CHAPTER

3

Biological environment

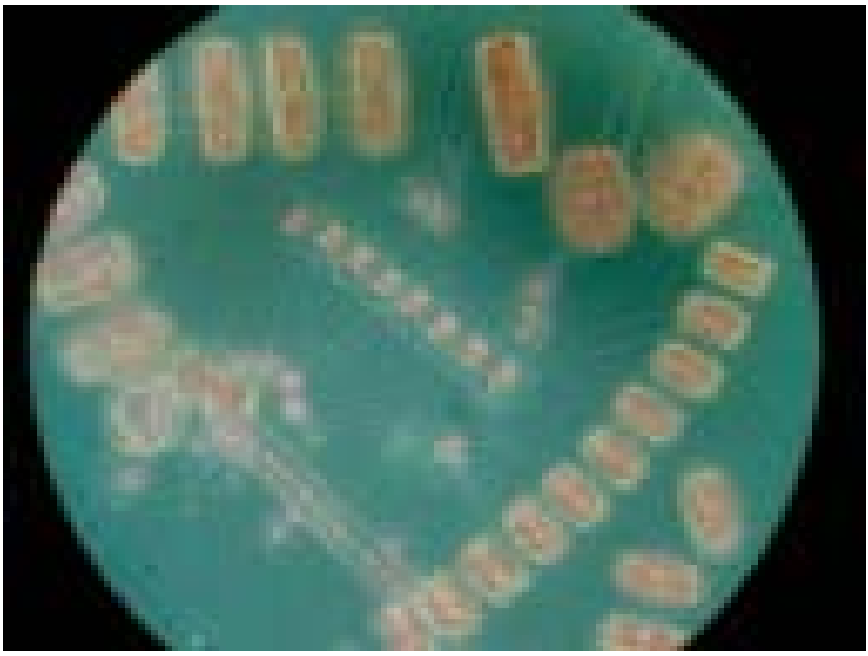
Fergus Molloy

The nutrients that fuel the biological environment, leading to primary production and all of the food webs that depend on it, are determined by the physical/chemical environments.

Primary production

The essential requirements for primary production are carbon and other chemicals as well as light. This form of photosynthetic primary production forms the basis of almost all food webs in the oceans apart from a very few that are based on primary production in the absence if light (chemosynthesis). The physical state and chemical constituents of the ocean effects the levels and availability of chemicals and light for photosynthesis and also the temperature of the water.

Carbon exists in abundance in the oceans as bicarbonate, carbonate and carbon dioxide. Nitrogen as nitrate, nitrite and ammonia, phosphorus as orthophosphate and phosphate and silicon as silicate. Levels of these chemical species vary and limit primary production; that is, low nitrogen, phosphorus and silicate levels lead to low primary production. Nitrogen, phosphorus and silicon (in the forms mentioned above) as well as essential trace elements are generally referred to as nutrients. These nutrients have their origins in decomposing tissues, cells and excretory products either on the seabed or in the water column and some may be of riverine origin. Nutrients that end up on the sea bed or below the illuminated euphotic zone (the zone in which enough light penetrates for photosynthesis to occur) may be lost to primary production for some time unless a mechanism exists by which these nutrients can be resuspended and brought up to the surface layers.



MFMR: D. Louw

Mixed filamentous diatoms from Namibia'a coastal waters. Diatoms are the fastest growing and most abundant of the primary producers in the Benguela Syatem. These microscopic photosynthetic organisms can occur as individuals, or in chains and have hard silicon shells. Because they are not motile they are totally reliant on currents to keep them in the illuminated upper layers.

The role of upwelling

As described in chapter 2, there are a number of upwelling cells along the west coast of South Africa and the coast of Namibia. The largest of these, indeed the largest of any upwelling cell in the world, is the Luderitz upwelling cell[13]. This cell is a permanent feature and active all year round[76]. The upwelling cells further north on the Namibian coast at Conception Bay and Palgrave Point (Fig. 2.1) are mostly active in the austral winter and the northern most cell, south of Cape Frio, though not as large as the Luderitz cell, is permanent[77]. What drives the Luderitz upwelling cell is the virtually constant southerly winds dictated by the position of the south Atlantic high pressure, coupled with this, the very narrow (30 kms) continental shelf just south of Luderitz allows deep water to easily reach the coastal zone[6]. Because of the Earth's rotation these longshore winds cause an Ekman movement of surface water off-shore (see text box 2.1). This water is replaced by water coming from the depths of 200-300 m facilitated by the narrow shelf. This water is cold, 7-10.5C[76] and nutrient rich (nitrate, 5-25 μM: Phosphate, 1.5-2.5μM; silicate, 5-20 μM).

Though the wind is the driving force, it can be too strong for optimal upwelling and prolonged wind after upwelling hampers primary production[78]. The ideal wind speed for upwelling is 5-6 m/sec[78]. Under these conditions cool, nutrient rich deep waters are brought to the surface. If strong winds persist, the surface continues to be turbulent, mixing the water column and removing phytoplankton from the surface layers to deeper layers where lack of light slows down the rate of population increase. The very productive nature of the Benguela system can be seen from surface chlorophyll satellite imagery (Fig. 3.1)

Plankton blooms

Seed phytoplankton are always present in the water column and when concentrations of nutrients, as well as light and temperature conditions are optimal, the population increases rapidly. Diatoms form dense spores that sink quickly and hence are not carried away from the upwelling centres[79]. Of the larger phytoplankton, the Benguela system is diatom dominated with dinoflagellates in a secondary role. Nanoplankton (5-60 μM) are a very important component and may even be more important from a primary production perspective than the larger diatoms in the Benguela system as a whole[80] but have been under sampled in the past[77]. The ideal conditions for primary production would be a southerly wind of 5-6 m/sec followed by a period of calm. The wind, through upwelling, brings nutrients to the illuminated surface layers and with a reduction in wind speed the water stratifies as the upper layers are warmed by the sun. There is a lag period between the upwelling of nutrient rich water and the rapid growth of phytoplankton. To illustrate this, in the Southern Benguela chlorophyll levels were measured in recently upwelled, maturing upwelled and aged upwelled water, the results were 1, 1-20 and 5-30 mg chl/m^3 respectively. High nutrients, abundant light and a stable water column trigger very rapid multiplication of phytoplankton. Diatom numbers increase to the greatest extent first as their rate of cell division is faster than that of dinoflagellates[81]. As the

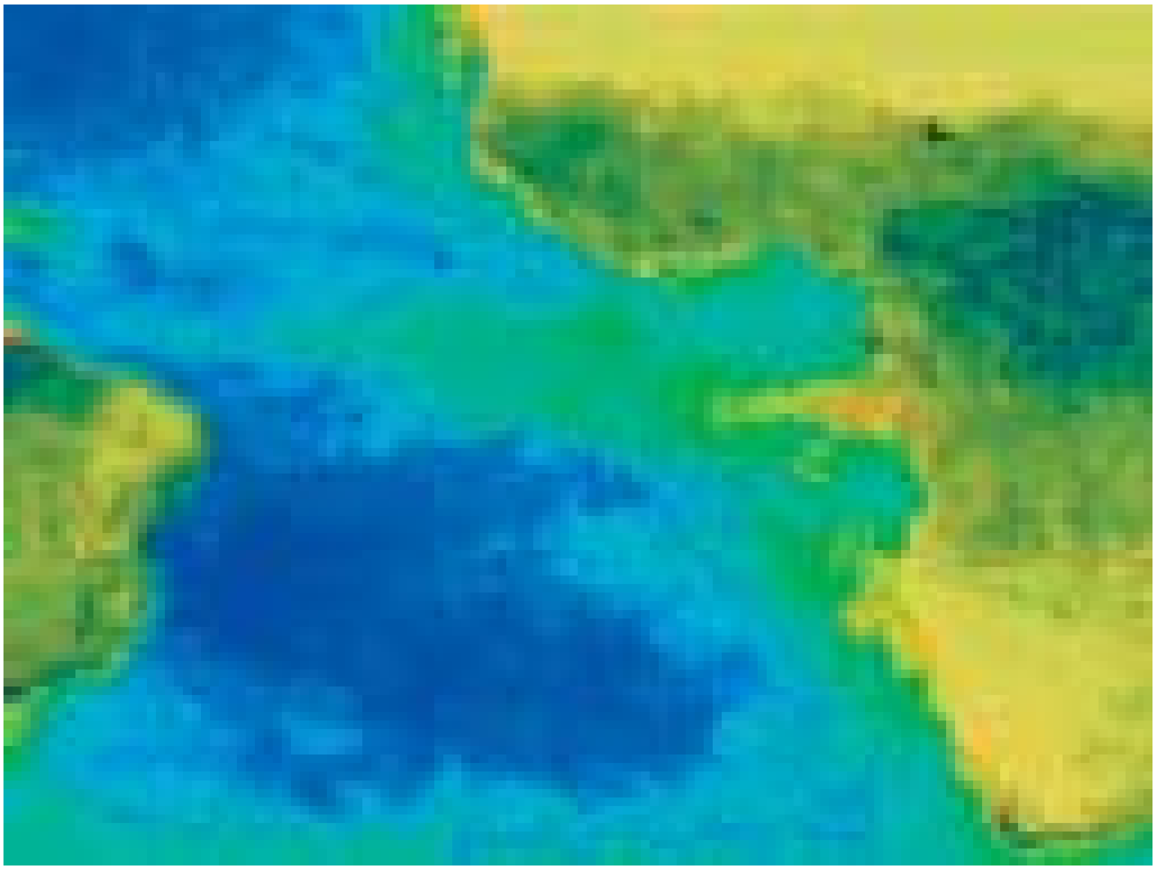


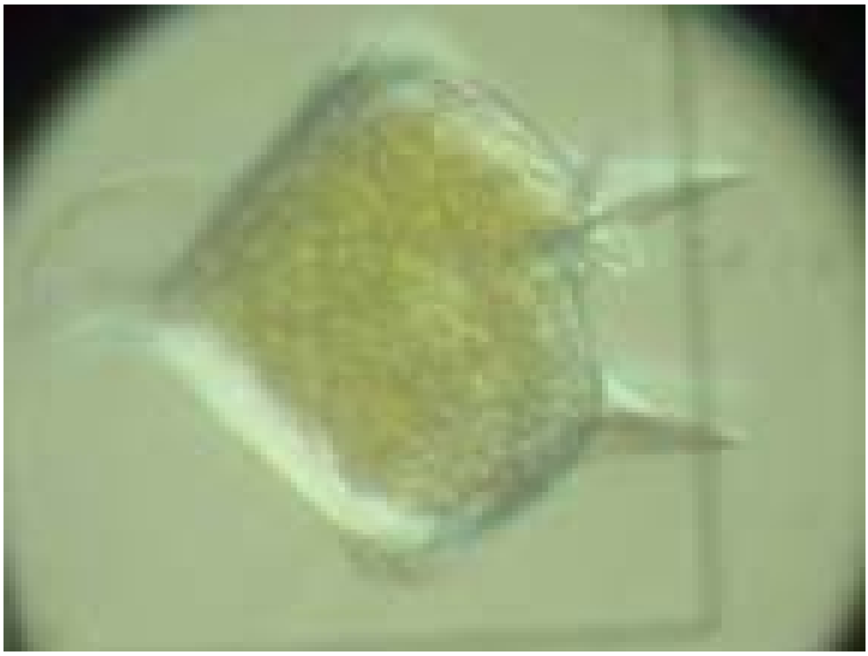
Figure 3.1 An example of chlorophyll concentration observed from SeaWiFS over the South Atlantic. Red indicates the higest levels and blue the lowest levels. A quick method of estimating primary production is to look at chlorophyll concentration. The primary production of the Benguela can clearly be seen and the area of high chlorophyll concentration further north is as a result of nutrients brought down by the Congo River.

phytoplankton bloom continues, nutrients are used up and as the bloom becomes more dense, light penetration through the water column decreases. Zooplankton feed on the phytoplankton and their numbers increase as well. The natural mortality rate in a phytoplankton bloom is high and mortality through herbivory by zooplankton is also high. A large proportion of phytoplankton, particularly diatoms, which are not mobile, fall out of the surface layers and become incorporated in to the sediments on the bottom. Dinoflagellates are mobile and can stay in the surface layers longer so their bloom will be more noticeable after the peak of the diatom bloom. Under more turbulent conditions, Dinoflagellates have an advantage over diatoms in that they can stay closer to the surface[82]. Light can be limiting for primary production if there is too little or too much consequently maximum primary production does not occur right at the surface but rather some meters below[83].

The Lüderitz upwelling cell

In the case of the Luderitz upwelling cell the situation is more complicated. Prevailing winds are often stronger than the optimum for upwelling but there is also a constant northward flow of surface water due to the Benguela current. This current carries the newly upwelled water further north where wind velocities may be lower and where stratification can occur. As the water moves in a northerly direction, the phytoplankton population increases as does the zooplankton population giving the effect of a food web that is spatially stretched out form south to north. This has been demonstrated by phytoplankton and chlorophyll studies which indicated lower levels at the site of upwelling and higher levels down stream[77]. From nutrients in the south near Luderitz through plankton and on to larger carnivores such as fish further north i.e. near Walvis Bay, the energy flows through the system. This is a very simplified description in that there are, of course, fish stocks near Luderitz, but it does serve to illustrate the impact the Luderitz upwelling cell has on the fish stocks of central Namibia.

If the south Atlantic high pressure is not in the right position, the southerly winds around Luderitz will not blow, upwelling will not happen, high nutrient levels will not be available and the sequence of events that lead to the high biomass of fish in central and northern Namibia will not take place. During winter, southerly winds are also crucially important to the lesser upwelling cells off northern Namibia.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A typical dinoflagellate. Neither plant nor animal, dinoflagellates are photosynthetic protists. Though not as abundant as diatoms, they can form very dence blooms particularly during calm periods after prolonged upwelling. They are motile and so do not rely on currents to keep them under optimum illumination conditions.

Other primary producers that also benefit from the abundance of nutrients are the attached macroalgae; the seaweeds (fig 2.9). During peak growth periods, *Gracilaria* (a red seaweed) can double its weight every 7 days[84] and *Laminaria* (a kelp) elongates at up to 1.8 cm per day[84]. Though not as important as phytoplankton to overall primary production, seaweeds are vital to shallow water populations of many organisms.

The zooplankton populations that graze on phytoplankton and smaller herbivorous zooplankton are dominated by copepods and euphausiids. These become the food of some of the commercial fish stocks such as sardine and anchovy. Other non-commercial fish species and juvenile commercial species that also feed on zooplankton and phytoplankton, in turn, become food the larger carnivorous commercial, such as hake and horse mackerel and non-commercial species. Any disruption in the activity of the upwelling cells will consequently affect these fish stocks.

The large seabird colonies residing on the off-shore islands supply nutrients to the littoral and sub-littoral communities living around these islands through their guano[85]. Similarly, the large seal colonies along the coast must have a similar localized impact.

THE DECAY OF ORGANIC MATERIAL

High levels of primary production and subsequent accumulation of organic material can have a

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High nutrient levels in Namibian coastal waters result in lush seaweed growth where substratum permits. As primary producers, over the entire shelf, seaweeds play a secondary role to phytoplankton but in shallow coastal waters, seaweeds are very important primary producers and also offer a refuge for the juveniles of a broad variety of organisms such as curstaceians and various fish species.

detrimental effect as well. From various trophic levels, organic material is lost through mortalities as well as excrement and waste. Some of these materials are recycled into the food webs quickly but the rest sinks to the bottom where it accumulates and decays over a period of time. Decay of organic materials usually consumes oxygen, so large quantities of decaying organic material deplete oxygen levels quite quickly. Bottom water layers near organically rich muds, such as off central and northern Namibia, consequently have low oxygen levels. Furthermore, after very intense phytoplankton blooms and subsequent calm periods, decaying phytoplankton cells consume oxygen in the water column. These conditions have adverse effects on fish and other oxygen dependant populations.

Organic material can also be decomposed in the absence of oxygen[77]. This is usually achieved in muds by sulphur bacteria. This is a common occurrence off central Namibia. When this type of decay occurs, hydrogen sulphide (H_2S) can accumulate in the mud layers. When a pocket of H_2S becomes too large to be contained within the mud layers, it escapes to the surface as a large bubble – a sulphur eruption (common in the Walvis Bay and Swakopmund area). Hydrogen sulphide is a potent toxin. Sulphur eruptions were thought to be confined to the near shore region but through satellite imagery it has become evident that the phenomenon occurs across the width of the shelf.

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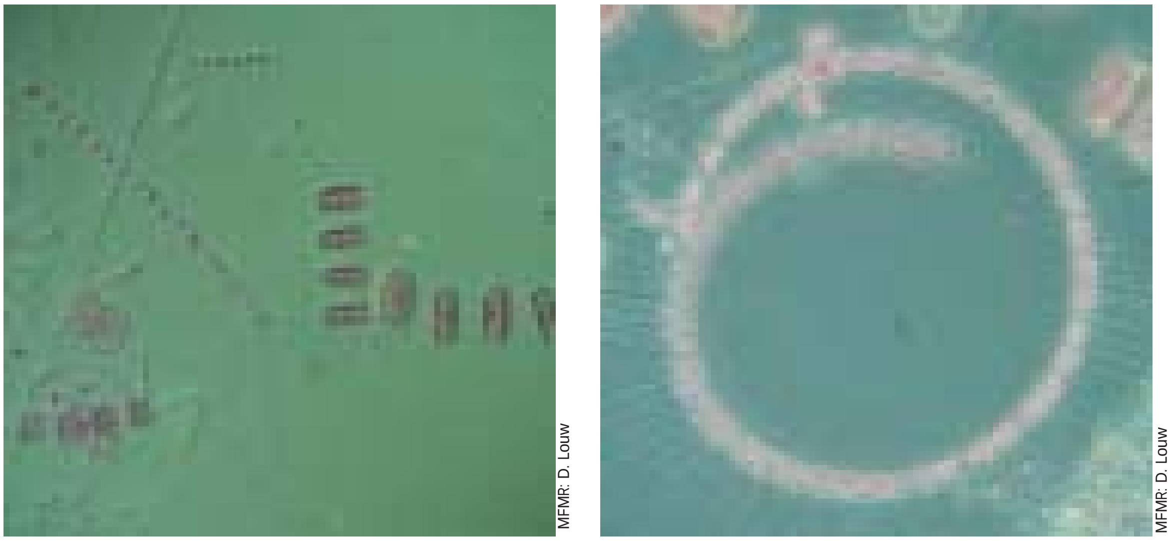

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The microscopic world of the marine environment offers a dazzling variety of shapes and colours of organisms. The two pictures opposite illustrate the variety of diatom variability.

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Water sampling (left) and Analysis (right). Water is sampled at set depths using a rosette. When the samples arrive at the lab identification of zooplankton and phytoplankton commences.

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When the tide is low, rock pools and exposed give a glimpse of the variety of marine species that exist.