SOUTH AFRICAN

WATER QUALITY GUIDELINES

FOR COASTAL MARINE WATERS

VOLUME 1

NATURAL ENVIRONMENT

Department of Water Affairs and Forestry

First Edition 1995

SOUTH AFRICAN WATER QUALITY GUIDELINES FOR COASTAL MARINE WATERS

Volume 1: Natural Environment

First Edition, 1996

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SOUTH AFRICA

South African Water Quality Guidelines for Coastal Marine Waters

Volume 1

Natural Environment

Department of Water Affairs and Forestry

First Edition

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FOREWORD

The Department of Water Affairs and Forestry is the custodian of South Africa's water resources. The water quality management goal of the Department is to ensure that the water quality of water resources remains fit for recognised uses and that the viability of aquatic ecosystems is maintained and protected. This is achieved through the involvement of role players from several tiers of government, from the private sector and from civil society.

Difficulties, however, in managing the quality of our coastal waters to ensure that both the user's water quality requirements are met and development of the coastal zone is accommodated, resulted in the establishment of *Water Quality Criteria for the South African Coastal Zone*, which was published by the South African National Committee for Oceanographic Research in 1984. Since its publication, the document formed a basis not only for feasibility studies and the planning of coastal discharges, but also for environmental impact assessments of areas subjected to waste discharges. This document was revised in 1992 in order that new national and international developments in technology and water quality policies, as well as increasing environmental pressure from both the formal and informal sectors, could be taken into account.

The revised document was, however, not in the same format as the *South African Water Quality Guidelines* which had recently been developed for inland water bodies. This necessitated the expansion of these revised water quality criteria for the coastal zone in order that similar information would be provided to that in the freshwater quality guidelines, which serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems.

The process that followed and the wide variety of organisations and individual involved in the development of these guidelines ensured the acceptance and the use of these guidelines by all significant role players, as the ***South African*** *Water Quality Guidelines*. These guidelines are technical documents aimed at users with a basic level of expertise concerning water quality management. However, the role players involved in the different water use sectors are expected to use these guidelines as a basis for developing material to inform water users in specific sectors about water quality and to empower them to effectively participate in processes aimed at determining and meeting their water quality requirements.

The Department recognises that water quality guidelines are not static and will therefore update and modify the guidelines on a regular basis, as determined by ongoing research and review of local and international information on the effects of water quality on water users and aquatic ecosystems. The process of developing water quality guidelines, and the involvement of key role players, is a continuing one. The first edition is published in a loose leaf, ring binder format to facilitate the regular updating of the guidelines. All those who want to comment on and make suggestions concerning the South African Water Quality Guidelines are invited to do so at any time by contacting the Director: Water Quality Management, Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001.

Finally, I wish to express my sincere appreciation to all those who have been involved in the development of these guidelines. I also look forward to their continued involvement in maintaining one of the corner-stones of the water quality management system in South Africa.

Kader Asmal

Professor Kader Asmal **MP**
Minister of Water Affairs and Forestry

May 1996

ACKNOWLEDGEMENTS

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Workshop participants for setting target values

The target values or guideline values for the South African coastal zone were reviewed at a workshop held in 1992 in Stellenbosch. The workshop consisted of a broad spectrum of representatives from the scientific and engineering community, national and local authorities, industries and environmental organisations. The list of participants is presented below:

Mr D Airey, Sappi Saiccor, Umkomaas Dr B R Allanson, Allanson and Associates Mr C Archibald, CSIR, Durban Prof D Baird, UPE Mr E Beesley, Sappi Saiccor, Umkomaas Ms A Belcher, DWAF, Pretoria Mr W A M Botes, CSIR, Stellenbosch Dr A D Connell, CSIR, Durban Mr A B Davis, Durban Corporation Ms A de Kock, Nature Conservation Dr A C de Kock, Technikon, Port Elizabeth Mr G Devey, City of Port Elizabeth Mr A P M Fijen, GFJ Consulting Engineers Dr H Furness, Umgeni Water Ms B Genthe, CSIR, Stellenbosch Prof W O K Grabow, University of Pretoria Mr L Gravelet-Blondin, DWAF, Natal Dr L Jackson, SFRI, Cape Town Mr J F Kapp, GFJ Consulting Engineers Mr H Karodia, DWAF, Natal Dr R Kfir, CSIR, Pretoria Dr D Livingstone, Private Consultant Dr D A Lord, Western Australia	Dr J A Lusher, DWAF, Western Cape Mr S MacBean, East London Municipality Dr D Malan, Department of Environment Affairs (DEA), Cape Town Mr S McGibbon, SFRI, Cape Town Mr R Mitchell, Western Cape Regional Services Council Mr A G S Moldan, SFRI, Cape Town Dr P M S Monteiro, SFRI, Cape Town Mr I Morrison, City of Cape Town Mr J L Pretorius, DWAF, Eastern Cape Dr H M du Plessis, Water Research Commission Mr G Purnell, DWAF, Natal Mr G W Richardson, Durban Corporation Mr K S Russell, CSIR, Stellenbosch Mr J Stander, DEA, Pretoria Ms S Taljaard, CSIR, Stellenbosch Mr R van der Elst, Oceanographic Research Institute Mr J L J van der Westhuizen, DWAF, Pretoria Mr O A van der Westhuyzen, Foundation for Research Development Dr H van Vliet, DWAF, Pretoria Ms K van Wyk, South African Nature Foundation Mr D Visser, Portnet, Cape Town Mr F S Vivier, Department of Health

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INTRODUCTION TO THE SOUTH AFRICAN WATER QUALITY GUIDELINE DOCUMENTS

The South African Water Quality Guidelines are a series of nine documents published by the Department of Water Affairs and Forestry (DWAF). They form an integral part of the water quality management strategy to maintain South Africa's water resources fit for use. The guideline documents are presently divided into two sets:

Water Quality Guidelines for Fresh Water

Volume 1: Domestic Water Use
Volume 2: Recreational Water Use
Volume 3: Industrial Use
Volume 4: Agricultural Use: Irrigation
Volume 5: Agricultural Use: Livestock Watering
Volume 6: Agricultural Use: Aquaculture
Volume 5: Aquatic Ecosystems
Volume 8: Field Guide

Water Quality Guidelines for Coastal Marine Waters

Volume 1: The Natural Environment
Volume 2: Recreational Use
Volume 3: Industrial Use
Volume 4: Mariculture (the effects and target values related to *human health* also apply to the *collection of seafood* along the coast)

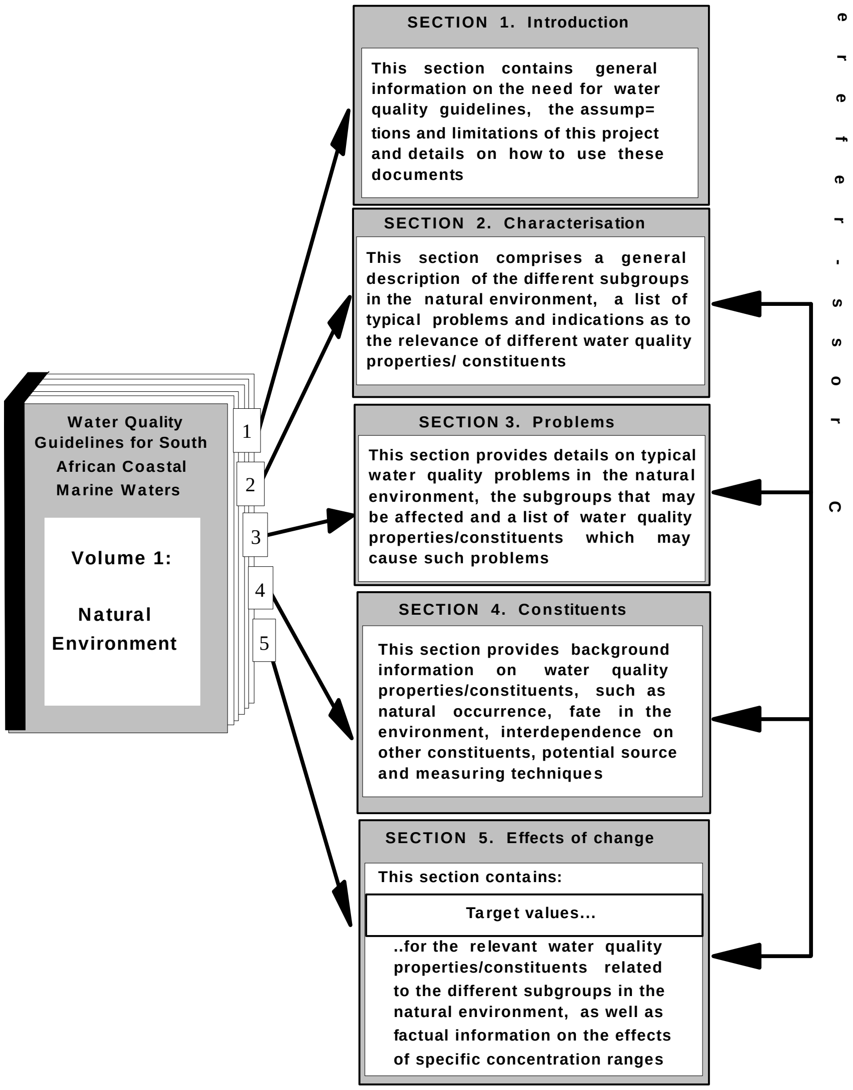
This volume is the first in a series of four documents comprising the first edition (Edition 1.0) of the South African Water Quality Guidelines for Coastal Marine Waters.

NOTES: **Should seawater be used for domestic purposes the guidelines (and target values) will be similar to those described in the set of documents for fresh water, Volume 1, i.e. Domestic Use of fresh water. Desalination of seawater is dealt with in the set of documents for coastal marine waters, Volume 2, i.e. Industrial Use of coastal marine waters.**

These documents do not specifically address estuaries or river mouths, although some of the information contained therein may be applicable. However, the need for expansion of the series to include estuaries will receive attention in the future.

HOW TO USE THIS DOCUMENT

The terms of reference for this project specified that the information contained in these documents had to address the needs of all parties involved in marine water quality, from the analyst to the manager. With the diversity of the user spectrum and the complexity of information in mind, the layout of the documents was designed in such a way so as to allow the user to 'enter' via a number of perspectives or subjects. This was accomplished by dividing the documents into different sections:

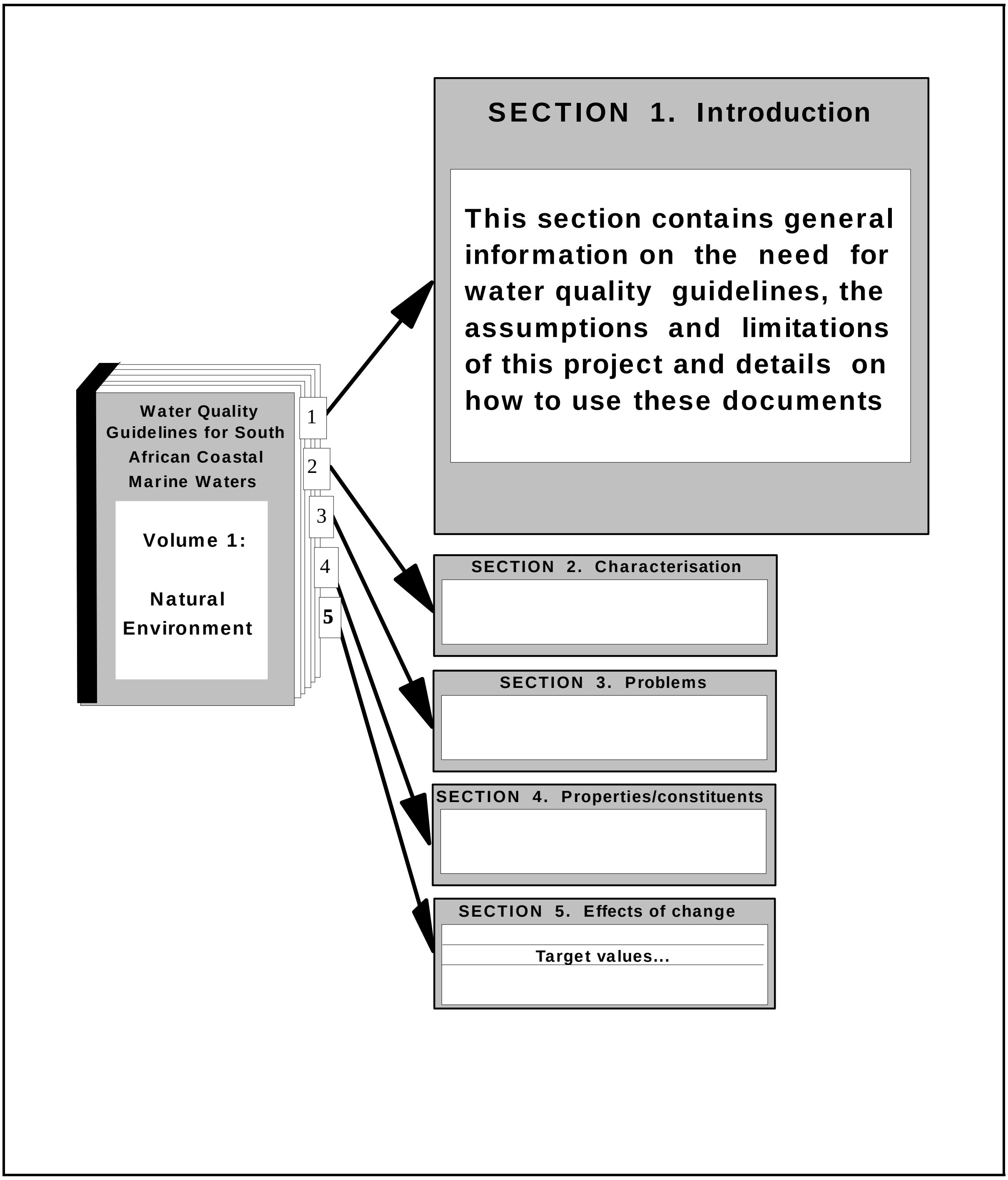


A certain degree of overlap and/or repetition was inevitable. However, to avoid unnecessary repetition of detailed information, a cross-reference system has been used. *Section 5 is regarded as the 'heart' of these documents (containing the target values), with the information contained in Sections 2-3 being complementary to that section.*

PRACTICAL EXAMPLES OF HOW TO USE THIS DOCUMENT

Issue	Reference method
A development with potential influence on water quality is planned in the vicinity of an ecologically sensitive area along the west coast.	The subject is *'the user-group, i.e. the biological communities along the west coast and their water quality requirements'*, therefore refer to *Section 2: Characterisation of the natural environment.* Select the chapter on the *west coast.* Find an overview of the important species, a list of typical problems and checklist of the relevance/non-relevance of water quality properties/constituents. Cross-references to Section 4 provide more details on, for example, the potential sources of the relevant properties/constituents, which in turn, could be matched to potential sources associated with the development. Cross-references to Section 5 provide factual details on effects of different concentration ranges of relevant constituents/properties on marine organisms. Where available, the target values for South African coastal marine waters are also provided.
A water quality manager is confronted by a member for the public complaining about dead fish which had washed up on the beach next to his house.	The subject is '*a problem*', therefore refer *Section 3: Water quality problems*. Select the problem which addresses fish kills, e.g. *mortalities*. Find a short description of the problem, the subgroups which could be affected and a list of relevant water quality properties/constituents which could cause such a problem. Cross-references to Section 4 will provide further details on the properties/ constituents, for example, potential sources , while cross-references to Section 5 will provide factual details on effects of different concentration ranges of the relevant constituents/properties on marine organisms.
A water quality analyst analysed a water quality sample and finds the concentration of trace metal A to be suspiciously high.	The subject is *'a particular water quality constituent'*, therefore refer to *Section 4: Water quality properties/ constituents*. Select the constituent, i.e. *Inorganic constituent: Trace metal A*. Find a short description of the constituent, including useful background information on its natural occurrence, its fate in the environment and potential anthropogenic sources. Cross-references to Section 3 provide details on typical water quality problems associated with the constituent, while cross- references to Section 5 provide factual details on effects of different concentration ranges of the constituent on marine organisms, as well as the target values for South African coastal marine waters, where available.

SECTION 1: INTRODUCTION



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THE NEED FOR WATER QUALITY GUIDELINES

Receiving water quality objectives approach

In South Africa, the ultimate goal in water quality management is to keep the water resources suitable for all designated uses. To achieve this goal, the Receiving Water Quality Objectives (RWQO) approach has been adopted. This implies that water quality objectives, set for a particular marine environment subjected to potential impact from a development, must be based on water quality requirements of designated uses in that particular area. Both point and diffuse waste loads must be taken into account, while it is also recognised that the marine environment has a certain capacity to assimilate waste without detrimental effect.

Different requirements

The water quality requirements of the different user groups are not necessarily the same. In some instances, they may even conflict. These differences imply that water which would be adequately fit for use for one specific user may not be suitable for another. In addition, water seldom becomes totally unfit for use when the quality deteriorates. Quality is thus not an intrinsic property of water, but is linked to the use made of the water. A definition of what constitutes fitness for use is thus a key issue in the evaluation and management of the quality of water resources.

Decision-making tool

The need arose for a set of documents that would contain the relevant information to assist decision-makers in defining water quality objectives or water quality requirements for the different uses.

The information captured in these documents is therefore aimed at giving a general overview of the different components which are important in marine water quality management, such as:

- the different uses and the associated water quality problems;
- information on the relevant water quality properties and constituents;
- effects of change in water quality (including target values, where available) on different uses or users.

Most of the abovementioned information has been published, but in many different books, journals and manuals.

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THE NEED FOR WATER QUALITY GUIDELINES continued...

Different uses

Water quality managers and scientists would use these documents to:

- serve as a scientific basis for the quantification of the water quality requirements for a water use;
- interpret and translate information obtained from water-quality monitoring and assessment programmes;
- assess the effect of anthropogenic activities on water quality;
- evaluate the impact of accidental spills;
- assess and evaluate management performance, effective control and auditing of water quality management practices which are essential and fundamental to good management;
- deal with public perceptions; in South Africa, as in the rest of the world, there is a growing awareness among the public of the natural environment and how it is being managed; decision-makers and water quality managers need sound scientific norms and guidelines to enable them to communicate effectively with the public on the impact of development on water quality and to deal with public perception, fears and complaints with regard to water pollution and its effects on water users;
- identify research needs (i.e. indicate where information is lacking).

These documents also provide the necessary information for water users and other interested and affected parties to assess water quality in general, as well as to evaluate the acceptability of the impact of development on water quality.

THE NEED FOR WATER QUALITY GUIDELINES continued on next page

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THE NEED FOR WATER QUALITY GUIDELINES continued...

Target values

In principle, the water quality objectives or requirements of a particular water body *are the target values of the different water quality properties/constituents which have been set for the designated beneficial uses.*

The target values, i.e. 'level of a particular water quality property/constituent at which no detrimental impact should occur', provided in Section 5, were taken from *Interim report: Water quality guidelines for the South African coastal zone*. Those target values were decided upon by a group of marine water quality experts in 1992 [(1)].

Practical application

At the workshop held in Stellenbosch in 1992, it was decided, in principle, that the target values set for the beneficial uses, *Recreation: Non-contact*, i.e. ensuring basic amenities (see Volume 2) and the *Natural Environment* (see Volume 1) should apply to **all** marine waters. Additional to these will be *Recreation: Primary contact and secondary contact, Mariculture and Industrial uses,* where these are designated beneficial uses of a particular water body.

In principle, a *zone of impact*, i.e. an area or volume of seawater where water quality does not comply with the target values, is allowed in the case of a marine discharge. This zone of impact should, however, be kept at a minimum and should be determined through an appropriate environmental impact assessment.

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ASSUMPTIONS AND LIMITATIONS

Scope

The scope for this phase of the project was to provide additional information to enhance the existing water quality guidelines for the South African coastal zone [1], similar to those documents produced for the fresh water environment of South Africa [2-5].

The information provided in these documents had to focus on the coastal marine environment, the outer boundary roughly going up to the edge of the continental shelf, but excluding estuaries. However, the need for expansion of the series to include estuaries will receive attention in the future. Some information provided in the present documents may, however, be applicable to estuaries.

It should be noted that although these documents focus on the area inshore of the continental shelf, South African marine waters extend up to 200 km offshore. Beyond the 200 km boundary, international conventions and agreements apply to all users of the ocean.

Time and budget

The present set of documents for the coastal marine environment had to be compiled within a period of one year and within a limited budget. Within these time and budget limits, it was therefore decided that the present set of documents, i.e. Edition 1.0, had to provide a **basic framework within which existing information could be consolidated and which would also allow for future updates**, as information and funding became available. To assist in directing future updates, it therefore had to indicate the relevance/non-relevance of different aspects, as well as highlight aspects where information was lacking.

Information sources

Taking into account the time and cost constraints, it was decided to select the internationally recognized databases best suited to obtaining information on water quality issues. The databases which were decided on were:

ASFA (1983 to 1993) which includes topics such as:
- biological resources and living resources;
- ocean technology, policy and non-living resources;
- aquatic pollution and environmental quality;
- aquaculture;
- marine biotechnology.

WATERLIT (1975 to 1994), a CSIR data base which contains information on water-related issues.

ASSUMPTIONS AND LIMITATIONS continued on next page

ASSUMPTIONS AND LIMITATIONS continued...

Information sources *continued...*

Relevant keyword selections, as provided by the different specialist groups, were used to extract information from the databases.

Appropriate databases on a *national* scale were found to be limited or, in some instances, non-existent. Where possible, the different universities and institutes involved in water quality studies were contacted individually. It was, however, assumed that specialists would be aware of important studies which have been conducted nationally in their field of expertise.

With particular reference to Section 5 (Effects of Change in Water Quality), South African (local) information was generally limited. For this reason, it was decided to include any international data which may assist in showing trends in effects at different concentration ranges in the different trophic levels, although these may not be of the exact species as found in South Africa. As more local information becomes available, international data can be excluded from later editions.

However, these documents are NOT detailed specialist publications on the physics, chemistry or biology of the marine environment. The aim was to include information from these expert fields which is considered to be relevant to marine water quality management. The reference lists can be used to obtain more detailed information.

REFERENCES

1. DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1992. Interim Report: Water quality guidelines for the South African coastal zone. Pretoria.

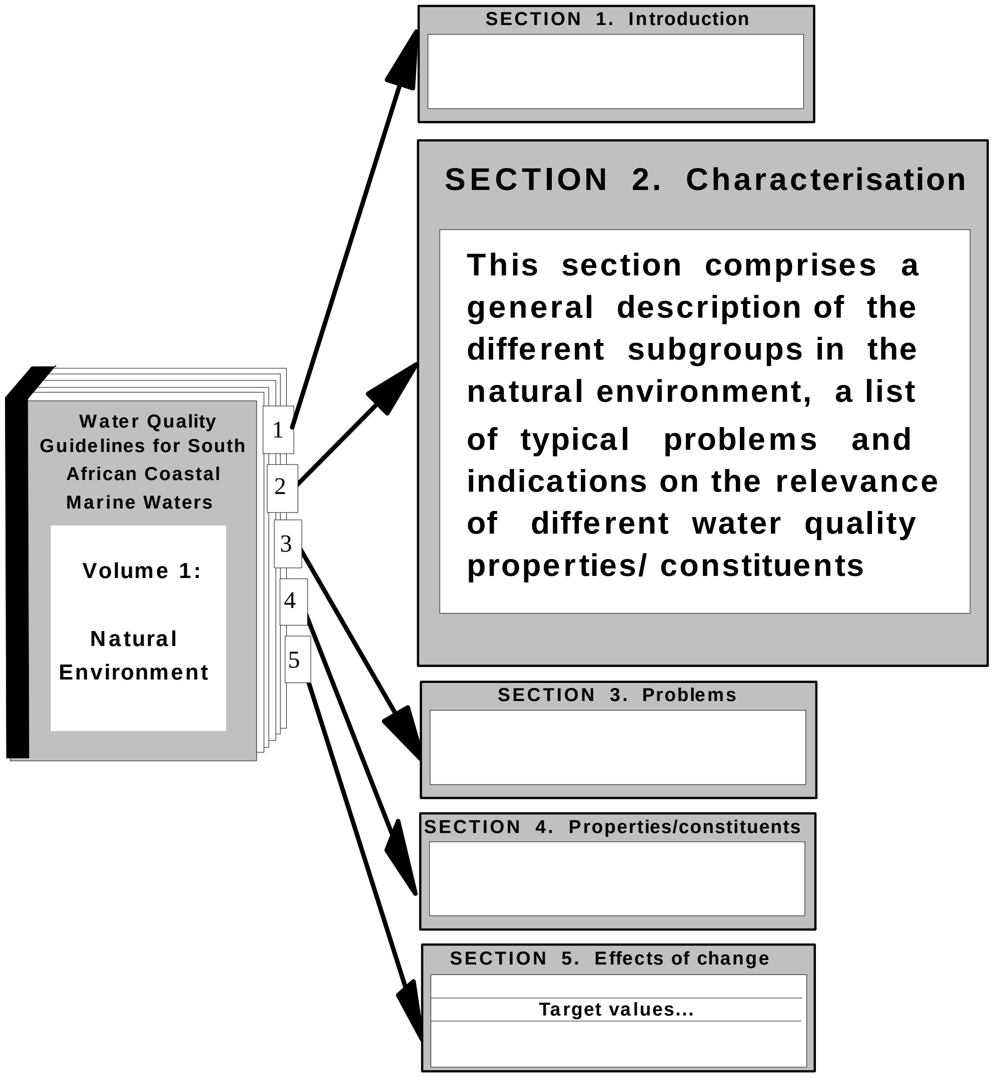
2. DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. South African Water Quality Guidelines. Volume 1: Domestic Use.

3. DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. South African Water Quality Guidelines. Volume 2: Recreational Use.

4. DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. South African Water Quality Guidelines. Volume 3: Industrial Use.

5. DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. South African Water Quality Guidelines. Volume 4: Agricultural Use.

SECTION 2: CHARACTERISATION OF THE NATURAL ENVIRONMENT



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Chapter 2.1
Description of the Natural Environment

GENERAL INTRODUCTION

Natural environment

The water resources can be divided into three broad categories:

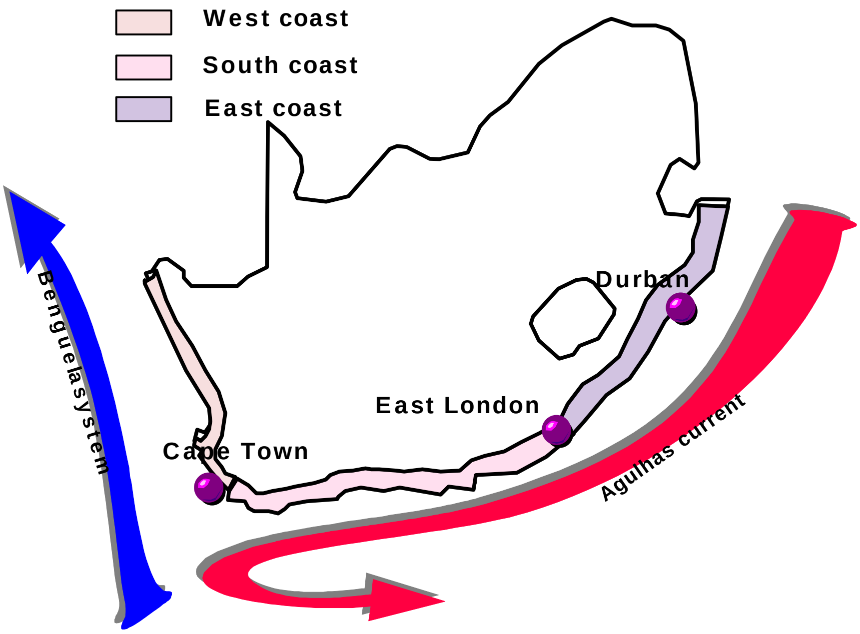
- fresh water, i.e. rivers and groundwater;
- estuaries;
- marine waters.

This volume deals with *marine* waters only.

Coastal regions

The South African coastline can typically be divided into three coastal regions, each of which sustains distinctive marine animals and plants [(1)]:

- West coast: cold temperate;
- South coast: warm temperate;
- East coast: subtropical.



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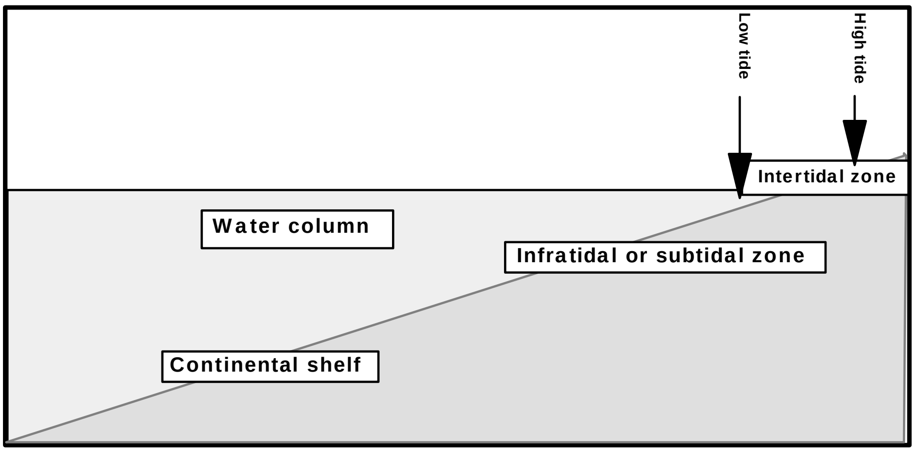
Zones

Generally, the different coastal regions can further be divided into a number of zones, each with its abiotic and biotic characteristics:

- the *intertidal zone*, defined as the zone between the spring tide low-water and high-water mark;
- the *infratidal (or subtidal) zone*, defined as the area beyond the spring low-water mark;
- the *continental shelf*, defined as the area beyond the infratidal zone up to the shelf edge (not discussed in detail in this document, being more focused on the *coastal* marine environment);
- the *water column*, comprising the surf zone, nearshore and offshore waters.

(In turn, these zones may support different types of *ecosystem,* but for the purpose of these documents the focus will be on the general characteristics of the zones. However, mention will be made of the important ecosystem types within each of these zones.)

These zones can be schematically illustrated as follows:



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Zones
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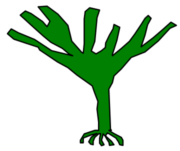
A*biotic characteristics.* Abiotic characteristics would typically include:

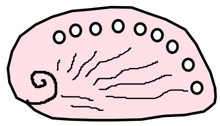
- water quality characteristics defined by temperature, salinity, pH, inorganic nutrients and other inorganic and organic constituents;
- substratum types, e.g. rocky shores or sandy beaches.

Biotic component. In terms of their trophic levels, the biotic component in the marine environment can be divided into three broad groups, i.e:

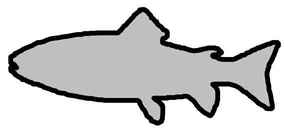
- **Primary producers**
  (defined as those organisms that synthesize complex organic substances, e.g. sugars, using simple inorganic substrates and sunlight, mainly through the process of photosynthesis)



- **Primary consumers**
  (defined as those organisms that live primarily on plants)



- **Secondary consumers**
  *(*defined as those organisms that live mainly on other animals)



NOTE: The biotic component of the natural environment can be grouped or classified in numerous ways. For the purpose of these documents, it was decided to group the biotic (living) component into three general trophic 'levels' as it was considered to be logical to do so in terms of water quality.

An important factor in understanding ecosystems is that interference with any one element or process, may have far-reaching effects on other parts of the system as a whole, because of the integrated nature of the system. This could result in the destabilisation of an ecosystem up to the point of its total collapse.

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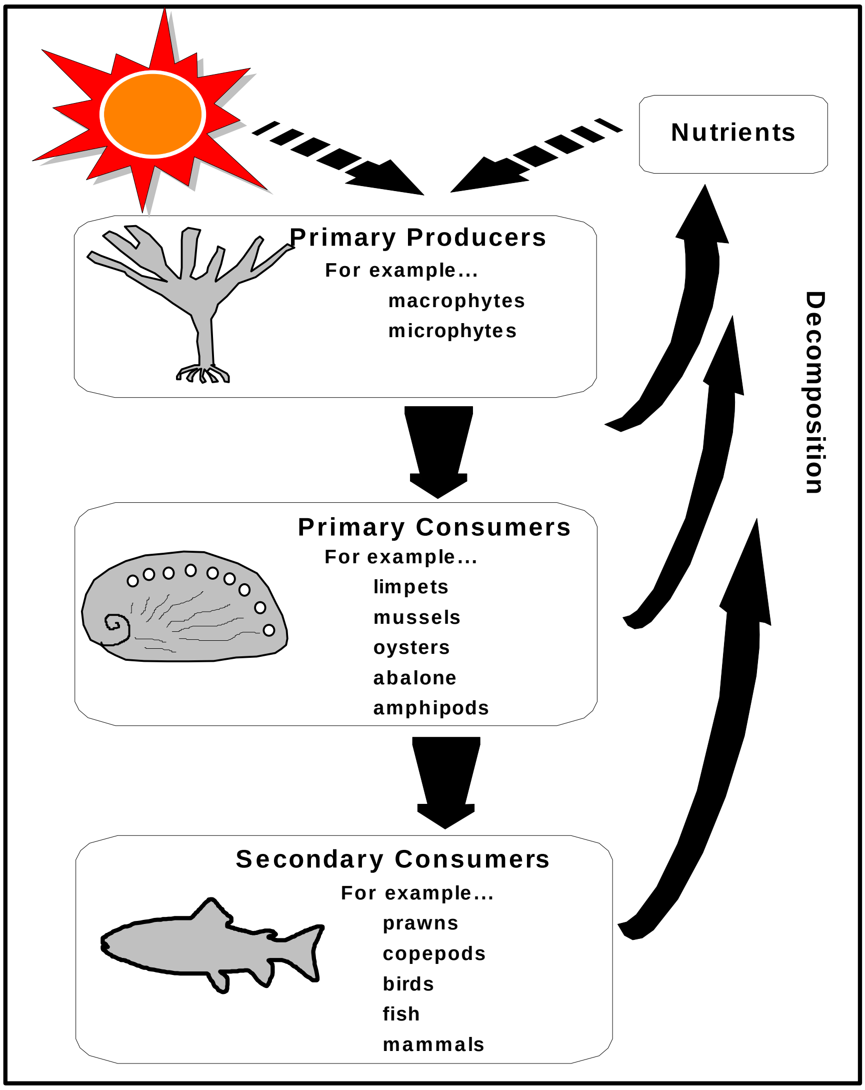
GENERAL INTRODUCTION continued...

Zones
continued...

The general relationship among the different biotic components can be illustrated as follows:



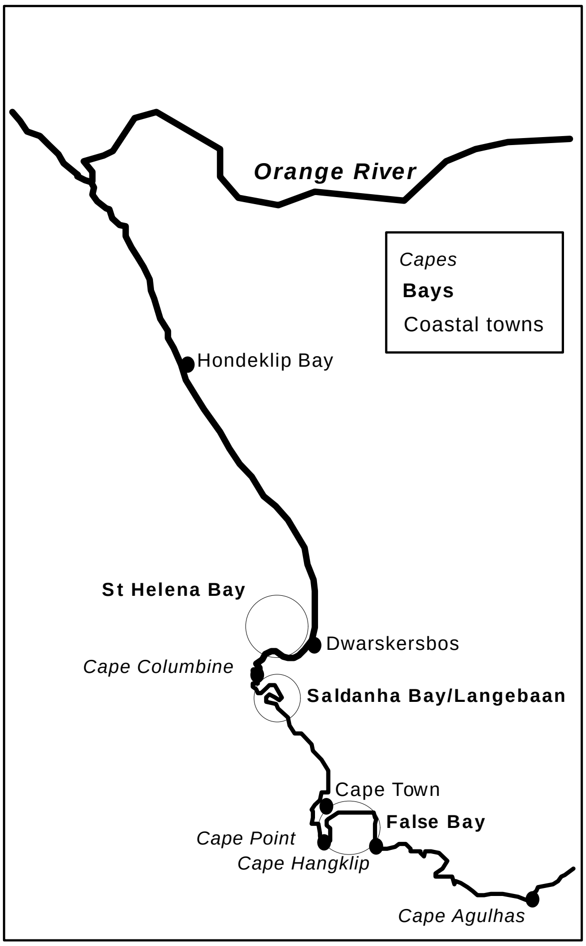
NOTE: The classification into trophic levels is not as simple as indicated above, but for the purpose of this document it had to be simplified to provide a system whereby the information contained in the document could be organised.

Chapter 2.1.1 West Coast

GENERAL DESCRIPTION

Location

The west coast of South Africa is defined as that section of coast extending from Cape Agulhas in the south-east to the Orange River in the north-west:



GENERAL DESCRIPTION continued on next page

West Coast

GENERAL DESCRIPTION continued...

Location *continued...*

It should be noted that although the oceanographic and biological features show some differentiation along the west coast, there are three areas which have certain characteristics distinct from the open coast of the region, i.e.:

- False Bay;
- St Helena Bay;
- Saldanha Bay/Langebaan system.

These differences are found in phenomena such as circulation patterns, thermal structure and biological community structures. However, for the purpose of these documents the focus will mainly on the *general* features of the west coast. For more details on the distinctive characteristics of the abovementioned areas, the reference list should be consulted.

General

The western coast of South Africa is dominated by coastal upwelling [2]. This upwelling is driven by south-easterly and southerly winds which, in combination with coriolis forces, leads to offshore drift of surface waters, thus allowing colder bottom water into the surface layer. The equatorward wind stress that leads to upwelling varies seasonally, with the strongest variation in the south where south-easterly winds are rare in winter but common in summer. This variation diminishes to the north-west and winds north of Dwarskersbos are generally from the south throughout the year although velocities are lower in winter [3]. These effects coupled with bathymetric features (e.g. width of the continental shelf) lead to the existence of three major upwelling sites in the region, namely Cape Peninsula, Cape Columbine and the Hondeklip Bay area [4]. Upwelling is strongly seasonal at the two southerly sites but perennial at Hondeklip Bay [2]. Upwelling between Cape Agulhas and Cape Hangklip appears to require sustained easterly winds which are a late summer feature of the area. St. Helena Bay, although adjacent to the Cape Columbine upwelling site is, due to its orientation and shallow bathymetry, protected from direct upwelling effects. Upwelling results in the introduction of cold, nutrient-rich waters to the west coast.

In False Bay, southerly and south-easterly winds (predominantly during summer months) result in upwelling of colder bottom water in False Bay. An intense upwelling area is situated just off Cape Hangklip on the south-eastern boundary of the Bay [9].

GENERAL DESCRIPTION continued on next page

West Coast

GENERAL DESCRIPTION continued...

General *continued..*

Along the South African coast, low-oxygen waters are also a feature of the Benguela system. Two local zones of formation of oxygen-deficient water have been identified on the South African west coast, one in the vicinity of the Orange River mouth and the other in St Helena Bay. Water from both these zones can advect southwards as compensation flow for the surface north-westerly drift [2]. This low-oxygen water rarely penetrates south of the Cape Peninsula, but the oxygen-depleted water that occasionally develops on the Agulhas Bank can impact this area [18].

More details on the water quality of the west coast can be obtained from *Section 4: Water Quality Properties/Constituents relevant to the Natural Environment*.

Biological ccommunities along the west coast generally exhibit low species richness, with high biomass values being achieved by a few species, including kelps, limpets, black mussels, white mussels, abalone, rock lobsters and a number of fish and bird species [24].

Intertidal zone

The intertidal zone along the west coast generally consists of rocky shores (about 590 km) or sandy beaches (about 640 km) [1].

Rocky shores. Four intertidal zones can be recognized and are named after the characteristic organisms of that zone. The upper shore is only splash-wet or inundated at spring high-tide and is named the Littorina zone after a snail which is found in abundance there. Seaward of this area lies the upper Balanoid zone marked by the presence of a large number of barnacles. This zone is also the home of a large number of limpets. Below this is the lower Balanoid zone which supports an increased stock of algae, together with often massive colonies of the sand tube worm. Lowest down the shore, and only exposed at low tide, is the Cochlear zone which is characterized by the pear-shaped limpet. In the northern region of the west coast large numbers of another limpet (*Patella argenvillei*) are a feature of this zone [1].

GENERAL DESCRIPTION continued on next page

West Coast

GENERAL DESCRIPTION continued...

Intertidal zone *continued...*

Sandy beaches. Physical factors control the form of the sandy beaches and sandy beaches and their associated fauna to a large extent. Cape west-coast beaches tend to be relatively steep and narrow with a well-sorted fine to medium sand, although sediments tend to be coarse on the steepest beaches [10]. Beaches can be divided into four zones, classified by the amount of water retained in the sand grains [30]. On the upper shore, the zone is named the zone of drying and is only inundated by the sea at spring high-tides and during storm events. It is characterised by large amounts of cast-up kelp which decomposes and dries here. The kelp forms an essential part of the beach ecosystem where animals from the land (insects and beetles) as well as those of marine origin feed on and break down the kelp, which eventually provides nutrients for the dune plant colonists, or the nearshore sea community. In addition, a number of bird species utilize this zone, not only for food, but also for nesting. Moving seaward, the zone of retention has the lowest species richness, with only three species of sea lice being recorded. These sea lice are widespread, extending down to the lower limits of the shore and are fed on by several species of smaller shore birds. The number of species increases in the zone of resurgence where the sea lice are joined by sand hoppers and white mussel, the latter occuring in high biomass. Finally, in the lowest zone (saturation) the largest number of species is found, with the addition of plough shells and several species of worms.

Islands. A number of islands on the west coast such as Robben, Dassen, Malgas, Marcus and Jutten, are home to a large population of breeding birds. The intertidal zone of these islands has been modified by the presence of guano enhancing primary production of the macrophytes [43].

Infratidal zone

Infratidally, the west coast is characterised by extensive kelp beds where rock is present. In the south and east the kelp (*Ecklonia maxima*) dominates the immediate infratidal zone, with L*aminaria pallida* only present in depths greater than 10 m. The pattern changes in the north where *L. pallida* penetrates the shallow water as far as low water of spring tide, with a resultant reduction in *E. maxima* stocks. Kelp not only provides shelter from the high wave energy regime for a range of animals, but also provides food to abundant stocks of primary consumers in the form of fragmented fronds (debris) and fine particles (detritus) [15,16]. Detritus feeders include mussels and sea cucumbers, while sea urchins and limpets feed on debris. In addition, a host of secondary consumers are either full- or part-time members of the kelp bed system. These range from rock lobsters to fish (e.g. hottentot, galjoen and pajama sharks), to birds (e.g. cormorants) and seals.

Although the infratidal communities show a common pattern along the west coast, distribution patterns in certain species may vary geographically. For example, abalone is not found throughout the region, but only extends from Cape Aghulas as far as St Helena Bay.

GENERAL DESCRIPTION continued on next page

Infratidal *continued...*

An important feature of the west coast is the dense concentration of seabirds, both resident and migrant, which make use of the sea for feeding and form an integral part of the nearshore Benguela system.

Water column

The upwelling of nutrient-rich water leads to high biological productivity which is manifested in the important fisheries of the west coast. Plankton biomasses are highested in the areas immediately downstream of the upwelling centres where water columns stabilise, though thermocline development and the phytoplankton in the upper mixed layers are maintained in high light levels (14). Primary production gradients exist from south-east to north, with low values to the east of Cape Point and high values north of Cape Point (24). These distribution patterns are linked to upwelling and the general hydrology, and in some instances may be linked to the occurrence of low-oxygen water in the nearshore region.

Red tides, dense aggregations of dinoflagellates or flagellates, are frequent phenomena on the west coast. Minor events occur throughout the region with the larger events being more common north of Cape Columbine in the St Helena Bay area. Red tides generally occur in quiescent periods after upwelling and are thus features of the late summer and early autumn periods in the southern Benguela.

The major primary consumer in the pelagic environment is the zooplankton. Populations of these animals develop downstream of the upwelling centres. The distribution of zooplankton is controlled by upwelling and follows the same seasonality (6).

There are a number of secondary consumers that occur in the phytoplankton, but the most important are the commercial fish populations, e.g. anchovy, pilchard and mackerel (4).

West Coast

LIST OF IMPORTANT SPECIES

Primary Producers Important species found along the west coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Porphyra capensis		Found on rocky shores [10]

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Ecklonia maxima *Laminaria pallida*	Kelp	Usually occur where rocks are present. In the south and east the kelp *E. maxima* dominates the immediate infratidal zone, with *L. pallida* only making its presence felt in depths greater than 10 m. This pattern changes in the north where *L. pallida* penetrates the shallow water as far as low water of spring tide, with a resultant reduction in the *E. maxima* stock [15,16] Below the kelp canopy, a number of seaweeds form a secondary macrophyte cover. Kelps not only provide shelter from the high-wave energy regime for a range of animals, but also provide food to abundant stocks of primary consumers in the form of fragmented fronds (debris) and fine particles (detritus) [15,16]
Gracilaria verrucosa		Form dense beds in Saldanha Bay, also occur in St Helena Bay [17]
Ulva lactuca	Green algae	Can be dominant in disturbed rocky shore environments (Saldanha Bay), but can also occur naturally [17]
Spartina		An important species in the Langebaan lagoon [17]
Zostera	Eelgrass	An important species in the Langebaan lagoon [17]

LIST OF IMPORTANT SPECIES continued on next page

Primary Producers
continued... *Water column:*

Species		Remarks
Scientific Name	Common Name	
Skeletonema costatum	Phytoplankton	
Chaetoceros sp. *Thalassiosira* sp. *Nitzschia* sp. *Asterionella* sp. *Rhizoselenia* sp. *Melosira* sp. *Thalassionema* sp. *Coscinodiscus* sp. *Frigidaria* sp.	Common diatom genera	Characteristically dominate the phytoplankton in upwelling areas (14)
Ceratium sp. *Peridinium* sp. *Prorocentrum* sp.	Common dinoflagellate genera	Characteristically, together with diatoms, dominate the phytoplankton in upwelling areas (14)
Heterocapsa sp. *Gymnodinium* sp. *Gonyaulax* sp. *Noctiluca* sp. *Peridinium* sp.	Red tide causing dinoflagellates	Red tides are regular phenomena on the South African west coast. Minor events occur throughout the region with the larger events being more common north of Cape Columbine in the St Helena Bay area (14). Red tides generally occur in quiescent periods after upwelling and are thus features of the late summer and early autumn periods in the southern Benguela (14). Large numbers of dinoflagellates do not appear to be present in Saldanha Bay, resulting in the lack of significant recording of red tides (14)
Mesodinium sp.	Ciliate	Red tide causing ciliate (14)

Primary Consumers Important species found along the west coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	Common Name	
Littorina sp.	Snail	Found in the Littorina zone on rocky shores (high biomass values) (1)
Patella argenvillei	Limpet	Found in the Cochlear zone of rocky shore in the northern regions of the west coast (high biomass values) (1)

LIST OF IMPORTANT SPECIES continued on next page

West Coast

LIST OF IMPORTANT SPECIES continued...

Primary Consumers
continued...

Intertidal continued...

Species		Remarks
Scientific Name	**Common Name**	
Patella cochlear	Pear-shaped limpet	Found in the Cochlear zone on rocky shores(high biomass values) (1)
Patella granularis *Patella granatina*	Limpets	Found in the upper Balanoid zone on rocky shores (high biomass values) (1) Along the west coast, limpets have exploitation potential (24,25)
Patriella exigua	Dwarf cushion star	
Capitella capitata	Polychaete worm	
Gunnarea capensis	Sand tube worms	Form massive colonies in the lower Balanoid zone on rocky shores (high biomass values) (26)
Choromytilus meridionalis	Black mussels	Found in the intertidal zone on rocky shores (high biomass values) (1) Dense beds are found on rocky shores and concrete harbour structures in Saldanha Bay. The natural stock provides seed mussels for commercial operations (27) Along the west coast mussels have exploitatation potential (24,25)
Mytilus galloprovincialis	Invasive Mediterranean mussel	Dense beds are found on rocky shores and concrete harbour structures in Saldanha Bay. The natural stock provides seed mussels for commercial operations (27)
Aulacomya ater	Ribbed mussel	
Donax serra	White mussels	Found in the zone of resurgence on sandy beaches (1)
Arenicola		Detritivore found in the Langebaan lagoon
Polychaete spp.		Found in Saldanha Bay and the Langebaan lagoon
Mactra glabrata	Mussel	Occur in the mouth of the Langebaan lagoon (29)
	Sea lice (3 species) Sand hoppers	Occur on sandy beaches. Number of species increases seaward where the sea lice are joined by seahoppers(associated with kelp beds) (30)
Assiminea globulus	Gastropod snail	Dominate the benthic fauna biomass in the intertidal habitat of the Langebaan lagoon (31)

LIST OF IMPORTANT SPECIES continued on next page

Primary Consumers
continued...

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Haliotis spp.	Abalone Siffies	Occur in high biomass values. Abalone are endemic to the west coast, extending from Cape Agulhas up to St Helena Bay [32] Abalone are commercially exploited by the fishing industries [24,25]
Mytilus galloprovincialis	Mediterranean mussel	Dense beds are found inrocky areas
Aulacomya ater	Ribbed mussel	Often found in kelp beds [15,16]
Pentacta doliolum	Sea cucumber	Often found in kelp beds [15,16]
Parechinus angulosus	Sea urchin	Often found in kelp beds [15,16]
Paridotea ungulata	Isopod (common herbivore)	Occur in Saldanha Bay and Langebaan lagoon, usually associated with macrophytes [33]
Mugilidae	Mullet	Common on the west coast
Liza richardsonii	Southern mullet	Shoals occur throughout the west coast. However, fish are generally not abundant in the clear lagoon water which provides little refuge from piscivorous birds [34]

Water column:

Species		Remarks
Scientific Name	**Common Name**	
Centropages brachiatus *Calanoides carinatus* *Metridia lucens* *Nannocalanus minor* *Clausocalanus arcuicornis* *Paracalanus parvus* *Paracalanus crassirostris* *Ctenocalanus vanus*	Zooplankton	Mesozooplankton dominated by the copepods of these genera. Copepod distributions are directly controlled by upwelling and follow the same seasonality [6]
Euphausia lucens *Euphausia recurva* *Euphausia similis* *Nyctiphanes capensis* *Nematoscelis megalops* *Thysanoessa gregaria*	Zooplankton	Omnivorous swarming species [6]

LIST OF IMPORTANT SPECIES continued on next page

West Coast

LIST OF IMPORTANT SPECIES continued...

Secondary Consumers

Important species found along the west coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Upogebia	Mudprawn	Found in the sheltered areas, e.g. Saldanha Bay and St Helena Bay [28]
Callianassa	Sandprawn	Found in the Langebaan lagoon [28]
Bullia spp.	Plough shells (whelk)	Occur in large numbers on sandy beaches [30]
Burnupena spp.	Whelk	Widely distributed on the west coast
	Seabirds	An important feature of the west coast is the dense concentrations of sea birds, both resident and migrant, which make use of the sea for feeding and form an integral part of the nearshore Benguela system. In addition, a number of islands such as Robben, Dassen, Malgas, Marcus and Jutten, are home to large populations of breeding sea birds. Deposits of guano on these islands have been exploited commercially for more than 100 years. The intertidal zone of these islands has been modified by the presence of guano, enhancing primary production of the macrophytes [42,43]
Haematopus moquini	African black oyster catcher	Endangered bird species found along the west coast [32]
	Waders	In Langebaan lagoon, the main aquatic birds are waders of which there are 24 species including 15 Palaearctic migrants [45]

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Upogebia	Mudprawn	Found in the sheltered areas of Saldanha Bay and in St Helena Bay [28]
Callianassa	Sandprawn	Found in the Langebaan lagoon [28]

LIST OF IMPORTANT SPECIES continued on next page

Secondary Consumers
continued...

Infratidal *continued...*

Species		Remarks
Scientific Name	**Common Name**	
Jasus lalandii	Cape rock lobster	Endemic to the west coast and occur in high biomass values [32]. Rock lobsters are often associated with kelp beds, a number of sea bird species (e.g. Cape Cormorant, *Phalacrocorax capensis*), and mammals (e.g. Cape fur seal, *Arctocephalus pusillus*) [15,16] Cape rock lobsters are commercially exploited by the fishing industries [24,25]
Pachymetapon blochii	Hottentot	These fish are often found in kelp beds [15,16]
Coracinus capensis (*Dichistius capensis*)	Galjoen	High biomass values
Poroderma africanum	Pyjama catshark	Often found amongst kelp beds [15,16]
Phalacrocorax neglectus	Bank cormorant	Endangered species [15,16]
Arctocephalus pusillus	Seal	Widespread along west coast
Spheniscus demersus	Jackass penguin	Endangered bird species found along the west coast [32]
Morus capensis *Sterna bergii* *Phalacrocorax* spp.	Cape gannet Swift tern Cormorant species	Important bird species breeding on the islands in the mouth of Saldanha Bay [44]
Rhinobatos annulatus	Sandsharks	Common in Langebaan lagoon where they feed on molluscs and crustaceans
Rhabdosargus globiceps	White stompnose	Found in Saldanha Bay around mussel rafts

LIST OF IMPORTANT SPECIES continued on next page

West Coast

LIST OF IMPORTANT SPECIES continued...

Secondary Consumers

continued...

Water column:

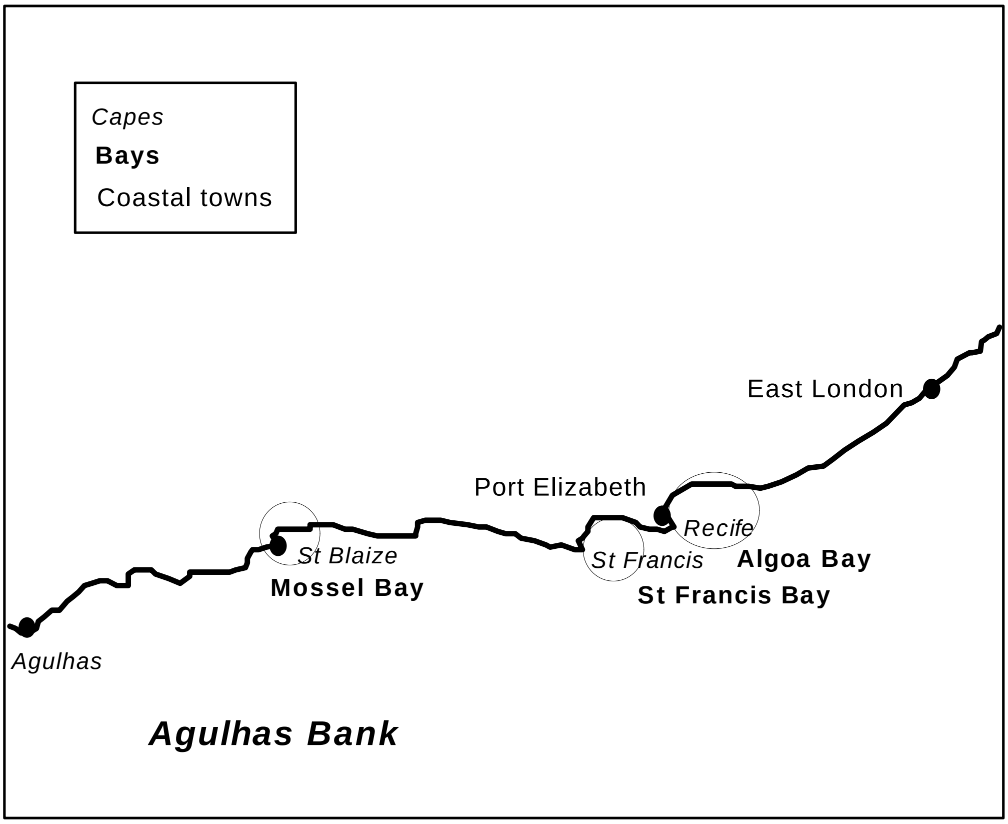
Species		Remarks
Scientific Name	**Common Name**	
Saggita friderici *Saggita minima* *Saggita enflata* *Saggita regularis*	Chaetognatha (arrow worms)	Planktonic [41]
Engraulis japonicus *Etrumeus whiteheadi* *Sardinops sagax* *Trachurus capensis* *Merluccius* spp.	Anchovy Roundherring Pilchard Mid-water horse mackerel Demersal hake	Important commercial fish species (pelagic/epi-pelagic) along the west coast [41] The pelagic species, horse mackerel spawn in the southern extremity of the area (Cape Agulhas to Cape Hangklip) [14] and the eggs and larvae are transported around the Cape Peninsula to the primary recruitment zone of St. Helena Bay [41]. Here the fish mature to subadult and adult stages and then commence their migration, back to the southern spawning ground during which they are caught by the fishery Hake spawning and recruitment are widely distributed in the study area and occur throughout the year, although there is a spring/summer maximum [14]
Scomber japonicus *Thyrsites atun* *Genypterus capensis* *Lophuis* spp. *Austroglossus microlepis* *Lampanyctodes hectoris* *Pteromaris axillares* *Trulla capensis* *Congiopus spinifer* *Gaidropsanus capensis* *Heteromyctreris capensis* *Diplodus sargus* *Lithognathus mormyrus*	Chub mackerel Snoek Kingklip Monkfish Sole Lantern fish Sand sole Horse fish Cape sole Blacktail Tuna	Other important fish species [41] (Only in the Orange River mouth area)
Spheniscus demersus *Morus* spp. *Phalacrocorax* spp.	Jackass penguin Gannets Cormorants	Important bird species along the west coast [42,43]
Arctocephalus sp. Delphiniids *Balaenoptera edeni*	Seal Dolphins Bryde's whale	Important mammals species

Chapter 2.1.2 South Coast

GENERAL DESCRIPTION

Location

The south coast of South Africa is defined as that section of coast extending from Cape Agulhas to East London.



GENERAL DESCRIPTION continued on next page

South Coast

GENERAL DESCRIPTION continued...

General

The south coast is considered to be a transition zone between the cold temperate and warm subtropical regions. The Agulhas bank area is a large mixing area between the cold Benguela and warm Agulhas currents. It is thus an interesting area seen from both the physico-chemical and ecological point of view. In the north, the Aghulas current hugs the coast because of the narrow continental shelf, but is deflected offshore due to the widening of the shelf opening onto the Agulhas banks. During winter, tongues of cold Benguela water move up the coast in a northerly direction under the influence of the west-east moving low presssure systems and their accompanying winds. Agulhas current water laps the coast. The result is an overlapping from both current systems.

Upwelling occurs along the south coast, albeit not on the same scale as experienced on the west coast, mainly near such capes as Recife, St. Francis, St. Blaize and Agulhas. Coastal upwelling along the south coast occurs when winds blow parallel to the coast from the east and brings water rich in nutrient salts such as nitrogen, phosphorous and silica, to the surface [11].

Further details on the water quality of the south coast can be obtained from *Section 4: Water Quality Properties/Constituents relevant to the Natural Environment*.

The overlapping of different current systems along the south coast is reflected in the biota which is characterised by high species diversity. Although high in species diversity, not many species occur in such magnitude as to sustain high rates of exploitation. Fishing consists mainly of lobster, demersal fish (e.g. hake and sole), pelagic fish and chokka squid, the latter being the only chokka squid line fishery in South African waters.

Intertidal zone

The south coast has rocky shores and sandy beaches, and these habitats support very different biological systems.

Rocky shores. The rocky shores consist of five zones, similar to the west coast, but support different species [1]. The highest zone on the shore, the Littorina zone, is occupied by a single tiny snail *(Littorina africana)*. A single algae, *Porphyra,* is also common to this zone. In the upper Balanoid zone, animals such as limpets, barnacles and winkles dominate, with few algae occurring. The lower Balanoid zone supports thick algal beds. Whelks are common in pools. At the low tide mark, the Cochlear zone is dominated by a limpet (*Patella cochlear)* [1].

GENERAL DESCRIPTION continued on next page

Intertidal zone *continued...*

Sandy beaches. The sandy beaches of the south coast are mostly high energy, intermediate to dissipative beaches with well-developed surf zones [12]. The sandy beaches have bacteria, diatoms and other phytoplankton as primary producers and mostly crustaceans and white mussels as primary consumers. The white mussel (*Donax serra*) is the most important filter feeder (primary consumer) on sandy beaches and dominates the benthos, constituting over 90% of the biomass. The interstitial, microbial and meiofaunal communities are very important along the sandy beaches of the south coast.

Infratidal zone

In rocky areas, the infratidal zone of the south coast supports thick strands of several algae such as corallines and kelp and the fauna associated with these algae include red bait, sea urchins, starfish and a variety of fish. Only one type of kelp occurs on the south coast in any number, and that is the spined kelp (*Ecklonia radiata*) that does not form solid strands like other kelp species [20].

Along the rocky areas, the infratidal zone also supports dense beds of red bait [1].

Water column

The dominant phytoplankton species in the surf zone of the south coast is *Anaulus australis*, generally found along the sandy beaches.

A variety of phytoplankton species are found in the nearshore waters, including diatoms, flagellates and cyanobacteria.

Off South Africa, the spawning grounds of pilchard and anchovy are located mainly over the Agulhas bank, and most spawning occurs from October to January. Shoals of pilchard and anchovy not only support the lucrative purse-seine fisheries, but are also important sources of forage for sea birds, seals and other predators.

Other pelagic fish found along the south coast include glassnose, round herring, mackerel and horse mackerel [20].

The most abundant squid in South African waters is the chokka squid that becomes concentrated in bays between Cape Point and Port Elizabeth [20].

The most common mammals found on the south coast include the southern right whale, the humpback whale, killer whale, sperm whale and a variety of dolphin species [20].

South Coast

LIST OF IMPORTANT SPECIES

Primary Producers Important species found along the south coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Anaulus australis	Diatom	Comprise 21.6% of the sand population [18]
Epipsammon	Benthic microflora	Attached to sand grains (on sandy beaches). Some micro-algal assemblages move actively through the sand, while those attached to sand grains are of necessity relatively immobile, moving very slowly from grain to grain. These epipsammic species generally attach themselves to the grains by means of raphe-bearing valves [12] Benthic microflora is usually relatively abundant on sheltered beaches [12]
Porphyra capensis	Flat-bladed algae	Found on the rocky shores of the south coast (Littorina zone) [1]
Ulva Iayngaria	Macro algae (sea lettuce)	Found on upper Balanoid zone [1]
Gigartina radula *Gigantina stiriata* *Gelidium prostoides*	Macro algae	Form thick beds (lower Balanoid zone) [1]

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Hypnea spicifera *Plocamium* spp. *Laurencia* spp. *Bifurcaria brassicaeformis*	Green tips Coralline algae	For thick algal stands [1]
Ecklonia biruncinata	Prickly bladed kelp [1]	
Gelidium spp. *Gracilaria verrucosa*	Kelps	All the *Gelidium* species that occur in South Africa occur on the south coast. *G. pristoides* is harvested commercially for extraction of their agar for use in food and for microbiological growth-media [20] *G. verrucosa* occurs on the south coast, but is only harvested, dried and exported for the extraction of agar at Saldanha Bay on the west coast [20]

LIST OF IMPORTANT SPECIES continued on next page

Primary Producers
continued...

Water column:

Species		Remarks
Scientific Name	**Common Name**	
Skeletonema costatum	Phytoplankton	
Aulacodiscus petersii *Anaulus birostratus*, *Asterionella glacialis*	Diatoms	Components of diatom blooms of the south coast [12]
Achnanthes sp. *Anaulus australis* *Asterionella glacialis* *Asteromphalus* sp. *Aulacodiscus petersii* *Biddulphia* sp *Campylosira cymbelliformis* *Thalassiosira* large spp. *Navicula* spp. Very small *Nitzschia* *Rhizosolenia stolterfothi*i *Surirella* sp. *Gyrosigma* spp.	Surf zone phytoplankton [18] Circular blue-green species Small square diatom	The dominant microplankton is *A. australis*. This diatom comprises 46.3% of the population in the water, 54.6% of the foam, 75.8% of patch foam and 21.6% of the sand population [18] Surf zone diatom species are important on dissipative beaches [12]
	Autrotrophic flagellates Cyanobacteria	Other phytoplanktonic forms which are also significant at times [19]

Primary Consumers Important species found along the south coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Gastrosaccus psammodytes	Zooplankton (mysids)	Sandy beach species commonly found along the south coast [1]
Donax serra	White mussel	The most important filter feeder on sandy beaches which dominates the benthos, constituting over 90% of the biomass [12]
Tetraclita serrata, *Chthalamus dentatus* *Octomeris angulosa*	Barnacles	In the East London area, the barnacles are the dominant suspension feeders [37]
Perna perna	Brown mussel	Common from the mid-tide up to the infratidal region [37]

LIST OF IMPORTANT SPECIES continued on next page

South Coast

LIST OF IMPORTANT SPECIES continued...

Primary Consumers

continued...

Intertidal zone continued...

Species		Remarks
Scientific Name	**Common Name**	
Choromytilus meridionalis	Black mussel	
Pomatoleios kraussi *Gunnarea capensis*	Sedentary polycheates	These form dense colonies at the mid-low tide levels (37)
Capitella capitata	Polychaete worm	
Scololepis	Polychaete worm	Found in large numbers where the sediment of sandy beaches is sufficiently stable and organic detritus is abundant (12)
Arenicola *Callianassa* spp.	Blood worm Sandprawn	Found in large numbers where the sediment of sandy beaches is sufficiently stable and organic detritus is abundant (detritus feeders) (12)
Patiriella exigua	Dwarf cushion star	
Patiria *Henricia*	Starfish[1]	Detritus feeders
Patella cochlear	Limpet	Dominate in the Cochlear zone of rocky shores (1)
Patella longicosta	Limpet	Grazer (1)
Haliotis spadicea	Small perlemoen	Grazer (1)

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Patella longicosta	Limpet	Grazer (1)
Haliotis spadicea	Small perlemoen	Grazer (1)
Aculacomya ater *Pentacta doliolum* *Pyura stolonifera* *Porifera* spp.	Ribbed mussel Sea cucumbers Red bait Sponges	Important filter feeders/detritus-feeders in kelp beds (1) Red bait form dense communities, often covering the rock face completely
Parechinus angulosus *Tripneustes gratilla*	Sea urchin	Usually associated with kelp beds (grazer) (1,20,37)
Echinocardium cordatum *Echinodiscus bisperforatus* *Echinolampas crassa*	Heart urchin Pansy shell Lamp urchin	Sand dwellers (detritivores) (20)

LIST OF IMPORTANT SPECIES continued on next page

Primary Consumers
continued...

Infratidal zone continued...

Species		Remarks
Scientific Name	**Common Name**	
Liza richardsonii *Liza dumerilii* *Mugil cephalus*	Southern mullet Groovy mullet Flathead mullet	Important mullet species (classified as opportunistic omnivorous feeders) [20] Southern mullets and groovy mullets are endemic to South Africa
Haliotis midae	Abalone	Grazer [38]
Neoscorpis lithophilus *Kyphosus bigibbus* *Siganus sutor* *Acanthurus sp*.	Stonebream Grey chub Whitespotted rabbitfish Surgeon	Herbivorous fish (feed on seaweed and algae) [20] Stonebreams are endemic species.

Water column:

Species		Remarks
Scientific Name	**Common Name**	
Euphausia lucens	Krill	On rare occasions they swarm densely at the surface in daylight along southern Africa's south and west coasts [35]
Paracalanus crassirostris *Paracalanus nanus,* *Oithona* spp. *Corycaeus* spp. *Acartia africana* *Acartia longipatella* *Pseudodiaptomus nudus*	Zooplankton Mollusc larvae Cirripede larvae Decapod larvae	Found off East London coastal waters. The zooplanktonic community as a whole appear to be typical of shallow coastal waters, with large numbers of benthic invertebrate larvae and copepods [36]
Sagitta friderici	Chaetognaths	The only coastal neritic species recorded off East London [36]
Rhyncalanus gigas	Chaetognaths (arrow worm)	An Antarctic and sub-Antarctic species recorded off East London [36]
	Surf zone zooplankton	Consists almost entirely of crustaceans. True planktonic forms resident in the surf zone may include mysid shrimps, small prawns and the larval stages of some sandy-beach animals [12]
Sardinops sagax *Engraulis japonicus*	Pilchard (sardines) Anchovy	Anchovy spawning grounds are located mainly over the Aghulas Bank [1]

LIST OF IMPORTANT SPECIES continued on next page

South Coast

LIST OF IMPORTANT SPECIES continued...

Secondary Consumers

Important species found along the south coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Bullia digitalis	Whelk	
Sesarma catenata	Crab	Detritus feeder which maily occurs on mud flats [1]
Morus capensis	Cape gannet	Breed on Bird Island (in Algoa Bay) which is the only gannetry on the South Coast [20]
Spheniscus demersus	Jackass penquin	Occur only in the southern hemisphere and occur on the South Coast only in Algoa Bay. It is thus a "special" species in this region in that they are ecologically important as predators [20]
Larus dominicanus *Charadrius marginatus* *Calidris alba* *Pluvalis squatorola* *Numenius phaeopus* *Tringa nebularia* *Sterna* spp.	Kelp gull Whitefronted plover Sanderling Grey plover Whimbrel Greenshank Tern species	Other common bird species found on the south coast [20]

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Palinurus gilchristi	Rock lobster	
Thryssa vitrirostris *Etrumeus whiteheadi* *Scomber japonicus* *Trachurus trachurus* *Symbolophorus boops* *Atherina breviceps* *Aeoliscus punctulatus* *Anthias squamipinnis* *Caesio caerulaureus* *Monodactylus falciformis* *Sarpa salpa* *Ambassis productus*	Glassnose Round herring Mackerel Horse mackerel Lanternfish Cape silverside Razorfish Sea goldie Blue-and-gold fusilier Cape moony Strepie Glassy	Important zooplanktivorous fish of the south coast [46,47]

LIST OF IMPORTANT SPECIES continued on next page

Secondary Consumers
continued...

Infratidal zone continued...

Species		Remarks
Scientific Name	**Common Name**	
Boopsoidea inornata *Diplodus cervinus hottentotus* *Diplodus sargus capensis* *Gymnocrotaphus curvidens* *Pachymetopon grande* *Rhabdosargus globiceps* *Dichistius capensis* *Oplegnathus conwayi* *Pomacanthus semicirculatus* *Chaetodon marleyi* *Abudefduf* spp. *Caffrogobius nudiceps* *Parablennius pilicornis* *Scartella emarginata*	Fransmadam Zebra Blacktail Janbruin Bronze bream White stumpnose Galjoen Cape knifejaw Semicircle angelfish Doublesash butterflyfish Sergeant major Barehead goby Ringneck blenny Maned blenny damsel	Important omnivorous fish (usually feed on seaweeds and their associated invertebrates) [20]
Chanos chanos *Plotosus lineatus* *Genypterus capensis* *Merluccius* spp.	Milkfish Striped eel-catfish Kingklip Hake	Important benthic feeding fish [20] Hake is an extremely important commercial species.
Pterois miles *Chelidonichthys capensis* *Kuhlia mugil* *Priacanthus hamrur* *Epinephelus* sp. *Plectorhinchus* sp. *Pomadasys* sp. *Chrysobephus* sp. *Pachymetopon aeneum* *Spondyliosoma emarginatum* *Rhabdosargus* sp. *Platax orbicularis* *Tripterodon orbis* *Pomacanthus rhomboides* *Centropyge acanthops* *Chaetodon* sp.	Toxic devil firefish Endemic Cape gurnard Barred flagtail Nocturnal Crescent-tail bigeye Rockcod Rubberlip Grunter Roman Blue hottentot Steentjie Cape and White stumpnose Batfish Spadefish Old woman Jumping bean Brownburnie	Important benthic feeding fish found on coral reefs [20]

LIST OF IMPORTANT SPECIES continued on next page

South Coast

LIST OF IMPORTANT SPECIES continued...

Secondary Consumers
continued...

Infratidal zone *continued...*

Species		Remarks
Scientific Name	**Common Name**	
Trachinotus africanus *Chirodactylus brachydactylus* *Halichoeres spp.* *Thalassoma* sp. *Lethrinus nebulosus* *Clinus* sp. *Chrysoblephus cristiceps* *Chrysoblephus gibbiceps* *Chellodactylus fasciatus* *Chaetodon* spp.	Southern pompano Common endemic Twotone fingerfin Wrasses Blue emperor Klipfish Dageraad Red-stumpnose Redfingers Butterflyfish	Important benthic feeding fish found on coral reefs [20]
Acanthistius sebastoide *Sparodon durbanensis* *Sarpa salpa* *Chorisochismus dentex* *Carangoides ferdau* *Lithognathus* spp. *Pagellus bellottii natalensis* *Dichistius multifasciatus* *Sillago sihama* *Umbrina canariensis* *Heteromycteris capensis* *Solea bleekeri* *Austroglossus pectorali* *Acanthopagrus berda*	Koester Musselcracker Strepie Endemic rocksucker Blue kingfish White and sand steenbras Sand soldier Endemic banded galjoen Silver smelt Baardman Endemic Cape sole Endemic blackhand sole Endemic east coast sole River bream	Important benthic feeding fish found on rocky areas [20]

Water column:

Species		Remarks
Scientific Name	**Common Name**	
	Sharks Rays Chimeara	0f the more than 100 species of shark, 64 rays and seven chimearas found in southern Africa, at least 48 sharks, 35 rays and three chimaeras occur off the south-east Cape
Halaelurus natalensis *Poroderma africanum* *Poroderma pantherinum*	Tiger cat shark Pyjama cat shark Leopard catshark	Endemic shark species in South Africa and are most abundant on the Cape south coast
Narke capensis	One-fin electric ray	Are common but have narrow niches

LIST OF IMPORTANT SPECIES continued on next page

LIST OF IMPORTANT SPECIES continued...

Secondary consumers
continued...

Water column *continued...*

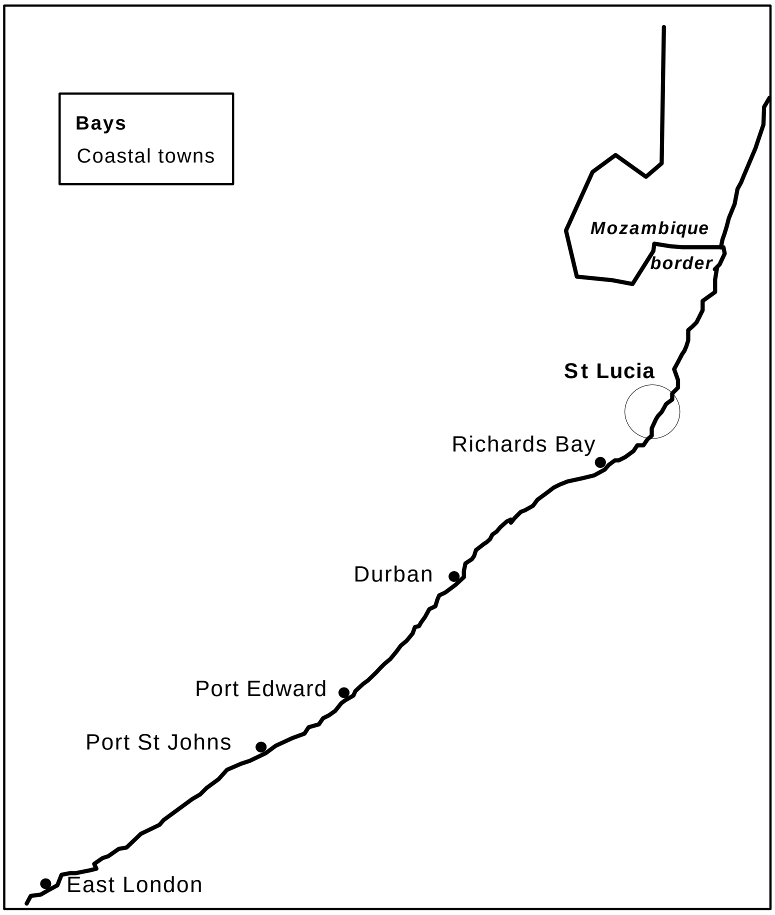
Species		Remarks
Scientific Name	**Common Name**	
Carcharhinus limbatus	Blacktip shark	
Carcharias taurus	Ragged tooth shark	Major nursery ground on the south-east coast
Elops machnata *Megalops cyprinoides* *Argyrozona argyrozona* *Chrysoblephus anglicus* *Cheimerius nufar* *Petrus rupestris* *Pterogymnus laniarius* *Polysteganus* sp *Argyrosomus hololepidotus* *Atractoscion aequidens* *Pomatomus saltatrix* *Caranx ignobilis* *Lichia amia* *Scomberoides commersonnianus* *Thyrsites atun* *Katsuwonus pelamis* *Scomberomorus* sp *Sphyraena jello* *Polysteganus praeorbitalis*	Ladyfish Oxyeye tarpon Carpenter Englishman Santer Red steenbras Panga Seventy-four Kob Geelbek Elf Giant kingfish Leervis Queenfish Snoek Skipjack tuna Queen and king mackerel Pickhandle barracuda Scotsman	Carnivorous fish (feeding on other smaller fish) [20]
Loligo vulgaris reynaudii	Chokka squid	The most abundant squid in South African waters that becomes concentrated in bays between Cape Point and Port Elizabeth in summer, when it breeds. It sustains an important fishery between Plettenberg Bay and Port Elizabeth [20]
Arctocephalus pusillus *Aonyx capensis* *Delphinus delphis* *Tursiops sp.* *Cephalorhynchus heavisidii* *Lagenorhynchus obscurus* *Sousa plumbea* *Stenella coeruleoalba* *Lagenodelphis hosei* *Balaena glacialis* *Megaptera novaeangliae* *Orcinus orca* *Physeter macrophalus*	South African fur seal Cape clawless otter Common dolphin Bottlenose dolphin Heaviside's dolphin Dusky dolphin Humpback dolphin Striped dolphin Southern wright whale dolphin Southern wright whale Humpback whale Killer whale Sperm whale	Marine mammals found along the south coast [20]

Chapter 2.1.3 East Coast

GENERAL DESCRIPTION

Location

The east coast of South Africa is defined as that section of coast extending from north of East London up to the Mozambique border. This region can typically be further subdivided into a tropical (north of Port Edward) and subtropical coast.



GENERAL DESCRIPTION continued on next page

East Coast

GENERAL DESCRIPTION continued...

General

The warm Agulhas current is the greatest factor influencing the coastal marine environment along the east coast of South Africa. The Agulhas current flows in a south-easterly direction along the edge of the continental shelf. The average surface speed is between 1 and 2 m s^{-1} [11]. The Agulhas current brings warm and generally nutrient-poor water from the tropics to the east coast [1].

The continental shelf along the east coast is generally narrow with the narrowest sections north of the Tugela. Sediments in the nearshore region are mostly of fine sand while coarse sands and gravel occur more commonly on the midshelf. Despite the large input of terrigenous sediment, true mud deposits are relatively rare along the east coast.

Water of tropical origin such as that of the east coast is usually nutrient poor. Upwelling does occur more frequently along the southern Natal coast, bringing bottom waters lower in temperature and higher nutrient contents onto the shelf.

Further details on the water quality of the east coast can be obtained from *Section 4: Water Quality Properties/Constituents relevant to the Natural Environment*.

Generally, the east coast fauna and flora are relatively low in total biomass, but species diveristy is high with distinct indopacific affinities.

Intertidal zone

Rocky shores. Highest on the rocky shore of the east coast, theLlittorina zone is dominated by the algae *Bostrichia*, and a few snail species. Dense beds of the Natal rock oyster occur at the top of the Balanoid zone. This gives way to a mixed community of brown mussels, barnacles and limpets. Several species of zoanthids shroud the lower Balanoid zone [1].

Sandy beaches. Along the northern, more tropical coastline, the ecology of sandy beaches, as with rocky shores, is greatly influenced by the large tidal fluctuations and the normally calm conditions [13]. Diatoms dominate the microalgae in sandy beaches.

Infratidal zone

Dense algae beds including *Hypnea* and *Spirida* species may occur in the rocky areas of the infratidal zone, while the more hardy corrolline species occurs in areas of higher wave action [1].

Perhaps the most important single characteristic which distinguishes the east coast from the other regions is the presence of coral reefs along the infratidal zone of its northern more tropical coastline. Two types of coral reef may be distinguished: barrier reefs separated from land by wide, relatively deep channels, and fringing reefs [13].

GENERAL DESCRIPTION continued on next page

Water column

The low nutrient status of the waters off the east coast results in relatively low primary production compared to the west coast. Generally, there is an indication of late winter/early spring peaks in phytoplankton production along the east coast.

The east also support numerous other fish species. Many of the important commercial and angling species are long distance summer migrants from tropical Indian ocean waters such as king mackerel, marlin and sword fish.

Biodiversity amongst the reef fishes such as eel and angelfish is high with a large number of Indo-pacific and Indo-west Pacific species.

Although the east coast does not support high biomass, import of biomass occurs through, for example, migration of west and south-coast species during winter. The famous Natal sardine run occurs each winter when large shoals of sardines follow an inshore countercurrent up the Natal coast. The narrowing and patchiness of the current often forces shoals inshore where large numbers become stranded on beaches. These shoals are also followed by numerous species of game fish, e.g. shad, yellow tail, geelbek and red steenbras. Dolphins occur in large numbers during this period.

The east coast also supports numerous shark and ray species of which the Zambesi shark is restricted to this region.

East Coast

LIST OF IMPORTANT SPECIES

Primary Producers

Important species found along the west coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Bostrichia. *Calothrix* species A & B	Algae	Dominant algae species occurring on rocky shores in the Littorina zone [23]
Ralfsia expansa *Gelidium pristoides*	Crustose corallines Saw-edged jelly weed	Dominant algae species occurring on rocky shores in the Balanoid zone [23]
Jania verrucosa *Arthrocardia anceps* *Gelidium amansii* *Hypnea spicifera*	Coralline algae Coralline algae Red algae Green tips	Algae found in rock pools [23] Often dominant
Hypnea rosea *Haliptilon subulata*, *Ceramium spp* *Polysiphonia spp*	Rosy curled hypnea	Epiphytes occurring lower down on rocky shores [23]
	Diatoms	Diatoms dominate the microalgae occurring in sandy beaches, but tend to be low in numbers and often attach to sand particles by means of specialised raphe-bearing valves. Some phytoplankton may be brought onto sandy beaches from the surf zone [23]
Ulva spp. *Enteromorpha* spp.	Sea lettuce	Opportunistic algae species which grow wherever clear substrates occur [23]

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Jania verrucosa *Arthrocardia anceps* *Gelidium amansii* *Hypnea spicifera dominant*	Corallines Corallines Red algae Green tips	Algae [23]
Hypnea rosea *Haliptilon subulata* *Ceramium* spp. *Polysiphonia* spp.	Epiphytes [23]	

LIST OF IMPORTANT SPECIES continued on next page

Primary Producers
continued...

Water column:

Species		Remarks
Scientific Name	**Common Name**	
Skeletonema costatum *Planktoniella sol* *Climacodium* spp. (2) *Ditylum sol* *Eucampia cornuta* *Bacteriastrum* spp. (12) *Dactyliosolen mediterraneus* *Guinardia flaccida* *Rhizosolenia* spp. (2) *Thalassionema* spp. (3) *Nitzschia* spp. (2)	Phytoplankton	Species of net phytoplankton commonly occurring along the east coast [21,22]

Primary Consumers

Important species found along the west coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Patella spp. *Dendrofissurella*	Limpets	Most common species on rocky shores [20]
Oxystele tabularis	Winkle [20]	
Aplysia oculifera *Dolabella auricularia* *Bursatella leachi*	Sea hares	Occupy sheltered pools, bays and weed beds [20]
Patiriella exigua	Dwarf cushion star	Occur abundantly in the intertidal zone [20]

LIST OF IMPORTANT SPECIES continued on next page

East Coast

LIST OF IMPORTANT SPECIES continued...

Primary Consumers
continued...

Intertidal zone continued...

Species		Remarks
Scientific Name	**Common Name**	
Haliclona spp. *Tethya* spp.	Sponges	The more common east coast species [20]
Cymadusa filosa	Nesting amphipod	Herbivorous amphipod [20]
Lepas sp. *Tetraclita serrata* *Tetraclita squamosa* *Octameris angulosa*	Barnacles	Common species [1]
Pontogeloides latipes *Excirolana natalensis*	Isopods	Sandy beach isopods [20]
Perna perna *Modiolus auriculatus*	Brown mussel Ear mussel	Common intertidal mussel species on rocky shores [40]
Donax spp.	White mussel	Sandy beach mussels [40]
Saccostrea cuccullata *Striostrea magaritacea*	Oysters	Common east coast oysters, the latter being harvested commercially [40]
Tridacna maxima	Clam	Common along the Zululand coast [40]
Dendropoma tholia	Colonial worm shell [40]	
Eudistoma coeruleum	Blue lollipop ascidean (sea squirt)	Common in rock pools

LIST OF IMPORTANT SPECIES continued on next page

Primary Consumers
continued...

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Bathynatalia gilchristi *Naudea larvae* *Parabathynomus natalensis*	Isopods	More notable species [20]
Haliclona spp. *Tethya* spp.	Sponges	The more common east coast species [20]
Echinometra mathaei *Stomponeustes variolaris* *Tripneustes gratilla*	Sea urchins	Common species,usually occuppying sheltered rock pools or subtidal areas [20]
Roweia frauenfeldii *Pseudonella sykion*	Horseshoe sea cucumber Black sea cucumber	Crevice dwellers [40]
Holothuria spp.	Sea cucumber	Certain species are exploited in Mozambique for export to the far east (detritus feeders) [40]
Pyura stolonifera *Ciona intestinalis*	Sea squirts, such as red bait [20]	

Water column:

Species		Remarks
Scientific Name	**Common Name**	
Centropages chierchiae C. *carinatus*	Copepods	Dominant species in the winter/spring period [39]
Paracalanus parvus	Copepod	Dominant species at other times [39]
Eucalanus mucronatus *Eucalanus pilateus* *Acrocalanus gracilis*	Copepods	Numerical dominant species [39]
Radiolaria Foraminifera Rotifera	Protozoan	Planktonic protozoan [39]
Sardinops sagax *Sarpa salpa* *Rhabdosargus holubi*	Pilchard Karanteen Cape stumpnose	Herbivorous winter migrants from the Cape [20]

LIST OF IMPORTANT SPECIES continued on next page

East Coast

LIST OF IMPORTANT SPECIES continued...

Secondary Consumers

Important species found along the west coast of South Africa are given below. These are organised into their occurrence in the intertidal zone, infratidal zone and water column:

Intertidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Anomastrea irregularis	Irregular honeycomb corals [20]	Occur in intertidal pools
Anthelia sp.	Blue soft coral [20]	Occur in intertidal pools
Zooanthus spp.	Zooanthids [20]	
Anemonia natalensis *Gyractis excavata*	Natal anemone Colonial anemone	Restricted to the east coast and occur in intertidal rock pools [20]
Alope orientalis	Oriental shrimp	Intertidal benthic shrimps [48]
 Emerita austroafricana *Hippa adactyla* *Clibanarius virescens* *Calcinus laevimanus* *Grapsus spp.* *Percnon planissimum* *Ocypode ryderi*	 Mole crabs Hermit crabs True crabs Pink ghost crab	Crabs occuring on the east coast [20] Occur on sandy beaches Occur on rocky shores Occur on rocky shores Occur on sandy beaches
Charonia lampas pustulata *Morula granulata*	Whelks - pink lady Mulberry shell	
Hydatina physis	Opisthobranch - striped bubble shell	
Phyllodesmium serratum *Aeolidiella indica*	Coral nudibranch Indian nudibranch	Sea slugs
	Fish	Rock pools are nursery areas for numerous fish species

Infratidal zone:

Species		Remarks
Scientific Name	**Common Name**	
Phyllodesmium serratum *Aeolidiella indica*	Coral nudibranch Indian nudibranch	Sea slugs
Thecocarpus formosus *Plumularia setacea* *Lytocarpus philippinus*	Rusty feather hydroid Plumed hydroid Smokey feather hydriod [20]	

LIST OF IMPORTANT SPECIES continued on next page

Secondary Consumers
continued...

Infratidal zone continued...

Species		Remarks
Scientific Name	**Common Name**	
Flavites spp. *Flavia* spp.	Honeycomb corals False honeycomb corals	May also occur intertidally [26]
Alcyonium spp. *Xenia crassa*	Soft corals [20]	
Palinurus homarus *Palinurus versicolor*	East coast rock lobster Painted rock lobster	*P. horamus* is commonly exploited on the east coast [20]
Metapeneus monoceros *Penaeus* spp.	Prawns [48]	
Gnathophyllum faciolatum *Stenopus hispidus*	Zebra shrimp Cleaner shrimp [20]	
Cypraea spp. *Trevia* spp *Nassarius* spp.	Gastropods [20]	
Epinepholus spp. *Pomadasys commersonnii* Sparidae	rock cods Spotted grunter Sparids (Carpenter, Santer, Englishman, Dageraad, Red stumpnose, Slinger, Zebra, Red and White Steenbras, Musselcracker, Seventy four, Scotsman, Panga and others).	Popular reef angling fish [50]

Water column:

Species		Remarks
Scientific Name	**Common Name**	
Physalia urticularis *Porpita pacifica* *Velella* sp.	Blue bottle Raft hydroid By-the-wind-sailor	Hydroids including the ubiquitous blue bottle [20]
Leptoseris sp.	Corals	Deep water corals occurring in Sodwana Bay
Glaucus atlanticus	Sea swallow	Curiously shaped sea swallow [20]
Rhizostoma sp.	Root mouth jellyfish [20]	

LIST OF IMPORTANT SPECIES continued on next page

East Coast

LIST OF IMPORTANT SPECIES continued...

Secondary Consumers
continued...

Water column continued...

Species		Remarks
Scientific Name	**Common Name**	
Nephrops andamanicus *Haliporoides triarthrus*	Prawns [48]	
Argonauta argo *Spirula spirula*	Paper nautilus Rams horn shell	Cephalopods occurring on the east coast
Palinurus delagoae	Lobster [48]	Deap sea lobster
Scomberomorus commerson *S. plurilineatus* *Elagatis bipinnulatus* *Thunnus albacares* *Katsuwonus pelamis*	King mackerel Queen mackerel Rainbow runner Yellowfin tuna Skipjack tuna Billfishes (Marlins, Sailfish, Swordfish)	Important commercial and angling species [49]
Epinepeolus spp. *Pomadasys commersonnii* Sparidae	Rock cods Spotted grunter Sparids (Carpenter, Santer, Englishman, Dageraad, Red Stumpnose, Slinger, Zebra, Red and White Steenbras, Musselcracker, Seventy four, Scotsman, Panga and others).	Popular reef angling fish [50]
Poroderma pantherinum *Poroderma africanum* *Haploblepharus edwardsii* *Carcharhinus leucas* *Carcharhinus limbatus*	Leopard cat shark Pyjama cat shark Puffadder shyshark Zambezi shark Blacktip shark	Sharks [20]
Rhinobatos annulatus	Ray [20]	
Dermochelys coriacea *Caretta caretta*	Leatherback turtle Loggerhead turtle	Loggerhead turtles nest on Zululand beaches
	Birds	Birds species occurring on the east coast are generally widespread
Morus capensis	Cape gannet	Increase in numbers following the "sardine run".
Megaptera novaeangliae *Delphinus delphis* *Tursiops truncatus*	Humpback whale Common dolphin Bottlenose dolphin	Mammals occurring on the east coast Bottlenose dolphins might be distinct on the east coast

Chapter 2.2
Summary of Problems, Norms and Relevance of Water Quality Properties/Constituents Associated with the Different Trophic Levels

Chapter 2.2.1 Primary Producers

SUMMARY OF PROBLEMS AND ASSOCIATED NORMS

Problems

Water quality problems associated with primary producers include:

i. eutrophication;
ii. general growth deficiencies;
iii. lowered reproduction;
iv. mortalities.

For more information on these problems refer to:

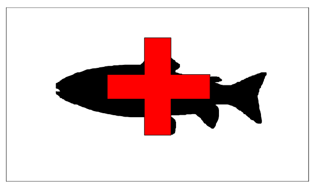
p 3-1
p 3-3
p 3-4
p 3-11

Norms

The quality of water can be described in terms of many different properties or constituents. It is therefore important to select specific norms upon which to base the selection of relevant water quality properties/constituents for a particular use or user group. Norms can also be described as types or 'boxes' of problems. Considering the primary producers in the natural environment, the following norms were selected:

Abnormal Growth Stimulation
(Refering to problem i)

Biological Health
(Refering to problems ii-iv)



RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

Legends

Different water quality properties/constituents can be used to measure the effect of change in water quality for the different norms. The relevance of different water quality properties/constituents to each norm is indicated below.

The legend used in the tables that follow are:

Relevant, addressed in this document	✓
Relevant, NOT addressed	✓✗
Indirectly relevant, NOT addressed	✓...
Not relevant	✗

Physico-chemical properties

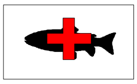
For more information on properties refer to:

	Algae! Growth Stimulation	Biological Health	For more information on properties refer to:
°C Temperature	✓	✓	p 4-1
Sal Salinity	✗	✓	p 4-3
pH	✗	✓	p 4-6
Floating matter	✗	✓	p 4-8
SS Suspended solids	✗	✓	p 4-9
Colour/Turbidity/ Clarity	✗	✓	p 4-11
O_2 Dissolved oxygen	✗	✗	

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Nutrients



		Growth Stimulation	Biological Health
NH_4^+	Ammonium	✓	✗
NO_2	Nitrite	✓	✗
NO_3	Nitrate	✓	✓
PO_4	Reactive phosphate	✓	✓
SiO_4	Reactive silicate	✓	✓
DOC	Dissolved organic carbon	✓✗	✗
Kjel	Kjeldahl nitrogen	✓✗	✓✗

For more information on nutrients refer to:

p 4-17

p 4-21

p 4-23

p 4-27

p 4-31

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Inorganic constituents

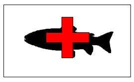
		Growth Stimulation	Biological Health
NH_3	Ammonia	✗	✗
CN	Cyanide	✗	✓
F	Fluoride	✗	✓
Cl_2	Chlorine	✗	✓
H_2S	Hydrogen sulphide	✗	✓
As	Arsenic	✗	✓
Cd	Cadmium	✗	✓
Cr	Chromium	✗	✓
Cu	Copper	✗	✓
Pb	Lead	✗	✓
Hg	Mercury	✗	✓
Ni	Nickel	✗	✓
Ag	Silver	✗	✓
Sn	Tin	✗	✓
Zn	Zinc	✗	✓
	Other metals	✗	✓✗

For more information on inorganics refer to:

p 4-36
p 4-38
p 4-40
p 4-44
p 4-47
p 4-50
p 4-53
p 4-55
p 4-57
p 4-59
p 4-61
p 4-63
p 4-65
p 4-67

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Organic constituents



		Growth Stimulation	Biological Health
TBT	Organotins, including tributyl tin	✗	✓
TPH	Total petroleum hydrocarbons	✓✗	✓
Algal	Algal toxins	✗	✓✗
Taint	Tainting substances	✗	✗
PAH	Polycyclic aromatics	✓✗	✓✗
	Halogenated aliphatics	✗	✓✗
	Halogenated ethers	✗	✓✗
	Monocyclic aromatics	✗	✓✗
	Nitrosamines	✗	✓✗
	Biocides	✗	✓✗
	Resin acids	✗	✓✗
	Surfactants	✗	✓✗

For more information on organics refer to:

p 4-71

p 4-74

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

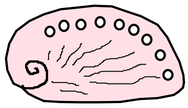
Microbiological indicator organisms and pathogens

		Algae! Growth Stimulation	Biological Health
F coli	Faecal coliform (including *E. coli*)	✗	✗
Entero	Enterococci	✗	✗
Pathogen	Pathogens	✗	✓✗

Radio-active substances

		Algae! Growth Stimulation	Biological Health
	Radioactive substances	✗	✓✗

REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5)



Chapter 2.2.2 Primary Consumers

SUMMARY OF PROBLEMS AND ASSOCIATED NORMS

Problems

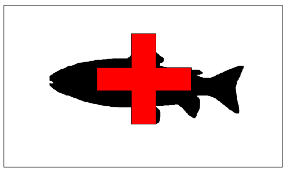
Water quality problems associated with primary consumers include:

		For more information on problems refer to:
i.	general growth deficiencies;	p 3-3
ii.	lowered reproduction;	p 3-4
iii.	changes in feeding habits;	p 3-5
iv.	changes in repiration patterns;	p 3-6
v.	changes in water pumping rates;	p 3-7
vi.	shell deformation;	p 3-9
vii.	formation of air blisters causing flotation;	p 3-10
viii.	mortalities;	p 3-11
ix.	abnormalities in movement;	p 3-13
x.	burrowing abnormalities	p 3-14

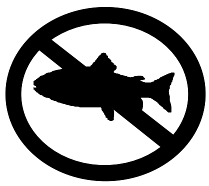
Norms

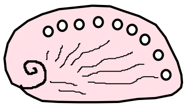
The quality of water can be described in terms of many different properties or constituents. It is therefore important to select specific norms upon which to base the selection of relevant water quality properties/constituents for a particular use or user group. Norms can also be described as types or 'boxes' of problems. Considering the primary consumers in the natural environment, the following norms were selected:

Biological Health
(Refering to problems i-viii)



External Behaviour Responses
(Refering to problems ix and x)





RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

Legends

Different water quality properties/constituents can be used to measure the effect of change in water quality for the different norms. The relevance of different water quality properties/constituents to each norm is indicated below.

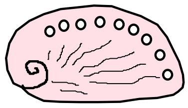
The legend used in the tables that follow are:

Relevant, addressed in this document	✓
Relevant, NOT addressed	✓✗
Indirectly relevant, NOT addressed	✓...
Not relevant	✗

Physico-chemical Properties

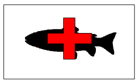
	Biological Health	External Responses	For more information on properties refer to:
°C Temperature	✓	✓	p 4-1
Sal Salinity	✓	✓	p 4-3
pH pH	✓	✓	p 4-6
Floating matter	✓	✓	p 4-8
SS Suspended solids	✓	✓	p 4-9
Colour/Turbidity/ Clarity	✓	✓	p 4-11
O_2 Dissolved oxygen	✓	✓	p 4-13

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page



RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Nutrients

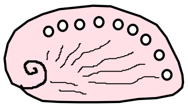
	 Biological Health	 External Responses
NH_4^+ Ammonium	✗	✗
NO_2 Nitrite	✓	✓✗
NO_3 Nitrate	✓	✓✗
PO_4 Reactive phosphate	✗	✗
SiO_4 Reactive silicate	✗	✗
DOC Dissolved organic carbon	✓●●●	✓●●●
Kjel Kjeldahl nitrogen	✓●●●	✓●●●

For more information on nutrients refer to:

p 4-21

p 4-23

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page



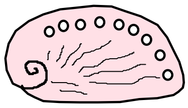
RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Inorganic constituents

For more information on inorganics refer to:

		Biological Health	External Responses	
NH_3	Ammonia	✓	✗	p 4-35
CN	Cyanide	✓	✗	p 4-36
F	Fluoride	✓	✗	p 4-38
Cl_2	Chlorine	✓	✗	p 4-40
H_2S	Hydrogen sulphide	✓	✗	p 4-44
As	Arsenic	✓	✗	p 4-47
Cd	Cadmium	✓	✗	p 4-50
Cr	Chromium	✓	✗	p 4-53
Cu	Copper	✓	✗	p 4-55
Pb	Lead	✓	✗	p 4-57
Hg	Mercury	✓	✗	p 4-59
Ni	Nickel	✓	✗	p 4-61
Ag	Silver	✓	✗	p 4-63
Sn	Tin	✓	✗	p 4-65
Zn	Zinc	✓	✗	p 4-67
	Other metals	✗	✗	

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page



RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Organic constituents

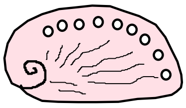
		Biological Health	External Responses
TBT	Organotins, including tributyl tin	✓	✓✗
TPH	Total petroleum hydrocarbons	✓	✓✗
PAH	Polycyclic aromatics	✓✗	✓✗
Algal	Algal toxins	✓✗	✓✗
Taint	Tainting substances	✗	✓✗
	Halogenated aliphatics	✓✗	✓✗
	Halogenated ethers	✓✗	✓✗
	Monocyclic aromatics	✓✗	✓✗
	Nitrosamines	✓✗	✓✗
	Biocides	✓✗	✓✗
	Resin acids	✓✗	✓✗
	Surfactants	✓✗	✓✗

For more information on organics refer to:

p 4-71

p 4-74

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page



RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

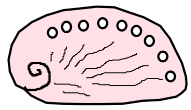
Microbiological indicator organisms and pathogens

		Biological Health	External Responses
F coli	Faecal coliform (including *E. coli*)	✓•••	✗
Entero	Enterococci	✓•••	✗
Pathogen	Pathogens	✓✗	✗

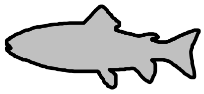
Radio-active substances

		Biological Health	External Responses
	Radioative substances	✓✗	✓✗

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page



REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5)



Chapter 2.2.3 Secondary Consumers

SUMMARY OF PROBLEMS AND ASSOCIATED NORMS

Problems

Water quality problems associated with secondary consumers include:

i. general growth deficiencies;
ii. lowered reproduction;
iii. changes in feeding habits;
iv. changes in repiration patterns;
v. changes in moulting patterns;
vi. shell deformation;
vii. formation of air blisters causing floatation;
viii. mortalities;
ix. abnormal movement;
x. burrowing abnormalities.

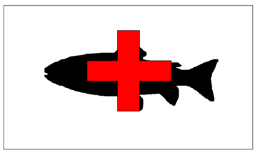
For more information on problems refer to:

p 3-3
p 3-4
p 3-5
p 3-6
p 3-8
p 3-9
p 3-10
p 3-11
p 3-13
p 3-14

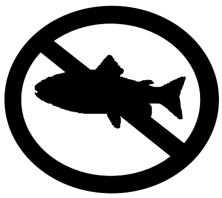
Norms

The quality of water can be described in terms of many different properties or constituents. It is therefore important to select specific norms upon which to base the selection of relevant water quality properties/constituents for a particular use or user group. Norms can also be described as types or 'boxes' of problems. Considering the secondary consumers in the natural environment, the following norms were selected:

Biological Health
(Refering to problems i-viii)



External Hehaviour Response
(refering to problems ix and x)



RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

Legends

Different water quality properties/constituents can be used to measure the effect of change in water quality for the different norms. The relevance of different water quality properties/constituents to each norm is indicated below.

The legend used in the tables that follow are:

Relevant, addressed in this document	✓
Relevant, NOT addressed	✓✗
Indirectly relevant, NOT addressed	✓...
Not relevant	✗

Physico-chemical properties

	Biological Health	External Responses	For more information on properties refer to:
°C Temperature	✓	✓	p 4-1
Sal Salinity	✓	✓	p 4-3
pH pH	✓	✓	p 4-6
Floating matter	✓	✓	p 4-8
SS Suspended solids	✓	✓	p 4-9
Colour/Turbidity/Clarity	✓	✓	p 4-11
O_2 Dissolved oxygen	✓	✓	p 4-13

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Nutrients

		Biological Health	External Responses
NH_4^+	Ammonium	✗	✗
NO_2	Nitrite	✓	✓✗
NO_3	Nitrate	✓	✓✗
PO_4	Reactive phosphate	✗	✗
SiO_4	Reactive silicate	✗	✗
DOC	Dissolved organic carbon	✓•••	✓•••
Kjel	Kjeldahl nitrogen	✓•••	✓•••

For more information on nutrients refer to:

p 4-21

p 4-23

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Inorganic constituents

		Biological Health	External Responses
NH_3	Ammonia	✓	✗
CN	Cyanide	✓	✗
F	Fluoride	✓	✗
Cl_2	Chlorine	✓	✗
H_2S	Hydrogen sulphide	✓	✗
As	Arsenic	✓	✗
Cd	Cadmium	✓	✗
Cr	Chromium	✓	✗
Cu	Copper	✓	✗
Pb	Lead	✓	✗
Hg	Mercury	✓	✗
Ni	Nickel	✓	✗
Ag	Silver	✓	✗
Sn	Tin	✓	✗
Zn	Zinc	✓	✗
	Other metals	✗	✗

For more information on inorganics refer to:

p 4-35
p 4-36
p 4-38
p 4-40
p 4-44
p 4-47
p 4-50
p 4-53
p 4-55
p 4-57
p 4-59
p 4-61
p 4-63
p 4-65
p 4-67

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Organic constituents

	Biological Health	External Responses
TBT Organotins, including tributyl tin	✓	✓✗
TPH Total petroleum hydrocarbons	✓	✓✗
PAH Polycyclic aromatics	✓✗	✓✗
Algal Algal toxins	✓✗	✓✗
Taint Tainting substances	✗	✓✗
Halogenated aliphatics	✓✗	✓✗
Halogenated ethers	✓✗	✓✗
Monocyclic aromatics	✓✗	✓✗
Nitrosamines	✓✗	✓✗
Biocides	✓✗	✓✗
Resin acids	✓✗	✓✗
Surfactants	✓✗	✓✗

For more information on organics refer to:

p 4-71

p 4-74

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Microbiological indicator organisms and pathogens

		Biological Health	External Responses
F coli	Faecal coliform (including *E. coli*)		
Entero	Enterococci		
Pathogen	Pathogens		

Radio-active substances

		Biological Health	External Responses
	Radioative substances		

REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5)

REFERENCES

1. BRANCH, M. and BRANCH, G. 1981. *The Living Shores of Southern Africa.* C. Struik Publishers, Cape Town. 277pp.

2. SHANNON, L. V. 1985. The Benguela Ecosystem. Part 1. Evolution of the Benguela, Physical features and processes. *Oceanogr. Mar. Biol. Ann. Rev.* **23**: 105-182.

3. NELSON, G. and HUTCHINGS, L. 1983. The Benguela upwelling area. *Prog. Oceanogr.* **12**: 333-356.

4. TAUNTON-CLARK, J. 1985. The formation, growth and decay of upwelling tongues in response to the mesoscale wind field during summer. In: *South African Ocean Colour and Upwelling Experiment.* Shannon, L.V. (Ed). Cape Town. p 47-61.

5. BOYD, A., TROMP, B.B.S. and HORSTMANN, D.A. 1985. The hydrology off the South African south-western coast between Cape Point and Danger Point in 1975. *S. Afr. J. mar. Sci.*, **3**: 145-168.

6. ANDREWS, W.R.H and HUTCHINGS, L. 1980. Upwelling in the southern Benguela current. *Prog. Oceanog.* **9**: 1-81.

7. MONTEIRO, P.M.S., PITCHER, G., BRUNDRIT, G.B., CARTER, R.A., NELSON, G. and C. ATTWOOD. 1994. The Saldanha Bay Mariculture - Environment Programme: Marine Science towards a sustainable growth of mariculture in Southern Africa. *South African Aquaculture Journal*. Proceedings of Aquaculture '94 Symposium

8. BAILEY, G.W. and CHAPMAN, P. 1985. The nutrient status of the St Helena region in February 1979. In: *South African Ocean Colour and Upwelling Experiment.* Shannon L.V. (Ed). Cape Town. p 125-145.

9. GRÜNDLINGH, M. L. and LARGIER, J. L. 1991. Physical oceanography of False Bay: A review. *Transactions of the royal society of South Africa* **47**(4 & 5): 387-400.

10. BRANCH, G.M. and GRIFFITHS C.L. 1988. The Benguela ecosystem. Part V. The coastal zone. *Oceanogr. Mar. Biol. Annu. Rev.* **26**: 395-486.

11. SHANNON, L.V., VAN DER ELST, R.P. and CRAWFORD, R.J.M. 1989. Tunas, bonitos, spanish mackerels and billfish. In: *Oceans of Life*, Payne, A.I.L. and Crawford, R.J.M. (Eds). Vlaeberg Publishers, Cape Town. p.188-197.

12. BROWN, A.C. and McLACHLAN, A. 1990. *Ecology of Sandy Shores*. Elsevier, Amsterdam.

13. BROWN, A.C. and JARMAN, N. 1978. Coastal marine habitiats. In: *Biogeography and ecology of southern Africa* **1**. Werger, M.J.A. (Ed.). Dr W Junk bv Publishers, The Hague.

REFERENCES continued on next page

REFERENCES continued...

14. SHANNON, L.V. and PILLAR, S.C. 1986. The Benguela Ecosystem. Part III. Plankton. *Oceanogr. Mar. Biol. Ann. Rev.*, **24**: 65-170.

15. VELIMIROV, B., FIELD,J.G., GRIFFITHS, C.L. and ZOUTENDYK, P. 1977. The ecology of kelp bed communities in the Benguela upwelling system: analysis of biomass and spatial distribution. *Helgolander Meeresunters*. **30**: 495-518.

16. FIELD, J.G., GRIFFITHS, C.L., GRIFFITHS, R.J., JARMAN, N., ZOUTENDYK, P., VELIMIROV, B. and BOWES, A. 1980. Variation in structure and biomass of kelp communities along the south-west Cape coast. *Trans. R. Soc. S. Afr*. **44**: 145-203.

17. CHRISTIE, N.D. 1981. Primary production in Langebaan lagoon. In: *Estuarine ecology with particular reference to southern Africa*. Day, J.H. (Ed.). A. A. Balkema, Cape Town. p 101-115.

18. CAMPBELL, E.E. and BATE, G.C. The flora of the sandy beaches of southern Africa III. The south coast microflora. *ICR Report* No **26.**

19. ROMER, G. (in prep). Bacterioplankton, pelagic heterotrophic Protozoa and other microplankton components of a surf phytoplankton based food chain: standing stocks and demands on phytoplankton production .

20. BRANCH, G.M., GRIFFITHS, C.L., BRANCH, M.L. and BECKLEY, L.E. 1994. *Two Oceans: A guide to the marine life of southern Africa*. David Philip. 360 pp.

21. TAYLOR, F.J.R. 1966. Phytoplankton of the Southwestern Indian Ocean. *Nova Hedwigia* **12**(3/4): 433 - 476.

22. THORNINGTON-SMITH, M. 1969. Phytoplankton studies in the Agulhas Region off the Natal Coast. *Investigational Report, Oceanographic Research Institute, Durban* **23**. 24pp.

23. LAMBERT, G. 1981. An intertidal survey of Umdoni Park's rocky shore. *Ph D Thesis,* University of Natal, Pietermaritzburg. 457pp.

24. BUSTAMANTE, R.H. 1994. Patterns and causes of intertidal community structure around the coast of southern Africa. *PhD thesis*, University of Cape Town.

25. EEKHOUT, S.,RAUBENHEIMER, C.M., BRANCH, G.M., BOSMAN, A.L. and BERGH, M.O. 1992. A holistic approach to the exploitation of intertidal stocks: Limpets as a case study. *S. Afr. J. mar. Sci*. **12**: 1017-1029.

26. BOLTON, J. 1986. Seaweed biogeography of the South African west coast - A temperature dependent perspective. *Bot. Mar.* **29**: 251-256.

REFERENCES continued on next page

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REFERENCES continued...

27. VON ERKOM SCHURINCK, C. and GRIFFITHS, C.L. 1990. Marine mussels of southern Africa - their distribution patterns, standing stocks, exploitation and culture. *J. Shellfish Res.* **9:** 75-85.

28. JACKSON, L.F. and McGIBBON, S. 1991. Human activities and factors affecting the distribution of macrobenthic fauna in Saldanha Bay. *Sth. Afr. J. aquat. Sci.* **17:** 89-102.

29. CHRISTIE, N.D. and MOLDAN, A. 1977. The distribution of benthic macrofauna in Langebaan Lagoon. *Trans. roy. Soc. S. Afr.* **42:** 273-284.

30. BALLY, R. 1983. Intertidal zonation of sandy beaches of the west coast of South Africa. *Cah. Biol. mar.* **24**: 85-103.

31. PUTTICK, G.M. 1977. Spatial and temporal variations in intertidal animal distribution at Langebaan Lagoon, South Africa. *Trans. roy. Soc. S. Afr.* **42:** 403-440.

32. BROOKE, R.K. 1984. South African red data book. Foundation for Research and Development *Report* No. **97**. Pretoria. 213 pp.

33. DAY, J.H. 1959. The biology of Langebaan Lagoon: A study of the effect of shelter from wave action. *Trans. roy. Soc. S. Afr.* **35:** 475-547.

34. DAY, J.H. 1981. Summaries of current knowledge of 43 estuaries in southern Africa. In: *Estuarine ecology with particular reference to southern Africa.* Day, J.H. (ed.). A.A. Balkema, Cape Town. p 251-329.

35. PILLAR, S.C. and HUTCHINGS, L. 1989. Chapter4. Plankton. In: *Oceans of Life*. Payne, A.I.L. & Crawford, R.J.M. (Eds). Vlaeberg Publishers, Cape Town. p. 28-40.

36. PEREYRA-LAQO, R. 1986. Zooplankton of East London coastal waters. In: East London Programme - Final report. Wooldridge, T. (Ed.) *ICR Report* No **7**: 90-98.

37. COETZEE, P.S., TREGONING, C. and DAVIDSON, I. 1986. Ecological monitoring of rocky shore intertidal organisms in the East London area: the effect of sewage and industrial effluent. In: East London Programme - Final Report. Wooldridge, T. (Ed.) *ICR Report* No **7**: 148-215.

38. TARR, R.J.Q. Abalone. In: *Oceans of Life*. Payne, A.I.L. and Crawford, R.J.M. (Eds). Vlaeberg Publishers, Cape Town. p. 62-69.

39. CARTER, R.A. and SCHLYER, M. H. 1988. Plankton distributions in Natal coastal waters. In: *Coastal Ocean Studies off Natal*. E.K. Schumann (Ed). Springer - Verlag. p. 152 - 177

REFERENCES continued on next page

REFERENCES continued...

40. McCLURG, T.P. 1988. Benthos of the Natal continental shelf. In : *Coastal Ocean Studies off Natal*. E.K. Schumann (Ed). Springer - Verlag. p. 178 - 208

41. CRAWFORD, R.J.M., L.V. SHANNON and POLLOCK, D.E. 1987). The Benguela Ecosystem. Part IV. The major fish and invertebrate resources. *Oceanogr. Mar. Biol. Ann. Rev.,* **25**: 353-505.

42. HOCKEY, P.A.R. 1983. The distribution, population size, movements and conservation of the African Black Oystercatcher. *Biol. Conserv.* **25**: 233-262.

43. BOSMAN, A.L., DU TOIT, J.T., HOCKEY, P.A.R. and BRANCH, G.M. 1986. A field experiment demonstrating the influence of sea bird guano on intertidal primary production. *Estuar. coast. Shelf Sci.* **23**: 283-294.

44. BERRUTI, A. 1989. Resident sea birds. In: *Oceans of Life*. Payne, A.l.L. and Crawford, R.J.M. (Eds). Vlaeberg Publishers, Cape Town. p. 257-273.

45. SUMMERS, R.W. 1977. Distribution, abundance and energy relationships of waders (Aves: Charadrii) at Langebaan Lagoon. *Trans. roy. Soc. S. Afr.* **42:** 483-494.

46 VAN DER ELST, R. 1988. Shelf Ichthyofauna of Natal. In : *Coastal Ocean Studies off Natal*. E.K. Schumann (Ed). Springer - Verlag : 209-225.

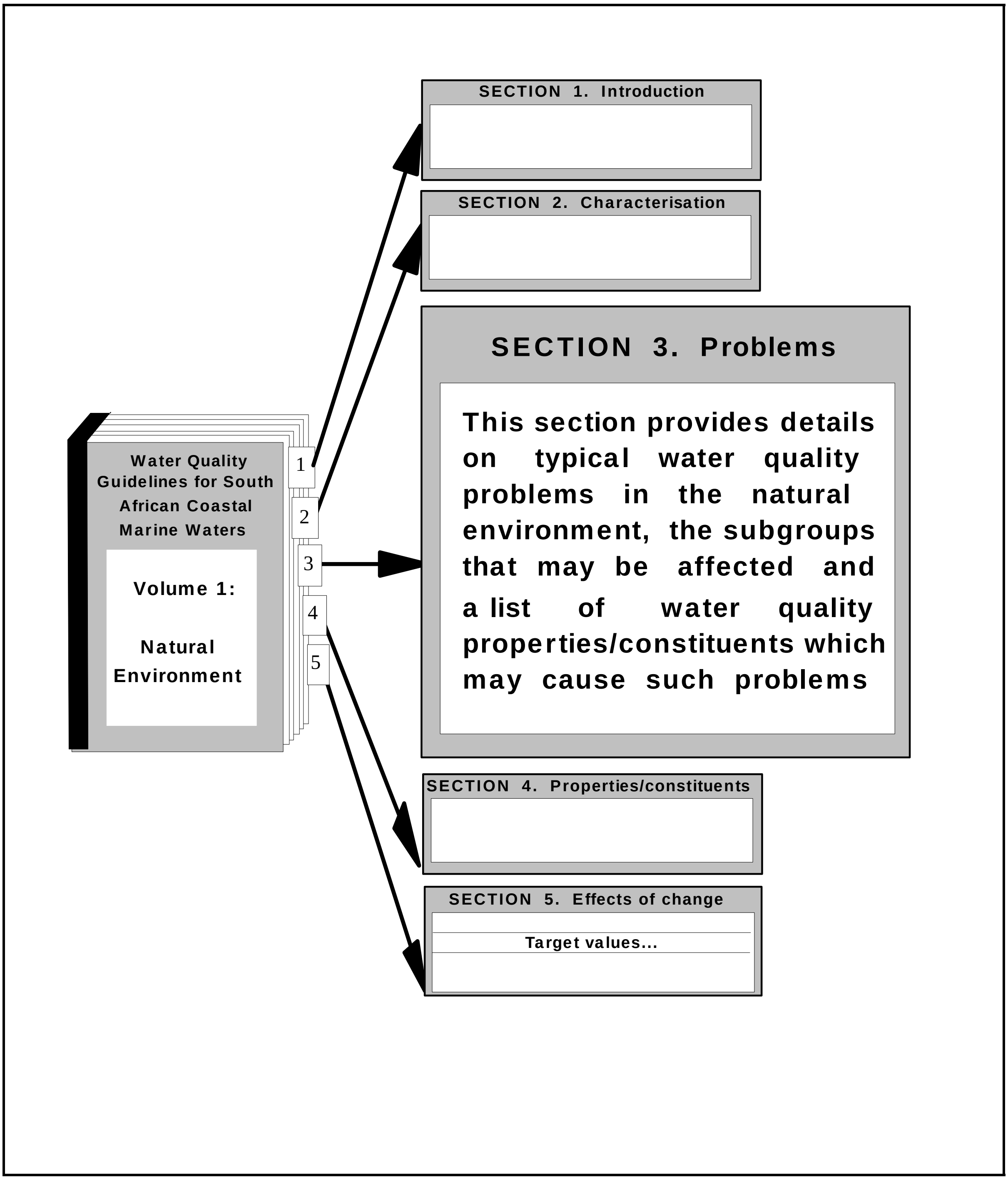
47. PROSCH, R.M, HULLEY, P.A. and CRUICKSHANK, R.A. 1989. Mesopelagic fish and some other forage species. In: *Ocean of life of southern Africa*. Payne, A.I.L. and Crawford, R.J.M. (eds.) Vlaeberg Publishers, Cape Town. p. 130-135.

48. KENSLEY, B.F. 1981. On the Zoogeography of southern African Decapod Crustacea, with a distributional checklist of the species. *Smithsonian Contributions to Zoology* No **338**. Smithsonian Institution Press , Washington. 64pp.

49. SMITH, M.M. 1980. Marine fishes of Maputaland. In : *Studies on the Ecology of Maputaland*. M.N. Bruton and K.H. Cooper (Eds). Rhodes University, Grahamstown. p. 164 -187.

50. PENNY, A.J., BEXTON, C.D., GARRATT, P.A. and SMALE, M.J. 1989. The commercial marine line fishery. In : *Oceans of life off southern Africa*. Payne A.I.L. and Crawford, R.J.M. (Eds). Vlaeberg Publishers, Cape Town. p. 214 - 229.

SECTION 3: TYPICAL WATER QUALITY PROBLEMS RELATED TO THE NATURAL ENVIRONMENT



SECTION 3: PROBLEMS
CONTENTS

NOTE: **For the purpose of this document, it will be assumed that, generally, changes in community structures and the invasion of alien species into a particular area could be classified as *secondary effects* to the problems which are *direct*ly *linked* to changes in water quality properties/constituents (problems described in this section) and will therefore not be discussed separately.**

Example: A particular organism may be sensitive to a high trace metal concentration resulting , for example, in lowered reproduction (direct problem). In turn, another organism in the community or even an alien species, which is less sensitive to high trace metal concentrations, may reproduce normally and thus increase its biomass relative to the former and in this way change the community structure (secondary effect).

Chapter 3.1 Abnormal Growth Stimulation

EUTROPHICATION

Description

Eutrophication refers to the occurrence of excessive algal or macrophyte growth. On decay, the algal matter may subsequently result in a marked decreased in dissolved oxygen levels which, in turn, may cause mortality in other marine organisms. Large amounts of algae or macrophytes may also increase suspended solids or levels of floating matter in the water which, in turn, may result in smothering of benthic communities or clogging of gills.

Related subgroups

Although eutrophication is directly associated with *primary producers*, the secondary effects, e.g. excessive suspended or floating matter and a reduction in dissolved oxygen levels, may have detrimental effects on both *primary consumers* and *secondary consumers*.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

Eutrophication is usually the result of abnormal input of *dissolved inorganic nutrients*, while its secondary effects, e.g. excessive algal matter and oxygen depletion will be reflected in water quality properties such as floating matter, suspended solids and dissolved oxygen levels.

For more information on the properties/ constituents refer to Section 4

Those for which more detailed information, e.g. concentration ranges, is provided in **Section 5** include:

Refer to Section 5:

- *Nitrate* p 5-39
- *Reactive phosphate*. P 5-41

Chapter 3.2 Biological Health

GENERAL GROWTH DEFICIENCIES

Description

Growth deficiencies generally refer to an inhibition of or abnormalities in growth in marine organisms, either linked to a particular life stage or otherwise throughout their life cycles.

Related subgroups

Growth deficiencies may occur in all three subgroups of the natural environment, i.e. *primary producers, primary consumers and secondary consumers*.

For more information on the subgroups refer to Section 2

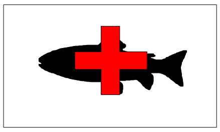
Related properties/ constituents and effects of change in water quality

A large variety of water quality properties/constituents may cause growth deficiencies. Those for which more detailed information, e.g. concentration ranges, is provided in **Section 5** include:

For more information on the properties/ constituents refer to Section 4

Refer to Section 5:

- *Temperature* — p 5-1
- *Salinity* — p 5-14
- *pH* — p 5-20
- *Floating matter* — p 5-24
- *Suspended solids* — p 5-25
- *Colour/turbidity/clarity* — p 5-28
- *Dissolved oxygen* — p 5-30
- *Nitrite* — p 5-36
- *Nitrate* — p 5-39
- *Ammonia* — p 5-43
- *Cyanide* — p 5-47
- *Chlorine* — p 5-50
- *Hydrogen sulphide* — p 5-54
- *Trace metals (As, Cd, Cu, Pb, Hg, Sn, Zn)* — p 5-56
- *Tributyltin* — p 5-87
- *Total petroleum hydrocarbons*. — p 5-92



LOWERED REPRODUCTION

Description

Lowered reproduction generally refers to a reduction in reproduction potential of an organism through inhibition of gamete production or egg producing capacity.

Related subgroups

Lowered reproduction may occur in all three subgroups of the natural environment, i.e. *primary producers, primary consumers and secondary consumers*.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

A large variety of water quality properties/constituents may cause lowered reproduction when present in abnormally high or low concentrations. Those for which more detailed information, e.g. concentration ranges, are provided in **Section 5** include:

For more information on the properties/ constituents refer to Section 4

Refer to Section 5:

- *Temperature* — p 5-4
- *Salinity* — p 5-17
- *Dissolved oxygen* — p 5-31
- *Cyanide* — p 5-48
- *Chlorine* — p 5-51
- *Trace metals (As, Cd, Cu, Pb, Zn)* — p 5-56
- *Tributyltin*. — p 5-87

CHANGES IN FEEDING HABITS

Description	Changes in feeding habits may occur through total inhibition of feeding or a reduction in the normal feeding rate of an organism.
Related subgroups	Changes in feeding habits generally occur in marine animals, i.e. the *primary consumers* and *secondary consumers,* in the natural environment.
Related properties/ constituents and effects of change in water quality	A number of water quality properties/constituents may cause changes in feeding habits when in abnormally high and/or low concentrations. Those for which more detailed information, e.g. concentration ranges, is provided in **Section 5** include: - *Temperature* - *Dissolved oxygen.*

For more information on the subgroups refer to Section 2

For more information on the properties/ constituents refer to Section 4

Refer to Section 5:

p 5-4

p 5-31

CHANGES IN RESPIRATION PATTERNS

Description

This problem refers to physiological stresses reflected in the respiration rate of marine organisms.

Related subgroups

Changes in respiration patterns may occur in marine animals, i.e. the *primary consumers* and *secondary consumers,* in the natural environment. *Primary producers* also respire, but not much information is available.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

A number of water quality properties/constituents may cause changes in feeding habits when in abnormally high and/or low concentrations. Those for which more detailed information, e.g. concentration ranges, is provided in **Section 5** include:

For more information on the properties/ constituents refer to Section 4

Refer to Section 5:

- *Temperature* — p 5-8
- *pH* — p 5-23
- *Dissolved oxygen* — p 5-31
- *Trace metals (As, Cd, Cu, Hg, Ag, Zn).* — p 5-57

CHANGES IN WATER PUMPING RATES (VALVE CLOSURES)

Description

This problem refers to a change in the rate at which organisms, usually bivalves, pump water for feeding purposes. In severe cases, the valves could close off completely.

Related subgroups

Changes in water pumping rates are usually associated with filter feeding organisms or bivalves which form part of the *primary consumers* in the natural environment. Pumping rates in filter feeders affect feeding and respiration and vice versa.

For more information on the subgroups refer to Section 2

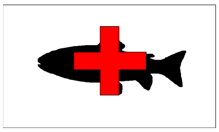
Related properties/ constituents and effects of change in water quality

A number of water quality properties/constituents may cause changes in water pumping rates when in abnormally high and/or low concentrations. Those for which more detailed information, e.g. concentration ranges, is provided in **Section 5** include:

- *Salinity* — p 5-15
- *pH* — p 5-21
- *Chlorine* — p 5-51
- *Trace metals (Cd, Cu, Zn).* — p 5-60

For more information on the properties/constituents refer to Section 4

Refer to Section 5:



CHANGES IN MOULTING PATTERNS

Description

Under stressed conditions the inter moulting period in certain marine organisms, like lobsters, may change with detrimental effects.

Related subgroups

This problem is usually associated with marine animals that moult, such as lobsters. These organisms generally form part of the *secondary consumers* in the natural environment.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

A number of water quality properties/constituents may cause changes in moulting patterns when in abnormally high and/or low concentrations. Those for which more detailed information, e.g. concentration ranges, is provided in **Section 5** include:

For more information on the properties/ constituents refer to Section 4

Refer to Section 5:

- *Salinity* p 5-17
- *Dissolved oxygen.* p 5-31

SHELL DEFORMATION

Description

This problem refers to abnormal shell deposition rates or a reduction in shell formation, e.g. to thin or to brittle, leading to a reduction in the survival rate of organisms.

Related subgroups

This problem is usually associated with marine mollusca and crustaceans, but can also affect egg-laying vertebrates such as birds. These organisms form part of the *primary consumers* and *secondary consumers* in the natural environment.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

Shell deformation may occur when water quality constituents necessary for shell formation are lacking or when substances are present which adversely affect shell formation. Those properties/constituents for which more detailed information e.g. concentration ranges, is provided in **Section 5** include:

For more information on the properties/ constituents refer to Section 4

- *pH*
- *Tributyltin.*

Refer to Section 5:

p 5-21

p 5-88

FORMATION OF AIR BLISTERS CAUSING FLOTATION

Description

This problem refers to the formation of air blisters as a result of super saturation, mainly in marine organisms, subsequently resulting in flotation.

Related subgroups

This problem generally occurs with bivalves which form part of the *primary consumers* in the natural environment.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

This problem is usually associated with super saturation conditions and is therefore reflected in dissolved oxygen concentrations. More detailed information on concentration ranges is provided in **Section 5** :

- *Dissolved oxygen.*

For more information on the properties/ constituents refer to Section 4

Refer to Section 5:

p 5-31

MORTALITIES

Description

This problem refers to the mortality or mass mortality of marine organisms over a relatively short period of time due to abnormal environmental conditions or the presence of certain water quality constituents at lethal concentrations.

Related subgroups

Mortalities may occur in all three subgroups of the natural environment, i.e. *primary producers, primary consumers and secondary consumers*.

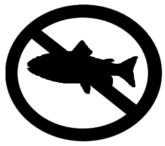
For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

A large variety of water quality properties/constituents may cause mortality in marine organisms. Those for which more detailed information, e.g. concentration ranges, is provided in **Section 5** include:

For more information on the properties/ constituents refer to Section 4

	Refer to Section 5:
- *Temperature*	p 5-1
- *Salinity*	p 5-14
- *pH*	p 5-20
- *Floating matter*	p 5-24
- *Suspended solids*	p 5-25
- *Colour/turbidity/clarity*	p 5-28
- *Dissolved oxygen*	p 5-30
- *Nitrite*	p 5-36
- *Nitrate*	p 5-39
- *Ammonia*	p 5-43
- *Cyanide*	p 5-47
- *Chlorine*	p 5-50
- *Hydrogen sulphide*	p 5-54
- *Trace metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn)*	p 5-56
- *Tributyltin*	p 5-87
- *Total petroleum hydrocarbons*	p 5-92



Chapter 3.3 External Behaviour Responses

ABNORMALITIES IN MOVEMENT

Description

This problem refers to stressed conditions which are reflected in the movement patterns of marine organisms. These include their swimming speeds.

Related subgroups

This problem is generally associated with marine animals which form part of the *primary consumers* and *secondary consumers* in the natural environment. In severe cases, large numbers of lobsters have been found to 'walk out' of the sea, usually due to low oxygen concentrations.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

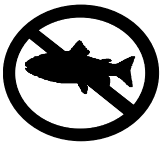
The influence of water quality properties/constituents on external behavioural changes, such as movement patterns, are not well-documented. Those for which more detailed information e.g. concentration ranges, are provided in **Section 5** include:

- *Dissolved oxygen*
- *Cyanide*
- *Chlorine*
- *Tributyltin.*

For more information on the properties/ constituents refer to Section 4

Refer to Section 5:

p 5-30
p 5-48
p 5-54
p 5-88



BURROWING ABNORMALITIES

Description

This problem generally refers to instances where stressed conditions cause burrowing to cease in certain organisms living in the intertidal zones on sandy beaches.

Related subgroups

This problem is generally associated with mollusca present along the intertidal zone of sandy beaches . These may form part of the *primary consumers* or *secondary consumers* in the natural environment.

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

Certain trace metals have been found to affect this activity in mollusca. More detailed information e.g. concentration ranges, is provided in **Section 5** and includes:

- *Trace metals (Cd, Cu, Hg, Zn).*

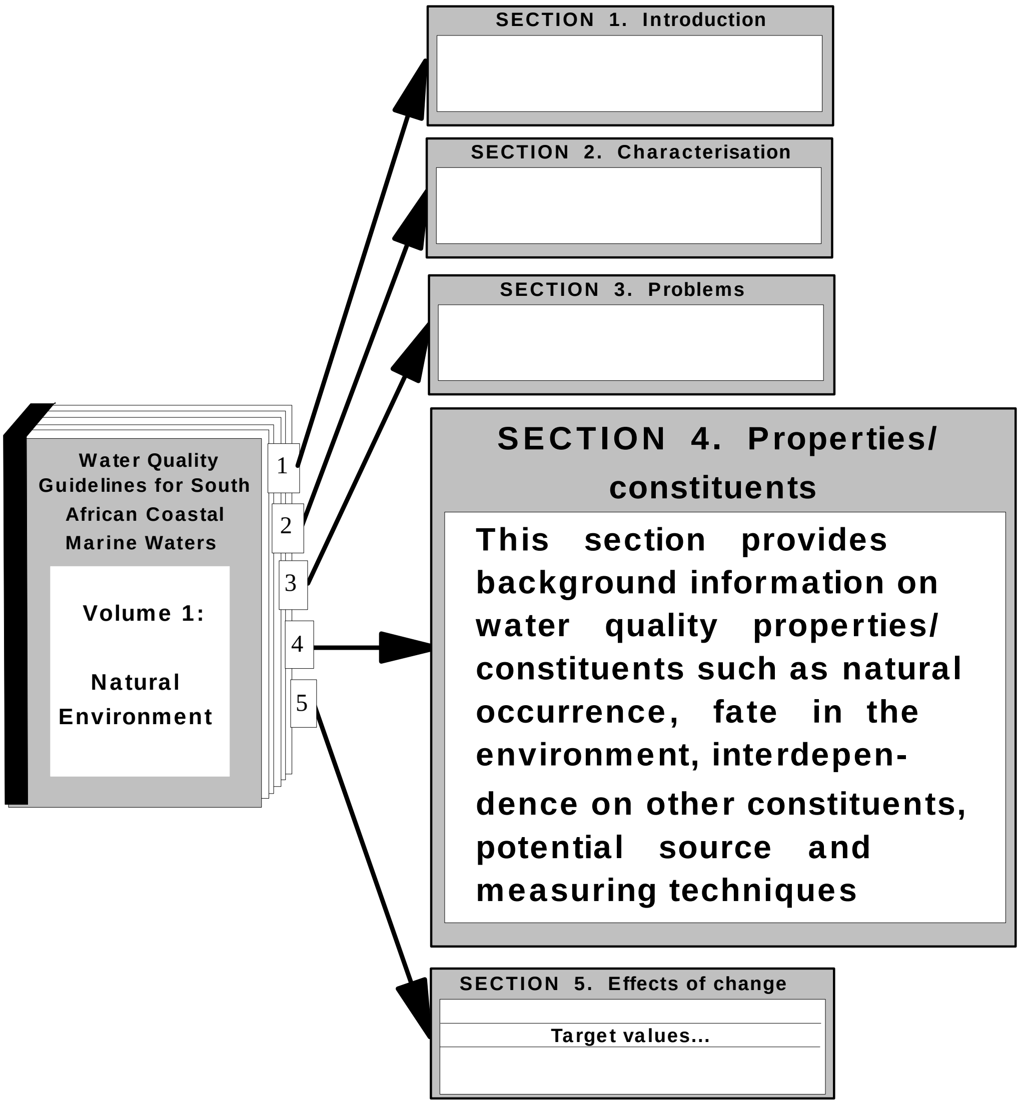
For more information on the properties/ constituents refer to

Section 4

Refer to Section 5:

p 5-60

SECTION 4: BACKGROUND INFORMATION ON WATER QUALITY PROPERTIES/ CONSTITUENTS RELATED TO THE NATURAL ENVIRONMENT



SECTION 4: BACKGROUND INFORMATION ON WATER QUALITY PROPERTIES/CONSITUENTS
CONTENTS

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CONTENTS continued...

Chapter 4.1 Physico-chemical Properties

TEMPERATURE

Description

Temperature is a basic property of water. Temperature, or changes in temperature, is important in the regulation or triggering of many physiological processes in marine organisms.

Natural occurrence

The temperature regime for South African marine waters differs from one coastal region to another:

West coast. Generally, the natural temperature regime along the west coast is largely influenced by wind-induced upwelling (south-easterly and southerly winds) which varies seasonally. Seasonality is strongest in the south where south-easterly winds are rare in winter but common in summer. Seasonality diminishes to the north-west where the wind generally comes from the south throughout the year, although velocities are lower in winter [1,2]. Temperatures of the upwelled waters range from 9 °C - 14 °C, depending upon the 'strength' of the upwelling process [1]. These temperatures can increase to 16 °C and higher through sun warming after being upwelled [4]. The mixed water is bound by an oceanic front which lies at or slightly offshore of the shelf break [5]. Temperatures of oceanic water in the area are about 20 °C [1].

South coast. Surface temperatures over most of the south coast are usually between 20-21 °C during summer and 16-17° C during winter. During summer, thermoclines are formed by the sun heating the surface water, while during winter months the water column is generally well mixed. Upwelling may also influence the temperature regime in the coastal zone, albeit not on the same scale as along the west coast [7].

East coast. The waters of the east coast are of tropical origin with a maximum of 25 EC occurring in February in inshore waters. The difference between summer and winter averages 4 EC with a generally well mixed regime. Further offshore, there is also a 4 EC change between summer and winter in the upper 50 m with summer maxima greater than 26 EC. At lower depths, seasonal variation is apparently not evident. However, short-term fluctuations in surface waters may be as high as 8-9 EC, often exceeding seasonal variations. There is evidence of localised upwelling on the inner shore along various areas of the coastline [8].

Although this section gives an indication of the temperature ranges found within the different coastal regions, detailed temperature regimes are very site specific. Detailed temperature data sets for a large selection of sites along the South African coast can be obtained form the South African Data Centre for Oceanography (SADCO), CSIR, Stellenbosch.

TEMPERATURE continued on next page

TEMPERATURE continued...

Fate in environment

Not relevant to temperature.

Interdependence on other constituents

Generally, temperature is not interdependent on any other water quality properties or constituents.

Measurement in seawater

For marine waters, temperature is usually measured *in situ*, using a Conductivity-Temperature-Depth-Salinity (CTDS) meter. An ordinary thermometer can also be used.

Units: °C.

Pollution sources

Anthropogenic sources which may influence water temperature in the marine environment are usually related to the discharge of cooling water from power stations and certain industries [9].

Related problems

Typical water quality problems which may be associated with temperature include:

	For more details on problems refer to:
- eutrophication;	p 3-1
- general growth deficiencies;	p 3-3
- lowered reproduction;	p 3-4
- changes in feeding habits;	p 3-5
- changes in respiration patterns.	p 3-6

Effects of change and target values

Factual information on the effect of different temperature ranges on the natural environment, as well as target values, are provided in Section 5 for:

	Refer to:
- primary producers;	p 5-1
- primary consumers;	p 5-4
- secondary consumers.	p 5-8

Sal

SALINITY

Description

Salinity refers to the dissolved salt content in seawater. Typically, the major constituents in 1 kg of average seawater with a salinity of $35x10^{-3}$ are [11]:

Na^{+}	-	10,78 *g*
Mg^{2+}	-	1,28 *g*
Ca^{2+}	-	0,41 *g*
K^{+}	-	0,40 *g*
Sr^{2+}	-	0,01 *g*
Cl^{-}	-	19,35 *g*
SO_4^{2-}	-	2,71 *g*
HCO_3^{-}	-	0,11 *g*
Br^{-}	-	0,07 *g*
CO_3^{-}	-	0,01 *g*
$B(OH)_4^{-}$	-	0,001 *g*
$B(OH)_3^{-}$	-	0,02 *g*.

Natural occurrence

The salinity regime for South African marine waters differs from one coastal region to another:

West coast. Salinities fall in the narrow range of $34,7x10^{-3}$ to $35,4x10^{3}$; the lower salinities being associated with cold upwelling water [1]. Land run-off is low and intermittent and thus dilution of these salinities only occurs in very localised areas, e.g. the Berg River mouth and the smaller estuaries further south. Due to evaporative loss, salinities as high as $37,0x10^{-3}$ have been recorded in Langebaan lagoon [12].

South coast. Salinities measured in coastal water of the south coast have revealed slight seasonal variations with highest salinities in summer ($35,4x10^{-3}$) and lowest values in winter ($35,0x10^{-3}$) [13].

East coast. Subtropical surface waters are usually characterised by relatively high salinities (>$35x10^{-3}$) caused by greater evaporation rates. However, input of fresh water from large rivers to the north (Zambezi and Limpopo) as well as input from east coast rivers result in slightly reduced summer salinities. There is generally a slight positive salinity gradient from the shoreline to the core of the Agulhas Current [8].

Fate in environment

Not relevant to salinity.

SALINITY continued on next page

Sal

SALINITY continued...

Interdependence on other constituents

Generally, salinity is not interdependent on other water quality properties or constituents.

Measurement in seawater

In marine waters, salinity is usually measured *in situ*, using a Conductivity-Temperature-Depth-Salinity (CTDS) meter.

According to *The International System of Units (SI) in Oceanography* salinity's unit is dimensionless, being the ratios between two electrical conductivities.

The practical salinity of a sample of seawater is defined in terms of the conductivity ratio, K_{15}, which is defined by [14]:

$$\frac{\text{conductivity of seawater sample}}{\text{conductivity of standard KCl solution}}$$

at 15 °C, 1 atm pressure and the standard KCl solution being 32,4356 g kg^{-1}

Where the ionic strength ('salt content') of seawater has been measured as Electrical Conductivity (EC), mS m^{-1}, conversion factors can be used. Conversion factors from EC to salinity in the range 32x10^{-3}-36x10^{-3}, at different temperatures are [16]:

ELECTRICAL CONDUCTIVITY (mS m^{-1})	**TEMPERATURE (°C)**			
	25	**20**	**15**	**10**
5 437,4	6,62			
5 302,5	6,60			
5 167,1	6,58			
5 031,4	6,56			
4 895,1	6,54			
4 910,5		7,33		
4 788,2		7,31		
4 665,6		7,29		
4 542,6		7,26		
4 419,2		7,24		
4 399,6			8,18	
4 289,6			8,16	
4 179,4			8,13	
4 068,8			8,11	
3 957,9			8,08	
3 906,1				9,22
3 808,0				9,19
3 709,6				9,16
3 611,0				9,14
3 512,2				9,11

Conversion:

$$\text{Salinity x}10^{-3} = \frac{\text{EC (mS m}^{-1}\text{) x factor}}{1\,000}$$

SALINITY continued on next page

SALINITY continued...

Measurement *continued...*

Where the salt content has been measured as mg l^{-1} Total Dissolved Solids (TDS), it can be converted to salinity by dividing the TDS value by 1 000.

Pollution sources

Anthropogenic influences on salinity in the marine environment are usually related to waste discharges (fresh water) which, depending on the volume discharged, may result in a short-term decrease in salinity in the immediate vicinity of the discharge.

Related problems

Typical water quality problems which may be associated with salinity include:

- general growth deficiencies;
- lowered reproduction;
- changes in water pumping rates;
- changes in moulting patterns;
- mortalities.

For more details on problems refer to:

p 3-3
p 3-4
p 3-7
p 3-8
p 3-11

Effects of change and target values

Factual information on the effect of different temperature ranges on the natural environment, as well as target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-14
p 5-15
p 5-17

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pH

Description

pH is a measure of the concentration of hydrogen ions in solution, according to the expression:

pH = $-\log_{10}[H^+]$, where H^+ is the hydrogen ion concentration.

At a pH of less than 7 water is acidic, while at a pH of greater than 7 water is alkaline.

Natural occurrence

The pH of seawater usually ranges between 7,9 and 8,2 [(15)].

Seawater in equilibrium with atmospheric CO_2 is slightly alkaline, with a pH of about 8,1-8,3. The pH may rise slightly through the rapid abstraction of CO_2 from surface waters during photosynthesis [(14)].

Decomposition of organic matter under anaerobic (anoxic) conditions involves the reduction of CO_2 itself, and leads to the formation of hydrocarbons, such as methane. Under these conditions, the pH may rise to a value as high as 12 [(14)].

Fate in environment

Aqueous solutions containing salts of weak acids or bases, such as seawater, show a resistance to pH change (known as buffering), on the addition of acids and bases [(16)].

Interdependence on other constituents

The pH of seawater can be influenced by certain gases which are soluble in seawater, such as carbon dioxide, ammonia (unionised) and hydrogen sulphide.

For example, carbon dioxide can be abstracted from seawater during phytoplankton blooms thereby causing an increase in pH.

(In seawater CO_2 [gas] + H_2O W H_2CO_3 W $H^+ + HCO_3^-$ W $2H^+ + CO_3^{2-}$)

In seawater remote from contaminated or anoxic regions, the pH is mainly controlled by the $CO_2/HCO_3^-/CO_3^{2-}$ system. Other weak electrolytes slightly augment this effect (e.g. borate, phosphate, silicate and arsenate) [(16)].

pH continued on next page

Measurement in seawater

pH is measured using a pH meter.

The pH of seawater cannot be measured against the low ionic strength National Bureau of Standards (USA) buffers. Seawater has a high ionic strength resulting in significant errors in measurements. Artificial seawater buffers should be used [10].

Pollution sources

Anthropogenic sources which may influence the pH of water are usually related to highly acidic or alkaline industrial waste waters.

Related problems

Typical water quality problems which may be associated with pH include:

- general growth deficiencies;
- changes in respiration patterns;
- changes in water pumping rates;
- shell deformation;
- mortalities.

For more details on problems refer to:

p 3-3
p 3-6
p 3-7
p 3-9
p 3-11

Effects of change and target values

Factual information on the effect of different pH ranges on the natural environment, as well as target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-20
p 5-21
p 5-23

FLOATING MATTER

Description

Floating matter refers to debris, oil, grease, wax, scum, foam, submerged (just below water surface) objects or any other visible substances.

Natural occurrence

Naturally occurring floating matter is usually limited to macrophytes and algae.

Fate in environment

Objectionable floating matter may end up on beaches or in sheltered areas where it becomes an aesthetic problem. It may also result in smothering or physical injury to marine life, e.g. benthic communities, sea birds and seals.

Interdependence on other constituents

Not relevant to floating matter.

Measurement in seawater

Floating matter is not usually measured quantitatively in the marine waters, but is rather 'measured ' in terms of a qualitative description.

Pollution sources

Anthrophogenic source of objectionable floating matter include:

- raw sewage (municipal waste);
- stormwater run-off (litter and debris);
- accidental oil spills (oil and grease);
- paper and pulp waste water (foaming);
- illegal dumping of ship refuse.

Related problems

Typical water quality problems which may be associated with the presence of objectionable floating matter include:

For more details on problems refer to:

- general growth deficiencies; p 3-3
- mortalities. p 3-11

Effects of change and target values

Information on the effects of objectionable floating matter on the natural environment, as well as target values, are provided in Section 5 for:

Refer to:

- primary producers; p 5-24
- primary consumers; p 5-24
- secondary consumers. p 5-24

SS

SUSPENDED SOLIDS

Description

Suspended solids refer to particulate inorganic and organic matter that are in suspension in the water column. The presence of suspended solids is usually attributed to a reduction in the clarity of water, i.e. light penetration or visibility.

Natural occurrence

Naturally occurring suspended materials include finely divided organic and inorganic matter, plankton and other microscopic organisms. These are usually more evident during stormy conditions, plankton blooms and large river run-off.

Suspended solids may also be introduced to the water column through resuspension of natural debris during turbulent conditions, usually cause by strong wind and wave action.

Fate in environment

Suspended solids are usually kept in suspension in water since their density is similar to that of seawater and turbulence in the water column. Under calmer conditions, solids may settle out from the water column and be deposited onto the sediments.

Interdependence on other constituents

Information on the interdependence of suspended solids on other water quality constituents or properties could not be obtained.

Measurement in seawater

Suspended solids can be determined by collecting the suspended matter from a known volume of water (usually one litre) onto GF/C glass fibre filter paper [17].

Units: mg l^{-1}.

Pollution sources

Anthropogenic sources of suspended solids include:

- storm water run-off;
- sewage discharges;
- industrial waste.

SUSPENDED SOLIDS continued on next page

S S

SUSPENDED SOLIDS continued...

Related problems	Typical water quality problems which may be associated with suspended solids include:	For more details on problems refer to:
	- general growth deficiencies;	p 3-3
	- mortalities.	p 3-11
Effects of change and target values	Information on the effects of suspended solids on the natural environment, as well as target values, are provided in Section 5 for:	Refer to:
	- primary producers;	p 5-25
	- primary consumers;	p 5-26
	- secondary consumers.	p 5-27

COLOUR/TURBIDITY/CLARITY

Description

The turbidity, colour and clarity of water are properties which are usually strongly linked to one another. Turbidity is caused by colloidal suspensions (particle size between 0,001 µm and 0,1 µm) which usually give water a 'murky' appearance, while colour is caused by substances which dissolve in water, and as a result the colour of the water changes. Both turbidity and colour, together with suspended solids, influence the clarity of water, i.e. the depth of light penetration or visibility in water. A constituent which may affect these properties of water is gypsum (calcium sulphate with two waters of hydration [$CaSO_4.2H_2O$]), a waste product of fertilizer industries.

Natural occurrence

Natural turbidity in water is caused by colloidal suspension (particle size between 0,001 µm and 0,1 µm) of, for example, clays and silt, usually introduced through river run-off. Turbidity may also be introduced to the water column through re-suspension of natural debris during turbulent conditions, usually caused by strong wind and wave action. Natural colour in water may result from the presence of natural metallic ions and humic substances, usually introduced through river run-off.

In the natural environment, gypsum only starts to precipitate from seawater at a salinity of 117×10^{-3} (e.g. through evaporation) [55].

Fate in environment

Owing to the high salt content of seawater, natural colloidal suspension (causing turbidity) and humic substances (natural colour) usually coagulate with specific ions and precipitate out.

Interdependence on other constituents

Turbidity and colour may be influenced by the salinity of water (see *Fate in Environment*).

The solubility product (K_{sp}) of gypsum in seawater is a function of the ionic strength (I), the solubility product at zero ionic strength (K_{sp}^{o}) and a number of other factors [25,56]. For example, the solubility product and the solubility (in g l^{-1}) of gypsum at 25 °C for different salinities are:

Salinity	K_{sp}	Solubility (g l^{-1})*
20×10^{-3}	0,0009	5,3
25×10^{-3}	0,0011	5,8
30×10^{-3}	0,0013	6,2
35×10^{-3}	0,0014	6,6

***Solubility (g l^{-1}) = / K_{sp} multiplied by the molecular mass of gypsum (172,17) multiplied by the density of seawater at 25 °C (1,023)**

COLOUR/TURBIDITY/CLARITY continued on next page

COLOUR/TURBIDITY/CLARITY continued...

Measurement in seawater

Turbidity can be measured on a Turbidimeter (Nephelometer) [17].

Units: NTU (Nephelometric turbidity units)

'True colour', i.e. the colour in water caused by substances in solution, can be measured through visual comparison methods using the platinum cobalt method or a Lovibond comparator [17].

Units: Pt-Co mg l^{-1} (defined as the colour being produced by 1 mg Pt l^{-1} in the form of the chloroplatinate ion or Hazen unit .
(1 Hazen unit = 1 Pt-Co mg l^{-1})

The clarity of water (combined effect of colour, turbidity and suspended solids) can be measured by using a Secchi disc.

Units: metres below water surface.

Pollution sources

Anthropogenic sources of colour and/or turbidity include:

- industrial waste, e.g. paper and pulp and textile industries;
- raw sewage discharges;
- waste from fertilizer industries (gypsum).

Related problems

Typical water quality problems which may be associated with the presence of objectionable colour/turbidity/clarity include:

- general growth deficiencies;
- mortalities.

For more details on problems refer to:
p 3-3
p 3-11

Effects of change and target values

General effects of colour/turbidity/clarity on the natural environment, as well as target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:
p 5-28
p 5-28
p 5-29

DISSOLVED OXYGEN

Description

This property refers to the amount of dissolved oxygen present in the water. Dissolved oxygen is an essential requirement for most heterotrophic marine life.

Natural occurrence

Dissolved oxygen is a non-conservative property of seawater and its natural levels in surface waters are largely governed by local temperature/salinity regimes, as well as organic content.

Dissolved oxygen levels in seawater below the thermocline are usually lower, owing to biological demand and limited replenishment from the air.

The surface waters along high energy coastlines, such as those found along most parts of the South African coast, are usually saturated with oxygen.

Along the South African coast, low oxygen waters are a feature of the Benguela system. Chapman and Shannon [(18)] identified two local zones of formation of oxygen-deficient water along the west coast: one in the vicinity of the Orange River mouth and the other in St Helena Bay. Water from both these zones can advect southwards as compensation flow for the surface north-westerly drift [(2)]. This low-oxygen water rarely penetrates south of the Cape Peninsula, but the oxygen-depleted water that occasionally develops on the Agulhas Bank can impact this area [(18)].

Fate in environment

Generally, the distribution of dissolved oxygen in the oceans is the net result of [(11)]:

- near equilibrium of atmospheric oxygen in the surface mixed layer. Because dissolved oxygen is a gas, its solubility in seawater is dependent on salinity and temperature [(19)]. Therefore, in surface waters, the dissolved oxygen concentration in seawater is close to the expected values for temperature and salinity.

- biological production in subsurface waters due to photosynthesis [(11)].

DISSOLVED OXYGEN continued on next page

O_2

DISSOLVED OXYGEN continued...

Fate in environment *continued...*

- biological use of oxygen in respiration and oxidation of plant materials. Water low in oxygen is common off central Namibia, in inshore regions north of Hondeklip Bay and in St Helena Bay (related to the presence of anoxic sediments). These low-oxygen waters can often be unfavourable to less mobile marine organisms. The 'walk-outs' of crayfish at Elands Bay may be attributed to this feature [7,20].

- in deep waters, the dissolved oxygen increases are due to the sinking of cold water rich in oxygen [11].

Interdependence on other constituents

The dissolved oxygen of water is a non-conservative property. The solubility of oxygen in water is largely dependent on the salinity and temperature of the water.

Air solubility of oxygen (mg l^{-1}) in seawater for a range of salinities and temperatures are (1 atm pressure) [21]:

Temperature (°C)	Salinity			
	25×10^{-3}	30×10^{-3}	35×10^{-3}	40×10^{-3}
10	9,621	9,318	9,024	8,739
11	9,412	9,117	8,832	8,556
12	9,210	8,925	8,648	8,379
13	9,017	8,739	8,470	8,210
14	8,830	8,561	8,300	8,046
15	8,651	8,389	8,135	7,888
16	8,478	8,223	7,976	7,737
17	8,311	8,064	7,823	7,590
18	8.151	7,910	7,676	7,449
19	7,995	7,761	7,533	7,312
20	7,846	7,617	7,395	7,180
21	7,701	7,479	7,262	7,052
22	7,561	7,344	7,134	6,929
23	7,426	7,214	7,009	6,809
24	7,295	7,089	6,888	6,693
25	7,168	6,967	6,771	6,581
26	7,045	6,849	6,658	6,472
27	6,926	6,734	6,548	6,366
28	6,810	6,623	6,441	6,263
29	6,698	6,515	6,337	6,164
30	6,589	6,410	6,236	6,066

DISSOLVED OXYGEN continued on next page

DISSOLVED OXYGEN continued...

Measurement in seawater

Dissolved oxygen in natural waters is usually measured titrametrically according to the Winkler method [19].

Units: mg l^{-1} O_2.

Where O_2 concentrations are given as ml l^{-1}, it can be converted to mg^{-1}l , by multiplying with $\dfrac{1,4290}{\text{density of seawater at the specific temperature}}$

NOTES:	**Often the chemical characteristics of effluents are given in terms that are not necessarily identical to those properties or constituents used to describe the receiving water quality.** **For example, the oxygen demand of an effluent is normally expressed as:** **- five-day biochemical oxygen demand (BOD_5);** **- chemical oxygen demand (COD); or** **- oxygen absorbed (OA).** **These parameters all give an indication of the amount of oxygen which might be consumed by the effluent when it is discharged into a receiving water body .** **However, in the receiving water body, it is more important to measure the actual amount of oxygen in solution in the water, expressed as dissolved oxygen (DO) [22].**

Pollution sources

Anthropogenic sources which may influence the dissolved oxygen in marine waters are those with high oxygen demand (reflected in high organic content, high biochemical oxygen demand or chemical oxygen demand) including:

- stormwater run-off;
- sewage discharges;
- certain industrial wastes.

DISSOLVED OXYGEN continued on next page

O_2

DISSOLVED OXYGEN continued...

Related problems	Typical water quality problems which may be associated with dissolved oxygen include:	For more details on problems refer to:
	- general growth deficiencies;	p 3-3
	- lowered reproduction;	p 3-4
	- changes in feeding habits;	p 3-5
	- changes in respiration patterns;	p 3-6
	- changes in moulting patterns;	p 3-8
	- formation of air blisters;	p 3-10
	- mortalities;	p 3-11
	- abnormalities in movement.	p 3-13
Effects of change and target values	Factual information on the effect of different dissolved oxygen ranges on the natural environment, as well as target values, are provided in Section 5 for:	Refer to:
	- primary consumers;	p 5-30
	- secondary consumers.	p 5-31

Chapter 4.2 Nutrients

AMMONIUM (also AMMONIA)

Description

In aqueous solution ammonia is present in two forms, ionised (NH_4^+) and un-ionised (NH_3).

$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$.

NH_3 is regarded as the toxic form of ammonia because it is uncharged and lipid soluble, whereas hydrated ammonium ions (NH_4^+) are non-toxic and a nutrient to primary producers. The permeability of plasma membranes to charged particles, such as ammonium ions, is relatively low [(30)].

Natural occurrence

In oxygenated unpolluted seawater samples, the amounts of NH_4^+-N and NO_3-N rarely exceed 70 µg N l^{-1}, but in deep anoxic stagnant water, such as in the Black Sea, the amount of NH_4^+ -N can be as high as 2 100 µg l^{-1} [(23)].

The concentration of ammonia in the seawater shows considerable variations and can change rapidly. The ionic state is highly dependent on pH, temperature and salinity (refer to *Interdependence on other constituents*, p 4-19).

Ammonia is excreted directly by animals together with urea and peptides [(23)].

Fate in environment

Ammonia is often the most abundant form of inorganic nitrogen in the surface layers after a period of productivity when the phytoplankton blooms have removed the greater part of nitrate and phosphate. In the assimilation processes of phytoplankton, ammonium is preferentially used for synthesising protein. When nitrate is incorporated it must first be reduced to ammonia before it can be transferred into amino acid compounds [(23)].

Soluble and particulate organic nitrogen compounds resulting from decaying organisms together with those excreted by plants and animals are rapidly broken down to NH_3 by various species of proteolytic bacteria [(23)].

AMMONIUM continued on next page

NH_4^+

AMMONIUM continued...

Fate in environment *continued...*

When organisms sink below the euphotic zone, they decompose as a result of oxidative bacterial action releasing nitrate and phosphate. As the water approaches anoxic conditions, bacteria utilise the nitrate ions to continue the oxidation process. This denitrification leads to the production of molecular nitrogen and ammonium. Interaction between nitrate and ammonia produces more nitrogen gas. At the onset of sulphate reduction, ammonia and hydrogen sulphide are often produced in high concentrations[23].

Ammonia-nitrogen is the dominant form of combined inorganic nitrogen when anoxic conditions have developed to the stage when all the nitrate-nitrogen has been reduced, and if the system becomes anoxic, the concentration of ammonia-nitrogen can become high. Dead or senescent algal cells will autolyse, and this effect coupled with bacterial action will release ammonia-nitrogen, a large proportion of the organic nitrogen originally bound in particulate form. For aquatic animals, ammonia-nitrogen is usually the main soluble form. Utilisation of proteinaceous organic matter by bacteria in the sea as a source of energy probably causes some liberation of ammonia-nitrogen as a result of oxidation-deamination reactions [(53)].

Under anoxic conditions, the following reactions may occur, i.e. denitrification, commonly defined as the biochemical reduction of NO_3^- or NO_2^- to N_2 or gaseous nitrogen oxides.

NO_3^- **6** NO_2^- **6** NO **6** N_2O **6** N_2 or NO_3^- **6** NO_2^- **6** NH_4^+.

Nitrification is defined as the biological oxidation of ammonium to nitrate with nitrite as an intermediate in the reaction sequence. Through these abovementioned processes, ammonia can either be added or removed from seawater due to the presence of certain bacteria [(31)].

AMMONIUM continued on next page

AMMONIUM continued...

Interdependence on other constituents

The relative proportions of NH_3 and NH_4^+ in solutions depend chiefly on temperature and pH and, to a lesser extent, on salinity. Concentrations of NH_3 increase with elevated temperatures and pH values, and decrease with higher salinities (30).

PERCENT UNIONISED AMMONIA (NH_3) IN SEAWATER (S = $32x10^{-3}$-$40x10^{-3}$) AT DIFFERENT TEMPERATURES AND pHs AT 1 ATMPRESSURE

Temp	pH			
EC	7,5	8,0	8.5	9,0
10	0,459	1,44	4,41	12,6
15	0,665	2,07	6,28	17,6
20	0,963	2,98	8.87	23,6
25	1,39	4,28	12.4	30,9

At salinities common in seawater ($32x10^{-3}$-$40x10^{-3}$) there is up to one fifth less unionised ammonia (NH_3) than in fresh water at the same temperature and pH.

Measurement in seawater

Total ammonia (NH_4 + NH_3) can be determined photometrically in seawater (19).

Units: µg l^{-1} (NH_4^+ + NH_3) -N or µmol l^{-1} (NH_4^+ + NH_3) -N (the latter can be converted to µg l^{-1} [NH_4^++ NH_3]-N by multiplying with the atomic mass of N, i.e. 14).

Pollution sources

Anthropogenic sources of ammonia include (9):

- sewage discharges;
- run-off from agricultural areas, especially where fertilizers are applied;
- septic tank seepage.

AMMONIA continued on next page

NH_4^+

AMMONIA continued...

Related problems	Typical water quality problems which may be associated with the presence of ammonia/ammonium include:	For more details on problems refer to:
	- eutrophication (NH_4^+)	p 3-1
	- general growth deficiencies (NH_3);	p 3-3
	- mortalities (NH_3).	p 3-11
Effects of change and target values	General effects of different ranges of ammonium/ammonia on the natural environment, as well as target values, are provided in Section 5 for:	Refer to:
	- primary producers;	p 5-35
	- primary consumers;	p 5-43
	- secondary consumers.	p 5-44

NO_2

NITRITE

Description

Nitrite occurs in seawater as an intermediate compound in the microbial reduction of nitrate or in the oxidation of ammonia [23]:

NO_3^- **6** NO_2^- **6** NO **6** N_2O **6** N_2 or NO_3^- **6** NO_2^- **6** NH_4^+.

Natural occurrence

Limited information is available on the natural occurrence of nitrite along the South African coast. The following mean nitrite concentrations (NO_2^--N) have been reported for South African coastal waters [24]:

WEST COAST	SOUTH COAST	EAST COAST
4,2 µg l^{-1}	2,8 µg l^{-1}	No data could be obtained

Fate in environment

Nitrite may be excreted by phytoplankton, especially during periods of luxury feeding, i.e. when a surplus of nitrate and phosphate stimulates a heavy bloom of plankton [23].

The natural level of nitrite in seawater is usually very low, but in transition zones, where oxic conditions change to anoxic ones, thin layers of high nitrite concentrations may occur together with rather low levels of dissolved oxygen [23]. In upwelling areas, elevated nitrite values indicate high activity of the primary producers [23].

The natural level of nitrite in seawater is less than 1,4 µg l^{-1} NO_2^--N. In anoxic zones with low levels of oxygen (less than 0,15 ml l^{-1}), nitrite concentrations in excess of 28 µg l^{-1} NO_2^--N have been measured. Under upwelling conditions, levels can be between 14 and 28 µg l^{-1} NO_2^--N [23].

Interdependence on other constituents

Low dissolved oxygen concentrations favour the formation of nitrite. Nitrite photolysis gives rise to a 10^4- fold supersaturation of nitrogen oxide in water with respect to its concentration in the air [25].

The toxicity of nitrite, while still formidable, is significantly reduced in seawater due to the high concentration of chloride and calcium [15].

NITRITE continued on next page

NO_2

NITRITE continued…

Measurement in seawater	Dissolved nitrite can be determined photometrically in seawater [19]. Units: µg l^{-1} NO_2^--N or µmol l^{-1} NO_2^--N (the latter can be converted to µg l^{-1} NO_2^--N by multiplying with the atomic mass of N, i.e. 14).	
Pollution sources	Anthropogenic sources of nitrite include[9]: - sewage discharges; - run-off from agricultural areas, especially where fertilizers are applied; - septic tank seepage.	
Related problems	Typical water quality problems which may be associated with the nitrite include: - eutrophication; - general growth deficiencies; - mortalities.	For more details on problems refer to: p 3-1 p 3-3 p 3-11
Effects of change and target values	General effects of different ranges of nitrite on the natural nnvironment are provided in Section 5 for: - primary producers; - primary consumers; - pecondary consumers. No target ranges for nitrite have been selected for primary and secondary consumers.	Refer to: p 5-36 p 5-36 p 5-37

NO_3

NITRATE

Description

Nitrate is the final oxidation product of nitrogen compounds in seawater and is considered to be the only thermodynamically stable oxidation level of nitrogen in the presence of oxygen in seawater [(23)]:

N_2 **6** N_2O **6** NO **6** NO_2^- **6** NO_3^-

Natural occurrence

Nitrate in oxygenated seawater with a salinity of $35x10^{-3}$ ranges from less than 1,4 to 630 $\mu g l^{-1}$ NO_3^--N, with an average concentration of 420 $\mu g l^{-1}$ NO_3^--N. Nitrate concentrations usually increase with depth, i.e surface depletion and enrichment at depth. This distribution is referred to as a nutrient type distribution [(25)].

West coast. Nutrient supply to the surface water occurs via the upwelling process [(18)]. The supply of nutrients to the euphotic zone by the upwelling process triggers the high biological productivity of the Benguela ecosystem and is the major feature driving the important commercial fish populations that occur in the area. Average nitrate concentrations (as NO_3^--N) reported for the west coast [(24)], as well as those specifically reported for upwelled waters are [(26)]:

AVERAGE	UPWELLED WATERS
16,4 $\mu g\ l^{-1}$	280 $\pm$ 56 $\mu g\ l^{-1}$

South coast. Along the south coast, coastal upwelling brings water rich in nutrients to the surface. The following average nitrate concentrations (NO_3^--N) have been reported for the south coast [(24)]:

AVERAGE
81 $\mu g\ l^{-1}$

East coast. Waters of tropical origin are usually poor in nutrients resulting in generally low primary productivity. Higher nutrient concentrations are usually associated with upwelling. Average nitrate (as NO_3^--N) concentrations such as those reported for the east coast are [(27)]:

AVERAGE		
PORT EDWARD	DURBAN	RICHARDS BAY
35 $\mu g\ l^{-1}$	47 $\mu g\ l^{-1}$	38 $\mu g\ l^{-1}$

NITRATE continued on next page

NO_3

NITRATE continued...

Fate in environment

Nitrate, as with phosphate, is a minor constituent and essential nutrient. It is extracted from the surface water by photosynthesising plankton to make organic tissue. Nitrate is totally depleted in surface waters where biological production is high, and is known as a biolimiting constituent. Together with phosphate, it limits production, i.e. when these nutrients are exhausted, production ceases. When the organisms are consumed or when they die and decompose, these nutrients are returned to the water column. Nitrate concentrations usually decrease with depth [(14)].

In many marine waters, nitrate is considered to be the micronutrient controlling primary production in the euphotic surface layers. The concentration of nitrate in these layers is governed by the advective transport of nitrate into surface layers, the microbial oxidation of ammonia and the uptake by the primary producers. If the light penetration into the water is sufficient, the uptake rate is usually much faster than the processes transporting the nitrate into the surface layers. Therefore, the nitrate concentration in most ocean surface waters is close to zero [(23)].

In temperate climatic zones, where winter cooling of the surface waters produces deep-reaching vertical mixing, the nitrate content of seawater follows a fairly regular cycle with high values in autumn, winter and early spring and low values in spring and summer. In upwelling areas, the supply rate of nitrate is very often considerably higher than the uptake rate. For this reason, the measurement of the concentration of nitrate can be usefully applied as an indicator for upwelling and, together with temperature measurements, as a means to separate the apparent decrease of micronutrients downstream of an upwelling area by a physical mixing process and biological uptake [(23)].

Nitrate and phosphate are used to form the soft tissue of organisms and the molar ratio of nitrate to phosphate in ocean water is close to the ratio of 15:1 for organic tissues; thus, when all the dissolved phosphate in surface waters has been used up, so has all the dissolved nitrate. Why nitrate and phosphate should occur in seawater in the same ratio required by that organisms remains one of the intriguing mysteries of seawater chemistry [(14)].

NITRATE continued continued on next page

NO_3

NITRATE continued...

Interdependence on other constituents

If the oxygen content of seawater becomes depleted as a result of microbial remineralisation processes, nitrate may be used as an alternative electron acceptor instead of oxygen. This process, called denitrification, leads to the reduction of a portion of nitrate to molecular nitrogen (N_2). It was found that the reduction of sulphate commences only after the available nitrate has been quantitatively used up. It is, therefore, very unlikely that nitrate may co-exist for any length of time in the presence of hydrogen sulphide. Usually the nitrate reduction zone is separated from waters containing sulphide by a layer in which the nitrate concentration has been reduced to less than 1,4 µg $l^{-1}NO_3^-$-N and where oxygen values are below 0,02 ml l^{-1}. The presence of nitrate in sulphide containing water indicates turbulent mixing processes between anoxic water and the water from the transition layer, or it may be the result of analytical errors [23].

Measurement in seawater

Dissolved nitrate can be determined photometrically in seawater [19] .

Units: µg l^{-1} NO_3^--N or µmol l^{-1} NO_3^--N (the latter can be converted to µg l^{-1} NO_3^--N by multiplying with the atomic mass of N, i.e. 14).

Pollution sources

Anthropogenic sources of nitrate include [9]:

- sewage discharges;
- run-off from agricultural areas, especially where fertilizers are applied;
- septic tank seepage.

NITRATE continued on next page

NO_3

NITRATE continued...

Related problems	Typical water quality problems which may be associated with the nitrite include:	For more details on problems refer to:
	- eutrophication;	p 3-1
	- general growth deficiencies;	p 3-3
	- mortalities.	p 3-11
Effects of change and target values	Factual information on effects of different ranges of nitrate on the natural environment, including target values, are provided in Section 5 for:	Refer to:
	- primary producers;	p 5-39
	- primary consumers;	p 5-40
	- secondary consumers.	p 5-40
	No target ranges for nitrite have been selected for primary and secondary consumers.	

PO 4

REACTIVE PHOSPHATE

Description

Phosphorus is an abundant element, with reactive phosphate being one of the most important nutrients. Phosphorus is normally found in the sea in the form of soluble inorganic phosphorus, i.e. reactive phosphate, particulate and organic forms. During weathering, solutions containing alkali phosphates and dissolved or colloidal calcium phosphate are carried to the sea [(23)].

A variety or organic phosphorus compounds are present in the upper layers of the sea. These compounds are decomposition and excretion products of organisms and, therefore, phospholipids, phospho-nucleotides and their derivatives may be found in seawater. Sugar phosphates and amino-phosphoric acids most probably exist [(23)].

Probable main species in oxygenated seawater are HPO_4^{2-}, $NaHPO_4^-$ and $MgHPO_4^o$ [25]. Other sources state that 1 % of the orthophosphate is present as $H_2PO_4^-$, 87 % as HPO_4^{2-} and 12 % as PO_4^{3-} , also that 96 % of the PO_4^{3-} and 44 % of the HPO_4^{2-} are apparently present in seawater as ion pairs, probably with calcium and magnesium. Probably because of this fact, calcium phosphate is more soluble in seawater than in distilled water (ion pair and complex formation) [(53)].

Nitrate and phosphate are used to form the soft tissue of organisms and the molar ratio of nitrate to phosphate in ocean water is close to the ratio of 15:1 for organic tissues; thus, when all the dissolved phosphate in surface waters has been used up, so has all the dissolved nitrate. This ratio remains one of the intriguing mysteries of seawater chemistry [(14)].

REACTIVE PHOSPHATE continued on next page

PO_4

REACTIVE PHOSPHATE continued...

Natural occurrence

The mean concentration of reactive phosphate in seawater has been estimated to be about 62 µg l^{-1} PO_4^{3-}- P [23]. Another source [25] reported reactive phosphate in seawater with salinity of $35x10^{-3}$, to range between less than 31 to 109 µg l^{-1} PO_4^{3-}-P, with an average concentration of 71 µg l^{-1} PO_4^{3-}- P. This distribution is called a nutrient type distribution [25].

West coast. Nutrient supply to the surface water occurs via the upwelling process [18]. Average total phosphorus concentrations (as P) reported for the west coast [24], as well as those specifically reported for upwelled waters (as PO_4^{3-}-P) are [26]:

AVERAGE	UPWELLED WATERS
53 µg l^{-1}	47 $\pm$ 1,6 µg l^{-1}

South coast. Along the south coast, coastal upwelling brings water rich in nutrients to the surface. The following average concentration for total phosphorus (as P) has been reported for the south coast [24]:

AVERAGE
37 µg l^{-1}

East coast. Waters of tropical origin are generally poor in nutrients resulting in generally low primary productivity. Higher nutrient concentrations are usually associated with upwelling. Average phosphate (as PO_4^{3-}-P) concentrations reported for the east coast are [27]:

AVERAGE		
PORT EDWARD	DURBAN	RICHARDS BAY
19 µg l^{-1}	19 µg l^{-1}	24 µg l^{-1}

REACTIVE PHOSPHATE continued on next page

Fate in environment

The enigma of the sea is that all the sunlight is at the top and most of the phosphate at the bottom. The phosphate concentration at the surface is low because of the steady down drift of organic debris. This is because phytoplankton only lives in the photic zone. They are consumed by zooplankton and other animals that package most of their waste products into faecal pellets. Only about 1% of this organic matter actually reaches the sediments. Because of the enormous pressures in the sea, most of this debris is crushed and its phosphate released before it reaches the bottom [28].

The phosphate concentration increases with depth, showing a nutrient type distribution [14]. Upwelling conditions can introduce phosphates to surface waters, while anoxic conditions will facilitate the return of phosphate from the sediment back into solution. Phosphate which is held in sediment as insoluble Fe PO_4 will be reduced to soluble Fe_3 $(PO_4)_2$, and insoluble CaH PO_4 will be acidified to soluble Ca $(H_2PO_4)_2$ [28].

Interdependence on other constituents

Precipitated inorganic phosphorus in sediments can resolubilise in anoxic conditions, i.e. under low *pH* and low *dissolved oxygen* levels [28].

Measurement in seawater

Dissolved reactive phosphate can be determined photometrically in seawater [19].

Units: $\mu g\ l^{-1}\ PO_4^{3-}$- P or $\mu mol\ l^{-1}\ PO_4^{3-}$- P (the latter can be converted to $\mu g\ l^{-1}\ PO_4^{3-}$- P. by multiplying with the atomic mass of P, i.e. 31).

REACTIVE PHOSPHATE continued on next page

PO_4

REACTIVE PHOSPHATE continued...

Pollution sources

Anthropogenic sources of phosphate include [9]:

- waste products from manufacturing phosphoric acid for fertilizer production;
- phosphatisation of metals in plating and metal processing industries;
- sewage discharges (including household detergents);
- agricultural run-off (over fertilization with super-phosphates is a common problem and enormous amounts are brought to the sea by rivers in some areas [23];
- run-off from dairy farms and piggeries.

Related problems

Water quality problems associated with dissolved reactive phosphate include:

- eutrophication.

For more details on problems refer to:

p 3-1

Effects of change and target values

Factual information on effects of different ranges of phosphate on the natural environment, including target values, are provided in Section 5 for:

- primary producers.

Refer to:

p 5-41

S iO $_4$

REACTIVE SILICATE

Description

During weathering of silicate material, silicon is brought into ionic solution, probably in the form of alkali salts of the orthosilicic acid, $Si(OH)_4$. High concentrations of silicon are found dissolved in rivers emanating from volcanic sources. It has been estimated that the total annual river output to oceans is about 200 million tons of dissolved silicon with over double this amount added by glacial weathering of rocks in Antarctica [(23)].

About half of the suspended matter in seawater is of inorganic origin and this part contains a large proportion of silicon identified in clays and other minerals. In surface waters, the concentration of suspended silicon generally exceeds that in solution, but at depths greater than about 100 m, it represents only a few percent of the total [(23)].

Silicon probably existing as hydrated silica, is a major constituent of diatoms, which form a large proportion of marine phytoplankton. Some fungi and siliceous sponges also have structural parts containing silica. The diatoms and radiolaria can also excrete silica in the form of opal, amorphous hydrated silica (SiO_2 nH_2O). When siliceous organisms die, silica is liberated into the seawater [(23)].

Natural occurrence

Seawater is quite undersaturated with respect to the element, since the solubility of silicate is around 50 mg l^{-1} (as Si) [(23)].

The silicon in solution in seawater is probably in the form of orthosilicic acid, H_4SiO_4 [(25)].

The concentrations in surface waters to deep waters range from less than 28 to 5 040 ug l^{-1} (as Si), with an average concentration of 2 800 ug l^{-1}. This distribution is called a nutrient type distribution [(25)].

West coast. Nutrient supply to the surface water occurs via the upwelling process [(18)]. Average reactive silicate concentrations (as Si) reported for the west coast [(24)], as well as those specifically reported for upwelled waters are [(26)]:

AVERAGE	UPWELLED WATERS
381 µg l^{-1}	420 $\pm$ 140 µg l^{-1}

REACTIVE SILICATE continued on next page

SiO_4

REACTIVE SILICATE continued...

Natural occurrence *continued...*

South coast. Along the south coast, coastal upwelling brings water rich in nutrients to the surface. The following mean reactive silicate concentrations (as Si) have been reported for the south coast [24]:

AVERAGE
146 μg l^{-1}

East coast. Waters of tropical origin are generally poor in nutrients resulting in generally low primary productivity. Higher nutrient concentrations are usually associated with upwelling. Average reactive silicate (as Si) concentrations reported for the east coast are [27]:

AVERAGE		
PORT EDWARD	**DURBAN**	**RICHARDS BAY**
83 μg l^{-1}	**104 μg l^{-1}**	**97 μg l^{-1}**

Fate in environment

Silica is a biolimiting nutrient, but is used only to make the hard parts of some planktonic organisms (diatoms, radiolarians). The skeletal remains dissolve slowly as they sink into deep water after death, and accumulate in sediments on the sea floor. Because it is a biolimiting nutrient whose availability in surface waters limits biological production, its characteristic vertical profiles show almost total depletion in surface waters because they are controlled principally by biological processes [14].

Interdependence on other constituents

The solubility of silica decreases as the temperature decreases. The solubility of amorphous opaline silica decreases by about 30 % for a drop in temperature from 25 to 5 EC. In deep oceans, because of high pressure, the solubility increases slightly [14,29].

Measurement

Dissolved reactive silicate can be determined photometrically in seawater [19].

Units: μg l^{-1} SiO_4^{4-}-Si or μmol l^{1} SiO_4^{4-}-Si (the latter can be converted to μg l^{-1} SiO_4^{4-}-Si by multiplying with the atomic mass of Si, i.e. 28).

REACTIVE SILICATE continued on next page

Pollution sources	Anthropogenic sources of silicate are not clearly defined.	
Related problems	Water quality problems associated with dissolved reactive silicate include: - eutrophication.	For more details on problems refer to: p 3-1
Target value	The target value for silicate in the natural environment is provided in Section 5 for: - primary producers.	Refer to: p 5-42

Chapter 4.3 Inorganic Constituents

AMMONIA

For background information on ammonia, refer to p 4-17, *Ammonium*

CYANIDE

Description

Cyanides are a diverse group of inorganic and organic compounds and are among the most toxic chemicals. Molecular HCN (hydrogen cyanide) refers to cyanide as an uncharged, undissociated molecule. Free cyanide refers to the summation of HCN and the cyanide ion in the marine environment. The equilibrium species found in marine waters are HCN (90 %) and CN^- (10%)[9], HCN being the most toxic form.

Natural occurrence

Information on natural concentrations of cyanide in marine water could not be obtained.

Fate in environment

Cyanide readily forms complexes with certain metal ions, e.g. copper. This means that large-scale dispersion of cyanide is unlikely and that any detrimental effects would be local in nature[9].

Interdependence on other constituents

The form of cyanide is dependent on pH, but is also influenced by temperature, dissolved oxygen, salinity, sunlight and complexing agents. There is therefore a possibility of a multitude of complex metallocyanides existing in the an aquatic environment, each with its own physical and chemical properties.

The toxicity of cyanide increases if the pH levels decreases, forming extremely toxic HCN[9].

Measurement in seawater

Methods for analysing cyanide in seawater could not be obtained. However, in fresh water, it is determined photometrically[17].

Pollution sources

Anthropogenic sources of cyanide include[9]:

- waste from the extraction of lead, zinc, gold and silver from ores;
- heat treating of metals, electroplating, various ionic reactions;
- waste from the petroleum, photographic, pharmaceutical, rubber and plastics industries;
- waste from the manufacturing of adiponitrile.

CYANIDE continued on next page

Related problems

Typical water quality problems which may be associated with cyanide include:

- general growth deficiencies;
- lowered reproduction;
- mortalities;
- abnormalities in movement.

For more details on problems refer to:

p 3-3
p 3-4
p 3-11
p 3-13

Effects of change and target values

Factual information on effects of different ranges of cyanide on the natural environment is provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-47
p 5-47
p 5-48

FLUORIDE

Description

Fluorides occur naturally in seawater [9]. The probable species in oxygenated seawater are F^-(50 %), Mg F^+(50 %) [25].

Natural occurrence

The average concentration of the probable main species (F^- and Mg F^+) in oxygenated seawater at a salinity of 35x10^{-3} was given as 1,292 mg l^{-1} [25].

Fluorides in the South African east coast waters showed fluoride concentrations ranging from 1.2 - 1,7 mg l^{-1} in unpolluted seawater [32].

Fate in environment

Fluoride shows a conservative type distribution in seawater, i.e. it shows a constant concentration relative to salinity (or chlorinity) as a result of the low reactivity of the element in seawater [25]. Usually the fluoride/chlorinity (in parts per thousand) ratio of 6,7 ± 0,1 x 10^{-5}. However in some very localised bottom waters the ratio may reach 9,5 x 10^{-5} [25].

Marine biota can accumulate fluoride [57].

Interdependence on other constituents

Information on the interdependence of fluoride on other water quality properties or constituents in the marine environment could not be obtained.

Measurement in seawater

In seawater, fluoride can be determined by molecular absorption spectro-photometry [33].

FLUORIDE continued on next page

F

FLUORIDE continued...

Pollution sources

Anthropogenic sources of fluoride include [9]:

- waste from phosphate fertilizer industries;
- waste from the manufacturing of orthophosphoric acid for industrial purposes;
- waste from electronics, glass, electroplating and metal treatment industries.

Related problems

Information on typical problems related to fluoride in the marine environment could not be obtained.

Target values

The target value for fluoride in the natural environment is provided in Section 5.

Refer to:

p 5-49

CHLORINE

Description

Chlorine is a chemical which is used as a disinfectant.

Natural occurrence

Chlorine does not occur naturally in seawater. However, compounds such as chloroform and bromoform, as well as other halogenated compounds are produced naturally in the marine environment, mainly by algae [34].

Fate in environment

Seawater chlorination differs greatly from that of fresh water primarily due to the high bromide concentration of seawater (average bromide concentration in seawater is 67 mg l^{-1}).

The chemistry associated with seawater chlorination is complex. However, for the purpose of this document, only a few of the reactions will be highlighted below.

In the presence of bromide, free residual chlorine cannot exist in seawater as it instantaneously oxidises bromide into bromine. When chlorine additions remain below bromide concentrations (i.e. 67 mg l^{-1}), the oxidation of bromide is quantitative in less than ten seconds at a pH of 8 (the pH of seawater) [34].

Due to the rapid hydrolysis of bromine, hypobromous acid (HOBr) and its ionic counterpart OBr^- are the active species. Under usual seawater conditions (pH between 7,8 and 8,2), the undissociated form (HOBr) predominates with consequently higher reactivity and biocidal activity. In chlorinated seawater, bromine and any other oxidants disappear very rapidly. Naturally occurring organic substances contribute to the major part of oxidant consumption [34].

In coastal seawater, ammonia concentrations are usually lower (typically less than 28 µg N l^{-1}) and therefore bromine remains as hypobromous acid. When ammonia increases, bromamines may be formed. At pH 8.1, ammonia and bromine reacts with chlorine at comparable rates. Monochloramine, the more persistent species among the various oxidised chlorine-produced oxidants, may be found when ammonia concentrations increase or in lower pH conditions [34].

In most cases, bromamines are the only combined forms and tri-and dibromamines are the main species. These bromamines are high oxidising species and thus behave similarly to free bromine. Bromamines disappear rapidly; organic bromamines are rapidly formed. Hypobromous acid can also disproportionate into bromide and bromate. Bromate is formed during seawater chlorination and this reaction is accelerated by sunlight [34].

CHLORINE continued on next page

Fate in environment

continued...

Paradoxically, chlorine chemistry establishes that no chlorine is found in chlorinated water; neither in seawater where bromide oxidation is instantaneous and quantitative, nor in waste water where monochloramine is the main reactive species [34].

Chlorine can also combine with phenolic compounds to form chlorophenols, some of which can taint fish flesh at concentrations as low as 0,001 mg l^{-1} [10].

Interdependence on other constituents

A decrease in pH increases the toxicity of chlorine [10].

A reduction in temperature reduces the toxicity of hypochlorous acid (HOCl) [10].

Measurement in seawater

Chlorine can be determined by [17]:

- a Lovibond comparator;
- N,N-Diethyl-p-phenylenediamine (DPD) method;
- iodometric titration; or
- amperometric titration.

Units: mg l^{-1} as free chlorine, combined chlorine or total available chlorine.

Pollution sources

Sources of chlorine in the marine environment are [35]:

- disinfection of municipal waste waters;
- chlorination of seawater for cooling systems to protect installation against fouling organisms. Continuous chlorination at about 1 mg l^{-1} is a very cheap, convenient and efficient way to protect the installation against biofouling from bacteria and mussels (at nuclear power stations and paper mills);
- waste from manufacturing chlorinated lime, bleaching of fabrics, defining and dezincing iron, synthetic rubber and plastics, chlorinating hydrocarbons.

For interest sake: The chlorine consumption in a 1 000 MW(e) power plant would equal that used in a waste water plant providing for 2,6 million equivalent inhabitants (flow 30 m^3s^{-1} seawater, chlorination dose 1 mg l^{-1} for 1 000 MW(e))

The waste products in chlorinated/disinfected waters are greatly dependent on whether the water is fresh (municipal waste water) or saline (cooling water).

CHLORINE continued on next page

Cl_2

CHLORINE continued…

Pollution sources *continued...*

Waste products from disinfected municipal waste waters. In the disinfection of fresh water with chlorine, three basic reactions can occur:

i. When added to fresh water as a free oxidant, chlorine rapidly reacts with any reducible compounds, either organic or inorganic. During these reactions, the oxidative capacity is lost and finally all added chlorine is found as chloride, the non-reactive non-toxic form of chlorine.

   Chlorination of urban waste water, containing high concentrations of organic carbon and ammonia, requires a higher chlorine dosage (5- 20 mg l^{-1}) to fulfill its disinfection requirements.

ii. When ammonia is present in waste water, combined chlorine is formed rapidly. The nature of these chloramines, either mono-, di- or trichloramines, depends on pH, and chlorine to ammonia molar ratios.

A limited number of chemical species are encountered, their concentrations being in the mg l^{-1} range. These species disappear rapidly and are responsible for the efficiency of the disinfection as well as for toxicity towards non-targeted organisms. During these reactions, oxidising capacity is lost or transformed from one chemical entity to another, until the toxicity disappears.

iii. When organic amines are present, these react with chlorine to produce organic chloramines. All these chloramines are still oxidising agents and efficient in water disinfection. However, these reactions result in the formation of organochlorinated derivatives which are of great environmental significance. During these reactions, the end products may be numerous and their concentrations will be in the microgram per litre range. The hazards associated with these chlorinated by-products are related to sublethal risks, and longer persistence in the environment. First signs of deleterious effects appear at concentrations as low as 0,1 mg l^{-1}, about two orders of magnitude lower than the actual concentrations in chlorinated effluents.

Chlorination of seawater used as cooling water. Refer to F*ate in environment* of chlorine on p 4-40.

CHLORINE continued on next page

Related problems

Typical water quality problems which may be associated with chlorine include:

- general growth deficiencies;
- lowered reproduction;
- changes in water pumping rates;
- mortalities;
- abnormalities in movement.

For more details on problems refer to:

p 3-3
p 3-4
p 3-7
p 3-11
p 3-13

Effects of change and target values

Factual information effects of different ranges of chlorine on the natural environment are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

No target values for chlorine have been selected for the South African coastal zone.

Refer to:

p 5-50
p 5-51
p 5-53

H_2S

HYDROGEN SULPHIDE

Description

Hydrogen sulphide is a poisonous gas which readily dissolves in water. No heterotrophic life can exist in water containing hydrogen sulphide, and such affected areas are therefore transformed into oceanic 'deserts' [(23)].

The speciation of H_2S in seawater at 25 °C, pH of 8,1 and salinity of 35×10^{3} is H_2S (3,07 %), HS^- (96,93 %) and S^{2-} ($1,9 \times 10^{-4}$ %) [(36)].

Natural occurrence

Hydrogen sulphide is a frequent component of anoxic waters, attaining concentrations as high as 70 mg l^{-1} under extreme conditions [(28)].

Fate in environment

Dissolved oxygen in seawater is utilised by bacteria for oxidising organic matter to carbon dioxide, water and inorganic ions. In deep water of stagnant basins and in sea areas with a very slow water exchange or a high load of organic matter, all the dissolved oxygen may be utilised, leading to anoxic conditions [(16)].

Hydrogen sulphide behaves as a weak acid, and is present in natural waters as both the undissociated compound and the HS^- ion (below pH 12 the concentration of S^{2-} ion is negligible). Hydrogen sulphide is very volatile and reacts rapidly with oxygen [(16)].

Hydrogen sulphide is produced in anaerobic environments by the activities of sulphate-reducing bacteria, which derive energy from a process of anaerobic respiration.

$$2\ CH_2O + SO_4^{2-}\ \underline{\text{desulfovibria}}\ 2\ HCO_3^- + H_2S$$

Probably only a small fraction of H_2S is released into the atmosphere. In many environments, it reacts instead with iron to form insoluble iron sulphide, an abundant constituent of anaerobic organic rich sediments. Much of the sulphide that is not immobilised in this fashion is oxidised by bacteria that derives energy from the following reaction as soon as it reaches the aerobic level of the water profile [(28)]:

$$H_2S + 2\ O_2\ 6\ SO_4^{2-} + 2\ H^+$$

Therefore H_2S is slowly oxidised to sulphate in seawater. Evidence of this is that molecular sulphur does not accumulate in sediments in natural stagnant sea basins e.g. the Black Sea [(28)].

HYDROGEN SULPHIDE continued on next page

Interdependence on other constituents

The solubility of hydrogen sulphide decreases with increasing temperature and salinity, e.g. the solubility of H_2S in acidified seawater (pH 2,8 - 3,0) expressed as mg l^{-1} at 1 atm pressure is as follows [37]:

TEMPERATURE (°C)	SALINITY		
	$30x10^{-3}$	$35x10^{-3}$	$40x10^{-3}$
0	6 730,8	6 672,9	6 611,5
10	4 975,7	4 945,0	4 910,9
15	4 338,4	4 314,5	4 287,3
20	3 817,0	3 796,5	3 776,1
25	3 380,7	3 367,1	3 350,1
30	3 019,5	3 005,9	2 992,2

In contact with oxygen, hydrogen sulphide is *rapidly* oxidised to sulphur in an *acid* medium, but *slowly* to sulphate in more neutral solutions like seawater[23].

Also refer to *Fate in the environment* (p 4-44).

Measurement in seawater

Hydrogen sulphide in seawater can be analysed photometrically or titrimetrically. The photometric method is more sensitive and accurate[19].

Pollution sources

Although hydrogen sulphide is usually not directly introduced to the marine environment through anthropogenic sources, those with high oxygen demand (reflected in high organic content, high biochemical oxygen demand or chemical oxygen demand) can favour conditions for the formation of hydrogen sulphide.

HYDROGEN SULPHIDE continued on next page

H_2S

HYDROGEN SULPHIDE continued…

Related problems

Typical water quality problems which may be associated with the hydrogen sulphide include:

- general growth deficiencies;
- mortalities.

For more details on problems refer to:
p 3-3
p 3-11

Effects of change and target values

Factual information on effects of different ranges of hydrogen sulphide on the natural environment are provided in Section 5 for:

- primary consumers;
- secondary consumers.

No target values for hydrogen sulphide have been selected for the South African coastal zone.

Refer to:
p 5-54
p 5-55

As

ARSENIC

Description

Major forms of arsenic in seawater include [41]:

- arsenite (As[III]) (regarded as the most toxic and the predominant form under anaerobic conditions);
- arsenate (As[V]) (the stable form in aerobic conditions);
- methylarsonic acid (CH_3 As O $(OH)_2$);
- dimethylarsinic acid ($(CH_3)_2$ As O (OH)).

At the normal pH value for surface seawater (8,2), As(III) exists mainly as an uncharged species, e.g. $As(OH)_3$ and As (V) as the ion $HAsO_4^{2-}$. The latter should be the predominant form at equilibrium [23,25].

Various forms of arsenic were measured in an experiment conducted in the North Atlantic. It was found that of a total arsenic concentration of 37,46 µg l^{-1}, 55 % was present as As(III), 10 % as As(V),10 % as particulate arsenic and 25 % as dissolved organic arsenic [23].

Volatile organic forms of arsenic, e.g. $(CH_3)_2$ AsH and $(CH_3)_3$ As, are extremely toxic [41].

Natural occurrence

The concentration of arsenic in seawater at a salinity of 35×10^{-3} has been given as 2,3 µgl l^{-1} [39].

A range between 1,12 and 1,87 µg l^{-1} with an average of 1,72 µg l^{-1} has been reported for the most probable species ($HAsO_4^{2-}$) in ocean water with a salinity of 35 [25].

The concentration range between 1 and 3 µg l^{-1} has been reported for dissolved arsenic in seawater [16].

Ranges of <1 to 4 ng l^{-1} for CH_3 As O $(OH)_2$ (methylarsonic acid) and 0,2 to 1 ng l^{-1} for $(CH_3)_2$ As O (OH) (dimethylarsinic acid) have been reported for seawater[16]. In seawater, the occurrence of methylarsenic compounds is usually associated with phytoplankton activity [42].

Arsenic concentrations in South African surface marine waters have been reported to be between 2,6 and 3 µg l^{-1} [22].

ARSENIC continued on next page

ARSENIC continued...

Fate in environment

The principal pathways that arsenic follows from the continent to the oceans in the absence of human interference are weathering, including solubilisation and transport of sediment, and vulcanism [(9)].

Methylation of inorganic arsenic to methyl - and dimethylarsenic acids is associated with biological activity[9]. Certain biological processes can convert these methyl compounds to di- and trimethylarsine $(CH_3)_2$ AsH and $(CH_3)_3$ As , which are volatile compounds and extremely toxic. These compounds are fat soluble and may concentrate in the food chain . Fish, plants and oysters enter the cycle by concentrating arsenic, especially as trimethylarsine $(CH_3)_3$ As [(43)]. Trimethylarsine ($(CH_3)_3$ As) has also been identified in seaweed and epiphytes [(41)].

Some marine organisms have been shown to transform inorganic arsenic into more complex organic compounds, such as arsenobetane (identified in rock lobsters), arsenocholine, and arsenophospholipids (identified in algae) [(42)].

Upon death, the organisms settle to the bottom where the arsenic is removed to the sediments or recycled, depending in the physical and chemical conditions [(43)].

Bioaccumulation of arsenic has been reported [(9,14)]. It was also found that plankton could concentrate arsenic by as much as 1 000 times above the ambient concentration in seawater [(23)].

Interdependence on other constituents

In oxygenated seawater, arsenic usually occurs as As (V), but under reducing conditions As (III) arsenite predominates.

Measurement in seawater

Arsenic can be determined in seawater by atomic absorption hydride generation [(17)].

Units: µg l^{-1} as total As.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [(56)].

ARSENIC continued on next page

Pollution sources

Anthropogenic sources of arsenic include [9]:

- burning of fossil fuels;
- manufacturing of arsenicals;
- waste from manufacturing of herbicides, fungicides, insecticides, algicides, sheep dips, wood preservatives, feed additives and human and veterinarian medicine (arsenic trioxide (As_2O_3) is a basic raw material for the manufacturing of the abovementioned products).

NOTE: Arsenic is a member of the same family as phosphorus, and occurs in the same rocks from which phosphorus chemicals are obtained. In many industrial phosphates, arsenic remains as an impurity, and thus is found in small amounts in detergents and fertilizers [43].

Related problems

Typical water quality problems which may be associated with the arsenic include:

- general growth deficiencies;
- lowered repoduction;
- changes in respiration patterns;
- mortalities.

For more details on problems refer to:

p 3-3
p 3-4
p 3-6
p 3-11

Effects of change target values

Factual information on effects of different ranges of arsenic on the natural environment, including target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-56
p 5-57
p 5-58

Cd

CADMIUM

Description

The most probable main species of cadmium in oxygenated seawater is $CdCl_2^0$ [25].

Natural occurrence

Weathering and erosion result in rivers transporting large quantities of cadmium to the world's oceans. Deep sea volcanism is also a source of cadmium release [44].

The average cadmium concentration of seawater is about 0,1 µg l^{-1} or less[44].

A range of between 0,11 x 10^{-3} and 0,12 µg l^{-1}, with an average of 0,079 µg l^{-1}, has been reported for the most probable species ($Cd\ Cl_2^0$) in oxygenated seawater with a salinity of 35x10^{-3} [25].

The concentration of cadmium in seawater has also been reported as being variable, with a range between 0,01 and 0,6 µg l^{-1} [16].

The average cadmium concentration in South African surface marine waters has been reported as 0,108 µg l^{-1} [22]. A review of the metal concentrations in South African coastal water, sediments and marine organisms was undertaken by Hennig in 1985 [46].

Fate in environment

The vertical distribution of dissolved cadmium in ocean waters is characterised by surface depletion and deep water enrichment. This distribution is considered to be the result of absorption of cadmium by phytoplankton in surface waters, its transport to the depth, incorporating biological debris, and its subsequent release. In contrast, cadmium is enriched in the surface waters of upwelling areas (not linked to pollution sources) which also leads to elevated levels of cadmium in plankton [44].

Cadmium levels between 30 and 1 000 µg l^{-1} have been reported for marine sediments [44].

The acute toxicity of cadmium to aquatic organisms is variable, even between closely related species, and is related to the free ionic concentration of the metal. It is readily accumulated by some organisms, particularly micro-organisms and molluscs where the bioconcentration factors are in the order of thousands, while it appears not to be taken up by fish. Shellfish have been reported to contain 0,05 mg kg^{-1} in non-polluted areas whereas this value reached 420 mg kg^{-1} in the livers of shellfish and cuttle fish [9]. The cadmium concentration in Knysna oysters has been reported to be 3,7 mg kg^{-1} dry weight [28]. Cadmium is bound to proteins in many tissues, referred to as heavy metal-binding proteins (metallothioneins) [44].

CADMIUM continued on next page

Interdependence on other constituents

Increasing temperature increases the uptake and toxic impact of cadmium [(44)].

The reduced cadmium accumulation and toxicity with increased salinities, observed in a variety of organisms, is most probably the result of chloride complexation of cadmium [(44)].

The solubility of cadmium decreases in anoxic waters due to the presence of hydrogen sulphide. Cadmium sulphide is very insoluble [(44)].

The organic content of seawater generally decreases the uptake and toxic effect by binding cadmium and reducing its availability to organisms. However, there is evidence that some organic matter may have the opposite effect [(44)].

Cadmium shows a highly significant positive correlation with phosphate and nitrate at all depths [(44)].

Zinc increases the toxicity of cadmium to aquatic invertebrates [(44)].

Measurement in seawater

The most commonly used analytical methods for the determination of cadmium at present are atomic absorption spectrometry, electrochemical methods, neutron activation analysis, atomic emission spectrometry, atomic fluorescence spectrometry and proton-induced X-ray emissions (PIXE) analysis [(44)].

Units: $\mu g\ l^{-1}$ as total Cd.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [(56)].

CADMIUM continued on next page

Cd

CADMIUM continued...

Pollution sources

Anthropogenic sources of cadmium include [9]:

- waste from manufacturing protective plating for steel;
- waste from manufacturing stabilisers for PVC;
- waste from manufacturing plastics and glass;
- electrode material in nickel-cadmium batteries;
- waste from manufacturing various alloys.

At global level, the smelting of non-ferrous metal ores has been estimated to be the largest human source of cadmium release to the aquatic environment [9].

Related problems

Typical water quality problems which may be associated with cadmium include:

For more details on problems refer to:

- general growth deficiencies; p 3-3
- lowered repoduction; p 3-4
- changes in respiration patterns; p 3-6
- changes in water pumping rates; p 3-7
- mortalities; p 3-11
- burrowing abnormalities. p 3-14

Effects of change and target values

Factual information on effects of different ranges of cadmium on the natural environment, including target values, are provided in Section 5 for:

Refer to:

- primary producers; p 5-60
- primary consumers; p 5-60
- secondary consumers. p 5-62

CHROMIUM

Description

Chromium occurs naturally in the elemental state (Cr[0]) or in the trivalent oxidation (Cr[III]) state [45]. Almost all the hexavelant chromium (Cr[VI]) in the environment arises from human activities, the most probable species being CrO_4^{2-} and Na CrO_4^- [25,45].

Cr (III) is an essential element, while Cr(VI) is extremely toxic. It is of great importance to realize that these two oxidation states have very different properties and biological effects on living organisms. Therefore, they must always be examined separately: a valid generalisation of the biological effects of chromium as an element cannot be made [45].

Natural occurrence

Concentrations of less than 1µg l^{-1} of chromium have been reported for seawater at a salinity of $35x10^{-3}$ (although the exact ionic forms were not indicated) [45].

A range between 0,1 and 0,26 µg l^{-1}, with an average of 0,21 µg l^{-1}, has been reported for the most probable species (CrO_4^{2-} and Na CrO_4^-) in oxygenated seawater with a salinity of $35x10^{-3}$ [25].

The concentration of dissolved chromium in seawater has also been reported as being within the range between 0,2 and 2 µg l^{-1} [16].

The average chromium concentration in South African surface marine waters has been reported as 0,071µg l^{-1} [22]. A review of the metal concentrations in South African coastal water, sediments and marine organisms was undertaken by Hennig in 1985 [46].

Fate in environment

In oxygenated seawaters, chromium should exist entirely as the CrO_4^{2-} ion [16], while under anoxic conditions it is stable as Cr (III) [25].

In the trivalent state (Cr[III]), chromium will form insoluble compounds unless protected by complex formation. The exact distribution between the trivalent and hexavelant state is unknown [45].

Theoretically, Cr (VI) is reduced to Cr(III) when it settles to the ocean bed. Substantial energy is needed to oxidise Cr(III) back to Cr(VI) [9].

For practical purposes, it can be stated that Cr(VI) never occurs in biological systems, since the reduction of Cr(VI) occurs spontaneously in organisms, unless present in an insoluble form [45].

Where the organic content of water is low, chromium should persist as Cr(VI) [16].

Bioaccumulation of chromium has been reported [9,14].

CHROMIUM continued on next page

Cr

CHROMIUM continued...

Interdependence on other constituents

The toxicity of chromium decreases with increasing pH changes [16].

The oxygen content also influences the ionic state of chromium. In oxygenated seawaters, chromium should exist entirely as the CrO_4^{2-} ion [16], while under anoxic conditions it is stable as Cr (III) [25].

Measurement in seawater

Chromium is determined in seawater by using sodium diethyldithiocarbamate/ chloroform extraction procedures prior to analysis on an atomic absorption spectrophotometer [40].

Units: $\mu g\ l^{-1}$ as total Cr.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [56].

Pollution sources

Anthropogenic sources of chromium include [9]:

- waste from ferrochrome production;
- waste from electroplating;
- waste from pigment production and tanning;
- the burning of fossil fuels;
- incineration.

Related problems

Typical water quality problems which may be associated withchromium include:

- mortalities.

For more details on problems refer to:

p 3-11

Effects of change and target values

Factual information on effects of different ranges of chromium on the natural environment, including target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-64
p 5-64
p 5-65

Cu

COPPER

Description

The most probable main species of copper in oxygenated seawater is $CuCO_3^0$, $CuOH^+$ and Cu_2^+ (25).

Copper in the marine environment poses no health risk to humans from consumption of seafood or seawater (9).

Natural occurrence

A range between 0,03 and 0,38 µg l^{-1}, with an average of 0,25 µg l^{-1}, has been reported for the most probable species ($CuCO_3^0$, $CuOH^+$ and Cu_2^+) in oxygenated seawater with a salinity of $35x10^{-3}$ (25).

The concentration of copper in seawater has also been reported as 2 µg l^{-1} (16).

Generally, the concentration of copper in surface waters is lower than in deep waters. This distribution is called a nutrient type distribution (25).

The average copper concentration in South African surface marine waters has been reported as 0,899 µg l^{-1} (22). A review of the metal concentrations in South African coastal water, sediments and marine organisms was undertaken by Hennig in 1985 (46).

Fate in environment

Observations suggest that seawater can retain a maximum of 50 µg l^{-1} of copper. At high concentrations, the copper is present in a colloidal form (56).

A significant fraction of Cu^{2+} may exist as complexes with dissolved organic compounds. Upon degradation, it results in an increase in the amount of free copper (53).

Anoxic near-shore sediments represent a significant sink for copper when compared with the accummulation rates for pelagic sediments (16).

The surface distributions of copper have been shown to be influenced by continental sources from river and/or shelf sediments. As a result, copper, together with manganese, have been shown to have much higher concentrations in shelf water than in oceanic surface waters (39). Cu^{2+} can also be adsorbed onto dead or living bacteria (11).

In addition to adsorption processes, active uptake of copper by phytoplankton in the photic zone can also be important, playing an important role in metal-requiring and metal-activated enzyme systems (25). Copper is incorporated in haemocyanin, the blood pigment of molluscs and crustaceans (29).

COPPER continued on next page

Cu

COPPER continued...

Interdependence on other constituents

Copper is usually strongly associated with dissolved organic carbon (DOC), presumably humic substances.

Measurement in seawater

Copper is determined in seawater by using sodium diethyldithiocarbamate/ chloroform extraction procedures prior to analysis on an atomic absorption spectrophotometer [40].

Units: $\mu g\ l^{-1}$ as total Cu.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [56].

Pollution sources

Anthropogenic sources of copper include [9]:

- metal-plating operations;
- jewellery and ornamental industries;
- electrical wiring industries;
- electronic industries;
- anti-fouling paints.

Related problems

Typical water quality problems which may be associated with copper include:

- general growth deficiencies;
- lowered repoduction;
- changes in respiration patterns;
- changes in water pumping rates;
- mortalities;
- burrowing abnormalities.

For more details on problems refer to:

p 3-3
p 3-4
p 3-6
p 3-7
p 3-11
p 3-14

Effects of change and target values

Factual information on effects of different ranges of copper on the natural environment, including target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-66
p 5-67
p 5-69

Pb

LEAD

Description

Lead, like mercury, is not known to be an essential trace element [28]. The most probable species in marine waters are $PbCO_3^o$, $(Pb\ CO_3)_2^{2-}$, $Pb\ Cl^+$ [25].

Natural occurrence

Natural sources of lead include weathering of rocks, vulcanism and forest fires [25].

In deep ocean waters, the lead concentrations have been measured at a level of 0,01 to 0,05, µg l^{-1}. Other measurements suggest that deep ocean lead levels may be as low as 0,002 µg l^{-1} [28].

A range between 0,0004 and 0,037 µg l^{-1}, with an average of 0,002 µg l^{-1}, has been reported for the most probable species ($PbCO_3^o$, $(Pb\ CO_3)_2^{2-}$, $Pb\ Cl^+$) in oxygenated seawater with a salinity of $35x10^{-3}$ [25].

The concentration of dissolved lead in ocean waters has also been reported as being in the range between 0,5 and 3 µg l^{-1} [16].

The average lead concentration in South African surface marine waters has been reported as 0,025 to 0,15 µg l^{-1} [22]. A review of the metal concentrations in South African coastal water, sediments and marine organisms was undertaken by Hennig in 1985 [46].

Fate in environment

Sediments are the primary sink for lead in the aquatic environment. Lead is adsorbed largely by organic matter and clays in soils and sediments. For deep ocean sediments, the natural average value is about 47 µg g^{-1} [28].

The precipitation of sparingly soluble species, the formation of stable organic complexes and the adsorption of lead to particulate matter are the main routes for environmental cycling of lead [28].

In anaerobic sediments, most of the lead will be present as lead sulphide [28].

There is strong evidence that a biological methylation of lead salts may occur under environmental conditions in polluted sediments, e.g. the conversion of inorganic lead to tetraethyl lead [28].

Bioaccumulation of lead has been reported [9,14].

Interdependence on other constituents

Information on the interdependence of lead on other water quality properties or constituents in the marine environment could not be obtained.

LEAD continued on next page

Pb

LEAD continued...

Measurement in seawater

Lead is determined in seawater by using sodium diethyldithiocarbamate/ chloroform extraction procedures prior to analysis on an atomic absorption spectrophotometer (40).

Units: $\mu g\ l^{-1}$ as total Pb.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion (56).

Pollution sources

Anthropogenic sources of lead include (9):

- waste from the manufacturing of car batteries, metal plating, petroleum additives (tetraethyl-lead);
- wastes from printing, pigment, fuel, photographic, match and explosive industries;
- waste from paint and pigment industries.

Lead is a good example of an element entering the oceans via the atmosphere. Release of lead to the atmosphere is largely due to man's activity. (60% originates from leaded petrol) (28).

Related problems

Typical water quality problems which may be associated with lead include:

- general growth deficiencies;
- lowered reproduction;
- mortalities.

For more details on problems refer to:

p 3-3
p 3-4
p 3-11

Effects of change and target values

Factual information on effects of different ranges of lead on the natural environment, including target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-71
p 5-72
p 5-73

Hg

MERCURY

Description

Mercury is a metal which is liquid at normal temperatures and pressures. It forms salts in two ionic states, namely Hg(I) and Hg(II), the latter being the most common form. The most probable Hg(II) form in seawater is Hg Cl_4^{2-} [47].

Hg(II) also forms organometalic compounds (e.g. methyl-mercury), some of which are generally more toxic to aquatic organisms than the inorganic forms, because the carbon-mercury bond is chemically stable [47].

Natural occurrence

Dissolved mercury concentrations reported for ocean waters range between 0,0005 and 0,003 µg l^{-1}, while those for coastal waters range between 0,002 and 0,015 µg l^{-1} [47]. Local variations from these values are considerable, especially in coastal seawater where mercury associated with suspended material may also contribute to the total load.

The average mercury concentration in South African surface marine waters has been reported as 0,055 µg l^{-1} [22]. A review of the metal concentrations in South African coastal water, sediments and marine organisms was undertaken by Hennig in 1985 [46].

Fate in environment

Bioaccumulation of mercury has been reported [9,14].

Mercury salts, and to a much greater extent, organic mercury, are readily taken up by organisms in water. Fish take up the metal and retain it in tissues principally as methyl-mercury, although most of the environmental mercury to which they are exposed is inorganic [47].

There is a strong indication that bacterial action leads to methylation, short-chain alkyl mercurials, e.g. methyl-, ethyl- or propyl-mercury [47].

Interdependence on other constituents

pH increases the uptake of mercury by fish, particularly methyl mercury [47].

The toxicity of mercury is reduced in the presence of high salt concentrations, it increases for vertebrates with an increase in temperature [47].

The solubility of mercury decreases in anoxic waters due to the formation of hydrogen sulphide leading to the formation of mercury sulphide which is very insoluble [47].

MERCURY continued on next page

Hg

MERCURY continued...

Measurement in seawater

Inorganic mercury is usually determined with the hydride generation cold-vapour method on atomic absorption, while organic mercury is determined with a gas chromatograph [40,47].

Units: µg l^{-1} as total Hg.

Pollution sources

Anthropogenic sources of mercury include [47]:

- mine tailings;
- burning of fossil fuels;
- waste from the chlor-alkali industry;
- waste from the wood pulping industry;
- agricultural run-off where mercury compounds have been used, principally as fungicides;
- waste from manufacturing electrical equipment and from paint industries.

Related problems

Typical water quality problems which may be associated with mercury include:

- general growth deficiencies;
- changes in respiration patterns;
- mortalities;
- burrowing abnormalities.

For more details on problems refer to:

p 3-3
p 3-6
p 3-11
p 3-14

Effects of change and target values

Factual information on effects of different ranges of mercury on the natural environment, including target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-74
p 5-75
p 5-76

Ni

NICKEL

Description

Nickel occurs in abundance in nature. The most probable species in marine waters are $NiCO_3^o$, Ni^{2+} and $NiCl^+$ [(25)]. Nickel in the marine environment does not pose a health risk to man [(9)].

Natural occurrence

Natural sources of nickel include volcanoes, forest fires and natural erosion of soils which are transported to the ocean via rivers and streams [(48)].

Nickel concentrations in marine water have been found to range from 0,2 to 0,7µg l^{-1} [(25)].

A range between 0,12 and 0,70 µg l^{-1}, with an average of 0,23 µg l^{-1}, has been reported for the most probable species ($NiCO_3^o$, Ni^{2+}, $NiCl^+$) in oxygenated seawater with a salinity of 35×10^{-3} [(25)].

The concentration of dissolved nickel in ocean waters has also been reported as being within the range between 0,5 and 3 µg l^{-1} [(16)].

The average nickel concentration in South African surface marine waters has been reported as 0,563 µg l^{-1} [(22)]. A review of the metal concentrations in South African coastal water, sediments and marine organisms was undertaken by Hennig in 1985 [(46)].

Fate in environment

Information on the fate of nickel in the marine environment could not be obtained, except that it is transported in the ionic form, mainly in association with organic matter (adsorption). The adsorption processes may be reversed, leading to the release of nickel from the sediment.

Interdependence on other constituents

Information on the interdependence of nickel on other water quality properties and constituents could not be obtained.

Measurement in seawater

Nickel is determined in seawater by using sodium diethyldithiocarbamate/ chloroform extraction procedures prior to analysis on an atomic absorption spectrophotometer[40].

Units: µg l^{-1} as total Ni.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [(56)].

NICKEL continued on next page

Ni

NICKEL continued…

Pollution sources

Anthropogenic sources of nickel include [9]:

- emissions from the nickel mining and refining industry;
- burning of fossil fuels;
- sewage sludge;
- waste incineration;
- waste from the manufacturing asbestos and cement;
- waste from the electroplating industry;
- leachates from land fills;
- waste from steel production, copper-nickel alloy production and nickel-cadmium battery manufacturing.

Related problems

Typical water quality problems which may be associated with nickel include:

- mortalities.

For more details on problems refer to:

p 3-11

Effects of change and target values

Factual information on effects of different ranges of nickel on the natural environment, including target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-77
p 5-77
p 5-78

SILVER

Description

Silver exists principally in the +1 oxidation state as the $Ag\ CL_2^-$ complexes in seawater[25].

Natural occurrence

Silver probably has a nutrient-type chemistry which is substantially depleted in the surface waters relative to deep waters[25].

Concentration of silver in seawater with a salinity of $35x10^{-3}$ has been given as 0,1 $\mu g\ l^{-1}$ [25].

A range between $53{,}9 \times 10^{-6}$ and $3{,}78 \times 10^{-3}$ $\mu g\ l^{-1}$ with an average concentration of 0,003 $\mu g\ l^{-1}$ has been reported for the most probable species ($Ag\ Cl_2$) in seawater at a salinity of $35x10^{-3}$ [25].

A range between 0,01 and 0,08 $\mu g\ l^{-1}$ has been reported for dissolved silver in ocean water. Considerably higher concentrations (up to at least 0,5 $\mu g\ l^{-1}$) may occur in coastal waters[16].

Data on silver concentrations in South African coastal waters could not be obtained.

Fate in environment

Little information is available on the occurrence of silver in oceanic particulate matter, but it has been found that in some coastal waters, more than half the total silver content is associated with the particulate phases[16].

Silver will adsorb onto clay particles and other organic matter in river water and may be desorbed when it reaches the sea[16].

Bioaccumulation of silver has been reported [9,14].

Interdependence on other constituents

The solubility of silver decreases in anoxic waters due to the presence of hydrogen sulphide. Silver sulphide is very insoluble[16].

SILVER continued on next page

Ag

SILVER continued…

Measurement in seawater

Silver is determined in seawater by using sodium diethyldithiocarbamate/ chloroform extraction procedures prior to analysis on an atomic absorption spectrophotometer [40].

Units: $\mu g\ l^{-1}$ as total Ag.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [56].

Pollution sources

Anthropogenic sources of silver include [9]:

- waste water from the silver-plating industries e.g. plating of cutlery; jewellery and ornaments;
- the photographic industry;
- the food and beverage industries where silver metal is used;
- the porcelain and ink manufacturing industries where silver nitrate is used.

Treatability

Practical treatment methods for removing silver from seawater could not be obtained.

Related problems

Typical water quality problems which may be associated with silver include:

- changes in respiration patterns; p 3-6
- mortalities. p 3-11

For more details on problems refer to:

Effects of change and target values

Factual information on effects of different ranges of silver on the natural environment, including target values, are provided in Section 5 for:

- primary producers; p 5-79
- primary consumers; p 5-79
- secondary consumers. p 5-80

Refer to:

Sn

TIN (INORGANIC)

Description

Inorganic tin is accepted to be relatively non-toxic, probably because the metal does not react and the oxides are insoluble at physiological pH. To date, there has been no systematic study of the distribution of tin in the oceans. One of the reasons being that most common water samplers are constructed, at least in part, of poly (vinyl) chloride, which can be a major source of tin contamination due to the presence of organotin stabalisers [9].

Inorganic tin constitutes no hazard to human health, seafood or seawater [9].

The most probable species of inorganic tin in marine waters is $SnO(OH)_3^-$ [25].

Natural occurrence

A range between 0,0001 and 0,001 µg l^{-1}, with an average of 0,0005 µg l^{-1} has been reported for the most probable species ($SnO(OH)_3^-$) in oxygenated seawater with a salinity of $35x10^{-3}$ [25].

The concentration of dissolved tin in ocean waters has also been reported as being within the range of 0,5 and 3 µg l^{-1} [16]. The difference in concentrations, compared to the abovementioned values, may be due to analytical contamination problems (refer to *Description* above).

No data on background inorganic tin concentrations in South African coastal waters could be obtained.

Fate in environment

Information on the fate of inorganic tin in the marine environment could not be obtained.

Interdependence on other constituents

Information on the interdependence of inorganic tin on other water quality properties or constituents in the marine environment could not be obtained.

Measurement in seawater

Inorganic tin can be determined via hydride generation and atomic absorption spectrophotometry.

Units: µg l^{-1} Total Sn.

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [56].

TIN continued on next page

Sn

TIN continued...

Pollution sources	Anthropogenic sources of inorganic tin include [9]: - waste from tin plating of steel food cans, bearing alloys, solder, pewter, type metal, bell metal, bronze and phosphor bronze; - waste from PVC industries.	
Related problems	Typical water quality problems which may be associated with tin include: - mortalities.	For more details on problems refer to: p 3-11
Effects of change in water quality	Factual information on effects of different ranges of tin on the natural environment are provided in Section 5 for: - primary producers; - primary consumers; - secondary consumers. No target values for tin have been set for the South African coastal zone.	Refer to: p 5-81 p 5-81 p 5-81

Zn

ZINC

Description

Zinc occurs abundantly in nature and is comparatively non-toxic. In the marine environment the equilibrium species of zinc are Zn^{2+}, $ZnOH^{+}$, $ZnCO_3^{o}$, $ZnCl^{+}$ [25].

Zinc in the marine environment poses no health risk to man [28].

Natural occurrence

The average concentration of zinc for unpolluted seawater with a salinity of 35.10^{-3} has been given as 5 µg l^{-1} [39].

A range between 0,003 and 0,59 µg l^{-1}, with an average of 0,39 µg l^{-1}, has been reported for the most probable species (Zn^{2+}, $ZnOH^{+}$, $ZnCO_3^{o}$, $ZnCl^{+}$) in oxygenated seawater with a salinity of $35x10^{-3}$ [25].

The concentration of dissolved zinc in ocean water has also been reported as being within the range of 0,5 and 4 µg l^{-1} [16].

The average zinc concentration in South African surface marine waters has been reported as 6,59 µg l^{-1} [22]. A review of the metal concentrations in South African coastal water, sediments and marine organisms was undertaken by Hennig in 1985 [46].

Fate in environment

Information on the fate of zinc in the marine environment could not be obtained. Zinc does, however, play a major role in enzyme activities and carbohydrate metabolism [9].

Interdependence on other constituents

The toxicity of zinc is increased in the presence of cadmium [16].

The solubility of zinc decreases in anoxic water due to the presence of hydrogen sulphide. Zinc sulphide is very insoluble [16].

The speciation of dissolved zinc is very sensitive to pH changes. At a pH of 8,2 the principal species are Zn^{2+} and $Zn\ CO_3^{o}$ [16].

Bioaccumulation of zinc has been reported [9,14].

ZINC continued on next page

Zn

ZINC continued…

Measurement in seawater

Zinc is determined in seawater by using sodium diethyldithiocarbamate/ chloroform extraction procedures prior to analysis on an atomic absorption spectrophotometer [40].

Units: µg l^{-1} as total Zn .

Stripping voltammetry (cathodic or anodic) can also be used in the analysis of trace metals. The method is less prone to contamination since the samples need not be preconcentrated and it also allows for the determination of the valency of the metal ion [56].

Pollution sources

Anthropogenic sources of zinc include [9]:

- waste from zinc and brass metal works, zinc and brass plating, steel galvanisation, silver and stainless steel tableware manufacture;
- waste from viscose rayon yarn and fibre production;
- waste from battery production;
- waste from paint and dye manufacturing,
- anti corrosion in cooling towers;
- waste from pulp and paper manufacturing.

ZINC continued on next page

Zn

ZINC continued...

Related problems

Typical water quality problems which may be associated with zinc include:

- general growth deficiencies;
- lowered reproduction;
- changes in respiration patterns;
- changes in water pumping rates;
- mortalities;
- burrowing abnormalities.

For more details on problems refer to:

p 3-3
p 3-4
p 3-6
p 3-7
p 3-11
p 3-14

Effects of change and target values

Factual information on effects of different ranges of zinc on the natural environment , including target values, are provided in Section 5 for:

- primary producers;
- primary consumers;
- secondary consumers.

Refer to:

p 5-82
p 5-82
p 5-85

TBT

Chapter 4.4 Organic Constituents

ORGANOTINS (TRIBUTYLTIN)

Description

Organotins include many compounds characterised by the presence of a carbon-tin bond. There is a lack of data on most organotin compounds and discussion in literature is usually restricted to the three groups, methyltins, butyltins and phenyltins.. Tributyltin (TBT) compounds are organic derivatives of tetravalent tin [(49)].

Although inorganic tin is relatively non-toxic, organotin compounds especially tri- and tetra-alkyl derivatives present a serious hazard [(50)].

Natural occurrence

TBT is not a natural component of seawater [(49)].

Fate in environment

The solubility of TBT in water is low, varying from less than 1,0 mg l^{-1} to greater than 100 mg l^{-1} according to the pH, temperature and anions present in the water. (which determine speciation). In seawater and under normal conditions, TBT exists as three species (hydroxide, chloride, and carbonate), which remain in equilibrium. At pH values less than 7,0, the predominant forms are $BuSnOH_2^+$ and Bu_3 SnCl, while at a pH of 8, they are Bu_3 SnCl, Bu_3 SnOH and Bu_3 $SnCO_3^-$ and at pH values above 10, Bu_3 SnOH, and Bu_3 $SnCO_3^-$ predominate[(49)].

As a result of its low water solubility and lipophylic character, TBT adsorbs readily onto particles. Progressive disappearance of adsorbed TBT is not due to desorption but to degradation. The degradation of TBT involves the splitting of the carbon-tin bond. This can result from various mechanisms occurring simultaneously in the environment including physico-chemical mechanisms (hydrolysis and photodegradation) and biological mechanisms (degradation by micro-organisms and metabolism by higher organisms) [(49)].

TBT bioaccumulates in organisms because of its solubility in fat. Bio-concentration factors up to 7 000 have been reported in laboratory investigations with molluscs and fish, and higher values have been reported in field studies [(49)].

It is known that TBT degradation rates in sediments are slower than in the water column, particularly in anaerobic conditions [(49).]

Interdependence on other constituents

The degree of adsorption of TBT onto particles depends on the salinity, nature and size of particles in suspension, amount of suspended matter, temperature, and the presence of dissolved organic matter [(49)].

TBT continued on next page

TBT

TBT continued...

Measurement in seawater

Tributyltin can be measured with gas chromatography or by using atomic absorption spectrophotometry[51].

Units: µg l^{-1} or ng l^{-1}.

Pollution sources

Tributyltin compounds have been registered as[49]:

- molluscicides;
- antifoulants on boats, ships, quays, bouys, crab pots, fish nets and cages;
- wood preservatives;
- slimicides on masonry;
- disinfectants;
- biocides for cooling systems, power station cooling towers, pulp and paper mills, breweries, leather processing and textile mills.

High levels of TBT in water, sediment, and biota have been found close to pleasure boating activities, especially in or near marinas, boat yards and dry docks. In the proximity of pleasure boating (especially marinas), TBT levels have been found to reach 1,58 ug l^{-1} in seawater, 26 300 µg kg^{-1} in coastal sediments, 6,39 mg kg^{-1} in bivalves, 1,92 mg kg^{-1} in gastropods, and 11 mg kg^{-1} in fish[49].

Algicidal concentrations of TBT range from less than 1,5 to 1 000 µg l^{-1} [49].

TBT continued on next page

TBT

TBT continued...

Related problems	Typical water quality problems which may be associated with tributyltin include:	For more details on problems refer to:
	- general growth deficiencies;	p 3-3
	- lowered reproduction;	p 3-4
	- shell deformation;	p 3-9
	- mortalities;	p 3-11
	- abnormalities in movement.	p 3-13
Effects of change in water quality	Factual information on effects of different ranges of tributyltin on the natural environment are provided in Section 5 for:	Refer to:
	- primary producers;	p 5-87
	- primary consumers;	p 5-88
	- secondary consumers.	p 5-90

TPH

TOTAL PETROLEUM HYDROCARBONS (TPH)

Description

Crude oils and oil products are extremely complex mixtures, predominantly hydrocarbons comprising all structural elements such as straight and branched carbon chains, saturated and aromatic rings, in all possible combinations [19].

Petroleum hydrocarbons contain a wide range of substances that are potential health hazards. These include aliphatic compounds, monocyclic aromatics, polycyclic aromatics and heavy metals. Most petroleum products have an objectionalbe taste and odour well below the level that might induce chronic toxicity in humans.

Generally, oil is lighter than water and tends to spread fairly rapidly, forming a thin layer which is moved over the surface by the influence of winds and tides. A much smaller amount can dissolve in water, known as the water soluble fraction (WSF) [9]. It is usually the WSF that is of most interest from an ecological point of view.

Polycyclic aromatic hydrocarbons (PAHs) are always formed when organic material containing carbon and hydrogen is subjected to temperatures exceeding 700 ^{o}C, i.e. in pyrolytic processes and with incomplete combustion [28].

PAHs can be grouped into two classes :

- lower molecular weight 2-3 ring aromatics, e.g. naphthalene, fluorenes, phenanthrene and anthracene which are volatile and relatively toxic compounds;

- higher molecular weight 3-4 ring aromatics, e.g. chrysene which is not acutely toxic but has been proven carcinogenic.

The toxicity of PAHs to marine organisms is highly variable, depending on species, compound and environmental conditions.

Natural occurrence

Hydrocarbons in seawater do not only result from human activities, but are also a consequence of biological processes. In contrast to mineral oils and their products, biogenic hydrocarbon mixtures are much less complex in composition [19].

Aromatic hydrocarbons have been shown to be biosynthesised by marine organisms [19]. PAHs are fairly abundant among fossil hydrocarbons, however, they has never been demonstrated unambiguously to be products of biosynthesis [19].

TPH continued on next page

Fate in environment

In temperate and tropical areas, oils are biodegradable and also polymerised; under the action of light and oxygen, density increases and the particles may become sufficiently dense as to sink. In very cold waters, the rate of biodegradation appears to be very low [9].

Sorption to suspended particulate matter and eventual deposition on the shore with other natural processes tend to remove the oil introduced to coastal waters. Oils with a high wax content or which are very viscous do not degrade so rapidly and are frequently found on beaches as lumps or tar balls [9].

It appears that all the hydrocarbons which are naturally present in petroleums can be degraded under certain conditions. It is questionable if any of the natural compounds in petroleums are persistent in water at low concentrations, yet many questions are still to be answered [9] .

During the degradation of petroleum hydocarbons, dissolved oxgen levels in the water are reduced, which may subsequently, also have an impact on marine life [9].

The overall environmental fate of PAHs depends on several factors such as solubility, adsorbtivity, photolysis, oxidation and volatilisation. The rate of the various transformation and removal processes in the environment depends on the physical and chemical properties of the individual compounds. Solubility and adsorbtivity are the most important physical properties in this context. Although the solubility of pure PAH in water is extremely low, these compounds can be solubilised by other organic substances, particularly detergents. PAHs can also form associates with colloids present in water and can be transported through water in this form [28].

Amongst the chemical properties, photochemical reactivity is particularly relevant. Tricyclic and larger PAHs have strong UV absorption at wavelengths longer than 300 mm and most are readily photooxidised [28].

Bacteria have also been reported to oxidise PAHs that range in size from benzene to benzo[a]pyrene, but for the more highly condensed PAHs this is not clear [28].

Bioaccumulation of hydrocarbons has been reported (58,59). The extent of accumulation depends on factors such as the exposure concentration, the time of exposure and the lipid content of the organsism tissue. Depuration rates of accumulated petroleum hydrocarbons from organism tissues are higher after short periods of exposure compared to chronic exposure.

TPH continued on next page

TPH

TPH continued..

Interdependence on other constituents

The toxicity of petroleum hydrocarbons varies greatly with temperature [9].

Oxidation or degradation of petroleum hydrocarbons is dependent on ambient dissolved oxygen concentrations [9].

The rate of sorption of TPH to sediments is dependent upon temperature and organic content of the sediment.

The interdependence of PAHs, in particular, on other constituents, is not well documented.

Measurement in seawater

A number of techniques exists for the analysis of petroleum hydrocarbons, which include:

- spectrofluorimetric analysis [9];
- gas cromatography;
- high-pressure liquid chromatography (HPLC).

Units: mg l^{-1} or µg l^{-1}.

Pollution sources

Anthropogenic sources of petroleum hydrocarbons include:

- accidental oils spills;
- stormwater run-off from roads;
- illegal disposal from ships;
- harbour activities;
- industrial processes where incomplete combustion of oil or other carbonaceous compounds occur;
- domestic heating.

TPH continued on next page

Related problems	Typical water quality problems which may be associated with TPH include:	For more details on problems refer to:
	- eutrophication;	p 3-1
	- general growth deficiencies;	p 3-3
	- mortalities.	p 3-11
Effects of change in water quality	Factual information on effects of different ranges of TPH on the natural environment are provided in Section 5 for:	Refer to:
	- primary producers;	p 5-92
	- primary consumers;	p 5-93
	- secondary consumers.	p 5-94
	No target values for TPH have been selected for the South African coastal zone.	

i

REFERENCES

1. SHANNON, L.V. 1985. The Benguela Ecosystem. Part 1. Evolution of the Benguela, physical features and processes. *Oceanogr. Mar. Biol. Ann. Rev.* **23**: 105-182.

2. NELSON, G. and HUTCHINGS, L. 1983. The Benguela upwelling area. *Prog. Oceanogr.* **12**: 333-356.

3. BOYD, A., TROMP, B.B.S. and HORSTMANN, D.A. 1985. The hydrology off the South African south-western coast between Cape Point and Danger Point in 1975. *S. Afr. J. mar. Sci.* **3**: 145-168.

4. BROWN, P.C. 1992. Spatial and seasonal variation in chlorophyll distribution in the upper 30 m of the photic zone in the southern Benguela/Agulhas ecosystem. *S. Afr. J. mar. Sci.* **12**: 515-526.

5. ANDREW, W.R.H. and HUTCHINGS, L. 1980. Upwelling in the southern Benguela system. *Prog. Oceanog.* **9**: 1-18.

6. MONTEIRO, P.M.S. and BRUNDRIT, G.B. (in press). Shelf/Bay interactions in the southern Benguela upwelling system: Implications for eutrophication.

7. SHANNON, L. V. 1989. The physical environment. In: *Oceans of life*. Payne, A.I.L and Crawford, R.J.M. (Eds.) Vlaeberg Publishers, Cape Town.

8. SCHUMANN, E.H., 1988. Physical oceanography off Natal. In : *Coastal Ocean Studies off Natal*. Schumann, E.K. (Ed). Springer - Verlag. p 101 - 130

9. WORLD HEALTH ORGANIZATION. 1982. *Waste discharge into the marine environment.* Principles and guidelines for the Mediterranean action plan. Published under the joint sponsorship of the World Health Organization and the United Nations Environment Programme. Pergamon Press. 422 pp.

10. HAWKINS, A D. 1981. *Aquarium systems*. Academic Press.

11. MILLERO, F.J. and SOHN M.L. 1992. *Chemical Oceanography*. CrC Press, Florida, USA. ISBN 0-8439-8840-6. 531 pp.

12. SHANNON, L.V. and STANDER, G.H 1977. Physical and chemical characteristics of water in Saldanha Bay and Langebaan Lagoon. *Trans. roy. Soc. S. Afr.* **42:** 441-459.

13 EAGLE, G.A. and ORREN, M.J. 1985. A seasonal investigation ot the nutrients and dissolved oxygen in the water column along tow lines of stations south and west of South Africa. *CSIR Research Report* **567**. 52 pp plus figures and tables.

REFERENCES continued on next page

REFERENCES continued...

14. OPEN UNIVERSITY. 1989. *Seawater: Its composition, properties and behaviours*, S 330, Volume 2. Published in association with Pergamon Press.

15. HUGUENIN, J.E. and COLT, J. 1989. Design and operating guide for aquaculture seawater systems. In: *Developments in Aquaculture and Fisheries Science*, Volume 20. Elsevier.

16. RILEY, J.P. and SKIRROW, G. 1975. *Chemical Oceanography*, 2nd edition, Volume 3. Academic Press, London.

17. STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. 1989. 17th edition. Lenore, S.C., Greenberg, A.E. and Trussel, R.R. (Eds.). ISBN 0-87553-161-X.

18 CHAPMAN, P. and SHANNON, L.V. 1985. The Benguela ecosystem Part II. Chemistry and related processes. *Oceanogr. Mar. Biol. Ann. Rev.* **23**: 183-251.

19. GRASSHOFF, K., EHRHARDT, M. and KREMLING, K. (Eds.). 1983. *Methods of Seawater Analysis.* Verlag Chemie, Weinheim.

20. BRANCH, G. and BRANCH, M. 1981. *The liivng shores of southern Africa.* C Struik, Cape Town. 272 pp.

21. BENSON, B.B. and KRAUSE, D. (Jr) 1984. The concentration and isotopic fractionation of oxygen dissolved in fresh water and seawater in equilibrium with the amosphere. *Limnol. Oceanogr.* **29**: 620.

22. LUSHER, J.A.(ed.) 1984. Water quality criteria for the South African coastal zone. *South African National Scientific Programmes Report* No **94**. 25 pp.

23. GRASSHOFF, K., EHRHARDT, M. and KREMLING, K. (Eds.). 1976. *Methods of Seawater Analysis.* Verlag Chemie, Weinheim.

24. ORREN, M.J., EAGLE, G.A., FRICKE, A.H., GLEDHILL, W.J., GREENWOOD, P.J. and HENNIG, H. F-K. O. 1981. The chemistry and meiofauna of some unpolluted sandy beaches in South Africa. *Water SA* **7**(4): 203-210.

25. RILEY, J.P. and CHESTER, R. 1983. *Chemical Oceanography*, Volume 8. Academic Press, London.

26. BAILEY, G.W. (1985). Distribution and cycling of nutrients at four sites in the Benguela system. *Int. Symp. Upw. W Afr., Inst. Inv. Pesq. Barcelona* **1**: 305-317.

27. CARTER, R.A. and D'AUBREY, J. 1988. Inorganic nutrients in Natal continental shelf waters. In: *Coastal Ocean Studies off Natal*. E. K. Schumann (Ed). Springer-Verlag. p 131 - 151

REFERENCES continued on next page

i

REFERENCES continued...

28. HUTZINGER, O. (Ed.) 1980. *The handbook of environmental chemistry*. Volume 1, Part A. Springer Verslag, Berlin.

29. OPEN UNIVERSITY. 1989. *Ocean chemistry and deap-sea sediments*, S330. Volume 5. Published in association with Pergamon Press.

30. BOWER, C.E. and BIDWELL, J.P. 1978. Ionization of ammonia in seawater: Effects of temperature, pH, and salinity. *J Fish Res. Board Can.,* Vol **35**: 1012-1016.

31. HUTZINGER, O. (Ed.) 1984. *The handbook of environmental chemistry*, Volume ,1 Part C. Springer Verslag, Berlin.

32. LORD, D.A. and GELDENHUYS, N.D. (Eds.) 1986. Richards Bay effluent pipeline. *South African National Scientific Programmes* Report N. **129**.

33. GOMEZ, M.G., CORVILLO, M.A.P. and RICA, C.C. 1988. *Analyst* **113**: 1109-1112.

34. ABARNOU, A. and MOISSEC, L. 1992. Chlorinated waters discharged to the marine environment chemistry and environmental impact - An overview. *The science of the total environment* **126**: 173-197. Elsevier, Amsterdam.

35. THE MERCK INDEX. 1983. Tenth edition. Merck and Co Inc. USA.

36. MILLERO, F.J. 1976. The thermodynamics and kinetics of the hydrogen sulphide system in natural Waters. *Marine Chemistry* **18**: 121-147.

37. DOUABUL, A.A. and RILEY, J.P. 1979. The solubility of gases in distilled water and seawater. Hydrogen sulphide. *Deep Sea Research* **26** (A): 259-268. Pergamon Press.

38. CSIR. 1981. Richards Bay ocean outfall. Final report. *CSIR Report* **C/SEA 8116**. 78 pp.

39. RILEY, J.P. and CHESTER, R.C. 1976. *Chemical Oceanography*. 2nd edition. Volume 6. Academic Press, Londen.

40. WATLING, R.J. (compiler) 1981. A manual of methods for use in the South African marine pollution monitoring programme. *South African National Scientific Programme Report* No **44**.

41. HUTZINGER, O. (Ed.) 1982. *The handbook of environmental chemistry*, Volume 3, Part B. Springer Verslag, Berlin.

42. WORLD HEALTH ORGANIZATION. 1981. Arsenic*. Environmental health criteria series* **18**, Geneva, Switzerland.

REFERENCES continued on next page

i

REFERENCES continued...

43. BAILEY, R. A., CLARKE, H.M., FERRIS, J.P., KRAUSE, S. and STRONG, R.L. 1978. *Chemistry of the environment*. Academic Press, New York, USA.

44. WORLD HEALTH ORGANIZATION. 1992. Cadmium. *Environmental aspects/environmental health criteria* **135**. Geneva, Switzerland.

45. WORLD HEALTH ORGANIZATION. 1988. Chromium. *Environmental health criteria series* **61**. Geneva, Switzerland.

46. HENNIG, H.F-K.O. 1985. Review of metal concentrations in southern African coastal waters, sediments and organisms. *South African National Scientific Programmes Report* No **108**. 140 pp.

47. WORLD HEALTH ORGANIZATION. 1989. Mercury. *Environmental aspects/environmental health criteria series* **86**. Geneva, Switzerland.

48. WORLD HEALTH ORGANIZATION. 1991. Nickel. *Environmental health criteria series* **108**. Geneva, Switzerland.

49. WORLD HEALTH ORGANIZATION. 1990. Tributyltin Compounds. *Environmental health criteria series* **116**. Geneva, Switzerland.

50. HEARD, C. S. 1989. Aquatic Toxicological Effects of organotins: An overview . *Oceans* **22**: 554-563.

51. WALDOCK, M.J., WAITE, M.E., MILLER, D., SMITH, D.J. and LAW, R.J. 1989. Ministry of Agriculture, fisheries and food, directorate of fisheries research, aquatic environmental protection: *Analytical Methods* **4**. Lowestoft, UK.

52. NEFF, J.M. and ANDERSON, J.W. 1981. *Response of marine animals to petroleum and specific petroleum hydrocarbons*. Applied Science Publishers Ltd. Barking, England. 177 pp.

53. RILEY, J.P. and SKIRROW, G. 1975. *Chemical Oceanography*. 2nd edition. Volume 2. Academic Press , London.

54. RILEY, J.P. and CHESTER, R.C. 1978. *Chemical Oceanography*. 2nd edition. Volume 7. Academic Press, London.

REFERENCES continued on next page

i

REFERENCES continued...

55. RILEY, J.P. and CHESTER, R.C. 1976. *Chemical Oceanography*. 2nd edition. Volume 5. Academic Press, London.

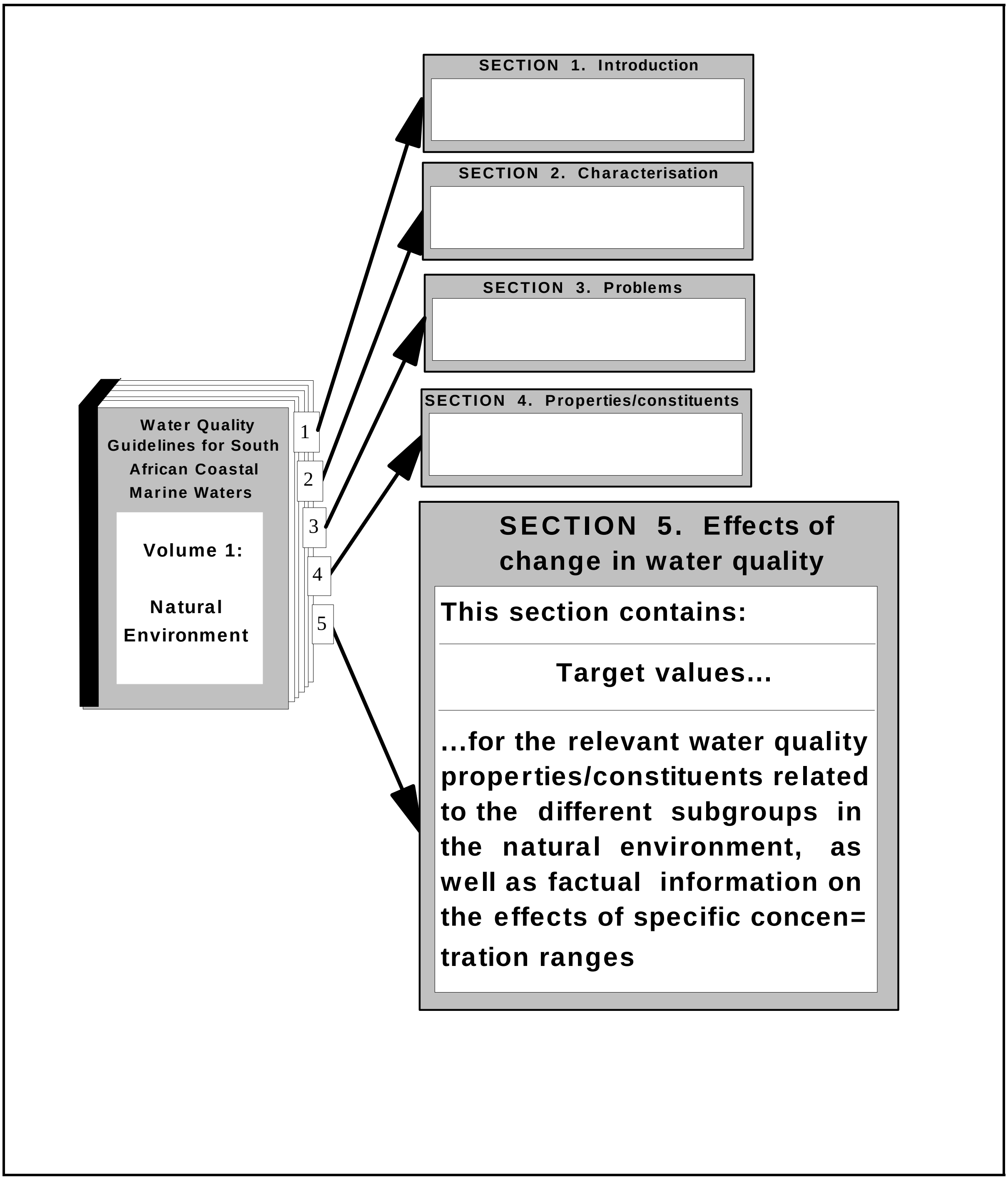
56. RILEY, J.P. and SKIRROW, G. 1975. *Chemical Oceanography*. 2nd edition. Volume 4. Academic Press , London.

57. WRIGHT, D.A. and DAVISON, A.W. 1975. The accumulation of fluoride by marine and intertidal animals. *Environ. Pollut.* **8**: 1-13.

58. MASON, R.P. 1988. Accumulation and depuration of petroleum hydrocarbons by black mussels. 1. Laboratory exposure trials. *S. Afr. J. mar. Sci*. **6**: 143-153.

59. MASON, R.P. 1988. Accumulation and depuration of petroleum hydrocarbons by black mussels. 2. Depuration of field exposed mussels. *S. Afr. J. mar. Sci*. **6**: 155-162.

SECTION 5: EFFECTS OF CHANGE IN WATER QUALITY ON THE NATURAL ENVIRONMENT (INCLUDING TARGET VALUES)



SECTION 5: EFFECTS OF CHANGE IN WATER QUALITY
CONTENTS

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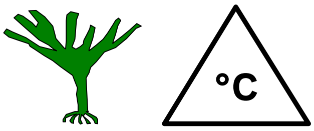


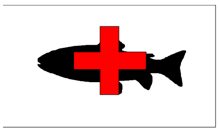
Chapter 5.1 Physico-chemical Properties

TEMPERATURE (Refer to p 4-1)

NOTE:	**The west, south and east coasts of South Africa have distinctly different temperature regimes. Typical seasonal temperature patterns are discussed in more detail in Section 4, p 4-1. The biota of the different regions are acclimated to the typical conditions and will therefore react differently to changes in temperature. For this reason, the data provided below are organised according to coastal regions.**

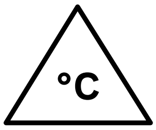
Primary producers

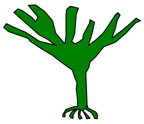
(Refer to p 2-12, 2-22, 2-34 and 2-43)

RANGE (°C)	 **Growth Stimulation**	 **Biological Health**
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1 °C		
West Coast:		
10-17		The optimum temperature range reported for the alga: *Porphyra** [3]
11-25		The alga: *Gracilaria verrucosa** grew best in this range[5]
12-15		Conditions were generally good for diatom population development [6]
> 15	Higher biomass diatom-dominated populations were replaced by lower biomass, flagellate-dominated populations [6]	

* Species found in South African marine waters

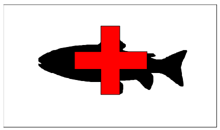
TEMPERATURE continued on next page





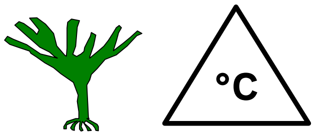
TEMPERATURE continued...

Primary producers *continued...*

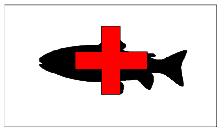
RANGE (°C)	 **Growth Stimulation**	 **Biological Health**
***West Coast** continued...:*		
> 26		The alga: *Gracilaria* spp.* became sensitive [11]
> 30		The growth rate in alga: *Skeletonema costatum** was affected significantly [10] Mortalities occurred in alga: *Gracilaria verrucosa** [5]
Ambient +6	Caused increased growth in the alga: *Laminaria palllida** [13]	Caused increased mortality in the alga: *Laminaria pallida** [13]
South and East Coasts:		
No data could be obtained		
Additional data from international sources:		
15-21		Landing (washed up on beach) of the kelp: *Lessonia nigrescens* decreased to well below the pre-ENSO level [8]
16-33,5		Tolerable range reported for the alga: *Alexandrium tamarense* [9]

* Species found in South African marine waters

TEMPERATURE continued on next page



Primary producers *continued...*

RANGE (°C)	 **Growth Stimulation**	 **Biological Health**
***Additional data** continued...:*		
25	The growth rate increased markedly in the dinoflagellate: *Prorocentrum lima* (2)	
28		Optimum level reported for the alga: *Alexandrium tamarense* (9)
37		The facultative chemolithoautotroph (bacteria), *Thiobacillus thyasiris* (found on the gills of marine bivalves) showed optimal growth at this temperature (12)

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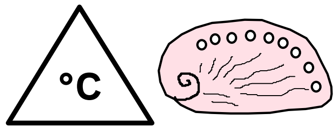
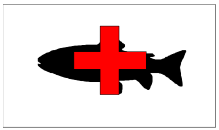
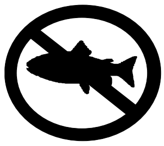


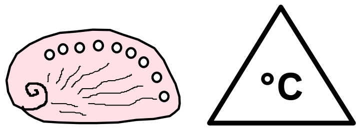
TEMPERATURE continued...

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

RANGE (ºC)	 Biological Health	 External Responses
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1 ºC		
West coast:		
8-24	Overall environmental tolerance temperature range reported for the abalone: *Haliotis midae** (21)	No data could be obtained
8-30	The mussel: *Choromytilus meridionalis* *(adults) survived in this range (62)	
< 12	Fecundity in zooplankton: *Calaniodes carinatus** was greatly reduced (6)	
12,5	Optimum level reported for the mussel: *Choromytilus meridionalis** (adults) (62)	
12,5-30	Metabolism increased in the mussel: *Choromytilus meridionalis**, feeding rates declined and growth was affected (62)	
> 15	Fecundity in zooplankton: *Calaniodes carninatus** was greatly reduced (6)	
> 16	The abalone: *Haliotis midae** grew best (CSIR observation)	
17-22	The growth rate of the black mussel: *Mytilus galloprovincialis* *(adults) was generally more sensitive to increasing environmental temperatures. In this range it outcompeted *Choromytilus meridionalis** and *Aulacomya ater** (30)	

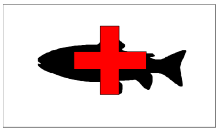
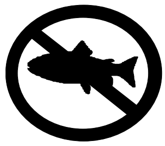
* Species found in South African marine waters

TEMPERATURE continued on next page



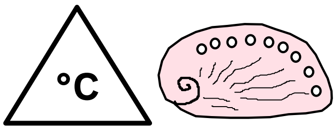
TEMPERATURE continued...

Primary consumers *continued...*

RANGE (°C)	 **Biological Health**	 **External Responses**
West coast *continued...:*		
24-29	Extended exposure resulted in 50% of the white mussel: *Donax serra** (adults) not burrowing (thus exposing them to predation) (31)	No data could be obtained
< 26	No effect reported for the white mussel: *Donax serra** (adults) (32)	
> 26	Caused acute temperature stress in the abalone: *Haliotis midae** (adults)(33). The onset of mortalities due to temperature were abrupt, usually 1-2 °C (30)	
> 32	Lethal temperature range reported for all sizes of the white mussel: *Donax serra** (adults) (31)	
Ambient +6	Survival rate did not change for the mussel: *Choromytilus meridionalis** (adults) (13) Survival of the mussel: *Aulacomya ater** (adult) was reduced (13) Survival of the mussels: *Choromytilus meridionalis** (juveniles) and *Aulacomya ater** (juvenile) was much reduced (13)	

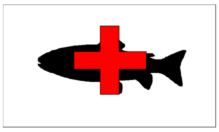
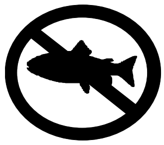
* Species found in South African marine waters

TEMPERATURE continued on next page



TEMPERATURE continued...

Primary consumers *continued...*

RANGE (ºC)	 Biological Health	 External Responses
South and East Coasts:		
No data could be obtained		
Additional data from international sources:		
6-24	No detrimental effect on fertilization in surf clam: *Spisula solidissima* (spermatozoa and ootcytes)[16]	No data could be obtained
7-15 and 20	The larvae of the bivalve: *Mytilus edulis* (eyed-veliger stage) concentrated towards light, but at 20 ºC they became more generally distributed, i.e. less photopositive [40]	
<8	Growth ceased in oyster: *Crassostrea gigas* (adults) [17-20]	
8-31	The oyster: *Crassostrea virginica* survived (feeding and growth) in this range [42,43]	
8-34	Tolerable range reported for oyster: *Crassostrea gigas* (adults)[17-20]	
< 10	Negative impact reported on the growth and evolution of biochemical contents in the oyster: *Crassostrea gigas* [23]	
14-28	The oyster: *Crassostrea virginica* survived anoxic conditions for 18 days in this range [50]	
15-18	Optimum range reported for the oyster: *Crassostrea gigas* (adults)[17-20]	
>15	Favourable range reported for the breeding of the oyster: *Ostrea edulis* [52]	
16-20	Breeding in the oyster: *Crassostrea virginica* only commenced above these levels [42,43]	

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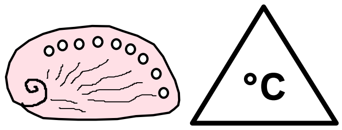

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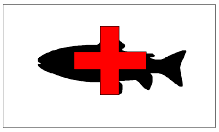
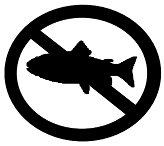
Primary consumers *continued...*

RANGE (°C)	 **Biological Health**	 **External Responses**
***Additional data** continued...:*		
16-26	Reduction in lysomal latency of coelenterate tissue reported in the anemone: *Anenomia viridis* (26)	No data could be obtained
> 17-18	Range required to trigger spawning (often not desirable) in the oyster: *Crassostrea gigas* (adults) (28)	
18-25	Temperature range in which the bivalve: *Solemya* spp. occurred among seagrass beds(29)	
23,5	Upper thermal limit reported for the sea urchin: *Strongylocentrotus purpuratus* (58)	
26,8-31,4	The oyster: *Crassostrea virginica* survived anoxic conditions for seven days in this range(50)	
>30	Negative impact reported on the growth and evolution of biochemical contents in the oyster: *Crassostrea gigas* (23)	
>34	Resulted in death among the oysters: *Crassostrea gigas*(17-20)	

TEMPERATURE continued on next page

TEMPERATURE continued ...

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

RANGE (ºC)	**Biological Health**	**External Responses**
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1 ºC		
West coast:		
13,5-17,5	Generally, this range showed little influence on purse-seine catches of the chub-mackerel: *Scomber japonicus**, except in the Namaqualand area where catches declined [54]	No data could be obtained
14	Oocytes in the pilchard: *Sardinops sagax** were heavier when temperature in the northern Benguela was at its lowest (winter/spring) [48]	
14-18	Lower lethal limit reported for the galjoen: *Dichistius capensis* * (larvae and eggs) [49]	
16-18	Ideal range reported for spawning of anchovy: *Engraulis capensis** on the Aghulas bank [53]	
18	The biomass of the demersal fish: *Merluccius capensis*, Austroglossus microlepis** and *Lophius vomerinus** was distinctly higher in warmer water [55]	
19	The Cape lobster: *Jasus lalandii** (adults) appeared stressed and showed a reduction in respiration rate [56]	
29 ±1	Upper lethal temperature reported for the mud prawn: *Upogebia africana** (adults) [34]	

* Species found in South African marine waters

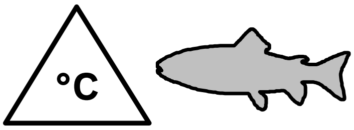
TEMPERATURE continued on next page

Secondary consumers *continued...*

RANGE (ºC)	Biological Health	External Responses
***West coast** continued...:*		
2-4 above normal	Favoured pilchard: *Sardinops sagax** and anchovy: *Engraulis capensis** above Cape hake: *Merluccius* spp.* (67,68)	
Ambient +5	Increased fecundity in the mud prawn: *Upogebia africana** (adults) through changes in sex ratio, the more rapid attainment of large sized females and the consequent increase in the number of eggs produced (34)	
South coast:		
< 10	An increase in respiration rate was reported for the crabs: *Cyclograpsus punctatus** and *Sesarma catenata**, attributed to stress experienced by the organisms in these cold conditions (24)	No data could be obtained
10	High mortality reported in the shrimp: *Palaemon pacificus* *(adults) (44)	
16-18	Ideal range reported for spawning of anchovy: *Engraulis capensis** on the Aghulas bank (53)	
17	Lethal level reported for the fish: *Maurolicus muelleri* * (eggs) (27)	
25	Most favourable temperature reported for the shrimp: *Palaemon pacificus** (adults) (44)	

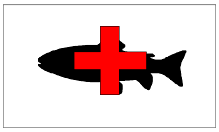
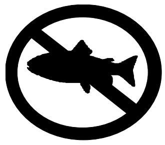
* Species found in South African marine waters

TEMPERATURE continued on next page



TEMPERATURE continued ...

Secondary consumers *continued...*

RANGE (ºC)	 **Biological Health**	 **External Responses**
East coast:		
Drop in temperature	Lower temperatures resulted in a drop in catches of the Blacktip shark: *Carcharhinus limbatus** [35]	No data could be obtained
< 10	An increase in respiration rate reported for the crabs: *Cyclograpsus pucntatus** and *Sesarma catenata**, attributed to stress experienced by the organisms in these cold conditions [24]	
11-39	The shrimp: *Penaeus indicus** was capable of tolerating this range if allowed gradual acclimation[46]	
24-34	Optimum temperature range reported for shrimp: *Penaeus monodon** (adults)[60,61]	
25-30	Optimum temperature range reported for the shrimps: *Penaeus monodon** and *Penaeus indicus** (adults) [60,61]	
26-30	Optimum temperature range reported for the prawn family: Penaeidae (adults)[63]	
27 ± 1,5	Optimum temperature range reported for the prawn family: Penaeidae (adults)[61]	
27-29	Optimum temperature range reported for the prawn family: Penaeidae (larvae)[63]	

* Species found in South African marine waters

TEMPERATURE continued on next page

Secondary consumers *continued...*

RANGE (ºC)	Biological Health	External Responses
***East coast** continued...:*		
27,9 ± 0,01	Optimum range required for maturation of broodstock in the prawn family: Penaeidae (65)	
26-31	Optimum temperature range reported for the prawn family: Penaeidae (larvae), where sudden changes in temperature should not exceed 2 ºC(60)	
Additional data from international sources:		
Low	Affected growth in the spiny lobster: *Panulirus polyphagus* in that the intermoulting duration was prolonged (36) Affected water balance through impact on 'drink' rate (osmotic balance) in fish: *Salmo salar* (adults), while high temperatures did not (37)	No data could be obtained
0-18	Optimal range reported for the barnacle: *Balanus balanoides* (outside this range they cannot feed efficiently) (38)	
5-10	Although the polychaete: *Nereis succinea* (temperate zones) survived in this range, feeding was totally inhibited. Positive feeding response was only triggered at 15-20 ºC (39)	
5-30	Optimal range reported for the barnacle: *Chthamalus stellatus* (outside this range they cannot feed efficiently) (38)	
8,5-9,7	Reduced ovulation and spermiation in the Sable fish: *Anoplopona fimbria* and Pacific halibut: *Hippogrossus stenolepis* (41)	

TEMPERATURE continued on next page

TEMPERATURE continued ...

Secondary consumers *continued...*

RANGE (°C)	**Biological Health**	**External Responses**
***Additional data** continued...:*		
10	The shrimp: *Penaeus aztecus* (post larvae) survived at this temperature at a salinity of 35, but not at a salinity of 8 [78]	No data could be obtained
10-20	The boring gastropod: *Urosalpinx cinerea* was capable of locomotor activity at 10, and drilled oysters at 15, but oviposition did not take place until temperatures reached 20 °C [4]	
Sudden change from 10 to 24,5	The LD_{50} for the Spring salmon: *Oncrohynchus ishawytscha* was 650 minutes [45]	
Sudden change from 10 to 26	The LD_{50} for the Spring salmon: *Oncrohynchus ishawytscha* was 90 minutes [45]	
12-14	Optimum range reported for the Atlantic salmon (adults)[151]	
12,1-16,9	Favourable range reported for the squid: *Illex argentinus* (larvae) measured in surface water during winter [47]	
< 14	Lethal range reported for the American lobster if dissolved oxygen is below 3 mg l^{-1} [7]	
15	No oocyte development took place in the scallop: *Aequipecten irradians* [51]	
15-30	Growth rate increased in the crab: *Callinectes sapidus* (juveniles) with increase in temperature [25]	
20	No hatching of eggs from the fish: *Sillago japonica* recorded [57]	
> 20	Unsuitable range for the Atlantic salmon (adults)[151]	

TEMPERATURE continued on next page

Secondary consumers *continued...*

RANGE (ºC)	Biological Health	External Responses
***Additional data** continued...:*		
22-32	Viable hatching occurred in eggs from the fish: *Sillago japonica* (57)	No data could be obtained
24	Suppressed growth in the spiny lobsters: *Panulirus argus* (post larvae) due to prolonged intermoulting periods and reduced size increments with each moult (59)	
> 24	Lethal range reported for the American lobster (7)	
> 27,5	100% mortality occurred in the fish eggs of *Cyprinodon macularis* in hypoxial water (64)	
29-30	Optimal growth of the spiny lobsters: *Panulirus argus* (post larvae) was reported for this range (59)	
32	No hatching in eggs from the fish: *Sillago japonica* recorded (57)	
> 36	100% mortality occurred in the fish eggs of *Cyprinodon macularis* in fully saturated water (64)	
37	Survival time of the polychaete worm: *Clymenella torquata* was markedly less at low salinity (66)	
High	Accelerated the early growth in the squid: *Illex illecebrosus, Todarodes pacificus, Illex argentinus, Illex coindetti* and *Todarodes angolensis*. It also accelerated sexual maturation and reduced adult growth rate by shifting the balance between metabolic and feeding rates (69)	
Abnormal increases	The density of the octopus: *Octopus* spp. increased about 100 fold after temperature increased in northern Chile due to El Nino (8)	

SALINITY (Refer to p 4-3)

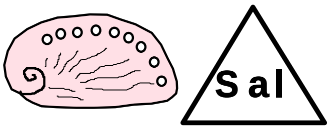
(Refer to p 4-3)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

RANGE	Biological Health
33×10^{-3}-36×10^{-3}	**Target range for the South African coastal zone** [1]
Hypo	Hypo salinity resulted in mass mortalities of animals, after which a flush of algal growth, e.g. *Enteromorpha** and *Ulva**, was reported [70]
Hypo/hyper	These salinity ranges had an impact on *Ulva lactuca**. This species was susceptible to rapid changes in salinites [71]
Gentle decline	Initially stimulated photosynthesis in the alga: *Cladophora rupestris,* but eventually inhibited photosynthesis as hypo-osmotic stress became greater [72]
Abrupt decline	Strongly inhibited photosynthesis in *Cladophora rupestris* during the period of low salinity and showed only partial recovery after re-immersion in new seawater, indicating damage to the photosynthetic apparatus [72]
Lower than natural levels	Increased growth reported in *Gracilaria millardetti* [14]
5×10^{-3}-40×10^{-3}	Tolerable range reported for the alga: *Alexandrium tamarense* (Taiwan) [9]
6×10^{-3}-12×10^{-3}	Maximum growth occurred in alga: *Fucus ceranoides* in terms of length and weight [74]
9×10^{-3}-45×10^{-3}	Tolerable salinity range reported for the alga: *Gracilaria verrucosa** [5]
10×10^{-3}-35×10^{-3}	Ideal range reported for the alga: *Alexandrium tamarense* (Taiwan) [9]
< 15×10^{-3}	Significantly affected growth in the alga: *Skletonema costatum* * [10]
> 30×10^{-3}	Significantly affected growth in the alga: *Skletonema costatum** [10]
45×10^{-3}	Minimum growth occurred in alga: *Fucus ceranoides* in terms of length and weight [74]
Wide range	The alga: *Gracilaria tenuistipitata* was able to survive in a wide salinity range (euryhaline) [75]

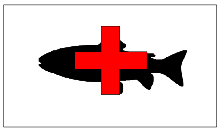
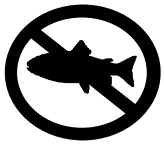
* Species found in South African marine waters

SALINITY continued on next page



SALINITY continued...

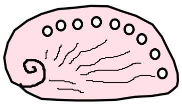
Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

RANGE	 **Biological Health**	 **External Response**
33x10^{-3}-36x10^{-3}	**Target range for the South African coastal zone** [(1)]	
Low	Byssogenesis was reduced in bivalves (adults) [(22)] Mortalities reported in limpets, mussels, chitions, sea urchins, red bait (*Pyura stolonifera**), barnacles and Cape reef worms (*Gunnarea capensis**) after abnormal dilution of seawater, primarily due to osmotic stress [(70)]	No data could be obtained
< 5x10^{-3}	Lethal range reported for *Vibrio anguillarum* (bacteria) in late-exponential growth phase [(73)]	
5x10^{-3}-60x10^{-3}	The mussel: *Mytilus edulis* (aduls) survived in this range [(28)]	
10x10^{-3}	Lethal level reported for *Vibrio salmonicida* (bacteria) in late-exponential growth phase [(73)]	
10x10^{-3}-44x10^{-3}	Survival range reported for the oyster: *Crassostrea gigas* (adults) [(18,79,17,80)]	
15x10^{-3}	Pumping in the oyster: *Crassostrea virginica* stopped [(81)]	
15x10^{-3}-40x10^{-3}	Fertilisation occurred in the bivalve: *Mytilus edulis* (larvae)[(83)]	
15x10^{-3}-44x10^{-3}	Survival range reported for the oyster: *Crassostrea gigas* (adults) [(28)]	
20x10^{-3}-35x10^{-3}	No detrimental effect on fertilisation in surf clam: *Spisula solidissima* (spermatozoa and ootcytes) [(16)]	
24x10^{-3}-37x10^{-3}	Optimum range reported for the oyster: *Crassostrea gigas* (adults) [(18,79,17,80)]	

* Species found in South African marine waters

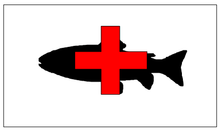
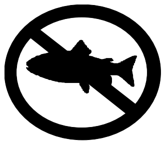
SALINITY continued on next page

Sal



SALINITY continued...

Primary consumers *continued...*

RANGE	 Biological Health	 External Response
$25x10^{-3}$-$39x10^{-3}$	Pumping in the oyster: *Crassostrea virginica* occurred normally [81]	No data could be obtained
> $30x10^{-3}$	Reduced negative geotactic behaviour in abalone [84]	
$30x10^{-3}$-$40x10^{-3}$	Successful development in the mussel: *Mytilus edulis* (larvae) to the trochophore stage only occurred in this range [40]	
> $37x10^{-3}$	No spawning occurred in bivalves	
Narrow range	Abalone (adults) tolerated narrow salinity ranges (stenohaline) [85] The abalone: *Haliotis discus* hannai (larvae) tolerated narrow salinity ranges [86]	

SALINITY continued on next page

SALINITY continued ...

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

RANGE	Biological Health	External Response
33×10^{-3}-36×10^{-3}	**Target range for the South African coastal zone [(1)]**	
Low salinity		Adult lobsters (*Homarus americanus*) were capable of detecting changes in salinity during natural fluctuations in coastal water. When exposed to low salinity of sufficient magnitude they tended to avoid it [(87)]
1×10^{-3}-75×10^{-3}	The shrimp: *Penaeus indicus** was capable of tolerating this range if allowed an acclimation time of around 48 hours [(46)]	
< 5×10^{-3}	The survival of the fish: Australian bass *Macquaria novemaculeata* (larvae) was less than 0,5 % [(88)]	
5×10^{-3}	High moulting frequency in prawn: *Penaeus chinensis* (juveniles) [(76)]	
5×10^{-3}-25×10^{-3}	The fish: *Liza parsier* (mugilidae) survived in this range (larvae) [(89)] Tolerable salinity range reported for the shrimp: *Penaeus monodon** (adults) [(63)]	
5×10^{-3}-40×10^{-3}	Tolerable salinity range reported for the shrimp: *Penaeus monodon** (adults) [(60,61)]	
7×10^{-3}-10×10^{-3}	After eight hours of exposure the mortality in the shrimp: *Penaeus duorarum* was 50 % [(77)]	

* Species found in South African marine waters

SALINITY continued on next page

Sal

SALINITY continued...

Secondary consumers *continued...*

RANGE	Biological Health	External Response
10×10^{-3}-35×10^{-3}	The survival of the fish: Australian bass *Macquaria novemaculeata* (larvae) was about 76 % [88]	No data could be obtained
$11{,}5 \times 10^{-3}$-12×10^{-3}	Successful reproduction in the fish: Baltic cob *Gadus morthua* still reported at this range [90]	
12×10^{-3}-13×10^{-3}	The shrimp: *Penaeus duorarum* started to die under experimental conditions [77]	
15×10^{-3}-25×10^{-3}	Optimum range reported for growth in the fish: *Liza parsier* (mugilidae) (larvae) plus food conversion efficiency [89]	
15×10^{-3}-30×10^{-3}	Optimum salinity range reported for the prawn: *Penaeus monodon** (adults) [60,61] Tolerable salinity range reported for the prawn family: Penaeidae(adults) [63]	
$17{,}5 \times 10^{-3}$	The blood osmolarity of the flatfish: *Scophthalamus maximus* (larvae) was greatly reduced [91]	
18×10^{-3}	Respiration rate fell and deaths occurred in the shrimp: *Penaeus semisulcatus** (adult intermoult) [83]	
20×10^{-3}	Low moulting frequency in prawn: *Penaeus chinensis* (juveniles) [76] Shrimp: *Penaeus aztecus* (post larvae) could survive at this temperature when the salinity was 35×10^{-3} and 8×10^{-3} [78]	
25×10^{-3}-40×10^{-3}	Tolerable salinity range reported for the shrimp: *Penaeus indicus** (adults) [60,61]	

* Species found in South African marine waters

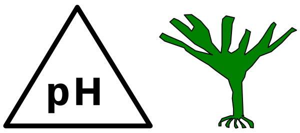
SALINITY continued on next page

SALINITY continued ...

Secondary consumers *continued...*

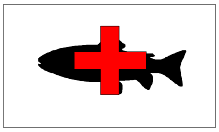
RANGE	Biological Health	External Response
$27x10^{-3}$-$32x10^{-3}$	Tolerable salinity range reported for the shrimp: *Penaeus japonicus* * (adults) (60,61)	No data could be obtained
$28x10^{-3}$-$35x10^{-3}$	Tolerable salinity range reported for the prawn family: Penaeidae (adults) (65)	
Drop from $30x10^{-3}$ to $20x10^{-3}$	Swimming activity in the shrimp: *Penaeus duorarum* increased (77)	
> $30x10^{-3}$	Mortality increased in the fish: *Liza parsier* (Mugilidae) (larvae) (89)	
$30x10^{-3}$-$32x10^{-3}$	Tolerable salinity range reported for the shrimp: *Penaeus monodon** (larvae) (60,61)	
$32x10^{-3}$-$36x10^{-3}$	Tolerable salinity range reported for the prawn family: Penaeidae(larvae) (63)	
$(33,5 \pm 0,08)x10^{-3}$	Range required for maturation of broodstock of the prawn family: Penaeidae (larvae) (65)	
$34,8x10^{-3}$-$35,2x10^{-3}$	Favourable salinity range reported for the squid: *Illex argentinus* (larvae) measured in surface water during winter (47)	
$40x10^{-3}$	High moulting frequency in prawn: *Penaeus chinensis* (juveniles) (76)	

* Species found in South African marine waters



pH (Refer to p 4-6)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

RANGE	 **Biological Health**
7,3-8,2	**Target range for the South African coastal zone** [1]
7,5	The facultative chemolithoautotroph (bacteria), *Thiobacillus thyasiris* (found on the gills of marine bivalves) showed optimal growth at this level [12]
7,95-8,15	Since the alga: *Gracilaria** extracts its carbon from CO_2 , it might become carbon limiting in growth outside this range (the range in which carbon exists primarily as CO_2 [195]
8	Optimum level reported for growth of the alga: *Gracilaria secundata* [92]
> 8,5	Dinoflagellate cell counts increased [93]
10	*Gracilaria tenuistipitata* can grow at this pH, but growth rates were reduced as the availability of CO_2 decreased [195]

* Species found in South African marine waters

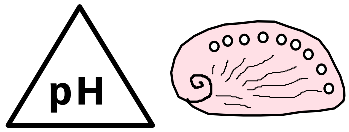
pH continued on next page

pH continued ...

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

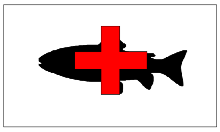
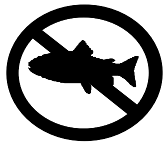
RANGE	Biological Health	External Response
7,3-8,2	**Target range for the South African coastal zone** [1]	
Low	Reduced byssogenesis in bivalves (adults) [22]	No data could be obtained
4,5	The pumping rate in the oyster: *Crassostrea virginica* was greatly reduced [95]	
6	Significant mortalities reported in the oyster: *Crassostrea gigas* (adults) after 60 days [96]	
6-9	Tolerable range reported for most bivalve species (adults) [28]	
6,5	Mortalities occurred in the clam: *Venerupis decussata* (adults) [97]	
6,6	Significant mortalities reported in the mussel: *Mytilus edulis* (adults) after 60 days [96]	
6,9	Significant mortalities reported in the oyster: *Ostrea edulis* (adults) after 60 days [96]	
< 7	Shells of bivalves eroded (general observation)	
7	Intolerable range reported for bivalve molluscs (adults) [96] Significant mortalities occurred in the spat of the oysters: *Crassostrea gigas, Ostreas edulis* and the mussel: *Mytilus edulis* [96]	
> 7,5	Tolerable range reported for the oyster: *Crassostrea gigas* (adults) [18,98,99]	

pH continued on next page



pH continued ...

Primary consumers *continued...*

RANGE	 **Biological Health**	 **External Response**
7,55	The shells of the clam: *Venerupis decussata* (adults) started to dissolve [97]	
Sudden drop from 7,75 to 6,75/7	The pumping rate in the oyster: *Crassostrea virginica* temporarily decreased followed by a rate lower than the original value [95]	
7,5-8	Abalone (juvenile) were sensitive to this range in that the outer layer of the shells dissolved down to the nacreous layer, shells also became brittle and broke along the respiratory pore axis [85]	
7,5-10,5	No detrimental effect on fertilisation in surf clam: *Spisula solidissima* (spermatozoa and ootcytes) [16]	
7,55	Abalone shells (adults) dissolved [85]	
>7,8	Optimal range reported for the oyster: *Crassostrea gigas* (adults) [18,98,99]	
7,9-8	Shell formation was affected in abalone (larvae) [85]	
Natural range of seawater	Tolerable range reported for clams [97]	

pH continued on next page

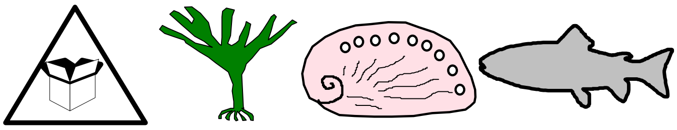
pH continued ...

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

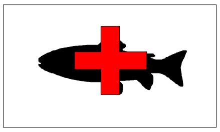
RANGE	Biological Health	External Response
7,3-8,2	**Target range for the South African coastal zone** [1]	
Low	Reduced growth in prawn family: Penaeidae (adults)[100]	
3,7	Lethal level reported for the shrimp: *Penaeus monodon** (juveniles 4,2- 5,5 g) at a salinity of 32 [94,100]	
< 5,0	Retarded growth in Penaeids (adults) [60,61]	
5,5	Reduced growth in the shrimp: *Penaeus monodon** [94]	
5,9	Minimum acceptable level reported for the shrimp: *Penaeus monodon** (juveniles) at a salinity of 30 [94,100]	
7,5-8,5	Ideal range reported for Penaeids (adults) [65]	
7,5-9,0	Tolerable range reported for Penaeids (adults) [60,61]	
7,6-8,4	Tolerable range reported for Penaeids (larvae) [63]	No data could be obtained
7,8-8,3	Ideal range reported for Penaeids (adults) [101]	
7,9 $\pm$ 0,14	Range required for maturation of broodstock in Penaeids [65]	
8,0	Optimum level reported for Penaeids (larvae) [101]	
8,1-8,3	Ideal range reported for Penaeids (adults) [65]	
> 9,5	Harmful to growth and survival of Penaeids (adults) [60,61]	

* Species found in South African marine waters

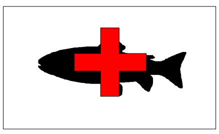
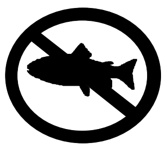


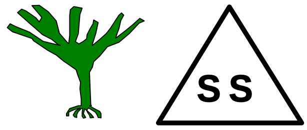
FLOATING MATTER (Refer to p 4-8)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

TYPE	 **Biological Health**
Target for the South African coastal zone [1]: - **Water should not contain floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance;** - **Water should not contain materials from non-natural land-based sources which will settle to form putrescence;** - **Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use**	
Oil	Although it could not be quantified, the presence of oil may result in a reduction in light penetration which could harm primary production
Crude oil	The presence of crude oil inhibited growth in algae substantially [102]

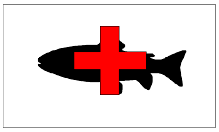
Primary consumers and Secondary consumers
(Refer to p 2-12, 2-22, 2-33 and p 2-47; 2-15, 2-25, 2-36 and 2-54)

TYPE	 **Biological Health**	 **External Response**
Target for the South African coastal zone: Refer to Primary producers (above)		
Oil	Although it could not be quantified, the presence of oil may result in smothering, especially of benthic communities	No data could be obtained

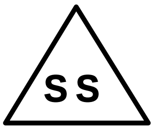


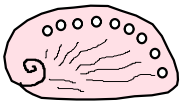
SUSPENDED SOLIDS (Refer to p 4-9)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION (mg l^{-1})	 **Biological Health**
Target range for the South African coastal zone: The concentration of suspended solids should not be increased by more than 10 % of the ambient concentration (1)	
	No quantitative data could be obtained on the effects of suspended solids. However, when present in relatively large concentrations, it may have an impact on seaweed through increasing the attenuation over the full light spectrum or portions thereof, thus decreasing the energy available to the plant. Reduced nutrient availability in the water column may occur through adsorption and subsequent sedimentation of settleable solids.

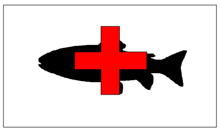
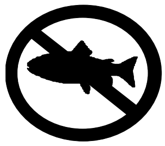
SUSPENDED SOLIDS continued on next page





SUSPENDED SOLIDS continued

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

CONCENTRATION (mg l^{-1})	 **Biological Health**	 **External Response**
Target range for the South African coastal zone: The concentration of suspended solids should not be increased by more than 10 % of the ambient concentration [1]		
	No quantitative data could be obtained on the effect of suspended solids. However, when present in relatively large concentrations, it may cause abrasion or clogging of sensitive organs such as gills, which in turn, results in stress and increased disease susceptibility	No data could be obtained
0-8	Optimal range for particulate inorganic matter (PIM) reported for the oyster: *Crassostrea gigas* (adults) [17,18,104]	
0-100	Tolerable range for PIM reported for the oyster: *Crassostrea gigas* (adults) [17,18,104]	
> 20	Affected the filter feeder efficiency in oysters, thus affecting growth [17,18,104]	
5 000-20 000 (turbulent fine silt)	Growth rates in the mussel: *Mytilus galloprovincialis** (larvae) were reduced by between 20-50 % [106]	
Increased sedimentation	Favoured the mussel: *Choromytilus merdionalis** over *Mytilus galloprovincialis** and *Aulacomya ater** (adults) [30]	

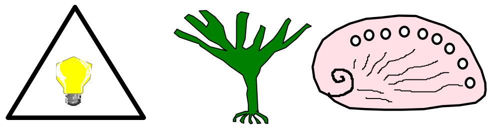
* Species found in South African marine waters

SUSPENDED SOLIDS continued on next page

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

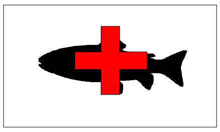
CONCENTRATION ($mg\ l^{-1}$)	**Biological Health**	**External Response**
Target range for the South African coastal zone: The concentration of suspended solids should not be increased by more than 10 % of the ambient concentration [1]		
	No quantitative data could be obtained on the effect of suspended solids. However, when present in relatively large concentrations, it may cause abrasion or clogging of sensitive organs such as gills, which in turn, results in stress and increased disease susceptibility	No data could be obtained
2-14	Desirable range reported for the prawn family: Penaeids (adults) [63]	
2 000-3 000	Although exposure of the fish: *Oncorhynchus kisutch* and *Salmo gairdneri* did not cause mortality, the plasm cortisol concentrations were temporarily elevated, indicating that such exposure might be stressful. Feeding rates were also reduced [105]	



COLOUR/TURBIDITY/CLARITY (Refer to p 4-11)

Primary producers

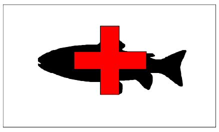
(Refer to p 2-12, 2-22, 2-34 and 2-43)

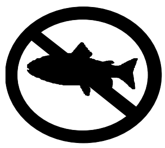


COLOUR/ TURBIDITY/ CLARITY	**Biological Health**
Target for the South African coastal zone [1]: **Turbidity and colour acting singly or in combination should not reduce the depth of the euphotic zone by more than 10 % of background levels measured at a comparable control site** **The colour (substances in solution) of water should not exceed bakground levels by more than 35 Hazen units**	
	No quantitative data could be obtained on the effect of turbidity/colour/clarity. However, the main effect of unnaturally high levels in these properties is a reduction in the light intensity resulting in reduced photosynthetic productivity and consequently lowered secondary productivity. Substances imparting colour to waters change both the quantity and quality of transmitted light which may result in changes in phytoplankton species composition.

Primary consumers

(Refer to p 2-12, 2-23, 2-35 and 2-51)





COLOUR/ TURBIDITY/ CLARITY	**Biological Health**	**External Response**
Target for the South African coastal zone: Refer to Primary producers (above)		
	No data could be obtained	

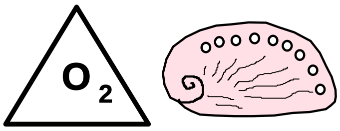
COLOUR/TURBIDITY/CLARITY continued on next page

COLOUR/TURBIDITY/CLARITY continued...

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

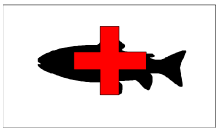
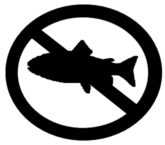
COLOUR/ TURBIDITY/ CLARITY	**Biological Health**	**External Response**
Target for the South African coastal zone: Refer to Primary producers (above)		
> 4 m (Secchi disc depth)	Desirable range reported for the prawn family: Penaeids (adults) [103]	
> 2,85 m (Secchi disc depth)		Behaviour suggesting reduced vision reported for the Blacktip shark: *Carcharhinus limbatus** [35]

* Species found in South African marine waters



DISSOLVED OXYGEN (Refer to p 4-13)

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

CONCENTRATION ($mg\ l^{-1}$)	 **Biological Health**	 **External Response**
Target range for the South African coastal zone: For the west coast, the dissolved oxygen should not fall below 10 % of the established natural variation. For the south and east coasts the dissolved oxygen should not fall below 5 $mg\ l^{-1}$ (99 % of the time) and below 6 $mg\ l^{-1}$ (95 % of the time) [1]		
Hypoxia	Led to decreases in intracellular pH of abalone: *Haliotis rufescens* (adults) [107] Organisms could, however, recover within 15 hours after exposure [108]	No data could be obtained
< 4	Led to mortality in the abalone: *Haliotis diversicolour supertaxa* (adults) [85]	
70-100 (% saturation)	Optimum range reported for the oyster: *Crassostrea gigas* (adults) [18,28,110,111]	
108-114 (% saturation)	Air supersaturation caused air blisters and flotation in the bivalves: *Mulinia* and *Mya* spp. (adult) [134]	
> 110 (% saturation)	Can cause abnormal behaviour in abalone (adults) [85]	
115 (% saturation)	The bivalve: *Mercenaria* spp. (adults) showed reduced growth [134]	
> 150 (% saturation)	Caused lesions, while prolonged exposure can cause death in abalone (adults) [85]	

DISSOLVED OXYGEN continued on next page

DISSOLVED OXYGEN continued...

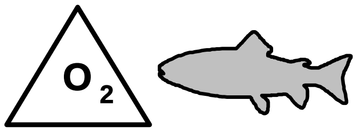
Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($mg\ l^{-1}$)	**Biological Health**	**External Response**
Target range for the South African coastal zone: For the west coast, the dissolved oxygen should not fall below 10 % of the established natural variation. For the south and east coasts the dissolved oxygen should not fall below 5 $mg\ l^{-1}$ (99 % of the time) and below 6 $mg\ l^{-1}$ (95 % of the time) [(1)]		
Low (hypoxia)	Caused higher prevalence of yolk sack, abnormal jaw articulation and head deformaties in the fish: *Hippoglossus hippoglosus* L. (larvae) [(112)] Slowed down the rate of development and the metabolic rate of the eggs of the Chum salmon [(113)]	
0	The polychaete worm: *Capitella capitata** did not feed or reproduce, although it survived for seven days [(109)]	
0,4	Lethal limit reported for rock lobsters: *Palinurus gilchristi* * and *Palinurus delagoae** [(56,114,115)]	
0,5-1,0	Lethal range reported for a number of Penaeids (adults) [(116)]	
0,5-1,2	Lethal range reported for Penaeids (adults) [(117)]	
< 0,7 (< 2 $ml\ l^{-1}$)		The Cape lobster: *Jasus lalandii* * tended to avoid such waters [(118)]
0,74 $\pm$ 0,03	Lethal concentration for shrimp: *Penaeus chinensis* (juveniles) [(119)]	

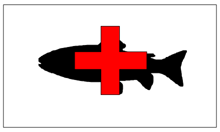
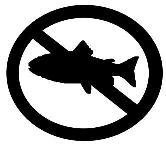
* Species found in South African marine waters

DISSOLVED OXYGEN continued on next page



DISSOLVED OXYGEN continued...

Secondary consumers *continued...*

CONCENTRATION ($mg\ l^{-1}$)	 **Biological Health**	 **External Response**
0,9	LC_{50} value, over 96 hours, reported for the shrimp: *Penaeus monodon** (juveniles) [116]	No data could be obtained
2	Mortalities increased in rock lobsters: *Palinurus gilchristi** and *Palinurus delagoae** [(56,114,115)]	
2,2	Critical level for the shrimp: *Penaeus monodon** (juveniles) [117]	
2,3-3,6	LC_{50} range, over 24 hours, reported for a number of marine fish (larvae): *Pachymetopon blochii*, Pteromaris axillares*, Trulla capensis*, Congiopodus spinifer** and *Gaidropsarus capensis** [(121)]	
2,7	The cod: *Gadus callaria* died at this level [(120)]	
2,9	The polychaete worm: *Capitella capitata** fed but did not reproduce [(109)]	
35 (% saturation)	The growth and ingestion in the rock lobster: *Jasus lalandii** was greatly reduced, while the intermoulting period and mortalities (because of moult stress) increased [(118)]	

* Species found in South African marine waters

DISSOLVED OXYGEN continued on next page

Secondary consumers *continued...*

CONCENTRATION (mg l^{-1})	**Biological Health**	**External Response**
< 3	Lethal range for the American lobster [7]	Initiated an 'escape response' in the prawn: *Penaeus indicus** [46]
> 3,5	Reproduction in the polychaete: *Capitella capitata** occurred [109]	
3,7	Level required by the shrimp: *Penaeus monodon** (adults) for normal life [117]	
> 4	Tolerable range reported for Penaeids (adults) [103]	
4,5	Lethal level for the American lobster at temperatures higher than 24 °C [7]	
> 5	Tolerable range reported for Penaeids (adults) [63,65]	
40-120 mm Hg (1,9-5,7 mg l^{-1})	There was no effect on the less active scup: *Stenotomus chrysops* [78]	
< 70 mm Hg (< 3.,3 mg l^{-1})	The very active mackerel: *Scomber scombrus* failed to withdraw oxygen [78]	
5-7	Range required by the Atlantic salmon (adults) for survival in the temperature range 14-16 °C [46]	
> 50 (% saturation)	Levels reported for survival of finfish (adults) [122]	

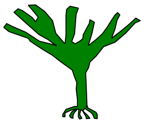
* Species found in South African marine waters

DISSOLVED OXYGEN continued on next page

DISSOLVED OXYGEN continued...

Secondary consumers *continued...*

CONCENTRATION ($mg\ l^{-1}$)	**Biological Health**	**External Response**
> 80 (% saturation)	Levels reported for maximum growth in finfish (adults) [122]	No data could be obtained
85-120 (% saturation)	Tolerable range reported for Penaeids (adults) [63]	
100 (% saturation)	Increased mortalities among the rock lobster: *Jasus lalandii** because of cannibalism of the newly moulted animals by those in intermoult [118] Required level to be maintained for Penaeid larvae reared in laboratory conditions [101]	
< 150 (% saturation)	Growth declined in finfish (adults) [122]	
High levels	Enhanced the ability to cope with stress and disease in rock lobsters: *Palinurus gilchristi** and *Palinurus delagoae** [56,114,115]	

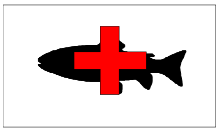


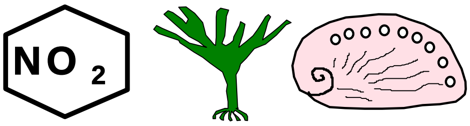
Chapter 5.2 Nutrients

AMMONIUM (Refer to p 4-17)

Note The NH_4^+ -N concentration is largely dependent on ambient pH, temperature and salinity (Refer to p 4-17).

Primary producers
(Refer to p 2-11, 2-22, 2-34 and 2-43)

CONCENTRATION ($\mu g\ l^{-1}$ as N)	 **Growth Stimulation**	 **Biological Health**
600 (NH_3 plus NH_4^+)	**Target value for the South African coastal zone** [(1)]	
	No data could be obtained	
1 400 (NH_4^+)		The alga: *Alexandrium tamarense* died within one day at a salinity of 30 [(9)]

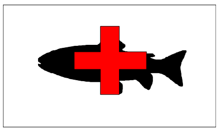


NITRITE (Refer to p 4-21)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION (µg l^{-1} as N)	**Growth Stimulation**
Target for the South African coastal zone: Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* (refer to p 5-30) [(1)]	
	No data could be obtained

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)



CONCENTRATION (µg l^{-1} as N)	**Biological Health**
No target value has been selected for the South African coastal zone [(1)]	
	No data could be obtained

NITRITE continued on next page

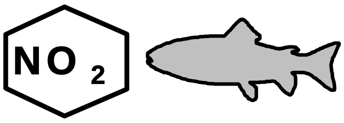
Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$ as N)	Biological Health
No target value has been selected for the South African coastal zone [1]	
100	Safe level reported for Penaeids (adults) [117]
100-300	Range required for maturation of broodstock in Penaeids (larvae) [65]
110	Safe level reported for the shrimp: *Penaeus monodon** nauplii (larvae) [125]
< 200-250	Desirable range reported for Penaeids (adults) [63]
> 300	Reduced growth rates in the fish: *Sparus auratus* (adults) [126]
< 710	Safe level reported for shrimp: *Penaeus chinensis* (larvae) [124]
1 360	Safe level reported for the shrimp: *Penaeus monodon** (post-larvae) [125]
2 300	Safe level reported for the shrimp: *Penaeus chinensis* (juvenile) [123]

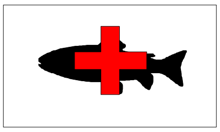
* Species found in South African marine waters

NITRITE continued on next page



NITRITE continued

Secondary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as N)	 **Biological Health**
3 800	'Safe level' reported for the shrimp: *Penaeus monodon** juveniles (33-37 mm TL) [127]
5 000	Recommended concentration for lobsters: *Palinurus gilchristi** and *Palinurus delagoae** [115]
10 600	'Safe level' reported for the shrimp: *Penaeus monodon** adolescents (100 mm TL) [123]
37 710	LC_{50} value over 96 hours reported for the shrimp: *Penaeus chinensis* (juvenile) at a salinity of 20, temperature of 24,5 °C and pH of 7,57 [123]
171 000	LC_{50} value over 96 hours reported for the shrimp: *Penaeus monodon** (adolescents) at salinity of 20, temperature of 24,5 °C and pH of 7,57 [123]
$1,2 \times 10^6$ to $2,4 \times 10^6$	LC_{50} range reported for five marine fish species (larvae) [121]

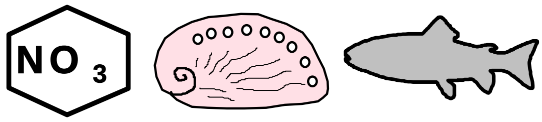
NITRATE (Refer to p 4-23)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION ($\mu g\ l^{-1}$ as N)	**Growth Stimulation**	**Biological Health**
Target for the South African coastal zone: Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* (refer to p 5-30)[(1)]		
< 14-28		Limited phytoplankton production in upwelling areas [(128)]
> 210		Resulted in elevated levels of *chlorophyll a* (phytoplankton*) in the euphotic zone on the Agulhas bank [(53)]
280	Elongation growth rates in the seaweed: *Laminaria saccharina* remained high in late spring as a result of nutrient enrichment, but winter growth was not enhanced [(129)]	

* Species found in South African marine waters

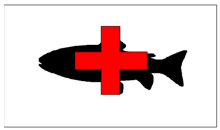
NITRATE continued on next page



NITRATE continued...

Primary consumers

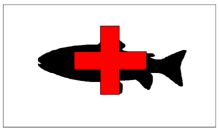
(Refer to p 2-13, 2-23, 2-35 and 2-51)



CONCENTRATION ($\mu g\ l^{-1}$ as N)	Biological Health
No target value has been selected for the South African coastal zone regarding primary consumers [1]	
	Although no quantitative data were available, regular enrichment of water with nitrate resulted in enhanced growth in the clam: *Tridacna derasa* (larvae) [130]

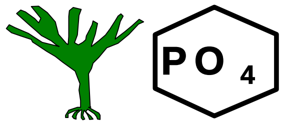
Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)



CONCENTRATION ($\mu g\ l^{-1}$ as N)	Biological Health
No target value has been selected for the South African coastal zone regarding secondary consumers [1]	
10-40	Range required for maturation of broodstock in Penaeids (larvae)[65]
1 000	Significant mortalities occurred within 40 hours in the shrimp: *Penaeus monodon**(larvae) [131]
> 100 000	Long-term exposure to these concentrations might be detrimental to marine fish: Clear-nose skate (*Raja enlanteria*), Florida pompano (*Trachinotus carolinus*), Black seabass (*Centropristis striata*), Plane-head filefish (*Monacanthus hispidus*) and Beaugregory (*Pomacentrus leucostritus*)[132]
100 000- 200 000	Desirable range reported for Penaeids (adults) [63]
300 000	Safe level reported for Penaeids (adults) [117]
4,2 x 10^6 to 8,7 x 10^6	LC_{50} range reported for five marine fish species (larvae): *Gaidropsarus capensis*, Heteromycteris capensis*, Diplodus sargus*, Lithognathus mormyrus** [121]

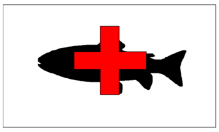
* Species found in South African marine waters



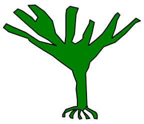
REACTIVE PHOSPHATE (Refer to p 4-27)

Primary producers

(Refer to p 2-12, 2-22, 2-34 and 2-43)

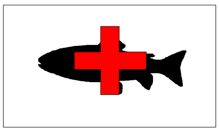
CONCENTRATION ($\mu g\ l^{-1}$ as P)	 **Growth Stimulation**	 **Biological Health**
Target for the South African coastal zone: Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* (refer to p 5-30) [(1)]		
6,7-45,3	The alga: *Ulva lactuca** was found to grow in this range (indicative of nutrient enrichment)[(133)]	
< 15 500		Elongation growth rates in the seaweed: *Laminaria saccharina* remained high in late spring as a result of nutrient enrichment, but winter growth was not enhanced [(129)]

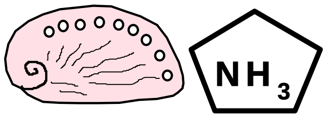
* Species found in South African marine waters

SiO_4 

REACTIVE SILICATE (Refer to p 4-31)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION (µg l^{-1} as Si)	 Growth Stimulation	 Biological Health
Target for the South African coastal zone: Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* (refer to p 5-30) [(1)]		
	No data could be obtained (This nutrient is an important component in diatom growth)	

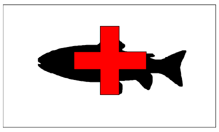


Chapter 5.3 Inorganic Constituents

AMMONIA (Refer to p 4-35)

NOTE:	The NH_3-N concentration is dependent on ambient pH, temperature, salinity (Refer to p 4-17)

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

CONCENTRATION ($\mu g\ l^{-1}$ as NH_3-N)	 Biological Health
20 (600 as NH_4-N)	**Target value for the South African coastal zone [(1)]**
100	Desirable range reported for rearing molluscs (larvae)[(28)]
500	Retarded growth in abalone [(85)]

AMMONIA continued on next page

AMMONIA continued ...

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$ as NH_3-N)	**Biological Health**
20 (600 as NH_3 plus NH_4^+)	**Target value for the South African coastal zone** [(1)]
10	Safe level reported for the shrimp: *Penaeus monodon** nauplii (larvae) [(135)]
< 20	Recommended range for shrimps: Penaeids (adults) in the presence of nitrite [(63)]
20-40	Range required for maturation of broodstock in Penaeids (larvae) [(65)]
32	Maximum acceptable toxicant concentration reported for the shrimp: *Penaeus monodon** (post-larvae) [(136)]
60-183	50% reduction in weight and length occurred in the shrimp: *Penaeus monodon** (post-larvae) [(137)]
72-240	Safe range reported for the rock lobster: *Homarus americanus* (larvae) at 20 °C [(138)]
80	Safe level reported for the shrimp: *Penaeus monodon** (adolescents) (80-100 mm TL) [(123)]
90-110	Desirable level reported for Penaeids (adults) [(37)]
100	Safe level reported for the shrimp: *Penaeus monodon** (juveniles -33-37 mm TL) [(127)] Safe level reported for the shrimp: *Penaeus monodon** (post-larvae) [(135)]

* Species found in South African marine waters

AMMONIA continued on next page

Secondary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as NH_3-N)	Biological Health
> 100	Tolerable range reported for Penaeids (larvae) [60] Reduced growth rates in finfish [122,126]
110	Maximum tolerable toxicant concentration reported for Penaeids (adults) after 40 days [139]
140	Safe level reported for the shrimp: *Penaeus chinensis* (juvenile) at 26 °C [140]
210	Maximum acceptable level' defined as that which reduced growth in *Penaeus monodon** (juveniles) by 5 % over 3 weeks [94]
< 210	Acceptable range reported for Penaeids (adults) [103]
220	Safe level reported for the shrimp: *Penaeus chinensis* (juvenile) at 25 °C [140]
320	Safe level reported for the rock lobster: *Homarus americanus* (adult) at 20 °C [138]
350	Maximum acceptable toxicant concentration reported for the shrimp: *Penaeus japonicus** (juveniles) (increased moulting frequency) [141]
450	Reduced growth in shrimps by 50 % [60]
512	Safe level reported for the rock lobster: *Homarus americanus* (adult) at 5 °C [138]
720-2 360	LC_{50} range over a period of 96 hours reported for the rock lobster: *Homarus americanus* (larvae) at 20 °C [138]
960	LC_{50} value over 96 hours reported for *Penaeus chinensis* (adolescent) at 24,5 °C and a salinity of 20 [140]
1 040	LC_{50} value over 96 hours reported for *Penaeus monodon** (post larvae) at 29,5 °C [135]

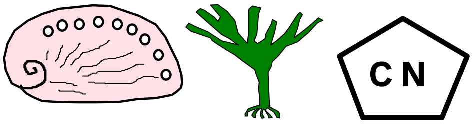
* Species found in South African marine waters

AMMONIA continued on next page

Secondary consumers *continued...*

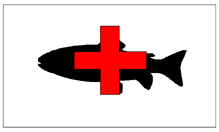
CONCENTRATION ($\mu g\ l^{-1}$ as NH_3-N)	**Biological Health**
1 530	LC_{50} value over 96 hours reported for the shrimp: *Penaeus chinensis* (juvenile) at 25 °C (140)
2 570	LC_{50} value over 96 hours reported for the shrimp: *Penaeus chinensis* (juvenile) at 26 °C (142)
3 250	LC_{50} value over a period of 96 hours reported for the rock lobster: *Homarus americanus* (larvae) at 20 °C (138)
3 500 (as NH_3 + NH_4^+)	Recommended level for the rock lobsters: *Palinurus gilchristi* * and *Palinurus delagoae** (115)
5 120	LC_{50} value over a period of 96 hours reported for the rock lobster: *Homarus americanus* (larvae) at 5 °C (138)

* Species found in South African marine waters



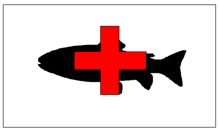
CYANIDE (Refer to p 4-36)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION ($\mu g\ l^{-1}$)	 **Biological Health**
12	**Target value for the South African coastal zone** [1]
No data could be obtained on marine species	
3 000	Inhibited enzyme activity in *Chlorella* sp. (fresh water) [143]
7 300	Inhibited photosynthesis in *Chlorella* sp. (fresh water) [143]

NOTE: Adverse effects of cyanide on aquatic plants are unlikely to occur at concentrations that cause acute effects to most species of marine fish and invertebrates [143]

Primary consumers
(Refer to p 2-12, 2-22, 2-35 and 2-51)

CONCENTRATION ($\mu g\ l^{-1}$)	 **Biological Health**
12	**Target value for the South African coastal zone** [1]
18	After exposure for 14 days, growth was reduced and glycine uptake was inhibited in the mussel: *Mytilus edulis* [143]
100	LC_{20} value over a period of 14 days for the mussel: *Mytilus edulis* [143]
150	Motor activity was suppressed after 10 minutes in the oyster: *Crassostrea* sp. [143]

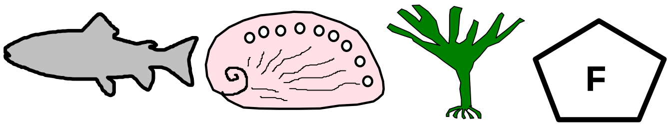
CYANIDE continued on next page

CN

CYANIDE continued ...

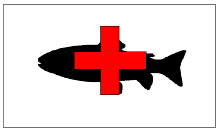
Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
12	**Target value for the South African coastal zone** [1]
5	Vitellogenin levels in the plasma and gonad declined after exposure of 12 days in the salmon: *Salmo salar* (females) [143]
7	After eight days of exposure there was a reduction of 50% in swimming performance in the salmon: *Oncorhynchus kisutch* [143]
10	Swimming speed was reduced after 2 hours of exposure in the salmon: *Oncorhynchus kisutch* [143] (external behaviour response) Abnormal embryonic development occurred in the salmon: *Salmo salar* after 58 days of exposure [143]
< 20	No measurable effect was found in the shrimp: *Mysidopsis bahia* [143]
20	Growth was reduced by 27% in the salmon: *Oncorhynchus tshawytscha* after exposure of 64 days [143]
24	LC_{50} value over 24 hours for the salmon: *Salmo salar* at a dissolved oxygen concentration of 3,5 mg l^{-1} [143]
43	Life cycle exposure (29 days) resulted in adverse effects on reproduction in the shrimp: *Mysidopsis bahia* [143]
70	Life cycle exposure (29 days) resulted in adverse effects on survival in the shrimp: *Mysidopsis bahia* [143]
73	LC_{50} value over 24 hours for the salmon: *Salmo salar* at a dissolved oxygen concentration of 3,5 mg l^{-1} [143]
80-100	Hatching was delayed by six to nine days in the salmon: *Salmo salar* [143]

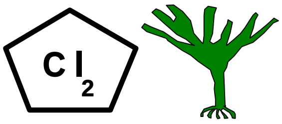


FLUORIDE (Refer to p 4-38)

All subgroups
(Refer to Section 2)

CONCENTRATION ($\mu g\ l^{-1}$)	 Biological Health
5 000	**Target value for the South African coastal zone [1]**
	No data could be obtained

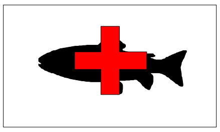
NOTE:	**The target value was obtained by assessing the sublethal toxicity of fluoride on the amphipods *Grandidierella lutesa* Barnard and *Grandidierella lignorum* Barnard by observing their reproduction success [144]**



CHLORINE (Refer to p 4-40)

Primary producers

(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	 **Biological Health**
No target value has been selected for the South African coastal zone [1]	
400	Exposure of the alga: *Skeletonema costatum* * for five minutes caused a two-day lag in growth [145]
1 000	Exposure of the alga: *Skeletonema costatum** for five minutes caused a 14-day lag in growth [145]
1 500 -2 300	Lethal range reported for the alga: *Skeletonema costatum** [145]
20 000	Lethal concentration reported for *Chlamydomonas* spp. [145]

* Species found in South African marine waters

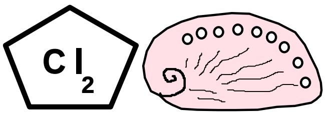
CHLORINE continued on next page

CHLORINE continued …

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

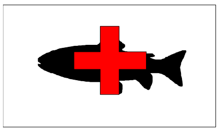
CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
2-20	The EC_{50} range (effective concentration which reduced fertilisation by 50 %) reported after five-minute exposures of sperm from the sea urchin: *Strongylocentrotus droebachiensis* and the sand dollar: *Dendraster excentriscus* [146]
10-180	LC_{50} value, over a period of 48 hours (exposure time 30 minutes), reported for the rotifer: *Brachionus plicatilis* (larvae) at 20 °C [147]
23	LC_{50} value over a period of 48 hours reported for the oyster: *Crassostrea virginica* (larvae) in the temperature range 19-28 °C [148]
26	LC_{50} value over a period of 48 hours reported for the oyster: *Crassostrea virginica* (juvenile) in the temperature range 19-28 °C [148]
50	LC_{50} value over a period of 48 hours reported for the copepod: *Acartia tonsa* in the temperature range 19-28 °C [148] Significant inhibition of fertilisation reported for three marine invertebrates: *Strongylocentrotus purpuratus* (sea urchin), *Urechis caupo* (echiuroid) and *Phragmatopoma california* (annalid), after five-minute exposures of sperm [149]
60	LC_{50} value over a period of 96 hours reported for the oyster: *Crassostrea virginica* (larvae) [150]
80-120	LC_{50} value, over a period of 48 hours (exposure time 30 minutes), reported for the rotifer: *Brachionus plicatilis* (larvae) at 20 °C [147]

CHLORINE continued on next page



CHLORINE continued ...

Primary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	 **Biological Health**
< 300	Immediate valve closure for six hours occurred in the mussel: *Donax serra** (34)
> 600	Immediate valve closure for eight days occurred in the mussel: *Donax serra** (34)
600-1 200	After 14 days' exposure, 90-100 % mortality occurred in the mussel: *Donax serra** (34)
820	LC_{50} value over a period of 48 hours (exposure time 30 minutes) reported for the copepod: *Acartia tonsa* (larvae) in the temperature range 10-20 °C (147)

* Species found in South African marine waters

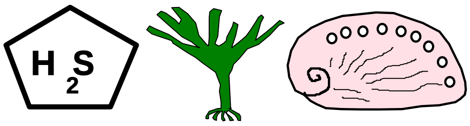
CHLORINE continued on next page

CHLORINE continued ...

Secondary consumers

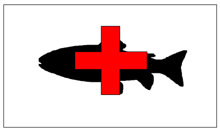
(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
37	LC_{50} value over a period of 48 hours reported for the shrimp: *Palaemonetes pugio* (adult) in the temperature range 19-28 °C [148]
50-250	LC_{50} value, over a period of 48 hours (exposure time 30 minutes), reported for the salmon: *Oncorhynchus tshawytscha* in the temperature range 11,6-11,7 °C [147]
100	LC_{50} value, over a period of 48 hours (exposure time 30 minutes), reported for the salmon: *Oncorhynchus gorbuscha* at 12,4 °C [147]
220	LC_{50} value over a period of 48 hours reported for the fish: *Menidia menidia* (juvenile) in the temperature range 19-28 °C [148]
250	LC_{50} value, over a period of 48 hours (exposure time 30 minutes), reported for the salmon: *Oncorhynchus gorbuscha* at 13,6 °C [147]
230	LC_{50} value over a period of 96 hours reported for the fish: *Leiostomus xanthurus* (juvenile) in the temperature range 16,8-27,6 °C [152]
410-2 900	LC_{50} value, over a period of 48 hours (exposure time 60 minutes), reported for the lobster: *Homarus americanus* (larvae) at 20°C [147]
1 200-1 400	LC_{50} range over a period of 96 hours reported for the crab: *Cancer productus* (adult) at 11 °C [153]

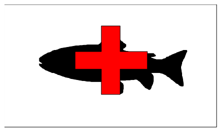


HYDROGEN SULPHIDE (Refer to p 4-44)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION (µg l^{-1} as unassociated H_2S)	 **Biological Health**
No target value has been selected for the South African coastal zone [1]	
	No data could be obtained

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

CONCENTRATION (µg l^{-1} as unassociated H_2S)	 **Biological Health**
No target value has been selected for the South African coastal zone [1]	
50	Retarded growth in abalone [85]
500	Mortalities occurred in abalone [85]

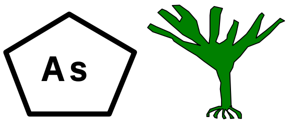
HYDROGEN SULPHIDE continued on next page

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

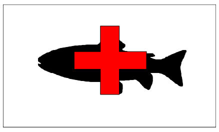
CONCENTRATION (µg l^{-1} as unassociated H_2S)	**Biological health**
No target value has been set for the South African coastal zone [1]	
< 0,002	Desirable level reported for Penaeids (adults) [63]
0,033	'Safe level' reported for *Penaeus monodon** (adults) [117]
0,1-2,0	Loss of equilibrium reported in shrimps (adults) [117]
1	Maximum concentration recommended for fish and crustaceans [154]
4,0	Large-scale mortality reported in Penaeids (adults) [62,63] Shrimps (adults) succumbed [117]

* Species found in South African marine waters



ARSENIC (Refer to p 4-47)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)



CONCENTRATION (µg l^{-1} as total As)	Biological Health
12	**Target value for the South African coastal zone [(1)]**
19-20	Reduced growth in algae [155]
65	Normal sexual reproduction occurred in the red alga: *Champia parvula* [(155)]
75	The biomass of phytoplankton populations was reduced in four days [(155)]
75	Reduced chlorophyll a in the alga: *Thalassiosira aestivalis* [(155)]
95	No sexual reproduction occurred in the red alga: *Champia parvula* [(155)]
130	Inhibited growth in the alga: *Skeletonema costatum** [(155)]
300	Death occurred in the red algae: *Champia parvula* [(155)]
580	Arrested spore development, seven days after treatment (exposure time 18 hours) in the red alga: *Plumaria elegans* [(155)]
1 000	No deaths occurred in algae [(155)]
10 000	Normal growth, but no sexual reproduction occurred in the red alga: *Champia parvula* [(155)]

* Species found in South African marine waters

ARSENIC continued on next page

ARSENIC continued ...

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

CONCENTRATION ($\mu g\ l^{-1}$ as total As)	**Biological Health**
12	**Target value for the South African coastal zone** [1]
330	LC_{50} value, over a period of 96 hours, reported for the oyster *Crassostrea gigas* (embryo) [155]
2 000	Depressed oxygen consumption in 72 hours in the mud snail: *Nassarius absoletus* [155]
2 000	LC_{50} value, over a period of 192 hours, reported for the copepod: *Acartia clausi* at 15 °C [155]
4 000	LC_{50} value, over a period of 140 hours, reported for the copepod: *Acartia clausi* at 15 °C [155]
7 500	LC_{50} value, over a period of 48 hours, reported for the oyster *Crassostrea virginica* (eggs) [155]
8 000	LC_{50} value, over a period of 230 hours, reported for the copepod: *Acartia clausi* at 5 °C [155] LC_{50} value, over a period of 150 hours, reported for the copepod: *Acartia clausi* at 10 °C [155] LC_{50} value, over a period of 74 hours, reported for the amphipod: *Acartia clausi* at 15 °C [155]
15 000	LC_{50} value, over a period of 192 hours, reported for the clam: *Macoma balthica* at 15 °C [155]
16 000	Lethal concentration, in 3 to 16 days, reported for the mussel: *Mytilus edulis* [155]
60 000	LC_{50} value, over a period of 192 hours, reported for the clam: *Macoma balthica* at 10 °C [155]
220 000	LC_{50} value, over a period of 192 hours, reported for the clam: *Macoma balthica* at 5 °C [155]

ARSENIC continued on next page

As

ARSENIC continued ...

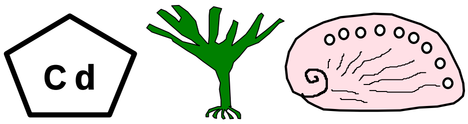
Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$ as total As)	**Biological Health**
12	**Target value for the South African coastal zone [1]**
25	No effect on the copepod: *Eurytemora affinis* [155]
100	Reduced survival reported for the copepod: *Eurytemora affinis* (juveniles) [155]
230	LC_{50} value, over a period of 96 hours, reported for the crab: *Cancer magister* (larvae) [155]
510	LC_{50} value, over a period of 96 hours, reported for the copepod: *Acartia clausi* [155]
630-1 270	Maximum acceptable toxicant concentration reported for the mysid: *Mysidopsis bahia* [155]
1 000	Reduced survival reported for the copepod: *Eurytemora affinis* (adults) [155]
2 300	LC_{50} value, over a period of 96 hours, reported for the mysid: *Mysidopsis bahia* [155]
2 500	No effect on the salmon: *Oncorhynchus gorbuscha* over 10 days [155]
3 800	LC_{54} value, for a period of 10 days, reported for the salmon: *Oncorhynchus gorbuscha* [155]
7 200	Mortalities (100 %) reported in the salmon: *Oncorhynchus gorbuscha* over 10 days [155]

ARSENIC continued on next page

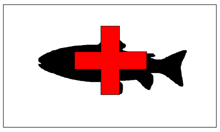
Secondary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as total As)	**Biological Health**
27 300	LC_{50} value, over a period of 96 hours, reported for the mullet: *Chelon labrosus* (some skin discolouration) (155)
28 500	LC_{50} value, over a period of 96 hours, reported for the dab: *Limanda limanda* (respiration problems) (155)
500 000	LC_{50} value, over a period of 130 hours, reported for the oligochaete: *Tubifex costatus* at 5 °C (155) LC_{50} value, over a period of 115 hours, reported for the oligochaete: *Tubifex costatus* at 10 °C (155) LC_{50} value, over a period of 85 hours, reported for the oligochaete: *Tubifex costatus* at 15 °C (155)



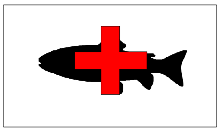
CADMIUM (Refer to p 4-50)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)



CONCENTRATION (µg l⁻¹ as total Cd)	Biological Health
4	**Target value for the South African coastal zone [1]**
	No data could be obtained

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)



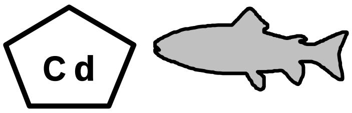
CONCENTRATION (Total Cd µg l⁻¹)	Biological Health
4	**Target value for the South African coastal zone [1]**
11	Minimum effect concentration on weight (four weeks exposure) reported for the amphipod: *Allorchestes compressa* [156]
25-400	Depressed oxygen uptake in the mussel: *Perna indica* (adults) [157]
25	Minimum effect concentration for survival (four weeks exposure) reported for the amphipod: *Allorchestes compressa* [156]
38	Minimum effect concentration on biomass (four weeks exposure) reported for the amphipod: *Allorchestes compressa* [156]
50	No visible change could be detected in larval development of the sea urchin: *Stronylocentrotus nudus* [158]
159	Population failed to increase (exposure of 24 days) in the copepod: *Tisbe holothuriae* [159]
180	LC_{50} value over 96 hours reported for the amphipod: *Elasmospus rapax* [160]

CADMIUM continued on next page

Primary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as total Cd)	**Biological Health**
200-400	LC_{50} value, over 120 hours at 16,8 °C, reported for the amphipod: *Allorchestes compressa* in a static bioassay (161)
450	LC_{50} value over 48 hours reported for the amphipod: *Elasmospus rapax* (160)
780	LC_{50} value over 96 hours reported for the amphipod: *Allorchestes compressa* (162)
1 620	LC_{50} value, over 96 hours at 18,5 °C, reported for the mussel: *Mytilus edulis planulatus* in a static bioassay (161)
3 500	LC_{50} value, over 96 hours, reported for the mussels: *Perna viridis and Perna indica* (adults) (157)
3 800	LC_{50} value reported for the oyster: *Crassostra virginica* (larvae) (28)
7 500-10 000	Reduced the pumping rate in the mussel: *Mytilus edulis* (adults) (33)

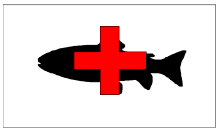
CADMIUM continued on next page



CADMIUM continued...

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)



CONCENTRATION (µg l^{-1} as total Cd)	Biological Health
4	**Target value for the South African coastal zone** [(1)]
4,9	'Safe level' reported for the crab: *Paragrapsus quadridentatus* (larvae)[(163)]
100	Threshold concentration affecting metabolism in the mysid: *Leptomsis ligvura* [(164)]
100	'Highest concentration without effect' reported for the whelk: *Bullia digitalis** (adults) [(165)]
200	Significant reductions in growth and survival reported for the prawn: *Penaeus japonicus** (larvae). Accumulated Cd levels decreased after 20 days once the larvae were transferred to clean seawater [(166)]
490	LC_{50} value, over 96 hours, reported for the crab: *Paragrapsus quadridentatus* (larvae) [(163)] LC_{50} value, over 14 days, reported for the shrimp: *Callianassa australiensis* [(167)]
500	Burrowing ceased in the whelk: *Bullia digitalis** (adults) [(165)] A 30% decrease in oxygen uptake reported for the whelk: *Bullia digitalis** (adults) [(165)]
> 500	100 % mortality occurred in the copepod: *Tisbe holothuriae* after 30 weeks [(168)]
500-1 000	LC_{50} value, over 48 hours, reported for the mysid: *Leptomsis ligvura* [(164)]
610	LC_{50} value, over 10 days, reported for the shrimp: *Callianassa australiensis* [(167)]
700-800	Caused irreversible stress in the whelk: *Bullia digitalis** (adults) [(165)]
750	A 20% decrease in oxygen uptake reported for the whelk: *Bullia digitalis** (adults) [(165)]

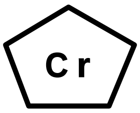
* Species found in South African marine waters

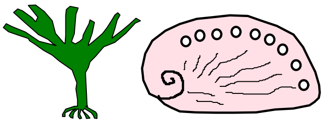
CADMIUM continued on next page

Secondary consumers *continued...*

CONCENTRATION (µg l^{-1} as total Cd)	Biological Health
900	LC_{50} value, over 96 hours, reported for the whelk: *Bullia digitalis** (adults) [165]
970	LC_{50} value, over seven days, reported for the shrimp: *Callianassa australiensis* [167]
1 850	LC_{50} value, over 168 hours at 18,7 °C, reported for the shrimp: *Palaemon* sp. in a static bioassay [161]
2 000	Mortalities occurred in the mysid: *Leptomsis ligvura* within 24 hours at 18 °C [164]
2 300	LC_{50} value, over 120 hours at 18,7 °C, reported for the shrimp: *Palaemon* sp. in a static bioassay [161]
6 330	LC_{50} value, over four days, reported for the shrimp: *Callianassa australiensis* [167]
6 400	LC_{50} value, over 168 hours at 18,5 °C, reported for the polychaete: *Neanthes vaali* in a static bioassay [161]
6 400-6 800	LC_{50} value, over 96 hours at 16,8-17,8 °C, reported for the shrimp: *Palaemon* sp. in a continuous flow bioassay [161]
10 000	LC_{50} value, over 96 hours at 19,8 °C, reported for the starfish: *Patiriella exigua** in a static bioassay [161]
14 000	LC_{50} value, over 168 hours at 17,8 °C, reported for the crab: *Paragrapsus quaridentatus* in a static bioassay [161]
16 700	LC_{50} value, over 160 hours at 17,1 °C, reported for the crab: *Paragrapsus quaridentatus* in a static bioassay [161]

* Species found in South African marine waters

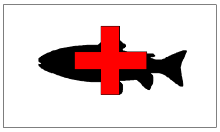




CHROMIUM (Refer to p 4-53)

Primary producers

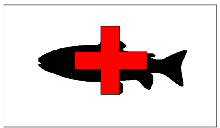
(Refer to p 2-12, 2-22, 2-34 and 2-43)



CONCENTRATION (µg l^{-1} as total Cr)	Biological Health
8	**Target value for the South African coastal zone [1]**
	No data could be obtained

Primary consumers

(Refer to p 2-13, 2-23, 2-35 and 2-51)



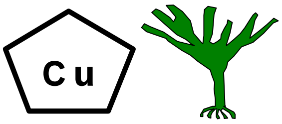
CONCENTRATION (µg l^{-1} as total Cr)	Biological Health
8	**Target value for the South African coastal zone [1]**
> 250	Minimum effect concentration on weight, survival and biomass (four weeks exposure) reported of the amphipod: *Allorchestes compressa* [156]
5 560	LC_{50} value, over 96 hours, reported for the amphipod: *Allorchestes compressa* [169]
10 800	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [28]

CHROMIUM continued on next page

CHROMIUM continued...

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

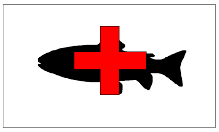
CONCENTRATION (Total Cr µg l^{-1})	**Biological Health**
8	**Target value for the South African coastal zone** [1]
15 770	LC_{50} value, over four hours at 18 °C, reported for the copepod: *Tisbe holothuriae* (ovigerous females) [168]
16 120	LC_{50} value, over four hours at 24 °C, reported for the copepod: *Tisbe holothuriae* (ovigerous females) [168]
17 360	LC_{50} value, over four hours at 14 °C, reported for the copepod: *Tisbe holothuriae* (ovigerous females) [168]



COPPER (Refer to p 4-55)

Primary producers

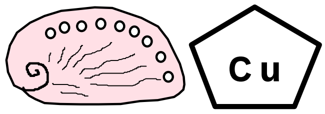
(Refer to p 2-12, 2-22, 2-34 and 2-43)



CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	Biological Health
5	**Target value for the South African coastal zone** [1]
< 10	No observed effects in sporophyte production, over 20 days, were reported for the kelp: *Macrocystis pyfirera* at 13-15 °C [171]
> 10	Inhibited growth in the seaweed: *Sargassum* [170]
10,2	No observed effects in sporophyte growth, over 20 days, reported for the kelp: *Macrocystis pyfirera* at 13-15 °C [171]
> 18	Inhibited sporophyte production in the kelp: *Macrocystis pyfirera* at 13-15 °C [171]
50	Growth was unaffected, over 10-14 days, in the phytoplankton: *Skeletonema costatum*, Thalassiosira pseudonana* and *Amphidinium carteri* [172] Growth was inhibited over eight days in the phytoplankton: *Dunaliella minuta* [173]
50,1	No observed effect in spore germination, over 20 days, reported for the kelp: *Macrocystis pyfirera* at 13-15 °C [171]
250	Growth was significantly affected over 10-14 days in the phytoplankton: *Phaeodactylum tricornutum* [172]

* Species found in South African marine waters

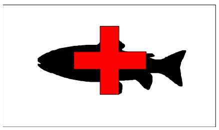
COPPER continued on next page



COPPER continued...

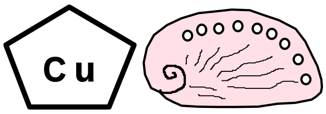
Primary consumers

(Refer to p 2-13, 2-23, 2-35 and 2-51)

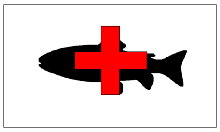


CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	**Biological Health**
5	**Target value for the South African coastal zone [1]**
3,7	'Minimum effect concentration' on biomass over four weeks reported for the amphipod: *Allorchestes compressa* [156]
4,9	LC$_5$, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
5,2	Minimum effect concentration on weight over four weeks reported for the amphipod: *Allorchestes compressa* [156]
10	LC$_5$, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
16,4	LC$_{50}$, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
20,8-25,6	Pumping ceased in the mussel: *Mytilus edulis* (adults) [33]
24	Minimum effect concentration on survival over four weeks reported for the amphipod: *Allorchestes compressa* [156]
25	Exposure of adult sea urchins: *Strongylocentrotus nudus*, over 30 days, resulted in accelerated development of the larvae at the stage of early palteus [158]
28	LC$_{95}$, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
32,8	LC$_{50}$, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
38,3	LC$_{50}$ value reported for the mussel: *Perna indica* (adults) [175]
40	A 100 % mortality occurred in the abalone: *Haliotis discus* hannai (larvae 0,92-1,7 mm) within 48 hours [177]

COPPER continued on next page



Primary consumers *continued...*



CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	Biological Health
50	Depressed oxygen uptake in the mussel: *Perna viridis* (adults) (157) Mortalities occurred in the abalone: *Haliotis rufescens* and *Haliotis cracherodii* (adults) (85) LC_{50} value, over 96 hours reported for the abalone: *Haliotis cracherodii* (adults) (85)
55,7	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) (174)
65	LC_{50} value, over 96 hours reported for the abalone: *Haliotis rufescens* (adults) (85)
80	Mortalities occurred in abalone larvae (85)
103	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) (28)
11	LC_{50} value, over 96 hours, reported for the amphipod: *Allorchestes compressa* (juveniles) (176)
114	LD_{50} value, over 96 hours, reported for abalone (larvae) (85)
480	LC_{50} value over, 96 hours at 20,3 °C, reported for the amphipod: *Allorchestes compressa* (adults) (162)
500	LC_{50} value over, 96 hours, reported for the amphipod: *Allorchestes compressa* (adults) (176)

COPPER continued on next page

COPPER continued...

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION (µg l^{-1} as total Cu)	Biological Health
5	**Target value for the South African coastal zone [1]**
1,7	'Safe level' reported for the crab: *Paragrapsus quadridentatus* (larvae)[163]
50	Lethal concentration reported for Penaeids (post larvae) [65]
100	'Highest concentration without effect' reported for the whelk: *Bullia digitalis** [165]
100	A reduction in egg production reported for the nematode: *Diplolaimella* sp. [168]
170	LC_{50} value, over 96 hours, reported for the crab: *Paragrapsus quadridentatus* (larvae) [163]
190	LC_{50} value, over 14 days, reported for the shrimp: *Callianassa australiensis* [167]
200	Burrowing ceased in the whelk: *Bullia digitalis** [165]

* Species found in South African marine waters

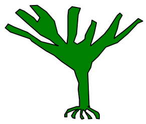
COPPER continued on next page

COPPER continued...

Secondary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	**Biological Health**
220	LC_{50} value, over 10 days, reported for the shrimp: *Callianassa australiensis* (167) A significant reduction in growth and survival reported for the prawn: *Penaeus japonicus** (larvae). Accumulated Cu decreased within 20 days once the larvae were transferred to clean seawater (166)
300	A 70 % decrease in oxygen uptake reported for the whelk: *Bullia digitalis** (165)
350	Caused irreversible stress in the whelk: *Bullia digitalis** (165)
500	LC_{50} value, over 96 hours, reported for the whelk: *Bullia digitalis** (165)
500	Net reduction in reproduction reported for the nematode: *Diplolaimella* sp.(168)
970	LC_{50} value, over seven days, reported for the shrimp: *Callianassa australiensis* (167)
1 000	Burrowing ceased in the whelk: *Bullia digitalis** (165)
2 200	EC_{50} value, over 96 hours at 17 °C, reported for the nematode: *Monphystera disjuncta* (178)
5 000	A slight, but significant decrease in oxygen uptake reported in the whelk: *Bullia digitalis** (165)
6 330	LC_{50} value, over four days, reported for the shrimp: *Callianassa australiensis* (167)

* Species found in South African marine waters

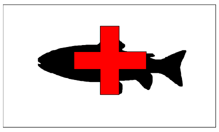


Pb

LEAD (Refer to p 4-57)

Primary producers

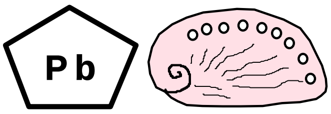
(Refer to p 2-12, 2-22, 2-34 and 2-43)



CONCENTRATION ($\mu g\ l^{-1}$ as total Pb)	**Biological Health**
12	**Target value for the South African coastal zone** [1]
0,05	No effect on growth, over 12 days, reported for the diatom: *Skeletonema costatum** [179]
5,1	A 50 % growth inhibition, over 12 days, reported for the diatom: *Skeletonema costatum** [179]
10	A 100 % growth inhibition, over 12 days, reported for the diatom: *Skeletonema costatum** [179]
> 5 000	LC_{50} value, over 96 hours, reported for the alga: *Phaeodactylum tricornum* [179]

* Species found in South African marine waters

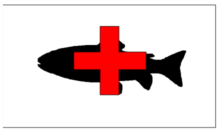
LEAD continued on next page



LEAD continued...

Primary consumers

(Refer to p 2-13, 2-23, 2-35 and 2-51)



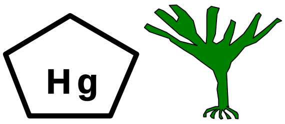
CONCENTRATION ($\mu g\ l^{-1}$ as total Pb)	**Biological Health**
12	**Target value for the South African coastal zone** [1]
1,27	The limiting concentration reported for the mussel: *Mytilus edulis* (adults) [122]
476	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* (larvae) [179]
547	LC_{50} value, over 96 hours, reported for the ampipod: *Ampelisca abdita* [179]
780	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [28]
1 100	No effect on development, over 48 hours, reported for the sea urchin: *Anthocidaris crassispina* (embryo) [179]
2 200	Inhibited development, over 48 hours, in the sea urchin: *Anthocidaris crassispina* (embryo) [179]
2 450	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [28]
> 500 000	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* (adults) [179]

LEAD continued on next page

Secondary consumers

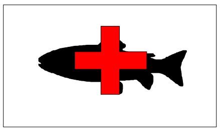
(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$ as total Pb)	**Biological Health**
12	**Target value for the South African coastal zone** [1]
17-37	'Maximum acceptable toxicant concentration', over a life-time exposure, reported for the mysid: *Mysidopsis bahia* [179]
50	Biochemical alteration in the antennal gland, over 30 days, reported in the lobster: *Homarus americanus* [179] A reduction in enzyme activity, over 30 days, reported in the lobster: *Homarus americanus* [179]
575	LC_{50} value, over 96 hours, reported for the crab: *Cancer magister* [179]
315	LC_{50} value, over 96 hours, reported for the fish: *Fundulus heteroclitus* [179]
3 100	Inhibited reproduction in the sandworm: *Neathes arenaceodentata*, over 28 days and at a salinity of 20 [179]
7 700	LC_{50} value, over 96 hours at 15 $^{\circ}$C, reported for the sand worm: *Neathes arenaceodentata* [179]
10 700	LC_{50} value, over 96 hours at 20 $^{\circ}$C, reported for the sand worm: *Neathes arenaceodentata* [179]
180 000	LC_{50} value, over 96 hours, reported for the fish: *Pleuronectes platessa* [179]
375 000	LC_{50} value, over 96 hours, reported for the shrimp: *Crangon crangon* [179]



MERCURY (Refer to p 4-59)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)



CONCENTRATION (µg l^{-1} as total Hg)	**Biological Health**
0,3	**Target value for the South African coastal zone** [1]
50	Inhibited growth in the phytoplankton: *Dunaliella minuta* [173]

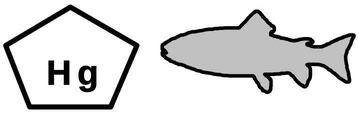
MERCURY continued on next page

MERCURY continued...

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

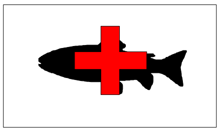
CONCENTRATION ($\mu g\ l^{-1}$ as total Hg)	**Biological Health**
0,3	**Target value for the South African coastal zone** [1]
1-10	Depressed oxygen uptake reported in the mussel: *Perna indica* (adults) [157]
3,3	LC_{50} over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
4	LC_{50} over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
4,8	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [28]
5,6	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [28]
10	LC_{50} value reported for the oyster: *Crassostrea gigas* (larvae) [28]
12	LC_{50}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
14,7	LC_{50}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
20,7	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
25,4	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
80	LC_{50} value, over 96 hours at 21 °C, reported for the amphipod: *Allorchestes compressa* [169]

MERCURY continued on next page

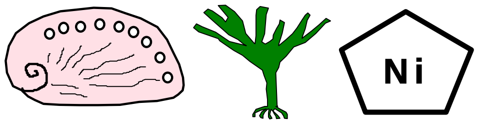


MERCURY continued...

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$ as total Hg)	 **Biological Health**
0,3	**Target value for the South African coastal zone** [(1)]
2	Some delays in emergence, hatching and growth reported for the shrimp: *Artemia francisana* over 72 hours [(180)]
< 56	No lethal effects reported for the shrimp: *Palaemonetes vulgaris* (larvae) within 48 hours. Delayed effects after 48 hour exposure include: reduced survival of post larvae stage, delayed moulting, extended developmental time and morphological deformities [(181)]
56	Toxic level reported for the shrimp: *Palaemonetes vulgaris* (larvae) within 24 hours [(181)]
20-1 003	Inhibited the developmental processes at the emergence and hatching stages in the shrimp: *Artemia francisana* over 72 hours [(180)]
500	Highest concentration without effect reported for the whelk: *Bullia digitalis** [(165)]
2 000	Burrowing ceased in the whelk: *Bullia digitalis** [(165)]
5 000	A 20 % decrease in oxygen uptake reported for the whelk: *Bullia digitalis** [(165)]
7 000	Caused irreversible stress to the whelk: *Bullia digitalis** [(165)]
2 300	EC_{50} value, over 96 hour at 17 °C, reported for the nematode: *Monhystera disjuncta* [(178)]

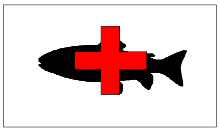
* Species found in South African marine waters



NICKEL (Refer to p 4-61)

Primary producers

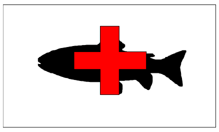
(Refer to p 2-12, 2-22, 2-34 and 2-43)



CONCENTRATION ($\mu g\ l^{-1}$ as total Ni)	Biological Health
25	**Target value for the South African coastal zone** [1]
	No data could be obtained

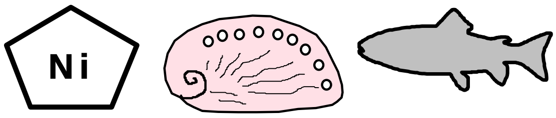
Primary consumers

(Refer to p 2-13, 2-23, 2-35 and 2-51)



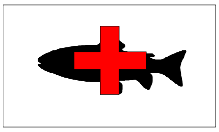
CONCENTRATION ($\mu g\ l^{-1}$ as total Ni)	Biological Health
25	**Target value for the South African coastal zone** [1]
30	LC_5, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
310	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [28]
1 100	LC_5, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
1 180	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [28]
1 200	LC_{50}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
2 500	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]

NICKEL continued on next page



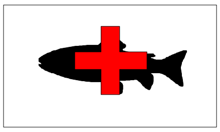
NICKEL continued...

Primary consumers *continued...*

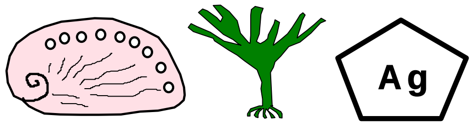


CONCENTRATION ($\mu g\ l^{-1}$ as total Ni)	Biological Health
5 700	LC_{50}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) (174)
10 300	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) (174)
34 680	LC_{50} value, over 96 hours at 20,8 °C, reported for the amphipod: *Allorchestes compressa* (169)

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)

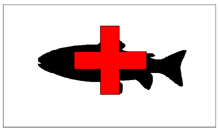


CONCENTRATION ($\mu g\ l^{-1}$ as total Ni)	Biological Health
25	**Target value for the South African coastal zone (1)**
20 300	EC_{50} value, over 96 hours at 17 °C, reported for the nematode: *Monhystera disjuncta* (178)



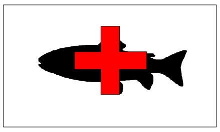
SILVER (Refer to p 4-63)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)



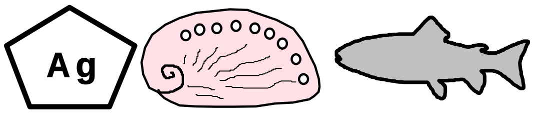
CONCENTRATION (µg l^{-1} as total Ag)	Biological Health
5	**Target value for the South African coastal zone** [1]
50	LC_{50} value reported for algae [182]

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)



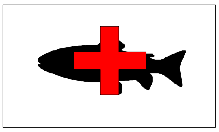
CONCENTRATION (µg l^{-1} as total Ag)	Biological Health
5	**Target value for the South African coastal zone** [1]
5,8	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [28]
10	Depressed oxygen consumption in the mussel: *Perna indica* (adults) [157]
14,2	LC_5, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]
18,6	LC_5, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
21	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [28]
25	LC_{50}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [174]

SILVER continued on next page



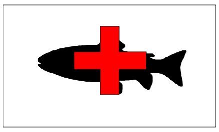
SILVER continued...

Primary consumers *continued...*

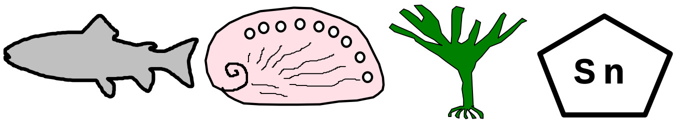


CONCENTRATION ($\mu g\ l^{-1}$ as total Ag)	Biological Health
32,4	LC_{50}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) (174)
35,7	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) (174)
46,2	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) (174)

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)



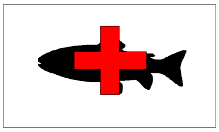
CONCENTRATION ($\mu g\ l^{-1}$ as total Ag)	Biological Health
5	**Target value for the South African coastal zone (1)**
10-40	LC_{50} value reported for fish (182)



TIN (INORGANIC) (Refer to p 4-65)

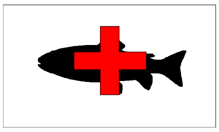
NOTE: **Inorganic tin compounds can be considered to of of low toxicologic risk due to their low solubility, poor absorbtion, low accumulation in tissues and rapid excretion** [183]

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)



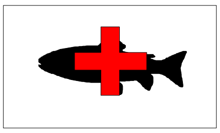
CONCENTRATION ($\mu g\ l^{-1}$ as total Sn)	Biological Health
No target value has been selected for the South African coastal zone [1]	
613-325	A 50% reduction in growth in 72 hours reported for two species of marine diatoms [183]

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

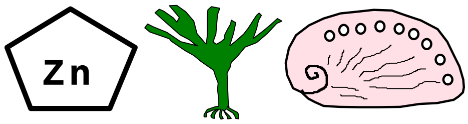


CONCENTRATION ($\mu g\ l^{-1}$ as total Sn)	Biological Health
No target value has been selected for the South African coastal zone [1]	
	No data could be obtained

Secondary consumers
(Refer to p 2-16, 2-26, 2-38 and 2-59)



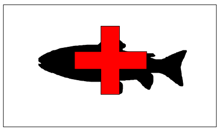
CONCENTRATION ($\mu g\ l^{-1}$ as total Sn)	Biological Health
No target value has been selected for the South African coastal zone [1]	
35	No effect, over 96 hours, on the fish: *Limanda limanda* [183]



ZINC (Refer to p 4-67)

Primary producers

(Refer to p 2-12, 2-22, 2-34 and 2-43)

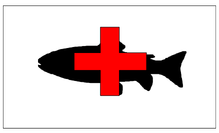


CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	Biological Health
25	**Target value for the South African coastal zone** [(1)]
0-500	No effect on photosynthesis, ultrastructure of nucleus, mitochondrion or cell membrane, over 24 hours, reported for the diatom: *Nitzschia closterium* [(184)]
> 80	Inhibited growth in the seaweed: *Sargassum* [(170)]
200	Growth was unaffected, over 10-14 days, in the phytoplankton: *Skeletonema costatum*, Thalassiosira pseudonana* and *Amphidinium carteri* [(172)]
4 000	Growth was unaffected, over 10-14 days, in the phytoplankton: *Phaeodactylum tricornutum* [(172)]

* Species found in South African marine waters

Primary consumers

(Refer to p 2-13, 2-23, 2-35 and 2-51)



CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	Biological Health
25	**Target value for the South African coastal zone** [(1)]
10-100	Depressed oxygen uptake reported in the mussel: *Perna indica* (adults) [(157)]
19	No effect observed in the abalone: *Haliotis rufescens* (larvae) over 48 hours [(185)]
39	No effect observed in the abalone: *Haliotis rufescens* (larvae) over nine days [(185)]
50	LC_5, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [(174)]

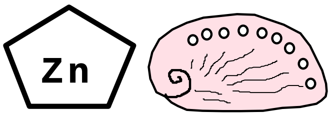
ZINC continued on next page

ZINC continued...

Primary consumers *continued...*

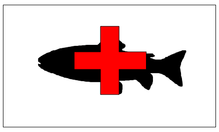
CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	**Biological Health**
50	No significant effect reported in the oyster: *Crassostrea gigas* (larvae) [186]
99	'Minimum effect concentration' on survival, over four weeks, reported for the amphipod: *Allorchestes compressa* [156]
100	Interferences with enzyme activities, over 30 days, reported for the sea urchin: *Strongylocentrotus nudus* [158]
116	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [28]
125-500	A decrease in growth and increase in abnormality and larval mortality, over 10 days (exposure time: five days), reported for the oyster: *Crassostrea gigas* (larvae) [186]
142	'Minimum effect concentration' on biomass, over four weeks, reported for the amphipod: *Allorchestes compressa* [156]
148	'Minimum effect concentration' on weight, over four weeks, reported for the amphipod: *Allorchestes compressa* [156]
195	LC_{50}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]
200	No growth occurred in the oyster: *Crassostrea gigas* (larvae) [186]
250-500	A suppression in spat growth reported for the oyster: *Crassostrea gigas* (larvae). Growth recovery was, however, rapid once the larvae were transferred to clean seawater [187]
310	LC_{50} reported for the oyster: *Crassostrea virginica* (larvae) [28]
341	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [174]

ZINC continued on next page



ZINC continued...

Primary consumers *continued...*



CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	**Biological Health**
470-860	Pumping stopped in the mussel: *Mytilus edulis* (adults) (33)
500	A 90 % reduction in egg development to larvae reported for the oyster: *Crassostrea gigas* over 48 hours (186)
580	LC_{50} value, over 96 hours, reported for the amphipod: *Allorchestes compressa* in a static bioassay (161)
1 000	Depressed oxygen uptake in the bivalve: *Meretix casta* (adults) (157)
2 000	LC_{50} value, over 96 hours at 20,3 °C, reported for the amphipod: *Allorchestes compressa* (162)
2 500	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis planulatus* in a static bioassay (161)
3 600-4 300	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis planulatus* in a continuous-flow bioassay (161)
10 500	LC_{50} value, over 120 hours, reported for the mussel: *Mytilus edulis planulatus* in a continuous-flow bioassay (161)

ZINC continued on next page

ZINC continued...

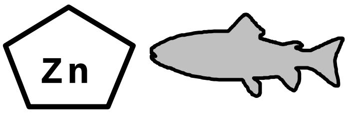
Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	**Biological Health**
25	**Target value for the South African coastal zone** [1]
12,3	Safe level reported for the crab: *Paragrapsus quadridentatus* (larvae)[163]
> 250	A significant reduction in growth and survival reported for the prawn: *Penaeus japonicus** (larvae). Accumulated Zn decreased within 20 days once the larvae was transferred to clean seawater [166]
1 000	Highest concentration without effect reported for the whelk: *Bullia digitalis** [165]
1 150	LC_{50} value, over 14 days, reported for the shrimp: *Callianassa australiensis* [167]
1 230	LC_{50} value, over 96 hours, reported for the shrimp: *Palaemon* sp. in a static bioassay [161]
1 540	LC_{50} value, over 10 days, reported for the shrimp: *Callianassa australiensis* [167]
1 980	LC_{50} value, over seven days, reported for the shrimp: *Callianassa australiensis* [167]
2 000	Burrowing ceased in the whelk: *Bullia digitalis** [165] A 40 % decrease in oxygen uptake reported for the whelk: *Bullia digitalis** [165]
2 300	EC_{50} value, over 96 hours at 17 °C, reported for the nematode: *Monhystera disjuncta* [178]

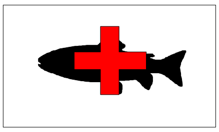
* Species found in South African marine water

ZINC continued on next page



ZINC continued...

Secondary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	 **Biological Health**
3 000	LC_{50} value, over 96 hours, reported for the whelk: *Bullia digitalis** (165)
5 500	LC_{50} value, over 96 hours, reported for the polychaete: *Neathes vaali* in a static bioassay (161)
9 500-13 100	LC_{50} value, over 96 hours, reported for the crab: *Paragrapsus quadridentatus* (larvae) (163)
> 10 000	LC_{50} value, over 96 hours, reported for the starfish: *Patiriella exigua** in a static bioassay (161)
10 200	LC_{50} value, over four days, reported for the shrimp: *Callianassa australiensis* (167)
10 500	LC_{50} value, over 96 hours, reported for the crab: *Paragrapsus quadridentus* in a continuous-flow bioassay (161)
11 000	LC_{50} value, over 96 hours, reported for the crab: *Paragrapsus quadridentus* in a static bioassay (161)

* Species found in South African marine waters

Chapter 5.4 Organic Constituents

ORGANOTIN (Tributyltin) (Refer to p 4-71)

Primary producers
(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
0,1	A reduction in growth over 48 hours reported for three species of marine algae [183]
0,33-0,36	A 50 % growth inhibition over 72 hours reported for the diatom: *Skeltonema costatum** [183]
3-16	A 50% reduction of primary productivity, over eight hours to eight days, reported for various species of algae [183]
14,7	LC_{50} value, over 72 hours, reported for the diatom: *Skeltonema costatum** [183]

* Species found in South African marine waters

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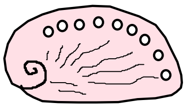
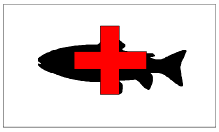
TBT 

TBT continued...

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)



CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
No target value has been selected for the South African coastal zone[1]	
0,01-0,02	Reduced spat growth and hypoxia compensation reported for the oyster: *Crassostrea gigas* after two weeks [183]
0,02	Little mortality and good growth reported in the oyster:*Crassostrea gigas* (larvae) [188] No effect on shell morphology observed in the oyster: *Crassostrea gigas* (adults) [188]
0,05	Significant mortalities reported in the oyster: *Crassostria gigas* (larvae) after 10 days [188]
0,1	LC_{50} value, over 15 days, reported for the mussel: *Mytilus edulis* (larvae) [183] Tolerable level reported for the development of molluscan larvae [28]
0,15	Reduced growth and shell thickening reported for the oyster: *Crassostrea gigas* after eight weeks [183]
0,24	Growth was reduced after 45 days in the mussel: *Mytilus edulis* (larvae) [183]
0,28	LC_{50} value, over 28 days, reported for the mussel: *Perna viridis* (adults) [189]
0,31	No shell growth occurred after 66 days in the mussel: *Mytilus edulis* [183]
0,4	Shell growth rate was reduced within seven days in the mussel: *Mytilus edulis* [183]
0,73-1,9	Reduced larval growth reported for the oyster: *Crassostrea virginica* within 66 days [183]

TBT continued on next page

TBT continued...

Primary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
0,9	50 % immobilisation in 48 hours reported for the oyster: *Crassostrea gigas* (larvae) [1830
0,97	LC_{50} value, over 66 days, reported for the mussel: *Mytilus edulis* (adults) [183]
1	LC_{100} value, over 12 days, reported for the oyster: *Crassostrea gigas* (larvae) [183] Total mortality reported for the oyster: *Crassostrea gigas* (larvae) within six days [188]
1,6	LC_{100} value, over 48 hours, reported for the oyster: *Crassostrea gigas* (larvae) [183]
1,6	No growth occurred in the oyster: *Crassostrea gigas* (adults) [183]
5	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* (larvae) [183]
10	LC_{50} value, over 28 days, reported for the oyster: *Crassostrea cuculata* (adults) [189]
50	Inhibited segmentation in the oyster: *Crassostrea gigas* (larvae) [188]
100	Inhibited fertilisation in the oyster: *Crassostrea gigas* [188]

TBT continued on next page

TBT

TBT continued...

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION ($\mu g\ l^{-1}$)	Biological Health
No target value has been selected for the South African coastal zone [1]	
0,02	Development of male characteristics occurred in 41 % of the females after 120 days in the dog whelk: *Nucella lapillus* [183]
0,09	'No observed effect concentration' on reproduction reported for the mysid shrimp: *Acanthomysis sculpa* [188]
0,1	Inhibited arm generation in the brittle star: *Ophioderma brevispina* [183]
0,5	Deformation of limbs generated during 19 days and retardation in regenerative growth reported in the crab: *Uca pugilator* [183]
0,5-1,0	Non-dose dependent reduction in burrowing occurred within 15 to 60 minutes in the crab: *Uca pugilator* [183] Hyperactivity occurred within one to three weeks in the crab: *Uca pugilator* [183] LC_{50} value, over 96 hours, reported for the mysid: *Metamysidopsis elongata* (larvae) [183]
1,0	No effect on larval metamorphosis, over six days, reported in the lobster: *Homarus americanus* [183]
1,5-36	LC_{50} range, over 96 hours, reported for different marine fish species [188]
4	LC_{50} value, over 24 hours reported for the barnacle: *Balanus amphitrite* nauplii [183]

TBT continued on next page

TBT continued...

Secondary consumers *continued...*

CONCENTRATION ($\mu g\ l^{-1}$)	Biological Health
5	LC_{100} value, over six days, reported for the lobster: *Homarus americanus* (larvae) [183]
5-6	Induced male characteristics in female, over 64 days, in the snail: *Nassarius obsoletus* [183]
8	LC_{50} value, over 96 hours, reported for the mysid: *Mysidopsis bahia* [183]
9	Avoidance reported in the fish: *Fundulus heteroclitus* [183]
10	LC_{50} value, over 96 hours, reported for the crab: *Carcinus maenus** [183]
20	LC_{100} value, over 24 hours, reported for the lobster: *Homarus americanus* (larvae) [183]
24	LC_{50} value, over 96 hours, reported for the fish: *Fundulus heteroclitus* [183]

* Species found in South African marine waters

TPH

TOTAL PETROLEUM HYDROCARBONS (TPH) (Refer to p 4-74)

NOTES:	**The effects described below are based on the water soluble fraction (WSF) of oils (the particulate fraction is dealt with under '*Floating matter*' on p 5-24).** **Because of their variability, the effects described below should not be regarded as representative of all these compounds, but merely gives some examples of concentration ranges and effects. Generally, the effects of the WSF varies between organisms and also according to the type of oil used.** **Generally, the fuel oils were more toxic to biota (two to three times) than the WSF of crude oils. This is presumably because the fuel oils contain a higher portion of aromatic and polycyclic hydrocarbons.** **The PAHs are a varied and complex group of constituents and there is much still not known on their effect on marine biota.**

Primary producers

(Refer to p 2-12, 2-22, 2-34 and 2-43)

CONCENTRATION ($mg\ l^{-1}$ WSF)	**Biological Health**
No target values have been selected for the South African coastal zone [1]	
4,6	Ekofisk crude oil. Exposure resulted in a 44-100 % inhibition of growth over four days in the phytoplankon: *Skeletonema costatum** at 13 °C [190]
< 50	No. 2 diesel fuel oil. No substantial effects reported for the alga: *Scenedesmus armatus* over 20 hours [191]

* Species found in South African marine waters

TPH continued on next page

TPH continued...

Primary consumers
(Refer to p 2-13, 2-23, 2-35 and 2-51)

CONCENTRATION ($mg\ l^{-1}$ WSF)	Biological Health
No target values have been selected for the South African coastal zone [1]	
3	Qatar crude oil. Resulted in immediate stress in the mussel: *Mytilus galloprovincialis* in that spawning was triggered in a large portion [194] Qatar crude oil. After six hours of exposure the concentration in the tissue of the mussel: *Mytilus galloprovincialis* was found to be 132 $\mu g\ g^{-1}$ (wet weight), compared to a control value of 6,7 $\mu g\ g^{-1}$ (wet weight) [194]
0,15	Qatar crude oil. After 96 hours of exposure the maximum concentration in the tissue of the mussel: *Mytilus galloprovincialis* was found to be 52,8 $\mu g\ g^{-1}$ (wet weight), compared to a control value of 6,7 $\mu g\ g^{-1}$ (wet weight) [194] When hydrocarbons were accumulated after exposure for short periods, the rate of depuration was significantly higher compared to chronic exposure [194]

TPH continued on next page

TPH

TPH continued...

Secondary consumers

(Refer to p 2-16, 2-26, 2-38 and 2-59)

CONCENTRATION (mg l^{-1} WSF)	**Biological Health**
No target values have been selected for the South African coastal zone [1]	
1,2	No. 2 fuel oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 28 °C [192]
1,6	No. 2 fuel oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 32 °C [192]
1,9	No. 2 fuel oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 24 °C [192]
2,2	Bunker C oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 32 °C [192]
2,6	Bunker C oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 21 °C [192]
3,1	Bunker C oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 24 °C [192]
3,5	No. 2 fuel oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 21 °C [192]
10,7	South Louisiana crude oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 32 °C [192]
15,9	South Louisiana crude oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 24 °C [192]
> 19,8	South Louisiana crude oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 21 °C [192]

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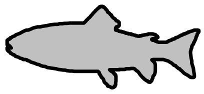
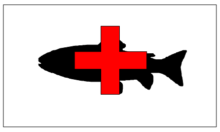


TPH

TPH continued...

Secondary consumers
continued...

CONCENTRATION (mg l^{-1})	 **Biological Health**
No target values have been selected for the South African coastal zone [(1)]	
0,3	Methylphenanthrene. LC_{50} value, over 96 hours, reported for the polychaete: *Neanthes arenacedentata* [(193)]
0,5	Fluoranthene. LC_{50} value, over 96 hours, reported for the polychaete: *Neanthes arenacedentata* [(193)]
0,6	Phenanthrene. LC_{50} value, over 96 hours, reported for the polychaete: *Neanthes arenacedentata* [(193)]
1,0	Fluorene. LC_{50} value, over 96 hours, reported for the polychaete: *Neanthes arenacedentata* [(193)]
2,0	Trimethylnaphthalene. LC_{50} value, over 96 hours, reported for the polychaete: *Neanthes arenacedentata* [(193)]
2,6	Dimethylnaphthalene. LC_{50} value, over 96 hours, reported for the polychaete: *Neanthes arenacedentata* [(193)]
3,8	Naphthalene. LC_{50} value, over 96 hours, reported for the polychaete: *Neanthes arenacedentata* [(193)]

REFERENCES

1. DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1992. Interim Report: Water quality guidelines for the South African coastal zone. Pretoria.

2. JACKSON, A.E., MARR, J.C. and McLACHLAN, J.L. 1993. The production of diarrhetic shellfish toxins by an isolate of *Prorocentrum lima* from Nova Scotia, Canada. In: *Toxic phytoplankton blooms in the sea* **3**: 513-518. Smayda, T.J. and Shimizu, Y. (eds.). Amsterdam, Netherlands, Elsevier.

3. YAMAMOTO, M., WATANABE, Y. and KINOSHITA, H. 1991. Affects of water temperature on the growth of red alga *Porphyra yezoensis* from *Narawaensis* (nori) cultivated in an outdoor raceway tank. *Nippon Suisan Gakkaishi Bull. Jap. Soc. Sci. Fish.*, **57**(12): 2211-2217.

4. STAUBER, L. A. 1950. The problem of physiological species with special reference to oysters and oyster drills. *Ecology* **31**: 107-118.

5. ENGLEDOW, H. R. and BOLTON, J.I. 1992. Environmental tolerances in culture and agar content of *Gracilaria verrucosa* (Hudson) Papenfus (Rhodophyta, Gigartinales) from Saldanha Bay. *S. Afr. J. Bot.*, **58**(4): 263-267.

6. MITCHELL-INNES, B.A. and PITCHER, G.C. 1992. Hydrographic parameters as indicators of the suitability of phytoplankton populations as food for herbivorous copepods. *S.Afr. J. mar. Sci.* **12**: 355-365

7. McLEESE, D.W. 1956. Effects of temperature, salinity and oxygen on the survival of the American lobster. *J. Fish. Res. Bd. Can.* **13**: 247-272.

8. CASTILLA, J.C. and CAMUS, P.A. 1992. The Humboldt-El Nino scenario: Coastal benthic resources and anthropogenic influences, with particular reference to the 1982/83 ENSO. *S Afr. J. mar. Sci.* **12**: 703-712.

9. SU, H. M., CHANG, Y. M. and LIAO, I.C. 1993. Role of temperature, salinity and ammonia on the occurrence of the Taiwanese strain of *Alexandrium tamerense.* In: *Toxic phytoplankton blooms in the sea* **3**: 837- 842. Smayda, T.J. and Shimizu, Y. (eds.). Amsterdam, Netherlands, Elsevier.

10. SU, H.M., LEI, C.H. and LAO, I.C. 1990. Effect of temperature, illuminance and salinity on the growth rates of *Skeletonema costatum*. *J. Fish. Soc. Taiwan* **17**(3): 213-222.

11. YOKOYA, N.S. and OLIVIERA, E.C. 1991. Temperature responses of economically important red algae and their potential for mariculture in Brazilian waters. *J. Appl. Phycol.*, **4**(4): 339-345.

12. WOOD, A.P. and KELLY, D.P. 1989. Isolation and physiological characterisation of *Thiobacillus thyasiris* sp. nov., a novel marine facultative autotroph and the putative symbiont of Thyasire flexuosa. *Arch. Microbiol.* **152**: 160-166.

REFERENCES continued on next page

i

REFERENCES continued...

13. COOK, P.A. 1978. A prediction of some possible effects of thermal pollution on marine organisms on the west coast of South Africa, with particular reference to the rock lobster *Jasus lalandii*. *Trans. Roy. Soc. S. Afr.* **43**: 107-118.

14. OYIEKE, H.A. and KOKWARO, J.O. 1993. Seasonality of some species of *Gracilaria* (Gracilariales, Rhodophyta) from Kenya. *J. Appl. Phycol.* **5**(1): 123-124.

15. WALDRON, H.N. and PROBYN, T.A. 1992. Nitrate supply and potential new production in the Benguela upwelling system. *S.Afr. J. mar. Sci.* **12**: 29-39.

16. CLOTTEAU, G. and DUBE, F. 1993. Optimization of fertilization parameters for rearing surf clams (*Spisula solidissima). Aquaculture* **114**(3-4):339

17. BERNARD, R.F. 1983. Physiology and the mariculture of some Northeastern Pacific bivalve molluscs. *Canadian Special Publication of Fisheries and Aquatic Sciences* **63**. 24 pp.

18. BROWN, J.R. and HARTWICK, E.B. 1988. A habitat suitability index model for suspended tray culture of the Pacific oyster, *Crassostrea gigas* Thunberg. *Aquaculture and Fisheries Management* **19**: 109-126.

19. MALOUF, R.E. and BREESE, W.P. 1977. Seasonal changes in the effects of temperature and water flow rate on the growth of juvenile Pacific oysters *Crassostrea gigas* Thunberg. *Aquaculture* **12**: 1-3.

20. QUALE, D B. 1969. Pacific oyster culture in BC. *Fisheries Research Board of Canada Bulletin* **169**. 192 pp.

21. TARR, R. 1994. Stock assessment and aspects of the biology of the South African abalone *Haliotis midae*. *M.Sc. Thesis*, University of Cape Town. 156 pp.

22. MATHEW, A. and FERNANDEZ, T.V. 1992. Environmental impact on the byssogenic responses of the mollusc *Perna indica*. *J. Ecobiol.* **4**(3): 161-168.

23. LE GALL, J.L. and RAILLARD, O. 1988. Influence of temperature on the physiology of the oyster Crassostrea gigas. Adaptation of marine organisms to warm waters: Seminar 26 November, 1987. **14**(5): 603-608.

24. DRAWE, T. 1994. The relationship between respiration rate and habitat in *Cyclograpsus punctatus* and *Sesarma catenata*. Honours Project. Zoology Department, University of Port Elizabeth.

25. CADMAN, L. 1990. Some effects of temperature and salinity on the growth of juvenile blue crabs. *Bull. Mar. Sci.* **46**(1): 244.

REFERENCES continued on next page

REFERENCES continued...

26. SUSHARSONO, PIPE, R.K. and BROWN, B.E. 1993. Cellular and ultrastructural changes in the endoderm of the temperate sea anemone *Anemonia viridis* as a result of increased temperature. *Mar. Biol.* **116**(2):311-318.

27. JOHN, H. C. and KLOPPMAN, M. 1993. The vertical distribution of eggs of *Maurolicus meulleri*. *S. Afr. J. mar. Sci.* **13**: 161:174.

28. BARNABÉ, G. 1989. *Aquaculture.* Volume 1. New York, Ellis Horwood. 528 pp.

29. FAINER, S.F. and WADLEY, V.A. 1991. Abundance, growth and production of the bivalve *Solemya sp.*, a food source for juvenile rock lobsters in a seagrass community in Western Australia. *J. Exp. Mar. Biol. Ecol.* **153**(2): 201-223.

30. VAN ERKOM SCHURINCK, C. and GRIFFITHS, C.L. 1993. Factors affecting relative rates of growth in four South African mussel species. *Aquaculture*, **109**: 257-273.

31. STENTON-DOZEY, J.M.E. and BROWN, A.C. 1994. Exposure of the sandy-beach bivalve *Donax serra* Röding to a heated and chlorinated effluent 1. Effects of temperature on burrowing and survival. *J. Shellfish Res.* **13**(2): 443-449.

32. STENTON-DOZEY, J.M.E. 1986. The effect of temperature and chlorination on the physiology of *Donax serra*. In: Workshop Report on the biology of the genus *Donax* in southern Africa. *UPE, Institute for Coastal Research, Report* No **5**: 15-20.

33. HECHT, T. 1994. Behavioural thermoregulation of the abalone, *Haliotis midae*, and the implications for intensive culture. *Aquaculture* **126**(1/2): 171-181.

34. HILL, B.J. 1977. The effect of heated effluent on egg production in the estuarine prawn *Upogebia africana* (Ortmann). *J. exp. mar. Biol. Ecol.* **29**: 291-302.

35. DUDLEY, S.F.J. and CLIFF, G. 1993. Sharks caught in the protective gill nets off Natal, South Africa. 7. The Blacktip shark, *Carcharhinus limbatus* (Valenciennes) *S.Afr. mar. Sci.* **13**: 237-254.

36. RADHAKRISHNAN, E.V. and DEVARAJAN, K. 1986. Growth of the spiny lobster *Panulirus polyphagus* (Herbst) reared in the laboratory. Proceedings of the symposium on coastal aquaculture, Cochin. Part 4: Culture of other organisms, environmental studies, training, extension and legal aspects **6**: 1164-1170. 12-18 January, 1980

37. LEGA, J.V., CHERNITIKY A.G. and BELKOVSKY, N.M. 1992. Effect of low seawater temperatures on water balance in the Atlantic salmon (*Salmo salar* L). *Fish Physiol. Biochem.*, **10**(2): 145-148.

38. SOUTHWARD, A.J. and CRISP, D.J. 1965. Activity rhythms of barnacles in relation to respiration and feeding. *J. mar. Biol. Ass. UK* **45**: 161-185.

REFERENCES continued on next page

REFERENCES continued...

39. MAGNUM, C. 1969. Low temperature blockage of the feeding response in boreal and temperate zone polychaetes. *Chesapeake Sci.* **10**: 64-65.

40. BAYNE, B.L. 1964. The responses of the larvae of *Mytilus edulis* (L.) to light and to gravity. *Oikos* **15**: 162-174.

41. CLARK, W.C. 1993. Temperature conditioning of marine brookstocks. In: *The International Symposium for sea ranching of cod and other marine species*, Ar Endal, Norway, 15-18 June. Programme and abstracts. Bergen, Norway, IMP 14 pp.

42. LOOSANOFF, V.L. and DAVIS, H.C. 1963. Rearing of bivalve molluscs. In: *Advances in Marine Biology*. F.S. Russell (ed.) **1**:1-136.

43. LOOSANOFF, V.L. & NOMEJKO, C.A. 1951. Existence of physiologically-different races of oysters, *Crassostrea virginica. Biol. Bull.* **101**: 151-156.

44. ACHITUV, Y. and COOK, P.A. 1984. The influence of temperature variations and thermal pollution on various aspects of the biology of the prawn *Palaemon pacificus* Stimpson. *J. Exp. Mar. Biol. Ecol.* **74**: 291-302.

45. BRETT, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. *J. Fish Res. Bd. Canada* **9**: 265-323.

46. McCLURG, T.P. 1974. Studies on some environmental requirements of *Penaeus indicus* M. EDW. Twenty-ninth Steering Committee Meeting on Marine Disposal of Effluents. CSIR, NIWR. 79 pp.

47. LETA, H.R. 1992. Abundance and distribution of Rhynchoteuthion larvae of *Illex argentinus* (Cephalopoda: Ommastrephidae) in the south-western Atlantic. *S. Afr. J. mar. Sci.* **12**: 927-941.

48. LE CLUS, F. 1992. Seasonal trends in sea surface temperature, dry mass per oocyte and batch fecundity of pilchard *Sardinips ocellatus* in the northern Benguela system. *S. Afr. J. mar. Sci.* **12**: 123-134.

49. VAN DER LINGEN, C.D. 1994. Aspects of the early life history of Galjoen *Dichistius capensis*. *S. Afr. J. mar. Sci.* **14**: 37-45.

50. LUND, E.J. 1957. Self-sitting, survival of oyster as a closed system, and reducing tendencies of the environment of the oyster. *Publ. Inst. Marine Sci.* **4**: 313-319.

REFERENCES continued on next page

REFERENCES continued...

51. SASTRY, A.N. 1968. The relationships among food, temperature, and gonad development of the bay scallop. Aequipecten irradians Lamark. *Physiol. Zool.* **41**: 44-53.

52. VERNBERG, F.J. and VERNBERG, W.B. 1970. *The Animal and the Environment*. Chapter 8: Population Continuity. Holt, Rinehart and Winston Inc. U.S.A. p 244-270.

53. LARGIER, J.L., CHAPMAN, P., PETERSON, W.T. and SWART, V.P. 1992. The western Agulhas Bank: Circulation, stratification and ecology. *S. Afr. J.mar. Sci*. **12**: 319-339.

54. VILLACASTIN-HERRORO, C.A., CRAWFORD, R.J.M. and FIELD, J.G. 1992. Statistical correlations between purse-seine catches of chub-mackerel off South Africa and select environmental parameters. *S. Afr. J. mar. Sci.* **12**: 157-165.

55. MacPHERSON, E. and GORDOA, A. 1992. Trends in the demersal fish community off Namibia from 1983 to 1990. *S.Afr. J. mar. Sci.* **12**: 635-649.

56. ZOUTENDYK, P. 1989. Oxygen consumption by the Cape rock lobster, *Jasus lalandii. S.Afr. J. mar. Sci.* **8**: 219-230.

57. KHAN, M.S., ZAKARIA, M.S., AMBAK, M.A., ALAM, M.J., KASHIWAGI, M. and IWAI, T. 1991. Effect of temperature on the hatching success of the eggs of Japanese whiting, *Sillago japonica* Temminck and Schlegel, during the spawning season. *Aquacult. Fish. Manage.* **22**(3): 317-321.

58. FARMANFARMAIAN, A. and GIESE, A.G. 1963. Thermal tolerance and acclimation in the western purple sea urchin, *Strongylocentrotus purpuratus*. *Physiol. Zool.* **36**: 237-243.

59. LELLIS, W.A. and RUSSELL, J.A. 1990. Effect of temperature on survival, growth and feed intake of postlarval spiny lobster. *Aquaculture* **90**(1): 1-9.

60. KUNGVANKIJ, P. *et al.* 1986. Shrimp hatchery design, operation and management. *NACA Training Manual Series* No **1**. Network of Aquaculture Centres in Asia, Regional Lead Centre in the Philippines. 88 pp.

61. KUNGVANKIJ, P. *et al.* 1986. Shrimp culture: pond design, operation and management. *NACA Training Manual Series* No **2**. Network of Aquaculture Centres in Asia, Regional Lead Centre in the Philippines. 68pp.

62. CLARKE, B.C. and GRIFFITHS, C.L. 1990. Ecological energetics of mussels under simulated intertidal rock pool conditions. *J. exp. Biol. Ecol.* **137**: 63-77.

63. LEE, D. O'C. and WICKENS, J.F. 1992. *Crustacean farming*. Blackwell Scientific Publications, Oxford. 392pp.

REFERENCES continued on next page

i

REFERENCES continued...

64. KINNE, O. and KINNE, E.M. 1962. Rates of development in embryos of cyprinodont fish exposed to different temperature-salinity-oxygen combinations. *Can. J. Zool.* **40**: 231-253.

65. SHRIMP FARMING SHORT COURSE. 1990. Course materials: Sept. 12-21, 1990. Texas A&M Sea Grant College Program.

66. KENNY, R. 1969. The effects of temperature, salinity and substrate on distribution of *Clymenella torquata* (Leidy) Polychorta. *Ecology* **50**: 624-631.

67. MANN, K.H. 1992. Physical influences on biological processes.: How important are they? *S. Afr. J. mar. Sci.* **12**: 107-121

68. SHANNON, L.V., CRAWFORD, R.J.M., BRUNDRIT, G.B. and UNDERHILL, L.G. 1988. Responses of fish populations in the Benguela ecosystem to environmental change. *J. Cons. perm. int. Explor. mer* **45**(1): 5-12.

69. O'DOR, R.K. 1992. Big squid in big currents. *S. Afr. J. mar. Sci.* **12**: 225-235.

70. BRANCH, G.M., EEKHOUT, S. and BOSMAN, A.L. 1990. Short-term effects of the 1988 Orange River floods on the intertidal rocky-shore communities of the open coast. *Trans Roy. Soc. S. Afr.* **47**(3): 331-354.

71. MURTHY, M.S., SHARMA, S.L.N.S and RAO, Y.N. 1988. Salinity induced changes in peroxidase activity in the green seaweed *ulva lactuca*. *Bot. Mar.*, **31**(4): 307-310.

72. WIENCHE, C. and DAVENPORT, J. 1987. Respiration and photosynthesis in the intertidal alga *Cladophora rupestris* (L.) Kuetz. under fluctuating salinity regimes. *J. Exp. Mar. Biol Ecol.* **114**(2-3): 183-197.

73. HOFF, K.A. 1989. Survival of *Vibrio anguillarum* and *Vibrio salmonicida* at different salinities. *Appl. Environ. Microbiol.* **55**(7): 1775-1786.

74. BAECK, S., COLLINS, J.C. and RUSSELL, G. 1992. Recruitment of the Baltic flora: The *Fucus ceranoides* enigma. *Bot. Mar.* **35**(1): 53-59.

75. HAGLIND, K. and PEDERSEN, M. 1992. Growth of the red alga *Gracilaria tennistipitata* at high pH. Influence of some environmental factors and correlation to an increased carbonic-anhydrase activity. *Bot. Mar.*, **35**(6): 579-587.

76. CHEN, J.C., LIN, M.N., LIN, J.L and TING, Y.Y. 1992. Effect of salinity on growth of *Penaeus chinensis juvelines*. *Comp. Biochem. Physiol.* **1024**(2):343-346.

REFERENCES continued on next page

REFERENCES continued...

77. NIMMO, D.R. and BAHNER, L.H. 1974. Some physiological consequences of polychlorinated biphenyl- and salinity stress in penaeid shrimp. In: *Pollution and Physiology of Marine Organisms*. Vernberg, F.J. and Vernberg, W.B. (Eds.). Academic Press. New York. pp. 427-444.

78. VERNBERG, W.B. and VERNBERG, F.J. 1972. *Environmental Physiology of Marine Animals*. Chapter V. The Coastal and Oceanic Environment. Springer-Verslag. New York. pp. 233-302.

79. REDPATH, K.J. and DAVENPORT, J. 1988. The effect of copper, zinc and cadmium on the pumping rate of *Mytilus edulis* L. *Aquatic Toxicol.* **13**(3): 217-226.

80. KING, M.G. 1977. Cultivation of the Pacific oyster, *Crassostrea gigas*, in a non-tidal hypersaline pond. *Aquaculture* **11**: 123-136.

81. HOPKINS, A.E. 1936. Adaptation of the feeding mechanism of the oyster (*Crassostrea gigas*) to changes in salinity. *Bull. U.S. Bur. Fish.* **48**: 345-363.

82. BAYNE, B.L. 1965. Growth and the delay of metamorphosis of larvae of *Mytilus edulis* L. *Ophelia.* **2**:1-47.

83. CLARK, J.V. 1992. Physiological responses of adult *Penaeus semisulcatus* (de Haan) to changes in salinity. *Comp. Biochem. Physiol. A.* **101**(1): 117-119.

84. RHO, S. 1991. Studies on the propagation of the abalones. 5. Effects of light and seawater of reduced salinity on vertical distribution of swimming larvae of *Haliotis discus hannai*. *Ino. Bull. Mar. Res. Inst. Chejn National University* **15**: 33-43.

85. HAHN, K.O. 1989. *Handbook of culture of abalone and other marine gastropods*. CRC Press Inc, Boca Raton, Florida. 348 pp.

86. NIE, Z.Q. and CHEN, W.H. 1984. Studies on rearing conditions of abalone, *Haliotis discus hannai* Ino Z., the effects of salinity and inorganic nutrients on the development of fertilised eggs and living of larvae. *Mar. Fish. Res.* **6**: 41-48.

87. JURY, S.H., KINNISON, M.T., HOWELL, W.H. and WATSON, W.H.III. 1994. The behaviour of lobsters in response to reduced salinity. *J. Exp. Mar. Biol. Ecol.* **180**: 23-37.

88. BATTAGLENE, S.C. and TALBOT, R.B. 1993. Effects of salinity and aeration on survival of an initial swim bladder inflation in larval Australian bass. *Prog. Fish Cult.* **55**(1):35-39.

89. PAULRAJ, R. and KIRON, V. 1988. Influence of salinity on the growth and feed utilisation in *Liza parsia* fry. The first Indian Fisheries Forum Proceedings - December 4-8 1987, *Mangalore KARNATAKA 1988*: 61-63.

REFERENCES continued on next page

REFERENCES continued...

90. PICKOVA, J. 1993. Rearing experiments with Baltic cod (*Gadus morhoa*) for stock enhancement release. In: The International Symposium for sea ranching of cod and other marine species, Ar Endal, Norway, 15-18 June, 1993. Programme and Abstracts. Bergen, Norway, IMR 16 pp.

91. BROWN, J.A. and TYTLER, P. 1993. Hypoosmoregulation of larvae of the turbot, *Scophthalamus maximus:* Drinking and gut function in relation to environmental salinity. F*ish Physiol. Biochem*. **10**(6): 475-483.

92. LIGNELL, A. and PEDERSEN, M. 1989. Effects of pH and inorganic carbon concentration on growth of *Gracilaria secundata*, *Br Phycol. J*., **24**(1): 83-89.

93. HINGA, K.R. 1992. Co-occurrence of dinoflagellate blooms and high pH in marine enclosure. *Mar. Ecol. Prog. Ser.* **86**(2):181-187.

94. ALLAN, G.L. and MAGUIRE, G.B. 1992. Effects of pH and salinity on survival growth and osmoregulation in *Penaeus monodon* Fabricius. *Aquaculture* **107**(1): 33-47.

95. LOOSANOFF, V.L. and TOMMERS, F.D. 1947. Effect of low pH upon rate of water pumping of oysters, *Ostrea virginica. Anat. Rec.* **99**: 112-113.

96. BAMBER, R.N. 1990. The effects of acidic seawater on three species of lamellibranch mollusc. *J. Exp. Mar. Biol. Ecol.* **143**: 181-191.

97. BAMBER, R N. 1987. The effects of acidic seawater on young carpet-shell clams *Venerupis decussata* (L.) (Mollusca: Veneracea). *J. Exp. Mar. Biol. Ecol.*, **108**(3): 241-260.

98. EPIFANIO, C.E., SRNA, R. and PRUDER, G. 1975. Mariculture of shellfish in controlled environments: a prognosis. *Aquaculture* **5**: 227-241.

99. KUWATANI, Y. and NISHII, T. 1969. Effects of pH of culture water on the growth of the Japanese pearl oyster. *Bulletin of the Japanese Society of Scientific Fisheries* **35**: 242-250.

100. ALLAN, G.L., MAGUIRE, G.B. and HOPKINS, S.J. 1990. Acute and chronic toxicity of ammonia to juvenile *Metapenaeus macleayi* and *Penaeus monodon* and the influence of low dissolved-oxygen levels. *Aquaculture* **91**: 265-280.

101. TREECE, G. D. and YATES, M.E. 1988. *Laboratory Manual for the Culture of Penaeid Shrimp Larvae*. Marine Advisory Service, Sea Grant College Program, Texas A&M University, College Station, Texas. 95pp.

102. D'CROZ, L., TORRES, J. and GOMEZ, J.A. 1989. Effects of the crude oil (BCF-24) on the growth of the tropical marine diatom *Cheatoceros gracilis*. *Rev. Com. Perm. Pac. Sur.* 171-178.

REFERENCES continued on next page

REFERENCES continued...

103. EVANS, L. 1993. The establishment of a commercial *Penaeus monodon* prawn farm in Zululand, South Africa. In: *Aquaculture '92, Proceedings of the Aquaculture Association of Southern Africa* No **1**. Hecht, T. and P. Britz (eds). pp. 109-116.

104. LOOSANOFF, V.L and TOMMERS F.D. 1948. Effects of suspended silt and other substances on the rate of feeding of oysters. *Science* **107**: 69-70.

105. REDDING, J.M., SCHRECK, C.B. and EVERST, F.H. 1987. Physiological effects on coho salmon and steelhead of exposure to suspended solids. *Trans. Am. Fish. Soc.* **116**(5): 737-744.

106. SEAMAN, M.N.L., HIS, E., KESKIN, M. and REINS, T. 1991. Influence of turbulence and turbidity on growth and survival of laboratory-reared bivalve larvae. Copenhagen-Denmark ICES. 6 pp.

107. TJEERDEMA, R.S., KANTEN, R.J. and CROSBY, D.G. 1991. Sublethal effects of hypoxia in the abalone (*Haliotis rufescens*) as measured by *in vivo* 31p NMR spectroscopy. *Comp. Biochem. Physiol*., **100B**(4): 653-659

108. TJEERDEMA, R.S., KANTEN, R.J. and CROSBY, D.G. 1991. Interactive effects of pentachlorophenol and hypoxia in the abalone (*Haliotis rufescens*) as measured by *in vivo* 31p NMR spectroscopy. *Aquat. Toxicol.* **21**(3-4): 279-294.

109. REISH, D.J. and BARNARD, J.L. 1960. Field toxicity tests in marine waters utilizing the polycheatous annalid *Capitella capitata* (Fabricius). *Pacific Nat.* **1**: 1-8.

110. WESTLEY, R.E. 1965. Some relationships between Pacific oysters, *Crassostrea gigas*, condition and the environment. *Proc. natn. Shellfish. Ass.* **55**: 19-33.

111. DAVIS, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. *J. Fish. Res. Bd Can.* **32**: 2295-2332.

112. JELMERT, A. and NAAS, K.E. 1990. Induced deformites on larvae of the Atlantic halibut (*Hippoglossus hippoglossus* L.). A new experimental approach. Copenhagen, Denmark, ICES. 12 pp.

113. ALDERICE, D.F., WICKETT, W.P. and BRETT, J.R. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. *J. Fish. Res. Bd. Canada.* **15**: 229-250.

114. HARVEY, R.A. PRZYBYLAK, P.K. 1985. Optimum conditions in live rock lobster tanks. *Fishing Industry Research Institute Annual Report* **39**: 19-21.

115. WESSELS, J.P.H. 1993. Code of Practice: Whole Frozen Cooked Lobster. *Fishing Industry Research Institute Memorandum* **386**.

REFERENCES continued on next page

i

REFERENCES continued...

116. ALLAN, G.L. and MAGUIRE, G.B. 1991. Lethal levels of low dissolved oxygen and effects of short-term oxygen stress on subsequent growth of juvenile *Penaeus monodon*. *Aquaculture* **94**: 27-37.

117. COASTAL AQUACULTURE . 1988. Rethinking shrimp pond management. *Coastal Aquaculture* **5**(2): 1-19.

118. BEYERS, C.J. DE B., WILKE, C.G. and GOOSEN, P.C. 1994. The effects of oxygen deficiency on growth, intermoult period, mortality and ingestion rates of aquarium-held juvenile rock lobster *Jasus lalandii*. *S. Afr. J. mar. Sci.* **14**: 79-87.

119. CHEN, J.C. and NAN, F.H. 1992. Effects of temperature, salinity and ambient ammonia on lethal dissolved oxygen of *Penaeus chinensis juveniles*. *Comp. Biochem. Physiol.* **101C**(3):459-461.

120. SUNDNES, G. 1957. On the transport of live cod and coalfish. *J. Cons. perm. int. Explor. Mer.* **22**: 191-196.

121. BROWNELL, C L. 1979. Stages in the early development of forty marine fish species with pelagic eggs from the Cape of Good Hope. J L B Institute of Ichthyology, Rhodes University, *Bulletin* **40**. 84 pp.

122. MORIMURA, S. 1993. Influence of the environment on fish farming. *Fish Farming Technology*. Reinertsen, Dahle, Jorgensen and Tuinnereim (eds). Balkema, Rotterdam. pp 155-161.

123. CHEN, J. C., LIU, P.C and LEI, S.C. 1990. Toxicities of ammonia and nitrite to *Penaeus monodon* adolescents. *Aquaculture* **89**: 127-137.

124. CHEN, J.C. and NAN, F.H. 1991. Lethal effect of nitrite on *Penaeus chinensis* (larvae). *J. World Aquacult. Soc.* **22**(1): 51-66.

125. CHEN, J.C. and CHIN, T.S. 1988. Acute toxicity of nitrite to the tiger prawn, *Penaeus monodon*, Larvae. *Aquaculture* **69**: 253-262.

126. TARAZONA, J. V., MUNOZ, M.J., CARBONELL, G., CARBALLO, M., ORTIZ, J.A and CASTANO, A. 1991. A toxicological assessment of water pollution and its relationship to aquaculture development in Algeciras Bay, Cadiz, Spain. *Arch. Environ.Contam. Toxicol.* **20**(4): 480-487.

127. CHEN, J.C. and LEI, S.C. 1990. Toxicity of ammonia and nitrite to *Penaeus monodon* juveniles. *J. World Aquacult. Soc.* **21**: 300-306.

REFERENCES continued on next page

REFERENCES continued...

128. BUSTAMENTE, R.H., BRANCH, G.M, EEKHOUT, S., ROBERTSON, B., ZOUTENDYK, P., SCHLEYER, M., DYE, A., HANEKO, N., KEATS, D., JUR, M. and McQUAID, C. In press. Gradients of intertidal primary productivity around the coast of South Africa, and their relationships with consumer biomass. Submitted to *Oecologia*.

129. INTERGRAAD, M., SKJAK-BREK, G. and JENSEN, A. 1990. Studies on the influence of nutrients on the composition and structure of alginate in *Laminaria saccharina* (L.) Lamour. (Laminariales, Phaeophyceae). *Bot. Mar.* **33**: 277-288.

130. HASTIE, L.C., WATSON, T.C., ISAUMU, T. and HESLINGA, G.A. 1992. Effect of nutrient enrichment on *Tridacna derasa seed*: Dissolved inorganic nitrogen increases growth rate. *Aquaculture* **106**(1): 41-49.

131. MUIR, P.R., SUTTON, D.C. and OWENS, L. 1991. Nitrate toxicity to *Penaeus monodon* protozoa. *Mar. Biol.* **108**(1): 67-71.

132. PIERCE, R.H., WEEKS, J.M. and PRAPPAS, J.M. 1993. Nitrate toxicity to five species of marine fish. *J. World Aquacult. Soc.* **24**(1): 105-107.

133. HO, Y.B. 1988. *Ulva lactuca* (Chlorophyta, Ulvales) in Hong Kong intertidal waters: Its nitrogen and phosphorus contents and its use as a bioindicator for eutrophication. In: *Proceedings on marine biology of the South China Sea*. Gongzhao, X. and Morton, B. (Eds). pp. 277-286.

134. BISKER, R. and CASTAGNA, M. 1985. The effect of various levels of air-supersaturated seawater on *Mercenaria mercenaria* (Linne), *Mulinia lateralis* (Say), and *Mya cerenaria* Linne, with reference to gas bubbles disease. *J. Shellfish Res.* **5**(2): 97-102.

135. CHIN, T.S. and CHEN, J.C. 1987. Acute toxicity of ammonia to larvae of the tiger prawn, *Penaeus monodon*. *Aquaculture* **66**: 247-253.

136. CHEN, J C and TU, C.C . 1991. Influence of ammonia on growth of *Penaeus monodon* Fabricius post-larvae. *Aquacult. Fish. Manage.*,**22**:457-462.

137. CHEN, J C, P C LIU and TI, C.C. 1990. Effect of ammonia on the growth of *Penaeus monodon* postlarvae. *J. Fish. Soc. Taiwan*,**17**: 207-212.

138. YOUNGLAI, W.W., CHARMANTIRDAURES, M. and CHARMANTIER, G. 1991. Effect of ammonia on survival and osmoregulation in different life stages of the lobster *Homarus americanus*. *Mar. Biol.* **110**(2): 293-300.

139. CHEN, J.C. and LIN, C.Y. 1992. Effects of ammonia on growth and moulting of *Penaeus monodon* juveniles. *Comp. Biochem. Physiol.* **101C**: 449-452.

REFERENCES continued on next page

i

REFERENCES continued...

140. CHEN, J.C, TING, Y.Y., LIN, J.N. and LIN, M.N. 1990. Lethal effects of ammonia and nitrite on *Penaeus chinensis* Juveniles. *Mar. Biol.* **107**(3): 427-431.

141. CHEN, J.C. and KOU, Y.Z. 1992. Effects of ammonia on growth and moulting of *Penaeus japonicus* juveniles. *Aquaculture* **104**: 249-260.

142. CHEN, J.C and LIN, C.Y. 1992. Lethal effects of ammonia on *Penaeus chinensis* Osbeck juveniles at different salinity levels. *Journal of Experimental Marine Biology and Ecology* **156**(1): 139-148.

143. EISLER, R. 1991. Cyanide hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish and Wildlife Service, *Biological Report* **85**(1.23). 55 pp.

144. LORD, D.A and GELDENHUYS, N.D. 1982. Richards bay effluent pipeline. *South African National Scientific Programmes Report* No **129**. 30 pp. Pretoria.

145. CARPENTER, E.J, PECK, B.B and ANDERSON, S.J. 1972. Cooling water chlorination and productivity of entrained phytoplankton. *Mar. Biol.* **16**: 37-40.

146. DINNEL, P.A, STOBER, Q.J. and DIJULIO, D.H. 1981. Sea urchin sperm bioassay for sewage and chlorinated seawater and its relation to fish bioassay. *Marine Environmental Research* **5**: 29-39.

147. CAPUZZO, J.M. 1979. The effect of temperature on the toxicity of chlorinated cooling waters to marine animals. A preliminary review. *Marine Pollution Bulletin* **10**(2): 45-47.

148. ROBERTS, M.H and GLEESON, R.A. 1978. Acute toxicity of bromochlorinated seawater to selected estuarine species with a comparison to chlorinated seawater toxicity. *Marine Environmental Research* **1**: 19-30.

149. MUCHMORE, D. and EPEL, D. 1973. The effects of chlorination of waste water on the fertilisation of some marine invertebrates. *Mar. Biol.* **19**: 93-95.

150. ROOSENBURG, W.H., RHODERICK, J.C, BLOCK, R.M, KENNEDY, V.S., GULLANS, S.R., VREENEGOOR, S.M., ROSENKRANZ, A. and COLLETTE, C. 1980. Effects of chlorine-produced oxidants on survival of larvae of the oyster *Crassostrea virginica*. *Mar. Ecol. Prog. Ser.* **3**: 93-96.

151. RUDI, H. and DRAGSUND, E. 1993. Localisation strategies. *Fish Farming Technology*. Reinertsen, Dahle, Jorgensen and Tuinnereim (eds). Balkema, Rotterdam, pp 169-175.

REFERENCES continued on next page

i

REFERENCES continued...

152. ROBERTS, M.H. 1980. Survival of juvenile spot (*Leiostomus xanthurus*) exposed to brominated and chlorinated sewage in estuarine waters. *Marine Environmental Research* **3**: 63-80.

153. ROESIJADI, G., JACOBSEN, D.M, BRIDGE, J.R. and CRECELIUS, E.A. 1979. Disruption of magnesium regulation in the crab *Cancer productus* exposed to chlorinated seawater. *Marine Environmental Research* **2**: 71-84.

154. HUGUENIN, J.E and COLT, J. 1989. Design and operating guide for aquaculture seawater systems. In: D*evelopments in aquaculture and fisheries science*, Volume 20. Elsevier.

155. EISLER, R. 1988. Arsenic hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish and Wildlife Service, *Biological Report* **85**(1.12). 92 pp.

156. AHSANULLAH, M. and WILLIAMS, A.R. 1991. Sublethal effects and bioaccumulation of cadmium, chromium, copper and zinc in the marine amphipod *Allorchestes compressa*. *Mar. Biol.* **108**(1): 59-65.

157. BABY, K.V. and MENON, N.R. 1986. Oxygen uptake in the brown mussel *Perna indica* (Kuriakose and Nair) under sublethal stress of Hg, Cd and Zn. *Indian J. mar. Sci.* **15**: 127-128.

158. DURKINA, V.B and EVTUSHENKO, Z.S. 1991. Changes in activity of certain enzymes in sea urchin embryos and larvae after exposure of adult organisms to heavy metals. *Mar. Ecol. Prog. Ser.* **72**(1-2): 111-115.

159. BRAND, G.W., FABRIS, G.J. and ARNOTT, G.H. 1986. Reduction of population growth in *Tisbe holothuriae* Humes (Copepoda : Harpacticoida) exposed to low cadmium concentrations. *Australian Journal of Marine and Freshwater Research* **37**: 475-479.

160. ZANDERS, I.P and ROJAS, W.E. 1992. Cadmium accumulation, LC_{50} and oxygen consumption in the tropical marine amphipod *Elasmopus rapax*. *Mar. Biol.* **113**(3): 409-413.

161. AHSANULLAH, M. 1976. Acute toxicity of cadmium and zinc to seven invertebrate species from Western Port, Victoria. *Australian Journal of Marine and Freshwater Research* **27**: 187-196.

162. AHSANULLAH, M., MOBLEY, M.C and RANKIN, P. 1988. Individual and combined effects of zinc, cadmium and copper on the marine amphipod *Allorchestes compressa*. *Australian Journal of Marine and Freshwater Research* **39**: 33-37.

163. AHSANULLAH, M. and ARNOTT, G.H. 1978. Acute toxicity of copper, cadmium and zinc to the larvae of the crab *Paragrapsus quadridentatus* (H. Milne Edwards) and implications for water quality criteria. *Australian Journal of Marine and Freshwater Research* **29**: 1-8.

REFERENCES continued on next page

REFERENCES continued...

164. GAUDY, R., GUERIN, J.P and KERAMBRUN, P. 1991. Sublethal effects of cadmium on respiratory metabolism, nutrition, excretion and hydrolase activity in *Leptomysis lingvura* (Crustacea, Mysidacea). *Mar. Biol.* **109**(3): 493-50.

165. BROWN, A.C. and McLACHLAN, A. 1990. *Ecology of Sandy Shores*. Elsevier. 328 pp.

166. LIAO, I. C. and HSIEH, C.S. 1988. Toxicity of heavy metals to *Penaeus japonicus*. I. Toxicities of copper, cadmium and zinc to *Penaeus japonicus*. *J. Fish. Soc. Taiwan* **15**: 69-78.

167. AHSANULLAH, M., NEGILSKI, D.S. and MOBLEY, M.C. 1981. Toxicity of zinc, cadmium and copper to the shrimp *Callianassa australiensis* I. Effects of individual metals. *Mar. Biol.* **64**: 299-304.

168. COULL, B.C., THOMAS, G. and CHANDLER, G.T. 1992. Pollution and meiofauna: field, laboratory, mesocosm studies. *Oceanography and Marine Biology Annual Review* **30**: 191-271.

169. AHSANULLAH, M. 1982. Acute toxicity of chromium, mercury, molybdenum and nickel to the amphipod *Allorchestes compressa*. *Australian Journal of Marine and Freshwater Research* **33**: 465-474.

170. JOSHI, H.V., CHANNAN, V.D. and RAO, P.S. 1982. Effect of metal ions on the growth of *Sargassim swartzii* (Turn) C. Ag. Germ hings. *Indian J. Mar. Sci.* **11**(4): 338.

171. ANDERSON, B.S., HUNT, J.W., TURPEN, S.L., COULON, A.R. and MARTIN, M. 1990. Copper toxicity to microscopic stages of giant kelp *Macrocystis pyrifera* - Interpopulation comparisons and temporal variability. *Mar. Ecol. Prog. Ser.* **68**: 147-156.

172. BRAEK, G.S. and JENSEN, A. 1976. Heavy metal tolerance of marine phytoplankton. III. Combined effects of copper and zinc ions on cultures of four common species. *Journal of Experimental Marine Biology and Ecology* 25: 37-50.

173. GOTSIS, O. 1982. Combined effects of selenium/mercury and selenium/copper on the cell population of the algae *Dunaliella minuta*. *Mar. Biol.* **71**: 217-222.

174. CALABRESE, A., MacINNES, J.R., NELSON, D.A. and MILLER, J.E. 1977. Survival and growth of bivalve larvae under heavy metal stress. *Mar. Biol.* **44**: 179-184.

175. PRABHUDEVA, K.N. and MENON, N.R. 1988. Toxicity of copper salts on the brown mussel *Perna indica*: individually and in combination. *Proceedings First Indian Fisheries Forum*: 277-279.

REFERENCES continued on next page

REFERENCES continued...

176. AHSANULLAH, M. and FLORENCE, T.M. 1984. Toxicity of copper to the marine amphipod *Allorchestes compressa* in the presence of water and lipid soluble ligands. *Mar. Biol.* **84**: 41-45.

177. LIU, S., PAN, Z. and CHEN. G. 1987. Toxic effect of zinc and copper ions on the development and growth of abalone (*Haliotis discus* hannaii) (Ino) in its larval phase. *J. Zheijiang. Coll. Fish. Zhejiang Shinchan Xneyan Xuibao.* **6**(1): 31-38.

178. VRANKEN, G., TIRE, C. and HEIP, C. 1988. The toxicity of paired metal mixtures to the nematode *Monhystera disjuncta* (Bastian, 1865). *Marine Environmental Research* **26**: 161-179.

179. EISLER, R. 1988. Lead hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish and Wildlife Service, *Biological Report* **85**(1.14). 134 pp.

180. GO, E.C., PANDEY, A.S. and MACRAE, T.H. 1990. Effect of inorganic mercury on the emergence and hatching of the brine shrimp *Artemia franciscana*. *Mar. Biol.* **107**(1): 93-102.

181. SHEALY, M.H. (jr) and SANDIFER, P.A. 1975. Effects of mercury on survival and development of the grass shrimp *Palaemonetes vulgaris*. *Mar. Biol.* **33**: 7-16.

182. WORLD HEALTH ORGANIZATION. 1982. *Waste discharge into the marine environment. Principles and guidelines for the Mediterranean action plan*. Published under the joint sponsorship of the WHO and the United Nations Environment Programme. Pergamon Press. 422 pp.

183. EISLER, R. 1989. Tin hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Fish and Wildlife Service, *Biological Report* **85**(1.15). 83 pp.

184. STAUBER, J.L. and FLORENCE, T.M. 1990. Mechanism of toxicity of zinc to the marine diatom *Nitzschia closterium*. *Mar. Biol.* **105**(3): 519-524.

185. HUNT, J.W. and ANDERSON, B.S. 1989. Sublethal effects of zinc and municipal effluent on larvae of the red abalone *Haliotis rufescens*. *Mar. Biol.* **101**: 545-552.

186. BRENTON, A., LORD, H., THORNTON, I. and WEBB, J.S. 1973. Effects of zinc on growth and development of the Pacific oyster *Crassostrea gigas*. *Mar. Biol.* **19**: 96-101.

187. BOYDEN, C.R., WATLING, H. and THORNTON, I. 1975. Effects of zinc on the settlement of the oyster *Crassostrea gigas*. *Mar. Biol.* **31**: 227-234.

188. WORLD HEALTH ORGANIZATION. 1990. Tributyltin compounds. *Environmental health criteria series* **116**. Geneva, Switzerland.

REFERENCES continued on next page

REFERENCES continued...

189. KARANDE, A. A., GANTI, S.S. and UDHYAKUMAR, M. 1993. Toxicity of tributyltin to some bivalve species. *Indian J. mar. Sci.* **22**: 153-154.

190. OSTGAARD, K., EIDE, I. and JENSEN, A. 1984. Exposure of phytoplankton to Ekofisk crude oil. *Marine Environmental Research* **11**: 183-200.

191. ZACHLEDER, V. and TUKAJ, Z. 1993. Effect of fuel oil and dispersant on cell cycle and the macromolecular synthesis in the chlorococcal algae *Scenedesmus armatus*. *Mar. Biol.* **117**: 347-353.

192. TATEM, H.E., COX, B.A. and ANDERSON, J.W. 1978. The toxicity of oils and petroleum hydrocarbons to estuarine crustaceans. *Estuarine and Coastal Marine Science* **6**: 365-373.

193. NEFF, J.M. and ANDERSON, J.W. 1981. *Response of marine animals to petroleum and specific petroleum hydrocarbons*. Applied Science Publishers Ltd, Barking, England 177 pp.

194. MASON, R.P. 1988. Accumulation and depuration of petroleum hydrocarbons by black mussels. 1. Laboratory exposure trials. *S. Afr. J. mar. Sci* **6**: 143-153.

195. CARTER, R.A., PROBYN, R.A. and MEDINA, L. 1994. Tank cultivation of *Gracilaria verrucosa* in St. Helena Bay, South Africa and La Paloma, Uruguay. In: Proceedings of the 11th Congress of Phycological Society of South Africa, January 1994.

i

ADDITIONAL INFORMATION

ALDERMAN, D., HINGA, K.R. and PILSON, M.E.Q. 1990. Biogeochemistry of butyltins in an enclosed marine ecosystem. *Environmental Science and Technology* **24**: 1027-1032.

ANDERSON, B.S., MIDDAUGH, D.P., HUNT, J.W. and TURPEN, S.L. 1991. Copper toxicity to sperm, embryos and larvae of topsmelt atherinops affins, with notes on induced spawning. *Marine Environmental Research* **31**: 17-35.

ANDERSON, J.W., NEFF, J.M., COX, B.A., TATEM, H.E. and HIGHTOWER, G.W. 1974. Characteristics of dispersions and water-soluble extracts of crude and refine oils and their toxicity to estuarine crustaceans and fish. *Mar. Biol.* **27**: 75-88.

ANNAAS, T., EINARSON S., SOUTHON, T. and E ZACHARIASSEN, K. 1990. The effects of organic and inorganic pollutants on intracellular phosphorus compound in blue mussels (*Mytilus edulis*). *Physiological and biochemical approaches to the toxicological assessment of environmental pollution*.

ARMSTRONG, D.A., CHIPPENDALE, D., KNIGHT, A.W. and COLT, J.E. 1978. Interactions of ionized and un-ionized ammonia on short-term survival and growth of prawn Larvae, *Macrobrachium rosbergii*. Biological Bulletin 154: 15-31.

BAY, S.M., GREENSTEIN, D.J., SZALAY, P. and BROWN, D.A. 1990. Exposure of scorpion fish (*Scorpaena guttata*) to cadmium - biochemical effects of chronic exposure. *Aquatic Toxicology* **16**(4): 311-320

BONSDROFF, E., BAKKE, T. and PEDERSEN, A. 1990. Colonization of amphipods and polychaetes to sediments experimentally exposed to oil hydrocarbons. *Marine Pollution Bulletin* **21**(7): 355-358.

BOWER, S. M., WHITAKER, D.J. and VOLTOLINA, D. 1989. Resistance to ozone of zoospores of the thranstochytrid abalone parasite, *Labyrinthuloides haliotidis* (Protozoa: *Labyrinthromorpha*). *Aquaculture* **78**(2): 147-152.

BROWN, P.C. and FIELD, J.C. 1986. Factors limiting phytoplankton production in a nearshore upwelling area. *J. Plankt. Res.* **8**(1): 55-68.

BROWN, A.C. 1985. The effects of crude oil pollution on marine organisms - a literature review in the South African context: Conclusions and recommendations. *South African National Scientific Programmes Report* No **99**. 33 pp.

BRYAN, G. W., BRIGHT, D. A., HUMMERSTONE, L. C. and BURT, G.R. 1993. ^{14}C-labelled tributylin (TBT) in the dog-whelk *Nucella lapillus*. *J. Mar. Biol. Assoc. UK.* **73**(4): 889-912.

ADDITIONAL INFORMATION continued on next page

ADDITIONAL INFORMATION continued...

CLEARY, J.J. 1991. Organotin in the marine surface microlayer and subsurface waters of south-west England: Related to toxicity thresholds and the UK environmental quality standard. *Marine Environmental Research* **32**: 213-222.

COGLIANESE, M.P. and MARTIN, M. 1981. Individual and interactive effects of environmental stress on the embryonic development of the Pacific oyster, *Crassostrea gigas*. I. The toxicity of copper and silver. *Marine Environmental Research* **5**: 13-27.

CONNELL, A.D., AIREY, D.D. and RATHBONE, P.A. 1991. The impact of titanium dioxide waste on fertilization in the sea urchin *Echinometra mathaei. Marine Pollution Bulletin* **22**(3): 119-122.

COOK, P.A. 1981-1984. Koeberg Nuclear Power Station. Marine Environmental Monitoring Programme, Baseline Ecological Report. University of Cape Town, Cape Town.

CUCCI, T.L. and EPIFANIO, C.E. 1979. Long-term effects of water-soluble fractions of Kuwait crude oil on the larvae and juvenile development of the mud crab *Eurypanopeus depressus*. *Mar. Biol.* **55**: 215-220.

DHARGALKAR, V. K. 1986. Effect of treated sewage on growth of marine algae. *Indian J. Mar. Sci.* **15**(1): 33-36.

ELGERSHUIZEN, J.H.B.W. and DE KRUIJF, H.A.M. 1976. Toxicity of crude oils and a dispersant to the stony coral Madracis mirabilis. *Marine Pollution Bulletin* **7**(2): 22-25.

FISHER, W.S. and FOSS, S.S. 1993. A simple test for toxicity of Number 2 fuel oils and oil dispersants to embryos of the grass shrimp, *Palaemonetes pugio*. *Marine Pollution Bulletin* **26**(7): 385-391.

GOKSOYR, A., SOLBERG, T.S. and SERIGSTAD, B. 1991. Immunochemical detection of cytochrome P450IA1 induction in cod larvae and juveniles exposed to a water soluble fraction of North Sea crude oil. *Marine Pollution Bulletin* **22**(3): 122-127.

HANSEN, J.I., MUSTAFA, T. and DEPLEDGE, M. 1992. Mechanisms of copper toxicity in the shore crab, *Carcinus maenas*. 1. Effects on Na, K-ATPase activity, hemolymph electrolyte concentrations and tissue water contents. Mar. Biol. 114(2): 253-257.

HANSEN, J.I., MUSTAFA, T. and DEPLEDGE, M. 1992. Mechanisms of copper toxicity in the shore crab, *Carcinus maenas*. 2. Effects on key metabolic enzymes, metabolites and energy-charge potential. *Mar. Biol.* **114**(2): 259-264.

HARRISON, P.J., COCHLAN, P.J., ACREMAN, J.C., PARSONS, T.R., THOMPSON, P.A. and DOVEY, H.M. 1986. The effects of crude oil and corexit 9527 on marine phytoplankton in an experimental enclosure. *Marine Environmental Research* **18**: 93-109.

ADDITIONAL INFORMATION continued on next page

i

ADDITIONAL INFORMATION continued...

HEARD, C.S., WALKER, W.W. and HAWKINS, W.E. 1989. Aquatic toxicological effects of organotins: An overview . In: *Oceans '89: The Global Ocean.* Volume 2: Ocean Pollution, pp 554-563.

HILL, B.J. and ALLANSON, B.R. 1971. Temperature tolerance of the estuarine prawn *Upogebia africana* (Anomura, Crustacea). *Mar. Biol.* **11**: 337-343.

KARYDIS, M. 1979. Short-term effects of hydrocarbons on the photosynthesis and respiration of some phytoplankton species. *Botanica Marina* **22**: 281-285.

KARYDIS, M. 1982. Toxicity of photooxidised crude oil on two marine microalgae. *Botanica Marina* **25**: 25-29.

LEE, W.Y. 1978. Chronic sublethal effects of the water soluble fraction of No. 2 fuel oils on the marine isopod, *Sphaeroma quadridentatum*. *Marine Environmental Research* **1**: 5-17.

LEE, W.Y., WELCH, M.F and NICOL, J.A.C. 1977. Survival of two species of amphipods in aqueous extracts of petroleum oils. *Marine Pollution Bulletin* **8**(4): 92-94.

LEE, W.Y. and NICOL, J.A.C. 1980. Toxicity of a fuel oil to the eggs of *Parhyale hawaiensis* and *Amphithoe valida* (Amphipoda). *Marine Environmental Research* **3**: 297-305.

LIN, H.P., THUET, P., TRILLES, J.P., MOUNETGUILLAUME, R. and CHARMANTIER, G. 1993. Effects of ammonia on survival and osmoregulation of various development stages of the shrimp *Penaeus japonicus*. *Mar. Biol.* **117**(4): 591-598.

LINDEN, O., LAUGHLIN, R. (jr), SHARP, J.R. and NEFF, J.M. 1980. The combined effect of salinity, temperature and oil on the growth pattern of embryos of the killifish, *Fundulus heteroclitus* Walbaum. *Marine Environmental Research* **3**: 129-144.

MORALES-LOO, M.R. and GUOTX, M. 1990. Effects of water soluble fraction of the Mexican crude oil "Isthmus Cactus" on the growth, cellular content of *chlorophyll a* and lipid composition of planktonic microalgae. *Mar. Biol.* **104**: 503-509.

MOSS, S.M., PRUDER, G.D., LEBER, K.M. and WYBAN, J.A. 1992. The relative enhancement of *Penaeus vannamei* growth by selected fractions of shrimp pond water. *Aquaculture* **101**: 229-239.

MUIR, P.R., SUTTON, D.C. and OWENS, L. 1991. Nitrate toxicity to *Penaeus monodon* protozoa. *Mar. Biol.* **108**: 67-71.

ORDZIE, C.J. and GAROFALO, G. 1981. Lethal and sublethal effects of short term acute doses of Kuwait crude oil and a dispersant Corexit 9527 on bay scallops, *Argopecten irradians* (Lamarck) and Two Predators at Different Temperatures. *Marine Environmental Research* **5**: 195-210.

ADDITIONAL INFORMATION continued on next page

ADDITIONAL INFORMATION continued...

OSHIDA, S.P., WORLD, S.P. and MEARNS, A.J. 1981. Effects of hexavalent and trivalent chromium on the reproduction of *Neanthes arenaceodentata* (Polychaeta). *Marine Environmental Research* **5**: 41-49.

PALMER, S.J., PRESLEY, B.J. and TAYLOR, R.J. 1992. Mercury bioaccumulation in oysters, *Crassostrea virginica*, the crabs, *Callinectes sapidus* and Penaeus shrimp in a contaminated estuary. *Aquaculture '92: Growing towards the 21st Century*. 179 pp.

PATEL, B. and ANTHONY, K. 1991. Uptake of cadmium in tropical marine lamellibranchs and effects on physiological behaviour. *Mar. Biol.* **108**(3): 457-470.

PATEL, B. and ANTHONY, K. 1991. Uptake of cadmium in tropical marine Lamellibranchs, and effects on physiological behavior. Mar. Biol. **108**(3): 457-470

PEARSON, W.H., MILLER, S.E. and BLAYLOCK, J.W. 1981. Detection of the water-soluble fraction of crude oil by the crab, *Callinectes sapidus*. *Marine Environmental Research* **5**: 3-11.

PIERCE, R.H., WEEKS, J.M. and PRAPPAS, J.M. 1993. Nitrate toxicity to five species of marine fish. *J. World Aquacult. Soc.* **24**(1):105-107.

POLLOCK, D.E. and SHANNON L.V. 1987. Response of rock lobster populations in the Benguela ecosystem to environmental change - a hypothesis. *S. Afr. J. mar. Sci.* **5**: 887-899.

RINGWOOD, A.H. 1989. Accumulation of cadmium by larvae and adults of an Hawaiian bivalve, *Isogomon californicum*, during chronic exposure. Mar. Biol. 102: 499-504.

RINGWOOD, A.H. 1991. Short-term accumulation of cadmium by embryos, larvae and adults of an Hawaiian bivalve, *Isognomon californicum*. *Journal of Experimental Marine Biology and Ecology* **149**(1): 55-66

SPICER, J.I. and WEBER, R.E. 1992. Respiratory impairment by water-borne copper and zinc in the edible crab *Cancer pagurus* (L) (Crustacea, Decapoda) during hypoxic exposure. *Mar. Biol.* **112**(3): 429-435

STEPHENSON, M. 1991. A field bioassay approach to determining tributyltin toxicity to the oysters in California. *Marine Environmental Research* **32**: 51-59.

SUNILA, I. 1988. Acute histological responses of the gill of the mussel, *Mytilus edulis*, to exposure by environmental pollutants. *J. Invertebr. Pathol.* **52**(1): 137-141.

TALLEAT, V. 1987. Relationship between lead concentrations in seawater and in the mussel *Mytilus edulis*: A water quality criteria. *Mar. Biol.* **94**(4): 557-560.

ADDITIONAL INFORMATION continued on next page

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ADDITIONAL INFORMATION continued...

VAN DER HORST, J.R., GIBSON, C.I and MOORE, L.J. 1976. Toxicity of No. 2 fuel oil to coon stripe shrimp. *Marine Pollution Bulletin* **7**(6): 106-107.

WAJBROT, N., GASITH, A., DIAMANT, A. and POPPER, D.M. 1993. Chronic toxicity of ammonia to juvenile gilthead seabream *Sparus aurata* and its related histopathological effects. *Journal of Fish Biology* **42**: 321-328.

WEBER, R.E., DE ZWAAN, A. and BANG, A. 1992. Interactive effects of ambient copper and anoxic, temperature and salinity stress on survival and hemolymph and muscle Tissue osmotic effectors in *Mytilus edulis*. *Journal of Experimental Marine Biology and Ecology* **159**(2): 135-156.

WEBER, R.E., LYKKE-MADSEN, M., BANG, A., DE ZWAAN, A. and CORTESI, P. 1990. Effects of cadmium on anoxic survival, haematology, erythrocytic volume regulation and haemoglobin-oxygen affinity in the marine bivalve *Scapharca inaequivalvis*. *Journal of Experimental Marine Biology and Ecology* **144**: 29-38

WINTERS, K., O'DONNELL, R., BATTERTON, J.C. and VAN BAALEN, C. 1976. Water-soluble components of four fuel oils: Chemical characterization and effects on growth of microalgae. *Mar. Biol.* **36**: 269-276.

YAMAMOTO, M., WAANABE, Y. and KINOSHITA, H. 1991. Effects of water temperature on the growth of red alga *Porphyra yezoensis* from. *narawaensis* (nori) cultivated in an outdoor raceway tank. *Bull. Jap. Soc. Sci. Fish.* **57**(12): 2211-2217.

APPENDICES

APPENDIX A: SUMMARY OF TARGET VALUES FOR INDUSTRIAL USE OF SEAWATER

Physico-chemical properties

	MAKE-UP WATER FOR MARINE OUTFALLS	OTHER INDUSTRIAL USES
Temperature	The maximum acceptable variation in ambient temperature is + or - 1 °C	-
Salinity	-	
pH	-	
Floating matter, including oil and grease	Water should not contain floating particulate matter, debris, oil, grease, wax, scum, foam or any similar floating materials and residues from land-based sources in concentrations that may cause nuisance; Water should not contain materials from non-natural land-based sources which will settle to form putrescence; Water should not contain submerged objects and other subsurface hazards which arise from non-natural origins and which would be a danger, cause nuisance or interfere with any designated/recognized use	
Colour/turbidity/ clarity	Should not be more than 35 *Hazen units* above ambient concentrations (colour) Should not reduce the depth of the euphotic zone by more than 10 % of ambient levels measured at a suitable control site (turbidity)	
Suspended solids	Should not be increased by more than 10 % of ambient concentrations	
Dissolved oxygen	-	

SUMMARY OF TARGET VALUES continued on next page

Target values

SUMMARY OF TARGET VALUES continued...

Nutrients

	SALT PRODUCTION	OTHER INDUSTRIAL USES
Ammonium	Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* (see p A-1)	-
Nitrite		-
Nitrate		-
Reactive phosphate		-
Reactive silicate		-

Inorganic constituents

	ALL INDUSTRIAL USES
Ammonia	-
Cyanide	-
Fluoride	-
Chlorine	-
Hydrogen sulphide	-
Arsenic	-
Cadmium	-
Chromium	-
Copper	-
Lead	-
Mercury	-
Nickel	-
Silver	-
Tin	-
Zinc	-

SUMMARY OF TARGET VALUES continued on next page

Target values

SUMMARY OF TARGET VALUES continued...

Organic constituents

	ALL INDUSTRIAL USES
Organotins (Tributyltin)	-
Total petroleum hydrocarbons	-
Polycyclic aromatic hydrocarbons	-

Microbiological indicator organisms

	ALL INDUSTRIAL USES
Faecal coliforms (including *E. coli*)	-

APPENDIX B: INTERNATIONAL TARGET VALUES FOR THE NATURAL MARINE ENVIRONMENT

Physico-chemical properties

	CANADA[1]	US-EPA[2]	EEC (afterUK)[3]	AUSTRALIA[4]
Temperature	-	Maximum acceptable increase in weekly average: 1 °C (during all seasons, providing the summer maximum is not exceeded) Daily cycles characterisitc of the water body should not be altered in amplitude or frequency	-	Not increased by more than 2 °C
Salinity	-	-	-	Change should be < 5 % from background
pH	-	6,5-8,5 (but not more than 0,2 outside normal occurring range)	6-8,5 (annual arithmetic mean)	< 0,2 units change
Floating matter, including oil and grease	-	-	-	-
Colour/turbidity/ clarity	-	-	-	Natural euphotic depth should not be changed by more than 10 % Seasonal mean nephelometric turbidity should not be changed by more than 10 %
Suspended solids	-	-	-	Natural euphotic depth should not be changed by more than 10 %
Dissolved oxygen	-	-	-	> 6 mg l^{-1} (> 80-90 % saturation) Measured over at least one, but preferably over several, diurnal cycles

INTERNATIONAL TARGET VALUES continued on next page

International

INTERNATIONAL TARGET VALUES continued...

Nutrients

	CANADA[1]	US- EPA[2]	EEC (after UK)[3]	AUSTRALIA[4]
General	-	-	-	-
Nitrite	-	-	-	-
Nitrate	-	-	-	No single value. Indication of levels at which problems have been experienced: 10-60 µg l^{-1}
Phosphate	-	-	-	No single value. Indication of levels at which problems have been experienced: 1-10 µg l^{-1}
Total phosphorous	-	0,1 µg l^{-1} (elemental)	-	-
Silicate	-	-	-	-

INTERNATIONAL TARGET VALUES continued on next page

INTERNATIONAL TARGET VALUES continued...

Inorganic Constituents

	CANADA[1]	US-EPA[2]	EEC (after UK)[3]	AUSTRALIA[4]
Ammonia	-	-	21 µg l^{-1} (unionized N) (annual arithmetic mean)	500 µg l^{-1}
Cyanide	-	1 µg l^{-1} (1 h average) (not to be exceeded more than once every three years)	-	5 µg l^{-1}
Fluoride	-	-	-	-
Chlorine	-	7,5 µg l^{-1} (four-day average) 13 µg l^{-1} (1 h average) (not to be exceeded more than once every three years)	-	-
Hydrogen sulphide	-	2µg l^{-1} (undiss. H_2S)	10 µg l^{-1} (undiss. H_2S) (24 h maximum average)	-
Arsenic	-	36 µg l^{-1} As[III] (four-day average) 96 µg l^{-1} As[III] (1 h average) (not to be exceeded more than once every three years)	25 µg l^{-1} (dissolved) (annual arithmetic mean)	50 µg l^{-1}
Cadmium	-	9,3 µg l^{-1} (four-day average) 43 µg l^{-1} (1 h average) (not to be exceeded more than once every three years)	2,5 µg l^{-1} (dissolved) (annual arithmetic mean)	2 µg l^{-1}
Chromium	-	50 µg l^{-1} Cr[VI] (four-day average) 1,1 mg l^{-1} Cr[VI] (1 h average) (not to be exceeded more than once every three years)	15 µg l^{-1} (dissolved) (annual arithmetic mean)	50 µg l^{-1}
Copper	-	2,9 µg l^{-1} (1 h average) (not to be exceeded more than once every three years)	5 µg l^{-1} (dissolved) (annual arithmetic mean)	5 µg l^{-1}
Iron	-	-	1 000 µg l^{-1} (dissolved) (annual arithmetic mean)	-
Lead	-	5,6 µg l^{-1} (four-day average) 140 µg l^{-1} (1 h average) (not to be exceeded more than once every three years)	25 µg l^{-1} (dissolved inorganic) (annual arithmetic mean)	5 µg l^{-1}
Manganese	-	-	-	-
Mercury	-	0,025 µg l^{-1} (four-day average) 2,1 µg l^{-1} (1 h average) (not to be exceeded more than once every three years)	0,3 µg l^{-1} (dissolved) (annual arithmetic mean)	0,1 µg l^{-1}

INTERNATIONAL TARGET VALUES continued on next page

International

INTERNATIONAL TARGET VALUES continued...

Inorganic Constituents *continued...*

	CANADA[1]	US-EPA[2]	EEC (after UK)[3]	AUSTRALIA[4]
Nickel	-	140 µg l^{-1} 54 µg l^{-1} (24 h average)	30 µg l^{-1} (dissolved) (annual arithmetic mean)	15 µg l^{-1}
Selenium	-	410 µg l^{-1} 7,1 µg l^{-1} (24 h average)	-	70 µg l^{-1}
Silver	-	2,3 µg l^{-1}	-	1 µg l^{-1}
Tin (inorganic)	-	-	10 µg l^{-1} (dissolved) (annual arithmetic mean)	-
Vanadium		-	100 µg l^{-1} (dissolved) (annual arithmetic mean)	-
Zinc	-	170 µg l^{-1} 581 µg l^{-1} (24 hr average)	40 µg l^{-1} (dissolved) (annual arithmetic mean)	50 µg l^{-1}

Organic constituents

	CANADA[1]	US-EPA[2]	EEC (after UK)[3]	AUSTRALIA[4]
Organotins (Tributyltin)	0,001 µg l^{-1} (TBT)	-	0,001µg l^{-1} (Total TBT) 0,008 µg l^{-1} (Total TPT) (95 %ile)	0,002µg l^{-1} (TBT)
Total petroleum hydrocarbons	-	-	-	-
Poly cyclic aromatic hydrocarbons	-	-	-	3 µg l^{-1}
Algal toxins	-	-	-	-
Tainting substances	-	-	-	-
Other organics	Refer to reference No. 1	Refer to reference No. 2	Refer to reference No. 3	Refer to reference No. 4

International

INTERNATIONAL TARGET VALUES continued...

Microbiological indicators organisms and Pathogens

	CANADA[1]	US-EPA[2]	UK[3]	AUSTRALIA[4]
Total coliform	-	-	-	-
Faecal coliform	-	-	-	
E. coli	-	-	-	-
Enterococci (faecal streptococci)	-	-	-	-
Salmonella	-	-	-	-
Enteroviruses	-	-	-	-
Protozoa	-	-	-	-

International

REFERENCES

1. CANADIAN WATER QUALITY GUIDELINES. 1992. Updated version of Canadian water quality guidelines 1987. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environmental Ministers. Canada.

2. EPA. 1986. *Quality criteria for water*. EPA 440/5-86-001. United States Environmental Protection Agency, Washington, USA.

3. WATER RESEARCH CENTRE. 1990. Design guide for marine treatment schemes. Volume II. Environmental design and data collection. *Report* No **UM 1009**. Water Research Centre, Swindon, UK.

4. AUSTRALIAN WATER QUALITY GUIDELINES FOR FRESH AND MARINE WATERS. 1992. Australian and New Zealand Environment and Conservation Council, Australia.

APPENDIX C: GLOSSARY OF TERMS

Abalone Perlemoen.

Abiotic The non-living component of an ecosystem**.**

Absorption Penetration or uptake of one substance into the body of another (chemical terms).

Adiponitrile An intermediate in the manufacture of nylon.

Adsorption Attachment of molecules or ions to a substrate by manipulation of electrical charge or pH.

Adsorbed *see* Adsorption.

Aerobic Where oxygen is available or where molecular oxygen is required for respiration.

Algicidal dose Amount of a chemical required to kill algae.

Alginate One of a class of salts of algin, such as sodium alginate.

Aliphatic Refers to an organic compound of hydrogen and carbon characterised by a straight chain of carbon atoms.

Amperometric titration A titration involved in measuring an electric current or changes in current during the cause of the titration.

Amphipod Invertebrates belonging to the order Crustaceans.

Anoxic Limited or no oxygen availability.

Anaerobic Where insufficient oxygen is available or where molecular oxygen is not required for respiration.

Anthropogenic External, e.g. storm water is an anthropogenic source of pollution to the sea.

Atomic spectrophotometry A method of measuring concentration of substances, usually trace metals, by measuring spectra arising from either emission or absorption of electromagnetic radiation by atoms

Autolyse (Autolysis) Return of a substance to solution as of phosphate removed from seawater by plankton and returned when these organisms die and decay (path).

Bacteria Extremely small, relatively simple prokaryotic microorganisms.

GLOSSARY OF TERMS continued on next page

Glossary

GLOSSARY OF TERMS continued...

Balanoid zone (upper)	One of four distinct zones recognised on most rocky beaches, high on the shore above the lower Balanoid zone. Limpets and barnacles are characteristic of this zone.
Balanoid zone (lower)	One of four distinct zones recognised on rocky shores, just above the infratidal (subtidal) zone. Algae dominate in this zone.
Barnacle	The common name for a number of species of crustaceans.
Bathymetric	(Bathymetry) The science of measuring ocean depth in order to determine the sea floor topography.
Benthic	Inhabiting the bottom of a water body.
Bioassay	A method for quantitatively determining the concentration of a substance by its effect on a suitable organism or plant under controlled conditions.
Biochemical oxygen demand (BOD)	The amount of dissolved oxygen required to meet the metabolic needs of aerobic organisms in water rich in organic matter.
Biolimiting nutrient	A nutrient whose availability in surface waters limit biological production when not available in sufficient concentrations.
Biomass	The dry weight of living matter, including stored food, present in a species population and expressed in terms of a given area or volume of habitat.
Biotic	Pertaining to life or living organisms and/or induced by actions of living organisms.
Broodstock	Animals used for breeding purposes.
Byssogenesis	The generation of the tuft of strong filaments by which bivalve molluscs are attached to the substratum.
Buffering capacity	A measure of the relative sensitivity of a solution to pH changes on addition of acids or bases.
Carnivorous	Eating flesh (animals).
Chaetognanth	(Chaetognatha) A phylum of abundant arrow worms.
Chemical oxygen demand (COD)	It is the amount of dissolved oxygen required to oxidise all organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant.
Chemolitho-autotroph	A type of bacteria that derives its energy from the assimilation of carbon dioxide from the oxidation of ammonia, sulphur compounds, iron compounds, methane and hydrogen.

GLOSSARY OF TERMS continued on next page

GLOSSARY OF TERMS continued...

Chephalopod	(Cephalopoda) Exclusively marine organisms constituting the most advanced class of mollusca, including squids, octopuses and Nautilus.
Chlorophyll a	Refers to the green pigment in plants and algae which is fundamentally part of the process of photosynthesis. Chlorophyll is used as a measure of the amount of algae (phytoplankton) in water.
Chromatographic	Preferential absorption of chemical compounds (gases or liquids) in an ascending molecular weight sequence onto a solid adsorbent material, such as activated carbon, silica gel or alumina.
Ciliate	(Ciliatea) Refer to the single class of protozoan subphylum Ciliophora.
Clarity	Refers to the depth to which light can penetrate in a water body.
Coastal zone	For the purpose of these documents, it refers to coastal marine waters.
Cochlear zone	A zone found on the south coast on rocky shores between the infratidal (subtidal) and lower Balanoid zone. It is named after the limpet *Patella cochlear* that forms a dense band at the low-tide mark.
Coelenterate	(Coelenterata). A phylum of the Radiata whose members typically bears tentacles and possess intrinsic nematocysts.
Colloidal suspension	A mixture of two substances, one of which, called the dispersed phase (or colloid), is uniformly distributed in a finely divided state through the second substance, called the dispersion medium (or dispersing medium). Both phases may be a gas, liquid or solid.
Continental shelf	The zone around a continent, extending from the shoreline to the continental slope.
Continuous flow bioassay	A bioassay where the test organisms are kept in a flow-through system where the water has a particular concentration of the substance/s to be tested for.
Copepod/s	(Copepoda). An order of crustaceans, containing free-living, parasitic and symbiotic forms.
Coriolis force	A velocity-dependent pseudo force in a reference frame which rotates with respect to an inertial reference frame. It is equal and opposite to the product of the mass of the particle on which the force acts and its Coriolis acceleration.
Crustaceans	Animals having joint feet and mandibles, two pairs of antennae and segmented, chitin-encased bodies, including lobster and prawns.
Cyst	A normal or pathogenic sac with a distinct wall, containing fluid or other material.

GLOSSARY OF TERMS continued on next page

Glossary

GLOSSARY OF TERMS continued...

Demersal fish	Fish living near or at the bottom of the sea.
Depuration rate	Rate at which bivalves loose accumulated substances.
Desorption	Detachment of molecules or ions from a substrate by manipulation of electrical charge or pH.
Detritivore	Any animal that feeds on loose organic material (detritus) removed directly from the water or that collects on the substratum at the bottom of the sea.
Diarrhetic shellfish poison	Algal toxin causing gastrointestinal problems.
Diatoms	The common name for a group of micro-algae, noted for their symmetry and sculpturing of siliceous cell walls.
Dinoflagellate	An order of flagellate protozoan, most members having fixed shapes determined by thick covering plates.
EC	Electrical conductivity.
EC_{50}	Effective concentration where 50% of the test organisms die.
Ecosystem	A functional system which includes the organisms of a natural community together with their abiotic environment.
EEC	European Economic Community.
El Nino	A warm current setting south along the coast of Peru generally developing during February to March concurrently with a southerly shift in the tropical rain belt.
Ephemeral	Carries water only during or immediately after rainfall or snow melt.
Epidemiological	(Epidemiology) The study or science of diseases in a community.
Epiphytes	Plants which grow non-parasitically on another plant or on some non-living structure, deriving moisture and nutrients from the air.
Epipsammic	Attached to sand particles.
Euphotic zone	The surface water layer up to a depth where 1% of the surface illumination still penetrates.
Euryhaline	In marine organisms, indicating the ability to tolerate a wide range of salinities.
Eutrophication	Excessive algal or plant growth caused by high nutrient concentrations.

GLOSSARY OF TERMS continued on next page

GLOSSARY OF TERMS continued...

External behaviour response	An external, as apposed to physiological response, to changes in water quality such as abnormalities in migration patterns, movement or swimming speed.
Facultative	Having the ability to live under different conditions.
Filter feeder	An organism that uses complex filtering mechanisms to trap food particles suspended in water, e.g. mussels and oysters.
Fitness for use	The suitability of the quality of water for one of the following five recognised uses: domestic use, agricultural (mariculture) use, industrial use, recreational use and water for the natural environment.
Flora	Plant life characterising a specific geographic region or environment.
Fauna	Animal life characterising a specific geographic region or environment.
Fecundity	The number of eggs produced by an individual or species.
Gas chromatography	A separation technique whereby a sample is distributed between two phases. One of these is a stationary bed of large surface area, and the other a gas (carrier gas) which percolates through the stationary phase.
Gastropod	(Gastropoda) A large morphologically diverse class of the phylum Mollusca, comprising, for example, the limpets and abalone.
Geotactic	Locomotion response to gravity.
Gram-positive	Refers to bacteria which hold the colour of the primary stain when treated with Gram's stain.
Gravid	Pertaining to a female animal when carrying young or eggs.
Grazers	Animals which feed of larger plant material, e.g. algae and kelp, such as abalone.
Herbivore	An animal that eats only vegetation or plant material.
Heterotrophic	Obtain nourishment from the ingestion and breakdown of organic matter.
High performance liquid chromatography	A separation technique in which the sample is introduced into a system of two phases. Differences in the distribution shown by the solutes cause them to travel at different speeds in the system. The mobile phase is a liquid.
Hydride generation cold-vapour method	A method where a volatile hydride is formed and decomposed thermally to enable measurement by atomic absorption.
Hydroid	(Hydrioda) An order of coelenterates, including colonial forms, with well developed polyp stages.

GLOSSARY OF TERMS continued on next page

Glossary

GLOSSARY OF TERMS continued...

Hydrolysis Decomposition or alteration of a chemical substance in water.

Hyper- Excessive, exceeding, above, over.

Hypo- Low, under, below.

Hypoxia Lack of sufficient oxygen.

Humic substances A general category of naturally occurring, biogenic, heterogeneous organic substances that can be characterised as being yellow to black in colour, of high molecular weight, and refractory. There are three major fractions of humic substances, i.e. humin (not soluble in water at any pH), humic acid (not soluble in water under acidic conditions, pH below 2, but becomes soluble at greater pH) and fulvic acid (soluble in water under all pH conditions).

Iodometric titration Titration performed with a standard solution of iodine.

Industrial uses For the purpose of these documents, industrial use of seawater means 'water that is taken from the sea to be used in industrial processes or to be processed for a particular use outside the sea'. Industrial uses of seawater therefore include:

- seafood processing;
- salt production;
- desalination;
- water supply to commercial aquariums/oceanariums;
- harbours/ports (excluding recreational use, mariculture practices, natural environment - these will be addressed elsewhere);
- cooling water;
- ballast water;
- coastal mining;
- make-up water for marine outfalls;
- exploration drilling;
- scaling and scrubbing.

Infratidal (Subtidal) Defined as the zone seaward from the spring-tide low-water mark to a water depth of about 10-20 m.

In situ In the original location.

Intertidal The zone between the spring-tide low-water and spring-tide high-water mark.

Invertebrate An animal lacking a backbone and internal skeleton.

Ionic strength A measure of the average electrostatic interactions among ions in an electrolyte.

Isopod (Isopoda) An order of crustaceans characterised by a cephalon bearing one pair of maxillipods in addition to the antennae, mandibles and maxillae.

GLOSSARY OF TERMS continued on next page

Glossary

GLOSSARY OF TERMS continued...

Lachrymal fluid	Tear-like fluid.
LC_{50}	Lethal concentration which brings about a 50 % mortality in an experimental population exposed to the substance.
LC_{5}	Lethal concentration which brings about a 5 % mortality in an experimental population exposed to the substance.
LC_{95}	Lethal concentration which brings about a 95 % mortality in an experimental population exposed to the substance.
LC_{100}	Lethal concentration which brings about a 100 % mortality in an experimental population exposed to the substance.
LD_{50}	Lethal dose which brings about a 50 % mortality in an experimental population exposed to the substance.
Longshore drift	Movement of materials by currents, caused by waves, that set parallel to the shore; usually within the nearshore region in the breaker zone.
Limpet	Several species of gastropod molluscs which have a conical and tent-like shell with ridges extending from the apex to the border.
Lipophylic	Refers to a substance that is soluble in a lipid.
Littorina zone	The highest zone on rocky shores with only a few species of plant and animal life. The tiny gastropod Littorina is very abundant.
Macrophytes	Refers to macroscopic forms of aquatic plants and includes of algae and aquatic vascular plants.
Mariculture	For the purpose of these documents, the mariculture use includes the official mariculture practices along the South African coast (including future possibilities): - seaweed; - molluscs - bivalves; - molluscs - gastropods; - crustaceans; - finfish.
Mesozooplankton	Organisms which take the of animal plankton for part of their life cycle.
mg l^{-1}	Milligrams per litre.
mm TL	Millimetres total length.

GLOSSARY OF TERMS continued on next page

Glossary

GLOSSARY OF TERMS continued...

Monocyclic	Refers to a molecule that contains one closed ring.
Motor activity	Locomotion.
Natural environment	For the purpose of these documents, the word Natural Environment is used as the collective word to describe the natural plant and animal life of the sea, subdivided into three trophic levels: - primary producers; - primary consumers; - secondary consumers.
Nematode	A segmented worm.
Neritic	Refers to the region of shallow water adjoining the coast, extending from the low-water mark to a depth of about 200 m.
Norm	Yardsticks by which changes in water quality can be measured.
NTU	Nepheloretic turbidity units in which the turbidity of water is measured.
Nudibranches	(Nudibranchia) Molluscs lacking a shell and a mantle cavity, while the gills vary in size and shape.
Nutrient type distribution	Refer to the distribution of a chemical constituent in the sea. This distribution exhibits surface depletion and bottom enrichment as a result of the involvement of the constituent in biogeochemical cycles.
Offshore drift	Movement of materials by currents flowing away from the shore.
Oligochaete	(Oligochaeta) A class of the phylum Annelida, including worms that exhibit both external and internal segmentation and setae which are not borne on parapodia.
Omnivorous	Eating both animals and plant material.
Oocytes	Eggs before the completion of maturation.
Opisthobranches	(Opisthobranchia) A subclass of to the class Gastropoda containing he sea hares, sea butterflies and sea slugs, generally characterised by having gills, a small external or internal shell and two pairs of tentacles.
Optimum range	Most favourable range.
Osmolarity	The molarity of an ideal solution of a undissociated substance that exerts the same osmotic pressure as the solution being considered.
Oviposition	The laying of eggs.

GLOSSARY OF TERMS continued on next page

GLOSSARY OF TERMS continued...

Oxic	Sufficient oxygen availability.
Oyster belt	A zone found on rocky shores along the east coast of South Africa between the Littorina and upper Balanoid zones.
Ozonation	Disinfection using ozone, an oxidising agent.
Palaearctic	Refers to animals migrating from the Arctic regions.
Pluteus	A free-swimming larvae of sea urchins and brittle stars.
Paralytic shellfish toxin	Algal toxin which may cause neurological effects.
Pathogen	(Pathogenic) Causing disease.
Pelagic	Living in the water column in contrast to living on the bottom of a water body.
Peptides	A compound of two or more amino acids joined by a peptide bond.
Phosphatisation	Forming a phosphate coating on a metal.
Phospholipids	Any of a class of esters of phosphoric acid containing one or two molecules of fatty acids, an alcohol and a nitrogenous base.
Phospho-nucleotides	Components of DNA.
Photodegeneration	Degradation by light e.g. ultraviolet light.
Photolysis	The use of radiant energy to produce chemical energy.
Photometrically	(Photometry) The calculation and measurement of quantities describing light, such as luminous intensity, sometimes taken to include measurement of near-infrared and near-ultraviolet radiation as well as visible light.
Photic zone	*see* Euphotic zone.
Phytoplankton	Planktonic plant life.
Plasm cortisol	A specific cell body.
Piscivorous	Feeding on fish.
Polychaete	(Polychaeta) The largest class of the phylum Annelida, distinguished by paired, fleshy appendages (parapodia) provided with setae on most segments.
Polycyclic	Refers to a molecule that contains two or more closed rings.

GLOSSARY OF TERMS continued on next page

Glossary

GLOSSARY OF TERMS continued...

Pre-ENSO Before El Nino southern oscillation.

Primary producer Defined as those organisms that synthesise complex organic substances using simple inorganic substances and sunlight.

Primary consumer Defined as those organisms that primarily live off plants.

Problems For the purpose of these documents, problems specifically refer to 'problems encountered by a particular use or user of marine water which are caused by a particular water quality property or constituent'.

Proteinaceous Pertaining to a substance having a protein base.

Proteolytic Catalising the breakdown of protein, usually by enzymes.

Protozoa A diverse phylum of eukaryotic micro-organisms; the structure varies from a simple uninucleate protoplast to colonial forms . The body is either naked or covered by a cyst. Locomotion is by means of pseudopodia or cilia or flagella.

Putrescence Rot.

Pyrolytic Decomposition of a substance by applying heat.

Raphe-bearing valves A slit-like line in diatom valves.

Recreational use For the purpose of this document, recreational use is water that is used for:
- full and intermediate contact recreation (swimming, water skiing, windsurfing);
- non-contact recreation (boating, fishing, bird watching, etc.)

Respiratory pore axis The axis on which the respiratory pores are situated, e.g. in abalone.

Salinity Refers to the salt content of soil or water.

Scaling The formation of dense coating of predominantly inorganic material formed from the precipitation of water soluble constituents.

Seasonality Refers to changes associated with the four seasons of the year.

Secchi disc An opaque white disk used to measure the transparency or clarity of seawater by lowering the disk into the water vertically and noting the greatest depth at which it can be visually detected.

Secondary consumer Defined as those organisms primarily living off other animals.

Senescent algal cells (Senescence) The study of biological changes related to ageing.

GLOSSARY OF TERMS continued on next page

GLOSSARY OF TERMS continued...

Seston	Minute living organisms and particles of non-living matter which float in water and contribute to turbidity.
Site specific	Refers to conditions that are unique or specific to a certain site or location.
Solubility product	A constant defining the equilibria between solids and their respective ions in solution.
Spectrophotometry	A procedure to measure photometrically the wavelength range of radiant energy absorbed by a sample under analysis. It can be visible light, ultraviolet light or x-rays.
Spermatozoa	A mature male germ cell, also known as sperm.
Sporophyte	An individual of the spore-bearing generation in plants exhibiting alternation of generation.
Static bioassay	A bioassay where the test organisms are placed into a tank which contains substances at fixed concentrations.
Stenohaline	In marine organisms, indicating the ability to tolerate a narrow range of salinities.
Stripping voltammetr	Technique whereby the concentration and speciation of trace metals can be determined using a hanging mercury drop electrode.
Sublethal	The concentration or dose of a toxic substance below the threshold which causes death.
Substrata	The substrate on which a plant grows or to which an organism is attached.
Subtidal	Refer to *Infratidal*.
Supersaturation	Refers to a solution containing more solute than equilibrium conditions will allow.
Surf zone	The area between the landward limit of wave up-rush and the furthest seaward breaker.
Thermocline	A temperature gradient as in a layer of seawater in which the temperature decrease with depth is greater than that of the overlying and underlying water.
Threshold concentration	The highest concentration of a water quality constituent that can be tolerated before damage is done to the organism or process.
Terrigenous	Derived from land.

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Glossary

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Titrimetrically A technique where the substance to be determined is allowed to react with an appropriate reagent added as a standard solution, and the volume of solution needed for complete reaction is determined.

Tolerable range The extreme values (upper and lower values) that are permitted by the tolerance

Treatability The ability and extent to which undesirable properties or constituents can be remove or converted from a water body.

Target value/range The value or range of a water quality property or constituent where there is no known impairment of use, or significant effect on a particular water use. It is this range which describes the desirable water quality and which should be strived for.

Trochophore A generalised but distinct free-swimming larvae found in several invertebrate groups.

Ubiquitous Abundantly, common occurrence.

Upwelling The phenomenon by which deep, colder and nutrient-rich ocean waters are introduced into the well-mixed surface layer.

$\mu g\ l^{-1}$ Micrograms per litre.

US EPA United States Environmental Protection Agency.

Valency The number of electrons required to be gained or lost by an atom to reach a state where the outermost electron shell is full.

Veliger A mollusc larval stage.

Vitellogenin To produce a protein which is present in the liver, which is then transported into the yolk protein.

Virus A typical virus consists of nucleic acid (DNA or RNA) neatly rapped in a protective protein coat (capsid). The latter carries a receptor site which will attach to matching receptor sites only on certain cells. This determines the host specificity of viruses.

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Water quality criteria (US EPA) A designated concentration of a constituent that, when not exceeded, will protect an organism, an organism community or a prescribed water use or quality with an adequate degree of safety.

(Canada) Scientific data evaluated to derive recommended limits for water uses.

(Australia) Scientific and technical information used to provide an objective means for judging the quality needed to maintain particular environmental value (water use).

Water quality guideline (South Africa) A description of the effects of changes in water quality of a water quality constituent on a recognised use in terms of selected norms.

(Canada) A numerical concentration or narrative statement recommended to support and maintain designated water use.

(Australia) Water quality guidelines translate the criteria into a form that can be used for management purposes

Water quality objective (Canada) A numerical concentration or narrative statement which has been established to support and maintain a designated water use.

(South Africa) A value, not to be exceeded, set for a specific water quality constituent in a defined water body portion or a water body, to ensure with a given measure of reliability, its agreed fitness for use. This is an achievable value determined by considering the water quality requirements of recognised water users as well as relevant physical, technological, economic and sociopolitical issues.

Water quality property/constituent A chemical (or biological) substance or physical property that describes the quality of a water body. For the purpose of this document water quality refers to water quality constituent, substance or property only.

Water quality standard (US EPA) A term used in the US EPA literature which is similar to a water quality objective. A standard connotes a legal entity for a particular reach of waterway or for an effluent.

winkle A gastropod snail.

WHO World Health Organisation.

Winkler Titration A titrimetric method for determining the dissolved oxygen concentration in seawater.

Zooanthids Colonial sea anemones.

Zooplankton Microscopic animals which move passively in aquatic ecosystems.

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