionally this area has been referred to as the “Azoic Zone”.

Namibia Brief, No. 20, January 1998
109
With the onset of winter and spring, upwelling intensifies and the prevailing south-southwest winds increase in strength. The ocean becomes cooler and the nutrient-rich low oxygen water is transported to the surface layers by upwelling where it is well mixed. Water circulation becomes more energetic and oxygen levels tend to rise with the increased mixing and current movement.

During much of 1994, the oxygen levels in the water close to the seabed were persistently low over a wide area of the continental shelf beyond the 100-m isobath. In summer months for example oxygen values were as low as 0.25 ml/l over much of the coastal waters between Cape Fria and Walvis Bay (Figure 1). This layer of oxygen deficient bottom water extended out to 50 nautical miles offshore. In contrast, further south towards the Lüderitz upwelling cell, the oxygen levels in the bottom water were somewhat higher. Under normal conditions, oxygen deficient water with a value below 0.5 ml/l extends over less than one third of the shelf in this area (Figure 1).

During the autumn, winter and spring of 1994 the oxygen levels remained low over the northern and central continental shelf with a layer of anoxic water (<0.5 ml/l) extending from the coast out to about 70 nautical miles offshore.

The vertical extent of the low oxygen on the continental shelf during 1994 ranged from 50 to 250 m in thickness. In winter the distribution of this low oxygen water was particularly extensive through the water column in the northern and central areas even reaching the surface layers at Walvis Bay (Figure 2). Conditions in 1994 were further aggravated by the movement of oxygen depleted bottom waters onto the shelf edge from deep layers offshore originating from Angola.
Changes in the distribution and availability of fish

Fish mortalities in coastal waters associated with unfavourable environmental conditions such as low levels of oxygen, increased levels of sulphur eruption and algal blooms (including red tides) have often been reported in the past especially along the central part of the Namibian coastline.

The widespread distribution of oxygen deficient water and associated environmental effects, including changes in biological productivity, seemed to have had an unfavourable impact on some of Namibia’s major commercial species during 1994. Fishermen reported a substantial decrease in the availability of pilchard and hake along parts of the coast. Pelagic fish stock assessment surveys carried out by the research vessels Dr Fridjof Nansen and Welwitschia between February and May 1994 had great difficulty in locating shoals of pilchard, anchovy and even juvenile horse mackerel.

Survey data for pilchard indicated a markedly reduced biomass in the inshore waters compared with the same period in 1993. These low biomass levels obtained from acoustic estimates were reflected in difficulties by the commercial fleet in locating pelagic fish shoals, much of which had moved to the far north and across the Angolan border. Pilchard shoals may have also moved offshore away from the traditional coastal areas to the safety of deeper oceanic waters.

A marked reduction in the availability of other pelagic species such as juvenile horse mackerel and anchovy which normally make up a significant proportion of the pelagic fishing industry catches were also observed.

The causes of the scarcity of the pelagic fish are not known but could be related to the low levels of suitable food organisms in the coastal waters. In contrast to the observed decline in fish abundance, large phytoplankton blooms and red tides were frequently observed in coastal waters during summer and autumn. These blooms were especially noticeable in the central region between Cape Cross and Conception Bay where reports of fish mortalities were frequently received by shore anglers. These red tides consisted of both diatoms and dinoflagellates with some species identified as being toxic to fish and shellfish.

The demersal fleet experienced difficulties in catching hake during parts of the 1994 fishing season. A decline in fish availability was recorded in the central region and there was a subsequent general increase in fish abundance in the south. Off the central part of Namibia, concentrations of Cape hake were reported further offshore along the shelf edge compared with 1993. This shift in distribution may have been attributed to the extensive low oxygenated water especially in inshore waters shallower than 200-m depth.

A large die-out of Cape fur seals (pups and adults) occurred all along the coast of Namibia during summer and autumn months of 1994 with mortalities estimated at over 300 000 animals. The primary cause of death was hypothermia due to loss of body fats because of starvation from the scarcity of fish within the normal feeding ranges of these animals.

Unusual weather patterns

A number of other observations indicated that unusual conditions characterised the Namibian marine environment during 1994.

In summer and autumn, there was an apparent shift in the wind regime at the coast with an increase in the north, northeast and easterly wind components. Wind patterns along the central and northern coasts during late autumn, winter and spring indicated prolonged periods of calm conditions with occasional north to northwest breezes. This was in contrast to the usually prevailing south to southwest winds that dominate the region at this time and are responsible for the generation of active coastal upwelling.

This resulted in greater periods of calm conditions overall especially along the central and northern parts of the coast. Fishermen, residents at the coast and data from some coastal weather stations supported these observations.

Compared with previous years, the bergwinds were more frequent and intense during the autumn and winter of 1994. Such winds tend to suppress coastal upwelling resulting in more sluggish conditions. These periods of prolonged calm also favour high phytoplankton growth and development of red tides.

High rainfall inland and over parts of the Namib Desert in late summer and early autumn resulted in floodwaters from a number of rivers including the Swakopmund River reaching the coast. The Meteo­rological Service recorded lower air temperatures than normal in the late autumn and winter. These
cold conditions caused snowfalls in parts of the Namib Desert and inland regions for the first time in nearly thirty years.

**The Benguela Niño warm water event**

From February to April 1995, the widespread distribution of unusually warm water was detected in the marine environment off northern and central Namibia. The *RV Welwitschia* reported the first indications of the occurrence of this major warm water event off the southern Angolan and northern Namibian coast during a routine pilchard stock assessment cruise in late February.

Sea surface temperatures recorded in the coastal waters of southern Angola were over 29°C and 27°C along the northern Namibian coast near the Kunene River. This deep layer of warm highly saline stratified water (17°C to 27°C and 35.4 to 35.8 ppt) occupied much of the upper 100 m of the water column (Figure 4). The influence of this warm water intrusion extended southwards along the Namibian coast with values of 20° to 21°C off Walvis Bay and 17°C at Lüderitz.

In March and April the *RV Dr Fridtjof Nansen* also detected the warm water event off central Angola where temperatures at depths of 20 to 40 m were 8°C above the normal values for that time of year. Surface salinities offshore were found to be abnormally low over a wide area extending beyond 300 km from the coast.

The occurrence of the Benguela Niño over the Namibian continental shelf can be clearly seen in the series of imagery of sea surface temperature captured by the NOAA 9 satellite at the National Marine Information and Research Centre in Swakopmund (Figure 5).

Anoxic conditions continued over the northern and central Namibian shelf with values of below 0.5 ml/l over much of the seabed and extending out to the 200 m isobath in places. Off the northern coast, deoxygenated water originating from Angola was present much of the continental slope and extended up to 200 m into the water column. Further south, the bottom water was more oxygenated with values somewhat higher than in 1993 and 1994.

A major change took place in the direction of coastal surface currents during the Benguela Niño event. A satellite tracked surface buoy, released 15 km off Swakopmund on February 6, after a period of northwesterly drift of several days suddenly reversed direction around February 13 and travelled steadily southeastwards at an average speed of about 10 cm/sec. It continued on this path until March 3 before moving offshore in a more usual northwesterly direction (Figure 6).

Sea surface temperatures off the coast gradually cooled off between May and July 1995 and indicated a return to more typical upwelling conditions for winter months. By July, strong upwelling was widespread along the entire coastline from the Orange River to Walvis Bay with temperatures of 12°C to 13°C up to 100 km offshore. Satellite images for the spring and early summer period (September to December) indicated continued and intense upwelling off much of the south and parts of the central Namibian shelf. These conditions resulted in unusually low temperatures, of between 2° and 3°C, cooler than normal for this time of the year.

During 1995, the marine environment off Namibia oscillated from unusually warm conditions at the start of the year to very cold conditions towards the end of the year. Although poorly oxygenated bottom water continued to be widely distributed over much of the northern and central Namibian shelf region in summer and autumn, values increased in coastal waters in late spring with a corresponding renewal of intense and persistent upwelling in the south and central region. By the end of 1995 indications were that the environment was returning to more normal conditions.
This was also reflected in increased hake availability and catches. Upwelling was very intense and persistent compared with the same period in 1994 which resulted in more extensive distribution of cold water. The low number of hake eggs seemed to indicate this intense upwelling could have delayed the hake-spawning season thereby affecting future recruitment success.

**Influence on fisheries**

Physical processes such as wind, upwelling intensity and currents have a major influence on the movement, migration and spawning success of fish populations. The plankton productivity and the oceanographic conditions such as temperature, salinity and oxygen levels also markedly influence the growth and survival of larval and juvenile stages. Pelagic fish such as pilchard, anchovy and young horse mackerel usually inhabit the coastal water areas where food production is concentrated. Each species has specific temperature regimes that are favourable for spawning, egg development and larval growth and where oceanographic processes concentrate and retain plankton of the right size and densities necessary for good survival and recruitment.

The warm water events off the Namibian coast in the summer and autumn of 1995 had a major impact on fish behaviour, spawning patterns and on plankton production.

During much of 1994, pilchard shoals were concentrated mainly to the north of the Kunene River in southern Angola with few fish shoals being reported in Namibian waters. However, following the push southwards of warm water from Angola in the summer of 1995, there was an increased availability of pilchard shoals further south. In early March off southern Angola (Baita dos Tigris), where unusually high water temperatures of 27°C occurred, large quantities of dead pilchard were observed floating on the surface over a wide area. Further south, mortalities of juvenile horse mackerel were reported in inshore waters southwards from the Kunene River to Möwe Bay. Dead and dying fish were found out to 20 km offshore. Mortalities amongst other species of fish such as kob and westcoast steenbras were noted but to a lesser extent. The causes of the mortalities are not known but may have been due to stress associated with a combination of high seawater temperatures and low oxygen.

The effects of past warm water events on the fish and plankton production of the northern Benguela system such as those that occurred in 1963 and 1984 have been well documented.

In late summer and autumn of 1963 unusually high temperatures resulted in low plankton biomass, an increase in warm oceanic plankton species, depressed fish egg productivity and poor survival of fish larvae. The fishing industry reported persistently low oil yields for pilchard which under normal circumstances should have been in peak condition. Fishing vessels close to Walvis Bay also caught unusual fish species of tropical origin.

Reports on the 1984 Benguela Niño indicated major shifts of pilchard shoals southwards and increased availability to the fishing fleet. During the pelagic fishing season of that year, anchovy stocks were reported to be the lowest on record with a marked decline in the abundance off the Namibian coast. Only 13 000 tons of anchovy out of an allocated quota of 200 000 tons were caught. In addition, the Angolan gilt sardine which usually inhabits warmer Angolan Current water was found off the coast of northern Namibia along with other tropical and equatorial fish species.
species. Mortalities of young horse mackerel and various coastal angling fish species such as steenbras and kob were recorded over one to two day periods at various locations along the coast between Cape Fria and Walvis Bay.

Research scientists found that production of plankton off Namibia during the summer and autumn of 1984 was four times lower than during the same period in 1982/83 or in the two previous summers. Phytoplankton was ten times less abundant than in previous years and the plankton was dominated by imported species. In addition, egg production of pilchard declined by one quarter compared with the previous two years levels. Poor anchovy spawning was recorded with egg production levels being one tenth of those of the 1982/83 season.

**Spawning and the environment**

Unfavourable environmental conditions such as too high temperatures, too deep thermoclines and low nutrient and food levels (namely Benguela-Niño conditions) can severely affect the movement, spawning behaviour and the development of the eggs and larvae. Too low temperatures due to prolonged and intense upwelling can result in the absence of thermoclines (where food is usually generated) and offshore transport of spawning products away from the coastal nursery grounds. Such conditions can slow egg and larval development.

Pilchard generally prefer to spawn in the upper 50 m surface layers when water temperatures range between 16° and 18°C. Horse mackerel have a wider spawning range of between 17° and 20°C whereas anchovy prefer to spawn in somewhat warmer waters offshore. Conditions favourable for spawning of pelagic fish generally occur off northern Namibia during summer and autumn months when there is high plankton productivity. These waters are also important nursery areas for pelagic fish.

On the central Namibian shelf favourable conditions for spawning usually occur in late spring and early summer when upwelling begins to moderate. Cape hake spawn in this region at depths of between 150 and 200 m when temperatures rise above 13°C. The spawning season and recruitment of young hake can be adversely affected by persistent deoxygenation over the spawning grounds and the interaction with the Angolan Current has a marked influence on upwelling, the seasonal cycles of plankton production and the migration and spawning of fish populations. In order to better understand the complex processes and interactions, a regional study of the Benguela Current as a whole needs to be undertaken. Such integrated and managed regional research can help to predict the effects of climate changes on oceanographic processes, plankton productivity and spawning success and recruitment of fish stocks off the coast of Namibia. This would greatly contribute to the overall understanding of the oceanography of the Benguela Current region and would assist in the management of fisheries on a more sustainable basis.

Oceanographic conditions which influence fish spawning success, larval survival and recruitment can be summarised as follows:

<table>
<thead>
<tr>
<th>Normal conditions</th>
<th>Unfavourable conditions</th>
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<tr>
<td>Moderate upwelling</td>
<td>Intense upwelling or warm water event</td>
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<tr>
<td>Shallow mixed layer with high light levels</td>
<td>Deep mixed layer with cloud cover</td>
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<tr>
<td>Shallow thermocline (20 to 45 m)</td>
<td>Deep thermocline or warm water event</td>
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<tr>
<td>Large flux of nutrients to surface layers</td>
<td>Nutrient-poor surface water</td>
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<tr>
<td>High primary production</td>
<td>Low primary production</td>
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<tr>
<td>Suitable densities of plankton</td>
<td>Local algal blooms or stagnant water</td>
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<tr>
<td>Relatively well-oxygenated water</td>
<td>Extensive deoxygenated water</td>
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