1. Introduction

Southern Africa lies with the Indian Ocean to the east, and the South Atlantic Ocean to the west. While Mocambique and the east and south coast of South Africa are bathed by the warm, south-flowing Agulhas Current, Namibia and the west coast of South Africa, are swept by the cold, northward flowing Benguela Current. Each of these different water masses has a unique fauna and flora associated with it. The distribution of this biota is obviously closely coupled to the distribution of the water mass, and its extent is termed a biogeographic province. Thus on the east coast and south coast of the region we have sub-tropical and warm-temperate provinces respectively. On the west coast we have cold temperate (to northern Namibia) and sub-tropical (southern Angola) provinces. Not only do these provinces differ in their biotic make-up and diversity, but they also differ in the way that they function biogeochemically. The sub-tropical provinces are characterised by warm, nutrient-poor water, and they are populated by a wide variety of species. The environment is not conducive to lush plant growth because the concentration of nutrients in the water is so low. This ultimately results in poor, largely subsistence fisheries. By contrast, the cold-temperate province is characterised by cold (obviously!), nutrient-rich waters and it is populated by a low diversity of species. The environment favours abundant plant growth because the nutrient concentration is high and this in turn means rich, largely industrial, fisheries. The link between fishery yield and plant growth is via the food chain . . . fish eat other fish which eat zooplankton which eat other zooplankton which eat phytoplankton which use nutrients.

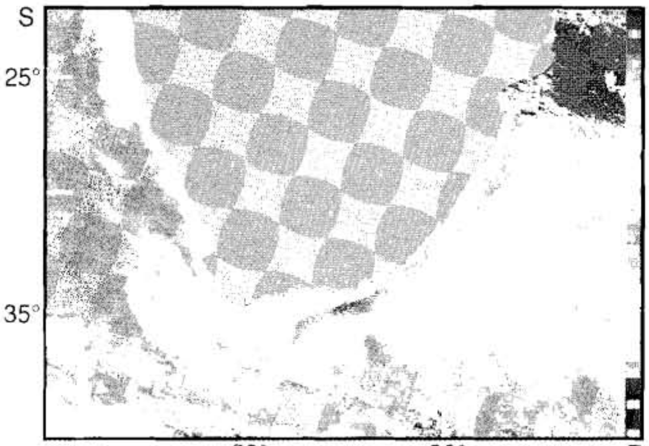

Fig. 1: Satellite image of the sea surface temperature around southern Africa on 31 January 1998 (Rosenthiel School of Marine and Atmospheric Sciences). The red colour indicates warm water, while the blue colour indicates cold water; the purple colour indicates cloud cover. Note the generally warm temperature of the water off the east and southern coasts, and the cold temperature of the water off the west coast.

Traditionally, a nation manages the commercial fisheries within its own "borders" (to the Economic Exclusion Zone, or EEZ), on its own. However, because fish do not respect national borders, it is possible that neighbouring states may catch fish from the same population (or stock) yet manage their fisheries differently, or in ignorance of each other. This has a number of implications for the sustainable utilisation of the fish stocks and can only really be resolved through a regional approach to fisheries management. One such regional method considers the concept of the Large Marine Ecosystem (LME). The LME concept is built around ecosystems as functionally distinct units, and is defined by the boundaries of the ecosystem and not by political borders. Three such LMEs have been identified around southern Africa: the Benguela Current LME (BCLME); the Agulhas Current LME (see Fig. 1) and the Gulf of Guinea LME. It should be realised that irrespective of nation state, the marine environment (including resources) of a shared LME is more or less the same for each national stake-holder. Consequently, there is a need for LME stake-holders to share and pool information.

Guides to the identification of common organisms found within the LME are among the sorts of information that are needed. After all, if you cannot identify the organisms present, then it will be difficult to manage them appropriately. This publication on zooplankton represents just such a guide, and is the first of several intended such guides. Although it is focussed on zooplankton from the BCLME, there is much information contained within that is applicable to zooplankton in the other LMEs.

The guide is intended for the "beginner" and every attempt has been made to ensure that the text is as user-friendly as possible. In simplifying some of the concepts encompassed I may have gone too far to satisfy the professional scientist, and for that I apologise.

2. What are Zooplankton?

Planktonic organisms are animals and plants which live freely in the water column. They do not have the ability to move horizontally against ocean currents, and must therefore "go with the flow". The plant components of the plankton are called phytoplankton, while the animals are referred to as zooplankton. These animals include representatives of all the major invertebrate phyla (some of which can only be found in the plankton), as well as some vertebrates.

Some animals spend their whole life in the plankton. These animals are referred to as holoplankton, and are born into the plankton and die as members of the plankton. The others spend only a portion of their early life in the plankton and are known as meroplankton. Life after plankton for these types of animals involves either their settlement on the sea-floor as (e.g.) a crab, a barnacle or a snail, or their metamorphosis into something which has the ability to move against currents such as a fish or a squid. Some of these meroplankton may only be resident in the plankton for a couple of days (e.g. abalone), but others may hang around for months if not years (e.g. rock lobster).

Having settled on the bottom of the sea, some of the more motile benthic animals may still move up into the plankton at certain times of the day to feed. Alternatively, they may join the plankton again if their benthic environment becomes unfavourable for them, such as when the oxygen content of the bottom water gets too low. While these individuals are not strictly zooplankton – in the sense that they show few of the adaptations of zooplankton to a pelagic existence (see page 4) – if they are small and have limited powers of independent movement then they are subject to much the same environmental pressures as their legitimate relations. Indeed, such a strategy may in part explain the origin of zooplankton.

Although zooplankton can be categorised in any one of a number of ways (e.g. life-cycle strategy, trophic guild or taxon), it is usual to assign them to size classes. The rationale for this is two-fold. Firstly, organisms of a particular size have common physiological rate processes irrespective of taxon. Secondly, the pelagic food web is essentially size based, in other words big organisms eat smaller organisms. The four zooplankton size classes are: micro-zooplankton (2–200 μm), meso-zooplankton (200 μm – 2 mm), macro-zooplankton (2 – 20 mm) and mega-zooplankton (> 20 mm).

3. The Place where Zooplankton Live

The environment that planktonic organisms occupy is the largest environment on planet earth . . . the sea, which covers over 70% of the surface of the globe, and which at its deepest depth is almost twice as deep as Mt Everest is high. Indeed, the average depth of the sea is over 3 km! It is a truly three-dimensional environment, as opposed to the environment that humans occupy which is relatively two dimensional. But just like our environment, so the watery environment of the plankton changes, although in this case it changes both horizontally and vertically (spatially), as well as on a seasonal and diurnal basis (temporally).

Vertical Characteristics of the Ocean

Everywhere in the world's ocean, the water gets colder as you go deeper. In fact we get a system of layers. At its simplest you can envisage the ocean as being comprised of just two layers, an upper, sun-warmed surface layer and a deeper cold layer that the sun can't get to. The boundary between the two layers is known as a thermocline, and it can act as a barrier which effectively prevents the movement of chemicals and organisms from one layer to the other. In reality, however, we often get more than two layers, because different currents from different places of origin move water as distinct layers at different depths . . . but that is another story.

It also gets darker as you go deeper (Fig. 2), because light gets absorbed by the water molecules and it gets reflected by suspended particles. The changes in light quantity are accompanied by changes in light quality; the red wavelengths get filtered out in the shallow water so that only green-blue light penetrates into deep water.

As you go deeper in the water column there are also marked changes in the concentration of some important dissolved salts and gases. Nutrients (such as NO_3) are generally found at low concentrations near the surface and increase in abundance below the 1% light level (Fig. 2). This is because they are incorporated by phytoplankton cells during growth, and get stripped from the surface waters when the cells die and sink out.

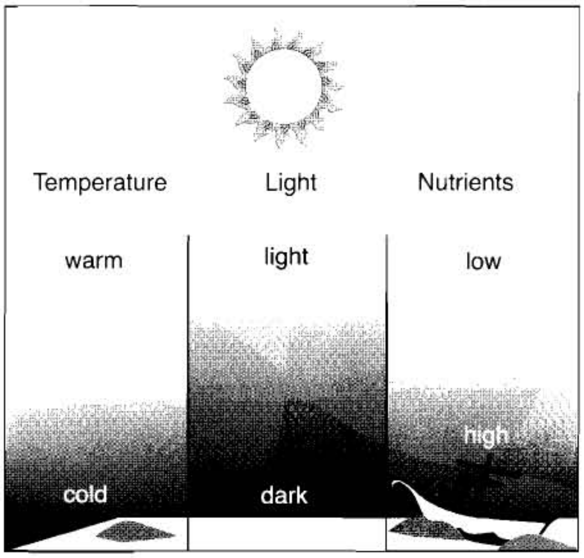

Fig. 2: A colour diagram showing how temperature, light intensity and nutrient concentration change with depth. The regions of rapid temperature and nutrient change are known as a thermocline and nutricline respectively.

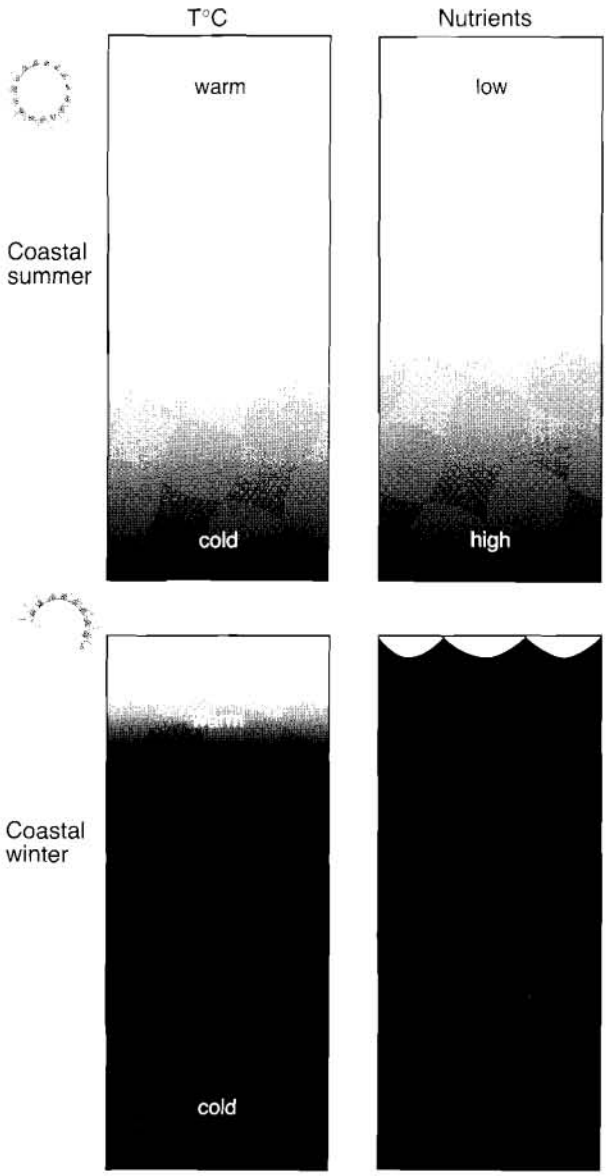

Fig. 3: Colour diagrams showing how the vertical distribution of temperature and nutrient concentration vary in coastal waters on a seasonal basis. In shallow water, winter storms mix the water column and prevent the establishment of a deep thermocline. Colour as in Fig. 2.

Dissolved oxygen, by contrast, tends to decrease with increasing depth, especially in upwelling areas. This is because bacteria use up much of the oxygen in their breakdown of the dead phytoplankton cells which have sunk out of the surface waters and this results in a layer of oxygen-poor water close to the seabed.

Horizontal Characteristics of the Ocean

There are a number of factors which influence the characteristics of seawater on a horizontal scale, and these are intimately associated with latitude and longitude.

The air temperature at the equator is warm throughout the year, and so too are the surface waters of the sea. These waters may be of relatively high salinity, owing to surface evaporation. The thermocline is often located at some depth in the water column which means that the surface waters tend to be poor in nutrients. By contrast, the air temperature at the poles is cold throughout the year, and so too are the surface waters of the sea. The thermocline may be absent because of perennial wind mixing, and the surface waters are usually rich in nutrients year-round. In the so-called temperate latitudes of the world, there is a hot summer and a cold winter. This seasonal change in air temperature is reflected by a seasonal change in surface water temperature. Nutrients may be scarce in summer because the thermocline may be well established, but they may be abundant during winter when the thermocline is broken down by wind-induced mixing.

The physical characteristics of seawater at the coast differ quite substantially from those in the open ocean because of the shallow water depth and the proximity of land. Seasonal changes in temperature tend to be more strongly pronounced and may be linked to changes in salinity associated with seasonal patterns in rainfall and river run-off. Although nutrients may not be scarce owing to freshwater inputs, wind mixing and the atmospheric fall-out of terrestrial particles, the turbidity of coastal waters tends to be high. In the open ocean, by contrast, seasonality is less pronounced (Fig. 3). The thermocline is generally deep throughout the year and the surface waters are warm. Nutrients are found in low concentrations at the surface which means that phytoplankton populations are small and the water is not turbid.

It should be clear then that the physical and chemical characteristics of any water mass vary with its latitudinal and longitudinal position, and that they can be used to identify its geographic origin. However, water does not stay in the same place for long – it is continually on the move. These moving waters are referred to as currents, and can be either of a surface or of a deep nature.

Surface currents are generated when the wind blows over the surface of the ocean. Global patterns of surface water flow therefore tend to reflect in part the patterns of atmospheric circulation. Deeper currents are more complex to explain simply, but they basically reflect the movement of water along density gradients. Given the 3-D nature of the ocean it is not unreasonable to expect surface water to move in one direction and deeper water to move in an opposite direction.

There are a number of important water masses and currents which influence zooplankton and zooplankton processes in the region, and these

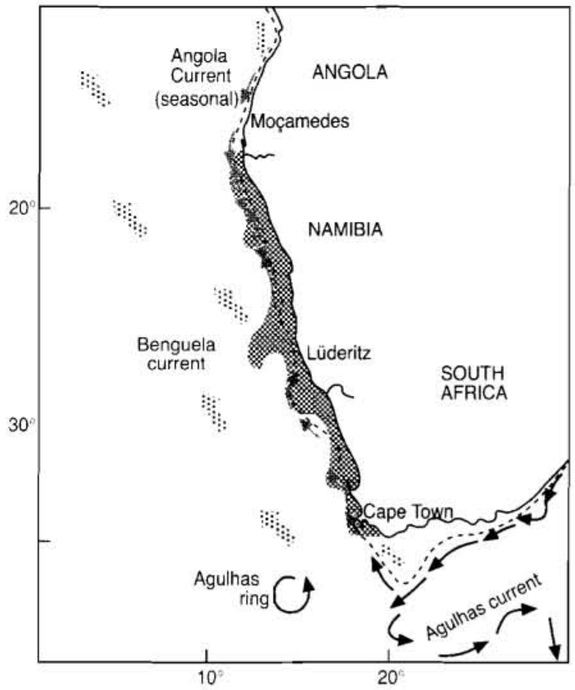

Fig. 4: Map of the west coast of southern Africa showing the major surface currents.

Fig. 5: The heteropod mollusc Carinaria cristata; *note the transparent, elongate body and the reduced shell (Dave Wrobel, 1998).*

are illustrated in Fig. 4. A fuller discussion of the physical oceanography and the planktonic assemblages that can be found along the west coast of southern Africa is presented on page 41, but the important point to remember here is that organisms which have evolved in, and have their centre of abundance in, one current system are poorly adapted to survive in another current system. This is because they have a suite of adaptations that allow them to survive, grow and reproduce in water that has a particular set of physical, chemical and biological characteristics, and when those characteristics are changed so the survival, growth and reproduction of the organism is compromised. Zooplankton which are characteristic of a particular water mass, or current system are referred to as indicators, because if they are recovered from a plankton sample then they indicate the origin of the water from which they were collected. In the keys below, an attempt has been made to indicate which species are indicative of which water masses; where no such statements are made it is assumed that they are characteristic of Benguela waters.

4. The Characteristics of Zooplankton

The dynamic, three-dimensional nature of the pelagic environment poses a number of problems for the animals which live there, and each must have a suite of adaptations that allow survival.

One of the biggest problems facing a zooplankton is that of sinking, because it should be remembered that anything which is denser than seawater will sink. It is a problem because most zooplankton need to stay close to the surface, where their phytoplankton food is found.

In order to stay near the surface, zooplankton have a number of options available to them.

They could swim all the time. But, and it is a big "but", this costs lots of energy . . . energy which could be used for other things. Few planktonic animals swim all the time just to stay near the surface. Instead, they have a number of adaptations which help to reduce the rate at which they sink.

Many zooplanktonic organisms which have cousins that live on land look completely different from them because they have shed the hard-parts. Some good examples here are the snails, which if they have a shell at all, will have a very reduced shell or a very thin shell (Fig. 5).

Another mechanism that is employed to reduce density is the possession of a gas float of some sort (Fig. 6). Some siphonophores have what are called pneumatophores. In the case of the blue-bottle, its float is so large that it literally bobs around on the surface of the sea and trails its tentacles below. There is a special term for animals which float at the air-sea interface, and that is neuston. There is a type of snail (*Janthina* spp) which feeds on blue-bottles, and in order for it to do so it too must have a float. In this case, however, the float is not an integral part of the animal but consists of a raft of bubbles which the animal has trapped and lashed together so that it too hangs suspended at the air-sea interface.

Organisms don't have to use gas to float near the