SOUTH AFRICAN

WATER QUALITY GUIDELINES

FOR COASTAL MARINE WATERS

VOLUME 4

MARICULTURE

Department of Water Affairs and Forestry

First Edition 1995

SOUTH AFRICAN WATER QUALITY GUIDELINES FOR COASTAL MARINE WATERS

Volume 4: Mariculture

First Edition, 1996

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South African Water Quality Guidelines for Coastal Marine Waters

Volume 4

Mariculture

Department of Water Affairs and Forestry
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1995

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Coordinated by:

**Earth, Marine and Atmospheric Science
and Technology
CSIR
P O Box 320
STELLENBOSCH
7599
Republic of South Africa**

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** May 1996
Minister of Water Affairs and Forestry

ACKNOWLEDGEMENTS

Executive committee	Mr J L J van der Westhuizen, Department of Water Affairs and Forestry Mr F C van Zyl, Department of Water Affairs and Forestry (DWAF) Ms A Belcher, DWAF
Project consultants	Mr W A M Botes, CSIR, Stellenbosch Ms S Taljaard, CSIR, Stellenbosch
Language editing	Ms E da Conceicao
Specialist contributors	Mr I Bickerton, CSIR, Stellenbosch Dr R Carter, CSIR, Stellenbosch Dr P Zoutendyk, CSIR, Stellenbosch Mr C N Windt, CSIR, Stellenbosch
Reviewers/commentators	Dr P Cook, Mariculture Association of Southern Africa Dr L Jackson, Sea Fisheries Research Institute (SFRI), Cape Town
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)

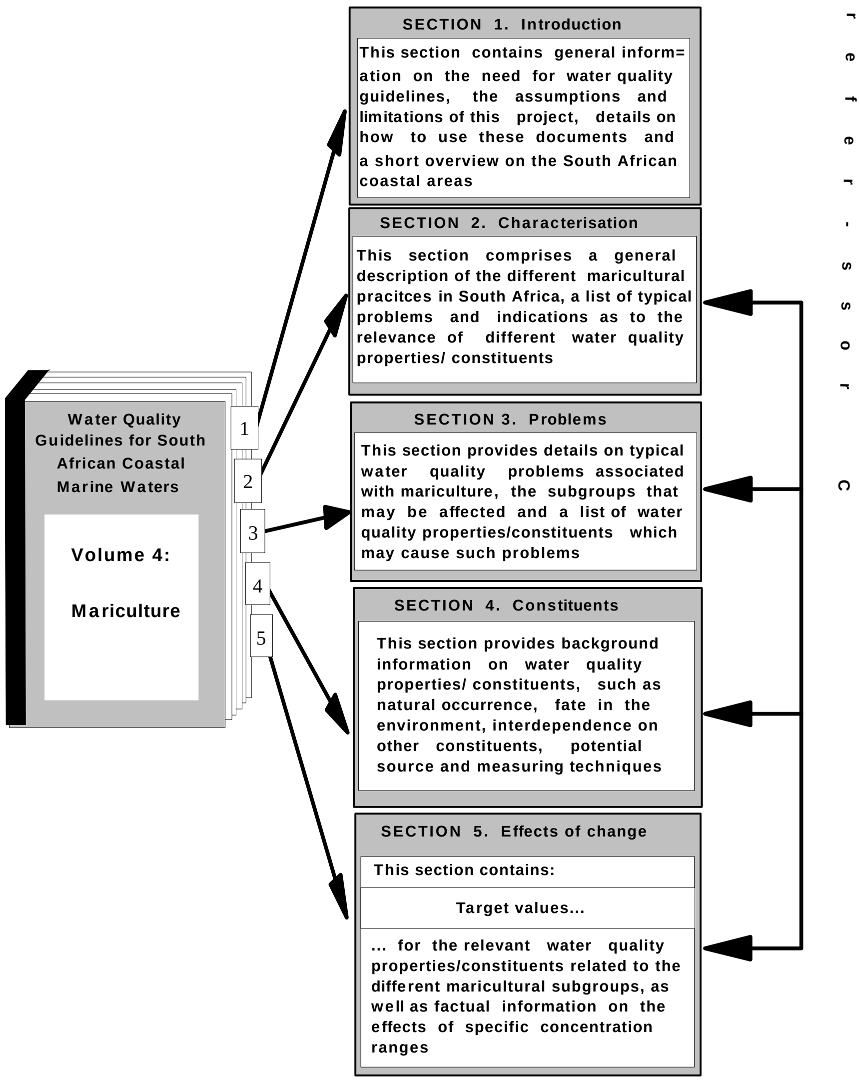
This volume is the fourth in a series of four documents comprising the first edition (Edition 1.0) of the South African Water Quality Guidelines for Coastal Marine Waters.

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:

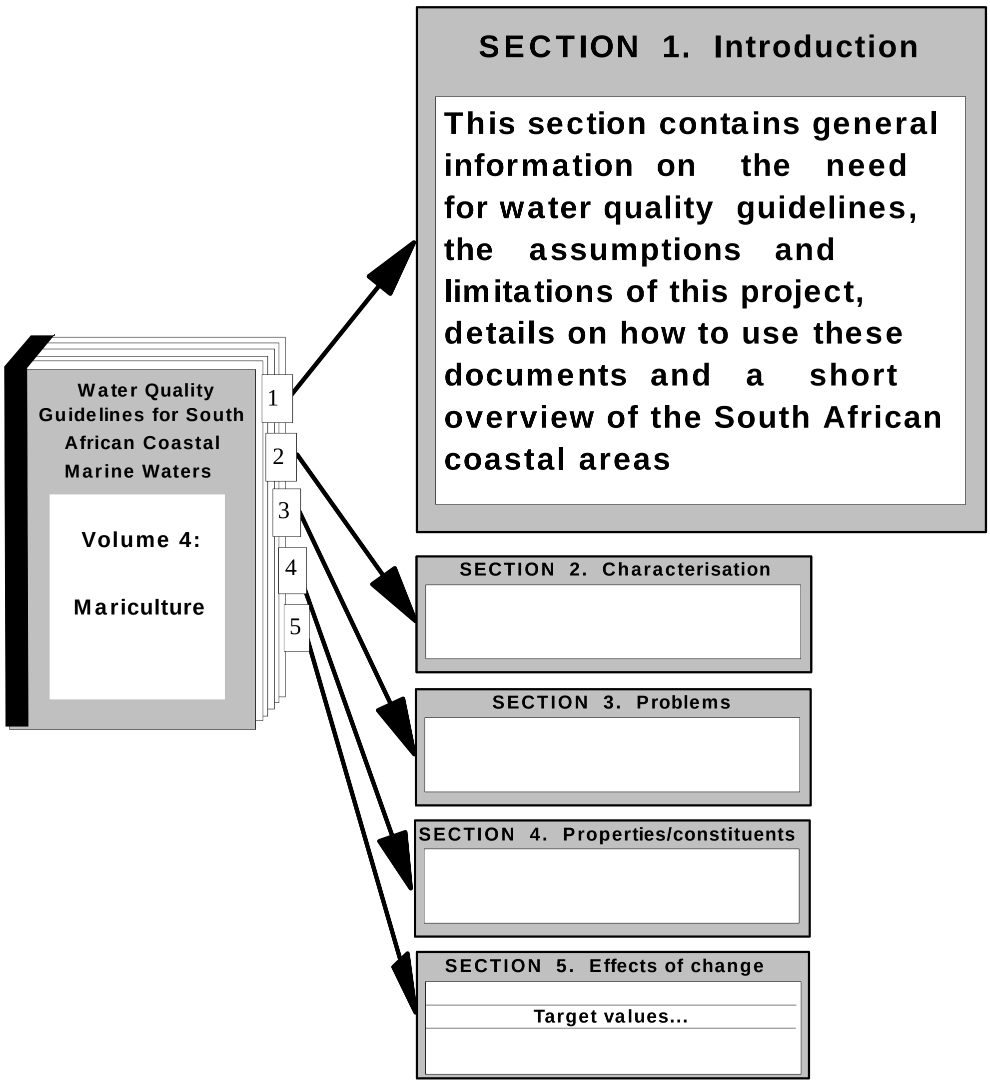


A certain degree of overlap and/or repetition was inevitable. However, to avoid unnecessary repetition of detailed information, a cross-reference system has been used. *Section 5 is regarded as the 'heart' of these documents (containing the target values), with the information contained in Sections 2-3 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 for close to a mussel farm	The subject is *'the user-group, i.e. 'molluscs - bivalves'*, therefore refer to *Section 2: Characterisation of maricultural practices'.* Find a description of the practices, a list of typical problems and a 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. Where available, 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 with mass mortalities in a oyster farm	The subject is '*a problem'* , therefore refer to *Section 3: Water quality problems*. Select the problem which addresses the issue, i.e. mortalities. Find a short description of the problem, the practices 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. Where available, cross-references to Section 5 will provide factual details on effects of different concentration ranges of the relevant constituents/properties.
A water quality analyst finds exceptionally high tributyltin (TBT) concentrations in a water sample	The subject is *'a particular water quality constituent*", therefore refer to *Section 4: Water quality properties/constituents*. Select the constituent, i.e. *Organic constituents - TBT*. 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. Where available, cross-references to Section 5 will provide factual details on effects of different concentration ranges of a constituent , as well as the target values for South African coastal marine waters.

SECTION 1: INTRODUCTION



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.

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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', described in Section 5, were taken form *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, could be considered acceptable 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 document had to be focused 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 recognised databases best suited for 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 database which contains information on water-related issues.

ASSUMPTIONS AND LIMITATIONS continued on next page

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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 data bases 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.

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OVERVIEW OF THE SOUTH AFRICAN COASTAL AREAS

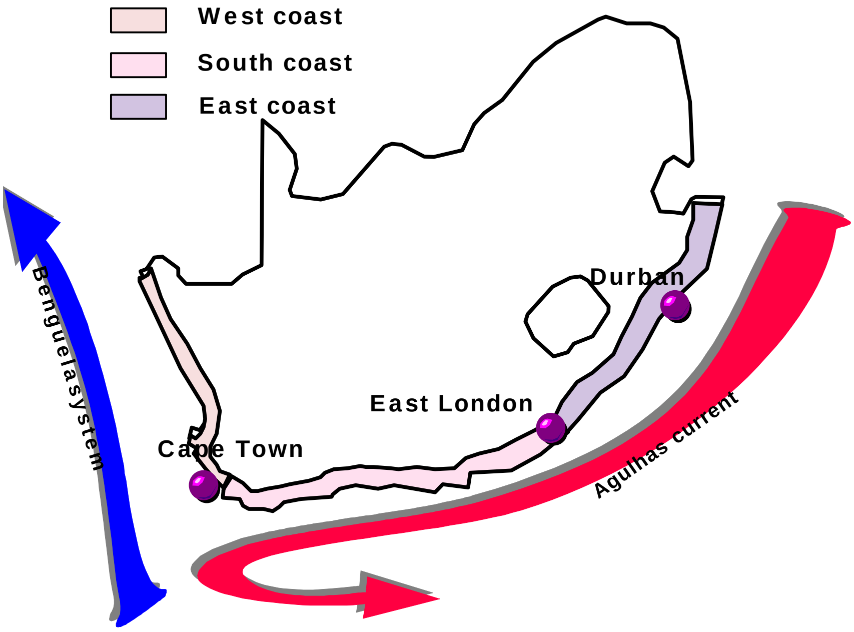
Uniqueness of seawater

Although the quality of seawater differs from fresh water in many ways, its high dissolved salt content is probably the most distinctive characteristic. This is discussed in more detail in *Section 4, Salinity*, *p 4-1*.

Coastal regions

The South African coastal water can typically be divided into three coastal regions, each of which sustains distinctive characteristics :

- West coast: cold temperate
- South coast: warm temperate
- East coast: subtropical/tropical.



OVERVIEW OF SA COAST continued on next page

Coastal regions *continued...*

West coast. 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. The cold Benguela system has a great influence on the physical and biotic characteristics of the west coast. The western coast of South Africa is dominated by coastal upwelling. This upwelling is driven by south-easterly and southerly winds which, in combination with Coriolis forces, leads to offshore drift of surface waters. Biological communities 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. The most important industry along the west coast is the fish-processing plants. The west coast is also a popular tourist area.

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

East coast. 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. The warm Agulhas current is the greatest factor influencing the coastal marine environment along the east coast of South Africa. Generally, the east coast fauna and flora are relatively low in total biomass, but species diversity is high with distinct Indo-Pacific affinities. Numerous industries e.g. paper and pulp, textile and chemical industries are situated along the southern part of the east coast. The east coast is also a very popular tourist attraction.

Detailed descriptions of the characteristics of the coastal regions , both abiotic and biotic features, are provided in *Volume 1: Natural Environment, Section 2.*

REFERENCES

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

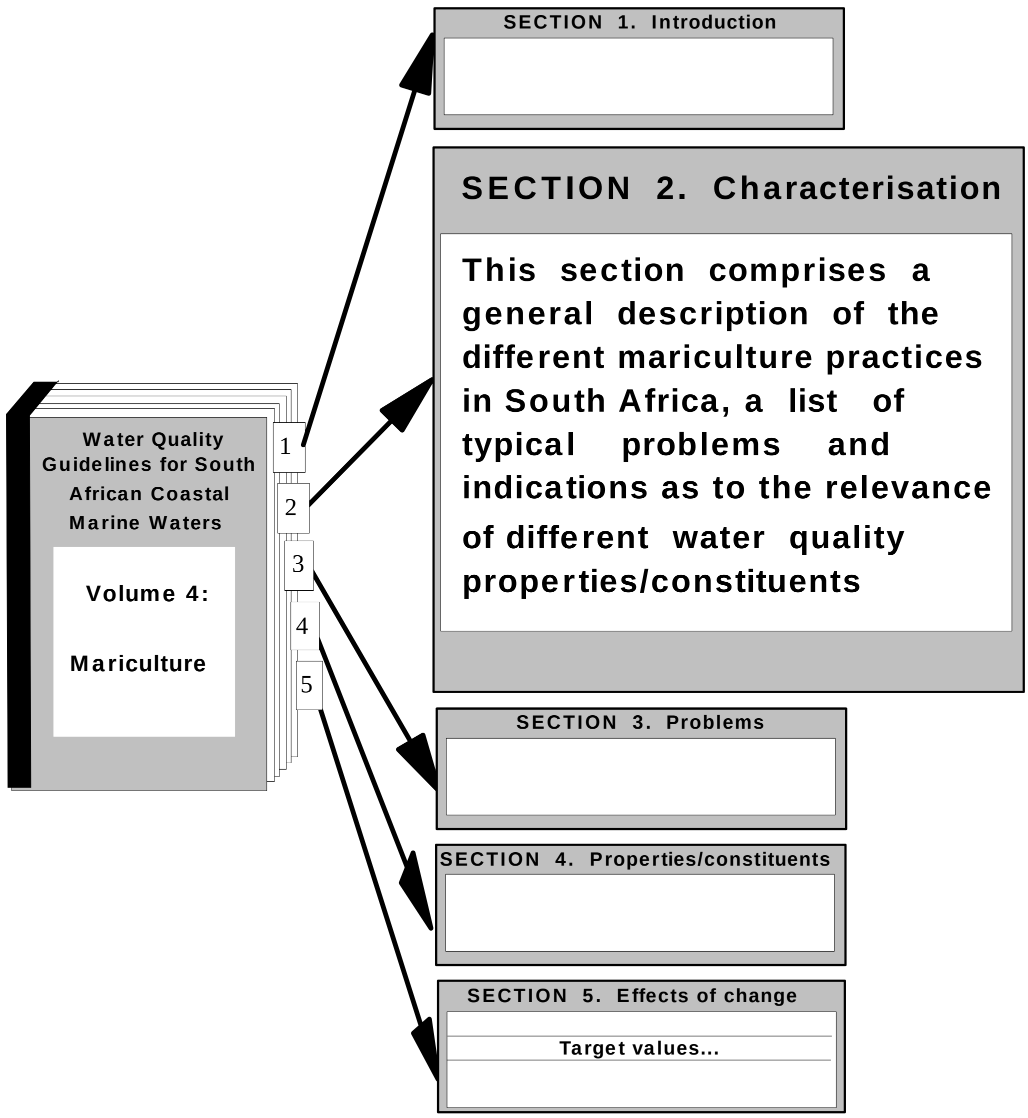
2. DEPARTMENT OF WATER AFFAIRS AND FORESTRY 1993. South African Water Quality Guidelines. Volume 1: Domestic Use.

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 MARICULTURE PRACTICES



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GENERAL INTRODUCTION

Definition. Mariculture is defined as the farming of marine and/or estuarine organisms in land-based or water-based brackish water and/or marine water environments [10]. Typically, mariculture is focused on seaweeds, molluscs, crustaceans and fish.

Production. World aquaculture production was estimated to be 19,3 x 10^6 tons in 1992 [1]. The major components of this in terms of value were finfish (53,2%), crustaceans (20,3%) molluscs (11,3%) and seaweeds (15,1%) etc. In contrast to this, South Africa's total mariculture output in 1991 was estimated at 2 769 tons [2], less than 0,02% of the world total for that year. The composition of South Africa's mariculture production was dominated by molluscan bivalves with mussels contributing 75,5%, oysters 20,06% and clams 1,1% [2].

South Africa's mariculture production is thus minute compared to world production estimates, and is also small in relation to capture fisheries in South Africa. However, the local mariculture industry is in a growth phase with the number of permits, issued by the Department of Environmental Affairs and Tourism, increasing from 2 in 1985 to 37 in 1992 [3]. This is mirrored by the growth in total production in the industry which, for the period 1985 - 1991, is estimated to have increased by 53% per annum [2]. Due to South Africa's paucity of protected waters, the mariculture industry has been concentrated in a few areas, Saldanha Bay being a prime example as it is the dominant producer in terms of mussels. Mariculture is socially and economically important for these areas. The disruption of the industry through pollution could therefore have implications for employment and, increasingly, foreign exchange earnings, as the industry is becoming more export oriented. Coupled with this, the focus of attention on expanding mariculture into the technologically demanding areas of abalone and high-value finfish will generate more employment and foreign exchange earnings and thus increase its importance in South Africa's economy. In view of this, mariculture can be considered to be a legitimate beneficial use of coastal waters.

Major practices. Hecht and Britz [2] reviewed South African mariculture and showed that the farming of molluscan bivalves (mussels: *Mytilus galloprovincialis, Choromytilus meridionalis* and *Perna perna*; oysters: *Crassostrea gigas* and to a lesser extent, clams: *Tapes* spp).) dominate the industry almost to the exclusion of all other species. Since that review, however, there has been progress in, *inter alia*, the development of techniques for farming seaweeds *(Gracilaria)*, the development of pilot and commercial scale culture of the South African abalone (*Haliotis midae*) and the initial technology development for the farming of finfish (*Sparidae*, *Salmonidae* and *Pomadasyidae*). Furthermore, prawns (*Penaeus monodon* and *Penaeus indicus*) have been taken through to commercial production, albeit on a small scale, by two farms in northern Kwazulu/Natal. The culture and water quality requirements for these species/species groups differ, as do their impacts on the environments in which they are cultured. The species/species groups are therefore defined as subusers within the beneficial use of mariculture.

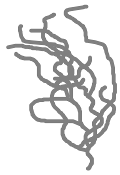
The South African Bureau of Standards (SABS) has compiled a concept document which is aimed at giving mariculture farmers directives on a quality management plan. This concept document is refered to as *Directives for compilation of documents pertaining to a quality management plan based on the 'HACCP' concept (2nd edition)*. The concept document can be obtained form the SABS in Cape Town.

GENERAL INTRODUCTION continued on next page

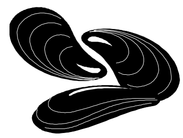
GENERAL INTRODUCTION continued…

The subuses have been identified from the current (1994) list of permits issued for mariculture by the Chief Director, Sea Fisheries, Department of Environmental Affairs and Tourism, the Hecht and Britz review [2] of South African mariculture and discussions with the mariculture practitioners. The subuses identified are:

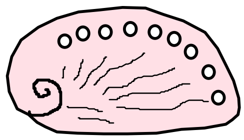
Seaweeds
(primarily *Gracilaria verrucosa*)



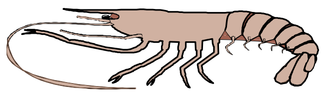
Molluscs - bivalves
(comprising mussels: *Mytilus galloprovincialis, Choromytilus meridionalis* and *Perna perna*; oysters: *Crassostrea gigas*; and to a lesser extent, clams: *Tapes* spp).

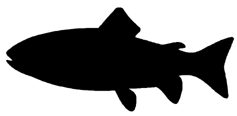


Molluscs - gastropods
(primarily abalone: *Haliotis midae*)



Crustaceans
(primarily prawns: *Penaeus monodon* and *Penaeus indicus*)





Finfish
(*Sparidae, Salmo, Pomadasydae,* Turbot)

Chapter 2.1 Seaweeds

DESCRIPTION OF USE

Use

Seaweed culture is well established internationally, making up 15,1% of the value of world mariculture production [1]. In southern Africa, attention is focused primarily on the agarophyte *Gracilaria verrucosa* with commercial scale production in Luderitz, Namibia [4]. *Eucheuma* is grown on the Tanzanian coast [5]. In South Africa, *G. verrucosa* is collected as beach cast in Saldanha Bay with annual yields of 10 000 kg (dry weight) [6]. Yields are variable, however, which has led to experimental work on raft culture [7] and tank culture [8], the results of both indicating that *Gracilaria* farming is potentially profitable.

Apart from producing high-value agar, *Gracilaria* can also be used as an abalone food [9] and is presently used as a primary food in an eastern Cape pilot-scale abalone farm.

Thus, despite the fact that there are no issued permits for the culture of *Gracilaria*, or any other seaweed in South Africa for that matter, because of its potential, seaweed farming is defined as subuser for the purpose of this study.

Seaweeds are autotrophs and require high light and nutrient levels for rapid growth. Commercial culture, therefore, will most probably be concentrated in the Benguela ecosystem area, except in cases where other nutrient sources are available, e.g. abalone farm effluents.

Problems

Water quality problems associated with seaweed culture include:

i. general growth deficiencies; p 3-1
ii. lowered reproduction; p 3-2
iii. mortalities; p 3-9
iv. gastrointestinal problems (if consumed by man); p 3-11
v. neurological effects; p 3-12
vi. tainting of products; p 3-13
vii. corrosion of equipment; p 3-15
viii. clogging and choking of equipment. p 3-16

For more information on problems refer to: p 3-1, p 3-2, p 3-9, p 3-11, p 3-12, p 3-13, p 3-15, p 3-16

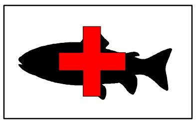
DESCRIPTION continued on next page

DESCRIPTION continued...

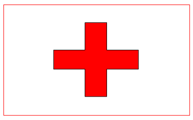
Norms

The aim of water quality guidelines is to provide a scientific yardstick upon which the fitness for use of a particular water body for a designated use may be evaluated. However, the quality of a water body can be described in many different ways. It is therefore important to select specific norms upon which water quality properties/constituents relevant to describing the fitness of use, could be selected. These norms are usually based on types or 'boxes' of problems associated with a particular use of seawater. For the culture of seaweed, the following norms are relevant:

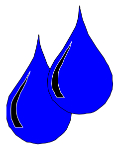
Biological Health
(Refering to problems i-iii)



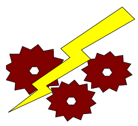
Human Health
(Refering to problems iv and v)



Aesthetics
(Refering to problem vi)



Mechanical/Process Interferences
(Refering to problems vii and viii)



RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

Legend

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 legends for the tables that follow are:

Relevant, addressed in these documents	✓
Relevant, NOT addressed	✓✗
Indirectly relevant, NOT addressed	✓...
Not relevant	✗

Physico-chemical properties

	Biological Health	Human Health	Aesthetics	Mechanical Interference	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	Human Health	Aesthetics	Mechanical Interference
NH_4^+ Ammonium	✓	✓●●●	✗	✓●●●
NO_2 Nitrite	✓	✓●●●	✗	✓●●●
NO_3 Nitrate	✓	✓●●●	✗	✓●●●
PO_4 Reactive phosphate	✓	✓●●●	✗	✓●●●
SiO_4 Reactive silicate	✓	✓●●●	✗	✓●●●

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

		Biological Health	Human Health	Aesthetics	Mechanical Interference	For more information on inorganics refer to:
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

For more information on organics refer to:

		Biological Health	Human Health	Aesthetics	Mechanical Interference	
TBT	Organotins (tributyl tin)	✓	✓✗	✗	✗	p 4-71
TPH	Total petroleum hydrocarbons	✓	✓✗	✗	✗	p 4-74
Algal	Algal toxins	✓✗	✓	✗	✗	p 4-78
Taint	Tainting substances	✗	✗	✓	✗	p 4-80
	Polycyclic aromatics	✓✗	✓✗	✗	✗	
	Halogenated aliphatics	✓✗	✓✗	✗	✗	
	Halogenated ethers	✓✗	✓✗	✗	✗	
	Monocyclic aromatics	✓✗	✓✗	✗	✗	
	Nitrosamines	✓✗	✓✗	✗	✗	
	Biocides	✓✗	✓✗	✗	✗	
	Resin acids	✓✗	✓✗	✗	✗	
	Surfactants	✓✗	✓✗	✗	✗	

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued

Microbiological indicator organisms and pathogens

		Biological Health	Human Health	Aesthetics	Mechanical Interference
F coli	Faecal coliform (including *E. coli*)	✗	✓	✗	✗
Entero	Enterococci	✗	✓	✗	✗
Pathogen	Pathogens	✓✗	✓	✗	✗

For more information on indicators/ pathogens refer to:

p 4-81

p 4-83

p 4-85

Radio-active substances

	Biological Health	Human Health	Aesthetics	Mechanical Interference
Radio-active substances	✓✗	✓✗	✗	✗

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

REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5) continued on next page

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

		Refer to:
Organic constituents		
	Organotins (tributyltin)	p 5-77
	Total petroleum hydrocarbons	p 5-81
	Algal toxins	p 5-85
	Tainting substances	p 5-86

		Refer to:
Microbiological indicators and pathogens	*Faecal coliform (including E. coli)*	p 5-89
	Enterococci	p 5-91
	Human pathogens	p 5-92

Chapter 2.2 Molluscs - Bivalves

DESCRIPTION OF USE

Use

In 1991, South African mariculture produced 2 674 tons of bivalves. This comprised 1 314 tons of the Mediterranean mussel, *Mytilus galloprovincialis*, 710 tons of the black mussel *Choromytilus meridionalis* and 650 tons of the Pacific or Japanese oyster, *Crassostrea gigas* [2]. It is interesting to note that of these only *Choromyilus meridionalis* occurs naturally in South African waters, *Mytilus galloprovincialis* being an invasive [11] and *Crassostrea. gigas* an imported exotic.

Bivalves are filter feeders and thus sequester their food from the naturally occurring phytoplankton and seston in seawater. The culture systems used are mainly suspended rope culture in the case of mussels, usually from rafts or buoys, and suspended crates or bags and racks for oysters. As mussels and oysters are filter feeders, they can accumulate pollutants and toxins during their feeding processes.

Mussel spat is collected from natural spawning and thus the industry is dependent, to some degree, upon natural beds of these organisms [12]. Therefore, apart from the water quality requirements of the mussel farms , overall water quality within the environment in which mussel culture occurs has to be maintained at the level which will allow the existence of natural beds and larval survival. Mussel farming is now concentrated almost exclusively in Saldanha Bay with some activity in St Helena Bay. In 1994, eight permits were issued for mussel farming. South African producers are world leaders in suspended mussel .

Oyster spat of the Pacific oyster (*Crassostrea gigas*) is produced in specialised hatcheries and nurseries as there are no `natural' beds of sufficient density outside of oyster farms in South Africa to allow collection of wild spat. Spawning events within farms are limited to infrequent occurrences of temperatures above 22 EC. Previously oyster spat was imported from South American or United Kingdom hatcheries/nurseries. This practice still continues, but there is now one hatchery/nursery operating in the St Helena Bay Area.

Oyster farms are more widely distributed than mussel farms, extending from Alexander Bay in the north-west to Port Alfred in the east. In 1994, 12 permits were issued for oyster culture. The technology is applied in environments ranging from shallow, tidal estuaries, e.g. Knysna and Zwartkops, to artificial seawater dams, e.g. Alexander Bay, to deeper waters in Saldanha Bay. This section of the mariculture industry can be considered to be in the mature stage.

Attempts have been made to produce the Manila clam (*Tapes philipinarum*) in some culture systems, but it has not grown at commercially viable rates. Research is undertaken in order to address this problem.

DESCRIPTION continued on next page

DESCRIPTION continued ...

Problems

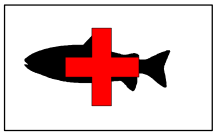
Water quality problems associated with the culture of bivalves include:

i. general growth deficiencies;
ii. lowered repoduction;
iii. changes in feeding habits;
iv. changes in water pumping rates;
v. shell deformation;
vi. formation of air blisters causing flotation;
vii. mortalities;
viii. gastrointestinal problems (if consumed);
ix. neurological effects;
x. tainting of products;
xi. corrosion of equipment;
xii. clogging and choking of equipment.

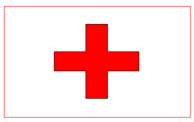
For more information on problems refer to:
p 3-1
p 3-2
p 3-3
p 3-5
p 3-7
p 3-8
p 3-9
p 3-11
p 3-12
p 3-13
p 3-15
p 3-16

Norms

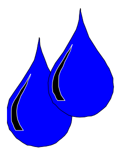
The aim of water quality guidelines is to provide a scientific yardstick upon which the fitness for use of a particular water body for a designated use may be evaluated. However, the quality of a water body can be described in many different ways. It is therefore important to select specific norms upon which water quality properties/constituents relevant to describing the fitness of use, could be selected. These norms are usually based on types or 'boxes' of problems associated with a particular use of seawater.
For the culture of bivalves, the following norms apply:



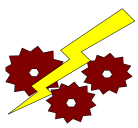
Biological Health
(Refering to problems i-vii)



Human Health
(Refering to problems viii and ix)



Aesthetics
(Refering to problem x)



Mechanical Interferences
(Refering to problems xi and xii)

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

Legend

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 legends for the tables that follow are:

Relevant, addressed in these documents	✓
Relevant, NOT addressed	✓✗
Indirectly relevant, NOT addressed	✓…
Not relevant	✗

Physico-chemical properties

	Biological Health	Human Health	Aesthetics	Mechanical Interference	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	✓	✗	✗	✗	p 4-13

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued on next page

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS continued...

Nutrients

	Biological Health	Human Health	Aesthetics	Mechanical Interference
NH_4^+ Ammonium	✗	✓•••	✗	✓•••
NO_2 Nitrite	✓	✓•••	✗	✓•••
NO_3 Nitrate	✓	✓•••	✗	✓•••
PO_4 Reactive phosphate	✗	✓•••	✗	✓•••
SiO_4 Reactive silicate	✗	✓•••	✗	✓•••

For more information on nutrients refer to:

p 4-21

p 4-23

Inorganic constituents,
Organic constituents,
Microbiological indicators and pathogens,
Radio-active substances

The relevance of inorganic constituents, organic constituents, microbiological indicators and pathogens and radio-active substances will be the same as for *Seaweeds*. Refer to p 2-5 to p 2-10

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

		Refer to:
Physico-chemical properties	*Temperature*	p 5-2
	Salinity	p 5-8
	pH	p 5-14
	Floating matter	p 5-18
	Suspended solids	p 5-19
	Colour/turbidity/clarity	p 5-22
	Dissolved oxygen	p 5-23

		Refer to:
Nutrients	*Nitrite*	p 5-28
	Nitrate	p 5-30

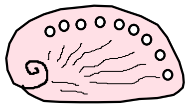
		Refer to:
Inorganic constituents	*Ammonia*	p 5-35
	Cyanide	p 5-38
	Fluoride	p 5-41
	Chlorine	p 5-42
	Hydrogen sulphide	p 5-45
	Arsenic	p 5-47
	Cadmium	p 5-50
	Chromium	p 5-53
	Copper	p 5-56
	Lead	p 5-59
	Mercury	p 5-61
	Nickel	p 5-64
	Silver	p 5-67
	Tin	p 5-70
	Zinc	p 5-72

REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5) continued on next page

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

		Refer to:
Organic constituents		
	Organotins (tributyltin)	p 5-77
	Total petroleum hydrocarbons	p 5-82
	Algal toxins	p 5-85
	Tainting substances	p 5-86

		Refer to:
Microbiological indicators and pathogens	*Faecal coliform (including E. coli)*	p 5-89
	Enterococci	p 5-91
	Human pathogens	p 5-92



Chapter 2.3 Molluscs - Gastropods

DESCRIPTION OF USE

Use

Hecht and Britz [(2)] classified abalone as a `threshold' species, indicating that commercial production units were being developed. In 1994, this was still true, to a large extent. Despite significant media coverage of `exciting new developments', none of the farms under development were regularly exporting farmed produce to foreign markets. However, significant investments in abalone farming have been made with the development of an artificial food, a commercial scale specialist hatchery and nursery coming on stream and at least three new farms entering the construction phase over and above four existing pilot/commercial scale enterprises. It is anticipated that significant amounts of South African produced abalone will reach markets in 1995/96.

The South African abalone industry is totally focused on producing *Haliotis midae* which is predominantly grown in on-shore tank/raceway systems. Food is provided, for example, through the addition of either macrophytes (kelps such as *Ecklonia maximal Laminaria pallida*, *Gracilaria verrucosa* or other smaller seaweeds) or fish meal based artificial food. The macrophytes can either be collected from beach cast or harvested in the case of kelps, or with *Gracilaria* grown in polyculture with the abalone. Pollution impacts on macrophytes will thus effect abalone farming. Post larval abalone are fairly robust, but are sensitive to food quality, oxygen levels, pH, trace metals and organic pollutants. Larval and early juvenile stages in commercial scale production, are more sensitive to oxygen and pH levels and may be impacted by high temperatures. Source water for the pump ashore systems must meet fairly strict water quality criteria.

There were 13 permits issued for abalone farming in 1994, with a geographic spread from Port Nolloth in the north-west to Port Alfred in the east. The bulk of the permits were issued for the Danger Point - Cape Hangklip area. Because of its production status as described above and some technical problems that have to be overcome, the abalone culture industry is still in the threshold stage.

DESCRIPTION continued on next page

DESCRIPTION continued ...

Problems

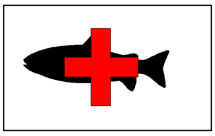
Water quality problems associated with the culture of gastropods include:

i. general growth deficiencies;
ii. lowered repoduction;
iii. changes in feeding habits;
iv. changes in respiration patterns;
v. shell deformation;
vi. mortalities;
vii. gastrointestinal problems (if consumed);
viii. neurological effects;
ix. tainting of products;
x. corrosion of equipment;
xi. clogging and choking of equipment.

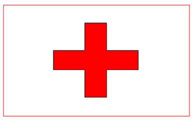
For more information on problems refer to:
p 3-1
p 3-2
p 3-3
p 3-4
p 3-7
p 3-9
p 3-11
p 3-12
p 3-13
p 3-15
p 3-16

Norms

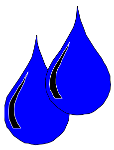
The aim of water quality guidelines is to provide scientific yardstick a upon which the fitness for use of a particular water body for a designated use may be evaluated. However, the quality of a water body can be described in many different ways. It is therefore important to select specific norms upon which water quality properties/constituents relevant to describing the fitness of use, could be selected. These norms are usually based on types or 'boxes' of problems associated with a particular use of seawater.
For the culture of gastropods, the following norms are relevant:



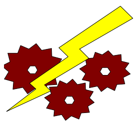
Biological Health
(Refering to problems i-vi)



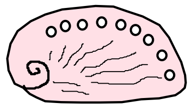
Human Health
(Refering to problems vii and viii)



Aesthetics
(Refering to problem ix)



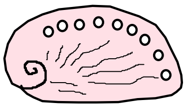
Mechanical Interferences
(Refering to problems x and xi)



RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

All properties/constituents

The relevance of ALL water quality properties/constituents (physico-chemical properties, nutrients, inorganic constituents, organic constituents, microbiological indicators and pathogens and radio-active substances) will be the same as for *Molluscs - Bivalves*. **Refer to p 2-15 to p 2-16**



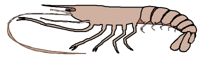
REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5)

REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5) continued on next page

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

		Refer to:
Organic constituents	*Organotins (tributyltin)*	p 5-79
	Total petroleum hydrocarbons	p 5-82
	Algal toxins	p 5-85
	Tainting substances	p 5-86

		Refer to:
Microbiological indicators and pathogens	*Faecal coliform (including E. coli)*	p 5-90
	Enterococci	p 5-91
	Human pathogens	p 5-92



Chapter 2.4 Crustaceans

DESCRIPTION OF USE

Use

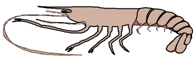
Hecht and Britz [2] classified *Penaeus monodon* and *Scylla serrata* (mud crab) as threshold species. *Penaeus monodon* and *Penaeus indicus* have become the focus of two prawn farms on the northern coast of Kwazulu/Natal. Both dependent on brackish water drawn from the Mlalazi (at Mtunzini) and Matigulu estuaries respectively, and have been using wild gravid females as brood stock. The post larvae produced are grown to market size in purpose built shallow ponds (~1 ha) utilising naturally produced phytoplankton as food sources.

One of the farms has been through some financial vicissitudes, but the 1994 combined production was 67 tons.

The temperature regime required to produce prawns efficiently for commercial purposes is restricted to the north-eastern coast of South Africa. Prawn culture will thus be geographically restricted in South Africa.

One permit was issued for prawn farming in 1994. The industry is considered to be in the emergent stage in South Africa but is a well established, mature industry in most tropical/subtropical maritime countries.

DESCRIPTION continued on next page



DESCRIPTION continued ...

Problems

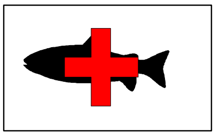
Water quality problems associated with the culture of crustaceans include:

i. general growth deficiencies;
ii. lowered repoduction;
iii. changes in feeding habits;
iv. changes repiration patterns;
v. changes in moulting patterns;
vi. shell deformation;
vii. mortalities;
viii gastrointestinal problems (if consumed);
ix. neurological effects;
x. tainting of products;
xi. corrosion of equipment;
xii. clogging and choking of equipment.

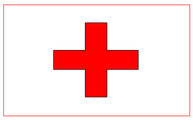
For more information on problems refer to:
p 3-1
p 3-2
p 3-3
p 3-4
p 3-6
p 3-7
p 3-9
p 2-11
p 2-12
p 3-13
p 3-15
p 3-16

Norms

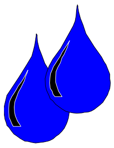
The aim of water quality guidelines is to provide a scientific yardstick upon which the fitness for use of a particular water body for a designated use may be evaluated. However, the quality of a water body can be described in many different ways. It is therefore important to select specific norms upon which water quality properties/constituents relevant to describing the fitness of use, could be selected. These norms are usually based on types or 'boxes' of problems associated with a particular use of seawater.
For the culture of crustaceans, the following norms are relevant:



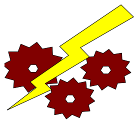
Biological Health
(Refering to problems i-vii)



Human Health
(Refering to problems viii and ix)



Aesthetics
(Refering to problem x)

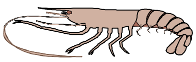


Mechanical Interferences
(Refering to problems xi and xii)

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

All properties/constituents

The relevance of ALL water quality properties/constituents (physico-chemical properties, nutrients, inorganic constituents, organic constituents, microbiological indicators and pathogens and radio-active substances) will be the same as for *Molluscs - Bivalves*. Refer to p 2-15 to p 2-16



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

		Refer to:
Physico-chemical properties	*Temperature*	p 5-5
	Salinity	p 5-10
	pH	p 5-16
	Floating matter	p 5-18
	Suspended solids	p 5-20
	Colour/turbidity/clarity	p 5-22
	Dissolved oxygen	p 5-24

		Refer to:
Nutrients	*Nitrite*	p 5-29
	Nitrate	p 5-31

		Refer to:
Inorganic constituents	*Ammonia*	p 5-36
	Cyanide	p 5-39
	Fluoride	p 5-41
	Chlorine	p 5-43
	Hydrogen sulphide	p 5-46
	Arsenic	p 5-48
	Cadmium	p 5-52
	Chromium	p 5-54
	Copper	p 5-58
	Lead	p 5-60
	Mercury	p 5-63
	Nickel	p 5-66
	Silver	p 5-69
	Tin	p 5-71
	Zinc	p 5-74

REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5) continued on next page

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

		Refer to:
Organic constituents		
	Organotins (tributyltin)	p 5-80
	Total petroleum hydrocarbons	p 5-83
	Algal toxins	p 5-85
	Tainting substances	p 5-86

		Refer to:
Microbiological indicators and pathogens	*Faecal coliform (including E. coli***)**	p 5-90
	Enterococci	p 5-91
	Human pathogens	p 5-92

Chapter 2.5 Finfish

DESCRIPTION OF USE

Use

Finfish farming in South Africa has been limited to seawater `conditioning' of trout (*Onchoryncus* spp.) in the western Cape in land tank systems. Furthermore, this industry has had very variable success rates. Thus, despite the Hecht and Britz [(2)] assertion of a stable production of ~30 tons per year over the period 1988-1991, no permits were apparently issued for this activity in 1994. In addition Moldan [(3)] did not include production estimates in his review of western Cape mariculture.

The bulk of international mariculture production is in the form of fish and there is considerable technology development in this field. This has led to preliminary investigations into the culture of salmon *Salmo* spp. [(13)], for example. Furthermore, there is experimental work being carried out on broodstock holding, conditioning and spawning in Sparid species[14] and exploratory research on farming the spotted grunter, *Pomadasys commersonii* at Rhodes University. Over and above this, a permit was issued in 1993 for the commercial farming of Turbot species in a western Cape pump ashore facility.

South African finfish culture is thus classified as being in the experimental stage, but in view of international developments and the probability of successful technological development, finfish have high potential and are included as a subuser in mariculture.

Successful technological development should open the door for a wide variety of fish to be cultured, ranging from some of the warmer water Sparidae to the cooler water Salmonids and Turbot. It is thus likely that selected sites along the entire South African coastline could be used for finfish culture, given access to the required seawater quality for pump ashore systems or relatively sheltered water for cage systems.

DESCRIPTION continued on next page

Chapter 2.5: Finfish

DESCRIPTION continued ...

Problems

Water quality problems associated with the culture of finfish include:

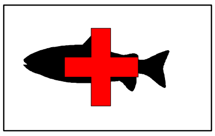
i. general growth deficiencies;
ii. lowered repoduction;
iii. changes in feeding habits;
iv. changes in respiration patterns;
v. mortalities;
vi. human health aspects (if consumed);
vii. neurological effects;
viii. tainting of products;
ix. corrosion of equipment;
x. clogging and choking of equipment.

For more information on problems refer to:

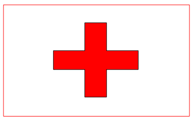
p 3-1
p 3-2
p 3-3
p 3-4
p 3-9
p 3-11
p 3-12
p 3-13
p 3-15
p 3-16

Norms

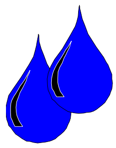
The aim of water quality guidelines is to provide a scientific yardstick upon which the fitness for use of a particular water body for a designated use may be evaluated. However, the quality of a water body can be described in many different ways. It is therefore important to select specific norms upon which water quality properties/constituents relevant to describing the fitness of use, could be selected. These norms are usually based on types or 'boxes' of problems associated with a particular use of seawater. For the culture of finfish, the following norms are relevant:



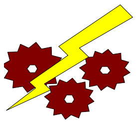
Biological Health
(Refering to problems i-v)



Human Health
(Refering to problems vi and vii)



Aesthetics
(Refering to problem viii)



Mechanical Interferences
(Refering to problems ix and x)

RELEVANCE OF WATER QUALITY PROPERTIES/CONSTITUENTS

All properties/constituents

The relevance of ALL water quality properties/constituents (physico-chemical properties, nutrients, inorganic constituents, organic constituents, microbiological indicators and pathogens and radio-active substances) will be the same as for *Molluscs - Bivalves*. Refer to p 2-15 to p 2-16

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

		Refer to:
Physico-chemical properties	*Temperature*	p 5-6
	Salinity	p 5-12
	pH	p 5-17
	Floating matter	p 5-18
	Suspended solids	p 5-21
	Colour/turbidity/clarity	p 5-22
	Dissolved oxygen	p 5-25

		Refer to:
Nutrients	*Nitrite*	p 5-29
	Nitrate	p 5-31

		Refer to:
Inorganic constituents	*Ammonia*	p 5-37
	Cyanide	p 5-40
	Fluoride	p 5-41
	Chlorine	p 5-44
	Hydrogen sulphide	p 5-46
	Arsenic	p 5-49
	Cadmium	p 5-52
	Chromium	p 5-54
	Copper	p 5-58
	Lead	p 5-60
	Mercury	p 5-63
	Nickel	p 5-66
	Silver	p 5-69
	Tin	p 5-71
	Zinc	p 5-75

REFERENCES TO EFFECTS OF CHANGE IN WATER QUALITY (SECTION 5) continued on next page

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

		Refer to:
Organic constituents	*Organotins (tributyltin)*	p 5-80
	Total petroleum hydrocarbons	p 5-84
	Algal toxins	p 5-85
	Tainting substances	p 5-86

		Refer to:
Microbiological indicators and pathogens	*Faecal coliform (including E. coli)*	p 5-90
	Enterococci	p 5-91
	Human pathogens	p 5-92

REFERENCES

1. FAO. 1994. Aquaculture production 1986-1992. *FAO Fisheries Circular* **815**/6:216pp

2. HECHT, T. and BRITZ, P.J. 1992. The current status, future prospects and environmental implications of mariculture in South Africa. *South African Journal of Science* **88**: 335-342.

3. MOLDAN, A. 1994. The current status of mariculture in the Western Cape and the role of the Department of Environment Affairs in the Management of this activity. *Workshop proceedings on Commercialisation of Aquaculture in the Western Cape* at Elsenburg Auditorium, Stellenbosch 24 and 25 May 1994.

4. ROTMANN, W. E. 1994. An industrial perspective of seaweed production in southern Africa. In: proceedings of the 11th Congress of Phycological Society of South Africa, January, 1994.

5. WILSON, A., CRITCHLEY, A.T. and BIRD, C.J. 1994. Taxanomic confusion surrounding a Namibian gracilarioid. In: Proceedings of the 11th Congress of Phycological Society of South Africa. January 1994.

6. ANDERSON, R. J., LEVITT, G. J., DAWES, C. P. and SIMONS, R.H. 1992. Experimental growth of Gracilaria in Saldanha Bay, South Africa. In: *Proceedings of the First International Workshop on Sustainable Seaweed Resource Development in Sub-Saharan Africa*. K.E. Mshigeni, pp 19-36.

7. ANDERSON, R. J., LEVITT, G. J., KEATS, D. W. AND SIMONS, R.H. 1993. The role of herbivores in the collapse of the *Gracilaria* resource at Saldanha Bay, South Africa. *Hydrobiologia*, **260/261**: 285-290,

8. 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.

9. CLAYDON, C. in press. Abalone *Haliotis midae* growth and temperature.

10. GESAMP. 1991. Reducing Environmental impacts of coastal aquaculture. *Reports and Studies* **47**: 35pp.

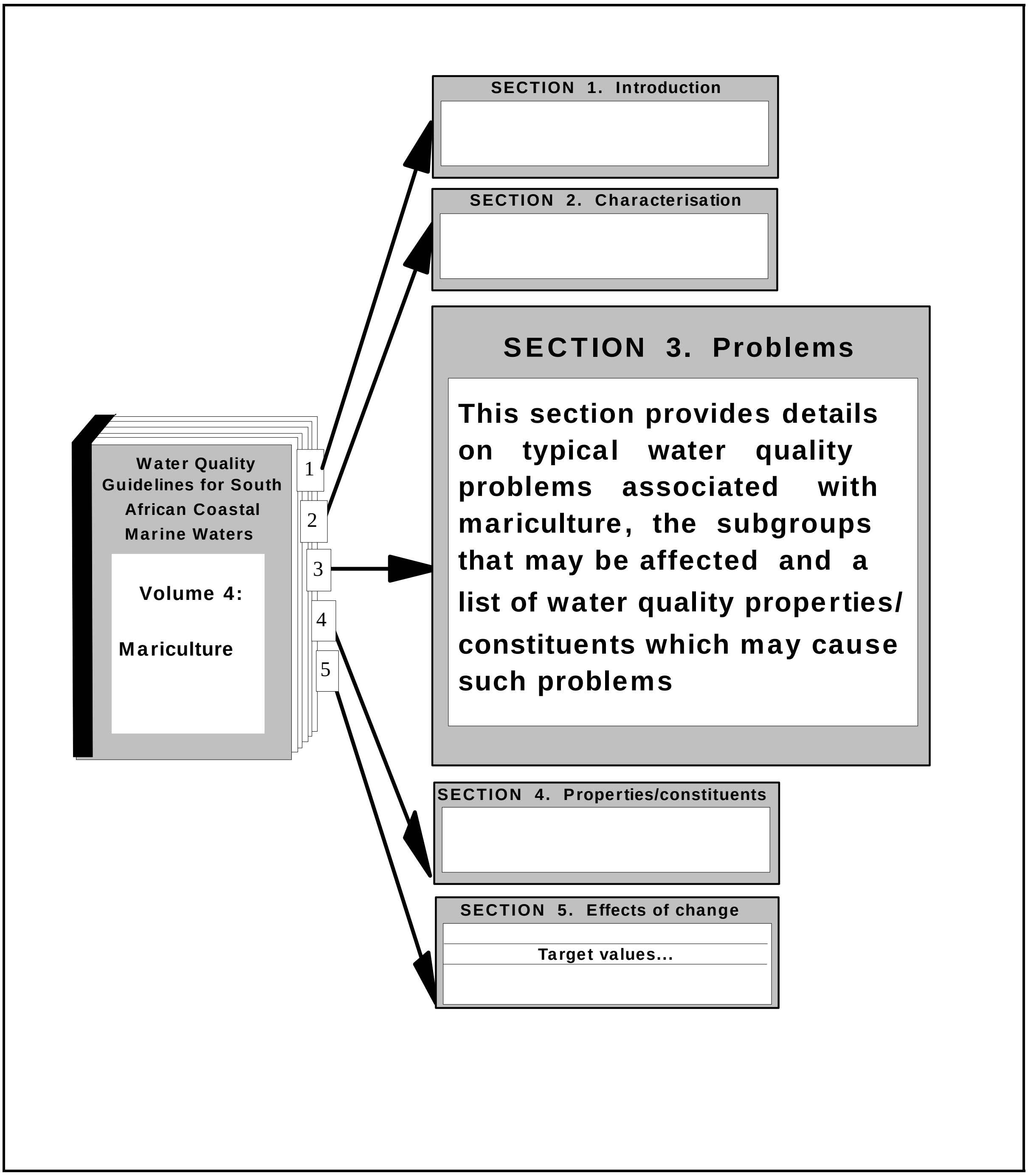
11. GRANT, S. W. and CHERRY, M. I. 1985. *Mytilus galloprovincialis* Lmk. In Southern Africa. *J. Exp. Mar. Biol. Ecol*. **90**: 179-191.

12. ZOUTENDYK, P. 1992. Mussel survey of the Saldanha ore jetty. *CSIR Report* **EMAS-C 92004**. 9pp.

13. KOURIE, R. M. 1994. Potential for Atlantic salmon (*Salmo salar* L) farming in South Africa. *Intensive Fish Farming report* **2/1993**: XIV + 206pp.

14. DAVIS, J. 1994. Artificial spawning of Sparids. *AASA Newsletter* **29:** 17-18.

SECTION 3: TYPICAL WATER QUALITY PROBLEMS RELATED TO MARICULTURE PRACTICES



SECTION 3: PROBLEMS
CONTENTS

Chapter 3.1 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 mariculture practices, i.e. in the culture of *seaweed, bivalves, gastropods, crustaceans and finfish.*

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:

- *Temperature*
- *Salinity*
- *pH*
- *Floating matter*
- *Suspended solids*
- *Colour/turbidity/clarity*
- *Dissolved oxygen*
- *Nitrite*
- *Nitrate*
- *Phosphate*
- *Ammonia*
- *Cyanide*
- *Hydrogen sulphide*
- *Trace metals (Cd, Cu, Cr, Pb, Zn)*
- *Tributyltin*

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

Refer to Section 5:
p 5-2
p 5-7
p 5-13
p 5-18
p 5-19
p 5-22
p 5-23
p 5-28
p 5-30
p 5-32
p 5-36
p 5-38
p 5-46
p 5-52
p 5-77

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 mariculture practices, i.e. in the culture of *seaweed, bivalves, gastropods, crustaceans and finfish.*

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, is provided in **Section 5** include:

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

Refer to Section 5:

Property/constituent	Section 5
- *Temperature*	p 5-2
- *Salinity*	p 5-8
- *Dissolved oxygen*	p 5-24
- *Cyanide*	p 5-39
- *Trace metals (As)*	p 5-47
- *Tributyltin*	p 5-77
- *Total petroleum hydrocarbons*	p 5-82

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

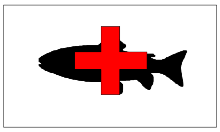
Changes in feeding habits may occur in mariculture practices where animals are cultured, i.e. *bivalves, gastropods, crustaceans and finfish*.

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. No data could be obtained on specific properties/constituents and their specific effects on the different mariculture practices.

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



CHANGES IN RESPIRATION PATTERNS

Description

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

Related subgroups

Generally, respiration problems may be associated with the culture of marine animals, i.e. *bivalves, gastropods, crustaceans and finfish*.

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 respiration 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 5-10
- *pH* — p 5-16
- *Dissolved oxygen* — p 5-24
- *Trace metals (Cd, Hg, Ag, Zn)* — p 5-47

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 close off completely.

Related subgroups

Changes in water pumping rates are usually associated with filter feeding organisms or *bivalves*. Pumping rates in filter feeders may 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*
- *pH*
- *Trace metals (Cd, Cu, Zn)*

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

Refer to Section 5:

p 5-8

p 5-14

p 5-50

CHANGES IN MOULTING PATTERNS

Description

Under stressed conditions, the intermoulting 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 *crustaceans*.

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:

- *Salinity*

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

Refer to Section 5:

p 5-10

SHELL DEFORMATION

Description

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

Related subgroups

In terms of mariculture practices, these problems are generally associated with marine *mollusca (bivalves and gastropods)* and *crustaceans*.

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:

- *pH* p 5-14
- *Tributyltin* p 5-77

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

Refer to Section 5:

FORMATION OF AIR BLISTERS CAUSING FLOTATION

Description

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

Related subgroups

This problem generally occurs in *bivalves,* e.g. mussels.

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 supersaturation 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 5-23

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 mariculture practices, i.e. in the culture of *seaweed, bivalves, gastropods, crustaceans and finfish.*

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:

- *Temperature*
- *Salinity*
- *pH*
- *Floating matter*
- *Suspended solids*
- *Colour/turbidity/clarity*
- *Dissolved oxygen*
- *Nitrite*
- *Nitrate*
- *Ammonia*
- *Cyanide*
- *Chlorine*
- *Hydrogen sulphide*
- *Trace metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn)*
- *Tributyltin*
- *Total petroleum hydrocarbons*

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

Refer to Section 5:
p 5-2
p 5-10
p 5-14
p 5-18
p 5-19
p 5-22
p 5-30
p 5-29
p 5-31
p 5-36
p 5-38
p 5-42
p 5-45
p 5-47
p 5-77
p 5-83

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 may generally be associated with marine animals, i.e. *bivalves, gastropods, crustaceans and finfish.*

For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change 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, is provided in **Section 5** include:

- *Temperature*
- *Salinity*
- *Cyanide*

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

Refer to Section 5:

p 5-2
p 5-10
p 5-40

Chapter 3. 2 Human Health

GASTROINTESTINAL PROBLEMS

Description

There are various gastrointestinal problems associated with the consumption of contaminated seafood. These may include gastrointestinal disorders with symptoms such as headaches, vomiting, diarrhoea, stomach ache and nausea. In severe cases, for example, where the seafood is contaminated with human pathogens or algal toxins, death can occur. These problems are more frequently associated with the consumption of raw seafood.

Related subgroups

Human illnesses may be caused by the consumption of any contaminated mariculture products, i.e. *bivalves, gastropods, crustaceans and finfish.* However, the most common occurrences are associated with filter feeding organisms (*bivalves*) which have the ability to accumulate contaminants.

For more information on the subgroups refer to Section 2

Related properties/ constituents and constituents and effects of change in water quality

A large variety of water quality properties/constituents may cause gatrointestinal problems through the consumption of seafood. The most common constituents include *algal toxins* and *human pathogens*.

For more information on algal toxins and human pathogens refer to p 4-78 and p 4-85

Pathogens which may cause gastrointestinal problems include:

- Bacteria (*Salmonella, Shigella, Vibrio cholerae, Vibrio parahaemolyticus, Klebsiella pneumoniae*);
- Viruses (enteroviruses and gastroenteric viruses);
- Protozoan parasites (*Giardia lambia, Entamoeba histloytica, Cryptosporidium parvum*).

Microbiological indicator organisms, such as faecal coliforms and enterococci, may indicate potential risks in this regard.

Algal toxins which may cause gastrointestinal problems include:

- *diarrhetic shellfish poison* (DSP).

No data could be obtained on specific concentration ranges of these constituents in seawater which may contaminate seafood products and subsequently cause human illnesses.

Chapter 3.2: Human Health

NEUROLOGICAL EFFECTS

Description

Neurological effects refer to problems associated with the nervous system. For example, the patient may have difficulty in breathing and in severe cases, heart failuremay occur.

Related subgroups

Neurological effects are usually associated with the consumption of contaminated *bivalves* (shellfish). However, the possibility of contracting such illnesses through consumption of contaminated products from the other sub-roups cannot be excluded.

Related properties/ constituents and effects of change in water quality

Neurological effects are usually caused by *algal toxins.*

Algal toxins which may cause these effects include:

- paralytic shellfish poison (PSP).

No data could be obtained on specific concentrations of these toxin and their specific effects on the different mariculture products, and subsequently on human consumers.

For more information on algal toxins refer to p 4-78

Chapter 3. 3 Aesthetics

TAINTING OF PRODUCTS

Description

This refers to the tainting of seafood products as a result of the presence of objectionable chemical constituents which may greatly influence the quality and market price of cultured products.

Related subgroups

Tainting may occur in all mariculture products, i.e in the culture of *seaweed, bivalves, gastropods, crustaceans and finfish.*

For more information on the subgroups refer to Section 2

Related properties constituents and effects of change in water quality

A large variety of constituents, generally organic onstituents, may taint products. A list of some of these constituents, and the concentration at which tainting can occur, are provided in **Section 5**:

- *Tainting substances*

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

Refer to Section 5:

p 5-86

Chapter 3.4 Mechanical and Process Interferences

CORROSION

Description

Certain metals have a tendency to corrode when immersed in water, especially soft water, acidic water or seawater, i.e. corrosion of certain metals occur in a weak electrolyte solution such as seawater.

Related subgroups

Corrosion may occur in all mariculture practices where metal equipment not suitable for seawater, is used.

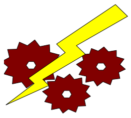
For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

Corrosion is usually associated with high *salinities*.

No data could be obtained on specific concentration ranges and problems.

For more information on salinity refer to p 4-3.



CLOGGING AND BLOCKAGE OF EQUIPMENT

Description

This problem refers to the mechanical interferences that occur when objectionable matter such as litter, oil and grease, debris, etc. clog and block equipment such as filters, screens, pipes and pumps.

Related subgroups

Clogging and blockages may occur in *all mariculture practices* where such equipment is being used.

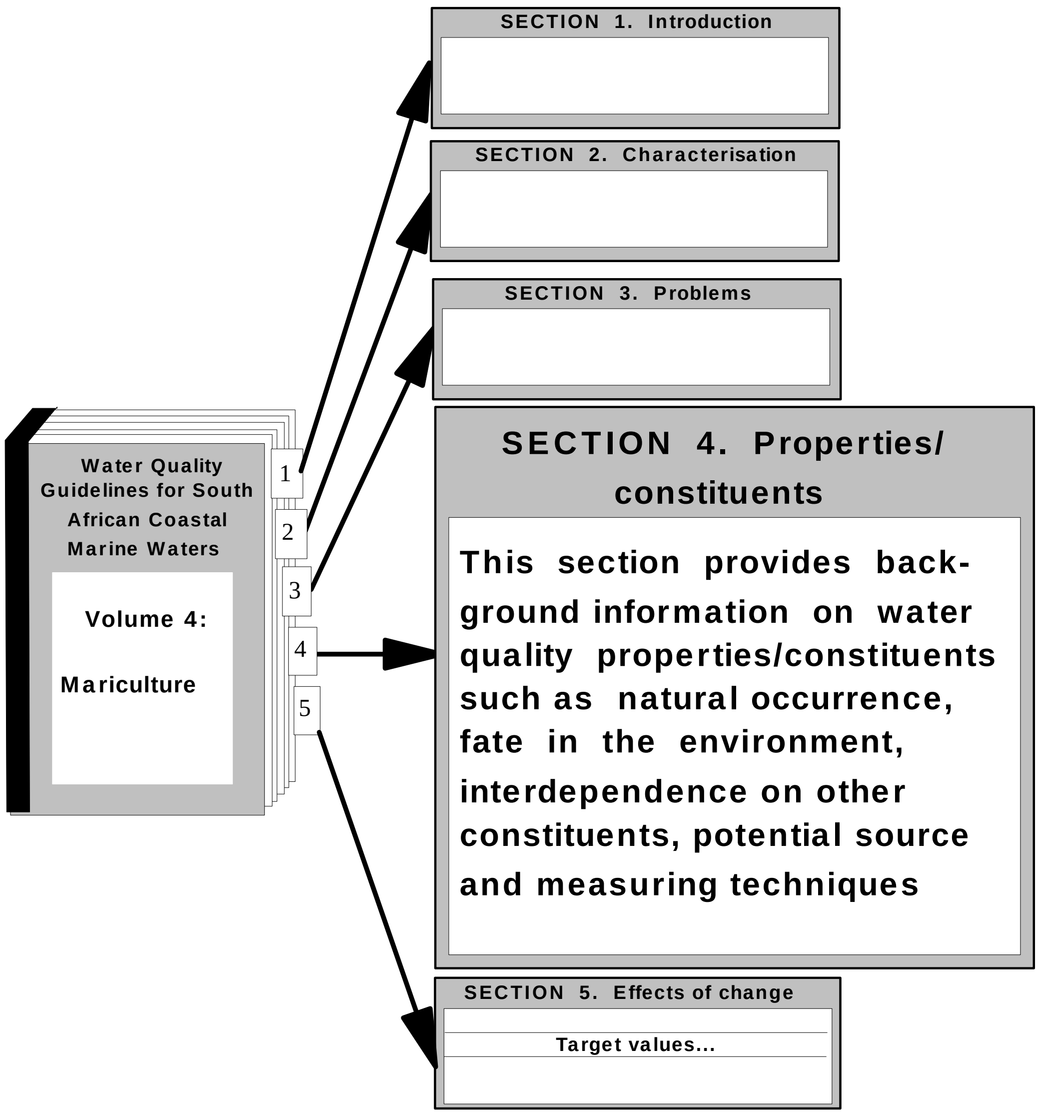
For more information on the subgroups refer to Section 2

Related properties/ constituents and effects of change in water quality

Clogging and blockages usually occur as a result of objectionable *floating matter*, *suspended solids and turbidity* being present. No data could be obtained on specific concentration ranges and problems.

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

SECTION 4: BACKGROUND INFORMATION ON WATER QUALITY PROPERTIES/ CONSTITUENTS RELATED TO MARICULTURE PRACTICES



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

CONTENTS continued on next page

CONTENTS continued...

°C

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 occurs 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

°C

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: ^{o}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].

Treatability

Where seawater is used in enclosed systems, e.g. aquariums and mariculture activities, heat exchangers can be used. The type of metal used in the heat exchanger should be chosen carefully. Generally, titanium is preferred in seawater [10].

Related problems

Typical water quality problems which may be associated with temperature, and which are addressed in this document, include:

	For more details on problems refer to:
- general growth deficiencies;	p 3-1
- lowered reproduction;	p 3-2
- mortalities.	p 3-9

Effects of change and target values

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

	Refer to:
- seaweed;	p 5-1
- molluscs - bivalves;	p 5-2
- molluscs - gastropods;	p 5-4
- crustaceans;	p 5-5
- finfish.	p 5-6

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 35×10^{-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 $34,7 \times 10^{-3}$ to $35,4 \times 10^{3}$; 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 $37,0 \times 10^{-3}$ 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 ($35,4 \times 10^{-3}$) and lowest values in winter ($35,0 \times 10^{-3}$) [13].

East coast. Subtropical surface waters are usually characterised by relatively high salinities ($>35 \times 10^{-3}$) 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* (Unesco, 1985) salinity is unitless, 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]:

$$K_{15} = \frac{\text{conductivity of seawater sample}}{\text{conductivity of standard KCl solution}}$$ 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 32×10^{-3}-36×10^{-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: $$\text{Salinity} \times 10^{-3} = \frac{\text{EC (mS m}^{-1}\text{) x factor}}{1\,000}$$

SALINITY continued on next page

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.

Treatability

Where seawater is used in an enclosed system, e.g. aquariums, salinity is often elevated due to evaporation. This is usually 'treated' by adding fresh water.

Related problems

Typical water quality problems which may be associated with salinity, and which are addressed in this document, include:

	For more details on problems refer to:
- general growth deficiencies;	p 3-1
- lowered reproduction;	p 3-2
- changes in respiration patterns;	p 3-4
- changes in water pumping rates;	p 3-5
- changes in moulting patterns;	p 3-6
- mortalities;	p 3-9
- abnormalities in movement;	p 3-10
- corrosion.	p 3-16

Effects of change and target values

Factual information on the effect of different salinity ranges on mariculture practices, as well as target values, are provided in Section 5 for:

	Refer to:
- seaweed;	p 5-7
- molluscs - bivalves;	p 5-8
- molluscs - gastropods;	p 5-9
- crustaceans;	p 5-10
- finfish.	p 5-12

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] + $H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$)

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

pH

pH continued...

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.

Treatability

In seawater, pH can be decreased by gasing with CO_2.

Related problems

Typical water quality problems which may be associated with pH, and which are addressed in this document, include:

For more details on problems refer to:

- general growth deficiencies; p 3-1
- changes in respiration patterns; p 3-4
- changes in water pumping rates; p 3-5
- shell deformation; p 3-7
- mortalities. p 3-9

Effects of change and target values

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

Refer to:

- seaweed; p 5-13
- molluscs - bivalves; p 5-14
- molluscs - gastropods; p 5-15
- crustaceans; p 5-16
- finfish. p 5-17

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 sources 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.

Treatability

Treatment is usually limited to the physical removal of objectionable floating matter, either through coarse grid systems or otherwise manually.

Related problems

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

- general growth deficiencies; p 3-1
- mortalities; p 3-9
- clogging and blockage of equipment. p 3-16

For more details on problems refer to: p 3-1, p 3-9, p 3-16

Effects of change and target values

Information on the effects of objectionable floating matter on mariculture practices, as well as target ranges, are provided in Section 5 for:

- all subgroups. p 5-18

Refer to: p 5-18

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. Under calm conditions suspended solids may settle from to water column to form objectionable deposits.

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...

Treatability

Suspended solids with a diameter greater than 60 µm can be removed from seawater by using filters, e.g. sand filters.

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 3-1
- mortalities;	p 3-9
- clogging and blockage of equipment.	p 3-16

Effects of change and target values

Information on the effects of suspended solids on mariculture practices, as well as target values, is provided in Section 5 for:

	Refer to:
- seaweed;	p 5-19
- molluscs - bivalves;	p 5-19
- molluscs - gastropods;	p 5-20
- crustaceans;	p 5-20
- finfish.	p 5-21

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 cause 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}) = SQRT$(K)_{sp}$ 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 such as 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/turbidity include:

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

Treatability

Activated carbon filters can be used to remove turbidity or colour, although, depending on the volume of water, this can be very expensive.

Related problems

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

- general growth deficiencies; p 3-1
- mortalities. p 3-9

For more details on problems refer to:

Effects of change and target values

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

- all subgroups. p 5-22

Refer to:

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 l^{-1} , by multiplying with

$$\frac{1{,}4290}{\text{density of seawater at the specific temperature}}$$

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.

Treatability

Where seawater is used in enclosed systems, e.g. aquariums, the dissolved oxygen can be increased through aeration with air under pressure (using fine bubbles).

DISSOLVED OXYGEN continued on next page

O_2

DISSOLVED OXYGEN continued...

Related problems	Typical water quality problems which may be associated with dissolved oxygen, and which are addressed in this document, include:	For more details on problems refer to:
	- general growth deficiencies;	p 3-1
	- lowered reproduction;	p 3-2
	- change in feeding habits;	p 3-3
	- change in respiration patterns;	p 3-4
	- changes in moulting patterns;	p 3-6
	- formation of air blisters;	p 3-8
	- mortalities;	p 3-9
	- abnormalities in movement.	p 3-10
Effects of change and target values	Factual information on the effect of different dissolved oxygen ranges on mariculture practices, as well as target values, are provided in Section 5 for:	Refer to:
	- molluscs - bivalves;	p 5-23
	- molluscs - gastropods;	p 5-23
	- crustaceans;	p 5-24
	- finfish.	p 5-25

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 an 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 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 4-9).

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^+

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 depends 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 ATM PRESSURE				
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.

Treatability

Where seawater is used in enclosed systems, e.g. aquariums, ammonia concentrations can be controlled in the short-term by bubbling with CO_2, which will reduce the pH of the water and, in doing so, shift the equilibrium of the NH_3/NH_4^+ reaction towards the less toxic ionised form.

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:
	- general growth deficiencies (NH_4^+ and NH_3);	p 3-1
	- mortalities (NH_3).	p 3-9
Effects of change and target values	General effects of different ranges of ammonium on mariculture practices could not be obtained, only target values. These together with effects and target values for ammonia are provided in Section 5 for:	Refer to:
	- seaweed (NH_4^+);	p 5-27
	- molluscs - bivalves (NH_3);	p 5-35
	- molluscs - gastropods (NH_3);	p 5-35
	- crustaceans (NH_3);	p 5-36
	- finfish (NH_3).	p 5-37

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.

Treatability

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

Related problems

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

	For more details on problems refer to:
- general growth deficiencies;	p 3-1
- mortalities.	p 3-9

Effects of change and target values

General effects of different ranges of nitrite on mariculture practices, as well as target values, are provided in Section 5 for:

	Refer to:
- seaweed;	p 5-28
- molluscs - bivalves;	p 5-28
- molluscs - gastropods;	p 5-28
- crustaceans;	p 5-29
- finfish.	p 5-29

No target ranges for nitrite have been set for molluscs, crustaceans or finfish.

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 µg l^{-1} NO_3^--N, with an average concentration of 420 µg 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 µg l^{-1}	280 ± 56 µg 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 µg 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 µg l^{-1}	47 µg l^{-1}	38 µg 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 down-stream 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 organisms remains one of the intriguing mysteries of seawater chemistry (14).

NITRATE continued continued on next page

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.

Treatability

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

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:
	- general growth deficiencies;	p 3-1
	- mortalities.	p 3-9
Effects of change and target values	Factual information on effects of different ranges of nitrate on mariculure practices, including target values, are provided in Section 5 for:	Refer to:
	- seaweed;	p 5-30
	- molluscs - bivalves;	p 5-30
	- molluscs - gastropods;	p 5-30
	- crustaceans;	p 5-31
	- finfish.	p 5-31
	No target values for nitrate have been set for molluscs, crustaceans and finfish.	

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, phospholipid, 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 a 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

PO 4

REACTIVE PHOSPHATE continued...

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.

Treatability

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

Related problems

Water quality problems associated with dissolved reactive phosphate include:

- general growth deficiencies.

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 mariculture practices, including target values, are provided in Section 5 for:

- seaweed.

Refer to:

p 5-32

SiO_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 usually 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 5EC. In deep oceans, because of high pressure, the solubility increases slightly [14,29].

Measurement in seawater

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.

Treatability

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

Related problems

Water quality problems associated with dissolved reactive silicate include:

- general growth deficiencies.

For more details on problems refer to:

p 3-1

Effects of change and target values

No data on the effects of specific concentration ranges could be obtained for silicate. The target value for silicate in mariculture practices is provided in Section 5 for:

- seaweed.

Refer to:

p 5-33

NH_3

Chapter 4.3 Inorganic Constituents

AMMONIA

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

C N

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 it 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 aquatic environment, each with its own physical and chemical properties.

The toxicity of cyanide increases if the pH level 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 manufacture of adiponitrile.

CYANIDE continued on next page

CYANIDE continued…

Treatability	Practical treatment methods for removing cyanide from seawater could not be obtained.	
Related problems	Typical water quality problems which may be associated with cyanide include:	For more details on problems refer to:
	- general growth deficiencies;	p 3-1
	- lowered reproduction;	p 3-2
	- mortalities;	p 3-9
	- abnormalities in movement.	p 3-11
Effects of change and target values	Factual information on effects of different ranges of cyanide on mariculture practices, as well as target values, are provided in Section 5 for:	Refer to:
	- seaweed;	p 5-38
	- molluscs - bivalves;	p 5-38
	- molluscs - gastropods;	p 5-39
	- crustaceans;	p 5-39
	- finfish.	p 5-40

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 reativity of the element in seawater [25]. Usually the flouride/chlorinity (in parts per thousand) ratio of $6,7 \pm 0,1 \times 10^{-5}$. However, in some very localised bottom waters the ratio may reach $9,5 \times 10^{-5}$ [25].

Marine biota can accumulate fluoride [62].

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 manufacture of orthophosphoric acid for industrial purposes;
- waste from electronics, glass, electroplating and metal treatment industries.

Treatability

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

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 mariculture practices is provided in Section 5.

Refer to:

p 5-41

Cl_2

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

Cl_2

CHLORINE continued...

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 of 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 fulfil 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.

Treatability

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

CHLORINE continued on next page

CHLORINE continued...

Related problems

Typical water quality problems which may be associated with chlorine, and which are addressed in this document, include:

- general growth deficiencies;
- mortalities.

For more details on problems refer to:

p 3-1
p 3-9

Effects of change and target values

Factual information on effects of different ranges of chlorine on mariculture practices is provided in Section 5 for:

- molluscs - bivalves;
- crustaceans;
- finfish.

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

Refer to:

p 5-42
p 5-43
p 5-44

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 $35x10^{-3}$ 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

H_2S

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* on 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.

Treatability

Where seawater is used in enclosed systems, e.g. aquariums, aeration is probably the most practical way to reduce hydrogen sulphide levels.

HYDROGEN SULPHIDE continued on next page

H_2S

HYDROGEN SULPHIDE continued…

Related problems

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

- general growth deficiencies; p 3-1
- mortalities. p 3-9

For more details on problems refer to:

Effects of change and target values

Factual information on effects of different ranges of hydrogen sulphide on mariculture practices is provided in Section 5 for:

- molluscs - gastropods; p 5-45
- crustaceans; p 5-46
- finfish. p 5-46

Refer to:

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

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 35×10^{-3} [25].

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

Ranges less than 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

As

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 on 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: $\mu g\ l^{-1}$ 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 herbicides, fungicides, insecticides, algicides, sheep dips, wood preservatives, feed additives and human and veterinarian medicinal (arsenic trioxide (As_2O_3) is a basic raw material for the manufacturing 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].**

Treatability

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

Related problems

Typical water quality problems which may be associated with arsenic, and which are addressed in this document, include:

For more details on problems refer to:

- general growth deficiencies; p 3-1
- mortalities. p 3-9

Effects of change and target values

Factual information on effects of different ranges of arsenic on mariculture practices, including target values, are provided in Section 5 for:

Refer to:

- seaweed; p 5-47
- molluscs - bivalves; p 5-47
- molluscs - gastropods; p 5-48
- crustaceans; p 5-48
- finfish. p 5-49

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 of 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 pre-concentrated 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;
- wastes from manufacturing various alloys.

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

Treatability

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

Related problems

Typical water quality problems which may be associated with the cadmium, and which are addressed in this document, include:

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

For more details on problems refer to:

p 3-1
p 3-4
p 3-5
p 3-9

Effects of change and target values

Factual information on effects of different ranges of cadmium on mariculture practices, including target values, are provided in Section 5 for:

- seaweed;
- molluscs - bivalves;
- molluscs - gastropods;
- crusaceans;
- finfish.

Refer to:

p 5-50
p 5-50
p 5-51
p 5-52
p 5-52

Cr

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 its 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.

Treatability

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

Related problems

Typical water quality problems which may be associated with chromium, and which are addressed in this document, include:

- mortalities.

For more details on problems refer to:

p 3-9

Effects of change and target values

Factual information on effects of different ranges of chromium on mariculture practices, including target values, are provided in Section 5 for:

- seaweed;
- molluscs - bivalves;
- molluscs - gastropods;
- crustaceans;
- finfish.

Refer to:

p 5-53
p 5-53
p 5-54
p 5-54
p 5-54

Cu

COPPER

Description

The most probable main species of copper in oxygenated seawater are $CuCO_3^0$, $CuOH^+$ 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 represents 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

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: µg 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.
Treatability	Practical treatment methods for removing copper from seawater could not be obtained.
Related problems	Typical water quality problems which may be associated with copper, and which are discussed in this document, include: - general growth deficiencies; p 3-1 - changes in water pumping rates; p 3-5 - mortalities. p 3-9 For more details on problems refer to:
Effects of change and target values	Factual information on effects of different ranges of copper on mariculture practices, including target values, are provided in Section 5 for: - seaweed; p 5-55 - molluscs - bivalves; p 5-56 - molluscs - gastropods; p 5-57 - crustaceans; p 5-58 - finfish. p 5-58 Refer to:

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} level. 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 35×10^{-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 pre-concentrated 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 manufacturing 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 activities (60% originates from leaded petrol) [28].

Treatability

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

Related problems

Typical water quality problems which may be associated with lead, and which are addressed in this document, include:

	For more details on problems refer to:
- general growth deficiencies;	p 3-1
- mortalities.	p 3-9

Effects of change and target values

Factual information on effects of different ranges of lead on mariculture practices, including target values, are provided in Section 5 for:

	Refer to:
- seaweed;	p 5-59
- molluscs - bivalves;	p 5-59
- molluscs - gastropods;	p 5-60
- crustaceans;	p 5-60
- finfish.	p 5-60

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, however, it increases for invertebrates 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.

Treatability

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

Related problems

Typical water quality problems which may be associated with mercury, and which are addressed in this document, include:

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

For more details on problems refer to:

p 3-1
p 3-4
p 3-9

Effects of change and target values

Factual information on effects of different ranges of mercury on mariculture practices, including target values, are provided in Section 5 for:

- seaweed;
- molluscs - bivalves;
- molluscs - gastropods;
- crustaceans;
- finfish.

Refer to:

p 5-61
p 5-61
p 5-62
p 5-63
p 5-63

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 $35x10^{-3}$ [(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 process 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.	
Treatability	Practical treatment methods for removing nickel from seawater could not be obtained.	
Related problems	Typical water quality problems which may be associated with nickel, and which are discussed in this document include: - mortalities.	For more details on problems refer to: p 3-9
Effects of change and target values	Factual information on effects of different ranges of nickel on mariculture practices, including target values, are provided in Section 5 for: - seaweed; - molluscs - bivalves; - molluscs - gastropods; - crustaceans; - finfish.	Refer to: p 5-64 p 5-64 p 5-65 p 5-66 p 5-66

Ag

SILVER

Description

Silver exists principally in the +1 oxidation state as the $AgCl_2^-$ 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 35×10^{-3} has been given as 0,1 $\mu g\ l^{-1}$ [25].

A range between 53,9 x 10^{-6} and 3, 78 x 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 35×10^{-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 diethyldithiocarbanate/ chloroform extraction procedures prior to analysis on an atomic absorption spectrophotometer [40].

Units: µg 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 the silver, and which are discussed in this document, include:

- changes in respiration patterns; p 3-4
- mortalities. p 3-9

For more details on problems refer to:

Effects of change and target values

Factual information on effects of different ranges of silver on mariculture practices, including target values, are provided in Section 5 for:

- seaweed; p 5-67
- molluscs - bivalves; p 5-67
- molluscs - gastropods; p 5-68
- crustaceans; p 5-69
- finfish. p 5-69

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 stabilisers [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 $\mu g\ l^{-1}$, with an average of 0,0005 $\mu g\ l^{1}$ has been reported for the most probable species ($SnO(OH)_3^-$) in oxygenated seawater with a salinity of 35×10^{-3} [25].

The concentration of dissolved tin in ocean waters has also been reported as being within the range of 0,5 and 3 $\mu g\ l^{-1}$ [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: $\mu g\ l^{-1}$ 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.

Treatability

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

Related problems

Typical water quality problems which may be associated with tin, and which are addressed in this document, include:

- mortalities.

For more details on problems refer to:

p 3-9

Effects of change and target values

Factual information on effects of different ranges of tin on mariculture practices is provided in Section 5 for:

- finfish.

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

Refer to:

p 5-71

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+}, $ZnOH^{+}$, $ZnCO_3^o$ and $ZnCl^{+}$ [(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 $ZnCO_3^o$ [(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.

Treatability

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

ZINC continued on next page

Related problems	Typical water quality problems which may be associated with zinc, and which are addressed in this document, include: - general growth deficiencies; - changes in respiration patterns; - changes in water pumping rates; - mortalities.	For more details on problems refer to: p 3-1 p 3-4 p 3-5 p 3-9
Effects of change and target values	Factual information on effects of different ranges of zinc on mariculture practices , including target values, are provided in Section 5 for: - seaweed; - molluscs - bivalves; - molluscs - gastropods; - crustaceans; - finfish.	Refer to: p 5-72 p 5-72 p 5-74 p 5-74 p 5-75

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	Tributyl tin 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 activity, 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 may range from less than 1,5 to 1 000 µg l^{-1} [49].
Treatability	Information on practical methods for the treatment of TBT in seawater could not be obtained.

TBT continued on next page

TBT

TBT continued...

Related problems

Typical water quality problems which may be associated with tributyltin, and which are discussed in this document include:

For more details on problems refer to:

- general growth deficiencies; p 3-1
- lowered reproduction; p 3-2
- shell deformation; p 3-7
- mortalities. p 3-9

Effects of change and target values

Factual information on effects of different ranges of tributyltin on mariculture practices is provided in **Section 5** for:

Refer to:

- seaweed; p 5-77
- molluscs - bivalves; p 5-77
- crustaceans; p 5-79
- finfish. p 5-80

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

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 objectionable 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 dissolved 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 °C, i.e. in pyrolytic processes and with incomplete combustion (28).

PAHs can be grouped into two classes :

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

- higher molecular weight three to four 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 solubilized 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 nm 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 petroleum hydrocarbon has been reported [63,64]. The extent of accumulation depends on factors such as the exposure concentration, the time of exposure and the lipid content of the organism 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 [9]:

- spectrofluorimetric analysis;
- gas chromatography;
- high-performance liquid chromatography (HPLC).

Units: mg l^{-1} or µg l^{-1}.

Pollution sources

Anthropogenic sources of petroleum hydrocarbons include [9]:

- accidental oil 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.

Treatability

Information on practical methods for the treatment of TPH in seawater could not be obtained. In its undissolved form, i.e. floating on the water surface, it could probably be physically removed with skimmers, filtration systems, etc.

TPH continued on next page

Related problems

Typical water quality problems which may be associated withTPH, and which are addressed in this document, include:

- lowered reproduction;
- mortalities.

For more details on problems refer to:

p 3-2
p 3-9

Effects of change and target values

Factual information on effects of different ranges of TPH on mariculture practices is provided in Section 5 for:

- seaweed;
- molluscs - bivalves;
- crustaceans;
- finfish.

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

Refer to:

p 5-81
p 5-82
p 5-83
p 5-84

Algal

ALGAL TOXINS

Description

Some natural inhabitants of the sea, e.g. marine algae, produce toxins which pose a health risk to humans and other marine organisms (the latter will not be addressed in this document). Although these are not typical water quality properties/constituents, it is important to be aware of these toxins, especially in areas where people are in contact with seawater or where seafood is cultured or collected for human consumption.

The most well-known toxins include [61]:

- paralytic shellfish poison (PSP) caused by the toxin known as saxitoxin in shellfish which has fed on toxic dinoflagellate plankton (red tide) of the genus *Gonyaulax;*
- diarrhetic shellfish poisoning (DSP);
- neurotoxic shellfish poisoning (NSP) (aerosol toxins), *Ptychodiscus breve*, which is the most widely studied organism causing NSP.

Human intoxication related to PSP has only been associated with the consumption of contaminated shellfish, and rarely, if ever, with recreation in seawater [61].

NPS toxins differ from PSP and DPS in that the toxic effects do not result from ingestion of affected shellfish. Algal physiological processes and/or cell lysis result in the release of these toxins in the water where they act as contact poisons. [61].

Natural occurrence

Algal blooms off the South African west and south coasts occur naturally throughout the year, but are most abundant during late summer and autumn. Some of these, for example, certain red tide species, do produce algal toxins [61].

Blooms of the algae *Gonyaulax polygramma* and *Gymnodinium* sp. have also been reported in False Bay [61].

Fate in environment

Information on the fate of algal toxins in the marine environment could not be obtained.

Interdependence on other constituents

The occurrence of algal blooms, including those producing algal toxins, are usually dependent on factors such as water temperature and nutrient availability [61].

ALGAL TOXINS continued on next page

Measurement in seawater

Methods for analysing algal toxins in seawater could not be obtained. However, chromatographic techniques have been used to analyse for these toxins in mussel tissue [65].

Pollution sources

Nutrient enrichment of the sea may stimulate algal blooms, including those producing algal toxins. Anthropogenic sources of nutrients include [9]:

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

Treatability

Practical methods of removing algal toxins from seawater could not be obtained.

Related problems

Typical problems associated with algal toxins, and which are discussed in this document, include:

- gastrointestinal problems;
- neurological effects.

For more details on problems refer to:

p 3-11

p 3-12

Effects of change and target values

No data could be obtained on specific concentration ranges of algal toxins and associated effects.

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

Taint

TAINTING SUBSTANCES

Tainting substances refer to a large variety of chemicals, usually organics, which can taint marine products, thus affecting their quality and market price.

This document will not provide background information on these compounds , mainly because they are so diverse and complex. However, a list of tainting substances, as well as the concentrations at which tainting can occur, are provided in Section 5, p 5-86.

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

F coli

Chapter 4.5 Microbiological Indicator Organisms and Human Pathogens

FAECAL COLIFORM (including *Escherichia coli*)

Description

Faecal coliforms refer to a group of total coliforms which are more closely related to faecal contamination, and which generally do not readily replicate in the water environment. *Escherichia coli* (*E. coli*) is a member of the group of faecal coliform bacteria. It is highly specific to the faeces of warm-blooded animals, and for all practical purposes, these bacteria cannot multiply in any natural water environment [(59)].

These bacteria were selected as indicators of faecal pollution because they typically occur in the faeces of man and warm-blooded animals.

However, some human diseases associated with polluted seawater are caused by viruses. Certain shortcomings of using faecal coliforms to indicate virological quality have been shown, which might be attributed to the following [(57)]:

- viruses are only excreted by infected individuals and coliform bacteria by almost all humans and warm-blooded animals;
- viruses are excreted for relatively short periods, while coliform bacteria are excreted fairly consistently;
- the structure, composition, morphology and size of viruses differ fundamentally from those of bacteria, which implies that behaviour and survival in water differ extensively.

Natural occurrence

Although faecal coliforms are not a natural water quality property/constituent of marine waters, they are fairly consistently excreted by humans and other warm-blooded animals.

Fate in environment

The survival of faecal coliforms in the marine environment is dependent on a variety of variables including temperature, exposure to ultraviolet light irradiation in sunlight, salinity, osmotic shock, microbiological antagonism, adsorption to solids and sediments and ingestion by molluscs.

The rate of bacterial die-off in the marine environment is usually expressed in T_{90} values, which is the time required for the bacterial density to decreased by 90 %. The T_{90} values are usually larger during day time compared to night time, primarily as a result of higher ultraviolet light irradiation during the day [(60)].

Faecal coliforms continued on next page

F coli

Feacal coliforms continued...

Interdependence on other constituents	Refer to *Fate in the Environment* on p 4-81.	
Measurement in seawater	In routine monitoring, faecal coliforms in seawater are usually measured according to the membrane filter technique [17]. Results are expressed as: Faecal coliform (*E. coli*) counts per 100 ml.	
Pollution sources	Major sources of faecal contamination in marine waters include [9]: - sewage discharges; - bathers themselves, especially at densely populated beaches; - septic tank seepage; - stormwater run-off; - contaminated river run-off.	
Treatability	Not relevant to indicator organisms. Treatment should be focused on the microbiological organisms that pose the actual health risk, i.e. the human pathogens.	
Related problems	Typical problems associated with the presence of microbiological indicators in seawater used in mariculture are usually related to human health, for example: - gastrointestinal problems.	For more details on problems refer to: p 3-11
Effects of change and target values	No data could be obtained on the specific faecal coliform counts in seawater, the associated effects on mariculture products and subsequently on human consumers. Target ranges for faecal coliforms (and *E. coli*) for the South African coastal zone are provided in Section 5 for the culture of: - molluscs - bivalves (filter feeders) .	Refer to: p 5-89

Entero

ENTEROCOCCI

Description

Enterococci and faecal streptococci refer to vaguely defined groups of Gram-positive spherical bacteria, some of which are of human and/or animal faecal origin, and some of which are members of the natural flora of various environments. Because of the limited specificity of tests commonly used for these groups, they can, for all practical purposes, be considered to be the same[(59)].

Enteroccoci has been shown to be a valuable indicator for determining the extent of faecal contamination in marine waters [(17)].

Natural occurrence

Although enterococci is not a natural water quality property/constituent of marine waters, it is fairly consistently excreted by warm-blooded animals [(17)].

Fate in environment

The survival of enterococci in the marine environment is dependent on a variety of variables including temperature, exposure to ultraviolet light irradiation in sunlight, salinity, osmotic shock, microbiological antagonism, adsorption to solids and sediments and ingestion by molluscs.

The rate of bacterial die-off in the marine environment is usually expressed in T_{90} values, which is the time required for the bacterial density to decrease by 90 %. The T_{90} values are usually larger during day time compared to night time, primarily as a result of higher ultraviolet light irradiation during the day [(60)].

Interdependence on other constituents

Refer to *Fate in the Environment* above.

Measurement in seawater

In routine monitoring, enterococci in seawater is usually measured according to the membrane filter technique [(17)].

Results are expressed as:

Enterococci counts per 100 ml.

Pollution sources

Major sources of faecal contamination in marine waters include [(9)]:

- sewage discharges;
- bathers themselves, especially at densely populated beaches;
- septic tank seepage;
- stormwater run-off;
- contaminated river run-off.

ENTEROCOCCI continued on next page

Entero

ENTEROCOCCI continued...

Treatability	Not relevant to indicator organisms. Treatment should be focused on the microbiological organisms that pose the actual health risk, i.e. the human pathogens.
Related problems	Typical problems associated with the presence of microbiological indicators in seawater used in mariculture are usually related to human health, for example: - gastrointestinal problems.
Effects of change and target values	No data could be obtained on the specific enterococci counts in seawater, the associated effects on mariculture products and subsequently on human consumers. No target ranges for Enterococci have been selected for the South African coastal zone.

For more details on problems refer to:

p 3-11

HUMAN PATHOGENS

Description

This document will deal with ***human*** pathogens, in particular. Human pathogens are microbiological organisms which may cause disease or other health problems in man. In terms of marine waters, this can either be through contact or ingestion of water containing these organisms or through the consumption of seafood which has been cultured in contaminated waters.

Generally, human pathogens can be divided into three broad groups, i.e.:

- *Bacteria*, including organisms such as *Salmonella*, *Shigella, Klebsiella pneumoniae, Pseudomonas aeruginosa*, *Staphylococcus aureus*, species of *Streptococcus* and *Micrococcus*, *Vibrio parahaemolyticus, Vibrio cholerae, Vibrio vulnificus* and *Listeria monocytogenes* [3,57,59];

- *Viruses*, including enteroviruses, gastroenteric viruses and adeno-viruses [57];

- *Protozoan parasites*, including *Giardia lambia*, *Cryptosporidium parvum* and *Entamoeba histolytica* [3,59,].

Natural occurrence

Some human pathogens which are known to cause infections in man, such as *Vibrio parahaemolyticus* and *Vibrio cholerae*, may be natural inhabitants of the marine environment.

Fate in environment

Not much detail is known on the fate of human pathogens in marine waters. Generally, the survival of human pathogens in the marine environment is dependent on a variety of variables including temperature, exposure to ultraviolet light irradiation in sunlight, salinity, osmotic shock, microbiological antagonism, adsorption to solids and sediments and ingestion by molluscs. Obviously survival is extensively prolonged in environments which protect against antimicrobial agents. Because of their small size, simple structure and resistant outer shell (capsid), viruses generally survive longer than bacteria.

Interdependence on other constituents

Refer to *Fate in the Environment* above.

Measurement in seawater

Methods for testing for human pathogens in seawater vary and largely depend on the type of organism. Because indicator organisms are usually measured in routine monitoring for pathogenic contaminants, methods for testing for human pathogens will not be discussed in detail in this document. These methods can, however, be obtained from a variety of publications [17,58,59].

HUMAN PATHOGENS continued on next page

Pathogen

HUMAN PATHOGENS continued...

Pollution sources

Major sources of faecal contamination in marine waters include [9]:

- sewage discharges;
- bathers themselves, especially at densely populated beaches;
- septic tank seepage;
- stormwater run-off;
- contaminated river run-off.

Treatability

Where seawater is used in enclosed systems or where it is extracted before use, UV-irradiation and ozonation can possibly be used to treat the water. This should, however, be done with great care since certain marine organisms are sensitive to such treatments.

In seawater, the effectiveness of chlorine as a disinfectant, e.g. in tidal pools, is doubtful. When chlorine is added to water the following reactions occur:

$Cl_2 + H_2O$ W $H^+ + Cl^- + HOCl$
$HOCl$ W $H^+ + OCl^-$

The disinfecting ability of the hypochlorous acid (HOCl) greatly exceeds that of the hypochlorite ion (OCl^-) and the equilibrium between the two is pH-dependent. At pH 5 available chlorine is almost entirely present as hypochlorous acid, but at pH 10 as hypochlorite. At the pH of seawater (i.e. about 8,2) it can therefore be expected that the disinfectant rate of chlorine will be much reduced [6].

Related problems

Typical problems associated with human pathogens, and which are discussed in this document, include:

- gastrointestinal problems.

For more details on problems refer to:

p 3-11

Effects of change and target values

No data could be obtained on the specific counts of human pathogens in seawater, the associated effects on mariculture products and subsequently on human consumers.

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

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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. BARSKY, S.M. 1990. *Diving in high risk environments*. Published by Dive Rescue Inc./International, Colorado. 118pp.

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. WATER RESEARCH CENTRE. 1979. Disinfection of sewage by chlorination. *Notes on Water Research* No **23**. Published by Water Research Centre. Printed in England by Clarendon Printers Ltd., Beaconfields, Buckinghamshire.

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 of 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

i

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 living shores of southern Africa.* C Struik, Cape Twon. 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 effuent 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, London.

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

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 PublishersLtd. 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

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. GRABOW, W.O.K. 1991. Human viruses in water. *Water Sewage and Effluent* **11**(4): 16-21.

58. STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. 1992. 18th Edition. ISBN 8755-3546.

59. GRABOW, W.O.K . in prep. Waterborne diseases: Update on quality assessment. Department of Virology, University of Pretoria.

60. BELLAIR, J.T., PARR-SMITH, G.A. and WALLIS, I.G. 1977. Significance of diurnal variations in faecal coliform die-off rates in the design of ocean outfalls. *Journal WPCF*. September. pp 2022-2030.

61. HORSTMAN, D.A., McGIBBON, S., PITCHER, G.C., CALDER, D., HUTCHINGS, L. and WILLIAMS, P. 1991. Red tides in False Bay, 1959-1989, with particular reference to recent blooms of *Gymnodimium* sp. *Trans Roy. Soc. S. Afr.* **47**(4&5): 611-628.

62. WRIGHT, D.A. and DAVISON, A.W. 1975. The accumulation of fluoride by marine and intertidal animals. *Environ. Pollut.* **8**: 1-13.

63. 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.

64. 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.

65. HOVE, H.T. and GRAHL-NEILSEN, O. 1989. Assay for dinoflagellate toxins in mussels by gas chromatography and principal components analysis. *Analytica Chimica Acta* **222**: 35-42.

i

ADDITIONAL INFORMATION

BEDER, S. 1990. Sun, surf and sewage. *New Scientist* 14 July: 40-45.

BROWN, A. C. 1987. Marine pollution and health in South Africa. *S. Afr. med. J* . **71**: 244-248.

COLE, M.T., KILGEN, M. B., REILY, L.A. and HACKNEY, C.R. 1986. Detection of enteroviruses and bacterial indicators and pathogens in Louisiana oysters and their overlying waters. *Journal of Food Protection* **49**(8): 596-601.

GRABOW, W.O.K. 1987. Dumping viruses at sea. *Scientiae* **28**(3): i-viii.

GRABOW, W.O.K., IDEMA, G.K., COUBROUGH, P. and BATEMAN, B. W. 1989. Selection of indicator systems for human viruses in polluted seawater and shellfish. *Wat. Sci. Tech.* **21**(3): 111-117.

GRABOW, W.O.K. 1989. Pathogenic organisms in sewage discharged to sea. In: Marine pollution - A 1988 perspective. A G S Moldan and J H Ridder (Eds.) *South African National Scientific Programme Report* No **161**: 49-61.

GRABOW, W.O.K., DE VILLIERS, J.C. and SCHILDHAUER, C.I. 1992. Comparison of selected methods for the enumeration of faecal coliforms and *Escherichia coli* in shellfish. *Applied and Environmental Microbiology* **58**(9): 3203-3204.

HUGHES, M.A., COYLE, P.V. and CONNOLLY, J. H. 1992. Enteroviruses in recreational waters of Northern Ireland. *Epidemiol. Infect.* **108**: 529-536.

NAGASHIMA, Y., MARUYAMA, J., NOGUCHI, T. and HASHIMOTO, K. 1987. Analysis of paralytic shellfish poison and tetrodotoxin by ion-pairing high performance liquid chromatography. *Nippon Suisan Gakkaishi* **53**(2): 819-823. (Formerly *Bull. Japan. Soc. Sci. Fish.*)

OMURA, T., ONUMA, M. and HASHIMOTE, Y. 1982. Viability and adaptability of *E. coli* and enterococcus group to salt water with high concentrations of sodium chloride. *Wat. Sci. Tech.* **14**: 115-126.

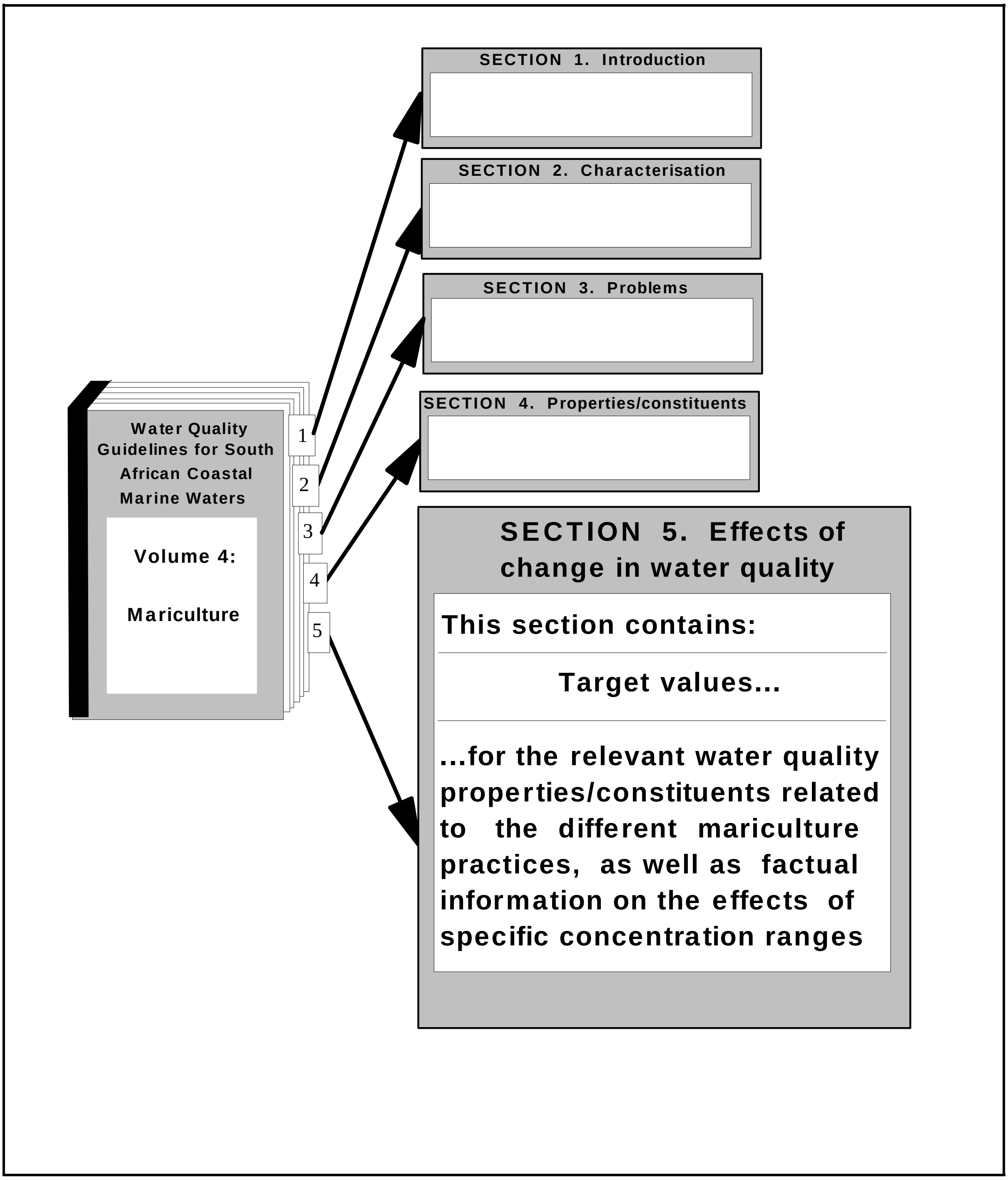
QUILLIAM, M.A. and WRIGHT, J.L. 1989. The amnesic shellfish poison mystery. *Analytical Chemistry* **61**(18): 1054A-1059A.

ROZAK, D.B. and COLWELL, R.R. 1987. Survival strategies of bacteria in the natural environment. *Microbiological Reviews* **51**(3): 365-379.

SULLIVAN, J.J. 1988. Methods of analysis for DSP and PSP toxins in shellfish: A review. *Journal of Shellfish Research* **7**(4): 587-595.

SUTTLE, C.A. and CHEN, F. 1992. Mechanisms and rate of decay of marine viruses in seawater. *Applied and Environmental Microbiology* **58**(11): 3721-3729.

SECTION 5: EFFECTS OF CHANGE IN WATER QUALITY ON MARICULTURE PRACTICES (INCLUDING TARGET VALUES)



SECTION 5: EFFECTS OF CHANGE IN WATER QUALITY CONTENTS

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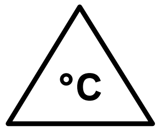
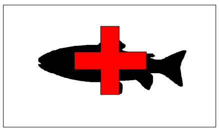


Chapter 5.1 Physico-chemical Properties

TEMPERATURE (Refer to p 4-1)

Seaweed
(Refer to p 2-3)



RANGE (°C)	Biological Health
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1 °C[1]	
10-17	The optimum temperature range reported for the alga: *Porphyra*[2]
11-25	The alga: *Gracilaria verrucosa* grows best in this range[3]
< 26	The alga: *Gracilaria* spp. became sensitive[4]
> 30	Mortalities occur in the alga: *Gracilaria verrucosa*[3]

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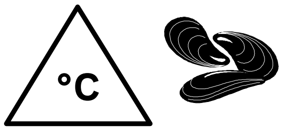
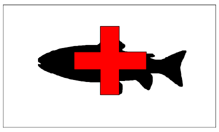


TEMPERATURE continued...

Molluscs - Bivalves
(Refer to p 2-13)



RANGE (°C)	Biological Health
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1°C [(1)]	
7-15	The larvae of the bivalve: *Mytilus edulis* (eyed-veliger stage) concentrated towards light. At 20 °C they became more generally distributed, i.e. less photopositive [(56)]
< 8	Growth ceased in oyster: *Crassostrea gigas* (adults) [(5-8)]
8-30	The mussel: *Choromytilus meridionalis* (adults) survived throughout this range [(9)]
8-31	The oyster: *Crassostrea virginica* survived (feeding and growth) in this range [(10,11)]
8-34	Tolerable range reported for the oyster: *Crassostrea gigas* (adults) [(5-8)]
< 10	Negative impact reported on the growth and evolution of biochemical contents in the oyster: *Crassostrea gigas* [(12)]
10 and 20	The mussel: *Mytilus edulis* showed an enhanced thermal tolerance when acclimated at 20 °C compared to 10 °C [(13)]
12,5	Optimum level reported for the mussel: *Choromytilus meridionalis* (adults) [(9)]
12,5-30	Metabolism increased in the mussel: *Choromyilus meridionalis,* feeding rates declined and growth was affected [(9)]
14-28	The oyster: *Crassostrea virginica* survived anoxic conditions for 18 days in this range [(14)]
15-18	Optimum range reported for the oyster: *Crassostrea gigas* (adults) [(5-8)]
> 15	Favourable range reported for the breeding of the oyster: *Ostrea edulis* [(15)]

TEMPERATURE continued on next page

TEMPERATURE continued...

Molluscs - Bivalves *continued...*

RANGE (°C)	Biological Health
16-20	Breeding in the oyster: *Crassostrea virginica* only commenced above this range [10,11]
> 17-18	Range required to trigger spawning in the oyster: *Crassostrea gigas* (adults) (often not desirable) [16]
17-22	The growth rate of the black mussel: *Mytilus galloprovincialis* (adults) was generally more sensitive to increasing environmental temperatures. In this range its outcompeted *Choromytilus meridionalis* and *Aulacomya ater* [17]
26,8-31,4	The oyster: *Crassostrea virginica* survived anoxic conditions for seven days in this range [14]
> 30	Negative impact reported on the growth and evolution of biochemical contents in the oyster: *Crassostrea gigas* [12]
> 34	Resulted in death of the oyster: *Crassostrea gigas* [5-8]
Ambient + 6	Survival rate did not change for the mussel: *Choromytilus meridionalis* (adults) [18] Survival of the mussel: *Aulacomya ater* (adult) was reduced [18] Survival in the mussels: *Choromytilus meridionalis* (Juveniles) and *Aulacomya ater* (juvenile) was much reduced [18]

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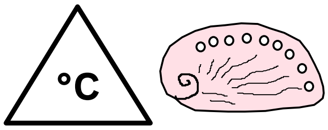
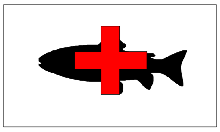


TEMPERATURE continued...

Molluscs - Gastropods

(Refer to p 2-19)

RANGE (°C)	 **Organism Health**
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1°C [1]	
8-24	Overall environmental tolerance temperature range reported for the abalone: *Haliotis midae* [19]
>16	*Haliotis midae* grew best in this range (CSIR observation)
>20	High mortalities and growth deformaties reported for the abalone: *Haliotis midae* trochphore and veliger larvae in hatcheries
>26	Caused acute temperature stress in the abalone: *Haliotis midae* (adults) [126] The onset of mortalities due to temperature was abrupt, usually 1-2 °C [17]

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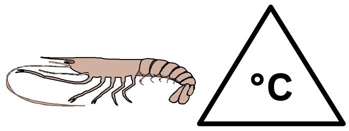
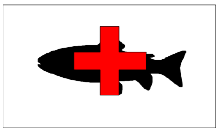
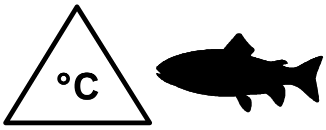


TEMPERATURE continued...

Crustaceans
(Refer to p 2-25)

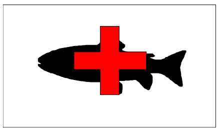
RANGE (ºC)	 **Biological Health**
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1ºC [1]	
24-34	Optimum temperature range reported for shrimp: *Penaeus monodon* (adults) in the family: Penaeidae [20,21]
25	Most favourable temperature reported for the shrimp: *Palaemon pacificus* (adults) [22]
25-30	Optimum temperature range reported for the shrimps: *Penaeus monodon* and *Penaeus indicus* (adults) in the family: Penaeidae [20,21]
26-30	Optimum temperature range reported for the prawn family: Penaeidae (adults) [23]
26-31	Optimum temperature range reported for the prawn family: Penaeidae (larvae), where sudden changes in temperature did not exceed 2 ºC [20,21]
27 $\pm$ 1,5	Optimum temperature range reported for the prawn family: Penaeidae (adults) [21]
27-29	Optimum temperature range reported for the prawn family: Penaeidae (larvae) [23]
27,9 $\pm$ 0,01	Optimum range required for maturation of broodstock in the prawn family: Penaeidae (larvae)[24]

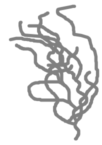
TEMPERATURE continued on next page

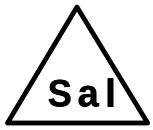


TEMPERATURE continued...

Finfish
(Refer to p 2-31)

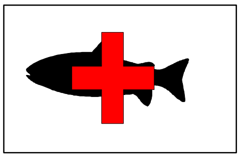
RANGE (ºC)	 **Biological Health**
Target value for the South African coastal zone: The maximum acceptable variation in ambient temperature is + or - 1 ºC [1]	
Low	Affected water balance through impacting on 'drink' rate (osmotic balance) in fish: *Salmo salar* (adults), while high temperatures did not [25]
Sudden change from 10 to 24,5	The LD_{50} for the Spring salmon: *Oncorhynchus tshawytscha* was 650 minutes [26]
Sudden change from 10 to 26	The LD_{50} for the Spring salmon: *Oncorhynchus tshawytscha* was 90 minutes [26]
12-14	Optimum range for the Atlantic salmon (adults) [27]
14-18	Lower lethal limit reported for the galjoen: *Dichistius capensis* (larvae and eggs) [28]
20	No hatching of eggs from the fish: *Sillago japonica* recorded [29]
> 20	Unsuitable range for the Atlantic salmon (adults) [27]
22-32	Viable hatching occurred in eggs from the fish: *Sillago japonica* [29]
> 27,5	100% mortality occurred in the fish eggs of *Cyprinodon macularis* in hypoxial water [30]
32	No hatching of eggs from the fish: *Sillago japonica* recorded [29]
> 36	100% mortality in the fish eggs of *Cyprinodon macularis* [30]





SALINITY (Refer to p 4-3)

Seaweed
(Refer to p 2-3)

RANGE	 Biological Health
$33x10^{-3}$-$36x10^{-3}$	**Target range for the South African coastal zone** [1]
Lower than natural range of seawater	Increased growth reported in the alga: *Gracilaria millardetti* [31]
Wide range	The alga: *Gracilaria tenuistipitata* was able to survive in a wide salinity range (euryhaline) [32]
$9x10^{-3}$-$45x10^{-3}$	Tolerable range (euryhaline) reported for the alga: *Gracilaria verrucosa* [3]

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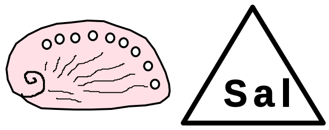
Sal

SALINITY continued...

Molluscs - Bivalves
(Refer to p 2-13)

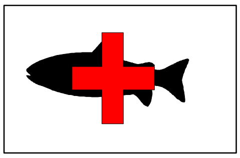
RANGE	**Biological Health**
33×10^{-3}-36×10^{-3}	**Target range for the South African coastal zone** [1]
Lower than the natural range of seawater	Byssogenesis reduced in bivalves (adults) [33]
5×10^{-3}-60×10^{-3}	The mussel: *Mytilus edulis* (adults) could survive in this range [16]
10×10^{-3}-44×10^{-3}	Survival range reported for the oyster: *Crassostrea gigas* (adults) [5,6,34]
15×10^{-3}	Pumping in the oyster: *Crassostrea virginica* stopped [35]
15×10^{-3}-40×10^{-3}	Fertilization still occurred in the bivalve: *Mytilus edulis* (larvae) [36]
15×10^{-3}-45×10^{-3}	Survival range reported for the oyster: *Crassostrea gigas* (adults) [16]
24×10^{-3}-37×10^{-3}	Optimum range reported for the oyster: *Crassostrea gigas* (adults) [5,6,34]
25×10^{-3}-39×10^{-3}	Pumping in the oyster: *Crassostrea virginica* occurred normally [35]
30×10^{-3}-40×10^{-3}	Successful development in the bivalve: *Mytilus edulis* (larvae) to the trochophore stage only occurred in this range [36]
$>37 \times 10^{-3}$	No spawning occurred in bivalves [16]

SALINITY continued on next page

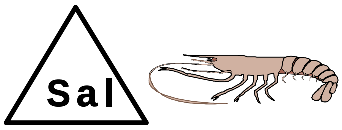


SALINITY continued...

Molluscs -Gastropods
(Refer to p 2-19)

RANGE	 **Biological Health**
33×10^{-3}-36×10^{-3}	**Target range for the South African coastal zone [1]**
> 30×10^{-3}	Reduced negative geotactic behaviour in abalone [37]
Narrow range	Abalone (adults) tolerated narrow salinity ranges (stenohaline) [38] The abalone: *Haliotis discus* hannai (larvae) tolerated narrow salinity ranges [39]

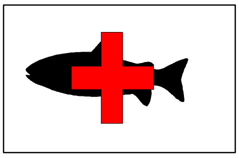
SALINITY continued on next page



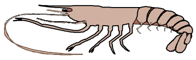
SALINITY continued...

Crustaceans

(Refer to p 2-25)

RANGE	 **Biological Health**
33×10^{-3}-36×10^{-3}	**Target range for the South African coastal zone [1]**
1×10^{-3}-75×10^{-3}	The shrimp: *Penaeus indicus* was capable of tolerating this range if allowed a acclimation time of around 48 hours [40]
5×10^{-3}	High molting frequency in the prawn: *Penaeus* sp. (juveniles) [41]
5×10^{-3}-25×10^{-3}	Tolerable salinity range reported for the shrimp: *Penaeus monodon* in the family: Penaeids (adults) [23]
5×10^{-3}-40×10^{-3}	Tolerable salinity range reported for the shrimp: *Penaeus monodon* in the family: Penaeids(adults) [20,21]
7×10^{-3}-10×10^{-3}	After eight hours of exposure mortality in the shrimp: *Penaeus* sp. was 50 % [42]
10×10^{-3}	The shrimp: *Penaeus* sp. (post larvae) could survive at this temperature at a salinity of 35×10^{-3}, but not at a salinity of 8×10^{-3} [43]
12×10^{-3}-13×10^{-3}	The shrimp: *Penaeus* sp. started to die under experimental conditions [42]
15×10^{-3}-30×10^{-3}	Optimum salinity range reported for the prawn: *Penaeus monodon* (adults) [20,21] Tolerable salinity range reported for the prawn family: Penaeidae(adults) [23]

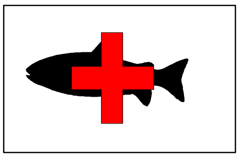
SALINITY continued on next page



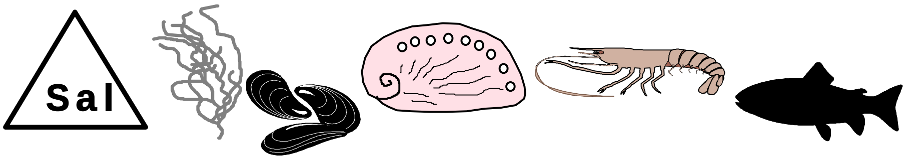
Sal

SALINITY continued...

Crustaceans *continued...*

RANGE	 **Biological Health**
$18x10^{-3}$	Respiration rate fell and deaths occurred in the shrimp: *Penaeus* sp. (adult intermoult) (44)
$20x10^{-3}$	Low moulting frequency in the prawn: *Penaeus* sp. (juveniles) (41) Shrimp: *Penaeus* sp. (post larvae) could survive at this temperature at a salinity of $35x10^{-3}$ and $8x10^{-3}$ (43)
$25x10^{-3}$-$40x10^{-3}$	Tolerable salinity range reported for the shrimp: *Penaeus indicus* (adults) (20,21)
$27x10^{-3}$-$32x10^{-3}$	Tolerable salinity range reported for the shrimp: *Penaeus japonicus* (adults) (20,21)
$28x10^{-3}$-$35x10^{-3}$	Tolerable salinity range reported for the prawn family: Penaeids (adults) (24)
Drop from $30x10^{-3}$ to $20x10^{-3}$	Swimming activity in the shrimp: *Penaeus* sp. increased (42)
$30x10^{-3}$-$32x10^{-3}$	Tolerable salinity range reported for the shrimp: *Penaeus monodon* (larvae) (20,21)
$32x10^{-3}$-$36x10^{-3}$	Tolerable salinity range reported for the prawn family: Penaeidae (larvae) (23)
$(33{,}5 \pm 0{,}08)x10^{3}$	Range required for maturation of broodstock of the prawn family: Penaeidae (larvae) (24)
$40x10^{-3}$	High moulting frequency in the prawn: *Penaeus* sp. (juveniles) (41)

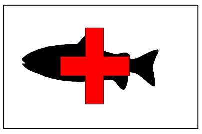
SALINITY continued on next page



SALINITY continued...

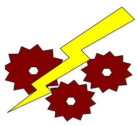
Finfish

(Refer to p 2-31)

RANGE	 **Biological Health**
33×10^{-3}-36×10^{-3}	**Target range for the South african coastal zone** [1]
< 5×10^{-3}	The survival of the Australian bass: *Macquaria novemaculeata* (larvae) was less than 0,5 % [45]
5×10^{-3}-25×10^{-3}	The fish: *Liza parsier* (mugillidae) survived in this range (larvae) [46]
10×10^{-3}-35×10^{-3}	The survival of the Australian bass: *Macquaria novemaculeata* (larvae) was about 76 % [45]
15×10^{-3}-25×10^{-3}	Optimum range for growth in the fish: *Liza parsier* (Mugilidae) (larvae) plus food conversion efficiency [46]
> 30×10^{-3}	Mortality increased in the fish: *Liza parsier* (Mugillidae) (larvae) [46]

All subgroups

(Refer to Section 2)

RANGE	 **Mechanical/Process Interferences**
Natural range of seawater	Results in the corrosion of metal equipment. Because this effect is anticipated where seawater is used, it is generally adequately controlled by using suitable materials and by introducing proper maintenance programmes.

pH

pH (Refer to p 4-6)

Seaweed
(Refer to p 2-3)

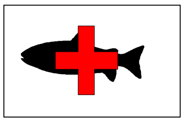
RANGE	Biological Health
7,3-8,2	**Target range for the South African coastal zone** [1]
7,95-8,15	Since *Gracilaria* extracts its carbon from CO_2, it may became carbon limiting in growth outside this range (the range in which carbon exists primarily as CO_2) [127]
8	*Gracilaria secundata* grew best at this pH [47]
10	*Gracillaria tenuistipitata* could grow at this pH, but growth rate reduced as the availability of CO_2 decreased [127]

pH continued on next page

pH

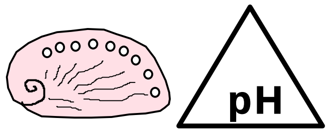
pH continued...

Molluscs - Bivalves
(Refer to p 2-13)



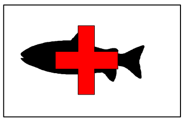
RANGE	Biological Health
7,3-8,2	**Target range for the South African coastal zone** [(1)]
Lower than natural range of seawater	Reduced byssogenesis in bivalves (adults) [(33)]
4,5	The pumping rate in the oyster: *Crassostrea virginica* was greatly reduced [(48)]
6	Significant mortalities reported in the oyster: *Crassostrea gigas* (adults) after 60 days [(49)]
6-9	Tolerable range reported for most bivalve species (adults) [(16)]
6,5	Mortalities occurred in the clam: *Venerupis decussata* (adults) [(50)]
6,6	Significant mortalities reported in the mussel: *Mytilus edulis* (adults) after 60 days [(49)]
6,9	Significant mortalities reported in the oyster: *Ostrea edulis* (adults) after 60 days [(49)]
< 7	Shells of bivalves eroded [(49)]
7	Intolerable value reported for bivalve molluscs (adults) [(49)] Significant mortalities occurred in the spat of the oysters: *Crassostrea gigas, Ostreas edulis* and the mussel: *Mytilus edulis* [(49)]
> 7,5	Tolerable range reported for the oyster: *Crassostrea gigas* (adults) [(6,51,52)]
7,55	The shells of the clam: *Venerupis decussata* (adults) started to dissolve [(50)]
Sudden drop from 7,75 to 6,75/6,7	The pumping rate in the oyster: *Crassostrea virginica* temporarily decreased followed by a rate lower than the original value [(48)]
> 7,8	Optimal range reported for the oyster: *Crassostrea gigas* (adults) [(6,51,52)]
Natural range of seawater	Tolerable range reported for clams [(50)]

pH continued on next page



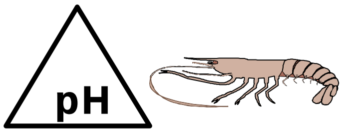
pH continued...

Molluscs - Gastropods
(Refer to p 2-19)



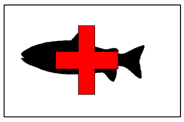
RANGE	Biological Health
7,3-8,2	**Target range for the South African coastal zone [1]**
7,5-8,0	Juvenile abalone were sensitive to this range in that the outer layer of the shell dissolves down to the nacreous layer, shells also become brittle and can break along the respiratory pore axis [38]
7,55	Abalone shells (adults) dissolved [38]
7,9-8,0	Affected shell formation in abalone(larvae) [38]

pH continued on next page



pH continued...

Crustaceans
(Refer to p 2-25)

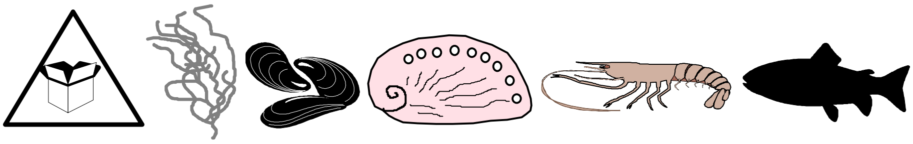
RANGE	 **Biological Health**
7,3-8,2	**Target range for the South African coastal zone [1]**
Low	Reduced growth in the prawn family: Penaeidae (adults) [53]
3,7	Lethal level reported for the shrimp: *Penaeus monodon* (juveniles 4,2- 5,5 g) at salinity of 32 [53,54]
< 5,0	Retarded growth in Penaeids (adults) [20,21]
5,5	Reduced growth in the shrimp: *Penaeus monodon* [54]
5,9	Minimum acceptable level reported for the shrimp: *Penaeus monodon* (juveniles) at a salinity of 30 [53,54]
7,5-8,5	Ideal range reported for Penaeids (adults) [24]
7,5-9,0	Tolerable range reported for Penaeids (adults) [20,21]
7,6-8,4	Tolerable range reported for Penaeids (larvae) [23]
7,8-8,3	Ideal range reported for Penaeids (adults) [55]
7,9 $\pm$ 0,14	Range required for maturation of broodstock in Penaeids [24]
8,0	Optimum level reported for Penaeids (larvae) [55]
8,1-8,3	Ideal range reported for Penaeids (adults) [24]
> 9,5	Harmful to growth and survival of Penaeids (adults) [20,21]

pH continued on next page

pH continued...

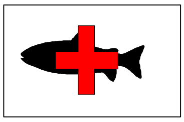
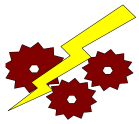
Finfish
(Refer to p 2-31)

RANGE	Biological Health
7,3-8,2	**Target range for the South African coastal zone** [(1)]
	No data could be obtained



FLOATING MATTER (Refer to p 4-8)

All subgroups
(Refer to Section 2)

<table>
<tr><th>TYPE</th><th>
Biological Health</th><th>
Mechanical/Process Interferences</th></tr>
<tr><td colspan="3">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</td></tr>
<tr><td>Oil</td><td>Although it could not be quantified, the presence of oil may result in a reduction in light penetration which could harm primary production.

The presence of oil may also result in smothering, especially of benthic communities.</td><td>Although seawater intake systems are usually capable of removing moderate amounts of floating matter, large quantities may cause blockages or clogging of filters. This may increase treatment costs such as the cleaning costs of filters and removal and dumping costs of matter.

In most instances, the effect is temporary and systems usually function normally once the floating matter has been removed, unless the floating object caused physical damage, in which case, the equipment will have to be repaired/replaced.</td></tr>
</table>

SUSPENDED SOLIDS (Refer to p 4-9)

Seaweed
(Refer to p 2-3)

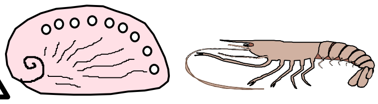
CONCENTRATION (mg l^{-1})	**Biological Health**
Target range for the South African coastal zone: The concentration of suspended solids should not be increased by more than 10 % of the ambient concentration [1]	
	No quantitative data could be obtained on the effects of suspended solids. However, when present in relatively large concentrations they 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.

Molluscs - Bivalves
(Refer to p 2-13)

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 ambient concentration [1]	
0-8	Optimal range for particulate inorganic matter (PIM) reported for the oyster: *Crassostrea gigas* (adults) [5,6,58]
0-100	Tolerable range for PIM reported for the oyster: *Crassostrea gigas* (adults) [5,6,58]
> 20	Affected the filter feeder efficiency in oysters, thus affecting growth [5,6,58]
5 000-20 000 (turbulent fine silt)	Growth rates in the mussel: *Mytilus galloprovincialis* (larvae) were reduced by between 20-50 % [59]
Sedimentation	Favoured the mussel: *Choromytilus meridionalis* over *Mytilus galloprovincialis* and *Aulacomya ater* (adults) [17]

SUSPENDED SOLIDS continued on next page

SS



SUSPENDED SOLIDS continued...

Molluscs - Gastropods

(Refer to p 2-19)

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 on the effects of suspended solids could be obtained. However, when present in relatively large concentrations they may cause abrasion or clogging of sensitive organs such as gills, which in turn, results in stress and increased disease susceptibility.

Crustaceans

(Refer to p 2-25)

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 ambient concentration [(1)]	
2-14	Desirable range reported for the prawn family: Penaeidae (adults) [(23)]

NOTE: **Where suspended particles (consisting of micro-algae and microbial-detrital aggegates) were between 0,5-5 µm, the growth of *Penaeus vannamei* increased by about 50 %. Where the particles were larger than 5 µm, the growth was increased by a further 36 % [(60)].**

Where seawater is used for rearing Penaeid larvae, suspended particles should be precipitated out and the seawater should be filtered [(55)].

SUSPENDED SOLIDS continued on next page

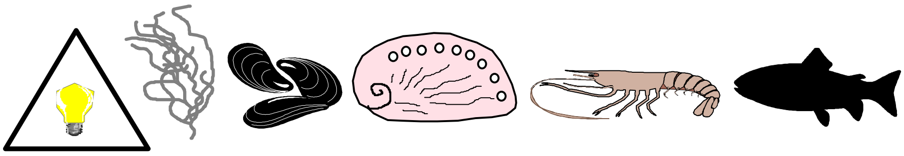
SUSPENDED SOLIDS continued...

Finfish
(Refer to p 2-31)

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 ambient concentration [1]	
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 [61]

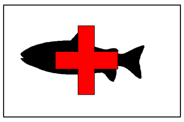
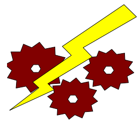
All subgroups
(Refer to Section 2)

SUSPENDED SOLIDS	**Mechanical/Process Interferences**
No target value has been selected for the South African coastal zone [1]	
	Although it could not be quantified, the presence of suspended solids may result in clogging and blockage of equipment such as pipes, screens, pumps, etc.



COLOUR/TURBIDITY/CLARITY (Refer to p 4-11)

All subgroups
(Refer to Section 2)

<table>
<tr><th>COLOUR/
TURBIDITY/
CLARITY</th><th>
Biological Health</th><th>
Mechanical/Process Interferences</th></tr>
<tr><td colspan="3">Target for the South African coastal zone [1]:

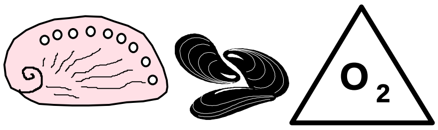
Turbidity and colour acting singly or in combination should not reduce the depth of the euphotic zone by more than 10 % of background levels measured at a comparable control site.

The colour (substances in solution) of water should not exceed background levels by more than 35 Hazen units</td></tr>
<tr><td></td><td>No quantitative data could be obtained on the effect of colour/turbidity/clarity. However, the main effect of unnaturally high levels of these parameters 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. Reduced nutrient availability in the water column may occur through adsorption and subsequent sedimentation of settleable solids.

Such materials may cause abrasion or clogging of sensitive organs such as gills, which in turn, results in stress and increased disease susceptibility.

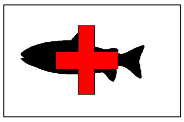
Deposits on the substrate may prevent invertebrate larval settlement, or smother benthic communities

The may also interfere with the feeding patterns of finfish.</td><td>Although it could not be quantified, turbidity in the water may result in clogging and blockage of equipment such as fine screens and filters.</td></tr>
<tr><td>> 0,4 m
(Secchi disc depth)</td><td>Desirable range reported for the prawn family: Penaeidae (adults) [57]</td><td></td></tr>
</table>



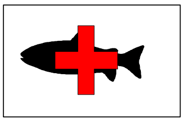
DISSOLVED OXYGEN (Refer to p 4-13)

Molluscs - Bivalves
(Refer to p 2-13)



CONCENTRATION ($mg\ l^{-1}$)	Biological Health
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)]	
70-100 (% saturation)	Optimum range reported for the oyster: *Crassostrea gigas* (adults) [(6,16,62,63)]
108-114 (% saturation)	Air supersaturation caused air blisters and flotation in the bivalves: *Mulinia* and *Mya* spp. (adult) [(64)]
115 (% saturation)	The bivalve: *Mercenaria* spp. (adults) showed reduced growth [(64)]

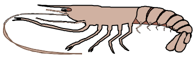
Molluscs - Gastropods
(Refer to p 2-19)



CONCENTRATION ($mg\ l^{-1}$)	Biological Health
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 coast, 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) [(65)] Organisms can however recover within 15 hours after exposure [(66)]
< 4	Led to mortality in the abalone: *Haliotis diversicolour* supertaxa (adults) [(38)]
> 110 (% saturation)	Can cause abnormal behaviour in abalone (adults) [(38)]
> 150 (% saturation)	Caused lesions, while prolonged exposure can cause death in abalone (adults) [(38)]

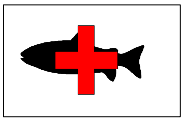
DISSOLVED OXYGEN continued on next page

O 2



DISSOLVED OXYGEN continued…

Crustaceans
(Refer to p 2-25)



CONCENTRATION (mg l^{-1})	**Biological Health**
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]	
0,5-1,0	Lethal range reported for a number of Penaeids (adults) [67]
0,5-1,2	Lethal range reported for Penaeids (adults) [68]
0,74 ± 0,03	Lethal concentration for the shrimp: *Penaeus* sp. (juveniles) [69]
0,9	LC_{50} value, over 96 hours, reported for the shrimp: *Penaeus monodon* (juveniles) [67]
2,2	Critical level for the shrimp: *Penaeus monodon* (juveniles) [68]
3,7	Level required by the shrimp: *Penaeus monodon* (adults) for normal life [68]
> 4	Tolerable range reported for Penaeids (adults) [57]
> 5	Tolerable range reported for Penaeids (adults) [23,24]
85-120 (% saturation)	Tolerable range reported for Penaeids (adults) [23]
100 (% saturation)	Required level to be maintained for Penaeid larval reared in laboratory conditions [55]

DISSOLVED OXYGEN continued on next page

Finfish

(Refer to p 2-31)

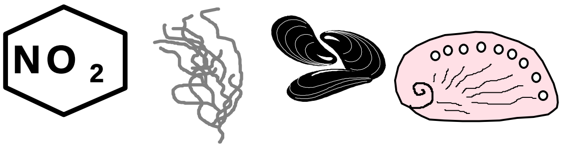
CONCENTRATION ($mg\ l^{-1}$)	**Biological Health**
Target range for the South African coastal zone: For the west coas,t the dissolved oxygen should not fall below 10 % of the established natural variation. For the south and east coasts the dissolved oxygen should not fall below 5 $mg\ l^{-1}$ (99 % of 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) [70] Slowed down the rate of development and the metabolic rate of the eggs of the Chum salmon [71]
2,3-3,6	LC_{50} range, over 24 hours, reported for a number of marine fish (larvae): *Pachymetoapon blochi, Pteromaris axillares, Trulla capensis, Congipodus spinifer* and *Gaidropsarus capensis* [72]
40-120 mm Hg (1,9-5,7)	The less active scup: *Stenotomus chrysops* showed no effect [43]
< 70 mm Hg (< 3,3)	The very active mackerel: *Scomber scombrus* failed to withdraw oxygen [43]
5-7	Range required by the Atlantic salmon (adults) for survival in the temperature range 14-16 °C [27]
> 50 (% saturation)	Levels reported for survival of finfish (adults) [73]
> 80 (% saturation)	Levels reported for maximum growth in finfish (adults) [73]
< 150 (% saturation)	Growth declined in finfish (adults) [73]

Chapter 5.2 Nutrients

AMMONIUM (Refer to p 4-17)

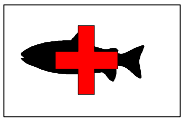
Seaweed
(Refer to p 2-3)

CONCENTRATION ($\mu g\ l^{-1}$ as N)	**Biological Health**
600 (as NH_3 plus NH_4^+)	**Target value for the South African coastal zone** [(1)]
	No data could be obtained



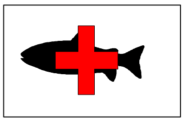
NITRITE (Refer to p 4-21)

Seaweed
(Refer to p 2-3)



CONCENTRATION ($\mu g\ l^{-1}$ as N)	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* (1)	
	No data could be obtained

Molluscs - Bivalves and Gastropods
(Refer to p 2-13 and p 2-19)



CONCENTRATION ($\mu g\ l^{-1}$ as N)	Biological Health
No target value has been seleced for the South African coastal zone (1)	
	No data could be obtained

NITRITE continued on next page

NO 2

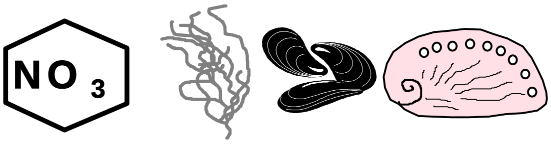
NITRITE continued...

Crustaceans
(Refer to p 2-25)

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) [(68)]
100-200	Range required for maturation of broodstock in Penaeids [(24)]
110	Safe level reported for the shrimp: *Penaeus monodon* nauplii (larvae) [(74)]
< 200-250	Desirable range reported for Penaeids (adults) [(23)]
< 700	Safe level reported for the shrimp: *Penaeus* sp. (larvae) [(75)]
1 360	Safe level reported for the shrimp: *Penaeus monodon* (post-larvae) [(74)]
2 300	Safe level reported for the shrimp:*Penaeus* sp. (juvenile) [(76)]
3 800	Safe level reported for the shrimp: *Penaeus monodon* juveniles (33-37 mm TL) [(77)]
10 600	Safe level reported for the shrimp: *Penaeus monodon* adolescents (100 mm TL) [(76)]
37 710	LC_{50} value over 96 hours reported for the shrimp: *Penaeus* sp. (juvenile) at a salinity of 20, temperature of 24,5 °C and pH of 7,57 [(76)]
171 000	LC_{50} value over 96 hours reported for the shrimp: *Penaeus monodon* (adolescents) at a salinity of 20, temperature of 24,5 °C and pH of 7,57 [(76)]

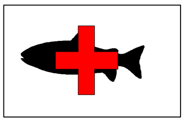
Finfish
(Refer to p 2-31)

CONCENTRATION ($\mu g\ l^{-1}$ as N)	Biological Health
No target value has been selected for the South African coastal zone [(1)]	
> 300	Reduced growth rates in the fish: *Sparus auratus* (adults)[(77)]
$1,2 \times 10^6$ to $2,4 \times 10^6$	LC_{50} range reported for five marine fish species (larvae) [(72)]

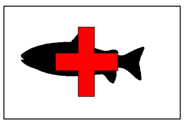


NITRATE (Refer to p 4-23)

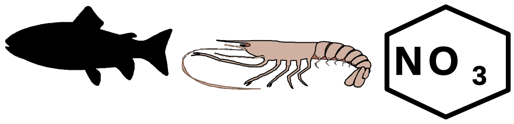
Seaweed
(Refer to p 2-3)

CONCENTRATION (µg l^{-1} as N)	 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* [(1)]	
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 [(78)]
High availability	High availability of nitrate, coupled with adequate light levels and carbon supply, can lead to rapid growth in *Gracalaria* spp. which reduces the agar/dry weight ratio of the plants. The exact level is hard to define as the nitrogen incorporation role depends upon flux rather than absolute concentrations

Molluscs - Bivalves and Gastropods
(Refer to p 2-13 and p 2-19)

CONCENTRATION (µg l^{-1} as N)	 Biological Health
[(1)] **No target value has been selected for the South African coastal zone regarding molluscs**	
Regular enrichment	Enhanced growth in the clam: *Tridacna derasa* (larvae) under experimental conditions [(79)]

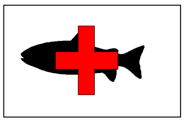
NITRATE continued on next page



NITRATE continued...

Crustaceans

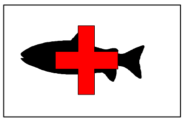
(Refer to p 2-25)



CONCENTRATION ($\mu g\ l^{-1}$ as N)	**Biological Health**
No target value has been selected for the South African coastal zone regarding crustaceans [1]	
10-40	Range required for maturation of broodstock in Penaeids (larvae) [24]
1 000	Significant mortalities occurred within 40 hours in the shrimp: *Penaeus monodon* (larvae) [80]
100 000- 200 000	Desirable range reported for Penaieds (adults) [23]
300 000	Safe level reported for Penaeids (adults) [68]

Finfish

(Refer to p 2-31)



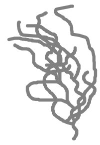
CONCENTRATION ($\mu g\ l^{-1}$ as N)	**Biological Health**
No target value has has been selected for the South African coastal zone regarding finfish [1]	
> 100 000	Long-term exposure to these concentrations might be detrimental to marine fish: Clear-nose skate (*Raja enlanteria*), Florida pompano (*Trachinotus carolinus*), Black seabass (*Centropristis striata*), Plane-head filefish (*Monacanthus hispidus*) and Beaugregory (*Pomacentrus leucostritus*)[81]
$4,2 \times 10^6$ to $8,7 \times 10^6$	LC_{50} range reported for five marine fish species (larvae): *Gaidropsarus capensis, Heteromycteris capensis, Diplodus sargus, Lithognathus mormyrus* [72]

PO_4

REACTIVE PHOSPHATE (Refer to p 4-27)

Seaweed
(Refer to p 2-3)

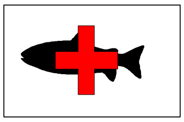
CONCENTRATION ($\mu g\ l^{-1}$ as P)	**Biological Health**
Target for the South African coastal zone: Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* [(1)]	
< 15 500	Elongation growth rates in *Laminaria saccharina* (seaweed) remained high in late spring as a result of nutrient enrichment, but winter growth was not enhanced [(78)] External phosphate concentrations affect the alginate composition and sequential structure in *Laminaria saccharina* [(78)]

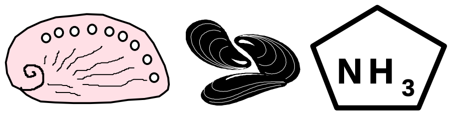


SiO_4

REACTIVE SILICATE (Refer to p 4-31)

Seaweed
(Refer to p 2-3)

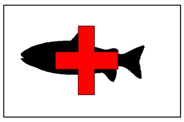
CONCENTRATION ($\mu g\ l^{-1}$ as Si)	 **Biological Health**
Target for the South African coastal zone: Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* [(1)]	
	No data could be obtained



Chapter 5.3 Inorganic Constituents

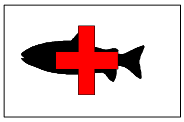
AMMONIA (Refer p 4-35)

Molluscs - Bivalves
(Refer to p 2-13)



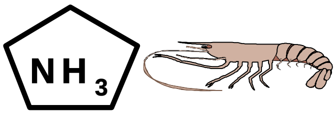
CONCENTRATION ($\mu g\ l^{-1}$ as NH_3-N)	Biological Health
20 (600 as NH_3 plus NH_4^+)	**Target value for the South African coastal zone** [(1)]
< 100	Desirable range reported for rearing molluscs (larvae) [(16)]

Molluscs - Gastropods
(Refer to p 2-19)



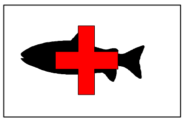
CONCENTRATION ($\mu g\ l^{-1}$ as NH_3-N)	Biological Health
20 (600 as NH_3 plus NH_4^+)	**Target value for the South African coastal zone** [(1)]
500	Retarded growth in abalone [(38)]

AMMONIA continued on next page



AMMONIA continued…

Crustaceans
(Refer to p 2-25)

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) [(82)]
< 20	Recommended range for shrimps: Penaeids (adults) in the presence of nitrite [(23)]
20-40	Range required for maturation of broodstock in Penaeids [(24)]
32	Maximum acceptable toxicant concentration for the shrimp: *Penaeus monodon* (post-larvae) [(83)]
60-183	50% reduction in weight and length occurred in the shrimp: *Penaeus monodon* (post-larvae) [(84)]
80	Safe level reported for the shrimp: *Penaeus monodon* (adolescents) (80-100 mm TL) [(76)]
90-110	Desirable level reported for Penaeids (adults) [(25)]
100	Safe level reported for the shrimp: *Penaeus monodon* (juveniles) (33-37 mm TL) [(85)] Safe level reported for the shrimp: *Penaeus monodon* (post-larve) [(82)]
> 100	Tolerable range reported for Penaeids (larvae) [(20)]
110	Maximum tolerable toxicant concentration reported for Penaeids (adults) after 40 days [(86)]
140	Safe level reported for the shrimp: *Penaeus* sp. (juvenile) at 26 °C [(87)]

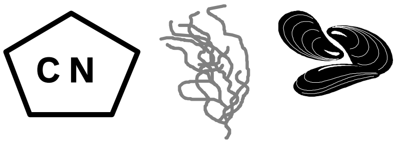
AMMONIA continued on next page

Crustaceans *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as NH_3-N)	Biological Health
210	Maximum acceptable level defined as that which reduced growth in *Penaeus monodon* (juveniles) by 5 % over three weeks [54]
< 210	Acceptable range reported for Penaeids (adults) [57]
220	Safe level reported for the shrimp: *Penaeus* sp. (juvenile) at 25 °C [87]
350	Maximum acceptable toxicant concentration reported for the shrimp: *Penaeus japonicus* (juveniles) (increased moulting frequency) [88]
450	Reduced growth in shrimps by 50 % [20]
960	LC_{50} value over 96 hours reported for *Penaeus* sp. (adolescent) at 24,5 °C and at a salinity of 20 [87]
1 040	LC_{50} value over 96 hours reported for *Penaeus monodon* (post larvae) at 29,5 °C [82]
1 530	LC_{50} value over 96 hours reported for the shrimp: *Penaeus* sp. (juvenile) at 25 °C [87]
2 570	LC_{50} value over 96 hours reported for the shrimp: *Penaeus* sp. (juvenile) at 26 °C [89]

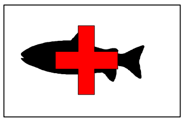
Finfish
(Refer to p 2-31)

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]**
> 100	Reduced growth rates in finfish [73,77]



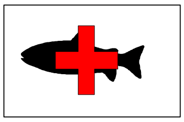
CYANIDE (Refer to p 4-36)

Seaweed
(Refer to p 2-3)



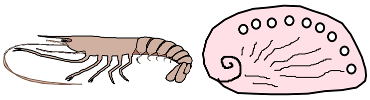
CONCENTRATION (µg l^{-1})	Biological Health
12	**Target value for the South African coastal zone [1]**
	No data could be obtained

Molluscs - Bivalves
(Refer to p 2-13)



CONCENTRATION (µg 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* [90]
100	LC_{20} value over a period of 14 days for the mussel: *Mytilus edulis* [90]
150	Motor activity was suppressed after 10 minutes in the oyster: *Crassostrea* sp. [90]

CYANIDE continued on next page

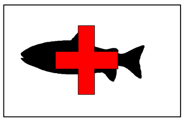


C N

CYANIDE continued...

Molluscs - Gastropods

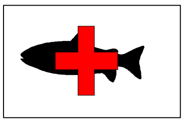
(Refer to p 2-19)



CONCENTRATION (µg l^{-1})	**Biological Health**
12	**Target value for the South African coastal zone** [1]
	No data could be obtained

Crustaceans

(Refer to p 2-25)



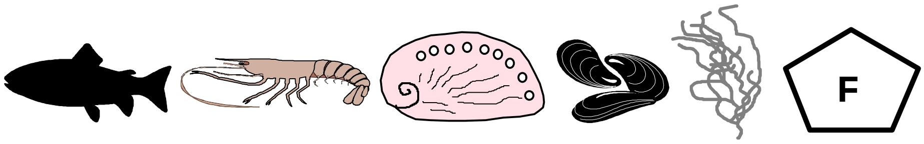
CONCENTRATION (µg l^{-1})	**Biological Health**
12	**Target value for the South African coastal zone** [1]
< 20	No measurable effect was found in the shrimp: *Mysidopsis bahia* [90]
43	Life cycle exposure (29 days) produced adverse effects on reproduction in the shrimp: *Mysidopsis bahia* [90]
70	Life cycle exposure (29 days) produced adverse effects on survival in the shrimp: *Mysidopsis bahia* [90]

CYANIDE continued on next page

CYANIDE continued...

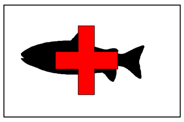
Finfish
(Refer to p 2-31)

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) [90]
7	During exposure over eight days there was a reduction of 50 % in swimming performance in the salmon: *Oncorhynchus kisutch* [90]
10	Swimming speed reduced after two hours of exposure in the salmon: *Oncorhynchus kisutch* [90] Abnormal embryonic development occurred in the salmon: *Salmo salar* after 58 days of exposure [90]
20	Growth was reduced by 27 % in the salmon: *Oncorhynchus tshawytscha* after exposure of 64 days [90]
24	LC_{50} value over 24 hours for the salmon: *Salmo salar* at a dissolved oxygen concentration of 3,5 mg l^{-1} [90]
73	LC_{50} value over 24 hours for the salmon: *Salmo salar* at a dissolved oxygen concentration of 3,5 mg l^{-1} [90]
80-100	Hatching was delayed by six to nine days in the salmon: *Salmo salar* [90]

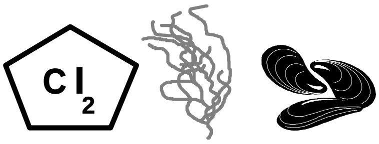


FLUORIDE (Refer to p 4-38)

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 *Grandidieralla lignorum* Barnard by observing their reproduction success** [(91)]**.**



CHLORINE (Refer to p 4-40)

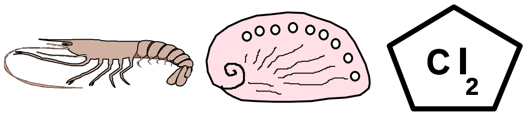
Seaweed
(Refer to p 2-3)

CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	Biological Health
No target value has been selected for the South African coastal zone [1]	
	No data could be obtained

Molluscs - Bivalves
(Refer to p 2-13)

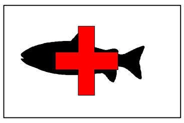
CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	Biological Health
No target value has been selected for the South African coastal zone [1]	
23	LC_{50} value over a period of 48 hours reported for the oyster: *Crassostrea virginica* (larvae) in the temperature range 19-28 °C [92]
26	LC_{50} value over a period of 48 hours reported for the oyster: *Crassostrea virginica* (juvenile) in the temperature range 19-28 °C [92]
60	LC_{50} value over a period of 96 hours reported for the oyster: *Crassostrea virginica* (larvae) [92]

CHLORINE continued on next page

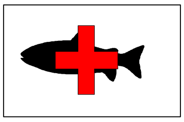


CHLORINE continued…

Molluscs - Gastropods
(Refer to p 2-19)

CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	 **Biological Health**
No target value has been selected for the South African coastal zone [1]	
	No data could be obtained

Crustaceans
(Refer to p 2-25)

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 [92]

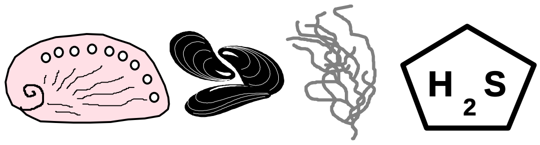
CHLORINE continued on next page

CHLORINE continued…

Finfish

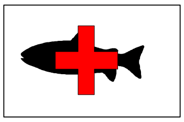
(Refer to p 2-31)

CONCENTRATION ($\mu g\ l^{-1}$ as residual Cl_2)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
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 of 11,6-11,7 °C [94]
100	LC_{50} value, over a period of 48 hours (exposure time 30 minutes), reported for the salmon: *Oncorhynchus gorbuscha* at 12,4 °C[94]
220	LC_{50} value over a period of 48 hours reported for the fish: *Menidia menidia* (juvenile) in the temperature range 19-28 °C [93]
250	LC_{50} value, over a period of 48 hours (exposure time 30 minutes), reported for the salmon: *Oncorhynchus gorbuscha* at 13,6 °C [94]
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 [95]



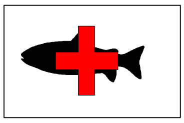
HYDROGEN SULPHIDE (Refer to p4-44)

Seaweed
(Refer to p 2-3)



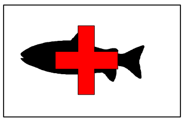
CONCENTRATION (µg l^{-1} as unassociated H_2S)	**Biological Health**
No target value has been selected for the South African coastal zone [(1)]	
	No data could be obtained

Molluscs - Bivalves
(Refer to p 2-13)



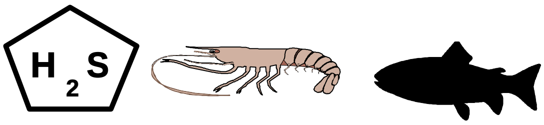
CONCENTRATION (µg l^{-1} as unassociated H_2S)	**Biological Health**
No target value has been selected for the South African coastal zone [(1)]	
	No data could be obtained

Molluscs - Gastropods
(Refer to p 2-19)



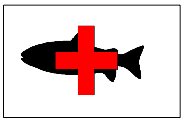
CONCENTRATION (µg l^{-1} as unassociated H_2S)	**Biological Health**
No target value has been selected for the South African coastal zone [(1)]	
50	Retarded growth in abalone [(38)]
500	Mortalities occurred in abalone [(38)]

HYDROGEN SULPHIDE continued on next page

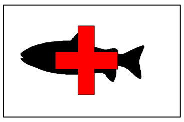


HYDROGEN SULPHIDE continued...

Crustaceans
(Refer to p 2-25)

CONCENTRATION (µg l^{-1} as unassociated H_2S)	 **Biological health**
No target value has been selected for the South African coastal zone [1]	
< 0,002	Desirable level reported for Penaeids (adults) [23]
0,033	Safe level reported for the shrimp: *Penaeus monodon* (adults) [68]
0,1-2,0	Loss of equilibrium reported in shrimps (adults) [68]
1	Maximum concentration recommended for crustaceans [96]
4,0	Large-scale mortality was reported in Penaeids (adults) [23] Shrimps (adults) succumbed [68]

Finfish
(Refer to p 2-31)

CONCENTRATION (µg l^{-1} as unassociated H_2S)	 **Biological health**
No target value has been selected for the South African coastal zone [1]	
1	Maximum concentration recommended for fish [96]

ARSENIC (Refer to p 4-47)

Seaweed
(Refer to p 2-3)

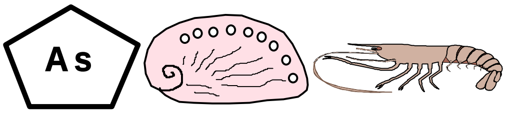
CONCENTRATION ($\mu g\ l^{-1}$ as total As)	Biological Health
12	**Target value for the South African coastal zone** [1]
65	Normal sexual reproduction occurred in the red alga: *Champia parvula* [97]
95	No sexual reproduction occurred in the red alga: *Champia parvula* [97]
300	Death occurred in the red alga: *Champia parvula* [97]
580	Arrested spore development after seven days treatment (exposure time 18 hours) in the red alga: *Plumaria elegans* [97]
10 000	Normal growth, but no sexual reproduction occurred in the red alga: *Champia parvula* [97]

Molluscs - Bivalves
(Refer to p 2-13)

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) [97]
7 500	LC_{50} value, over a period of 48 hours, reported for the oyster: *Crassostrea virginica* (eggs) [97]
16 000	Lethal concentration, in 3 to 16 days, reported for the mussel: *Mytilus edulis* [97]

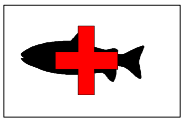
NOTE: **According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit of arsenic in shellfish is 3 $\mu g\ g^{-1}$.**

ARSENIC continued on next page



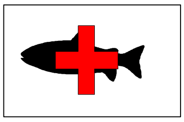
ARSENIC continued...

Molluscs - Gastropods
(Refer to p 2-19)



CONCENTRATION ($\mu g\ l^{-1}$ as total As)	**Biological Health**
12	**Target value for the South African coastal zone [1]**
	No data could be obtained

Crustaceans
(Refer to p 2-25)



CONCENTRATION ($\mu g\ l^{-1}$ as total As)	**Biological Health**
12	**Target value for the South African coastal zone [1]**
630-1 270	Maximum acceptable toxicant concentration reported for the mysid: *Mysidopsis bahia* [97]
2 300	LC_{50} value, over a period of 96 hours, reported for the mysid: *Mysidopsis bahia* [97]

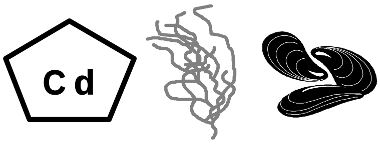
ARSENIC continued on next page

ARSENIC continued...

Finfish
(Refer to p 2-31)

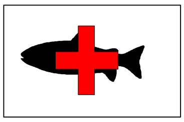
CONCENTRATION ($\mu g\ l^{-1}$ as total As)	**Biological Health**
12	**Target value for the South African coastal zone** [(1)]
2 500	No effect occurred in the salmon: *Oncorhynchus gorbuscha* over 10 days [(97)]
3 800	LC_{50} value, for a period of 10 days, reported for the salmon: *Oncorhynchus gorbuscha* [(97)]
7 200	Mortalities (100 %) reported in the salmon: *Oncorhynchus gorbuscha* over 10 days [(97)]

NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs) the maximum limit of arsenic in fish is 1 $\mu g\ g^{-1}$.**



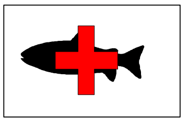
CADMIUM (Refer to p 4-50)

Seaweed
(Refer to p 2-3)



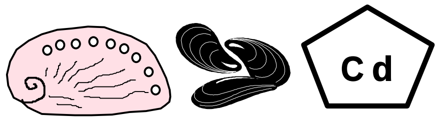
CONCENTRATION ($\mu g\ l^{-1}$ as total Cd)	Biological Health
4	**Target value for the South African coastal zone** [(1)]
	No data could be obtained

Molluscs - Bivalves
(Refer to p 2-13)



CONCENTRATION ($\mu g\ l^{-1}$ as total Cd)	Biological Health
4	**Target value for the South African coastal zone** [(1)]
25-400	Depressed oxygen uptake in the mussel: *Perna indica* (adults) [(98)]
1 620	LC_{50} value, over 96 hours at 18,5 °C, reported for the mussel: *Mytilus edulis planulatus* in a static bioassay [(99)]
3 500	LC_{50} value, over 96 hours, reported for the mussels: *Perna viridis and Perna indica* (adults) [(98)]
3 800	LC_{50} value reported for the oyster: *Crassostra virginica* (larvae) [(16)]
7 500-10 000	Reduced the pumping rate in the mussel: *Mytilus edulis* (adults) [(100)]

CADMIUM continued on next page



CADMIUM continued...

Molluscs - Bivalves *continued...*

NOTES:

Cadmium has an impact on bivalves by reducing the metabolically active phosphorus [39,51]. Cadmium can also lead to lesions in gills of bivalves [27].

Enrichment factors* reported for cadmium composition of shellfish compared to concentrations in the marine environment are [101]:

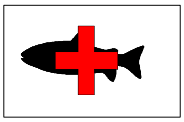
Oysters	**-**	**318 700**
Mussels	**-**	**100 000**

*** Enrichment factor = <u>weight of metal per unit dry weight of whole soft tissue</u>**

weight of metal per unit weight of seawater

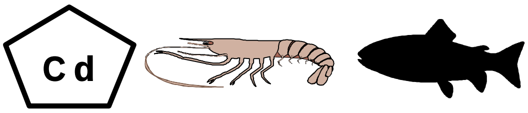
According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for cadmium in shellfish is 3 µg g^{-1}.

Molluscs - Gastropods
(Refer to p 2-19)



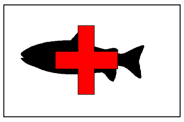
CONCENTRATION (µg l^{-1} as total Cd)	**Biological Health**
4	**Target value for the South African coastal zone [1]**
	No data could be obtained

CADMIUM continued on next page



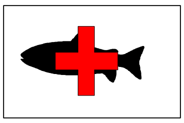
CADMIUM continued...

Crustaceans
(Refer to p 2-25)



CONCENTRATION ($\mu g\ l^{-1}$ as total Cd)	Biological Health
4	**Target value for the South African coastal zone** [1]
100	Threshold concentration affecting metabolism in the mysid: *Leptomsis ligvura* [102]
200	Significant reductions in growth and survival were reported for the prawn: *Penaeus japonicus* (larvae). Accumulated Cd levels decreased after 20 days once the larvae were transferred to clean seawater [103]
500-1 000	LC_{50} value, over 48 hours, reported for the mysid: *Leptomsis ligvura* [102]
1 850	LC_{50} value, over 168 hours at 18,7 °C, reported for the shrimp: *Palaemon* sp. in a static bioassay [99]
2 300	LC_{50} value, over 120 hours at 18,7 °C, reported for the shrimp: *Palaemon* sp. in a static bioassay [99]
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 [99]

Finfish
(Refer to p 2-31)



CONCENTRATION ($\mu g\ l^{-1}$ as total Cd)	Biological Health
4	**Target value for the South African coastal zone** [1]
	No data could be obtained

NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for cadmium in fish is 1 $\mu g\ g^{-1}$**

CHROMIUM (Refer to p 4-53)

Seaweed
(Refer to p 2-3)

CONCENTRATION ($\mu g\ l^{-1}$ as total Cr)	Biological Health
8	**Target value for the South African coastal zone** [1]
	No data could be obtained

Molluscs - Bivalves
(Refer to p 2-13)

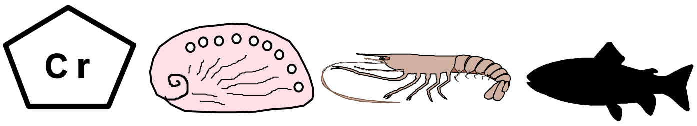
CONCENTRATION ($\mu g\ l^{-1}$ as total Cr)	Biological Health
8	**Target value for the South African coastal zone** [1]
10 800	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [16]

NOTE: **Enrichment factors* reported for chromium composition of shellfish compared to concentrations in the marine environment are** [101]**:**

Oysters	**-**	**60 000**
Mussels	**-**	**320 000**

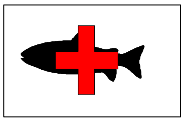
*** Enrichment factor =** $\frac{\textbf{weight of metal per unit dry weight of whole soft tissue}}{\textbf{weight of metal per unit weight of seawater}}$

CHROMIUM continued on next page



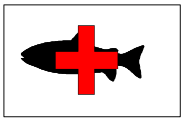
CHROMIUM continued...

Molluscs - Gastropods
(Refer to p 2-19)



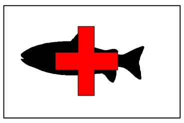
CONCENTRATION (µg l^{-1} as total Cr)	**Biological Health**
8	**Target value for the South African coastal zone** [(1)]
	No data could be obtained

Crustaceans
(Refer to p 2-25)



CONCENTRATION (µg l^{-1} as total Cr)	**Biological Health**
8	**Target value for the South African coastal zone** [(1)]
	No data could be obtained

Finfish
(Refer to p 2-31)



CONCENTRATION (µg l^{-1} as total Cr)	**Biological Health**
8	**Target value for the South African coastal zone** [(1)]
	No data could be obtained

COPPER (Refer to p 4-55)

Seaweed
(Refer to p 2-3)

CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	Biological Health
5	**Target value for the South African coastal zone [1]**
> 10	Inhibited growth in the seaweed: *Sargassum* [104]
< 10,2	No observed effects in sporophyte production over 20 days reported for the kelp: *Macrocystis pyfirera* at 13-15 °C [105]
10,2	No observed effects in sporophyte growth over 20 days reported for the kelp: *Macrocystis pyfirera* at 13-15 °C [105]
> 18	Inhibited sporophyte production in the kelp: *Macrocystis pyfirera* at 13-15 °C [105]
50,1	No observed effect in spore germination over 20 days reported for the kelp: *Macrocyctic pyfirera* at 13-15 °C [105]

COPPER continued on next page

COPPER continued…

Molluscs - Bivalves
(Refer to p 2-13)

CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	Biological Health
5	**Target value for the South African coastal zone** [1]
10	LC_5, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
20,8-25,6	Pumping ceased in the mussel: *Mytilus edulis* (adults) [100]
32,8	LC_{50}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
38,3-41,1	LC_{50} value reported for the mussel: *Perna indica* (adults) [107]
50	Depressed oxygen uptake in the mussel: *Perna viridis* (adults) [98]
55,7	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
103	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [16]

NOTES:

Copper reduced byssogenesis in bivalves [33] and also led to lesions in their gills [25].

Enrichment factors* reported for copper composition of shellfish compared to concentrations in the marine environment are [101]:

Oysters - 13 700
Mussels - 3 000

$$\text{* Enrichment factor} = \frac{\text{weight of metal per unit dry weight of whole soft tissue}}{\text{weight of metal per unit weight of seawater}}$$

According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for copper in shellfish is 50 $\mu g\ g^{-1}$.

COPPER continued on next page

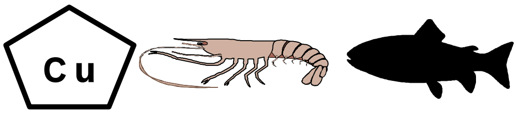
COPPER continued...

Molluscs - Gastropods

(Refer to p 2-19)

CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	Biological Health
5	**Target value for the South African coastal zone [1]**
40	A 100 % mortality occurred in the abalone: *Haliotis discus* hannai (larvae 0,92-1,7 mm) within 48 hours [109]
50	Mortalities occurred in the abalone: *Haliotis rufescens* and *Haliotis cracherodii* (adults) [38] LC_{50} value, over 96 hours, reported for the abalone: *Haliotis cracherodii* (adults) [38]
65	LC_{50} value, over 96 hours reported for the abalone: *Haliotis rufescens* (adults) [38]
80	Mortalities occurred in abalone (larvae) [38]
114	LD_{50} value, over 96 hours, reported for abalone (larvae) [38]

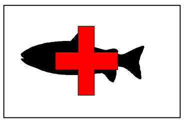
COPPER continued on next page



COPPER continued…

Crustaceans

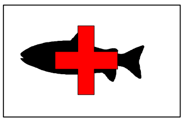
(Refer to p 2-25)



CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	Biological Health
5	**Target value for the South African coastal zone** [1]
50	Lethal concentration reported for Penaeids (post larvae) [24]
220	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 [103]

Finfish

(Refer to p 2-31)



CONCENTRATION ($\mu g\ l^{-1}$ as total Cu)	Biological Health
5	**Target value for the South African coastal zone** [1]
	No data could be obtained

NOTE: **According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for copper in fish is 30 $\mu g\ g^{-1}$.**

LEAD (Refer to p 4-57)

Seaweed
(Refer to p 2-3)

CONCENTRATION ($\mu g\ l^{-1}$ as total Pb)	Biological Health
12	**Target value for the South African coastal zone** [1]
> 5 000	LC_{50} value, over 96 hours, reported for the alga: *Phaeodactylum tricornum* [110]

Molluscs - Bivalves
(Refer to p 2-13)

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) [73]
476	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* (larvae) [110]
780	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [16]
2 450	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [16]
> 500 000	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* (adults) [110]

NOTES:

Lead reduced byssogenesis in bivalves[33] and also led to lesions in their gills[25].

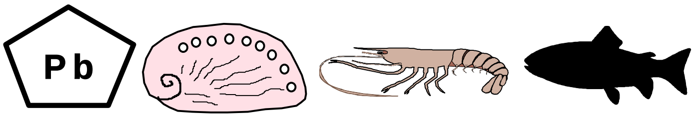
Enrichment factors* reported for lead composition of shellfish compared to concentrations in the marine environment are[101]:

Oysters	**-**	**3 300**
Mussels	**-**	**4 000**

*** Enrichment factor** $= \dfrac{\textbf{weight of metal per unit dry weight of whole soft tissue}}{\textbf{weight of metal per unit weight of seawater}}$

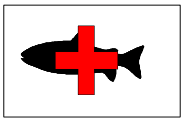
According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for lead in shellfish is 4 $\mu g\ g^{-1}$.

LEAD continued on next page



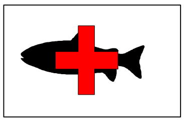
LEAD continued…

Molluscs - Gastropods
(Refer to p 2-19)



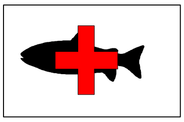
CONCENTRATION ($\mu g\ l^{-1}$ as total Pb)	**Biological Health**
12	**Target value for the South African coastal zone** [(1)]
	No data could be obtained

Crustaceans
(Refer to p 2-25)



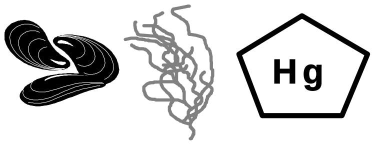
CONCENTRATION ($\mu g\ l^{-1}$ as total Pb)	**Biological Health**
12	**Target value for the South African coastal zone** [(1)]
17-37	'Maximum acceptable toxicant concentration', over a life-time exposure, reported for the mysid: *Mysidopsis bahia* [(110)]

Finfish
(Refer to p 2-31)



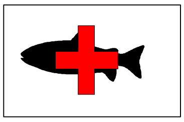
CONCENTRATION ($\mu g\ l^{-1}$ as total Pb)	**Biological Health**
12	**Target value for the South African coastal zone** [(1)]
315	LC_{50} value, over 96 hours, reported for the fish: *Fundulus heteroclitus* [(110)]
180 000	LC_{50} value, over 96 hours, reported for the fish: *Pleuronectes platessa* [(110)]

NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for lead in fish is 1 $\mu g\ g^{-1}$.**



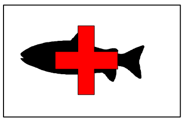
MERCURY (Refer to p 4-59)

Seaweed
(Refer to p 2-3)



CONCENTRATION (µg l^{-1} as total Hg)	Biological Health
0,3	**Target value for the South African coastal zone** [1]
	No data could be obtained

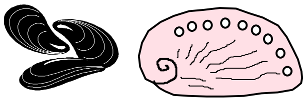
Molluscs - Bivalves
(Refer to p 2-13)



CONCENTRATION (µg 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) [98]
3,3	LC_5, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
4	LC_5, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]
4,8	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [16]
5,6	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [16]
10	LC_{50} value reported for the oyster: *Crassostrea gigas* (larvae) [16]
12	LC_{50}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
14,7	LC_{50}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]

MERCURY continued on next page

Hg



MERCURY continued...

Molluscs - Bivalves *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as total Hg)	**Biological Health**
0,3	**Target value for the South African coastal zone** [1]
20,7	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
25,4	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]

NOTES:

Mercury has an impact on bivalves by reducing the metabolically active phosphorus [39]**.**

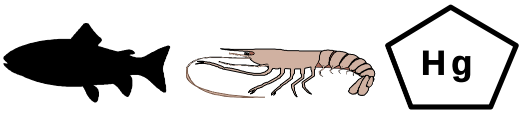
Mercury accummulation in bivalves has also been implicated in Minamata disease in humans [16]**.**

According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for mercury in shellfish is 1 $\mu g\ g^{-1}$ (as methyl mercury).

Molluscs - Gastropods
(Refer to p 2-19)

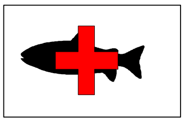
CONCENTRATION ($\mu g\ l^{-1}$ as total Hg)	**Biological Health**
0,3	**Target value for the South African coastal zone** [1]
	No data could be obtained

MERCURY continued on next page



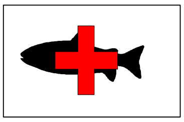
MERCURY continued...

Crustaceans
(Refer to p 2-25)



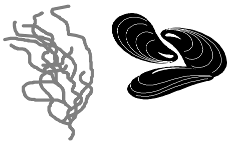
CONCENTRATION ($\mu g\ l^{-1}$ as total Hg)	Biological Health
0,3	**Target value for the South African coastal zone** [(1)]
< 56	No lethal effects reported for the shrimp: *Palaemonetes vulgaris* (larvae) within 48 hours. Delayed effects after 48 hour exposure include: reduced survival of post larvae stage, delayed moulting, extended developmental time and morphological deformities [(111)]
56	Toxic level reported for the shrimp: *Palaemonetes vulgaris* (larvae) within 24 hours [(111)]

Finfish
(Refer to p 2-31)



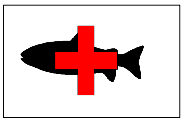
CONCENTRATION ($\mu g\ l^{-1}$ as total Hg)	Biological Health
0,3	**Target value for the South African coastal zone** [(1)]
	No data could be obtained

NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for mercury in fish is 0,5 $\mu g\ g^{-1}$ (as methyl mercury).**



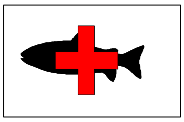
NICKEL (Refer to p 4-61)

Seaweed
(Refer to p 2-3)



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

Molluscs - Bivalves
(Refer to p 2-13)



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) [106]
310	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [16]
1 100	LC_5, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]
1 180	LC_{50} value reported for the oyster: *Crassostrea virginica* (larvae) [16]
1 200	LC_{50}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
2 500	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]

NICKEL continued on next page

NICKEL continued...

Molluscs - Bivalves *continued...*

CONCENTRATION (µg 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) (106)
10 300	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) (106)

NOTE: **Enrichment factors* reported for nickel composition of shellfish compared to concentrations in the marine environment are (101):**

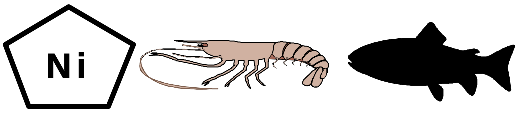
Oysters	**-**	**4 000**
Mussels	**-**	**14 000**

*** Enrichment factor = <u>weight of metal per unit dry weight of whole soft tissue</u>**
weight of metal per unit weight of seawater

Molluscs - Gastropods
(Refer to p 2-19)

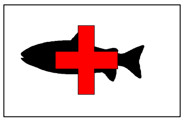
CONCENTRATION (µg l^{-1} as total Ni)	Biological Health
25	**Target value for the South African coastal zone (1)**
	No data could be obtained

NICKEL continued on next page



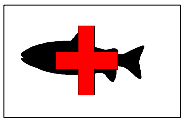
NICKEL continued...

Crustaceans
(Refer to p 2-25)



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

Finfish
(Refer to p 2-31)



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

SILVER (Refer to p 4-63)

Seaweed
(Refer to p 2-3)

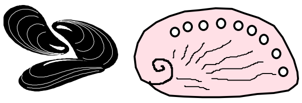
CONCENTRATION ($\mu g\ l^{-1}$ as total Ag)	Biological Health
5	**Target value for the South African coastal zone** [1]
50	LC_{50} value reported for algae [112]

Molluscs - Bivalves
(Refer to p 2-13)

CONCENTRATION ($\mu g\ l^{-1}$ 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) [16]
10	Depressed oxygen consumption in the mussel: *Perna indica* (adults) [98]
14,2	LC_5, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
18,6	LC_5, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]
21	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [16]
25	LC_{50}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]

SILVER continued on next page

Ag



SILVER continued...

Molluscs - Bivalves *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) [106]
35,7	LC_{95}, over 12 days at 25 °C, reported for the oyster: *Crassostrea virginica* (larvae) [106]
46,2	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]

NOTES: **Silver caused to inflammatory lesions in the gills of bivalves [25].**

Enrichment factors* reported for silver composition of shellfish compared to concentrations in the marine environment are [101]:

Oysters	**-**	**18 700**
Mussels	**-**	**330**

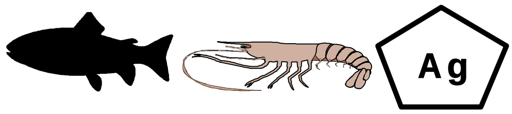
*** Enrichment factor = <u>weight of metal per unit dry weight of whole soft tissue</u>**

weight of metal per unit weight of seawater

Molluscs - Gastropods
(Refer to p 2-19)

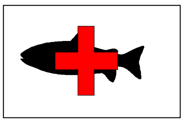
CONCENTRATION ($\mu g\ l^{-1}$ as total Ag)	**Biological Health**
5	**Target value for the South African coastal zone [1]**
	No data could be obtained

SILVER continued on next page



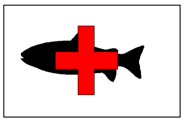
SILVER continued...

Crustaceans
(Refer to p 2-25)



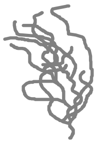
CONCENTRATION ($\mu g\ l^{-1}$ as total Ag)	**Biological Health**
5	**Target value for the South African coastal zone** [1]
	No data could be obtained

Finfish
(Refer to p 2-31)



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 [112]

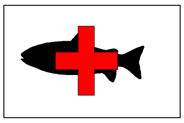
Sn



TIN (INORGANIC) (Refer to p 4-65)

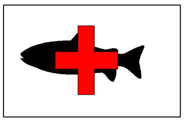
NOTE:	**Inorganic tin compounds can be considered to be of low toxicological risk due to their low solubility, poor absorption, low accumulation in tissues and rapid excretion [113].**

Seaweed
(Refer to p 2-3)



CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
	No data could be obtained

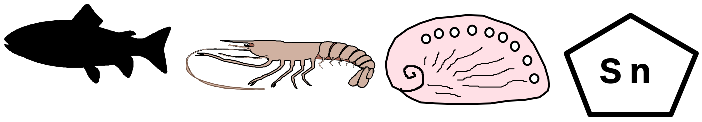
Molluscs - Bivalves
(Refer to p 2-13)



CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
	No data could be obtained

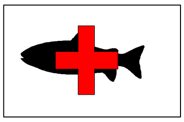
NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for tin in shellfish is 40 $\mu g\ g^{-1}$.**

TIN continued on next page



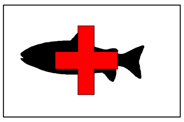
TIN continued...

Molluscs - Gastropods
(Refer to p 2-19)



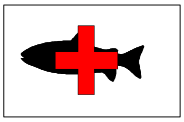
CONCENTRATION (µg l^{-1})	Biological Health
No target value has been selected for the South African coastal zone [(1)]	
	No data could be obtained

Crustaceans
(Refer to p 2-25)



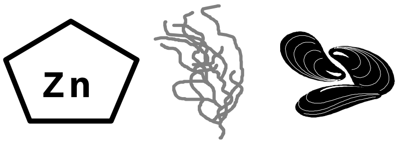
CONCENTRATION (µg l^{-1})	Biological Health
No target value has been set for the South African coastal zone [(1)]	
	No data could be obtained

Finfish
(Refer to p 2-31)



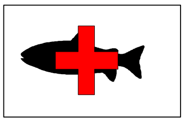
CONCENTRATION (µg l^{-1} as total Sn)	Biological Health
No target value has been set for the South African coastal zone [(1)]	
35 (total Sn)	No effect, over 96 hours, occurred in the fish: *Limanda limanda* [(113)]

NOTE: **According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for tin in fish is 40 µg g^{-1}.**



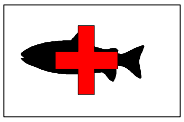
ZINC (Refer to p 4-67)

Seaweed
(Refer to p 2-3)



CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	Biological Health
25	**Target value for the South African coastal zone** [1]
> 80	Inhibited growth in the seaweed: *Sargassum* [104]

Molluscs - Bivalves
(Refer to p 2-13)



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) [98]
50	LC_5, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]
50	No significant effect reported in the oyster: *Crassostrea gigas* (larvae) [114]
116	LC_{50} value reported for the clam: *Mercenaria mercenaria* (larvae) [16]
125-500	A decrease in growth and increase in abnormality and larval mortality, over 10 days (exposure time of five days), reported for the oyster: *Crassostrea gigas* (larvae) [114]
195	LC_{50}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]
200	No growth occurred in the oyster: *Crassostrea gigas* (larvae) [114]

ZINC continued on next page

Molluscs - Bivalves *continued...*

CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	**Biological Health**
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 [115]
310	LC_{50} reported for the oyster: *Crassostrea virginica* (larvae) [16]
341	LC_{95}, over 8-10 days at 25 °C, reported for the clam: *Mercenaria mercenaria* (larvae) [106]
470-860	Pumping stopped in the mussel: *Mytilus edulis* (adults) [100]
500	A 90 % reduction in egg development to larvae reported for the oyster: *Crassostrea gigas* over 48 hours [114]
1 000	Depressed oxygen uptake in the bivalve: *Meretix casta* (adults) [98]
2 500	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* planulatus in a static bioassay [99]
3 600-4 300	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* planulatus in a continuous-flow bioassay [99]
10 500	LC_{50} value, over 120 hours, reported for the mussel: *Mytilus edulis* planulatus in a continuous-flow bioassay [99]

NOTE: **Enrichment factors* reported for zinc composition of shellfish compared to concentrations in the marine environment are [101]:**

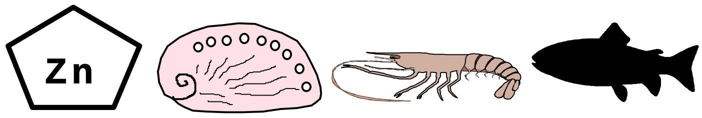
Oysters - 110 300
Mussels - 9 100

*** Enrichment factor = <u>weight of metal per unit dry weight of whole soft tissue</u>**

weight of metal per unit weight of seawater

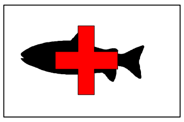
According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for zinc in shellfish is 300 $\mu g\ g^{-1}$.

ZINC continued on next page



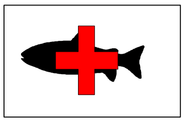
ZINC continued...

Molluscs - Gastropods
(Refer to p 2-19)



CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	Biological Health
25	**Target value for the South African coastal zone** [1]
19	No effect was observed in the abalone: *Haliotis rufescens* (larvae) over 48 hours [116]
39	No effect was observed in the abalone: *Haliotis rufescens* (larvae) over nine days [116]

Crustaceans
(Refer to p 2-25)



CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	Biological Health
25	**Target value for the South African coastal zone** [1]
> 250	A significant reduction in growth and survival reported for the prawn: *Penaeus japonicus* (larvae). Accumulated Zn decreased within 20 days once the larvae were transferred to clean seawater [103]
1 230	LC_{50} value, over 96 hours, reported for the shrimp: *Palaemon* sp. in a static bioassay [99]

ZINC continued on next page

ZINC continued...

Finfish
(Refer to p 2-31)

CONCENTRATION ($\mu g\ l^{-1}$ as total Zn)	**Biological Health**
25	**Target value for the South African coastal zone** [(1)]
	No data could be obtained

NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation related to metals in foodstuffs), the maximum limit for zinc in fish is 40 $\mu g\ g^{-1}$.**

TBT

Chapter 5.4 Organic Constituents

ORGANOTIN (TRIBUTYLTIN) (Refer to p 4-71)

Seaweed
(Refer to p 2-3)

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 [113]
3-16	A 50% reduction of primary productivity, over eight hours to eight days, reported for various species of algae [113]

Molluscs - Bivalves
(Refer to p 2-13)

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 [113]
0,02	Little mortality and good growth reported in the oyster: *Crassostrea gigas* (larvae) [117] No effect on shell morphology observed in the oyster: *Crassostrea gigas* (adults) [117]
0,05	Significant mortalities reported in the oyster: *Crassostrea gigas* (larvae) after 10 days [117]

TBT continued on next page

TBT continued...

Molluscs - Bivalves *continued...*

CONCENTRATION ($\mu g\ l^{-1}$)	Biological Health
0,1	LC_{50} value, over 15 days, reported for the mussel: *Mytilus edulis* (larvae) [113] Tolerable level reported for the development of molluscan larvae [16]
0,15	Reduced growth and shell thickening reported for the oyster: *Crassostrea gigas* after eight weeks [113]
0,24	A reduction in growth occurred after 45 days in the mussel: *Mytilus edulis* (larvae) [113]
0,28	LC_{50} value, over 28 days, reported for the mussel: *Perna viridis* (adults) [118]
0,31	No shell growth occurred after 66 days in the mussel: *Mytilus edulis* [113]
0,4	A reduction in shell growth rate occurred within seven days in the mussel: *Mytilus edulis* [113]
0,73-1,9	Reduced larval growth reported for the oyster: *Crassostrea virginica* within 66 days [113]
0,9	50 % immobilization in 48 hours reported for the oyster: *Crassostrea gigas* (larvae) [113]
0,97	LC_{50} value, over 66 days, reported for the mussel: *Mytilus edulis* (adults)[113]
1	LC_{100} value, over 12 days, reported for the oyster: *Crassostrea gigas* (larvae) [113] Total mortality reported for the oyster: *Crassostrea gigas* (larvae) within six days [117]
1,6	LC_{100} value, over 48 hours, reported for the oyster: *Crassostrea gigas* (larvae) [113]
1,6	No growth occurred in the oyster: *Crassostrea gigas* (adults) [113]

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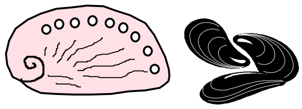
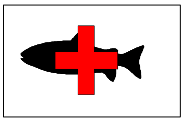


TBT

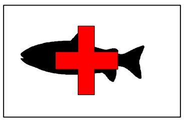
TBT continued...

Molluscs - Bivalves *continued...*



CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
5	LC_{50} value, over 96 hours, reported for the mussel: *Mytilus edulis* (larvae) (113)
10	LC_{50} value, over 28 days, reported for the oyster: *Crassostrea cuculata* (adults) (118)
50	Inhibited segmentation in the oyster: *Crassostrea gigas* (larvae) (117)
100	Inhibited fertilization in the oyster: *Crassostrea gigas* (117)

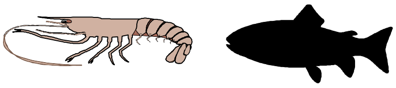
Molluscs - Gastropods
(Refer to p 2-19)



CONCENTRATION ($\mu g\ l^{-1}$)	**Biological Health**
No target value has been selected for the South African coastal zone (1)	
	No data could be obtained

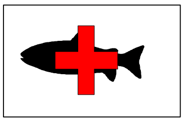
TBT continued on next page

TBT



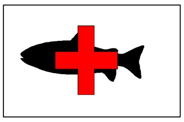
TBT continued...

Crustaceans
(Refer to p 2-25)



CONCENTRATION (μg l^{-1})	Biological Health
No target value has been selected for the South African coastal zone [(1)]	
0,09	'No observed effect concentration' on reproduction reported for the mysid shrimp: *Acanthomysis sculpa* [(117)]
0,5-1,0	LC_{50} value, over 96 hours, reported for the mysid: *Metamysidopsis elongata* (larvae) [(113)]
8	LC_{50} value, over 96 hours, reported for the mysid shrimp: *Mysidopsis bahia* [(113)]

Finfish
(Refer to p 2-31)



CONCENTRATION (μg l^{-1})	Biological Health
No target value has been selected for the South African coastal zone [(1)]	
1,5-36	LC_{50} range, over 96 hours, reported for different marine fish species [(117)]
24	LC_{50} value, over 96 hours, reported for the fish: *Fundulus heteroclitus* [(113)]

TOTAL PETROLEUM HYDROCARBONS (TPH) (Refer to p 4-74)

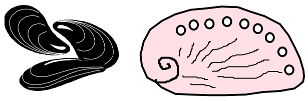
NOTES:	**The effects described below are based on the water soluble fraction (WSF) of oils (the particulate fraction is dealt with under '*Floating matter*' on p 5-18).** **Because of their variability, the effects decribed below should not be regarded as representative of all these compounds, but merely gives some examples of concentration ranges and effects. Generally, the effects of the WSF varies between organisms and are 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.**

Seaweed
(Refer to p 2-3)

CONCENTRATION (mg l^{-1} WSF)	Biological Health
No target value has been selected for the South African coastal zone [1]	
< 50	No. 2 diesel fuel oil. No substantial effects reported for the alga: *Scenedesmus armatus* over 20 hours [119]

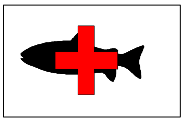
TPH continued on next page

TPH



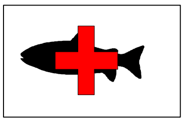
TPH continued...

Molluscs - Bivalves
(Refer to p 2-13)



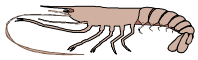
CONCENTRATION (mg l^{-1} WSF)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
3	Qatar crude oil. Resulted in immediate stress in the mussel: *Mytilus galloprovincialis* in that spawning was triggered in a large portion [125] Qatar crude oil. After six hours of exposure the concentration in the tissue of the mussel: *Mytilus galloprovincialis* was found to be 132 µg g^{-1} (wet weight), compared to a control value of 6,7 µg g^{-1} (wet weight) [125]
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 µg g^{-1} (wet weight), compared to a control value of 6,7 µg g^{-1} (wet weight) [125] When hydrocarbons were accumulated after exposure for short periods, the rate of depuration was significantly higher compared to chronic exposure [125]

Molluscs - Gastropods
(Refer to p 2-19)



CONCENTRATION (mg l^{-1} WSF)	**Biological Health**
No target value has been selected for the South African coastal zone [1]	
	No data could be obtained

TPH continued on next page



TPH

TPH continued...

Crustaceans
(Refer to p 2-25)

CONCENTRATION (mg l^{-1} WSF)	Biological Health
No target value has 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 [120]
1,6	No. 2 fuel oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 32 °C [120]
1,9	No. 2 fuel oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 24 °C [120]
2,2	Bunker C oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 32 °C [120]
2,6	Bunker C oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 21 °C [120]
3,1	Bunker C oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 24 °C [120]
3,5	No. 2 fuel oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 21 °C [120]
10,7	South Louisiana crude oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 32 °C [120]
15,9	South Louisiana crude oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 24 °C [120]
> 19,8	South Louisiana crude oil. LC_{50} value, over 96 hours, reported for the shrimp: *Palaemonetes pugio* at 21 °C [120]

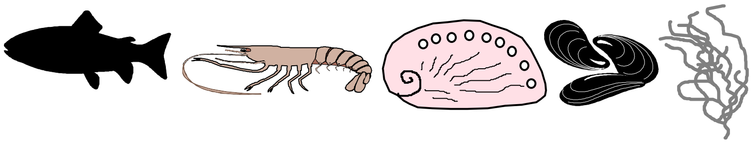
TPH continued on next page

TPH

TPH continued...

Finfish
(Refer to p 2-31)

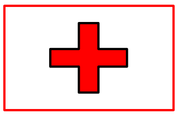
CONCENTRATION (mg l^{-1} WSF)	**Biological Health**
No target value has been selected for the South African coastal zone [(1)]	
	No data could be obtained



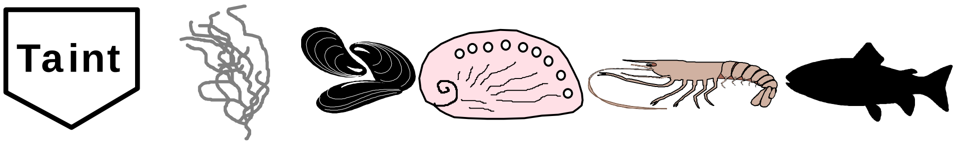
Algal

ALGAL TOXINS (Refer to p 4-78)

All subgroups
(Refer to Section 2)

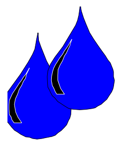
ALGAL TOXINS	 Human Health
No target values have been selected for the South African coastal zone [1]	
	No data could be obtained

NOTE:	**Although paralatytic shellfish poison (PSP) is usually associated with contaminated filter feeding organisms such as mussels, oysters and clams, the effect of human consumption of other organisms such as abalone is not known and needs to be investigated [121].**

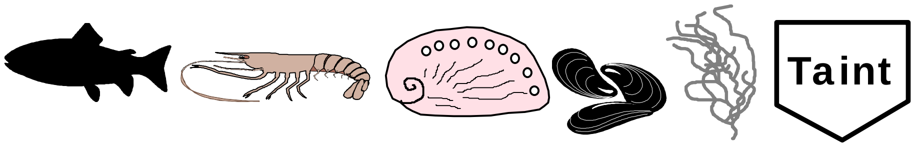


TAINTING SUBSTANCES (Refer to p 4-80)

All subgroups
(Refer to Section 2)

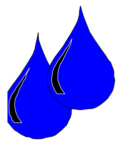
CONCENTRATION THAT CAN CAUSE TAINTING [108] (µg l^{-1})	 **Aesthetics**
No target values have been selected for the South African coastal zone [1]	
500	Acetophenone
18 000	Acrylonitrile
200	m-cresol
400	o-cresol
120	p-cresol
200	cresylic acid (meta, para)
60	n-butylmercaptan
300	0-sec. butylphenol
30	p-tery. butylphenol
1	0-chlorophenol
10	p-chlorophenol
84	2,3,-dichlorophenol
1	2,4-dichlorophenol
23	2,5-dichlorophenol
35	2,6-dichlorophenol
75	2-methyl, 4-chlorophenol
3	2-methyl, 6-chlorophenol
1 000	o-phenylphenol
3	2,4,6-trichlorophenol
1 000	phenol
50	diphenyloxide
90	B,B-dichlorodiethyl ether
250	p-dichlorobenzene
250	ethylbenzene
240	ethanethiol
600	ethlacrylate
95 000	formaldehyde

TAINTING SUBSTANCES continued on next page



TAINTING SUBSTANCES continued...

All subgroups *continued...*

CONCENTRATION THAT CAN CAUSE TAINTING [108] **($\mu g\ l^{-1}$)**	 **Aesthetics**
5	petrol
100	kerosene
1 000	kerosene plus kaolin
250	isopropylbenzene
100	naphtha
1 000	naphthalene
500	naphthol
300	2-naphthol
7 000	dimethylamine
250	a-methylstyrene
15 000	oil, emulsifiable
5 000	pyridine
800	pyroatechol
500	pyrogallol
500	quinoiine
500	p-quinone
250	styrene
250	toluene
500	outboard motor fuel, as exhaust
82	guaiacol

NOTE: **When chlorine combines with phenolic compounds it forms chlorophenols, some of which can produce tainting in flesh of marine organisms at concentrations as low as 1 $\mu g\ l^{-1}$** [12]**.**

Chapter 5.5 Microbiological Indicator Organisms and Pathogens

FAECAL COLIFORMS (including *Escherichia coli*) (Refer to p 4-81)

Seaweed
(Refer to p 2-3)

Faecal coliforms (counts per 100 ml)	Human Health
No target range has been selected for the South African coastal zone [(1)]	
	No data could be obtained

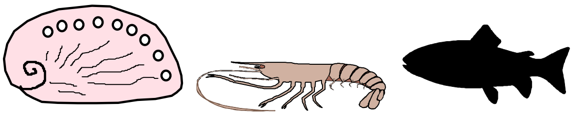
Molluscs - Bivalves (Filter feeders)
(Refer to p 2-13)

Faecal coliforms (counts per 100 ml)	Human Health
Target range for the South African coastal zone [(1)]: **Maximum acceptable count per 100 ml:** **20 in 80 % of the samples** **60 in 95 % of the samples**	
	No data could be obtained

NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation - Marine food), the number of organisms of *E. coli* Type 1 shall not exceed 500 per 100 g in uncooked oyster, mussel and clam.**

FAECAL COLIFORMS continued on next page

F coli



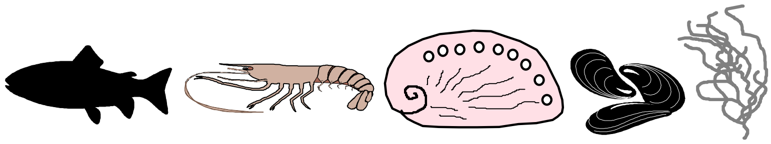
FAECAL COLIFORMS continued...

Molluscs - Gastropods, Crustaceans and Finfish

(Refer to p 2-19, p 2-25 and p 2-31)

Faecal coliform (counts per 100 ml)	**Human Health**
No target range has been selected for the South African coastal zone [1]	
	No data could be obtained

NOTE:	**According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation - Marine Food), the number of organisms of *E. coli* Type 1 shall not exceed 10 per 100 g in uncooked prawn, shrimp, lobster, crayfish, crab meat, eel and fish.**



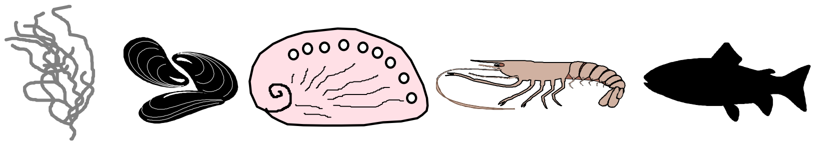
Entero

ENTEROCOCCI (Refer to p 4-83)

All subgroups
(Refer to Section 2)

Enterococci (counts per 100 ml)	**Human Health**
No target range has been selected for the South African coastal zone [(1)]	
	No data could be obtained

Pathogen



HUMAN PATHOGENS (Refer to p 4-85)

All subgroups
(Refer to Section 2)

PATHOGENS (counts)	**Human Health**
No target values have been selected for the South African coastal zone [1]	
	No data could be obtained

NOTES:

According to the Foodstuffs, Cosmetics and Disinfectant Act 54 of 1972 (Regulation - Marine food), organisms of the genera *Salmonella*, *Shigella* and of the species *Vibrio cholerae* shall not be present in uncooked oyster, mussel, clam, prawn, shrimp, lobster, crayfish, crab meat, eel and fish. The number of organisms of coagulase-positive *Staphylococcus aureus* shall not exceed 10 per gram in these organisms.

A total colony count of organisms by the pour-plate method on plate count agar at 35 °C for 48 hours shall not exceed 1 000 000 per gram uncooked prawn, shrimp, lobster, crayfish, crab meat, eel and fish.

According to a Dutch publication, the minimum infection dose (MID_{50}) in man for a number of faecal pathogens are as follows[123]:

Vibrio cholerae	**10^9**
Escherichia coli	**$10^4 - 10^5$**
***Salmonella* sp.**	**$10^5 - 10^9$**
Salmonella typhi	**$10^2 - 10^3$**

Examples of disease in humans as a result of consumption of contaminated shellfish include the outbreak in Shanghai in 1988 with some 25 000 cases of viral gastroenteritis and 300 000 cases of hepatitis A due to the consumption of clams harvested from a sewage-contaminated bay[124].

REFERENCES

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

2. YAMAMOTO, M., WATANABE, Y. and KINOSHITA, H. 1991. Affects of water temperature on the growth of red alga *Porphyra yezoensis* form narawaensis (nori) cultivated in an outdoor raceway tank. *Nippon Suisan Gakkaishi Bull. Jap. Soc. Sci. Fish.* **57**(12): 2211-2217.

3. 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.

4. 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.

5. BERNARD, R.F. 1983. Physiology and the mariculture of some north-eastern Pacific bivalve molluscs. *Canadian Special Publication of Fisheries and Aquatic Sciences* **63**. 24 pp.

6. 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.

7. 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.

8. QUALE, D B. 1969. Pacific oyster culture in BC. *Fisheries Research Board of Canada Bulletin* **169**. 192 pp.

9. 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.

10. LOOSANOFF, V.L. and DAVIS, H.C. 1963. Rearing of bivalve molluscs. In: *Advances in Marine Biology*. F.S. Russell (ed.) **1**:1-136.

11. LOOSANOFF, V.L. and NOMEJKO, C.A. 1951. Existence of physiologically-different races of oysters, *Crassostrea virginica. Biol. Bull.* **101**: 151-156.

12. 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.

REFERENCES continued on next page

REFERENCES continued...

13. BAYNE, B.L., WIDDOWS, J. and WORRAL, C. 1977. Some temperature relationships in the physiology of two ecologically distinct bivalve populations. In: *Physiological responses of marine biota to pollutants*. Vernberg, F.J., Calabrese, A., Thurberg, F.P.and Vernberg, W.B. (Eds.). Academic Press, New York. pp 379-400.

14. LUND, E.J. 1957. Self-sitting, survival of oysters as a closed system, and reducing tendencies of the environment of the oyster. *Publ. Inst. Marine Sci.* **4**: 313-319.

15. 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.

16. BARNABÉ, G. 1989. *Aquaculture.* Volume 1. New York, Ellis Horwood. 528 pp.

17. 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.

18. 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.

19. 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 p.

20. 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.

21. 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.

22. 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.

23. LEE, D. O'C. and WICKENS, J.F. 1992. *Crustacean Farming*. Blackwell Scientific Publications, Oxford. 392pp.

REFERENCES continued on next page

REFERENCES continued...

24. SHRIMP FARMING SHORT COURSE. 1990. Course materials: Sept. 12-21, 1990. Texas A&M Sea Grant College Program.

25. LEGA, J.V., CHERNITIKY A.G. and BELKOVSKY, N.M. 1992. Effect of low sea water temperatures on water balance in the Atlantic salmon (*Salmo salar* L). *Fish Physiol. Biochem.*, **10**(2): 145-148.

26. BRETT, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. *J. Fish Res. Bd. Canada* **9**: 265-323.

27. RUDI, H and E DRAGSUND. (1993). Localisation strategies. *Fish Farming Technology*, Reinertsen, Dahle, Jorgensen and Tuinnereim (eds). Balkema, Rotterdam, pp 169-175.

28. VAN DER LINGEN, C.D. 1994. Aspects of the early life history of Galjoen *Dichistius capensis*. *S. Afr. J. mar. Sci.* **14**: 37-45.

29. 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.

30. 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.

31. OYIEKE, H.A. and KOKWARO, J.O. 1993. Seasonality of some species of Gracilaria (Gracilariales, Rhodaphyta) from Kenya. *J. Appl. Phycol.* **5**(1): 123-124.

32. 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.

33. MATHEW, A. and FERNANDEZ, T.V. 1992. Environmental impact on the byssogenic responses of the mollusc *Perna indica*. *J. Ecobiol.*, **4**(3): 161-168.

34. KING, M.G. 1977. Cultivation of the Pacific oyster, *Crassostrea gigas*, in a non-tidal hypersaline pond. *Aquaculture* **11**: 123-136.

35. 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.

REFERENCES continued on next page

REFERENCES continued...

36. BAYNE, B.L. 1965. Growth and the delay of metamorphosis of larvae of *Mytilus edulis* L. *Ophelia.* **2**:1-47.

37. 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.

38. HAHN, K.O. 1989. *Handbook of culture of abalone and other marine gastropods*. CRC Press Inc, Boca Raton, Florida. 348 pp.

39. 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.

40. 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.

41. 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.

42. 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.

43. 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.

44. CLARK, J.V. 1992. Physiological responses of adult *Penaeus semisulcatus* (de Haan) to changes in salinity. *Comp. Biochem. Physiol. A.* **101**(1): 117-119.

45. 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.

46. 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.

47. 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.

REFERENCES continued on next page

REFERENCES continued...

48. LOOSANOFF, V.L. and TOMMERS, F.D. 1947. Effect of low pH upon rate of water pumping of oysters, *Crassostrea virginica. Anat. Rec.* **99**: 112-113.

49. BAMBER, R.N. 1990. The effects of acidic seawater on three species of lamellibranch mollusc. *J. Exp. Mar. Biol. Ecol.* **143**: 181-191.

50. 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.

51. EPIFANIO, C.E., SRNA, R. and PRUDER, G. 1975. Mariculture of shellfish in controlled environments: a prognosis. *Aquaculture* **5**: 227-241.

52. 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.

53. 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.

54. 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.

55. 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.

56. BAYNE, B.L. 1964. The responses of the larvae of *Mytilus edulis* (L.) to light and to gravity. *Oikos* **15**: 162-174.

57. 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.

58. 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.

59. 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.

REFERENCES continued on next page

i

REFERENCES continued...

60. 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.

61. 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.

62. WESTLEY, R.E. 1965. Some relationships between Pacific oysters, *Crassostrea gigas*, condition and the environment. *Proc. natn. Shellfish. Ass.* **55**: 19-33.

63. 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.

64. 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.

65. 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

66. 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.

67. 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.

68. COASTAL AQUACULTURE . 1988. Rethinking shrimp pond management. *Coastal Aquaculture* **5**(2): 1-19.

69. 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.

70. 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.

71. 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.

REFERENCES continued on next page

REFERENCES continued...

72. 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.

73. MORIMURA, S. 1993. Influence of the environment on fish farming. *Fish Farming Technology*. Reinertsen, Dahle, Jorgensen and Tuinnereim (eds). Balkema, Rotterdam. pp 155-161.

74. CHEN, J.C. and CHIN, T.S. 1988. Acute toxicity of nitrite to the tiger prawn, *Penaeus monodon*, Larvae. *Aquaculture* **69**: 253-262.

75. CHEN, J.C. and NAN, F.H. 1991. Lethal effect of nitrite Penaeus chinensis (larvae). *J. World Aquacult. Soc.* **22**(1): 51-66.

76. CHEN, J. C., LIU, P.C and LEI, S.C. 1990. Toxicities of ammonia and nitrite to *Penaeus monodon* adolescents. *Aquaculture* **89**: 127-137.

77. 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.

78. 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.

79. HASTIE, L.C., WATSON, T.C., ISAUMU, T. and HESLINGA, G.A. 1992. Effect of nutrient enrichemnt on *Tridacna derasa seed*: Dissolved inorganic nitrogen increases growth rate. *Aquaculture* **106**(1): 41-49.

80. MUIR, P.R., SUTTON, D.C. and OWENS, L. 1991. Nitrate toxicity to *Penaeus monodon* protozoa. *Mar. Biol.* **108**(1): 67-71.

81. 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.

82. CHIN, T.S. and CHEN, J.C. 1987. Acute toxicity of ammonia to larvae of the tiger prawn, *Penaeus monodon*. *Aquaculture* **66**: 247-253.

83. CHEN, J C and C C TU. (1991). Influence of ammonia on growth of *Penaeus monodon* Fabricius post-larvae. *Aquacult. Fish. Manage.*,**22**:457-462.

REFERENCES continued on next page

REFERENCES continued...

84. CHEN, J C, P C LIU and C C TU. (1990). Effect of ammonia on growth of *Penaeus monodon* postlarvae. *J. Fish. Soc. Taiwan*,**17**: 207-212.

85. CHEN, J.C. and LEI, S.C. 1990. Toxicity of ammonia and nitrite to *Penaeus monodon* juveniles. *J. World Aquacult. Soc.* **21**: 300-306.

86. 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.

87. 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.

88. CHEN, J.C. and KOU, Y.Z. 1992. Effects of ammonia on growth and moulting of *Penaeus japonicus* juveniles. *Aquaculture* **104**: 249-260.

89. 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.

90. 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.

91. LORD, D.A and GELDENHUYS, N.D. 1982. Richards bay effluent pipeline. *South African National Scientific Programmes Report* No **129**. 30 pp. Pretoria.

92. ROBERTS, M.H anf 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.

93. 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.

94. 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.

95. 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.

REFERENCES continued on next page

REFERENCES continued...

96. 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.

97. 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.

98. 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.

99. 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.

100. 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.

101. OPEN UNIVERSITY. 1989. *Ocean chemistry and deep-sea sediments*, S330. Volume 5. Published in association with Pergamon Press.

102. 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.

103. 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.

104. 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.

105. 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.

106. 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.

107. 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.

108. LUSHER, J.A. (Ed.). 1984. Water quality criteria for the South African coastal zone. *South African National Scientific Programmes Report* No **94**. 25 pp.

REFERENCES continued on next page

REFERENCES continued...

109. 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.

110. 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.

111. 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.

112. 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.

113. 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.

114. 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.

115. 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.

116. 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.

117. WORLD HEALTH ORGANIZATION. 1990. Tributyltin compounds. *Environmental health criteria series* **116**. Geneva, Switzerland.

118. KARANDE, A. A., GANTI, S.S. and UDHYAKUMAR, M. 1993. Toxicity of tributyltin to some bivalve species. *Indian J. mar. Sci.* **22**: 153-154.

119. 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.

120. 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.

REFERENCES continued on next page

REFERENCES continued...

121. 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.

122. HAWKINS, A.D. 1981. *Aquarium systems*. Academic Press.

123. HUIZMAN, J. 1982. Water and Siekte. *H_2O* **15**(19): 512-517

124. HALLIDAY, M.L., KANG, L.Y., ZHOU, T.K., HU, M.D., PAN, Q.C., FU, T.Y., HUANG, Y.S and HU, S.L. 1991. An epidemic of hepatitis A attributable to the ingestion of raw clam in Shanghai, China. *J infect Dis* **164**: 852-859.

125. 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.

126. HECHT, T. 1994. Behavioural thermoregulation of the abalone, *Haliotis midae*, and the implications for intensive culture. *Aquaculture* **126**(1/2): 171-181.

127. 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

AHSANHULLAH, 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 Fresh Water Research* **29**: 1-8.

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, 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 refined 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 scorpionfish (*Scorpaena guttata*) to cadmium - biochemical effects of chronic exposure. *Aquatic Toxicology* **16**(4): 311-320.

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.

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.

BRANCH, G.M., S. EEKHOUT and A.L. BOSMAN. (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.

BROWN, A.C. and A. McLACHLAN. (1990). *Ecology of Sandy Shores*. Elsevier. 328pp.

BROWN, P.C. and FIELD, J.C. 1986. Factors limiting phytoplankton production in a nearshore upwelling area. *J. Plankt. Res.* **8**(1): 55-68.

ADDITIONAL INFORMATION continued on next page

i

ADDITIONAL INFORMATION continued...

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 tributyltin (TBT) in the dog-whelk *Nucella lapillus*. *J. Mar. Biol. Assoc. UK.* **73**(4): 889-912.

CADMAN, L. 1990. Some effects of temperature and salinity on the growth of juvenile blue crabs. *Bull. Mar. Sci.* **46**(1): 244.

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.

CLOTTEAU, G. and DUBE, F. 1993. Optimization of fertilization parameters for rearing surf clams (*Spisula solidissima). Aquaculture* **114**(3-4): 339

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.

DINNEL, P.A., STOBER, Q.J. and DIJULIO, D.H. 1981. Sea urchin spermbioassay for sewage and chlorinated seawater and its relation to fish bioassay. *Marine Environmental Research* **5**: 29-39.

DRAWE, T. 1994. The relationship between respiration rate and habitat in *Cyclograpsus punctatus* and *Sesarma catenata*. Honours Project. Zoology Department, University of Port Elizabeth.

ADDITIONAL INFORMATION continued on next page

i

ADDITIONAL INFORMATION continued...

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. *Marine Ecology Progress Series* **72**(1,2): 111-115.

FARMANFARMAIAN, A. andGIESE, A.G. 1963. Thermal tolerance and acclimation in the western purple sea urchin, *Strongylocentrotus purpuratus*. *Physiol. Zool.* **36**: 237-243.

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.

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*. Marine Biology 107(1): 93-102.

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.

HARVEY, R.A. and PRZYBYLAK, P.K. 1985. Optimum conditions in live rock lobster tanks. *Fishing Industry Research Institute Annual Report* **39**: 19-21.

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.

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.

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.

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.

ADDITIONAL INFORMATION continued on next page

ADDITIONAL INFORMATION continued...

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.

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.

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.

MUIR, P.R., SUTTON, D.C. and OWENS, L. 1991. Nitrate toxicity to *Penaeus monodon* protozoea. *Mar. Biol.* **108**: 67-71.

MURTHY, M.S., SHARMA, C.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.

NEFF, J.M. and ANDERSON, J.W. 1981. *Response of marine animals to petroleum and specific petroleum hydrocarbons*. Applied Science Publishers Ltd, Barking, England. 177pp.

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.

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.

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, 12-18 January, 1980. Part 4: Culture of other organisms, environmental studies, training, extension and legal aspects. 6: 1164-1170.

RINGWOOD, A.H. 1989. Accumulation of cadmium by larvae and adults of a Hawaiian bivalve, *Isogomon californicum*, during chronic exposure. Mar. Biol. 102: 499-504.

ADDITIONAL INFORMATION continued on next page

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ADDITIONAL INFORMATION continued...

RINGWOOD, A.H. 1991. Short-term accumulation of cadmium by embryos, larvae and adults of a Hawaiian bivalve, *Isognomon californicum*. *Journal of Experimental Marine Biology and Ecology* **149**(1): 55-66.

ROESIJADI, G., JACOBSEN, D.M., BRIDGE, D.M and CRECELIUS, E.A. 1979. Disruption of magnesium regulation in the crab *Cancer productus* exposed to chlorinated seawater. *Marine Environmental Research* **2**: 71-84.

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.

STAUBER, L.A. 1950. The problem of physiological species with special reference to oysters and oyster drills. *Ecology* **31**: 107-118.

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 II. Effects of chlorine on burrowing and survival. *J. Shellfish Res.* **13**(2):451-454.

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.

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* **5**: 15-20.

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.

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.

ADDITIONAL INFORMATION continued on next page

ADDITIONAL INFORMATION continued...

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.

WESSELS, J.P.H. 1993. Code of Practice: Whole Frozen Cooked Lobster. *Fishing Industry Research Institute Memorandum* **386**. South Africa.

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.

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.

YOUNGLAI, W.W., CHARMANTIERDAURES, M. and CHARMANTIER, G. 1991. Effect of ammonia on survival and osmoregulation in different life stages of the lobster *Homarus americanus*. Marine Biology 110(2): 293-300.

ZOUTENDYK, P. 1989. Oxygen consumption by the Cape rock lobster, *Jasus lalandii*. *S.Afr. J. mar. Sci.* **8**: 219-230.

APPENDICES

APPENDIX A: SUMMARY OF TARGET VALUES FOR THE MARICULTURE PRACTICES

Physico-chemical properties

	SEAWEED	BIVALVES	GASTROPODS	CRUSTACEANS	FINFISH
Temperature	The maximum acceptable variation in ambient temperature is + or - 1 ^{o}C				
Salinity	33-36				
pH	7,3-8,2				
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 sub-surface 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 the ambient concentrations				
Dissolved oxygen	-	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)			

SUMMARY OF TARGET VALUES continued on next page

Target values

SUMMARY OF TARGET VALUES continued...

Nutrients

	SEAWEED	BIVALVES	GASTROPODS	CRUSTACEANS	FINFISH
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 above)	-	-	-	-
Nitrite		-	-	-	-
Nitrate		-	-	-	-
Reactive phosphate		-	-	-	-
Reactive silicate		-	-	-	-

Inorganic constituents

	SEAWEED	BIVALVES	GASTROPODS	CRUSTACEANS	FINFISH
Ammonia	-	20 µg N l^{-1} (as NH_3) 600 µg N l^{-1} (as NH_3 plus NH_4^+)			
Cyanide	12 µg l^{-1}				
Fluoride	5 000 µg l^{-1}				
Chlorine	-				
Hydrogen sulphide	-				
Arsenic	12 µg l^{-1}				
Cadmium	4 µg l^{-1}				
Chromium	8 µg l^{-1}				
Copper	5 µg l^{-1}				
Lead	12 µg l^{-1}				
Mercury	0,3 µg l^{-1}				
Nickel	25 µg l^{-1}				
Silver	5 µg l^{-1}				
Tin	-				
Zinc	25 µg l^{-1}				

SUMMARY OF TARGET VALUES continued on next page

Target values

SUMMARY OF TARGET VALUES continued...

Organic constituents

	SEAWEED	BIVALVES	GASTROPODS	CRUSTACEANS	FINFISH
Organotins (Tributyltin)	-	-	-	-	-
Total petroleum hydrocarbons	-	-	-	-	-
Polycyclic aromatic hydrocarbons	-	-	-	-	-

Microbiological indicator organisms

	SEAWEED	BIVALVES	GASTROPODS	CRUSTACEANS	FINFISH
Faecal coliforms (including *E. coli*)	-	Maximum acceptable count per 100 ml: 20 in 80 % of the samples 60 in 95 % of the samples	-	-	-

APPENDIX B: INTERNATIONAL TARGET VALUES FOR MARICULTURE PRACTICES

Note	**Generally, international target values listed for the *Natural Environment* apply, i.e. protection of marine organisms, apply (refer to Volume 1, APPENDIX B). Additional target values, including those specifically related to the protection of the human consumer, are listed below.**

Physico-chemical properties

	CANADA[1]	US-EPA[2]	EEC (afterUK)[3]	AUSTRALIA[4]
Temperature	-	-	*Shellfish:* Should not exceed natural temperatures by more than 2 °C (75%ile)	-
Salinity	-	-	*Shellfish:* 12-38 (guide) < 40 (mandatory)	-
pH	-	-	*Shellfish*: 7-9 (75%ile) *Fisheries:* 6-8,5 (annual arithmetic concentration)	-
Floating matter, including oil and grease	-	-		-
Colour/turbidity/ clarity	-	-		-
Suspended solids	-	-		-
Dissolved oxygen	-	-		-

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	-	-	-	-
Phosphate	-	-	-	-
Total phosphorous	-	-	-	-
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	-	-	-	-
Cyanide	-	200 µg l^{-1}	-	-
Fluoride	-	-	-	-
Chlorine	-		-	-
Hydrogen sulphide	-	-	-	-
Gypsum	-	-	-	-
Arsenic	-	1,75-175 ng l^{-1}	-	0,02 µg l^{-1}
Cadmium	-	-	-	-
Chromium	-	3 433 mg l^{-1}(Cr[III]) 50 µg l^{-1} (Cr[VI])	-	-
Copper	-	-	-	-
Iron	-	50 µg l^{-1}	-	-
Lead	-	-	-	-
Manganese	-	100 µg l^{-1}	-	100 µg l^{-1}
Mercury	-	146 ng l^{-1}	-	-
Nickel	-	4,77 mg l^{-1}	-	100 µg l^{-1}
Selenium	-	-	-	-
Silver	-	50 µg l^{-1}	-	-
Tin (inorganic)	-	-	-	-
Vanadium	-	-	-	-
Zinc	-	5 mg l^{-1}(tainting)	-	5 µg l^{-1} (tainting)

INTERNATIONAL TARGET VALUES continued on next page

International

INTERNATIONAL TARGET VALUES continued...

Organic constituents

	CANADA[1]	US-EPA[2]	EEC (after UK)[3]	AUSTRALIA[4]
Organotins (Tributyltin)	-	-	-	-
Total petroleum hydrocarbons	-	-	-	-
Polycyclic aromatic hydrocarbons	-	3,11-311 ng l^{-1}	-	0,03 µg l^{-1}
Algal toxins	-	-	-	*Gonyaulax* shellfish toxins should be less than 0,8 µg g^{-1} shellfish Ciguatera-like toxins should be less than 20 mouse units per 100 g shellfish
Tainting substances	-	Material should not be present in concentrations that individually or in combination produce undesirable flavour which is detectable by organoleptic tests performed on the edible portions of aquatic organisms	-	Refer to reference No.4
Other organics	-	Refer to reference No. 2	-	Refer to reference No.4

Microbiological indicator organisms and Pathogens

	CANADA[1]	US-EPA[2]	UK[3]	AUSTRALIA[4]
Total coliform	-	-		-
Faecal coliform	-	14 MPN per 100 ml (median) with no more than 10 % of samples exceeding 43 MPN per 100 ml		14 MPN per 100 ml (median) with no more than 10 % of samples exceeding 43 MPN per 100 ml
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	A bioassay where the test organisms are kept in a flow-through system where the
bioassay	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 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.

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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.

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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.

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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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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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