Coastal & Marine Water Quality Management in [Country]

Proposed Interim Water and Sediment Quality Objectives and Targets

(based on series of documents on M&CWQM in the WIO region by UNEP Nairobi Convention Secretariat & CSIR)

Content

1. Introduction

Following agreement by the countries in the Western Indian Ocean (WIO) the Nairobi Convention Secretariat, in consultation with Regional Task Force for Coastal and Marine Water Quality Management (C&MWQM), commissioned the CSIR (South Africa) to undertake the *Development a Strategic Framework for C&MWQM for the WIO region*, including *Guidelines for Setting Water and Sediment Quality Targets for the Coastal and Marine Environment* (Reference WIO Documents when officially issued). The aim of Guidelines is to assist responsible national authorities and water quality managers to prepare Quality Objectives and Targets for their particular coastal and marine environments towards effective implementation of national-level C&MWQM.

The *ecosystem-based Implementation Framework for C&MWQM*, developed as part of the above-mentioned project, are conceptualised in Figure 1 also showing the context of Quality Objectives and Targets.

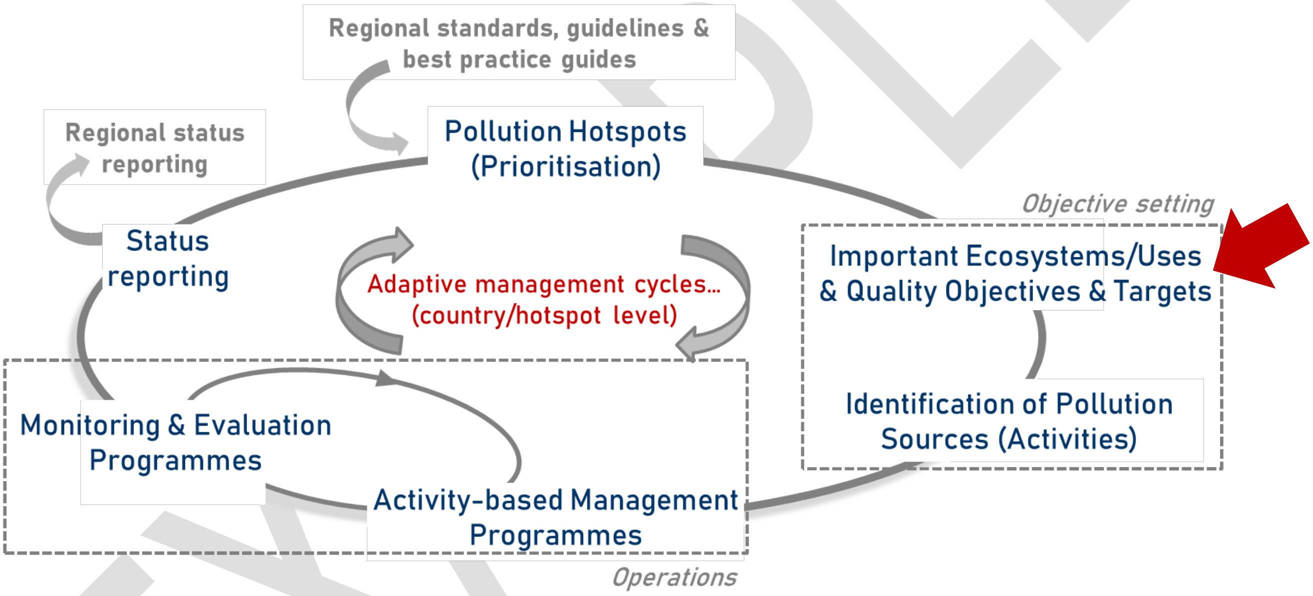

Figure 1: Implementation Framework for C&MWQM, also showing where allcoation of sediment and water quality objectives and targets fits (Reference WIO Documents when officially issued)

To wisely apply human and financial resources, it may be necessary to tackle C&MWQM in a phased approach. In this regard, the identification of marine pollution **hotspots** or emerging hotspots, provide a transparent mechanism to prioritise study areas where coastal and marine environmental quality is most at risk or impacted by human activities. The identification and mapping of **important ecosystems, and key socio-economic beneficial uses** in a specific area, as well as their environmental quality objectives and associated targets are key components in a C&MWQM programme. Agreement on important aquatic ecosystems and other the beneficial uses within a specific coastal management area (or hotspot), as well as associated water and sediment QTs, should be negotiated a consultative process using the appropriate institutional structures, e.g. stakeholder fora. As part of the objective setting phase, another key component is the identification and characterisation (including location and quantification) of potential **marine pollution sources** (both land-based and sea-based) that may alter water and sediment quality within a specific study area, as well as setting limits. **Activity-based management**

programmes, involve the operational management of specific activities potentially contributing to marine pollution. The design and implementation of environmental quality **monitoring and evaluation programmes** form an integral and critical element in the Implementation Framework's operational phase. **Status reporting** provides for a high-level reflection on progress and transparency on issues of concern which need to be addressed through a cycle of adaptive management.

The primary purpose of C&MWQM is to mitigating coastal and marine pollution, so as to keep the natural resource suitable for designated uses. To achieve this goal, it is important to identify **important aquatic ecosystems and other beneficial uses** of coastal and marine areas that rely on good water and sediment quality. For the WIO region, the following were considered appropriate (Reference WIO Documents when officially issued):

- Protection of aquatic ecosystems
- Recreational use (including tourism)
- Marine aquaculture (including collection of seafood for human consumption)
- Industrial uses (e.g. intakes for desalination, cooling water intake and seafood processing).

Based on a thorough international review, the WIO region proposed a set of quality objective and target associated with each of the above categories for a range of biogeochemical and microbiological properties as illustrated in Table 1.

Table 1: Constituent types for which QTs are provided in these guidelines pertaining to the protection of aquatic ecosystems and the other beneficial uses

PARAMETER CATEGORY		PROTECTION OF AQUATIC ECOSYSTEMS	RECREATION	MARINE AQUACULTURE	INDUSTRIAL USE
Water	Objectionable matter	●	●	Similar to Protection of Aquatic Ecosystems	Based on site-specific requirements of industries
	Physico-chemical properties	●	Refer to Drinking water guidelines		
	Nutrients	●			
	Toxicants	●			
	Microbiological indicators		●	●	
	Tainting substances			●	
Sediment	Toxicants	●		Similar to Protection of Aquatic Ecosystems	

However, to accommodate for natural variability within countries, but still minimize risk of impact, these QTs are usually broad-based and fairly conservative. Therefore, these recommended QTs should be considered as a first phase in setting QTs for individual countries. Depending on site-specific conditions (ecological, social and/or economic) these may have to be refined at specific national or local seascapes. As a result, the recommended QTs proposed in these regional guidelines cannot automatically become legally binding (Ragas et al. 2005). However, once the water and sediment QTs have been verified and refined to accommodate site-specific needs these can become legally binding standards in themselves (e.g. water and sediment quality standards) (Ragas et al. 2005). However, it is very important to note that the existence of QTs does not imply that water and sediment quality should or could automatically be degraded to those levels.

A continuous effort should be made to ensure that coastal and marine environment are of the highest attainable quality, taking into account economic and social opportunities and constraints, and considering principles such as:

- Precautionary approach
- Pollution prevention
- Waste minimisation
- Recycling and re-use
- Best available or best attainable technologies.

Within this light, the phased approach in proposed for the integration of these Guidelines as tools for C&MWQM at national level. First, it is proposed that the quality objectives and targets for sediment and water quality, as recommended for the WIO region at large (Reference WIO Document when officially issued), be adopted as **interim national sediment and water quality guidelines**. Thereafter, it is proposed that a country's responsible authorities commission a few pilot or case studies to test the applicability of these objectives and targets (e.g. pollution hot spots along a country's coastal and marine environment). This should be done in collaboration with local authorities, local universities, as well as local stakeholders, in accordance with the Framework for C&MWQM (Figure 1).

This document presents **proposed national interim quality objectives and targets** for each of four beneficial uses categories identified.

2. Protection of Aquatic Ecosystems

In Protecting Aquatic Ecosystems, the primary environmental quality objective, a narrative statement describing the desired quality for a particular environment, is:

> *The physical, chemical and biological conditions defining the structure of, and processes within a particular coastal ecosystem are maintained*

From a C&MWQM perspective, this broad objective needs to be translated into measurable targets, in this instance water and sediment quality targets (QTs). Water and sediment quality-related problems or impacts on the coastal and marine aquatic ecosystems typically manifest in terms of:

- Abnormal growth stimulation (e.g. excessive nutrients)
- Biological health (e.g. toxic compounds affecting, for example, the reproductive rate of organisms)
- External behaviour responses (e.g. pollutant affecting movement and burrowing habits of organisms or entanglement).

Types of constituents (key indicators) that are typically used to set QTs for the protection of aquatic ecosystems in coastal and marine areas, and their relevance to various impacts, are indicated in Table 2.

Table 2: **Type of constituents (key indicators) typically used to set QTs for the protection of aquatic ecosystems in coastal and marine areas, as well as potential associated impacts**

TYPE OF CONTITUENT	GROWTH STIMULATION	BIOLOGICAL HEALTH	EXTERNAL BEHAVIOUR RESPONSE
Objectionable matter		●	●
Physico-chemical properties		●	●
Nutrients	●		
Toxicants		●	●

Grow stimulation, primarily relates to excessive eutrophication associated with nutrient pollution. Biological health mainly related to the impact of chemical on one of more life stages of marine organism, either chronic or acute, while objectionable matter and high levels of pollutants (e.g. suspended solids), for example can impact on the natural migration of marine organisms.

2.1 Proposed Interim Quality Targets

Table 3 lists the proposed interim national water and sediment quality guidelines for coastal and marine environments (based on recommended guidelines for WIO region – Reference WIO document when officially issues). Background information to these targets as provided in Appendix A.

Table 3: **Interim QTs in waters and sediment for the protection of aquatic ecosystems**

CONSTITUENT	INTERIM QUALITY TARGET
Objectionable matter	• Water should not contain litter, 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 objectionable deposits. • 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/recognised use.
Physico-chemical properties:	
Temperature (°C)	The concentration of the physico-chemical property defined by the 20%ile and/or 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in a study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.
Salinity	
pH	
Turbidity (NTU)	
Total Suspended solids (mg/ℓ)	
Dissolved oxygen (mg/ℓ)	
Inorganic nutrients	
Dissolved nitrite and nitrate	The concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in a study area or comparable site elsewhere), considering possible differentiation between seasons or episodic events.
Dissolved total ammonia	
Dissolved reactive phosphate	

Toxicants	WATER	SEDIMENT	
	Recommended QT (µg/ℓ)	Recommended QT	Probable Effect Level
Non-metallic inorganic toxicants			
Total Ammonia-N	500 (99% protection); 910 (95% protection)	-	-
Free Chlorine-Cl	0.5	-	-
Cyanide (CN^-)	2 (99%); 4 (95%)	-	-
Fluoride (F^-)	5 000	-	-
Sulphide (H_2S)	2	-	-

Toxicants	WATER	SEDIMENT	
	Recommended QT (µg/ℓ)	Recommended QT	Probable Effect Level
Metals		**(µg/g dry weight)**	
Arsenic (As)	As[III] 2.3; As[V] 4.5	7.24	41.6
Cadmium (Cd)	0.7 (99%); 5.5 (95%)	0.68	4.21
Chromium (Cr)	Cr[III] 7.7 (99%); 27 (95%) Cr[VI] 0.14 (99%); 4.4 (95%)	52.3	160
Copper (Cu)	0.3 (99%); 1.3 (95%)	18.7	108
Lead (Pb)	2.2 (99%); 4.4 (95%)	30.2	112
Mercury (Hg)	0.1 (99%); 0.4 (95%)	0.13	0.7
Nickel (Ni)	7 (99%); 70 (95%)	15.9	42.8
Silver (Ag)	0.8 (99%); 1.4 (95%)	0.73	1.77
Tributyltin as Tin (Sn)	0.0004 (99%); 0.006 (95%)	0.009	0.07
Vanadium (V)	50 (99); 100 (95%)	-	-
Zinc (Zn)	7 (99%); 15 (95%)	124	271
Petrochemicals (Mono- and polycyclic aromatic hydrocarbons)		**(ng/g dry weight)**	
Benzene (C6)	600(99%); 950 (95%)	-	-
Toluene (C7)	110 (99%); 180 (95%)	-	-
Ethylbenzene (C8)	50 (99%); 80 (95%)	-	-
m-Xylene (C8)	50 (99%); 75 (95%)	-	-
Naphthalene (C9)	50 (99%); 70 (95%)	34.6	391
Acenaphthene (C12)		6.71	88.9
Acenaphthylene (C12)		5.87	128
Fluorene (C13)		21.2	144
Anthracene (C14)	0.01 (99%); 0.4 (95%)	46.9	245
Phenanthrene (C14)	0.6 (99%); 2 (95%)	86.7	544
Fluoranthene (C15)	1 (99%); 1.4 (95%)	113	1 494
Pyrene (C16)		153	1 398
Benzo(a)anthracene (C18)		74.8	693
Chrysene (C18)		108	846
Benzo(a)pyrene (C20)	0.1 (99%); 0.2 (95%)	88.8	763
Dibenzo(a,h)anthracene (C22)		6.22	135
Total PAH		1 684	16 770
Agrochemicals (Pesticides and herbicides)		**(ng/g dry weight)**	
Aldrin	0.003	-	-
Chlordane	0.001	2.26	4.79
Chloropyros	0.0005 (99%); 0.009 (95%)	-	-
DDT	0.004	3.89	51.7
p,p DDT	-	1.19	4.77
p,p DDD	-	1.22	7.81
p'p'- DDE	-	2.07	374
Dieldrin	0.0019	0.72	4.3
Endosulfan	0.005 (99%); 0.01 (95%)	-	-
Endrin	0.004 (99%); 0.008 (95%)	2.7	60
Fenitrothion	0.001	-	-
Lindane	0.007	0.32	0.99
Methoxychlor	0.004	-	-
Temephos	0.0004 (99%); 0.05 (95%)	-	-
Toxaphene	0.1 (99%); 0.2 (95%)	-	-
Pharmaceuticals			
Carbamazepine	1 (99%); 9.2 (95%)	-	-
Diclofenac	180 (99%); 770 (95%)	-	-
Fluoxetine	0.23 (99%); 1.6 (95%)	-	-
Propranolol	3.5 (99%); 14 (95%)	-	-
Other organic toxicants		**(ng/g dry weight)**	
Phenol	270 (99%); 400 (95%)		
Polychlorinated Biphenyls (PCBs)	0.03	21.6	198

2.2 Application and Refinement of interim Quality Targets

2.2.1 Water

The Reference Data Approach has been recommended for derivation of QTs for physico-chemical properties and inorganic nutrients in the WIO region. This method uses an appropriate percentile (e.g. 20th and/or 80th percentile) of the physico-chemical data collected from a specific site prior to modification (or an appropriate Reference site) to derive QTs as is lustrated in Figure 2.3.

Where the QTs need to be derived using the Reference Data Approach (e.g. physico-chemical properties and inorganic nutrients), monthly data collected over a two-year period are considered sufficient to incorporate ecosystem variability if variables do not show large seasonal or event-scale effects (ANZECC 2000). However, in ecosystems where concentrations of physico-chemical properties (and ecological and biological responses) do show strong seasonal and event-scale effects, it will be necessary to monitor (and/or model) to detect these seasonal influences or events. Therefore, where seasonal or event-driven processes dominate, data need to be grouped and QTs need to be derived for corresponding key periods.

It is recommended that target values derived from the Reference Data Approach be compared with the median or average (whichever is considered most appropriate) of the measured data from the study area (either measured spatially across various locations within a test area or over an appropriate time period at specific sites). Statistically, the median usually represents the most robust descriptor of the test site data and is the recommended approach.

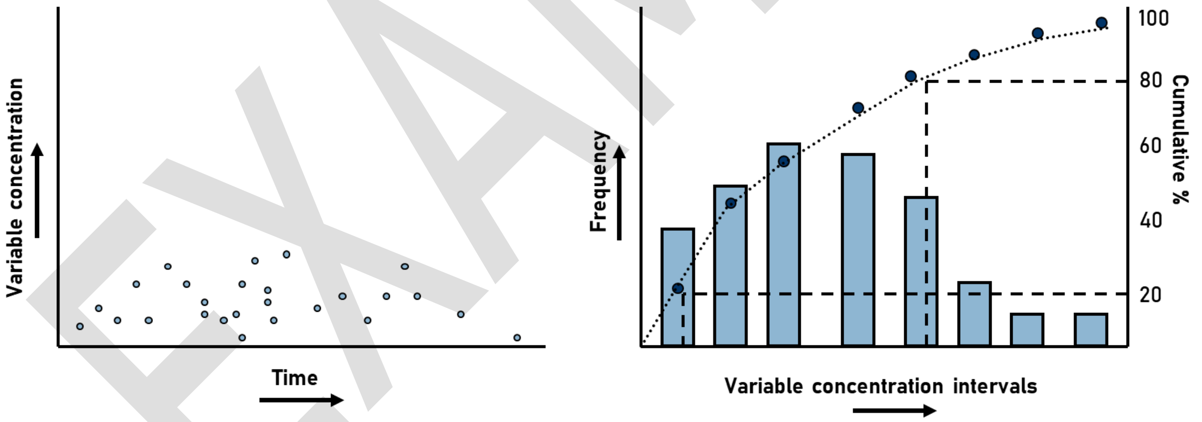

Figure 2: Illustration of using Reference data approach to derive QTs, using the 20th and/or 80th percentiles

In countries where few site-specific reference data are available and seasonal and event influences are poorly defined for the physico-chemical properties, single value QTs could be derived from available data based on professional judgement, as an interim measure. To assist in establishing such interim QTs, impacts and thresholds considered relevant to critical ecosystems within the WIO region were sourced and were translated into potential interim QT ranges for consideration by practitioners in the different countries (Table 4).

Table 4: Potential interim QT ranges in water to be consider for protection of aquatic ecosystems

CONSTITUENT	POTENTIOAL INTERIM QT RANGES FOR WATER		
	Seagrass	Mangroves	Coral reefs
Temperature (°C)	15-28	Tropical: 18-38 Subtropical: 16-36	20-29
Salinity	15-36	5-40	30-40
Dissolved oxygen (mg/ℓ)	4-12	2-12	4-10
Total inorganic N (μg/ℓ)	500	1 000	15
Total inorganic P (μg/ℓ)	50	100	5

Recommended (single) value QTs for toxicants were based on large, international toxicological data sets, and provide a general (conservative) tolerance of biota to constituent concentrations, but it does not necessarily take into account site-specific (natural) background conditions. Therefore, where site-specific studies show non-compliance to recommended QTs (or in the event that recommended QTs are considered to underestimate site-specific tolerance levels), a phased risk assessment process should be applied to refine QTs as illustrated in Figure 3. Incremental refinements may include, for example:

- Natural background concentrations of a particular variable exceed QTs
- Site-specific toxicity or bioavailability testing (i.e. exploring different lines of evidence) show need to refine QTs, for examples as a result of site-specific water quality characteristics such as dissolved organic matter, pH, and the toxicity of different metal species
- Continuous and extensive ecological monitoring shows that exceedances of the recommended QT are consistently assessed as posing no risk to the ecosystem (i.e. QT may be relaxed).

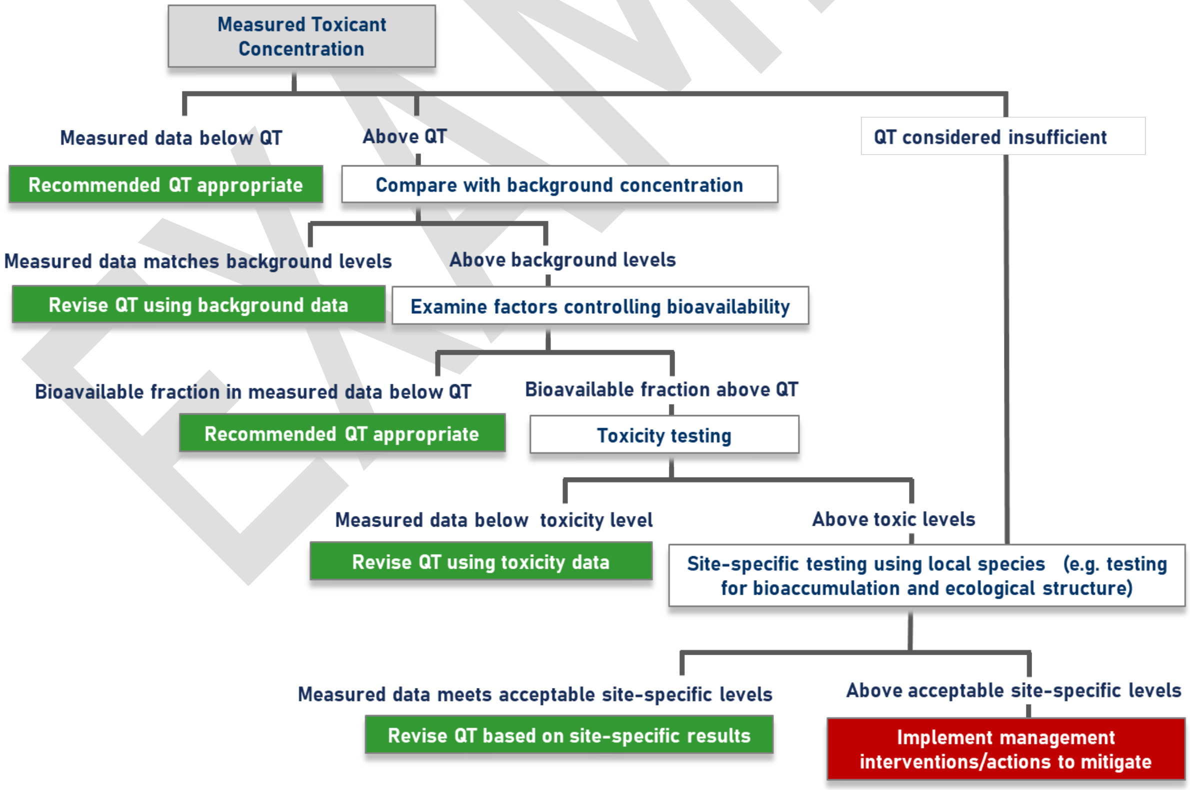

Figure 3: **Proposed phased process for refinement of recommended QTs for site-specific application in the protection of aquatic ecosystems in the WIO region**

When applying these (single) recommended QTs to measured data to test for compliance, **all data points should comply with such target values**. It is good practice to apply the recommended QTs for the **protection of coastal and marine aquatic ecosystems** as widely as possible in coastal and marine areas, and not just limit its application to protected or conservation areas.

2.2.2 Sediments

As with recommended QTs for toxicants in water, QTs for sediment derived from international toxicological data sets provide a general (conservative) tolerance of biota for constituent concentrations, and does not necessarily consider site-specific (natural) background conditions. Therefore, where site-specific studies show non-compliance to recommended QTs (or in the event that recommended QTs are considered to underestimate site-specific tolerance levels) a phased risk assessment process should be applied to refine QTs, as illustrated in Figure 3. In the case of sediment toxicants it is also critically important to consider **sediment particle size** and **organic content (OC)**.

Sediment particle size influences the contaminant binding capacity of sediments, which decreases with increasing particle size, and as a result the concentrations of contaminants tend to be higher in finer grained sediment fractions (unless pollutant source is a particulate such as paint particles) (UNEP 2007). Data sets applied in the derivation of QTs usually consider finer sediment fractions rather than sandy sediments, so these targets are most applicable to finer sediments. Therefore, the <63 µm sediment particle size fraction (clay and silt) is considered most appropriate for comparison with recommended QTs. However, where whole sediment samples are used the particle size distribution of the samples must be taken into account when interpreting results against QTs. This is especially important for metals, which are ubiquitous, naturally occurring chemicals of which the concentration in uncontaminated sediment can vary by orders of magnitude over relatively small spatial scales. **Therefore, it is good practice to include particle grain size in toxicant monitoring programmes as lithological normaliser in estimating bioavailable fractions.**

Note:

Normalisation of toxicant data can only be recommended if there is a strong statistical relation between the contaminant concentration and the normaliser. In the contrary, it can distort the interpretation of data (UNEP 2007)

An approach that could be applied to consider the influence of sediment particle size on metals, and to distinguish between natural concentrations vs anthropogenic contamination, is geochemical normalisation (e.g. Newman and Watling 2007). Geochemical normalisation involves the development of metal baseline models using sediments of varying particle size (e.g. gravel to mud) from a specific area that have been subject to minimal impacts from anthropogenic activities (UNEP 2007). Aluminium is generally considered as the most suitable normaliser since it is a major constituent of fine grained alumino-silicates (clays). Also, it shows a strong inverse correlation to particle size and positive correlations to co-occurring metal concentrations. Therefore, normalisation serves as a means of comparing Aluminium vs metal concentration ratios of uncontaminated locations to those in potentially metal-enriched sediment, as illustrated in Figure 4.

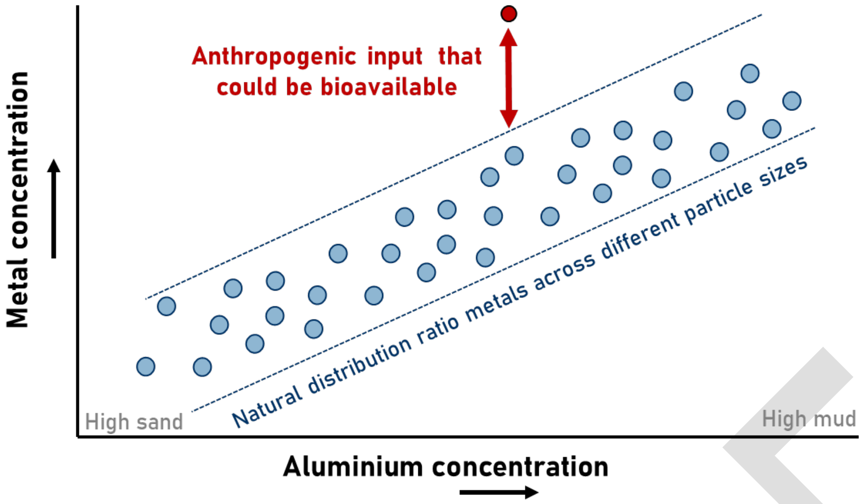

Figure 4: **Illustration of the concept of geochemical normalisation using aluminium as normaliser (adapted from Newman and Watling 2007)**

Most metals in unpolluted sediment tend show a linear relationship with Aluminium concentrations in sediments (typically increasing with increase in mud content). As a result one can establish a natural ratio across different particles sizes for a particular ecosystem. Measured data can then be compared with this ratio bands. Where the measured data plots within the natural ratio band, it is most likely of natural origin, and not bio-available. However, when the measured data plots above the natural ratio band, it could suggest anthropogenic input, and the fraction outside the natural ratio band should be compared with the recommended sediment QT for test for compliance. Because geological and geochemical properties can differ between regions (or catchments) it is most appropriate to develop these models for specific systems. **It is therefore good practice to include aluminium (and possibly iron) analysis in metal monitoring programmes as geochemical normalisers in estimating bioavailable fractions.**

Organic content (OC) also affects the partitioning of certain metals and organic chemicals to sediment particles (UNEP 2007). Partitioning to OC may affect the bioavailability of chemicals. **It is therefore good practice to include total organic carbon measurements in toxicant monitoring programmes as geochemical normalisers in estimating bioavailable fractions.** Such normalisation is typically done for hydrophobic organic toxicants to 1.0% OC (dry weight) in sediments before comparing to QT. Such normalisation should only be applied to sediments with total organic carbon [TOC] concentration between 0.5% and 10% because at lower concentrations, other physical and chemical factors were found to influence partitioning.

At higher concentrations carbon may be present as oils or tar, and not organic binding substances (e.g. humic substances) (Simpson et al. 2013; Batley et al. 2002). For example, if sediment contains 5 µg/g of a hydrophobic toxicant with a TOC of 2% (dry weight), then the normalised concentration of the hydrophobic organic toxicant would be equal to 5 divided by 0.5 = 2.5 µg/g (Australia and New Zealand 2018).

3. RECREATIONAL USE

For recreational use of coastal and marine waters the overarching environmental quality objective is:

Environmental quality is suitable for recreational use from an aesthetic, safety and hygienic point of view

Recreational use of coastal and marine waters varies from bathing to mere enjoyment of its scenic aspects. Recreational activities can be classified by the degree of water contact as follows (WHO 2003; Australian Government 2008):

- Whole-body contact (primary contact) — activity in which the whole body or the face and trunk are frequently immersed or the face is frequently wet by spray, and where it is likely that some water will be swallowed or inhaled, or come into contact with ears, nasal passages, mucous membranes or cuts in the skin (e.g. swimming, diving, surfing or white-water canoeing).
- Incidental contact (secondary contact) — activity in which only the limbs are regularly wet and in which greater contact (including swallowing water) is unusual (e.g. boating, fishing, wading), and including occasional and inadvertent immersion through slipping or being swept into the water by a wave.
- No contact (aesthetic uses) — activity in which there is normally no contact with water (e.g. angling from shore), or where water is incidental to the activity (such as sunbathing on a beach).

In whole-body contact activities, the probability that some water will be ingested is high, although data on the quantities swallowed during recreational water use are difficult to obtain (WHO 2003). Inhalation can be important where there is a significant amount of spray, such as in water skiing or even sunbathing at a surf beach. In water sports, the skill of the participant will also be important in determining the extent of involuntary exposure, particularly ingestion.

Typical water quality problems associated with recreational use of coastal and marine waters include:

- Aesthetics (e.g. bad odours, discolouration of water and presence of objectionable matter)
- Human health and safety (e.g. gastrointestinal problems, skin, eye, ear and respiratory irritations, physical injuries and hypo-/hyperthermia)
- Mechanical interference (e.g. clogging and choking of mechanical equipment in the waters such as boat engines and diving gear).

Parameters typically used to assess the status regarding the above-mentioned problems are indicated in Table 5.

Table 5: Type of constituents (key indicators) typically used to set QTs for recreational use of coastal and marine waters, as well as associated potential problems

TYPE OF CONTITUENT	AESTHETICS	HUMAN HEALTH & SAFETY	MECHANICAL INTERFERENCE
Objectionable matter (including algal blooms)	●	●	●
Microbiological indicator organisms		●	
Physico-chemical properties		●	
Toxicants (including toxic algal blooms)		●	

3.1 Proposed Interim Quality Targets

The proposed interim QTs for recreational waters in the [Country] is listed in Table 6. Background information to these targets as provided in Appendix B.

Table 6: Proposed interim QTs for recreational waters

PARAMETER	INTERIM QUALITY TARGET		
Objectionable Matter	• Water should not contain litter, 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 objectionable deposits. • 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. • Water should not contain substances producing objectionable colour, odour, taste, or turbidity.		
Temperature (°C)	For prolonged exposure, temperatures should be in the range 15–35°C		
pH	pH of water should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low near the extremes of the pH limits		
Enterococci (counts per 100 mℓ)	Excellent: ≤ 100 (95th percentile)	OR	A: ≤40 (95th percentile)
	Good: ≤ 200 (95th percentile)		B: 41 – 200 (95th percentile)
	Sufficient: ≤ 185 (90th percentile) (QT)		**C (min QT): 201 – 500 (95th percentile)**
	Poor: > 185 (90th percentile)		D: > 500 (95th percentile)
E. coli (counts per 100 mℓ)	Excellent: ≤ 250 (95 percentile)		No guidelines provided
	Good: ≤ 500 (95 percentile)		
	Sufficient: ≤ 500 (90 percentile) (QT)		
	Poor: > 500 (90 percentile)		
C. perfringens	Geometric mean ≤ 5 counts per 100 mℓ		

3.2 Application of Quality Targets

Where pollution sources are present in recreational areas that may introduce pollutants that can cause deterioration in aesthetics or put users at risk due to unacceptable pH, temperature or toxicants, conditions should be monitored and compared with interim QTs.

Based on international best practice (for more information, refer to Appendix A), the **assessment of the quality of marine recreational waters** should ideally comprise of:

- A microbiological quality assessment (applying the rating as per the recommended QT)
- Regular sanitary inspections.

In the **microbiological water quality assessment**, statistical analyses are required for comparison with the recommended target values. Where microbiological assessments are rated against a percentile target value it is important to ensure an appropriate sample size. For example, in **rating beach water quality using microbiological data collected weekly or bi-weekly, it is recommended that a 12-month running period is applied (in contrast to the typical 5 year period recommended internationally).** This is considered most appropriate for situations where the microbiological quality of recreational waters can change markedly over a short period. This approach allows for a more real-time classification process (e.g. monthly rather than yearly), recognising such variability (RSA DEA 2012).

Calculation of percentile values for microbiological parameters

Parametric: Based upon percentile evaluation of the $\log_{10}$ normal probability density function of microbiological data acquired from a bathing water, the percentile value is derived as follows (CEC 2006a):

- Take the $\log_{10}$ value of all bacterial enumerations in the data sequence to be evaluated (if a zero value is obtained, take the $\log_{10}$ value of the minimum detection limit of the analytical method used instead)
- Calculate the arithmetic mean of the $\log_{10}$ values (μ)
- Calculate the standard deviation of the $\log_{10}$ values (σ)

The upper 95 percentile point of the data probability density function is derived from the following equation: upper 95 percentile = antilog $(\mu + 1{,}65\ \sigma)$

The upper 90 percentile point of the data probability density function is derived from the following equation: upper 90 percentile = antilog $(\mu + 1{,}282\ \sigma)$

Non-parametric: Firstly, the data are ranked into ascending order and then the "rank" of the required percentile calculated using an appropriate formula - each formula giving a different result. There is no one correct way to calculate percentiles in this manner although the Hazen method is typically considered most appropriate as the "middle of the road" option (e.g. the Excel method always give the lowest percentile while Weibull method always gives the highest). The Hazen procedure is as follows (NZME 2003):

- For n data, X_i, such that i = 1, 2, …, n, rank the n data from lowest to highest where ranked data is Y_i: i = 1, 2, …, n
- Compute the percentile fraction (i.e., proportion) as $p = P/100$ (P is e.g. 95percentile)
- Check if there are enough data to make the calculation, i.e., if $n >= 1/[2(1-p)]$ and $n >= 1/(2p)$ [first limit applies for an upper percentile ($p > 1/2$), and vice versa]
- If there are enough data, then calculate the Hazen rank (usually non-integer) $r_{Hazen} = 1/2 + pn$
- Interpolate between integer ranks (i.e., ranked data) adjacent to the Hazen rank using Hazen *P*th percentile = $(1-rf)Y_{ri} + rfY_{ri+1}$, where ri = the integer part of r_{Hazen} and rf = fractional part of r_{Hazen} [note that the formula still works if there is just enough data, i.e., for equalities, instead of inequalities, in the equations in item 3 above].

Percentile values can be calculated by different percentile calculation approaches, based on data availability, statistical considerations and local resources. Two main approaches can be used, either parametric or non-parametric (WHO 2003). The parametric approach assumes that the samples have been drawn from a particular distribution, typically the $\log_{10}$ normal distribution for microbiological data, while the non-parametric approach does not assume any particular distribution and uses data ranking. The Hazen method is the preferred procedure although the Excel spreadsheet method can also be applied where users do not have access to a suitable Hazen template.

The **sanitary inspection** aims to identify all potential sources of faecal pollution (particularly human faecal pollution) and to grade a recreational area accordingly (Table 7).

Table 7: Example of a Sanitation Inspection checklist (adapted from NZME 2003)

SITE NAME		
LOCATION		
MAP POSITION	**Latitude**	**Longitude**
PERSON COMPLETING CHECKLIST		
INFORMATION ABOUT AREA		
Key features of area		
Total annual rainfall (mm)		
Seasonal rainfall pattern		
Water use activities		

Seasonal loading patterns					
LAND-USE OR HUMAN ACTIVITIES SURROUNDING RECREATION SITE (Tick all that apply and note key findings)					
Natural vegetation		Cultivated land		Road/rail	
Urban area		Residential		Landfill/dump sites	
Sand dunes		Commercial		Other potential polluting activities (specify)	
Pastures		Industry (specify)			
NOTES:					

EFFLUENT/WASTEWATER/STORMWATER DIRECT TO RECREATIONAL WATER		**Present ?**	**Likely to cause effect?**
1	Discharge of untreated human effluent onto or adjacent to a recreational area		
2	Storm water outlet with potential sewage contamination onto or adjacent to recreational area		
3	Urban stormwater outlet protected from sewage ingress		
4	On-site or other private sewage disposal systems (e.g. septic tank /conservancy tanks/package plant)		
5	Sewage discharge: untreated, primary or secondary treatment		
6	Sewage discharge: tertiary treatment		
7	Intensive agricultural use in immediate catchment and potential for run-off from untreated animal effluent (e.g. dairy farms, livestock)		
8	Incidence and density of bird life (particularly lagoons/estuaries)		
9	Water craft mooring or use (for boats, proximity, densities and pump-outs).		
QUALITY OF RIVER/STREAM INFLOWS TO RECREATIONAL AREA (if present)		**Present ?**	**Likely to cause effect?**
10	Discharge of untreated human effluent, primary or secondary wastewater treatment plant discharge, on-site or other private sewage disposal systems (e.g. septic tank /conservancy tanks/package plant)		
11	Storm water outlets with potential sewage contamination		
12	Sewage discharge after tertiary treatment		
13	High-intensity agricultural/rural activities, incidence and density of feral animal/bird population		
14	Focal points of drainage, as run-off from low-intensity agriculture/urban/rural catchment		
15	Potential for run-off from feral animals (e.g. forest or bush)		
OTHER INFLUENCES		**Present ?**	**Likely to cause effect?**
16	Tidal movements or onshore winds likely to carry water polluted by untreated/ primary/secondary treated effluent or onsite waste treatment systems into recreational area		
17	Tidal movements or onshore winds that are likely to carry water polluted by tertiary treated wastewater into recreational area		
Note: If the box is ticked indicating the presence of any of the above, the answer as to whether it is causing an effect may be obvious (e.g. discharge of human or animal effluent onto or adjacent to a recreational area). If it is unclear whether it is causing an effect, a more detailed investigation may be required to establish relative importance and magnitude of the effect.			

OTHER CONSIDERATIONS	**Yes**	**No**
Does rainfall trigger contamination events?		
Does microbiological water quality data exceed single sample guideline (280 counts per 100 ml) on any occasion?		
Is there additional information implying risk (such as notified illness related to recreational water activities)?		

In this regard, the three most important sources of human faecal contamination are considered to be:

- Sewage (e.g. wastewater discharges, sewage pump station overflow, seepage from septic/conservancy tanks, contaminated storm-water run-off)
- Riverine discharges (e.g. where rivers are receiving sewage discharges)
- Contamination from bathers (e.g. excreta), and
- Shipping and boating activities (e.g. inappropriate sewage disposal practices).

The sanitation inspection should be conducted at least once a year, or when significant change in sanitary conditions is expected. Figure 3.1 illustrate how the results from the sanitation inspection (Table 7) can be rated.

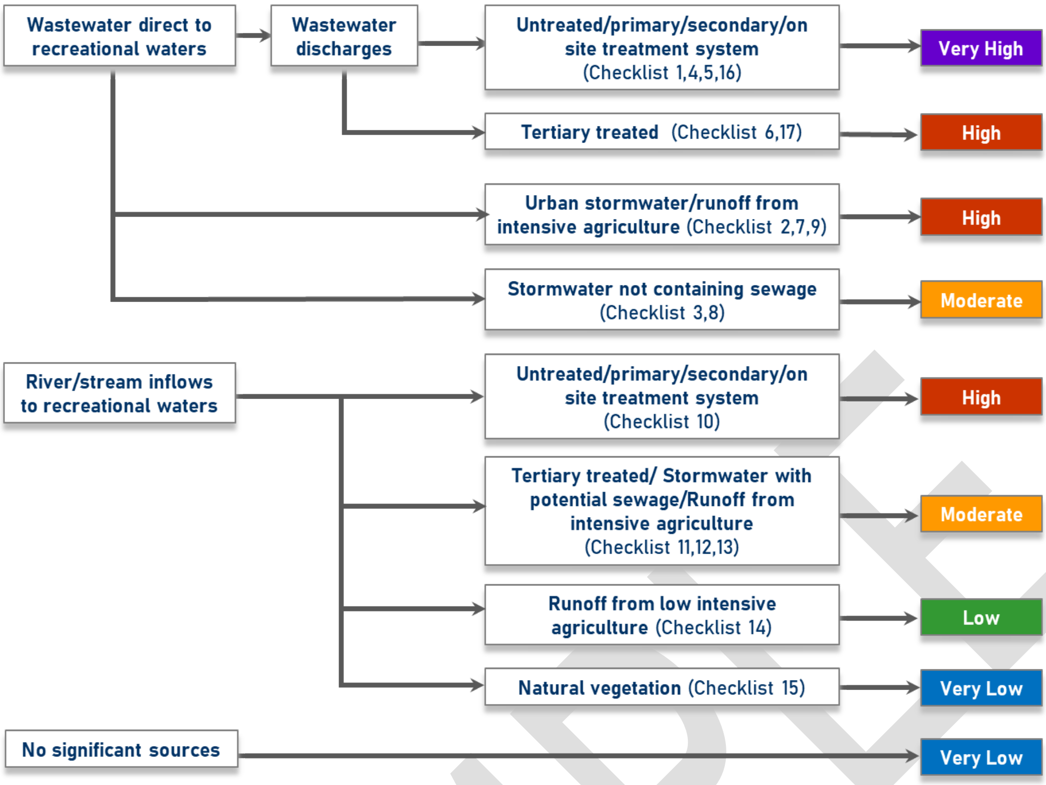

Figure 5: **Rating recreational areas based on the results from a Sanitation Inspection (see Table 6)**

Recreational water can also be classified using the Microbiological Quality Assessment results and the Sanitary Inspection as illustrated in Table 8, linked to the recommended QTs (Table 7) and the Sanitation inspection ratings (Figure 5).

Table 8: **Classification matrix for recreational waters (WHO 2003)**

		MICROBIOLOGICAL QUALITY ASSESSMENT CATEGORY (95TH PERCENTILE ENTEROCOCCI per 100 ml)				
		Excellent/A	**Good/B**	**Sufficient/C**	**Poor/D**	**Exceptional circumstances[3]**
SANITARY INSPECTION CATEGORY	**Very Low**	Very good	Very good	Follow-up[1]	Follow-up[1]	Action
	Low	Very Good	Good	Fair	Follow-up[1]	
	Moderate	Good	Good	Fair	Poor	
	High	Good	Fair	Poor	Very poor	
	Very high	Follow-up[2]	Fair	Poor	Very poor	
	Exceptional circumstances	Action				

1 Implies non-sewage sources of faecal indicators (e.g. livestock), and this should be verified

2 Indicates possible discontinuous/sporadic contamination (often driven by events such as rainfall). This is most often associated with Combined Sewer Overflow presence. These results should be investigated further, and initial follow-up should include verification of sanitary inspection category and ensuring samples recorded include "event" periods. Confirm analytical results. Review possible analytical errors

3 Exceptional circumstances relate to known periods of higher risk, such as during an outbreak with a pathogen that may be waterborne, sewer rupture in the recreational water catchment, etc. Under such circumstances, the classification matrix may not fairly represent risk/safety.

A grade of 'Very Good' reflects consistent compliance with microbiological targets with few sources of faecal contamination in the area and surrounds. Consequently, there is a low risk of illness from contact recreation. At the other extreme, 'Very Poor' reflects significant sources of faecal contamination and rare compliance with microbiological targets. The risk of illness from contact recreation in such waters is high, and swimming is not recommended.

4. MARINE AQUACULTURE

Marine aquaculture refers to the farming of marine (or estuarine) organisms, either in off-stream (land-based) facilities or in-stream in the marine environment. Marine aquaculture typically focuses on seaweeds, shellfish, crustaceans and fish culture. Water quality related requirements that apply to marine aquaculture are also relevant to activities in which marine organisms are collected (e.g. subsistence use) or harvested from natural stocks for human usages (e.g. fisheries). These include activities such as:

- Seaweed collection (e.g. *Gracilaria*)
- Shellfish collection (for human consumption)
- Recreational fishing
- Subsistence fishing
- Commercial fisheries.

With respect to marine aquaculture and the harvesting of seafood for human consumption, the pollution impacts typically comprise:

- Mechanical interference (e.g. where floating matter damages equipment)
- Biological health (e.g. toxic compounds affecting, for example, the reproductive rate of organisms)
- Human health (e.g. through bacteriological contamination and bioaccumulation of toxicants)
- Organoleptic effects (e.g. pollutants causing tainting of seafood).

For marine aquaculture activities (including harvesting or collecting of organisms for human consumption), the following general environmental quality objective is proposed:

Environmental quality sustains acceptable product quality and prevents any health risks to consumers

Parameters typically used to assess the status regarding the above-mentioned problems are indicated in Table 9.

Table 9: Type of constituents (key indicators) typically used to set QTs for marine aquaculture in coastal and marine areas as well as associated potential impacts

TYPE OF CONSTITUENT	MECHANICAL INTERFERENCE	BIOLOGICAL HEALTH	HUMAN HEALTH	AESTHETICS (TAINTING)
Objectionable matter	●	●		
Physico-chemical properties		●		
Nutrients		●		
Toxicants		●	●	
Microbiological indicator organisms			●	
Tainting substances				●

4.1 Proposed Interim Quality Targets

Table 10 provides a proposed interim for objectionable matter linked to mechanical interference in marine aquaculture areas.

Table 10: Interim QTs for objectionable substances linked to Marine Aquaculture areas

Interim Target	Water should not contain litter, 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 objectionable deposits. 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/recognised use. Water should not contain substances producing objectionable colour, odour, taste, or turbidity.

Apply QTs for physico-chemical properties, nutrients and toxicants in water for the protection of aquatic ecosystems (see Chapter 2)

Table 11 provides a summary of the Interim QTs for shellfish harvesting areas (see Appendix C for details).

Table 11: Interim QTs for microbiological parameters (water and flesh) for application in shellfish water classification (adapted from ANCEZZ 2000 and US-EPA 2002)

Interim Target	***E. coli* (direct consumption)** **Systematic random sampling strategy**[1] - • Membrane Filtration (MF) - 14 per 100 mℓ and estimated 90th percentile in water not to exceed 21 per 100 mℓ or • Most Probable Number (MPN) - 14 per 100 mℓ and estimated 90th percentile in **water** not to exceed 43 per 100 mℓ for a 5 tube decimal dilution test, or 49 per 100 mℓ for a 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 230 counts per 100 g of flesh and intravalvular liquid and estimated 90th percentile not to exceed 700 counts per 100 g **Adverse pollution condition sampling strategy**[2] - • MF - 14 per 100 mℓ and not more than 10% of **water** samples exceed 21 per 100 mℓ **or** • MPN - 14 per 100 mℓ and not more than 10% of **water** samples exceed 43 per 100 mℓ for 5 tube decimal dilution test, or 49 per 100 mℓ for 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 230 counts per 100 g of flesh and intravalvular liquid and not more than 10% of samples exceed 700 counts per 100 g.
	***E. coli* (relaying or depuration required)** **Systematic Random Sampling Strategy** - • MF - 70 per 100 mℓ and estimated 90th percentile in **water** samples not to exceed 85 per 100 mℓ or • MPN - 88 per 100 mℓ and estimated 90th percentile in **water** samples not to exceed 260 per 100 mℓ for a 5 tube decimal dilution test, or 300 per 100 mℓ for a 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 46 000 counts per 100 g of flesh and intravalvular liquid and estimated 90th percentile not to exceed 14 100 counts per 100 g. **Adverse pollution condition sampling strategy** - • MF - 70 per 100 mℓ and not more than 10% of **water** samples exceed 85 per 100 mℓ or • MPN - 88 per 100 mℓ and not more than 10% of **water** samples exceed 260 per 100 mℓ for 5 tube decimal dilution test, or 300 per 100 mℓ for 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 46 000 counts per 100 g of flesh and intravalvular liquid and not more than 10% of samples exceed 14 1000 counts per 100 g.

Estimated threshold concentrations for tainting substances for consideration in the WIO region are listed in Table 12.

Table 12: **Interim QTs for tainting substances in coastal waters used for marine aquaculture (adapted from ANCEZZ 2000 and US-EPA 2002)**

TAINTING SUBSTANCE	THRESHOLD QT (mg/ℓ)	TAINTING SUBSTANCE	THRESHOLD QT (mg/ℓ)
Acenaphthene	0.02	Dimethylamine	7
Acetophenone	0.5	Diphenyloxide	0.05
Acrylonitrile	18	B,B-dichlorodiethyl ether	0.09
Copper	1	*o*-dichlorobenzene	< 0.25
m-cresol	0.2	p-dichlorobenzene	0.25
o-cresol	0.4	Ethylbenzene	0.25
p-cresol	0.12	Momochlorobenzene	0.02
Cresylic acids (meta, para)	0.2	Ethanethiol	0.24
Chlorobenzene	-	Ethylacrylate	0.6
n-butylmercaptan	0.06	Formaldehyde	95
o-sec. butylphenol	0.3	Gasoline/Petrol	0.005
p-tert. butylphenol	0.03	Guaicol	0.082
2-chlorophenol	0.001	Kerosene	0.1
3-chlorophenol	0.001	Kerosene plus kaolin	1
3-chlorophenol	0.001	Hexachlorocyclopentadiene	0.001
o-chlorophenol	0.001	Isopropylbenzene	0.25
p-chlorophenol	0.01	Naphtha	0.1
2,3-dinitrophenol	0.08	Naphthalene	1
2,4,6-trinitrophenol	0.002	Naphthol	0.5
2,3 dichlorophenol	0.00004	2-Naphthol	0.3
2,4-dichlorophenol	0.001	Nitrobenzene	0.03
2,5-dichlorophenol	0.023	a-methylstyrene	0.25
2,6-dichlorophenol	0.035	Oil, emulsifiable	15
3,4-dichlorophenol	0.0003	Pyridine	5
2-methyl-4-chlorophenol	0.75	Pyrocatechol	0.8
2-methyl-6-cholorophenol	0.003	Pyrogallol	0.5
3-methyl-4-chlorophenol	0.02 – 3	Quinoline	0.5
o-phenylphenol	1	*p*-quinone	0.5
Pentachlorophenol	0.03	Styrene	0.25
Phenol	1	Toluene	0.25
2,3,4,6-tetrachlorophenol	0.001	Outboard motor fuel as exhaust	0.5
2,4,5-trichlorophenol	0.001	Zinc	5
2,3,5-trichlorophenol	0.001		
2,4,6-trichlorophenol	0.003		
2,4-dimethylphenol	0.4		

4.2 Application of Quality Targets

Where pollution sources are present in marine aquaculture areas that potentially introduce pollutants that can cause mechanical interference (e.g. objectionable matter) or affect the health of marine organisms or potentially taint seafood, conditions should be monitored and compared with Interim QTs.

It is Interim that a classification system for shellfish growing areas be adopted for the WIO region in terms of human health. **Major export markets may eventually dictate** such an approach for countries in the WIO region that export seafood internationally. The classification of coastal and estuarine areas for the harvesting of shellfish (e.g. clams, oysters, scallops, mussels and other bivalve molluscs) is based on the results for a sanitary survey that consists of:

- Sanitary survey - identification and evaluation of all potential and actual pollution sources in the harvesting area (for details see ASSAC 2019 or US-FDA 2019)

- Microbiological survey - based on faecal coliform monitoring results obtained from harvesting area (for details see ASSAC 2019 or US-FDA 2019).

The proposed classification system for shellfish growing areas in the WIO region is provided in Table 13.

Table 13: Interim classification of shellfish waters in the WIO region (adapted from ASSAC 2019 or US-FDA 2019)

CATEGORY	MICROBIOLOGICAL STANDARD (WATER QUALITY)
Approved	Sanitary survey determines area is not subject to contamination from human or animal faecal matter presenting actual or potential public health hazard or toxic substances exceed required levels Microbiological levels must comply with *E. coli* QTs (direct consumption) (Table 4.3)
Conditionally Approved	Sanitary survey finds that area meets criteria for approved classification for a reasonable period and factors determining that period are known, predictable, and not so complex as to prevent a practical management approach Microbiological levels must comply with *E. coli* QTs (direct consumption) (Table 4.3)
Restricted	Sanitary survey finds area is subject to only a limited degree of pollution and level(s) of faecal pollution, and human pathogens and toxic or deleterious substances are at such an amount that shellfish can be made fit for human consumption by either relaying or depuration Microbiological levels must comply with *E. coli* QTs (relaying or depuration required) (Table 4.3)
Conditionally Restricted	Sanitary survey finds area open for purposes of harvesting shellfish for relaying or depuration for a reasonable period of time and factors determining this period are known, predictable, and are not so complex as to preclude a reasonable management approach Microbiological levels must comply with *E. coli* QTs (relaying or depuration required) (Table 4.3)
Prohibited	Shellfish so highly or frequently contaminated that harvesting controls cannot be implemented to adequately ensure protection of public health

5. INDUSTRIAL USE

It is proposed that industrial water use be recognised as a (beneficial) use of coastal waters in the WIO region. In waters used for industrial purposes, the primary environmental quality objectives is:

Environmental quality does not result in mechanical interferences, sustains acceptable product quality and prevents any health risks to consumers

While industrial activities are intuitively sources of marine pollution, there are numerous industries that also rely on acceptable quality of coastal and marine waters, including (UNEP et al. 2009):

- Fish processing – seawater intake used in the processing, washing and canning of seafood which requires good quality intake to ensure product quality and safety for human consumption
- Salt production – pumping of seawater into solar evaporation ponds
- Desalination – abstracting seawater to produce potable water
- Oceanariums - abstracting seawater directly from the sea
- Cooling water – seawater intake for cooling purposes in various industries
- Ballast water intake – intake of seawater for vessel trim, stability and manoeuvrability, usually occurs inside harbours and ports
- Exploration drilling – using seawater in oil and gas exploration drilling operations

- Scrubbing and scaling – using seawater to scrub smokestack to remove dust particles.

With respect to the industrial uses of seawater, pollution impacts primarily relate to (UNEP et al. 2009):

- Human health (e.g. where contaminated seawater may be used for food processing)
- Aesthetics (e.g. tainting of seafood during processing)
- Biological health (e.g. animals in oceanariums)
- Mechanical and process interferences (e.g. through clogging of filters).

Parameters that may have to be considered to assess the suitability of marine waters for the various industrial uses are indicated in Table 14.

Table 14: Type of constituents (key indicators) typically used to set QTs for industrial uses in coastal and marine areas as well as associated potential impacts

TYPE OF CONSTITUENT	MECHANICAL INTERFERENCE	BIOLOGICAL HEALTH	HUMAN HEALTH	AESTHETICS (TAINTING)
Objectionable matter	●	●		
Physico-chemical properties		●		
Nutrients		●		
Toxicants		●	●	●
Microbiological indicator organisms			●	

Internationally, Interim QTs for industrial use are generally no longer posed given the large variation in environmental quality requirements that are mainly driven by specific processes and technologies applied by industries. QTs should be derived site-specifically, based on the specific requirements of industries in the area.

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APPENDIX A: Background to Aquatic Ecosystem Quality Targets

Objectionable substances

Interim target	**• Water should not contain litter, 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 objectionable deposits.** **• 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/recognised use.**
Description	Objectionable substances refer to visible non-natural particles, debris, oil, grease, wax, scum, foam, submerged (just below water surface) objects or any other visible substances, including plastics.
Natural occurrence	Objectionable substances typically do not occur naturally, although nutrient enrichment often results in nuisance algal growth that then becomes an 'objectionable substance'.
Interdependence & Fate in the environment	Objectionable substances are transported by sea currents and tend to accumulate in areas where sea currents converge, are deposited in areas of low turbulence ('depositional areas'), or are washed onto seashores.
Method	Objectionable substances can be measured quantitatively in marine waters (see marine litter monitoring).
Impacts & Thresholds	
Typical impacts which may be associated with the presence of objectionable substances include smothering, ingestion entanglement or physical injury to marine life (e.g. benthic communities, sea birds and seals). Objectionable matter may end up on beaches and make these unpleasant for bathing and negatively affect tourism.	

Physico-chemical properties

Temperature

Interim Target	**Temperature range defined by the 20%ile and 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	Temperature is a basic property of water and is important in the regulation or triggering of many physiological processes in marine organisms.
Natural occurrence	In the WIO region, mostly situated in tropical regions, seawater temperature typically varies between 20-30°C, but is lower along the south and west coasts of South Africa. Upwelling is a seasonal phenomenon in some parts of the region, when warmer surface waters are replaced by cooler bottom water (Bakun et al. 1998, Kanagev et al. 2009).
Interdependence & Fate in the environment	Generally, temperature is not interdependent on other water quality properties or constituents, but is primarily driven by atmospheric temperatures and oceanic processes although excessive suspended solids also can lead to increase in temperature due to insolation.
Method	Temperature is best measured using a calibrated *in situ* probe, but a thermometer can also be used. Unit: °C

Impacts & Thresholds

Biota	Range (°C)	Effect	Reference
Seagrass	<9	*Zostera marina* mortality within 12 hrs (100% population mortality)	Biebl and McRoy (1971)
	> 30	*Zostera marina* displays decrease in photosynthesis rates	Biebl and McRoy (1971)
	> 34	*Zostera marina* tissue death within 12 hrs	Biebl and McRoy (1971)
	38	*Zostera marina* mortality within 12 hrs (100% population mortality)	Biebl and McRoy (1971)
	11.5-26	Optimal growth for temperate species	Lee et al. (2007)
	23-32	Optimal growth for tropical/subtropical species	Lee et al. (2007)
Shrimp	11 – 39	Optimum temperature range for the shrimp *Penaeus indicus* (adults)	McClurg (1974)

Biota	Range (°C)	Effect	Reference
	24–34	Optimum temperature range for the shrimp *Penaeus monodon* (adults)	Kungvankij et al. (1986 a,b)
	26–31	Optimum temperature range for shrimp larvae, but sudden changes should not exceed 2°C	Kungvankij et al. (1986 a,b)
	27.9	Optimum range for maturation of brood stock of Penaeid prawns	Shrimp Farming Short Course (1990)
	26-30	Optimum temperature range for Penaeid prawns larvae	Lee and Wickens (1992)
Coral	29	Loss of zooxanthellae and coral tissue protein in *Pocillopora damicornis*	Glynn and D'Croz (1990)
	30	Severe bleaching in *Pocillopora damicornis*, and death within 9 weeks	Glynn and D'Croz (1990)
	32	Severe bleaching in *Pocillopora damicornis*, and death within 4 weeks	Glynn and D'Croz (1990)
Coral fish	<20	Spawning ceased in angelfish (*Centropyge argi*) and Bluehead wrasse (*Thalassoma bifasciatum*)	Holt and Riley (unpublished report)
	<22	Spawning ceased in Clown wrasse (*Halichoeres maculipinna*)	Holt and Riley (unpublished report)
	23-25.5	Temperature range for optimal egg production in angelfish (*Centropyge argi*)	Holt and Riley (unpublished report)
	27–30	Temperature range for optimal egg production in Bluehead wrasse (*Thalassoma bifasciatum*)	Holt and Riley (unpublished report)
	24-29	Temperature range for optimal egg production in Clown wrasse (*Halichoeres maculipinna*)	Holt and Riley (unpublished report)
	>28	Spawning ceased in angelfish (*Centropyge argi*)	Holt and Riley (unpublished report)

Salinity

Interim Target	**Salinity range defined by the 20%ile and 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	Salinity refers to the dissolved salt content in seawater. The major constituents in 1 kg of seawater with a salinity of 35 are: 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 (Millero and Sohn 1992). The practical salinity of a sample of seawater is defined in terms of the conductivity ratio, K_{15}, defined by (Open University 1989): Conductivity of seawater sample (at 15°C, 1 atm pressure) ÷ Conductivity of standard KCl solution (32.4356 g/kg)
Natural occurrence	Salinity in the WIO region shows large variations as a result of high seasonal and annual variability in rainfall and evaporation rates. Sea surface salinity is also affected by anomalous anticyclonic winds blowing in the Southeast Indian Ocean and preventing the export of saltier water from the WIO region. Overall, the salinity ranges between 32 and 37, but with large local differences (Kanagev et al. 2009).
Interdependence & Fate in the environment	Salinity is not dependent on other water quality properties or constituents.
Method	Salinity is best measured using a calibrated *in situ* probe. Where the ionic strength ('salt content') of seawater has been measured as Electrical Conductivity (EC in mS/m) conversion factors can be used (Riley and Skirrow 1975). Where the salt content has been measured as mg/ℓ Total Dissolved Solids (TDS), it can be converted to salinity by dividing the TDS value by 1 000. Unit: According to The International System of Units (SI) salinity is unitless, being the ratio between two electrical conductivities.

Impacts and Thresholds

Biota	Range	Effect	Reference
Phytoplankton	<15	Significant growth changes in *Skletonema costatum*	Su et al. (1990)
	>30	Significant growth changes in *Skletonema costatum*	Su et al. (1990)
Green algae	Hyposalinity	*Ulva* and *Enteromorpha* are vulnerable to changes in salinity - flush of algal growth	Branch et al. (1990)
	Declining salinity	*Cladophara* sp. shows inhibited photosynthesis and increase in osmotic stress	Wieche and Davenport (1987)
Sea grass	15 - 35	Maximum growth of *Zostera capensis*	Adams and Bate (1994)
	40	*Zostera capensis* Setchell displays tissue alteration	Iyer and Barnabas (1993)
	60	*Zostera capensis* Setchell leaf blade cells damaged	Iyer and Barnabas (1993)
	>20	inhibition of seed germination and seedling survival of	Kamermans et al. (1999)

Biota	Range	Effect	Reference
		Zostera marina.	
	>32	Decrease in shoot and leaf production in mature *Zostera marina*	Kamermans et al. (1999)
	<30	Significant decrease in *Thalassia testudinum* seedling survival	Kahn and Durako (2006)
	>40	Significant decrease in *Thalassia testudinum* seedling survival	Kahn and Durako (2006)
	0 and 70	100% mortality in *Thalassia testudinum* seedling survival	Kahn and Durako (2006)
Shrimp	1 - 75	*Penaeus indicus* can tolerate such a wide salinity range if acclimation time is at least 48 hrs (adults)	McClurg (1974)
	15 - 30	Tolerant salinity range, above and below which *Penaeus monodon* displays physiological stress (adults)	Kungvankij et al. (1986 a,b)
	18	Salinity limit for *Penaeus semisulcatus,* above which respiration decreased and mortality occurs (adults)	Clark (1992)
	25 - 40	Tolerant salinity range, above and below which *P. indicus* displays physiological stress (adults)	Kungvankij et al. (1986 a,b)
	27 - 32	Tolerant salinity range, above and below which *P. japonicus* displays physiological stress (adults)	Kungvankij et al. (1986 a,b)
	30 - 32	*P. monodon* larval tolerant range (larvae)	Kungvankij et al. (1986a,b)
	33.5	Maturation of *P. monodon* broodstock (larvae)	Lee and Wickens (1992)
Crabs	<5	*Scylla serrata* zoeae mortality within 4 months	Hill (1974)
	<10	*S. serrata* female crabs do not release their eggs	Hill (1974)
	<10	*S. serrata* larvae inactive	Hill (1974)
	<17,5	*S. serrata* significant larval mortality	Hill (1974)
	15-25	*S. serrata* oxygen uptake of adult crabs decreased significantly at 22, 27, and 32 °C	Hill (1974)
	23 - 25	*S. serrata* 46 % survival of first stage zoeae	Hill (1974)
	21 -24	*S. serrata* faster growth rate of postlarvae	Hill (1974)
	>25	*S. serrata* 100% zoeae mortality and significant growth rate reduction of postlarvae	Hill (1974)
Bivalve Molluscs	7	*Macoma litoralis* lowest salinity tolerance	Matthews and Fairweather (2004)
	13-45	Optimum salinity range for *Solen cylindraceus*, above which physiological functioning is impaired	De Villiers and Allanson (1989)
Fish	5 - 25	Tolerance range for fish larvae from the family Mugilidae	Paulraj and Kiron (1988)
	>30	Larval mortality	Paulraj and Kiron (1988)

Dissolved oxygen

Interim Target	**Dissolved oxygen concentration defined by the 20%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	This property refers to the amount of dissolved oxygen present in water and is an essential requirement for most heterotrophic marine life.
Natural occurrence	Dissolved oxygen is a non-conservative property of seawater and its natural concentrations in surface waters are largely governed by local temperature/salinity regimes, organic content and extent of primary productivity (Grasshoff et al. 1999). Dissolved oxygen concentrations in seawater below thermo- or haloclines can be naturally low, owing to biological demand and limited replenishment from the atmosphere.
Interdependence & Fate in the environment	Generally, the distribution of dissolved oxygen in the oceans is the net result of near equilibrium of atmospheric oxygen in the surface mixed layer and *in situ* biological processes. In oxygenated surface waters the dissolved oxygen saturation levels are dependent on water temperature and salinity (Grasshoff et al. 1999). *In situ* primary production may result in a diurnal signal in dissolved oxygen - during daytime photosynthesis increases concentrations while at night respiration decreases concentrations (Baumann and Smith, 2018). Often wastewater's oxygen-related characteristics are presented, for example as a five-day biochemical oxygen demand (BOD) or chemical oxygen demand (COD). These parameters give an indication of the amount of oxygen which might be consumed by a wastewater plume when discharged into a receiving water body. However, in receiving marine waters it is more appropriate to measure the actual amount of oxygen in solution, expressed as dissolved oxygen (DO) (Lusher et al. 1984).

Method	Dissolved oxygen is best measured using a calibrated *in situ* probe. Water samples can be taken to conduct a Winkler titration. However, care should be taken when sampling sub-surface waters to prevent aeration (e.g. use flow through system to collect sample) (Strickland and Parsons 1972). Unit: mg/ℓ (where DO is recorded in mℓ/ℓ it can be converted to mg/ℓ by multiplying with 1.4290 divided by density of seawater at specific temperature).

Impacts and Thresholds

Biota	Range (mg/ℓ)	Effects	Reference
Coral	4.0 - 4.5	Optimum range for coral productivity	Edwards (1987)
Shrimp	0.5 - 1.2	Lethal range from *Penaeid* adults	Allan and Maguire (1991) Chamberlain (1988)
	3.7	Level necessary for normal biological functioning in *Penaeus monodon* (adult)	Chamberlain (1988)
	>4	Tolerable range for adults of Penaeid family (adult)	Evans (1993)
	0.74	Lethal concentration for *Penaeus chinensis* juveniles	Chen and Nan (1992)
	0.9	LC$_{50}$ (96hrs) concentration for *P. monodon* juveniles	Allan and Maguire (1991)
	2.2	Critical concentration for *P. monodon* juveniles	Chamberlain (1988)
Abalone	<4	Mortality of abalone adults	Hahn (1989)
	>110	Adults display abnormal behaviour	Hahn (1989)
	>150	Prolonged exposure results in death	Hahn (1989)
Rock Lobster	0.4	Critical limit for *Palinurus* sp.	Harvey and Przybylak (1985), Wessels (1993)
	2	Significant mortality in *Palinurus* sp.	Harvey and Przybylak (1985), Wessels (1993)

pH

Interim Target	**pH range defined by the 20%ile and 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
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 less than seven, water is acidic, while at a pH greater than seven, water is alkaline.
Natural occurrence	The pH of seawater typically ranges between 7.9 and 8.2 (Huguenin and Colt 1989). Seawater in equilibrium with atmospheric CO_2 is slightly alkaline, with a pH of about 8.1 – 8.3. The pH may rise through rapid uptake of CO_2 during photosynthesis (Open University 1989). *In situ* primary production, therefore, may result in a diurnal signal in pH where during daytime photosynthesis increases levels, while at night respiration decreases levels in water (Baumann and Smith, 2018).
Interdependence & Fate in the environment	Aqueous solutions containing salts of weak acids or bases, such as seawater, show a resistance to pH change (known as buffering) (Riley and Skirrow 1975). The pH of water can be affected by algal photosynthesis – algae extract CO_2 from the water, decreasing the carbonic acid concentration and increasing the pH in the process.
Method	pH is best measured using a calibrated *in situ* probe, but can also be measured using a probe in the laboratory. Unit: Unitless ($\log_{10}$ of the hydrogen ion concentration)

Impacts and Thresholds

Biota	Range	Effects	References
Coral	7.2	Decreased calcification rate in *Stylophora pistillata*	Venn et al. (2013)
	7.3	Shift in associated bacterial community in *Acropora eurystoma* towards pathogenic-type bacteria	Meron et al. (2011)
	6.2	Shift in associated bacterial community in *Porites compressa* towards pathogenic-type bacteria	Vega-Thurber et al. (2009)
Molluscs	7.1- 7.8	Reduction in settlement of benthic molluscs	Gigliano et al. (2010)

Total Suspended solids (TSS)

Interim Target	**Total suspended solid (TSS) defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events**
Description	TSS is a measure of water clarity and refers to particulate inorganic and organic matter that is in suspension in the water column.
Natural occurrence	Naturally occurring suspended materials include fine inorganic (e.g. silt and clays) and organic matter (e.g. plankton and other microscopic organisms). These are usually more evident during stormy conditions, plankton blooms and periods of high river runoff. TSS may also be introduced to the water column through resuspension of natural bottom debris and sediment during turbulent conditions, usually as a result of strong wind and

	wave action.
Interdependence & Fate in the environment	Suspended solids are usually kept in suspension as their density is like that of the water. However, suspended solids may settle from the water column and be deposited onto sediments under calmer conditions.
Method	Suspended solids are determined gravimetrically by collecting the suspended matter from a known volume of seawater (usually one litre) onto GF/C glass fibre filter paper (Standard Methods 1989). It is critically important to rinse the filter with deionised water prior to drying to wash out salts that may crystalize on the filter, resulting in an over-estimation of the suspended solids concentration. Unit: mg/ℓ

Impacts and Thresholds

Suspended solids (e.g. clay, silt and organic matter, plankton and other microscopic organisms) interfere with light penetration and thus cause turbidity. When light penetration is blocked, photosynthesis can be reduced, affecting the productivity of marine flora such as seagrasses. Suspended solids also can smother aquatic organisms, and carry contaminants, such as metal and toxic organic compounds. High suspended solids concentrations may also contribute to increased water temperature through greater adsorption of heat. Further, lower visibility can affect predator–prey interactions, affecting foraging efficiency and prey escape behaviour.

Turbidity

Interim Target	**Turbidity is defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), considering possible differentiation between seasons or episodic events.**
Description	Turbidity is another measure of water clarity and is caused by colloidal suspensions (particle size between 0.001 µm and 0.1 µm) giving water a 'murky' appearance.
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 sediment deposits during turbulent conditions caused by strong wind and wave action.
Interdependence & Fate in the environment	Owing to the high salt content of seawater, natural colloidal suspensions (causing turbidity) usually coagulate with specific ions and precipitate out.
Method	Turbidity is best measured using a calibrated *in situ* probe, but can also be measured using a turbidimeter in the laboratory. Unit: NTU (Nephelometric turbidity units) or Formazin Nephelometric Unit (FNU), which are similar in that both measure scattered light at 90 degrees from the incident light beam, but the FNU is measured with an infrared light source method whereas NTU is measured with a white light.

Impacts and Thresholds

High turbidity reduces light penetration, which may reduce photosynthesis, and affect the productivity of marine flora such as seagrasses. Associated colloidal matter also can smother aquatic organisms, and carry contaminants, such as metal and toxic organic compounds. Such matter may also contribute to increased water temperature through greater adsorption of heat. Further, lower visibility can affect predator–prey interactions, affecting foraging efficiency and prey escape behaviour.

Inorganic nutrients

Dissolved Nitrite

Interim Target	**The nitrite (NO_2^-) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events**
Description	Nitrite (NO_2^-) occurs in seawater as an intermediate compound in the microbial reduction of nitrate, or in the oxidation of ammonia (Grasshoff et al. 1976): $NO_3^- \leftrightarrow \mathbf{NO_2^-} \leftrightarrow NO \leftrightarrow N_2O \leftrightarrow N_2$ or $NH_4^+ \leftrightarrow \mathbf{NO_2^-} \leftrightarrow NO_3^-$
Natural occurrence	The natural concentration of NO_2^--N in seawater is usually very low at < 1.4 µg/ℓ. However, in zones where dissolved oxygen concentrations are low, higher NO_2^--N concentrations may occur. Following upwelling, concentrations can also increase, indicative of higher primary production (Grasshoff et al. 1976).
Interdependence & Fate in the environment	Low dissolved oxygen concentrations favour the formation of nitrite. Nitrite photolysis gives rise to a 10^4 fold supersaturation of nitrogen oxide in water compared with atmospheric levels (Riley and Chester 1983).
Method	NO_2^- in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff et al. 1983). Unit: µg/ℓ NO_2^--N or µmol/ℓ NO_2^--N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).

Impacts and Thresholds

Biota	Range (µg/ℓ as N)	Effects	References
Coral	14 000 (Total DIN)	Maximum limit for coral productivity	Lapointe et al. (1992)
Shrimp	100 - 250	Safe level of nitrite for Penaeid adults	Chamberlain (1988), Lee and Wickens (1992)
	100 – 300	Concentration required for maturation of Penaeid broodstock	Shrimp Farming Short Course (1990)
	110	Safe level for *Penaeus monodon* larvae	Chen and Chin (1988)
	1 360	Safe level for *P. monodon* post-larvae	Chen and Chin (1988)
	2 300	Safe concentration for *Penaeus chinensis* juveniles	Chen et al. (1990a)
	3 800	Safe concentration for *P. monodon* juveniles	Chen and Lei (1990)
	10600	Safe concentration for *P. monodon* adolescents	Chen et al. (1990a)
	171 000	LC$_{50}$ value (over 96 hrs) for *P. monodon* adolescents	Chen et al. (1990a)
Rock Lobster	5 000	Favourable concentration for *Palinurus* sp.	Wessels (1993)
The toxicity of nitrite, while still formidable, is significantly reduced in seawater due to the high concentration of chloride and calcium (Huguenin and Colt 1989).			

Dissolved Nitrate

Interim Target	**The nitrate (NO_3^-) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Description	Nitrate (NO_3^-) is the final oxidation product of inorganic nitrogen compounds in water and is the only thermodynamically stable oxidation level of nitrogen in water in the presence of oxygen (Grasshoff et al. 1976): $N_2 \leftrightarrow NO_2^- \leftrightarrow NO \leftrightarrow N_2O \leftrightarrow \mathbf{NO_3^-}$ **or** $NH_4^+ \leftrightarrow NO_2^- \leftrightarrow \mathbf{NO_3^-}$
Natural occurrence	Natural concentrations of NO_3^--N in oxygenated seawater have been found to range between 1.4 – 630 µg/ℓ. Concentrations usually increase with depth, i.e. surface depletion versus enrichment at depth (Grasshoff et al. 1983). Nitrate is depleted in surface waters where biological production is high, usually the limiting nutrient in seawater (i.e. when this nutrient is exhausted, production ceases) (Open University 1989). In upwelling areas, the supply rate of NO_3^--N is considerably higher than uptake rates, resulting in high net concentrations. For this reason, the NO_3^- concentration can be applied as an indicator for upwelling, together with temperature measurements (Grasshoff et al. 1976).
Interdependence & Fate in the environment	In many marine waters, nitrate is considered 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 primary producers. If light penetration 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 (Grasshoff et al. 1976).
Method	NO_3^--N in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff et al. 1983). Unit: µg/ℓ NO_3^--N or µmol/ℓ NO_3^--N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).

Impacts and Thresholds

Biota	Range (µg/ℓ as N)	Effects	References
Coral	14 000 (Total DIN)	Maximum limit for coral productivity	Lapointe et al. (1992)
Shrimp	1 000-2 000	Favourable range for Penaeid adults	Lee and Wickens (1992)
	10 - 40	Concentration required for maturation of Penaeid broodstock	Shrimp Farming Short Course (1990)
	1 000	High mortality rate of *Penaeus monodon* larvae within 40 hrs	Muir et al. (1991)

Dissolved total ammonia

Interim Target	**The total ammonia (NH_3 plus NH_4^+) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events.**
Potential interim targets for WIO (Total inorganic N)	**Seagrass** **500 µg/ℓ** **Mangroves** **1 000 µg/ℓ** **Coral reefs** **15 µg/ℓ**
Description	In aqueous solutions ammonia is present in two forms, ionised (NH_4^+) and unionised (NH_3) (Bower and Bidwell 1978): $NH_4^+ + H_2O \leftrightarrow NH_3 + H_3O^+$ NH_3 is regarded as the toxic form of ammonia because it is uncharged and lipid soluble,

	whereas hydrated ammonium ions ($NH4^+$) are non-toxic and acts as a nutrient to primary producers.
Natural occurrence	Ammonia is excreted directly by animals together with urea and peptides. The concentration of ammonia in seawater shows considerable variations and can change rapidly. In oxygenated unpolluted seawater, Total ammonia-N concentrations are usually low, but in deeper anoxic water, concentrations can be naturally high (Grasshoff et al. 1976).
Interdependence & Fate in the environment	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. The relative proportions of NH_3 and NH_4^+ in solutions depend on temperature, pH, and to a lesser extent salinity. The concentration of NH_3 increases with elevated temperatures and pH values, and decreases with higher salinities. At salinities common in seawater (~35) there is up to one fifth less unionised ammonia (NH_3) than in freshwater at the same temperature and pH. Thus, in seawater Total ammonia-N is primarily present as NH_4^+ (Bower and Bidwell 1978).
Method	Total ammonia-N (NH_3-N plus NH_4^+-N) in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff et al. 1983). Unit: µg/ℓ Total Ammonia-N or µmol/ℓ Total Ammonia-N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).

Impacts and Thresholds

Biota	Range (µg/ℓ as N)	Effects	References
Coral	14 000 (Total DIN)	Maximum limit for coral productivity	Lapointe et al. (1992)

Dissolved reactive phosphate

Interim Target	**The reactive phosphate (PO_4^{2-}) concentration defined by the 80%ile of an appropriate data set from a reference system (i.e. near-pristine site in study area or comparable site elsewhere), also considering possible differentiation between seasons or episodic events**
Description	Reactive phosphate (or inorganic phosphate) is the most common form of phosphorous (P) used by primary producers, and therefore provides a good indication of the amount of available P for photosynthesis. The most probable reactive phosphate species (PO_4^{2-}) in oxygenated seawater are H_2PO_4, $NaHPO_4$ and $MgHPO_4$ (Riley and Skirrow 1975).
Natural occurrence	Phosphorus (P) occurs naturally and abundantly in rocks and other mineral deposits and is gradually released by the weathering rocks and mineral deposits forming ions soluble in water. In seawater, P is typically found as inorganic phosphorus (referred to as inorganic phosphate or reactive phosphate), but also as particulate and dissolved organic forms (Grasshoff et al. 1976). Natural concentrations of PO_4^{2-}-P in seawater can vary greatly, but have been found to range between 31 and 109 µg/ℓ, usually depleted in surface waters with bottom waters more enriched (Riley and Chester 1983). Upwelling also introduces higher PO_4^{2-}-P concentrations into surface waters.
Interdependence & Fate in the environment	PO_4^{2-} is taken up by primary producers in the euphotic zone, contributing to the removal of this nutrient in surface waters. In turn, phytoplankton is consumed by zooplankton and other animals that package most of their waste products into faecal pellets. On the decomposition of organic matter, this nutrient is returned to the water column. Under anoxic conditions, precipitated P can be re-solubilised from sediments.
Method	PO_4^{2-}-P in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff et al. 1983). Unit: µg/ℓ PO_4^{2-}-P or µmol/ℓ PO_4^{2-}-P (the latter can be converted to µg/ℓ by multiplying with atomic mass of P, i.e. 31).

Impacts and Thresholds

Biota	Range (µg/ℓ as P)	Effects	References
Algae	6.7 - 45.3	Concentration for normal growth in *Ulva lactuca*, sublethal concentration and effects unknown.	Ho (1988)
Coral	1 400	Maximum limit for coral productivity	Lapointe et al. (1992)

Non-metallic inorganic toxicants

Total ammonia (as toxicant)

Interim Target	**Total ammonia-N (NH_3-N plus NH_4^+-N) concentration should not exceed 500 µg/ℓ (99% protection) or 910 µg/ℓ (95% protection)**
Description	In aqueous solution ammonia is present in two forms, ionised (NH_4^+) and unionised (NH_3) (Bower and Bidwell 1978): $NH_4^+ + H_2O \Leftrightarrow NH_3 + H_3O^+$

	NH_3 is regarded as the toxic form of ammonia because it is uncharged and lipid soluble, whereas hydrated ammonium ions ($NH4^+$) are non-toxic and acts as a nutrient to primary producers.
Natural occurrence	Ammonia is excreted directly by animals together with urea and peptides. The concentration of ammonia in seawater shows considerable variations and can change rapidly. In oxygenated unpolluted seawater, Total ammonia-N concentrations are usually low, but in deeper anoxic water, concentrations can be naturally high (Grasshoff et al. 1976).
Interdependence & Fate in the environment	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. The relative proportions of NH_3 and NH_4^+ in solutions depend on temperature, pH, and to a lesser extent salinity. The concentration of NH_3 increases with elevated temperatures and pH values, and decreases with higher salinities. At salinities common in seawater (~35) there is up to one fifth less unionised ammonia (NH_3) than in freshwater at the same temperature and pH. Thus, in seawater Total ammonia-N is primarily present as NH_4^+ (Bower and Bidwell 1978).
Method	Total ammonia-N (NH_3-N plus NH_4^+-N) in seawater is usually determined photometrically using a water sample filtered through a 0.45 µm filter (Grasshoff et al. 1983). Unit: µg/ℓ Total Ammonia-N or µmol/ℓ Total Ammonia-N (the latter can be converted to µg/ℓ by multiplying with atomic mass of N, i.e. 14).

Impacts and Thresholds

Biota	Range (µg/ℓ as N)	Effect	Reference
Amphipoda	49 000	LC$_{50}$ value (96 hrs) for *Ampelisca abdita*	Kohn et al. (1994)
Shrimp	<20	Tolerable range for Penaeid adults in the presence of nitrite	Lee and Wickens (1992)
	80	Safe level for *Penaeus monodon* adults	Chen et al. (1990a)
	90 – 110	Safe level for Penaeid adults	Lega et al. (1992)
	110	Maximum level for Penaeid adults over 40 days	Chen and Lin (1992)
	450	Growth rate of Penaeid shrimps drastically declined by 50%	Kungvankij et al. (1986a)
	12 900	LC$_{50}$ value (24 hrs) for *Palaemonetes pugio*	Burton and Fisher (1990)
	6 100 – 8 100	LC$_{50}$ value (96 hrs) for *Penaeus japonicus* zoeae	Lin et al. (1993)
	10	Safe level for *Penaeus monodon* nauplii	Chin and Chen (1987)
	20 - 40	Concentration required for maturation of broodstock in Penaeid larvae	Shrimp Farming Short Course (1990)
	32	Maximum limit for ammonia to *P. monodon* post-larvae	Chen and Tu (1991)
	52 700	LC$_{50}$ value (96 hrs) for *P. japonicus* juveniles	Lin et al. (1993)
	60 - 183	*P. monodon* post-larvae displayed a 5% decline in growth and body condition	Chen et al. (1990b)
	100	Safe level for *P. monodon* juveniles	Chen and Lei (1990)
	>210	*P. monodon* displays a 5% reduction of growth rates over 3 weeks	Evans (1993)
	350	Maximum limit of ammonia to *P. japonicus* juveniles	Chen and Kou (1992)
	1040	LC$_{50}$ value (96hrs) for *P. monodon* post-larvae	Chin and Chen (1987)
	1 200 – 2 570	LC$_{50}$ value (48hrs) for *P. pugio* juveniles	Burton and Fisher (1990)
	4 050	LC$_{50}$ value (24 hrs) for *Scylla serrata* zoeae	Neil et al. (2005)
	6 540	100% mortality of *S. serrata* larvae	Neil et al. (2005)
	320–512	Safe ammonia level for *Homarus americanus* adult	Young-Lai et al. (1991)
	720 – 3 250	LC$_{50}$ value (96 hrs) for *H. americanus* larvae	Young-Lai et al. (1991)
	3 500	Tolerable level for *Palinurus* sp.	Wessels (1993)
Molluscs	100	Favoured level for molluscan growth, above which severe physiological functioning is altered	Barnabe (1989)
Abalone	500	Growth inhibition in abalone	Hahn (1989)
Fish	>100	Growth inhibition of finfish	Morimura (1993), Tarazona et al. (1991)

Free Chlorine (Total Bromine)

Interim Target	**Total free chlorine should not exceed 0.5 µg/ℓ***
Description	Chlorine (Cl_2) is a chemical which is used as a disinfectant. Reactive oxygen species that are formed during the chlorination of seawater include hypobromous acid, hypobromite ion and bromamines
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, for example by algae (Abarnou and Moissec 1992).
Interdependence	Seawater chlorination differs greatly from that of freshwater primarily due to the high

& Fate in the environment	bromide concentration of seawater (~67 mg/ℓ). In the presence of bromide, free chlorine cannot exist in seawater as it instantaneously oxidises bromide into bromine (which also acts as disinfectant harmful to marine organisms. Under typical seawater conditions (pH between 7.8 and 8.2), the un-dissociated form (HOBr) predominates with consequently higher reactivity and biocidal activity (Abarnou and Moissec 1992). In coastal waters, ammonia concentrations are usually lower (typically < 28 µg N/ℓ) N) and therefore bromine remains as hypobromous acid. When ammonia increases, bromamines may be formed. At pH 8.1, ammonia and bromine react 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 (Abarnou and Moissec 1992). Hypobromous acid can also disproportionate into bromide and bromate. Bromate is formed during seawater chlorination and this reaction is accelerated by sunlight (Abarnou and Moissec 1992). Chlorine can also combine with phenolic compounds to form chlorophenols, some of which can taint fish flesh at concentrations as low as 0,001 mg/ℓ (Hawkins 1981). Paradoxically, free chlorine is therefore not found in seawater because of instantaneous bromide oxidation or combination with phenolic compounds to form chlorophenols.
Method	Free Chlorine cannot exist in seawater as it instantaneously oxidises bromide into bromine. Therefore, when measuring 'free chlorine' in seawater, total bromine should be measured (which can be converted to chlorine equivalents using an appropriate *in situ* probe (Process Instruments 2017). Unit: ug/ℓ as total bromine translated into free chlorine equivalent

** No QT provided for Australia and New Zealand, recommend Canadian QT (CCME 199, as revised 2002)*

Impacts and Thresholds

Biota	Range (µg/ℓ as N)	Effect	Reference
Phytoplankton	>400	Growth inhibition in *Skeletonema costatum*	Carpenter et al. (1972)
	1 500 – 2 300	Lethal range for *S. costatum*	Carpenter et al. (1972)
	20 000	Lethal range for *Chlamydomonas* spp.	Carpenter et al. (1972)
Molluscs	<300	Valve closure for 6 hrs in *Donax serra*	Hill (1977)
	>600	Immediate valve closure for 8 days in *D. serra*	Hill (1977)
	600 – 1 200	>90% mortality of *D. serra* after 14 days of exposure	Hill (1977)
Shrimp	37	LC_{50} value (48 hrs) for *Palaemonetes pugio* (adults)	Roberts and Gleeson (1978)
Rock lobster	410 – 2 900	LC_{50} value (over 48 hrs) for *Homarus americanus* larvae	Capuzzo (1979)

Free Cyanide

Interim Target	**Free cyanide concentration should not exceed 2 µg/ℓ (99% protection) or 4 µg/ℓ (95% protection)**
Description	Free cyanide is bioavailable and refers to either molecular hydrogen cyanide (HCN) or ionic cyanide (CN^-), with HCN being the most toxic form (WHO 1982). At a pH<7 free cyanide is present entirely as HCN. Above pH 11, free cyanide exists entirely as CN^-. In seawater the equilibrium species are HCN (90 %) and CN^- (10%)
Natural occurrence	No information could be obtained on natural occurrence of cyanide in marine waters.
Interdependence & Fate in the environment	The form of cyanide is dependent on pH, but is also influenced by temperature, as well as other properties such as constituents dissolved oxygen, salinity, sunlight and complexing agents. There is therefore a possibility of a multitude of complex metallo-cyanides existing in aquatic environments, each with its own physical and chemical properties. The toxicity of cyanide increases if the pH levels decreases, forming extremely toxic HCN (WHO 1982).
Method	Common methods for measuring cyanide include colorimetry, titrimetry and potentiometry (ANZECC 2000). Unit: µg/ℓ as CN^-

Impacts and Thresholds

Cyanide interferes with cellular respiration. Chronic effects of cyanide include developmental abnormalities and lower reproductive potential, and negatively affect endocrine function. However, no specific data relevant to WIO region could be obtained.

Fluoride

Interim Target	**Fluoride concentration should not exceed 5 000 µg/ℓ***
Description	Fluoride (F^-) is the stable form of fluorine, a very reactive element.
Natural occurrence	Fluoride occurs at a relatively high concentration in seawater, where concentrations of 1 300 µg/ℓ have been reported (Slooff et al. 1988).

Interdependence & Fate in the 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 its low reactivity in seawater, with a fluoride/chlorinity ratio (in parts per thousand) of 6.7 ± 0.1 x 10^{-5}. However, in some localised bottom waters the ratio may reach 9.5 x 10^{-5} (Riley and Chester 1983). Deviations from this narrow fluoride/chlorinity ratio generally indicate that man-made pollution is occurring or that seawater is mixing with fresh water in estuarine areas.
Method	In seawater, fluoride can be determined by molecular absorption spectrophotometry (Gomez et al. 1988) or using an ion-selective electrode. Unit: µg/ℓ

** No QT provided for Australia and New Zealand, recommend limit provided by Slooff et al. (1988)*

Impacts and Thresholds

Concentrations below 5 000 µg/ℓ are not expected to have detrimental effects on marine organisms (Slooff et al. 1988)

Hydrogen sulphide

Interim Target	**Hydrogen sulphide concentration should not exceed 2 µg/ℓ***
Description	Hydrogen sulphide is a poisonous gas that readily dissolves in water. No heterotrophic life can exist in water containing hydrogen sulphide and affected areas are, therefore, transformed into oceanic 'deserts' (Grasshoff et al. 1976). The speciation of H_2S in seawater at 25 °C, pH of 8.1 and salinity of 35 is H_2S (3.07 %), HS^- (96,93 %) and S^{2-} (1.9 x 10^{-4} %) (Millero 1976).
Natural occurrence	Hydrogen sulphide is a frequent anoxic water component, attaining concentrations as high as 70 mg/ℓ under extreme conditions (Hutzinger 1980).
Interdependence & Fate in the environment	Hydrogen sulphide behaves as a weak acid and is present in natural waters as both the un-dissociated compound and the HS^- ion (below a pH of 12 the concentration of S^{2-} ion is negligible). Hydrogen sulphide is very volatile and reacts rapidly with oxygen. Hydrogen sulphide is produced in anaerobic environments by the activities of sulphate-reducing bacteria, which derive energy from a process of anaerobic respiration: $2\ CH_2O + SO_4^{2-}\ \underline{\text{desulfovibrio}}\ 2\ HCO_3^- + H_2S$ The solubility of hydrogen sulphide in seawater is dependent on temperature and salinity (Douabul and Riley 1979). 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 (Grasshoff et al. 1976).
Method	Hydrogen sulphide in seawater can be measured photometrically or titrimetrically, with the photometric method being most sensitive and accurate (Grasshoff et al. 1983). Unit: µg/ℓ

** No QT provided for Australia and New Zealand, recommend QT of US-EPA (US-EPA 2002, as updated)*

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Shrimp	<0.002	Favoured level for Penaeid adults	Lee and Wickens (1992)
	0.033	Safe level for *Penaeus monodon* (adults)	Chamberlain (1988)
	4	Severe mortality in Penaeid adults	Chamberlain (1988), Lee and Wickens (1992), Clark and Griffiths (1990)
	0.117	LC_{50} value (96 hrs) for *Penaeus indicus* juveniles at pH 6 - 6.3	Gopakumar and Kuttyamma (1996)
	0.189	LC_{50} value (96 hrs) for *P. indicus* juveniles at pH 7 - 7.3	Gopakumar and Kuttyamma (1996)
	4 000	100% mortality in *Penaeus japonicus*	Gopakumar and Kuttyamma (1996)
	5 900	No effect on growth or survival of *Penaeus indicus*	Hemens et al. (1975)
Crab	5 900	No effect on growth or survival of *Tylodiplax blephariskios*	Hemens et al. (1975)
Bivalve	2 400	No lethal effects in *Mytilus edulis* after 42 days	Wright and Davidson (1975)
	10 000	75% mortality in in *Mytilus edulis* after 14 days	Wright and Davidson (1975)
	30 000	100% mortality in in *Mytilus edulis* after 21 days	Wright and Davidson (1975)
Abalone	50	Growth inhibition in abalone	Hahn (1989)
	500	Mortalities in abalone	Hahn (1989)

Metals

Arsenic (As)

Interim Target	**Water**	**Total As[III] concentration should not exceed 2.3 µg/ℓ***
		Total As[VI] concentration should not exceed 4.5 µg/ℓ*
	Sediment	**As concentration should not exceed Threshold Effect Level = 7.24 µg/g (dry weight)**
		Probable Effect Level = 41.6 µg/g (dry weight)
Description	The dominant forms of inorganic As in seawater are arsenite (As[III]) (regarded as the most toxic and the predominant form under anaerobic conditions) and arsenate (As[V]) (the stable form in aerobic conditions). At typical pH of surface seawater (~8.2) As(III) exists mainly as an uncharged species, e.g. As(OH) and As (V) as the ion HAsO, the latter should be the predominant form at equilibrium (Hutzinger 1982, Riley and Chester 1983, Neff 1997).	
Natural occurrence	The main natural pathways through which arsenic enters the marine environment from land are through weathering, including solubilisation and transport of sediment, and vulcanism (WHO 1982). The concentration of total arsenic in clean coastal and ocean waters is 1 000-3 000 µg/ℓ, with a mean of about 1700 µg/ℓ (Andreae 1979, Andreae and Andreae 1989, Li 1991). Lowest As concentrations occur in the spring when dissolved arsenate is scavenged by phytoplankton and suspended particles; concentrations increase in winter due to the remobilisation of arsenic from sediments. The behavior of arsenate resembles that of phosphate [29], which is known to undergo seasonal remineralization and mobilization, with peak remobilisation often in late summer [30]. A good correlation usually exists between concentrations of arsenate and phosphate in ocean water, suggesting that the vertical distribution of arsenic in the ocean is controlled by biological activity.	
Interdependence & Fate in the environment	In oxygenated seawater, arsenic usually present as arsenate (As[V]), but under reducing conditions arsenite (As [III]) predominates.	
Method	Arsenic in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), ICP/mass spectrometry (MS), and LC/MS/MS. The strength of acids used to digest sediment will influence the concentration determined. Unit: Total As - µg/ℓ (water) and µg/g dry weight (sediment)	

** Not sufficient data to derive a reliable QT (Australia and New Zealand Government, 2018), these should be treated as low reliability QT*

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Phytoplankton	75	Phytoplankton biomass reduced	Eisler (1988)
	130	Growth inhibition in *Skletonema costatum*	Eisler (1988)
	1 000	*Tetraselmis chui* and *Hymenomonas carterae* are not affected	Bottino et al. (1978)
Algae	19 – 20	Reduced growth in algae	Eisler (1988)
	75	Reduction of chlorophyll-*a* in *Thalassiosira aestivalis*	Eisler (1988)
	300	Death of red algae species (*Champia parvula*)	Eisler (1988)
	580	Spore development of red algae *Plumaria elegans* stopped	Eisler (1988)
	27 300	LC_{50} value (96 hrs) for mullet species (*Chelon labrosus)*	Eisler (1988)
	60 000	LC_{50} value (192 hrs) for *Macoma balthica*	Eisler (1988)
Molluscs	2 000	Reduction of oxygen consumption in mud snail *Nassarius absoleus*	Eisler (1988)
	3 490	LC_{50} value (96 hr) for juvenile scallops *Argopecten irradians*	Nelson et al. (1976)
Crustacea	232	LC_{50} value (96 hr) for *Cancer* magister larvae	Martin et al. (1981)
	1 100 2 750	Acute toxicity to amphipods *Corophium insidiosum* and *Elasmopus bampo*	Reish (1993)
	7 500	Highest concentration tolerated by crab *Scylla serrata* for 96 hr without mortalities	Krishnaja et al. (1987)
	17 000	LC_{50} value (96 hr) for crab *S. serrata*	Krishnaja et al. (1987)
	2 319	Acutely lethal concentration for mysid *Mysidopsis bahia*	US-EPA (1994)
	25 000	Concentrations in excess required to affect	Madsen (1992)

Biota	Range (µg/ℓ)	Effect	Reference
		survival of shrimp *Crangon crangon* (adult)	

Cadmium (Cd)

Interim Target	**Water**	**Total Cd concentration should not exceed 0.7 µg/ℓ (99% protection) or 5.5 µg/ℓ (95% protection)**
	Sediment	**Cd concentration should not exceed Threshold Effect Level = 0.68 µg/g (dry weight)**
		Probable Effect Level = 4.21 µg/g (dry weight)
Description	The most probable main species of cadmium in oxygenated seawater is $CdCl^+$, $CdCl_2$ and $CdCl_3^{-1}$ (Neff 2002).	
Natural occurrence	Weathering and erosion result in rivers transporting large quantities of cadmium to the world's oceans. Deep sea vulcanism is also a source of cadmium. Concentrations ranging between 0.11 x 10^{-3} and 0.6 µg/ℓ have been reported for the most probable species ($CdCl_2$) in oxygenated seawater with a salinity of 35, while reported levels in marine sediment porewater range between 30 and 1 000 µg/ℓ (Riley and Chester 1983; WHO 1992a).	
Interdependence & Fate in the environment	Up to about 80 %, but usually less, of the cadmium in coastal seawater is complexed with dissolved or colloidal organic matter (Muller 1996, 1998). The relative amounts of dissolved cadmium in the different cadmium complexes vary with seawater salinity (Neff 2002). Increasing temperature increases the uptake and toxic impact of Cd. A decrease in Cd toxicity with increased salinities has been attributed to chloride complexation. The solubility of cadmium decreases in anoxic waters due to the presence of hydrogen sulphide (CdS is very insoluble). The organic content of seawater generally decreases the uptake and toxicity of Cd by binding and reducing its availability to organisms. (WHO 1992a, de Baar et al. 1994, Yeats et al. 1995). The vertical distribution of Cd in ocean waters is characterised by surface depletion and deep-water enrichment as a result of absorption of cadmium by phytoplankton in surface waters, which then settles to bottom sediments from where is it subsequently released. 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 and shellfish (WHO 1992a).	
Method	Cadmium in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Cd - µg/ℓ (water) and µg/g dry weight (sediment)	

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Diatoms	60	Growth inhibition in Chaetoceros species	Ismail et al. (2002)
Coral	5 000	Reduction of fertilization in *Acropora tenuis*	Reichelt-Brushett and Harrison (2005)
Copepod	1 370	LC $_{50}$ value (over 24 hrs) for *Acartia simplex*	Arnott and Ahsanullah (1979)
Polychaete	2 800	LC_{50} value (96 hrs) for *Sabellaria clandestinus* (adult)	Mohan et al. (1984)
Amphipod	1 320	LC_{50} value (96 hrs) for *Ampelisca abdita*	Kohn et al. (1994)
Molluscs	170 -250	LC_{50} value (over 96 hrs) for *Donax faba*	Ong and Din (2001)
	>1 000	Inhibition of enzyme activity in *Donax trunculus*	Mizrahi and Achituv (1989)
	530	LC_{50} value for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Pesch and Stewart (1980)
	1 010	LC value for estuarine clams (species not reported)	Bonifacio and Montaño (1998)
Shrimp	1 850	LC_{50} value (over 168 hrs) for *Palaemon* sp. (adult)	Ahsanullah (1976)
	200 - 400	LC_{50} value for *Palaemon pugio (*adult)	Pesch and Stewart (1980)
	420 - 760	LC_{50} (over 48 hrs) for *Palaemon pugio* (adult)	Burton and Fisher (1990)
	200	Severe growth and survival of *Penaeus japonicus* larvae	Brown and Mclachlan (1990)
	490	LC_{50} value (14 days) for *Callianassa australiensis*	Ahsanullah and Arnott (1978)
	800	LC_{50} value (48 hrs) for *Palaemontes vulgaris* juveniles	Burton and Fisher (1990)
	1 300	LC_{50} value (48 hrs) for *Palaemontes pugio* juveniles	Burton and Fisher (1990)
	3 100	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda (2000)
Mollusc	1 800	LC_{50} value (96 hrs) for *Donax spiculum* (adult)	Mohan et al. (1984)

Biota	Range (µg/ℓ)	Effect	Reference
	2 500	LC$_{50}$ value (96 hrs) for *Perna viridis* (adult)	Mohan et al. (1984)
	5 600	LC$_{50}$ value (96 hrs) for *Modiolus carvalhoi* (adult)	Mohan et al. (1984)
Echinoderms	95	Reduction of fertilization rate by 50% in *Diadema setosum*	Reichelt-Brushett and Harrison (2005)
	>100	Reduction of fertilization rate by 50% in *Echinometra mathaei*	Reichelt-Brushett and Harrison (2005)
Crab	1 350	LC$_{50}$ value (96 hrs) for *Emerita* sp (adult)	Mohan et al. (1984)
Fish	27 300	LC$_{50}$ value for milkfish (species not reported)	Bonifacio and Montaño (1998)

Chromium (Cr)

Interim Target	**Water**	**Total Cr[III] concentration should not exceed 7.7 µg/ℓ (99% protection) or 27 µg/ℓ (95% protection)**
		Total Cr[VI] concentration should not exceed 0.14 µg/ℓ (99% protection) or 4.4 µg/ℓ (95% protection)
	Sediment	**Cr concentration should not exceed Threshold Effect Level = 52.3 µg/g (dry weight)**
		Probable Effect Level = 160 µg/g (dry weight)
Description	Cr occurs naturally in the elemental state (Cr[0]) or in the trivalent oxidation (Cr[III]) state. Almost all the hexavalent chromium (Cr[VI]) in the environment arises from human activities, the most probable species being CrO_4^{2-} and $NaCrO_4^-$. Cr[III] is an essential element, while Cr[VI] is extremely toxic. These two oxidation states have very different properties and biological effects on living organisms and should therefore be examined separately (a generalisation of biological effects of Cr as an element cannot be made (45).	
Natural occurrence	Concentrations ranging between 0.1 and 2 µg/ℓ have been reported for the most probable species (CrO_4^{2-} and $NaCrO_4^-$) in oxygenated seawater with a salinity of 35 (Riley and Chester 1983; Riley and Skirrow 1975).	
Interdependence & Fate in the environment	The toxicity of Cr decreases with increasing pH (Riley and Skirrow 1975). The oxygen content influences the ionic state of Cr. In oxygenated seawaters, Cr should exist entirely as CrO_4^{2-}, while under anoxic conditions it is stable as Cr[III] (Riley and Chester 1983). As Cr[III] it forms insoluble compounds unless protected by complex formation. In theory 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]. Where the organic content of water is low, Cr should persist as Cr[VI] (WHO 1982; Riley and Skirrow 1975).	
Method	Chromium in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Cr[III] or Cr[VI] - µg/ℓ (water) and µg/g dry weight (sediment)	

Impacts and Thresholds

Biota	Range (µg/ℓ) Cr(III)	Effect	Reference
Diatom	>5	LC$_{50}$ value (72 hr) for *Nitzschia closterium*	Florence and Stauber 1991
Amphipod	5 560	LC$_{50}$ value (96 hr) for *Allorchestes compressa*	Ahsanullah (1982)
Copepod	5 900	LC$_{50}$ value (96 hr) for *Tisbe battagliai* (adult)	Hutchinson et al. (1994)
	1 600	LC$_{50}$ value (96 hr) for *Tisbe battagliai* (nauplii)	Hutchinson et al. (1994)
	19 300	LC$_{50}$ value (48 hr) for *Acartia clausi*	Moraitou-Apostolopoulou and Verriopoulos (1982)
Polychaete	12 500	LC$_{50}$ value (96 hr) for *Neanthes arenaceodentata* (juveniles)	Mearns et al. (1976)
Mollusc	10 300	LC$_{50}$ value (96 hr) for oyster *Crassostrea virginica* (embryos)	Calabrese et al. (1973)
	2	EC$_{50}$ – decreased filtering rate in mussel *Perna perna*	Watling and Watling (1982)
Fish	53 000	LC$_{50}$ value (96 hr) for *Aldrichetta forsteri* (juvenile)	Negilski (1976)
	5	Sperm damage to marine *Oncorhyncus mykiss*	Billard and Robaud, 1985

Copper (Cu)

Interim Target	**Water**	**Total Cu concentration should not exceed 0.3 µg/ℓ (99% protection) or 1.3 µg/ℓ (95% protection)**

	Sediment	**Cu concentration should not exceed Threshold Effect Level = 18.7 µg/g (dry weight)**
		Probable Effect Level = 108 µg/g (dry weight)
Description	The most probable main species of Cu in oxygenated seawater are $CuCO_3$, $CuOH+$ and Cu_2^+ (Riley and Chester 1983).	
Natural occurrence	A range between 0.03 and 2 µg/ℓ has been reported for the most probable species in oxygenated seawater with a salinity of 35 (Riley and Chester 1983). Generally, the concentration of copper in surface waters is lower than in deep waters, referred to as a nutrient type distribution (Riley and Chester 1983).	
Interdependence & Fate in the environment	Seawater can retain a maximum of 50 µg/ℓ of Cu, but at high concentrations is usually present in a colloidal form (Riley and Skirrow 1975a). A significant fraction of Cu^{2+} may exist as complexes with dissolved organic compounds which on degradation can result on the increase of free Cu (53). Anoxic near-shore sediments represent a significant sink for Cu when compared with the accumulation rates for pelagic sediments (Riley and Skirrow 1975). Cu^{2+} can also be adsorbed onto dead or living bacteria. 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 (Riley and Chester 1983).	
Method	Copper in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Cu - µg/ℓ (water) and µg/g dry weight (sediment)	

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Phytoplankton	>50 – 80	Inhibits 50% growth after 96 hrs in *Chaetoceros calcitrans*	Ismail et al. (2002)
	250	Growth inhibited over 10 – 14 days in *Phaeodactylum tricornutum*	Braek and Jensen (1976)
Diatoms	70	Growth inhibition in *Chaetoceros* sp.	Ismail et al. (2002)
Macroalgae	>10	Reduced growth rates of *Sargassum* seaweed	Joshi et al. (1982)
Copepod	200	LC_{50} (24 hrs) for *Acartia simplex*	Arnott and Ahsanullah (1979)
Shrimp	35 900	LC_{50} (48 hrs) for adult *Palaemonetes pugio*	Burton and Fisher (1990)
	50	Lethal level for Penaeid post-larvae	Shrimp Farming Short Course (1990)
	190	LC_{50} (over 14 days) for *Callianassa australiensis*	Ahsanullah et al. (1981)
	2 100	LC_{50} (48 hrs) for *Palaemonetes pugio* juveniles	Burton and Fisher (1990)
	2 500	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda, 2000
	3 130	LC_{50} (96 hrs) for juveniles of *Penaeus monodon* (salinity 15)	Chen and Lin, 1999
	7 730	LC_{50} (96 hrs) for juveniles of *Penaeus monodon* (salinity 25)	Chen and Lin, 1999
	2 820	EC_{50} (30 days) (50% reduced weight gain for juveniles of *P. monodon*)	Chen and Lin, 1999
	1 890	EC_{50} (60 days) (50% reduced weight gain for juveniles of *P. monodon*)	Chen and Lin, 1999
	5 000	Decreased feeding patterns in *P. monodon* juveniles	Chen and Lin, 1999
	900	Shortened time to first molt and decreased growth and molting frequency in *P. monodon* juveniles	Chen and Lin, 1999
	29	LC_{50} value (96 hrs) for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Nelson et al. (1976)
	51	LC_{50} value (96 hrs) for juvenile surf clams *Spisula solidissima* (Belonging to the family Mactridea)	Nelson et al. (1976)
	750 – 1 240	LC_{50} value (96 hrs) for *Donax faba*	Ong and Din (2001)
Coral	14.5 – 18.5	Reduction of fertilisation rate by 50% in *Goniastrea aspera*	Reichelt-Brushett and Harrison (2005)
	15.2	Reduction of fertilisation rate by 50% in A*cropora longicyathus.*	Reichelt-Brushett and Harrison (2005)
	17.4	Reduction of fertilisation rate by 50% in *Acropora millepora.*	Reichelt-Brushett and Harrison (2005)
	17.4	Reduction of fertilisation rate by 50% in *Acropora corporamillepora*	Reichelt-Brushett and Harrison (2005)

	24.9	Reduction of fertilisation rate by 50% in *Goniastrea retiformis*	Reichelt-Brushett and Harrison (2005)
	39.7	Reduction of fertilisation rate by 50% in *Acropora tenuis*	Reichelt-Brushett and Harrison (2005)
	48	LC_{50} value (96 hrs) of adult *Montipora verrucosa*	Reichelt-Brushett and Harrison (2005)
Abalone	40	100% mortality (within 48 hrs) of *Haliotis discus* larvae	Chamberlain (1988)
	50	LC_{50} value (96 hrs) for *Haliotis cracherodii* adults	Hahn (1989)
	65	LC_{50} value (96 hrs) for *Haliotis rufescens* adults	Hahn (1989)
	80	Mortalities in abalone larvae	Hahn (1989)
Rock lobster	95.5	LC_{50} value (24 hrs) for *Panulirus homarus*	Maharajan and Vijayakumaran (2004)
	158.5	LC_{50} value (96 hrs) for *Panulirus homarus*	Maharajan and Vijayakumaran (2004)
Echinoderms	7	Reduction of fertilization rate by 50% in *Diadema setosum*	Reichelt-Brushett and Harrison (2005)
	14	Reduction of fertilization rate by 50% in *Echinometra mathaei*	Reichelt-Brushett and Harrison (2005)

Lead (Pb)

Interim Target	**Water**	**Total Pb concentration should not exceed 2.2 µg/ℓ (99% protection) or 4.4 µg/ℓ (95% protection)**
	Sediment	**Pb concentration should not exceed Threshold Effect Level = 30.2 µg/g (dry weight)**
		Probable Effect Level = 112 µg/g (dry weight)
Description	Pb is not known to be an essential trace element, with most probable species in marine waters being $PbCO_3$, $(PbCO_3)^{2-}$ and $PbCl^+$ (Riley and Chester 1983).	
Natural occurrence	Natural sources of Pb include weathering of rocks, vulcanism and forest fires. In deep marine waters, reported Pb concentrations range between 0.0004 and 3 µg/ℓ (Riley and Chester 1983; Riley and Skirrow 1975).	
Interdependence & Fate in the environment	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 Pb. In anaerobic sediments, most of the Pb is present as PbS (Hutzinger 1980).	
Method	Lead in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Pb - µg/ℓ (water) and µg/g dry weight (sediment)	

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Phytoplankton	>5000	LC_{50} value (96 hrs) for *Phaeodactylum tricornutum*	Eisler (1988)
	5.1	Growth reduced by 50% (over 12 days) in *Skeletonema costatum*	Eisler (1988)
	10	100% growth retardation in *Skeletonema costatum*	Eisler (1988)
Amphipod	0.547	LC_{50} value (96 hrs) for amphipods from the genus *Ampelisca*	Eisler (1988)
Molluscs	8.6	LC_{50} value (96 hrs) for juvenile bay scallops *Argopecten irradians* (Belonging to the family Pectinidae)	Nelson et al. (1976)
	5.4	LC_{50} value (96 hrs) for juvenile surf clams *Spisula solidissima* (Belonging to the family Mactridea)	Nelson et al. (1976)
Shrimp	7 200	LC_{50} value for *Penaeus indicus* postlarvae	Chinni and Yallapragda (2000)
Coral	1 453	Reduction of fertilization rate by 50% in *Acropora longicyathus.*	Reichelt-Brushett and Harrison (2005)
	1 801	Reduction of fertilisation rate by 50% in *Acropora tenuis*	Reichelt-Brushett and Harrison (2005)
	2 467	Reduction of fertilisation rate by 50% in *Goniastrea aspera*	Reichelt-Brushett and Harrison (2005)
Rock Lobster	50	Alteration of enzyme activity and biochemical functions in *Homarus americanus*	Eisler (1988)

Mercury (Hg)

Interim Target	**Water**	**Total Hg (as methyl mercury) concentration should not exceed 0.1 µg/ℓ (99% protection) or 0.4 µg/ℓ (95% protection)**
	Sediment	**Hg concentration should not exceed Threshold Effect Level = 0.13 µg/g (dry**

		weight)
		Probable Effect Level = 0.7 µg/g (dry weight)
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 with most probable form in seawater being $HgCl_4^{2-}$. Hg [II] also forms organometallic compounds (e.g. methylmercury), some of which are generally more toxic to aquatic organisms than inorganic forms because the carbon-mercury bond is chemically stable (WHO 1989, Neff 2002).	
Natural occurrence	Concentrations of Hg in coastal waters and estuaries generally are much higher than those in the open ocean. Concentrations in relatively uncontaminated coastal and estuarine waters may be as high as 0.02 µg/ℓ (Neff 2002). Hg concentrations in ocean waters range between 0.0005 - 0.003 µg/ℓ. Local variations from these values are considerable, especially in coastal seawater where mercury associated with suspended material may also contribute to the total load (WHO 1989, Neff 2002).	
Interdependence & Fate in the environment	The solubility of mercury decreases in anoxic waters due to hydrogen sulphide formation, leading to the formation of mercury sulphide which is very insoluble. pH increases the uptake of mercury by fish, particularly methylmercury. The toxicity of mercury is reduced in the presence of high salt content, but increase for invertebrates with an increase in temperature (WHO 1989). Mercury salts, and to a much greater extent, organic (methyl) mercury, are readily taken up by marine organisms and there is a strong indication that bacterial action leads to methylation of short-chain alkyl mercurials, e.g. methyl-, ethyl- or propyl-mercury (WHO 1989).	
Method	Mercury in seawater and sediment can be measured using a direct mercury analyser (DMA), atomic absorption spectroscopy (AAS), atomic fluorescence spectrometry, inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). Unit: Total Hg - µg/ℓ (water) and µg/g dry weight (sediment)	

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Phytoplankton	50	Growth retardation in *Dunaliella minuta*	Gotsis (1982)
Shrimp	16	Threshold level for *Penaeus monodon*	Das and Sahu (2002)
	24	Threshold level for *Penaeus indicus*	Das and Sahu (2002)
	36	LC$_{50}$ value (96 hrs) for *Penaeus monodon*	Das and Sahu (2002)
	42	LC$_{50}$ value (96 hrs for *Penaeus indicus*	Das and Sahu (2002)
	<56	Reduced survival of *Penaeus vulgaris* postlarvae after 48 hrs	Shealy and Sandifer (1975)
	56	Critical limit for *Penaeus vulgaris* postlarvae within 24 hrs	Shealy and Sandifer (1975)
Molluscs	>1 000	Inhibition of enzyme activity in *Donax trunculus*	Mizrahi and Achituv (1989)
Fish	380	LC value for milkfish (species not reported)	Bonifacio and Montaño (1998)

Nickel (Ni)

Interim Target	**Water**	**Total Ni concentration should not exceed 7 µg/ℓ (99% protection) or 70 µg/ℓ (95% protection)**
	Sediment	**Ni concentration should not exceed Threshold Effect Level = 15.9 µg/g (dry weight)**
		Probable Effect Level = 42.8 µg/g (dry weight)
Description	Nickel occurs in abundance in nature with the most probable species in marine waters being $NiCO_3$, Ni^{2+} and $NiCl^+$ (Riley and Cheser 1983). Ni and Vanadium (V) are the two most abundant metals in petroleum (Schlesinger et al. 2017).	
Natural occurrence	Natural sources of Ni in marine waters include volcanoes, forest fires and natural erosion of soils transported via rivers (WHO 1991). In natural waters, at a pH range of 5-9, the divalent ion Ni_2^+ is the dominant form. In this pH range, it may also be adsorbed onto iron and manganese oxides, or form complexes with inorganic ligands (WHO 1991). Reported Ni concentrations range between 0.2 and 0.7 µg/ℓ for the most probable species ($NiCO_3$, Ni^{2+}, $NiCl^+$) in oxygenated seawater at salinity 35, and between 0.5 and 3 µg/ℓ for oceanic waters (Riley and Chester 1983; Riley and Skirrow 1975).	
Interdependence & Fate in the environment	The fate of Ni in seawater is affected by several factors including pH, ionic strength, type and concentration of organic and inorganic ligands, as well as the presence of solid surfaces for adsorption (WHO 1991).	
Method	Nickel in seawater and sediment can be measured using atomic absorption spectroscopy	

	(AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Hg - µg/ℓ (water) and µg/g dry weight (sediment)

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Algae	100 000 – 1000 000	Growth rates of *Chlorella vulgaris* effected	Sakaguchi et al. (1977)
Copepods	13 180	LC_{50} value for *Eurytemora affinis* (adult)	Lussier and Cardin (1985)
	3 466	LC_{50} value for *Acartia clausi* (adult)	Lussier and Cardin (1985)
Polychaetes	49 900	LC_{50} value for *Nereis arenaceodentata* (adult)	Petrich and Reish (1979)
	25 000	LC_{50} value for *Nereis virescens* (adult)	Petrich and Reish (1979)
	17 000	LC_{50} value for *Ctenodrilus serratus* (adult)	Petrich and Reish (1979)
	>50 000	LC_{50} value for *Capitella capitata* (adult)	Petrich and Reish (1979)
Flatworms	16 800	LC_{50} value (96 hrs) for *Dugesia tigrina*	See et al. (1974)
Mollusca	72 000	LC_{50} value for *Nassarius obsoletus* (adult)	Eisler and Hennekey (1977)
	1 180	LC_{50} value for *Crassostrea virginica* (embryo)	Calabrese et al. (1973)
	133	EC_{50} value for Mytilus edulis (larvae)	Blewett et al. (2018)
Amphipods	40 000	EC_{50} value (10 days) for *Ampelisca abdita*	Haley and Kurnas (1996)
	310	LC_{50} value for *Mercenaria mercenaria* (embryo)	Calabrese and Nelson (1974)
Mysids	1 517	LC_{50} value for *Heteromysis formosa* (juvenile)	Gentile et al. (1982)
	508	LC_{50} value for *Mysidopsis bahia* (juvenile)	Gentile et al. (1982)
	634	LC_{50} value for *Mysidopsis bigelowi* (juvenile)	Gentile et al. (1982)
Echinoids	207	EC_{50} value (96 hr) for *Strongylocentrotus purpuratus* (embryo)	Blewett et al. (2018)
Coral	>100	Reduction of fertilization rate by 60% in *Goniastrea aspera*	Reichelt-Brushett and Harrison (2005)

Silver (Ag)

Interim Target	**Water**	**Total Ag concentration should not exceed 0.8 µg/ℓ (99% protection) or 1.4 µg/ℓ (95% protection)**
	Sediment	**Ag concentration should not exceed Threshold Effect Level = 0.73 µg/g (dry weight)**
		Probable Effect Level = 1.77 µg/g (dry weight)
Description	Ag exists principally in the +1 oxidation state as $AgCl_2^-$ complexes in seawater (Riley and Chester 1983).	
Natural occurrence	Ag probably has a nutrient-type chemistry, which is substantially depleted in surface relative to deep waters. Concentrations between 53.9×10^{-6} and 3.78×10^{-3} µg/ℓ have been reported for the most probable species ($AgCl_2^-$) in seawater with a salinity of 35, and between 0.01 and 0.08 µg/ℓ for dissolved Ag in oceanic waters (Riley and Chester 1983; Riley and Skirrow 1975).	
Interdependence & Fate in the environment	In coastal waters it was observed that more than half the total Ag is associated with particulate phases. Ag adsorbs onto clay particles and other organic matter in river water and may be desorbed when it reaches the sea. The solubility of Ag decreases in anoxic waters due to the presence of hydrogen sulphide (Ag_2S is very insoluble) (Riley and Skirrow 1975).	
Method	Silver in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Ag - µg/ℓ (water) and µg/g dry weight (sediment)	

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Macroalgae	50	LC_{50} value for algae (species not reported)	WHO (1982)
Fish	10 – 40	LC_{50} value for fish (species not reported)	WHO (1982)
	2 700	LC_{50} value (96 hrs) for *Fundulus heteroclitus* (adult)	Dorfman (1977)
	1 170	LC_{50} value (96 hrs) for *Cyprinodon variegatus* (juvenile)	US-EPA (1993)
	356	LC_{50} value (96 hrs) for *Cymatogaster aggregata* (adult)	Dinnel et al. (1983)
	800	LC_{50} value (96 hrs) for *Parophrys vetulus* (adult)	Dinnel et al. (1983)
	487	LC_{50} value (96 hrs) for *Oncorhynchus mykiss* (adult)	Dinnel et al. (1983)

Sn (as tributyltin)

Interim Target	**Water**	**Sn (as tributyltin) concentration should not exceed 0.0004 µg/ℓ (99% protection) or 0.006 µg/ℓ (95% protection)**
	Sediment	**TBT concentration should not exceed Threshold Effect Level = 0.009 µg/g (dry weight)***
		Probable Effect Level = 0.07 µg/g (dry weight)*
Description	The most probable species of inorganic tin in marine waters is $SnO(OH)_3^-$. Inorganic Sn is accepted to be relatively non-toxic because the metal does not react, and its oxides are insoluble at physiological pH (Riley and Chester 1983). Tributyltin (TBT) compounds are organic derivatives of tetravalent Sn, and although inorganic Sn is relatively non-toxic, organotin compounds are toxic. In seawater TBT exists as three species (hydroxide, chloride, and carbonate) which remain in equilibrium. At pH values less than 7, the predominant forms are BuSnOH2 and Bu SnCl, while at a pH of 8, they are Bu SnCl, Bu SnOH and Bu SnCO and at pH values above 10, Bu SnOH, and Bu SnCO predominate (WHO 1990; Heard 1989).	
Natural occurrence	A range between 0.0001 and 0.001 µg/ℓ has been reported for the most probable species ($SnO(OH)_3^-$) in oxygenated seawater with a salinity of 35 (Riley and Chester 1983). TBT is not a natural component of seawater (WHO 1990).	
Interdependence & Fate in the environment	The extent 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. 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. TBT bioaccumulates in organisms because of its solubility in fat. It is known that TBT degradation rates in sediments are slower than in the water column, particularly in anaerobic conditions (WHO 1990).	
Method	Tributyltin can be analysed using Gas Chromatography-Mass Spectrometry (GC-MS) and high-performance liquid chromatography (HPLC). Unit: Total Sn - µg/ℓ (water) and µg/g dry weight (sediment)	

** Not available in MacDonald et al. (1996), adopted from Australia and New Zealand Government (2018)*

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Diatom	0.14	LC_{50} value (72 hrs) for *Skeletonema costatum*	Nehring (1999)
Copepod	18	LC_{50} value (96 hrs) for *Tigriopus japonicus*	Bao et al. (2011)
Amphipod	9.4	LC_{50} value (96 hrs) for *Elasmopus rapax*	Bao et al. (2011)
Coral	0.38	LC_{50} value (24 hrs) for *Acropora tumida* larvae	Bao et al. (2011)
Barnacle	31	LC_{50} value (24 hrs) for *Balanus amphitrite* (larvae)	Bao et al. (2011)
Polychaete	0.97	LC_{50} value (48 hrs) for *Hydroides elegans* (embryos)	Lau et al. (2007)
	2.36	LC_{50} value (48 hrs) for *Hydroides elegans* (larvae)	Lau et al. (2007)
	2.86	LC_{50} value (48 hrs) for *Hydroides elegans* (juveniles)	Lau et al. (2007)
	4.36	LC_{50} value (48 hrs) for *Hydroides elegans* (adults)	Lau et al. (2007)
Mollusc	1.78	LC_{50} value (48 hrs) for *Nassarius reticulatus* (larvae)	Sousa et al. (2005)
Shrimp	0.88	LC_{50} value (48 hrs) for *Penaeus japonicus* (nauplii)	Lignot et al. (1998)
	19.4	LC_{50} value (48 hrs) for *Penaeus japonicus* (post-larva 5)	Lignot et al. (1998)
	370	LC_{50} value (96 hrs) for *Penaeus japonicus* (juveniles)	Lignot et al. (1998)

Vanadium (V)

Interim Target	**Water**	**Total V concentration should not exceed 50 µg/ℓ (99% protection) or 100 µg/ℓ (95% protection)**
	Sediment	**No Interim target could be set**
Description	Vanadium (V) can exist in three common oxidation states, largely present as found as vanadate ($H_2VO_4^-$) in oxidized waters of near-neutral pH. V is widely recognized as a trace contaminant in coal and oil (V and Ni are the two most abundant metals in petroleum) (Schlesinger et al. 2017).	
Natural occurrence	V is naturally mobilised from the Earth's crust mainly through mechanical and chemical rock weathering. The dissolved concentration in seawater has been reported as ~1.8 µg/ℓ. This is higher than in river water indicative additional sources of V in seawater, most likely released from suspended or accumulating sediments under higher pH of seawater under oxic conditions (Schlesinger et al. 2017).	
Interdependence & Fate in the environment	The transport and partitioning of V in water and sediments is influenced by pH, redox potential, and the presence of particulate. Upon entering the marine waters, V in suspension or adsorbed and/or absorbed onto particulate is deposited upon the sea bed. Adsorption/absorption and biochemical processes are thought to contribute to the	

	extraction of vanadium from sea water. Only about 0.001% of V entering the oceans is estimated to persist in soluble form (WHO 1988).
Method	Vanadium in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total V - µg/ℓ (water) and µg/g dry weight (sediment)

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Dinoflagellate	3	LC_{50} value (15 days) for *Prorocentrum micans* (adults)	Miramand and Unsal (1978)
Green alga	0.5	LC_{50} value (15 days) for *Dunaliella salina* (adults)	Miramand and Unsal (1978)
Diatom	2	LC_{50} value (15 days) for *Asterionella japonica* (adults)	Miramand and Unsal (1978)
Polychaete	10	LC_{50} value (9 days) for *Asterionella japonica* (adults)	Miramand and Unsal (1978)
Mysid shrimp	7.7	LC_{50} value (7 days) for *Americamysis bahia* (juveniles)	Woods et al. (2004)
Crab	35	LC_{50} value (9 days) for *Carcinus maenas* (adults)	Miramand and Unsal (1978)
Fish	0.62	LC_{50} value (96 hrs) for *Terrapon jarbua* (juveniles)	Gajbhiye et al. (1983)

Zinc (Zn)

Interim Target	**Water**	**Total Zn concentration should not exceed 7 µg/ℓ (99% protection) or 15 µg/ℓ (95% protection)**
	Sediment	**Zn concentration should not exceed Threshold Effect Level = 124 µg/g (dry weight)**
		Probable Effect Level = 217 µg/g (dry weight)

Description	Zn occurs abundantly in nature and is comparatively non-toxic. In the marine environment, the equilibrium species are Zn^{2+}, $ZnOH^+$, $ZnCO_3$ and $ZnCl^+$ (Riley and Chester 1983).
Natural occurrence	A range from 0.003 - 0.59 µg/ℓ has been reported for the most probable species (Zn^{2+}, $ZnOH^+$, $ZnCO_3$ and $ZnCl^+$) in oxygenated seawater with salinity of 35, and in oceanic waters between 0.5 - 4.0 µg/ℓ (Riley and Chester 1983; Riley and Skirrow 1975). Zinc concentrations in estuaries and coastal waters frequently are much higher than those in the ocean, with concentrations often as high as 4 µg/ℓ and occasionally as high as 25 µg/ℓ (Morse et al. 1993, Law et al. 1994).
Interdependence & Fate in the environment	The toxicity of Zn increases in the presence of Cd, while it decreases in anoxic water due to the presence of hydrogen sulphide (ZnS is very insoluble). Also, the speciation of dissolved Zn is very sensitive to pH changes. At a pH of 8.2 (seawater), the principal species are Zn^{2+} and $ZnCO_3$ (Riley and Skirrow 1975). A significant fraction of the total zinc in seawater may be adsorbed to particles or complexed with dissolved organic matter.
Method	Zinc in seawater and sediment can be measured using atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP), and ICP/mass spectrometry (MS). The strength of acids used to digest sediment will influence the concentration determined. Unit: Total Zn - µg/ℓ (water) and µg/g dry weight (sediment)

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Phytoplankton	0.00065	Growth in *Thalassiosira pseudonana* and *T. weissflogii* is inhibited	Sunda and Huntsman (1992)
	0.00065-0.65	Growth in *Thalassiosira pseudonana* and *T. weissflogii* is optimal	Sunda and Huntsman (1992)
	>0.65	Growth in *Thalassiosira pseudonana* and *T. weissflogii* is inhibited	Sunda and Huntsman (1992)
Macroalgae	50	LC_{50} value for algae (species type not reported)	WHO (1982)
	>80	Reduced growth rates of *Sargassum* seaweed	Joshi et al. (1982)
Copepod	1 860	LC_{50} value (24 hrs) for *Acartia simplex*	Arnott and Ahsanullah (1979)
Molluscs	2 250	LC_{50} value (96 hrs) for juvenile bay scallops *Argopecten irradians*	Nelson et al. (1976)
	2 950	LC_{50} value (96 hrs) for juvenile surf clams *Spisula solidissima*	Nelson et al. (1976)
	1 940 – 4 740	LC_{50} value (96 hrs) for *Donax faba*	Ong and Din (2001)
	>10 000	50% Inhibition of enzyme activity in *Donax trunculus*	Mizrahi and Achituv (1989)
Shrimp	>10 000	LC_{50} value (96 hrs) for *Palaemon* sp. (adult)	Ahsanullah and Arnott (1978)
	1 230	LC_{50} value (96 hrs) for *Palaemon* sp. (adult)	Ahsanullah (1976),
	13 100	LC_{50} value (48 hrs) for adult *Palaemon* sp. (adult)	Burton and Fisher (1990)
	6 200	LC_{50} value for *Penaeus indicus* post larvae	Chinni and Yallapragda

Biota	Range (µg/ℓ)	Effect	Reference
			(2000)
	11 300	LC$_{50}$ value (48 hrs) for *Palaemonetes pugio* juveniles	Burton and Fisher (1990)
Abalone	19	No observed effects in *Haliotis rufescens* larvae (48 hrs)	Hunt and Anderson (1989)
	39	No observed effects in *Haliotis rufescens* larvae over nine days	Hunt and Anderson (1989)
Fish	10 – 40	LC$_{50}$ value for fish (specific species not reported)	WHO (1982)

Petrochemicals (mono- and polycyclic aromatic hydrocarbons)

Interim Target	Compound	Water (µg/ℓ)	Sediment (ng/g dry weight)	
			Target	Probable effects concentration
	Benzene (C6)	600 (99% protection) 950 (95% protection)	-	-
	Toluene (C7)	110 (99%); 180 (95%)	-	-
	Ethylbenzene (C8)	50 (99%); 80 (95%)	-	-
	m-Xylene (C8)	50 (99%); 75 (95%)	-	-
	Naphthalene (C9)	50 (99%); 70 (95%)	34.6	391
	Acenaphthene (C12)	-	6.71	88.9
	Acenaphthylene (C12)	-	5.87	128
	Fluorene (C13)	-	21.2	144
	Anthracene (C14)	0.01 (99%); 0.4 (95%)	46.9	245
	Phenanthrene (C14)	0.6 (99%); 2 (95%)	86.7	544
	Fluoranthene (C15)	1 (99%); 1.4 (95%)	113	1 494
	Pyrene (C16)	-	153	1 398
	Benzo(a)anthracene (C18)	-	74.8	693
	Chrysene (C18)	-	108	846
	Benzo(a)pyrene (C20)	0.1 (99%); 0.2 (95%)	88.8	763
	Dibenzo(a,h)anthracene (C22)	-	6.22	135
	Total PAH	-	1 684	16 770
Description	The mono-aromatic hydrocarbons - benzene, toluene, ethylbenzene and xylene (BTEX) – are constituents of petroleum and its products such as petrol and diesel fuel (Phelps and Young 1999). Polycyclic aromatic hydrocarbons (PAHs) comprise multi-ring hydrocarbon compounds and can be categorised into (ANZECC 2000): • Low molecular weight two- to three-ring PAHs, including naphthalene, acenaphthene, acenaphthylene, phenanthrene, anthracene and fluorenes (usually display acute toxicity with short half-life in water) • High molecular weight three- to four-ring PAHs, including fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(a)pyrene and dibenzo(a,h)anthracene (usually displaying chronic toxicity, with longer half-life in water). The toxicity of aromatic hydrocarbons to marine organisms is highly variable, depending on species, compound and environmental conditions.			
Natural occurrence	PAHs are found naturally, but anthropogenic activity has markedly increased environmental levels of PAHs. There are four categories of PAH inputs to the marine environment, namely biogenic (produced by organism), pyrogenic (from incineration processes), petrogenic (derived from fossil fuels) and diagenic (derived from transformation processes in soils and sediments) (Lima et al. 2005; Hylland 2006).			
Interdependence & Fate in the environment	The overall environmental fate of aromatic hydrocarbons depends on several factors such as solubility, absorptivity, 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 absorptivity are the most important physical properties in this context. Although the solubility of pure PAHs 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. 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 photo-oxidised (Hutsinger 1980). Concentrations of PAHs in aquatic ecosystems are generally highest in sediments, intermediate in aquatic biota and lowest			

	in the water column.
Method	Various techniques exist for the analysis of petroleum hydrocarbons in seawater and sediment, including spectro-fluorimetric analysis, gas chromatography (GC) and high-performance liquid chromatography (HPLC). Unit: µg/ℓ (water) and ng/g dry weight (sediment)

Impacts and Thresholds

BTEX and PAHs also bio-accumulate through aquatic food chains, contributing to morbidities and mortalities (Akinsanya et al. 2020). PAHs are known to be carcinogenic. Carcinogenic PAHs are metabolised through cellular phases I and II, present in all vertebrates including fish. Their non-carcinogenic effects include oxidative stress, impacts on immune systems and endocrine regulation, and well as development (Hylland 2006).

Agrochemicals (organochlorine pesticides)

	Compound	**Water (µg/ℓ)**	**Sediment (ng/g dry weight)**	
			Target	**Probable effects concentration**
Interim Target	**Aldrin**	**0.003**	**-**	**-**
	Chlordane	**0.001**	**2.26**	**4.79**
	Chloropyros	**0.0005 (99% protection)** **0.009 (95% protection)**	**-**	**-**
	DDT	**0.0004**	**3.89**	**51.7**
	p,p DDT	**-**	**1.19**	**4.77**
	p,p DDD	**-**	**1.22**	**7.81**
	p'p'- DDE	**-**	**2.07**	**374**
	Dieldrin	**0.0019***	**0.72**	**4.3**
	Endosulfan	**0.005 (99%); 0.01 (95%)**	**-**	**-**
	Endrin	**0.004 (99%); 0.008 (95%)**	**2.7****	**60****
	Fenitrothion	**0.001**	**-**	**-**
	Lindane	**0.007**	**0.32**	**0.99**
	Methoxychlor	**0.004**	**-**	**-**
	Temephos	**0.0004 (99%); 0.05 (95%)**	**-**	**-**
	Toxaphene	**0.1 (99%); 0.2 (95%)**	**-**	**-**

Description	Pesticides (including insecticides, herbicides and fungicides) are typically categorised as organochlorine, organophosphate, and carbamate compounds. Insecticides are primarily designed to disrupt nervous system function, while herbicides target mainly photosynthetic pathways (e.g. to control weeds) (DeLorenzo et al. 2001; Lewis et al. 2009).
Natural occurrence	Pesticides (in the context used here) do not occur naturally and are manufactured compounds aimed at destroying pests.
Interdependence & Fate in the environment	Pesticide characteristics (water solubility, tendency to adsorb to the soil and pesticide persistence) and soil characteristics (clay, sand and organic matter) are important in determining the fate of the chemicals in the environment. Organochlorine pesticides (OCP) are typically resistant to environmental degradation, while organophosphate insecticides were found not to be long-lived in environment. Triazine herbicides also are persistent in environment, but acetanilide herbicides were found to be less persistent (Tiryaki and Temur 2010). In general, OCPs have a low solubility and other properties that make them adsorb strongly into suspended material and sediment. As a result, in the aquatic environment OCPs are usually found in much higher concentrations in sediments than in the overlying water.
Method	Various techniques exist for the analysis of pesticides in seawater and sediment, including gas chromatography (GC) and high-performance liquid chromatography (HPLC). Unit: µg/ℓ (water) and ng/g dry weight (sediment)

** No QT provided for Australia and New Zealand, recommend QT of US-EPA (US-EPA 2002, as updated)*

*** No QT provided in McDonald et al. 1996, adopted from Australia and New Zealand Government (2018)*

Impacts and Thresholds

Biota	**Range (µg/ℓ)**	**Effect**	**Reference**
Algae	>0.3	DDT: Biological effects on *Chlorella* sp.	DeLorenzo et al. (2001)
	3.6 - 36	p,p'-DDT: Inhibited photosynthetic processes in Green algae *Selenastrum capricornutum*	DeLorenzo et al. (2001)
	>10	DDT: Photosynthesis inhibited in marine algae	DeLorenzo et al. (2001)
	1 000	DDT: Blue-green algae *Anabaena* sp. display negative physiological effects	DeLorenzo et al. (2001)
	1 000	DDT: Population growth rates in Green algae	Lowe (1965)

Biota	Range (µg/ℓ)	Effect	Reference
		Chlorella sp. Declines	
	50	Lindane: Accumulation in Green algae *Chlorella* sp. (24 hrs)	Geyer et al. (1984)
	300	Lindane: Mortality of Green algae *Anabaena* sp. (72 hrs)	Bringmann and Kuhn (1978)
	1 000	Lindane: Accumulation in Green algae *Anabaena* sp.	Mathur and Saxena (1986)
	60 000	Lindane: Mortality of Green algae *Anabaena* sp. (72 hrs)	Das and Singh (1977)
	>1 000	Dieldrin: Significant effects on respiration of Blue-green algae	DeLorenzo et al. (2001)
	15 000	Dieldrin: Mortality of blue-green algae *Anabaena cylindrica* (7 days)	Vance and Drummond (1969)
Diatoms	50	DDT: Growth of *Skeletonema costatum* reduced (48 hrs)	Fisher (1975)
	1.7	Dieldrin: Accumulation in *Skeletonema costatum* (2 hrs)	Sikka and Rice (1974)
Sea grass	50	DDT: Photosynthesis and respiration in *Halophila ovalis* affected	Ramachandra et al. (1984)
	50	DDT: Photosynthesis and respiration in *Halophila uninervis* affected	Ramachandra et al. (1984)
	50	Lindane: Reduction of photosynthetic processes in *Hadodule uninervis* (6 hrs)	Ramachandran et al. (1984)
	50	Endosulfan: Reduction of photosynthetic processes in *Hadodule uninervis* (6 hrs)	Ramachandran et al. (1984)
Coral	10	Endosulfan: Visual bleaching observed in *Acropora millepora* after 6-12 hrs	Markey et al. (2007)
	>30	Endosulfan: Fertilization of *Acropora millepora* gametes declined	Markey et al. (2007)
Copepods	1 000	Aldrin: Mortality of *Cyclops* copepods (24 hrs)	Ludemann and Neumann (1962)
	>5	DDT: Mortality (48 hrs) of *Cyclops* sp.	Naqvi and Ferguson (1964)
	10 - 13	DDT: LC$_{50}$ (I day) for *Eucalanus sp.* (Calanoid copepod)	Rajendran and Venugopalan (1988)
	28	DDT: LC$_{50}$ (I day) for *Acartia sp.* (Calanoid copepod)	Rajendran and Venugopalan (1988)
	1 000	Aldrin: Mortality (24 hrs) of *Cyclops* sp.	Ludemann and Neumann (1962)
	0.8	Lindane: EC$_{50}$ value for *Acartia tonsa*	Chen (1991)
	6.2	Lindane: Growth inhibition in *Acartia tonsa*	Chen (1991)
	400 – 600	Lindane: Mortality of *Cyclops* copepods (48 hrs)	Naqvi and Ferguson (1968)
	0.03	Endosulfan: LC$_{50}$ value (96 hrs) for *Acartia tonsa*	Schimmel (1981)
	0.1	Endosulfan: LC$_{50}$ value (48 hrs) for *Eucyclops* sp.	Naqvi and Hawkins (1989)
	0.6	Endosulfan: LC$_{50}$ value (48 hrs) for *Diaptomus* sp.	Naqvi and Hawkins (1989)
	176	Endosulfan: LC$_{50}$ value (24 hrs) for *Eucalanus* sp.	Rajendran and Venugopalan (1988)
Amphipods	60	Dieldrin: LC$_{50}$ value 24 hrs for *Ampelisca abdita*	Werner and Nagel (1997)
Shrimp	0.6	Aldrin: EC$_{50}$ value (48 hrs) for Penaeid juveniles	Lowe et al. (1970)
	6.3	Aldrin: Enzyme disruption in *Penaeus indicus* (96 hrs) (adult)	Reddy and Rao (1991)
	0.10	DDT: Growth inhibition in Penaeid adults (30 days)	Nimmo and Blackmann (1972)
	0.6	DDT: EC$_{50}$ value (48 hrs) for Penaeid juveniles	Lowe et al. (1970)
	1 000	Lindane: Mortality of *Penaeus* sp. (24 hrs) (adult)	Reddy and Rao (1989)
	0.5 – 10	Lindane: Reduction of growth in *Penaeus monodon* (30 days) (juvenile)	Reddy and Rao (1989)
	1	Lindane: *P. monodon* display development inhibition (24 hrs) (juvenile)	Reddy and Rao (1989)
	0.13	Endosulfan: LC$_{50}$ value (96 hrs) for *Penaeus indicus* juvenile	Rao et al. (1988)
	0.35	Endosulfan: LC$_{50}$ value (72 hrs) for *Penaeus indicus* juvenile	Rao et al. (1988)
	0.46	Endosulfan: LC$_{50}$ value (48 hrs) for *Penaeus indicus* juvenile	Rao et al. (1988)
	0.98	Endosulfan: LC$_{50}$ value (24 hrs) for *Penaeus indicus* juvenile	Rao et al. (1988)
	4.64	Endosulfan: LC$_{50}$ value (48 hrs) for *Penaeus monodon* post-larvae	Joshi and Mukhopadhyay (1990)
	7.53	Endosulfan: LC$_{50}$ value (24 hrs) for *Penaeus monodon* post-larvae	Joshi and Mukhopadhyay (1990)
	12.2	Endosulfan: LC$_{50}$ value (48 hrs) for *Penaeus monodon* juveniles	Joshi and Mukhopadhyay (1990)

Biota	Range (µg/ℓ)	Effect	Reference
	17.6	Endosulfan: LC_{50} value (24 hrs) for *Penaeus monodon* juveniles	Joshi and Mukhopadhyay (1990)
	26.3	Endosulfan: LC_{50} value (96 hrs) for *Penaeus monodon* intermoult stage	Rao et al. (1988)
	37.3	Endosulfan: LC_{50} value (48 hrs) for *Penaeus monodon* intermoult stage	Rao et al. (1988)
Mud crab	178	Endosulfan: LC_{50} value (96 hrs) for *Scylla serrata*	Rao et al. (1987)
	257	Endosulfan: LC_{50} value (72 hrs) for *Scylla serrata*	Rao et al. (1987)
	389	Endosulfan: LC_{50} value (48 hrs) for *Scylla serrata*	Rao et al. (1987)
	478	Endosulfan: LC_{50} value (24 hrs) for *Scylla serrata*	Rao et al. (1987)

Pharmaceuticals

Interim Target (water)	**Carbamazepine***	**Concentration in water should not exceed 1 µg/ℓ (99% protection) or 9.2 µg/ℓ (95% protection)**
	Diclofenac*	**Concentration in water should not exceed 180 µg/ℓ (99%) or 770 µg/ℓ (95%)**
	Fluoxetine*	**Concentration in water should not exceed 0.23 µg/ℓ (99%) or 1.6 µg/ℓ (95%)**
	Propranolol*	**Concentration in water should not exceed 3.5 µg/ℓ (99% protection) or 14 µg/ℓ (95%)**
Description	Human and veterinary pharmaceuticals are chemicals that are continuously introduced to water bodies mainly through municipal wastewater (Fabbri and Franzellitti 2016). Pharmaceuticals are classified, based on their therapeutic uses, into the following groups (Ojemaye and Petrik 2018): • anti-diabetics (e.g. alpha-glucosidase inhibitor), β-blockers (e.g. atenolol, metoprolol) • antibiotics (e.g. trimethoprim) • lipid regulators (e.g. gemfibrozil) • anti-epileptic (e.g. acetazolamide) • tranquilizers (e.g. diazepam) • antimicrobials (e.g. penicillins) • antiulcer and antihistamine drugs (e.g. cimetidine and famotidine) • antianxiety/hypnotic agents (e.g. diazepam) • anti-inflammatories and analgesics (e.g. ibuprofen, paracetamol, diclofenac) • antidepressants (e.g. benzodiazine-pines) • anticancer drugs (e.g. cyclophosphamide, ifosfamide) • antipyretics and stimulants (e.g. dexamphetamine, methylphenidate and modafinil) • estrogens and hormonal compounds (estriol, estradiol, and estrone)	
Interdependence & Fate in the environment	The fate of pharmaceuticals in the marine environment (either in water column, sediments or biota) is a function of their physico-chemical properties, their interactions with the different matrices and hydrodynamic conditions (Bayen et al. 2013). These compounds can undergo biotic and abiotic transformations (degradation), or adsorbed to suspended solids or sediments, or accumulated in tissue of organisms, depending on their partition (Branchet et al. 2020).	
Method	Various techniques exist for the analysis of pharmaceutical compounds in seawater and sediment, including gas chromatography-mass spectrometry (GC-MS) and high-performance liquid chromatography-mass spectrometry (HPLC-MS). Unit: µg/ℓ (water) and ng/g dry weight (sediment)	

** QTs provided for Australia in Kumar et al. 2016*

Impacts and Thresholds

Pharmaceuticals are biologically active compounds specifically designed to interact with physiological pathways of targeted organisms, but may cause a risk to the health of non-targeted marine organisms. Adverse ecological effects can act at sub-lethal levels and alter biochemical and cellular responses, disrupting vital functions such as reproduction, growth, metabolism, immunity, feeding and locomotion (Branchet et al. 2020).

Other organic toxicants

Phenols

Interim Target	**Water: Total phenol concentration should not exceed 270 µg/ℓ (99%) or 400 µg/ℓ (95%)**
Description	Phenols comprise a group of chemicals with one or more hydroxyl groups (-OH) bonded to an aromatic hydrocarbon molecule. Phenolic compounds in the marine environment can arise from industrial activities, agricultural practices and natural substance

	degradation. They can be by-products in petrochemical industries, coal liquefaction plants, plastic and dye production, as well as pulp industries (Dimou et al. 2006).
Natural occurrence	Phenols occur naturally during the decomposition of organic matter. A concentration ~1.5 µg/litre has been reported for coastal waters (WHO 1994).
Interdependence & Fate in the environment	Based on their relatively high solubility in water and relatively low vapour pressure at room temperature, phenols largely end up in the water phase upon distribution between air and water (WHO 1994). Phenols are not expected to be adsorbed by sediments and suspended particulates in the aquatic environment, but have been detected in sediments in polluted systems. Biodegradation and indirect reactions with photochemically produced hydroxyl radicals and peroxyl radicals are the most likely transport mechanisms (WHO 1994; Duan et al. 2018).
Method	Phenols can be analysed using gas chromatography (GC). Unit: µg/ℓ (water) and ng/g dry weight (sediment)

Impacts and Thresholds

In addition to overt toxicities at higher concentrations, phenols can also result in subtle effects to biota, including reduced fertility, decreased survival of young, and growth inhibition. The toxicity of phenol to aquatic biota is modified by several abiotic (e.g. dissolved oxygen, salinity, and temperature) and biotic (e.g. age, size, nutritional status) factors (Babich and Davis 1981).

Polychlorinated Biphenyls (PCBs)

Interim Target	**Water: Total PCB concentration not to exceed 0.03 µg/ℓ***
	Sediment: Total PCB concentration not to exceed 21.6 ng/g
Description	Polychlorinated biphenyls (PCBs) are a group of man-made chemicals consisting of carbon, hydrogen and chlorine atoms. Due to their non-flammability, chemical stability, high boiling point and electrical insulating properties they are used in a wide range of products including hydraulic oils, electrical transformers and capacitors, concrete constructions, sealants and paint (Jartun et al. 2009).
Natural occurrence	PCBs are exclusively anthropogenic and do not occur naturally (Wolska et al. 2012).
Interdependence & Fate in the environment	PCBs have low water solubility, a high n-octanol/water partition coefficient, and resistance potential, particularly those which are highly chlorinated. As a result, in the aquatic environment PCBs are usually found in much higher concentrations in sediments than in the overlying water. They are persistent in the environment and it may take decades for them to degrade. The persistence and stability of PCBs increase with an increase in the number of chlorine atoms per molecule (Wolska et al. 2012). PCBs readily bio-accumulate in many organisms in the environment (Geyer et al. 1984).
Method	PCBs can be analysed using gas chromatography-mass spectrometry (GC-MS). Unit: µg/ℓ (water) and µg/g dry weight (sediment)

** No QT provided for Australia and New Zealand, recommend QT of US-EPA (US-EPA 2002, as updated)*

Impacts and Thresholds

Biota	Range (µg/ℓ)	Effect	Reference
Coral	1000	Aroclor 1254: significant decrease in photosynthetically generated oxygen production in *Montastrea annularis, Acropora cervicornis*, and *Madracis mirabilis*.	McCloskey & Chesher (1971)
Marine mammals	-	Bioaccumulation known to result in reproductive failure in sea mammals (e.g. dolphins)	WHO (1992b)

APPENDIX B: Background to Recreation Quality Targets

Objectionable substances

Interim Target	• Water should not contain litter, 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 objectionable deposits. • 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. • Water should not contain substances producing objectionable colour, odour, taste, or turbidity.
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, or organic foams generated at sea during storm events.
Interdependence & Fate in the environment	Objectionable floating matter accumulates on beaches and in sheltered areas.
Method	Floating matter is not usually measured quantitatively in marine waters, but is rather 'measured ' in terms of a qualitative description.
Impacts & Thresholds	
Typical water quality problems which may be associated with the presence of objectionable floating matter include: • physical injuries • unpleasant aesthetics • clogging and blockage of equipment	

Physico-chemical properties

Temperature

Interim Target	For prolonged exposure, temperatures should be in the range 15–35°C
Description	Temperature is a fundamental property of water.
Natural occurrence	In the WIO region, mostly situated in the tropics, seawater temperature typically between 20-30°C, but is much lower along the south and west coasts of South Africa. Upwelling is a seasonal phenomenon in some parts of the region and results in warmer surface waters being replaced by cool bottom water of about 14 °C (Kanagev et al. 2009; Bakun et al. 1998).
Interdependence & Fate in the environment	Generally, the temperature is not interdependent on any other water quality properties or constituents.
Method	Temperature is usually measured *in situ*, using a Conductivity-Temperature-Depth-Salinity (CTDS) meter. An ordinary thermometer can also be used. Units: °C
Impacts & Thresholds	
<15	Extended periods of continuous immersion may cause death in some individuals and will be extremely stressful for anyone who is not wearing underwater protective clothing (Health Canada 2017)
15-35	No detrimental effect (Health Canada 2017)
26-30	Comfortable for most individuals throughout prolonged periods of moderate physical exertion (Von Schirnding et al. 1992)

pH

Interim Target	The pH of water should be within the range 5.0–9.0, assuming that the buffering capacity of the water is low near the extremes of the pH limits
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. Water is acidic at pH less than seven, while at a pH greater than seven, water is alkaline .
Natural occurrence	The pH of seawater usually ranges between 7.9 and 8.2 (Huguenin and Colt 1989) 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 (Open University 1989). 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 values as high as 12 (Open University 1989)
Interdependence & Fate in the 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 (Riley and Skirrow 1975).
Method	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 (Hawkins 1981).
	Impacts & Thresholds
<5.0	Severe eye irritations occur (NAS/NAE 1973) Skin, ear and mucous irritations are likely to occur (NAS/NAE 1973)
5.0–6.5	Where the buffering capacity of the water is low, swimming in water with this pH is acceptable. However, in seawater where the buffering capacity can be very high eye, ear, skin and mucous irritations may occur (NAS/NAE, 1973)
6.5–8.5	No detrimental effects. Minimal eye irritations may occur. The pH is well within the buffering capacity of the lachrymal fluid of the human eye (NAS/NAE 1973)
8.5–9.0	Where the buffering capacity of the water is low, swimming in water with this pH is acceptable. However, in seawater where the buffering capacity of water is high, eye, ear, skin and mucous irritations may occur (NAS/NAE 1973)
<5 or >9.0	Eye irritations can occur (Health Canada 2017)

Microbiological indicator organisms

Enterococci (Interim for marine waters)

	CATEGORY	ESTIMATED RISK PER EXPOSURE	COUNT PER 100 mℓ
Interim Target (EU, SA)	Excellent	2.9% gastrointestinal (GI) illness risk	≤100 (95th percentile)
	Good	5% GI illness risk	≤200 (95th percentile)
	Sufficient (min QT)	**8.5% GI illness risk**	**≤185 (90th percentile)**
	Poor	>8.5% GI illness risk	>185 (90th percentile)
		OR	
Interim Target (WHO, Australia, NZ)	A	<1% gastrointestinal (GI) illness risk; <0.3% acute febrile respiratory (AFRI) risk	≤40 (95th percentile)
	B	1–5% GI illness risk; 0.3–1.9% AFRI risk	41–200 (95th percentile)
	C (min. QT)	**5–10% GI illness risk; 1.9–3.9% AFRI risk**	**201–500 (95th percentile)**
	D	>10% GI illness risk; >3.9% AFRI risk	>500 (95th percentile)

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 in these groups, they can be considered the same for all practical purposes Enterococci have been shown to be a valuable indicator for determining the extent of faecal contamination in marine waters (Standard Methods 1989).
Natural occurrence	Although enterococci are not a natural water quality property/constituent of marine waters, they are consistently excreted by warm-blooded animals (Standard Methods 1989).
Interdependence & Fate in the environment	The survival of enterococci in the marine environment depends on various variables, including temperature, exposure to ultraviolet light irradiation in sunlight, salinity, osmotic shock, microbiological antagonism, and 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 T90 values are usually greater during daytime than night time, primarily due to higher ultraviolet light irradiation during the day (Bellair et al. 1977).
Method	In routine monitoring, enterococci in seawater are usually measured according to the membrane filtration (Standard Methods 1989) or most probable number (MPN) techniques. Unit: Enterococci counts per 100 mℓ
Impacts & Thresholds	
Typical problems associated with the presence of microbiological indicators include gastrointestinal problems and skin, eye, ear and respiratory irritations. A number of large epidemiological studies have been conducted across the world to determine risk exposure ranges for a microbiological indicator organism (Von Schrinding et al. 1992, Fatal et al. 1986, Cheung et al. 1990, Cheung et al. 1991a, Cheung et al. 1991b, Corbett et al. 1993, Cabelli et al. 1982, Fleischer 1991, Alexander et al. 1992, Huisman 1982, WHO 2003)	

Escherichia coli (thermotolerant coliform)

	CATEGORY	ESTIMATED RISK PER EXPOSURE	COUNT PER 100 mℓ
Interim Target (EU, SA)	Excellent	2.9% gastrointestinal (GI) illness risk	≤250 (95 percentile)
	Good	5% GI illness risk	≤500 (95 percentile)
	Sufficient (QT)	**8.5% GI illness risk**	≤500 (90 percentile)
	Poor	>8.5% GI illness risk	>500 (90 percentile)
Description	Thermotolerant coliform refers to a group of total coliforms that are more closely related to faecal contamination, and which generally do not readily replicate in the water environment. *Escherichia coli* (*E. coli)* are thermotolerant coliform bacteria. It has the important feature of being highly specific to warm-blooded animals' faeces, and for all practical purposes, these bacteria cannot multiply in any natural water environment. 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 thermotolerant coliforms as indicators of virological quality have been shown which might be attributed to the following: • 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 that of bacteria, which implies that behaviour and survival in water differ extensively.		
Natural occurrence	Although thermotolerant coliforms are not a natural water quality property/constituent of marine waters, they are consistently excreted by humans and other warm-blooded animals.		
Interdependence & Fate in the environment	The survival of thermotolerant coliforms in the marine environment is dependent on a variety of constituents 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 T90 values,		

	which is the time required for the bacterial density to decrease by 90 %. The T90 values are usually greater during daytime than night time, primarily due to higher ultraviolet light irradiation during the day (Bellair et al. 1977).
Method	In routine monitoring, thermotolerant coliform in seawater is usually measured according to the membrane filter or MPN techniques (Standard methods 1989) Unit: *E. coli* counts per 100 mℓ
Impacts & Thresholds	
Typical problems associated with the presence of microbiological indicators in seawater used for recreational purposes are usually related to human health, for example gastrointestinal problems and skin, eye, ear and respiratory irritations. A number of large epidemiological studies have been conducted across the world to determine risk exposure ranges for microbiological indicator organism (Von Schrinding et al. 1992, Fatal et al. 1986, Cheung et al. 1990, Cheung et al. 1991a, Cheung et al. 1991b, Corbett et al. 1993, Cabelli et al. 1982, Fleischer 1991, Alexander et al. 1992, Huisman 1982, WHO 2003)	

Clostridium perfringens

Interim Target	*C. perfringens:* Geometric mean ≤ 5 counts per 100 mℓ*
* Whilst waiting on the outcome of scientific studies by organisations such as the WHO, interim measures to mitigate potential issues in tropical water include the use of an additional microbiological indicator - *Clostridium perfringens*, a spore-forming obligate anaerobe - in the assessment of recreational waters along tropical coasts (Hawaii Department of Health, 2000). The use of this indicator **has shortcomings (e.g. although C. perfringens is not capable of re-growth in aerobic environments, it** persists for long periods, and its detection in the environment may not be an indicator of recent sewage contamination).	
Description	*Clostridium perfringens* is a spore-forming, obligate anaerobic bacterium
Natural occurrence	Although *C. perfringens* is not a natural water quality constituent/property of marine waters this species is ubiquitous in nature, including soil and marine sediments (Butler et al. 1986). Type A strains form part of the microflora of both soil and the intestinal tracts of humans, while Types B, C, D and E are obligate parasites of warm-blooded animals and occasionally are found in man (Smith 1975).
Interdependence & Fate in the environment	In the absence of fermentable carbohydrates *C. perfringens* tends to form spores, a highly resistant resting phase whereby it can survive in a dormant state through long periods of starvation or other adverse environmental conditions (Cruichshank 1969). In this state the organism can remain viable for many years. When external conditions become favourable for growth, i.e. access to moisture, nutrients and anaerobic growth conditions (*C. perfringens* is an obligate anaerobe), germination of the spores occurs, and the organism reverts to a vegetative state.
Method	In routine monitoring, *C. perfringens* in seawater are enumerated by the membrane filtration method using mCP agar and incubation under anaerobic conditions
Impacts & Thresholds	
Sub-cutaneous invasion by *C. perfringens* through existing deep tissue wounds can result in gas gangrene and septicaemia. Direct oral ingestion of seawater contaminated with the spore form of the organism does not have a detrimental effect	

APPENDIX C: Background to Marine Aquaculture Quality Targets

Microbiological parameters (water and flesh) for application in shellfish water classification

Recommended Target	***E. coli* (direct consumption)** **Systematic random sampling strategy**[1] – • Membrane Filtration (MF) – 14 per 100 mℓ and estimated 90th percentile in water not to exceed 21 per 100 mℓ or • Most Probable Number (MPN) – 14 per 100 mℓ and estimated 90th percentile in **water** not to exceed 43 per 100 mℓ for a 5 tube decimal dilution test, or 49 per 100 mℓ for a 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 230 counts per 100 g of flesh and intravalvular liquid and estimated 90th percentile not to exceed 700 counts per 100 g **Adverse pollution condition sampling strategy**[2] – • MF – 14 per 100 mℓ and not more than 10% of **water** samples exceed 21 per 100 mℓ **or** • MPN – 14 per 100 mℓ and not more than 10% of **water** samples exceed 43 per 100 mℓ for 5 tube decimal dilution test, or 49 per 100 mℓ for 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 230 counts per 100 g of flesh and intravalvular liquid and not more than 10% of samples exceed 700 counts per 100 g.
	***E. coli* (relaying or depuration required)** **Systematic Random Sampling Strategy** – • MF – 70 per 100 mℓ and estimated 90th percentile in **water** samples not to exceed 85 per 100 mℓ or • MPN – 88 per 100 mℓ and estimated 90th percentile in **water** samples not to exceed 260 per 100 mℓ for a 5 tube decimal dilution test, or 300 per 100 mℓ for a 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 46 000 counts per 100 g of flesh and intravalvular liquid and estimated 90th percentile not to exceed 14 100 counts per 100 g. **Adverse pollution condition sampling strategy** – • MF – 70 per 100 mℓ and not more than 10% of **water** samples exceed 85 per 100 mℓ or • MPN – 88 per 100 mℓ and not more than 10% of **water** samples exceed 260 per 100 mℓ for 5 tube decimal dilution test, or 300 per 100 mℓ for 3 tube decimal dilution test • Median or geometric mean (MPN) in **flesh** not to exceed of 46 000 counts per 100 g of flesh and intravalvular liquid and not more than 10% of samples exceed 14 1000 counts per 100 g.
Description	Thermotolerant coliforms refer to a group of total coliform bacteria that are more closely related to faecal contamination, and which generally do not readily replicate in the water environment. *E. coli* are thermotolerant coliform bacteria. It has the important feature of being highly specific to the faeces of warm-blooded animals and for all practical purposes these bacteria cannot multiply in any natural water environment. 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 thermotolerant coliforms as indicators of virological quality have been shown and might be attributed to the following: • 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 consistently • structure, composition, morphology and size of viruses differs fundamentally from that of bacteria, which implies that their behaviour and survival in water differs extensively.
Natural occurrence	Although thermotolerant coliforms are not a natural property/constituent of marine waters, they are consistently excreted by humans and other warm-blooded animals.
Interdependence & Fate in the	Survival of thermotolerant coliforms in the marine environment depends on a variety of constituents, including temperature, exposure to ultraviolet light irradiation in sunlight,

environment	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 T90 values, which is the time required for the bacterial density to decrease by 90 %. The T90 values are usually greater during daytime than night-time, primarily due to higher ultraviolet light irradiation during the day (Bellair et al. 1977).
Method	In routine monitoring, thermotolerant coliforms in seawater are usually measured according to the MF or MPN techniques (Standard methods 1989) Unit: *E. coli* counts per 100 mℓ
Impacts and Thresholds	
E. coli food infection causes abdominal cramping, water or bloody diarrhea, fever, nausea, and vomiting	
1: Systematic random sampling means a method of water sampling and data analysis (which may be applied to a growing area which is not impacted by point source pollution) *2: Adverse pollution sampling strategy means a water quality sampling programme designed to target adverse pollution conditions*	