Waikato Regional Council Internal Series 2017/25

Summary of Green and Cornelisen's (2016) Review of ecological thresholds and options for developing marine water quality standards for the Waikato region

www.waikatoregion.govt.nz

Waikato
REGIONAL COUNCIL
Te Kaunihera ā Rohe o Waikato

Prepared by:
Malcolm Green (Streamlined Environmental Ltd), Chris Cornelisen (Cawthron Institute) and Pete Wilson (Waikato Regional Council).

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

May 2017

Document #: 10425597

Disclaimer

This internal series report has been prepared for the use of Waikato Regional Council as a reference document and as such does not constitute Council's policy.

Council requests that if excerpts or inferences are drawn from this document for further use by individuals or organisations, due care should be taken to ensure that the appropriate context has been preserved, and is accurately reflected and referenced in any subsequent spoken or written communication.

While Waikato Regional Council has exercised all reasonable skill and care in controlling the contents of this report, Council accepts no liability in contract, tort or otherwise, for any loss, damage, injury or expense (whether direct, indirect or consequential) arising out of the provision of this information or its use by you or any other party.

Summary of Green and Cornelisen's (2016) Review of Ecological Thresholds and Options for Developing Marine Water Quality Standards for the Waikato Region

www.streamlined.co.nz

Action	Name	Date
Draft prepared by	Malcolm Green Chris Cornelisen (Cawthron Institute) Pete Wilson (Waikato Regional Council)	February 2017
Reviewed by	Pete Wilson (Waikato Regional Council)	March 2017
Final prepared	Malcolm Green Chris Cornelisen (Cawthron Institute) Pete Wilson (Waikato Regional Council)	May 2017

Report WRC1507–2
Prepared for Waikato Regional Council
May 2017

Green, M.O., Cornelisen, C.D. and Wilson, P.S. (2017) *Summary of Green and Cornelisen's (2016) Review of Ecological Thresholds and Options for Developing Marine Water Quality Standards for the Waikato Region.* Report WRC1507–2, Streamlined Environmental, Hamilton, 29 pp.

Streamlined Environmental Ltd
Hamilton, New Zealand

Contents

1. Introduction

To support Waikato Regional Council's (WRC) review of the Regional Coastal Plan, Green and Cornelisen (2016) reviewed ecologically relevant thresholds for informing marine water-quality standards and identified options for defining standards and requirements for assessing or implementing those options.

Herein, we summarise Green and Cornelisen's (2016) [hereinafter GC16] review and options.

The management approach espoused in the National Policy Statement for Freshwater Management (2014), which is based on notions of values, aspects to be managed and attributes, is useful for organising thinking around marine water quality standards. In Table 1, the value is ecosystem health of the coastal marine area, and five aspects to be managed to provide for that value are listed. For each aspect to be managed, attributes are identified. Those attributes that are the subject of GC16's review are displayed in red text.

Table 1. A method of organising thinking around marine water quality standards based on the management approach espoused in the National Policy Statement for Freshwater Management (2014). Attributes that are the subject of Green and Cornelisen's (2016) review are displayed in red text.

VALUE	ASPECTS TO BE MANAGED	ATTRIBUTES							
Ecosystem health	Eutrophication	Water-column N	Water-column P	Water-column chla	Water-column DO	Harmful algal blooms	pH	TOC	
		Sediment N	Sediment P	Seagrass cover	Denitrification efficiency	Depth to RPD	N load	P Load	
	Sediments	TSS/SSC	Light penetration	Visual clarity	Seabed muddiness %	Seabed muddiness cover	Sedimentation rate	Light for seagrass	Turbidity
	Habitat	Seagrass spatial extent	Mangrove spread	Shellfish spatial extent	Intertidal unvegetated	Rocky reefs			
	Heavy metals	Bed-sediment metal concentration	Water-column metal concentrations	Metal loads	Benthic health index				
	Temperature	Water temperature							

2. Summary of GC16's options and requirements

Table 2, spread over the next two pages, summarises GC16's options for defining standards and the requirements for assessing or implementing those options.

Table 2. Summary of Green and Cornelisen's (2016) options for defining standards and the requirements for assessing or implementing those options.

Parameter(s)	Options	Requirements
Nitrogen and phosphorus	1. No standard - problems with using water-column nutrient concentrations as standards (load based may be more appropriate) 2. Retain/refine WRC guideline values – these are conservative ANZECC guidelines, however 3. Develop reference conditions for nutrient concentrations for the different marine water types of the Waikato region, and then develop a standard in terms of an acceptable departure from the reference (ANZECC approach) 4. Develop a standard, or adopt an existing standard such as the NZ ETIT or pilot NOF for Estuaries recommendations, based on a relationship between freshwater nutrient loads and the symptoms of eutrophication for each of the different marine water types of the Waikato region	1. Nothing 2. Nothing 3. Assuming the existence of a suitable reference site(s), and in order to give as true a picture as possible of the natural temporal variability, at least an entire year of weekly sampling (preferably two years; Hunt, 2016) would be required to establish the reference condition 4. For each system to be investigated, at least an entire year of weekly sampling (preferably two years; Hunt, 2016) would be required in order to give as true a picture as possible of the natural temporal variability
Chlorophyll a	1. No standard 2. Retain/refine WRC guideline values – these are conservative ANZECC guidelines, however 3. Develop reference conditions for chlorophyll a for the different marine water types of the Waikato region, and then develop a standard in terms of an acceptable departure from the reference 4. Adopt an existing effects-based threshold	1. Nothing 2. Nothing 3. Identify reference site(s) for each water type. Monitor for at least one year (e.g., moored sensors for high frequency measurement) 4. Review of available thresholds. May have difficulty deciding on a way to account for natural temporal and spatial variability in phytoplankton (not unique to this parameter)
Dissolved oxygen	1. No standard – however, "DO is a well-vetted indicator of eutrophication and there is considerable experience with its use in a regulatory context to manage eutrophication" 2. Retain/refine WRC guideline values – these are conservative ANZECC guidelines, however 3. Develop reference conditions for dissolved oxygen for the different marine water types of the Waikato region, and then develop a standard in terms of an acceptable departure from the reference 4. Adopt an effects-based threshold such as Vaquer-Sunyer and Duarte's (2008) widely quoted threshold of 4.6 mg DO L^{-1}	1. Nothing 2. Nothing 3. Identify "reference site(s)" for each water type. Monitor for at least one year (e.g., moored sensors for high frequency measurement). Difficulty identifying reference site(s) 4. Review of available thresholds
pH	1. No standard – not included by Auckland Council as considered unlikely to be an issue 2. Retain/refine WRC guideline value 3. Develop a standard based on departure from "normal" pH	1. Nothing 2. Nothing 3. For each system to be investigated, at least an entire year of sampling (e.g., moored sensors for high frequency measurements)
Suspended sediment	1. No standard - Williamson et al. (2015) note that "clarity guidelines are currently not applied in the Auckland coastal environment" but that	1. Nothing 2. Nothing

	"clarity and turbidity are very important indicators of water quality in terms of recreation and ecology, and should be addressed and managed as best as possible" 2. Retain/refine WRC guideline value 3. Develop reference conditions for water-column sediments for the different marine water types of the Waikato region, and then develop a standard in terms of an acceptable departure from the reference 4. Adopt an existing effects-based threshold	3. Assuming the existence of a suitable reference site(s), measurements would need to be made over at least a two-year period to capture as wide a range as possible of wind conditions and rainfall intensities 4. Review available thresholds (e.g., requirements for seagrass)
Temperature	1. No standard 2. Retain standard in Coastal Plan 3. Adopt the ANZECC approach and derive a standard from upper and lower low-risk trigger values 4. Tailor standards according to water types	1. Nothing 2. Depending on the water body, the current limit of 3°C may need to be reviewed to ensure that it does not represent a significant change above the normal range (e.g., 3°C change in estuary but smaller change in open ocean) 3. Basing upper and lower limits on distribution of temperature will require considerable time series data to establish ranges of variability across all water types and to account for seasonal and inter-annual temperature cycles. Temperature variability will likely vary considerably by water body type. Hence, baseline data would need to be collected from at least one example of each water body type 4. Tailoring criteria according to water body type will require time series data, or at least a review of what levels of change may be appropriate for different types
Microbiological	1. No standard 2. Retain MfE/MoH guideline 3. Develop standard around new indicators, including Quantitative Microbial Risk Assessment (QMRA) and faster qPCR-based tests to complement culture-based tests	1. Nothing 2. Nothing 3. Developing new approaches or indicators will require considerable resources. Regulations are typically a number of years behind technology. Once methods are developed and proven to be sound and reliable, then WRC may take advantage of the improved methods
Toxicants	1. No standard – may be better addressed in sediment quality standards 2. Apply ANZECC (2000) guideline values (only available information for informing standards at this time) 3. Develop new standards based on data relevant to the Waikato CMA	1. Nothing 2. Nothing 3. Beyond the scope of regional council
Emerging contaminants	Limited options with regard to setting standards for emerging contaminants due to a lack of data and knowledge	

3. Development of standards

GC16 do not actually develop standards; further analyses of existing datasets and new data may be required to set and implement standards for different water types, for which a draft classification exists for the Waikato region. WRC anticipates that only minimum standards will ultimately be required. Some attributes for gauging water quality, such as nutrient concentrations and turbidity, may prove to be too variable for setting standards.

The **ANZECC (2000) guidelines "default trigger values**" are referred to extensively in GC16's review. Hunt (2016) notes that the ANZECC guidelines are widely used in New Zealand, particularly by regional councils, and that, while they are not "national standards", they can be "conferred regulatory status if they are incorporated into a regional plan".

The **Horizons One Plan** (the combined Regional Plan and Regional Policy Statement for the Manawatu–Wanganui Region) is examined as an example of the way water quality standards for the coastal marine area have been expressed. The steps taken to define the water quality standards were: identify values; define what aspects of each value are associated with water quality; define how and when water is used in relation to each value; define the water quality parameters that are relevant to each value (e.g., dissolved oxygen, pH); define, for each parameter, the numerical level beyond which the value would be compromised.

The **baseline or reference condition** is often used to set standards. The reference condition refers to a natural condition, which implies absence of significant human disturbance or alteration. Stoddard et al. (2006) note a range of approaches that may be used to ascertain the reference condition, including the reference-site approach (determining the condition at minimally- or least-disturbed sites), using best professional judgement, interpretation of historical condition, extrapolation of empirical models, and evaluation of ambient distributions. Depending on management objectives and desired levels of protection, standards can then be expressed in terms of an acceptable departure from a reference condition. The reference-condition approach is central to the ANZECC guidelines.

4. Thresholds reviewed by GC16

4.1 Eutrophication

Excessive loading of nitrogen and phosphorus (collectively, "nutrients") can cause eutrophication. The excessive nutrients accelerate primary production of organic matter (phytoplankton and/or macroalgal growth) which, in extreme cases, can lead to reduced water clarity, physical smothering of biota and a reduction in dissolved oxygen concentration as a result of the ultimate microbial decay of the organic matter.

Water-column indicators of eutrophication such as chlorophyll *a* (indicative of phytoplankton biomass) are best suited for deep estuaries with a long residence time relative to the phytoplankton growth cycle. For estuaries with shorter residence times, phytoplankton are flushed from the system before they accumulate to nuisance levels, and in this situation eutrophication is more likely to be expressed as nuisance macroalgae. In this case, sediment or seabed indicators are more appropriate. It is important that indicators, thresholds for assessing trophic state and standards properly reflect the way the symptoms of eutrophication are expressed in any given system. Sediment/seabed indicators of eutrophication are beyond the scope of GC16's report.

4.1.1 Water-column nutrient concentrations

For New Zealand examples, GC16 review recommendations in the pilot National Objectives Framework (NOF) for Estuaries on the use of potential nutrient concentrations as attributes; the compilation of default trigger values for water-column nutrient concentrations in the ANZECC (2000) guidelines; and Waikato Regional Council's thresholds for nitrogen and phosphorus relevant to nuisance plant growth, which are based on a combination of the ANZECC guidelines default trigger values and expert judgement.

GC16 mention Auckland Council's TP168 "marine trigger values" for total ammonia nitrogen, but note that these are for nitrogen toxicity, as opposed to nitrogen as a driver of eutrophication. Standards for ammonia nitrogen are routinely included as part of consented activities that increase nitrogen loading and create a risk of ammonia toxicity, as in the case of finfish aquaculture.

For international examples, GC16 review Bricker et al.'s (2003) ranges (not standards) for dissolved nitrogen and phosphorus measured in surface waters of U.S. estuaries, Sheldon and Alber's (2011) recommendations on the use of the NEEA criteria for Georgia (U.S.) coastal waters, Borja et al.'s (2004) thresholds for "high" and "bad" quality based on nutrient concentrations for different water bodies in the Basque region, northern Spain, and thresholds used by Souchu et al. (2000) to assess trophic state of French Mediterranean estuaries.

Sheldon and Alber (2011) noted that the linkages between nutrient concentrations and the actual symptoms of eutrophication are "dependent on a variety of estuary-specific characteristics including transit time, temperature, light availability for photosynthesis, and grazing pressure". Even making allowances for those factors, linkages between nutrient concentrations and eutrophication may be difficult or even impossible to discern. The use of potential nutrient concentrations is a way around that particular dilemma; however, the problem of the estuary-specific characteristics remains. For these reasons, it is challenging to use nutrient concentrations in a management context, for example, as standards or to set limits (Sutula et al., 2011).

Table 3 provides a summary of information presented in this section on water-column nutrient concentrations.

Table 3. Summary of information in the section on water-column nutrient concentrations: New Zealand examples and U.S. examples.

New Zealand examples			
Pilot NOF for Estuaries	Excellent: <25 Good: 25–70 Poor: >70	mg DIN m^{-3}	Potential nutrient concentrations
ANZECC default trigger values	30 mg P m^{-3} (TP), 5 mg P m^{-3} (filterable reactive phosphorus), 300 mg N m^{-3} (TN), 15 mg N m^{-3} (NO_X), 15 mg N m^{-3} (NH_4^+)		Estuaries
	25 mg P m^{-3} (TP), 10 mg P m^{-3} (filterable reactive phosphorus), 120 mg N m^{-3} (TN), 5 mg N m^{-3} (NO_X), 15 mg N m^{-3} (NH_4^+)		Marine
WRC	Excellent: <5 Satisfactory: 5–15 Unsatisfactory: >15	mg NO_3-N m^{-3}	Nitrate nitrogen
	Excellent: <10 Satisfactory: 10–30 Unsatisfactory: >30	mg TP m^{-3}	Total phosphorus
U.S. examples			
Bricker et al. (2003)	High: ≥1000 Medium: 100–1000 Low: 0–100	mg nitrogen m^{-3}	Ranges for dissolved nitrogen and phosphorus in surface waters of U.S. estuaries
	High: ≥100 Medium: 10–100 Low: 0–10	mg phosphorus m^{-3}	
Sheldon and Alber (2011)	Poor: >1000 Fair: 1000–100 Good: <100	mg total dissolved nitrogen m^{-3}	Georgia (U.S.) coastal waters
	Poor: >100 Fair: 10–100 Good: <10	mg total dissolved phosphorus m^{-3}	

4.1.2 Nutrient loads

GC16 review the recommendations in the **pilot NOF for Estuaries** for areal loading (land-side loading per unit area of estuary) of total nitrogen for the value of ecological health, where bands are set by estuary type to account for the different physical factors (e.g., flushing time, light availability) that mediate the expression of actual symptoms of eutrophication, and **Wriggle Coastal Management's (2012)** recommendations for nitrogen areal loading to protect against nuisance algal blooms in tidal river estuaries and shallow tidal lagoons. The **ANZECC (2000) guidelines** recommend that load-based guidelines for nutrients be derived on a site-specific basis.

GC16 summarise the methodology presented in Tool 1 of the **New Zealand Estuary Trophic Index Toolbox (ETIT)** (Robertson et al., 2016a) which combines physical susceptibility with nutrient loads to produce a combined physical and nutrient load susceptibility rating. The physical susceptibility is assessed primarily from the extent to which input loads are both diluted within and flushed from (or, conversely, retained within) the estuary. Separate methods for assessing susceptibility are provided for ICOLLs (intermittently closed and open lake or lagoon), SIDEs (shallow intertidal dominated estuary), SSTREs (shallow, short residence time tidal river, and tidal river with adjoining lagoon, estuary) and DSDEs (deeper, subtidal-dominated, estuary).

Olsen et al.'s (2008) **critical nutrient loading rate** (CNLR) is the nutrient loading that cannot be exceeded without loss of ecosystem integrity. Accurately determining CNLRs requires experimental mesocosm data, but literature values may provide a means of setting conservative CNLRs in the absence of data.

The linkages between nutrient concentrations and the actual symptoms of eutrophication may vary significantly by estuary type and may vary from season to season. The same problem holds for nutrient loads. A further problem is that ocean-side nutrient loading and internal (seabed sediment) loads may add to the land-side loading to drive primary production. Nevertheless, ANZECC (2000) notes that in some situations guidelines are better expressed in terms of nutrient loads instead of concentrations.

Figure 1 provides a summary of information presented in this section on nutrient loads.

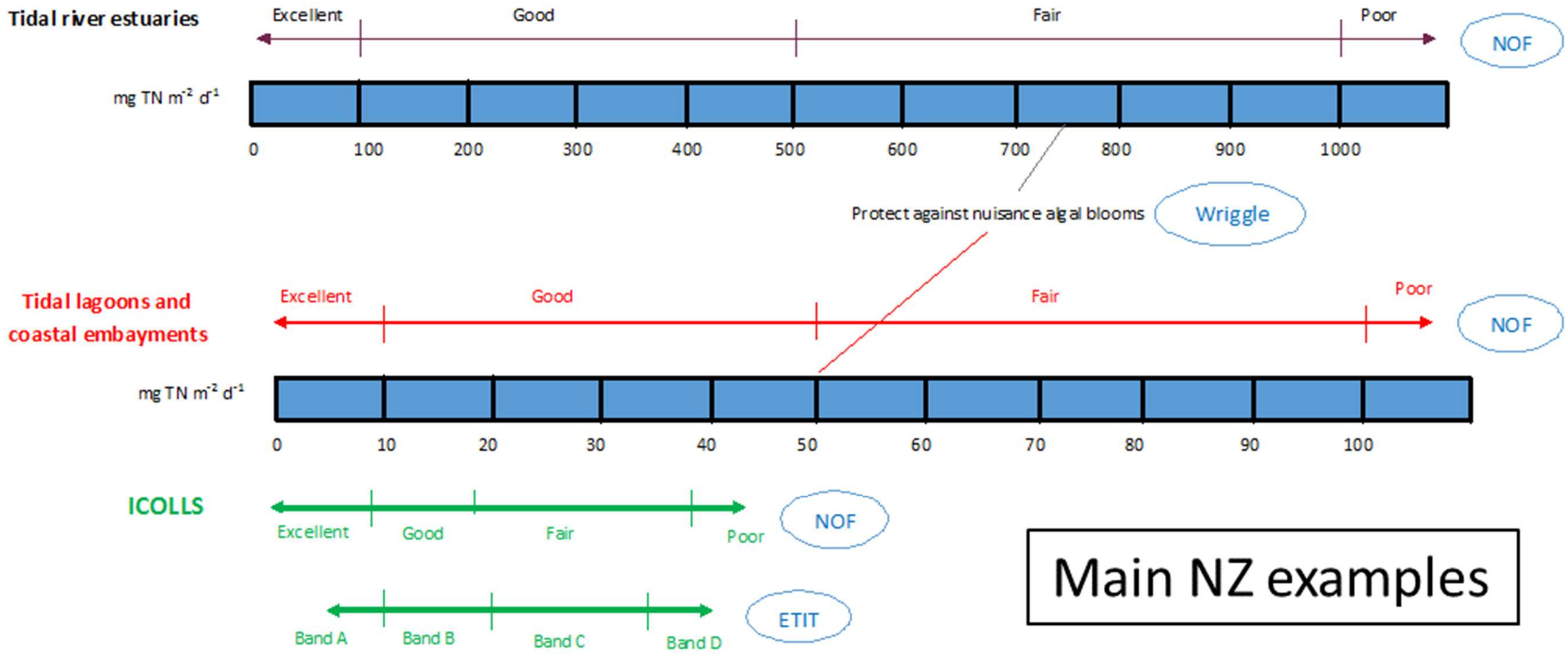

Figure 1. Summary of information in the section on nutrient loads: main New Zealand examples.

4.1.3 Water-column chlorophyll *a*

Water-column chlorophyll *a* is indicative of phytoplankton biomass. A high concentration of phytoplankton is recognised as a primary symptom of eutrophication, which is mainly driven by excessive nutrients in the water column. Often associated with the primary symptom are shifts in phytoplankton community composition and increased frequency and duration of harmful algal blooms.

Hunt (2016) notes that, while "chlorophyll *a* is not a definitive indicator of eutrophication, it may provide clues about the possible effects of higher nitrogen levels in the estuary. [Trigger values and standards for chlorophyll *a*] could be used as initial reference points to suggest whether increased algal growth may have occurred in association with elevated levels of nutrients. However, it should also be noted that eutrophication in New Zealand estuaries will not necessarily result in phytoplankton blooms, and thus may not be reflected by chlorophyll *a* levels. For example, in shallow New Zealand estuaries, increased growth of macroalgae may be a more common response to elevated nutrient levels".

Williamson et al. (2015) note that "there are relatively few definitive studies" in New Zealand of problem phytoplankton blooms in response to nutrient enrichment and that, more usually, undesirable biological growths in response to high nutrient loading take the form of nuisance blooms of macroalgae, such as *Ulva* spp.

In the Waikato region, the longer residence time of the west-coast estuaries compared to the east-coast estuaries makes the west-coast estuaries more susceptible to phytoplankton blooms, although the more turbid water, and accompanying reduction in light penetration, that is also characteristic of the west-coast estuaries may counteract that tendency. The Firth of Thames is a special case, which Green and Zeldis (2015) noted had a number of features that make it sensitive to nutrient enrichment.

For New Zealand examples, GC16 review the **ANZECC (2000) guidelines** default trigger values for water-column chlorophyll *a*, the **pilot NOF for Estuaries** proposed bands for chlorophyll *a*, and the recommendations in Tool 2 of the **New Zealand ETIT** (Robertson et al., 2016b) for interim values for phytoplankton chlorophyll *a* thresholds. The panel that produced the pilot NOF for Estuaries noted that their suggested bands are derived from the literature and are not well correlated with compromised trophic states in the New Zealand context, and the ETIT recommendations are interim until more New Zealand data are available. GC16 note that **Auckland Council** adopted the ANZECC guideline default trigger values for their Environmental Response Criteria for chlorophyll *a*, and **Waikato Regional Council's** thresholds for chlorophyll *a* relevant to algal blooms are based on a combination of the ANZECC guidelines default trigger values and expert judgement. In the **Marlborough Sounds**, standards for chlorophyll *a* have been developed for managing new salmon farm consents.

For international examples, GC16 review **Revilla et al.'s (2010)** 90^{th} percentile threshold chlorophyll *a* concentrations for Basque (northern Spain) estuaries and **Borja et al.'s (2004)** use of chlorophyll *a* concentration combined with number of exceedances, also for the Basque region; thresholds used by **Souchu**

et al. (2000) to assess trophic state of French Mediterranean estuaries; the NEEA/ASSETS[1] thresholds for chlorophyll *a* for U.S. estuaries, based on the annual bloom period, given by **Bricker et al. (2003)**; **Sheldon and Alber's (2011)** recommendations for the use of the NEEA criteria for Georgia (U.S.) coastal waters; and chlorophyll *a* thresholds designed to provide appropriate light for seagrass in a range of U.S. estuaries by **Sutula et al. (2011)**. The **state of Oregon** (U.S.) currently has a "numeric water quality criterion" for chlorophyll to "protect beneficial uses" of both rivers and estuaries (Brown et al., 2007).

Figure 2 provides a summary of information presented in this section on water-column chlorophyll *a*.

[1] Assessment of Estuarine Trophic Status.

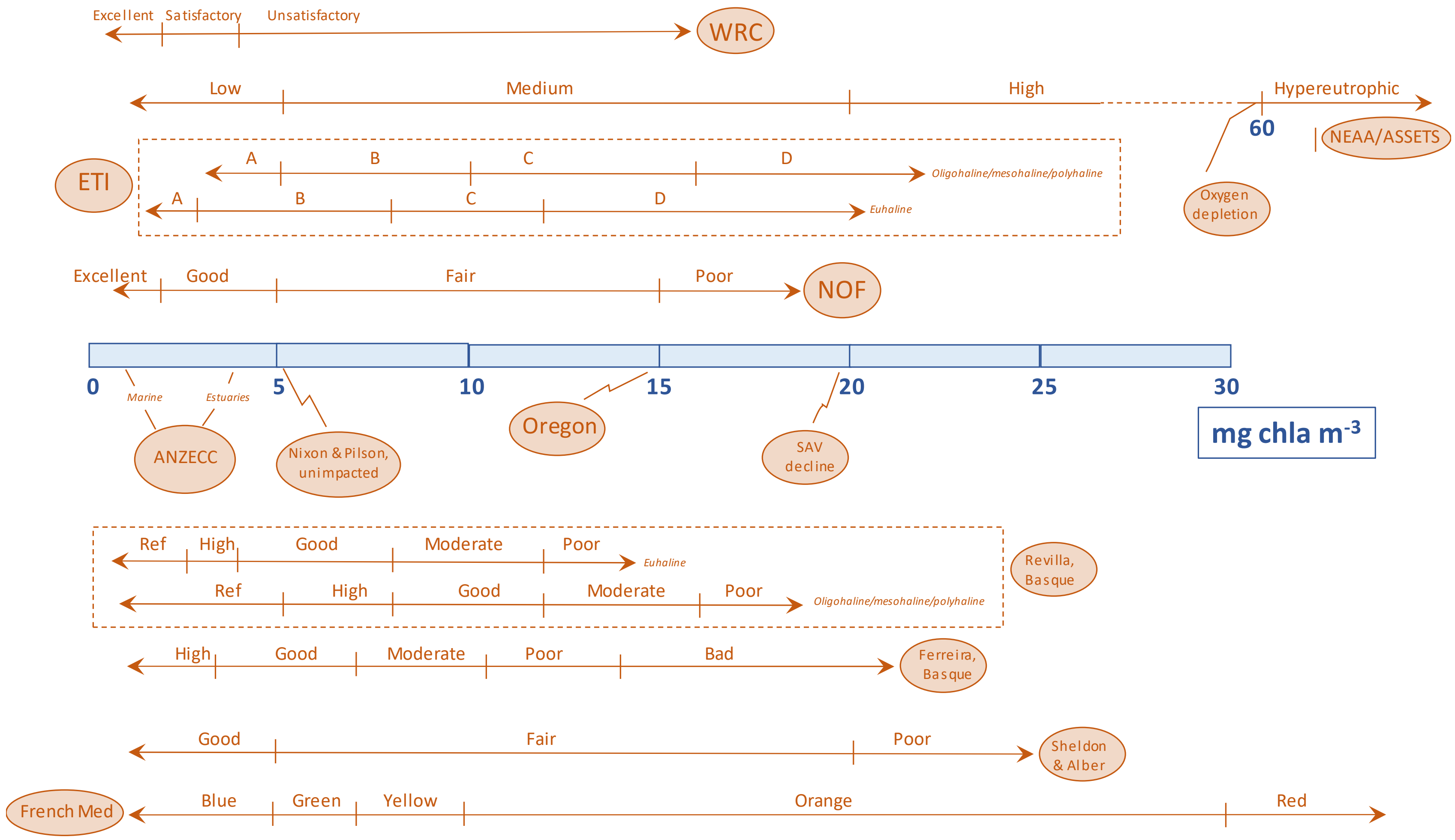

Figure 2. Summary of information in the section on water-column chlorophyll *a*: New Zealand and overseas examples.

4.1.4 Water-column dissolved oxygen

Dissolved oxygen is a key water-quality attribute that sustains life and needs to be managed to meet water-quality objectives. A low level of dissolved oxygen (DO) is a secondary symptom of eutrophication, which can have a wide range of adverse effects on aquatic life (plants, bacteria, shellfish and other invertebrates, fish) that use oxygen to respire. The risk of eutrophication, and in turn a reduction in DO, is of concern mainly in estuaries and is less of an issue in open water. However, DO needs to be managed in areas used for marine aquaculture, which includes open water.

DO thresholds are typically expressed in absolute units as opposed to deviation from a "norm" or reference condition. This is because there is a good body of experimental evidence on the oxygen requirements of a range of organisms. DO may be expressed as a concentration (mg of DO per litre of water) or as a percentage saturation, where 100% saturation means the dissolved oxygen is in equilibrium with the atmosphere.

For New Zealand examples, GC16 review the **ANZECC (2000) guidelines** default trigger values for water-column dissolved oxygen; recommendations in Tool 2 of the **New Zealand ETIT** (Robertson et al., 2016b) for DO thresholds based on a combination of NZ freshwater data and a range of U.S. estuarine and marine data; and recommendations in the **pilot NOF for Estuaries** for dissolved oxygen for providing for the value of ecological health.

Auckland Council's TP168 notes that no guidelines for DO have been developed specifically for New Zealand estuaries; they have adopted the ANZECC guidelines default trigger values and best professional judgement for their Environmental Response Criteria. **Waikato Regional Council** used a combination of the ANZECC guidelines default trigger values and expert judgement to derive thresholds for dissolved oxygen, considering the need for oxygen for aquatic animals to respire. In the **Marlborough Sounds**, water quality standards for DO have been implemented for managing new salmon farms located in high-flow areas of the outer Sounds.

For international examples, GC16 review **Borja et al.'s (2004)** thresholds for DO saturation for the Basque (northern Spain) region, the NEEA/ASSETS thresholds for dissolved oxygen for U.S. estuaries given by **Bricker et al. (2003)**, and thresholds used by **Souchu et al. (2000)** to assess trophic state of French Mediterranean estuaries, expressed as change in percentage DO saturation relative to a reference condition.

GC16 note that **Vaquer-Sunyer and Duarte (2008)**, who performed an extensive review of existing data, are widely quoted. Vaquer-Sunyer and Duarte concluded that "waters with oxygen concentrations below 4.6 mg O_2/liter, the 90th percentile of the distribution of mean lethal concentrations, would be expected to maintain the population for most, except the 10% most sensitive species. This oxygen level could thus be considered as a precautionary limit to avoid catastrophic mortality events, except for the most sensitive crab species, and effectively conserve marine biodiversity". Reviews by **Gray et al. (2002)** and **U.S. Environmental Protection Agency (2002)** are consistent with the findings of Vaquer-Sunyer and Duarte (2008).

Sutula et al. (2012) present an extensive review of science supporting DO objectives in California estuaries and suggest important considerations concerning the development of a protocol for determining oxygen “impairment". Sutula et al. drew from the **Virginia Province Salt Water DO Criteria**, the goal of which is to maintain and support aquatic life communities and their designated uses. **Batiuk et al. (2009)** adapted the Virginia Province approach to deriving dissolved DO “criteria” for Chesapeake Bay. The criteria have been adopted by the Chesapeake Bay states – Maryland, Virginia, and Delaware – as state regulatory standards, which has then triggered the development of Total Maximum Daily Loads that can be used to establish numerical limits on loads discharged from land. The **state of Oregon** (U.S.) currently has a “numeric water quality criterion” (standard) for DO of 6.5 mg L^{-1} to “protect beneficial uses” of estuaries (Brown et al., 2007).

Ideally, oxygen standards should be based on local data (fish and invertebrate responses to low DO). There are some New Zealand data available to apply this approach. For example, Waikato Regional Council commissioned a review (**Herbert, 2013**) of the effects of hypoxia on New Zealand fish species to assess the potential impacts of DO variability in the Hauraki Gulf, and **Alfaro (2005)** reported laboratory tests on the effects of reduced DO on *Perna canaliculus*.

Figure 3 (DO as a concentration) and Figure 4 (DO as percentage saturation) provide a summary of information presented in this section on water-column dissolved oxygen.

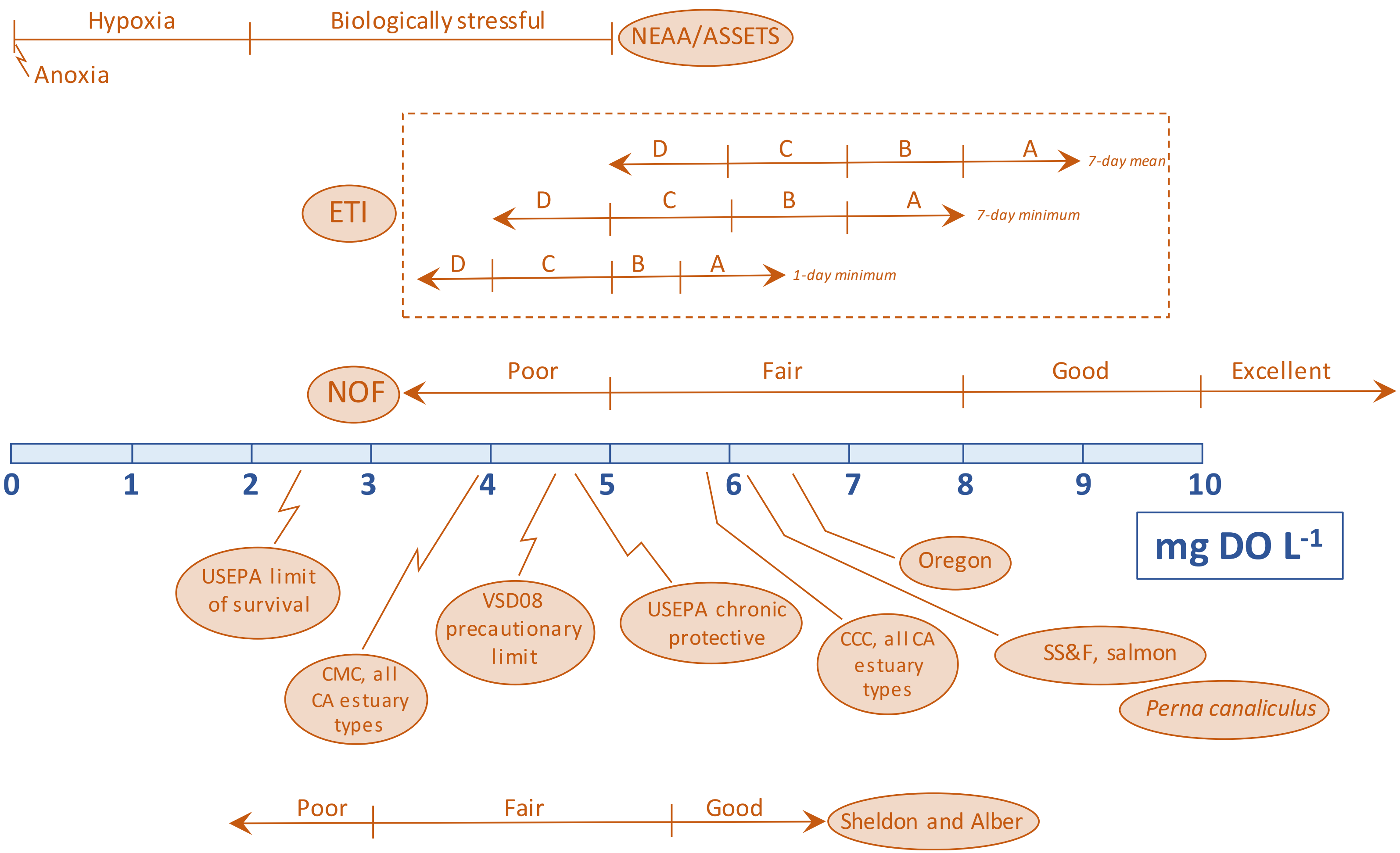

Figure 3. Summary of information in the section on water-column dissolved oxygen (DO expressed as a concentration): New Zealand and overseas examples.

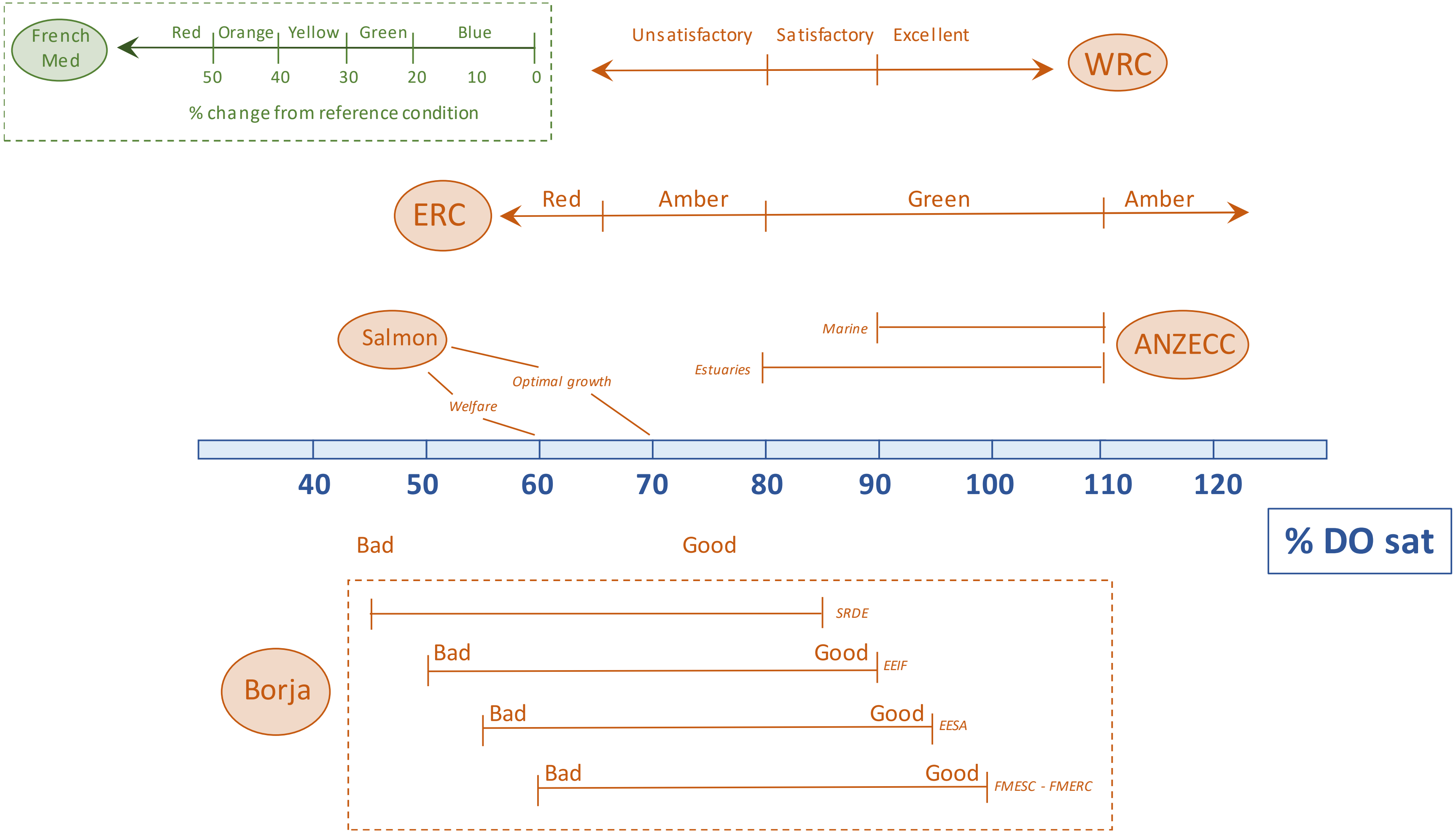

Figure 4. Summary of information in the section on water-column dissolved oxygen (DO expressed as percentage saturation): New Zealand and overseas examples.

4.1.5 pH

pH is naturally highly variable in coastal waters, from estuary to estuary and within estuaries, and also between the water column and the bed sediments. pH can vary on a diurnal cycle in response to daily cycles of primary production and respiration, and it can change episodically due to, for instance, algal blooms and changes in freshwater inputs. Globally, a continuing increase in anthropogenic CO_2 emissions will cause ocean acidification, and nutrient loading in coastal waters can also lead to acidification. As oceans acidify, the diurnal and seasonal variations in pH that are typical of estuarine and coastal waters will also shift, and the time that organisms are exposed to an unfavourable pH will increase. Adverse effects include inhibition of shell, coral and exoskeleton growth (because solubility of calcium carbonate is increased), modification of fish behaviour, including reproduction, and direct toxic effects. In addition, heavy metals become more soluble and therefore more bioavailable with a reduction in pH, which increases their toxicity; the solubility of phosphorus and other nutrients is increased, which makes them more bioavailable to phytoplankton; and pH affects ammonia toxicity.

The **ANZECC (2000) guidelines** note that "[f]or marine waters, guidelines tend to focus more on the requirement that changes to the normal pH be limited (generally to a maximum of 0.2 pH units)". The **1992 ANZECC guidelines** recommended that the pH of coastal and marine waters should not be permitted to vary by more than 0.2 units from the normal values. **Sheldon and Alber (2011)**, writing about Georgia (U.S.) waters, noted that pH varies with salinity along the length of an estuary, so pH criteria are best described in terms of deviations from normal. The **pilot NOF for Estuaries** proposed a "bottom line between fair and poor" as being "0.5 pH units from expected", which aligns with Sheldon and Alber's approach and the approach in the 1992 ANZECC guidelines. **Waikato Regional Council** used a combination of the ANZECC guidelines default trigger values and expert judgement to derive thresholds for pH, considering that pH can affect plants and fish.

4.2 Water-column sediments

GC16 define and discuss a number of metrics relating to sediments in the water column. Suspended-sediment concentration (SSC) and total suspended solids (TSS), which differ by the analytical method used to determine them, are often used interchangeably to describe the concentration in water of solid-phase material. Visual clarity and light penetration are the two main components of "water optics". Visual clarity, which is the sighting range as it affects human recreational users and visual habitat for fish and aquatic birds, is expressed as the horizontal sighting range of a black target. Light penetration is expressed as the irradiance attenuation coefficient, which is defined as the proportional decline of downwelling irradiance per unit depth. Visual clarity and light penetration are not immediately inter-relatable. SSC/TSS, visual clarity and light penetration all have direct effects on aquatic ecosystem health.

Turbidity can be used as a practical proxy for the more ecologically meaningful metrics of SSC/TSS, visual clarity and light penetration. This requires local calibration of turbidity against the desired metric. Turbidity is cheap and easy to measure (with a turbidimeter)., but requires on-going calibration and maintenance of instrumentation.

The **ANZECC (2000) guidelines** compile default trigger values for turbidity, but they also note that turbidity "is not a very useful indicator in estuarine and marine waters" and a "move towards the measurement of light attenuation in preference to turbidity is recommended". The **pilot NOF for Estuaries** did not propose numeric bands for turbidity because of a current inability to "distinguish trends from natural variability". **Waikato Regional Council** used a combination of the ANZECC guidelines default trigger values and expert judgement to derive thresholds for turbidity, recognising that turbidity "can restrict plant growth".

GC16 review ranges for turbidity in surface waters of U.S. estuaries reported by **Bricker et al. (2003)**; thresholds for turbidity used by **Souchu et al. (2000)** to assess trophic state of French Mediterranean estuaries; and **Borja et al.'s (2004)** bands for Secchi depth for the Basque (northern Spain) region.

GC16 quote extensively from the **Environmental Protection Division of the Ministry of Environment's (British Columbia, Canada)** ambient water quality guidelines for turbidity, suspended sediments and benthic sediments[2], and the **Canadian Environmental Quality Guidelines** for turbidity and suspended sediments[3]. Many of these criteria specifically differentiate between "clear flow" and "high flow or turbid waters". GC16 also quote extensively from the **U.S. Environmental Protection Agency (1988)**, who compiled U.S. state and federal turbidity "criteria" by water-body designated use[4]. GC16 note that, although many of these are probably now out of date, they are interesting to look at as they demonstrate a wide range of approaches.

GC16 review thresholds pertaining to the availability of light for seagrass. **Turner and Schwarz (2006)** note that "[c]hanges in light regime are thought to have caused large-scale loss of seagrasses in the natural environment, and it is evident from international studies that maintaining adequate light regimes is a minimal requirement for the preservation of seagrass beds". Turner and Schwarz conclude that "the most ubiquitous and pervasive cause of seagrass decline is reduction in the amount of photosynthetically available radiation", for which they ascribe three principal causes: (1) eutrophication, leading to the "proliferation of phytoplankton, macroalgae or algal epiphytes on seagrass leaves and stems", (2) chronically increased turbidity, reducing light levels, and (3) "pulsed" increases in suspended sediments and/or phytoplankton, which cause a dramatic reduction in light penetration for a limited time.

The "preferred water clarity for seagrass" in Tool 2 of the **New Zealand ETIT** (Robertson et al., 2016b) is "an average value of at least 20% of the sunlight that strikes the water's surface (incident light) should reach the estuary bed". Furthermore, clarity should not "reduce from baseline". **Matheson and Wadhwa (2012)** analyse the requirements for restoring seagrass beds in Porirua Harbour, including requirements for light.

---

[2] http://www.env.gov.bc.ca/wat/wq/BCguidelines/turbidity/turbidity.html

[3] http://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/

[4]
http://nepis.epa.gov/Exe/ZyNET.exe/00001NCW.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1986+Thru+1990&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C86thru90%5CTxt%5C00000001%5C00001NCW.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

Duarte (1991) explored the relationship between seagrass colonization depth and light attenuation for a wide range of seagrass species, geographic locations and habitats, and concluded that "seagrasses colonize littoral zones with suitable sediments down to the depth where the irradiance reaches on average 10.8% … of the irradiance available at the water surface". Turner and Schwarz (2006) gave the **Indian River Lagoon (Florida)** as an example of managing light to restore seagrass beds, and **Steward et al. (2005)** describe in detail how light targets were set for restoring the Indian River lagoon. **Sheldon and Alber (2011)** recommended using a measure of water transparency for Georgia (U.S.) waters, such as % transmission of photosynthetically available radiation or Secchi depth[5], which they noted was in line with U.S. Environmental Protection Agency recommendations. **Sutula et al. (2011)** give examples of chlorophyll *a* thresholds designed to provide appropriate light requirements for seagrass in a range of U.S. estuaries, and **Dennison et al. (1993)** tabulate the minimal light requirements for a wide range of species. The single New Zealand seagrass species (*Zostera muelleri)* is not represented in their dataset.

4.3 Water temperature

Water temperature is a key control on many life-sustaining processes in the marine environment including organism metabolism and growth, photosynthesis and respiration, and aspects of reproduction. Water temperature can also affect whole-of-ecosystem metabolism and a coastal water body's capacity to process and assimilate organic inputs. Discharges most commonly affect water temperature, including outfalls from processing plants that use water for cooling or changes in freshwater flows from rivers. In general, changes in temperature will be less of a concern in large coastal embayments or tide-dominated estuaries, whereas coastal lagoons and poorly mixed estuaries will be more susceptible to changes. Standards for water temperature are typically applied in cases of consented activities where a thermal discharge could potentially impact the receiving water body.

GC16 review the **ANZECC (2000) guidelines**, which recommend that managers define their own upper and lower low-risk trigger values; adoption of temperature standards from the **European Union Water Framework Directive** in the United Kingdom aimed at protecting or improving coastal waters in order to support shellfish; the **Canadian Water Quality Guidelines**, which state that the natural temperature cycle characteristic of the site should not be altered in amplitude or frequency by human activities; and the **U.S. Clean Water Act**, which provides guidance for development of standards and criteria for water temperature.

4.4 Microbial contamination

Contamination of water by faecal pollution presents a risk to humans of acquiring pathogenic viruses and bacteria through contact recreation and consumption of contaminated shellfish. Common sources of contamination include ruminant animals, faulty septic tanks, birds and dogs.

[5] Secchi depth or distance is the maximum water depth at which a black and white disc (30-cm diameter) can be seen from the surface.

Faecal indicator bacteria (FIB) such as *Escherichia coli* and enterococci are used as proxies for faecal pollution and as indicators of the presence of pathogens such as enteric viruses, *Campylobacter* and protozoans such as *Cryptosporidium* spp. and *Giardia* spp. The FIB are not typically disease causing themselves; rather, they correlate with the presence of pathogens.

High concentrations of FIB can trigger closures of bathing waters and shellfish harvest areas. With a few exceptions, most point sources of human faecal contamination, such as sewage outfalls, are suitably managed in New Zealand. Faecal contamination caused by diffuse runoff carrying faecal contaminants from multiple sources tends to be more complex and difficult to address. An important consideration is that the presence of FIB does not necessarily indicate recent faecal contamination of water since, amongst other things, faecal bacteria can persist in sediments, from which they may be resuspended by wave action in the absence of any rainfall and associated increase in freshwater runoff. Bacteria and viruses are also more prevalent in turbid waters where microbes attach to particles, which can prolong viability due to solar shading. Natural patchiness can impede our ability to identify trends over time in response to changes in anthropogenic pressures; for instance, enterococci concentrations in coastal waters have been shown to vary by 60% on average and by as much as 700% between samples that are collected only minutes apart.

The **Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas** (Ministry for the Environment, 2003) are commonly used for coastal water quality monitoring (SoE and public health) in New Zealand. The Guidelines are based on concentrations of FIB, typically *E. coli* in freshwater and enterococci in marine water. The Guidelines include a beach risk-assessment component, whereby swimming beaches are assessed in a two-stage process. The first stage assesses a beach's suitability for recreation based on five years of enterococci test results, and the second stage assesses the risk of human faecal pollution. Beaches graded good, fair or poor in the risk assessment have the potential to be affected by faecal contamination and must be tested routinely (e.g., weekly) for enterococci. The routine FIB measurements are used to trigger "action points". Hunt (2016) notes that "the [Guidelines] have no regulatory status and are not standards. However, regulatory status can be conferred by incorporation in a regional plan". Hunt (2016) also notes that the Guidelines are overdue for a revision by the Ministry for the Environment, and that MfE is to keep the Coastal Special Interest Group and councils informed around the timing of any revision. **Waikato Regional Council's** standards for bathing water quality are based on the Guidelines.

The **U.S. Environmental Protection Agency** updated their microbiological water quality guidelines for recreational water in 2012 (U.S. Environmental Protection Agency, 2012). It is anticipated that the pending MfE update of New Zealand's Guidelines will reflect the EPA's update, and will include revised microbiological thresholds and a greater emphasis on the importance of risk assessment.

Development of standards and monitoring of microbial contamination of shellfish is closely linked to food safety advice, and therefore falls under the jurisdiction of public health and commercial shellfish sanitation programmes. The Guidelines include advice for recreational shellfish gathering, viz., median faecal coliform content of samples taken over a shellfish gathering season shall not exceed a most probable number (MPN) of 14 per 100 mL and not more than 10% of samples should exceed an MPN of 43 per 100 mL. As part of its estuary water quality monitoring, WRC has a shellfish-gathering indicator that is derived from this guideline; it is intended only for recreational harvesting. Because it can be expensive to test shellfish beds at a high enough frequency to detect faecal coliforms, closures of shellfish areas can be managed in response to trigger points from proxy measurements of water quality, such as rainfall or river flows.

GC16 review emerging technologies for monitoring FIB. The most likely technology to be put into practice soon is the use of molecular-based tests. These will address the current challenge around delayed results. Typically, results using standard culture methods cannot be produced for at least 24 hours following sample collection. As a result, a decision on a beach closure today may be based on results from yesterday or a few days prior. Recognising the need to speed up results from water quality monitoring at beaches, the U.S. Environmental Protection Agency recently approved some rapid methods based on quantitative polymerase chain reaction (qPCR) for estimating FIB. There are also new technologies, which may be implemented within monitoring programmes, for identifying and quantifying different sources of bacteria and viruses associated with faecal contamination.

4.5 Toxicants

Toxicants are a form of contaminant that include metals, hydrocarbons and pesticides, which come from many sources, including urban stormwater runoff, landfill leachate, diffuse runoff of pesticides from agriculture, runoff from ports, mining and marine farming. Because toxicant concentrations are likely to be low and highly variable within the water column, monitoring of toxicants tends to focus on seabed sediments or, in some cases, filter-feeding organisms such as mussels. Because toxicants accumulate in shellfish, shellfish can be unsafe for consumption in areas that receive large inputs of stormwater and/or wastewater.

A comprehensive list of priority toxicants is provided in the **European Union Water Framework Directive Strategy on Priority Substances**[6] (Table 4).

[6] European Union Water Framework Directive Strategy on Priority Substances Directive 2000/60/EC.

Table 4. Priority toxicants in the European Union Water Framework Directive Strategy on Priority Substances.

Metals and metalloids	Cadmium, lead, mercury, nickel, tributyltin, and their compounds
Aromatic hydrocarbons	Anthracene, benzene, fluoranthene, naphthalene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, trichlorobenzene, pentachlorobenzene,
Pesticides (insecticides, herbicides, fungicides)	Alachlor, atrazine, chlorpyrifos, chlorfenvinphos, 1,2-dichloroethane, dichloromethane, diuron, endosulfan, hexachlorobutadiene, hexachlorobenzene, hexachlorocyclohexane, isoproturon, pentachlorophenol, simazine, trifluralin
Flame retardants	Brominated diphenylether (pentabromodiphenylether congeners 28, 47, 99, 100, 153, 154)
Chloroalkanes	$C_{10\text{-}13}$, trichloromethane (chloroform)
Alkylphenols	Nonylphenol, octylphenol
Plasticizer	Di(2-ethylhexyl)phthalate (DEHP)

Trigger values for toxicants are provided in the **ANZECC (2000) guidelines**, which specify low to high Interim Sediment Quality Guideline (ISQG) concentrations, which apply to sediment concentrations, not water-column concentrations. The seabed is often a good integrator of what is happening in the water column, and the concentration of toxicants within sediments can provide an indication of levels within the water body. The ISQG-Low concentration represents a 10% probability that a significant toxicity effect will occur in a sensitive species (low likelihood of observable biological effects), and the ISQG-High concentration represents a 50% probability (high likelihood of observable biological effects). The ISQG concentrations are based largely on international ecotoxicological studies; assays using New Zealand species are currently being developed and applied.

GC16 tabulate a wide range of toxicant thresholds/trigger values/standards/guidelines from Australia, Canada, the U.K., the U.S.A., Japan and ASEAN, including for metals and metalloids, chlorinated alkanes, chlorinated aromatic hydrocarbons, chlorinated alkenes, phenols, other organics, organochlorine pesticides, organophosphorus pesticides, carbamate pesticides, neonicotinoids pesticides, urea insecticides, herbicides and fungicides.

4.6 Emerging contaminants

Two reports (**Tremblay, 2011; Stewart et al., 2016**) have reviewed the literature on emerging contaminants (ECs) and their relevance to New Zealand. An EC is defined by the **US Geological Survey**[7] as “any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and (or) human health effects”. Despite there being a number of workshops since 2011, there is as yet no New Zealand strategy

[7] see http://toxics.usgs.gov/regional/emc/

on emerging contaminants. Key government departments and industry bodies remain reluctant to acknowledge emerging contaminants as an issue of importance in New Zealand.

GC16 tabulate sources and classes of ECs (Table 5). Land and marine farming potentially contribute a different profile of emerging contaminants to the marine receiving environment compared to urban settings such as Auckland. In addition, compared to urban-sourced ECs, which are potentially intercepted by wastewater treatment plants, ECs from land and marine farming are not readily removed from runoff.

Table 5. Sources and classes of ECs tabulated by Green and Cornelisen (2006).

Sewage disposal	Stormwater	Landfill leachate	Agriculture	Aquaculture	Recreation
Pharmaceuticals	Plasticisers	Pharmaceuticals	Steroid hormones	Veterinary medicines	Pharmaceuticals
Plasticisers	Antimicrobials	Plasticisers	Veterinary medicines		Antimicrobials
Antimicrobials	Corrosion inhibitors	Antimicrobials	Agrochemicals		UV-filters
Corrosion inhibitors	Flame retardants	Surfactants			
Flame retardants	Surfactants				
Surfactants	UV-filters				
UV-filters					
Steroid hormones					

Managing emerging contaminants according to standards is limited to application of the **ANZECC (2000) guidelines** trigger values for emerging contaminants. The ANZECC guidelines are currently being reviewed and updated.

5. References

Alfaro, A.C. (2005) Effect of water flow and oxygen concentration on early settlement of the New Zealand green-lipped mussel, *Perna canaliculus*. *Aquaculture*, 246: 285–294.

ANZECC (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Retrieved from http://www.mfe.govt.nz/publications/fresh-water/anzecc-2000-guidelines

Batiuk, R., Breitburg, D., Diaz, R., Cronin, T., Secore, D. and Thursby, G. (2009) Derivation of habitat-specific dissolved oxygen criteria for Chesapeake Bay and its tidal tributaries. *Journal of Experimental Marine Biology and Ecology*, 381: S204–S215.

Borja, A., Franco, J., Valencia, V., Bald, J., Muxika, I., Belzunce, M.J. and Solaun, O. (2004) Implementation of the European water framework directive from the Basque country (northern Spain): a methodological approach. *Marine Pollution Bulletin*, 48(3/4): 209–18.

Bricker, S., Ferreira, J. and Simas, T. (2003) An integrated methodology for assessment of estuarine trophic status. *Ecological Modelling*, 169: 39–60.

Brown, C.A., W.G. Nelson, B.L. Boese, T.H. DeWitt, P.M. Eldridge, J.E. Kaldy, H. Lee II, J.H. Power, and D.R. Young (2007) *An Approach to Developing Nutrient Criteria for Pacific Northwest Estuaries: A Case Study of Yaquina Estuary, Oregon*. U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Laboratory, Western Ecology Division, EPA/600/R-07/046. Retrieved from http://nepis.epa.gov/Exe/ZyPDF.cgi/P10077PT.PDF?Dockey=P10077PT.PDF

Dennison, W.C. et al. (1993) Assessing water quality with submersed aquatic vegetation. *BioScience*, 43(2): 86–94.

Duarte, C.M. (1991) Seagrass depth limits. *Aquatic Botany*, 40: 363–377.

Gray, J.S., Wu, R.S.S. and Or, Y.Y. (2002) Effects of hypoxia and organic enrichment on the coastal marine environment. *Marine Ecology Progress Series*, 238: 249–279.

Green, M.O. and Cornelisen, C.D. (2016) *Marine Water Quality Standards for the Waikato Region – Literature Review*. Report WRC1507–1, Streamlined Environmental, Hamilton, 123 pp.

Green, M.O. and Zeldis, J. (2015) *Firth of Thames Water Quality and Ecosystem Health – A Synthesis*. NIWA Client Report HAM2015–016, April 2015, 81 pp. Retrieved from http://www.waikatoregion.govt.nz/tr201523/

Herbert, N. (2013) *Potential Biological Impact of Dissolved Oxygen Variability in the Hauraki Gulf*. Prepared for Waikato Regional Council. Report provided by Waikato Regional Council.

Hunt, A. (2016) *Waikato Regional Council Coastal Water Quality – Part 1: Current Status and Potential Future Revisions of New Zealand Guideline. Part 2: Summary and Interpretation of Waikato Regional Council Guidelines, Standards and Monitoring data. Part 3: Policy Requirements and Recommendations for Monitoring*. Report prepared for Waikato Regional Council, draft (supplied by Waikato Regional Council, April 2016).

Matheson, F. and Wadhwa, S. (2012) *Seagrass in Porirua Harbour. Preliminary Assessment of Restoration Potential*. NIWA Client Report HAM2012-037, NWA Hamilton.

Ministry for the Environment (2003) *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas*. Ministry for the Environment, Wellington, New Zealand.

Olsen, L.M., Holmer, M. and Olsen, Y. (2008) *Perspectives of Nutrient Emission from Fish Aquaculture in Coastal Waters: Literature Review with Evaluated State of Knowledge*. Final report for The Fishery and Aquaculture Industry Research Fund, 87 pp.

Revilla, M., Franco, J., Garmendia, M. and Borja, Á. (2010) A new method for phytoplankton quality assessment in the Basque estuaries (northern Spain), within the European Water Framework Directive. *Revista de Investigación Marina*, 17(7): 149–164.

Robertson, B.M., Stevens, L., Robertson, B., Zeldis, J., Green, M.O., Madarasz-Smith, A., Plew, D., Storey, R. and Oliver, M. (2016a) *NZ Estuary Trophic Index Screening Tool 1. Determining Eutrophication Susceptibility Using Physical and Nutrient Load Data*. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420, 47 pp.

Robertson, B.M., Stevens, L., Robertson, B., Zeldis, J., Green, M.O., Madarasz-Smith, A., Plew, D., Storey, R. and Oliver, M. (2016b). *NZ Estuary Trophic Index Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State*. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420, 68 pp.

Sheldon, J.E. and Alber, M. (2011) Recommended indicators of estuarine water quality for Georgia. *Proceedings of the 2011 Georgia Water Resources Conference*, April 11–13, 2011, University of Georgia. Retrieved from http://gwri.gatech.edu/sites/default/files/files/docs/2011/5.1.2Sheldon.pdf

Souchu, P., Ximenes, M.C., Lauret, M., Vaquer, A. and Dutrieux, E. (2000) Mise à jour d'indicateurs du niveau d'eutrophisation des milieux lagunaires méditerranéens, août 2000, Ifremer-Créocean-Université Montpellier II, 412 pp. Quoted in Sutula et al., 2011, Table 4.3, p. 90.

Steward, J.S., Virnstein, R.W., Morris, L.J. and Lowe, E.F. (2005) Setting seagrass depth, coverage, and light targets for the Indian River lagoon system, Florida. *Estuaries*, 28(6): 923–935.

Stewart, M., Northcott, G., Gaw, S. and Tremblay, L. (2016) *An Update on Emerging Organic Contaminants of Concern for New Zealand with Guidance on Monitoring Approaches for Councils*. Prepared by Streamlined Environmental Ltd, Northcott Research Consultants Ltd, University of Canterbury, Cawthron Institute and the University of Auckland for Auckland Council, Greater Wellington Regional Council and Environment Canterbury Regional Council. Auckland Council Technical Report, TR2016/006.

Stoddard, J.L., Larsen, D.P., Hawkins, C.P., Johnson, R.K. and Norris, R.H. (2006) Setting expectations for the ecological condition of running waters: the concept of the reference condition. *Ecological Applications*, 16(4): 1267–1276.

Sutula, M. et al. (2011) *Review of Indicators for Development of Nutrient Numeric Endpoints in California Estuaries*. Southern California Coastal Water Research Project Technical Report No. 646. Retrieved from http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/planningtmdls/amendments/estuarineNNE/E-NNE%20Indicator%20Review%20Document%20v8%204-28-2011.pdf

Sutula, M., Bailey, H. and Poucher, S. (2012) *Science Supporting Dissolved Oxygen Objectives in California Estuaries*. Prepared for the California Environmental Protection Agency State Water Resources Control Board. University, Galveston, TX, TAMU-SG-92–109. Retrieved from http://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/684_DO_NNE.pdf

Tremblay, L.A., Stewart, M., Peake, B.M., Gadd, J.B. and Northcott, G.L. (2011) *Review of the Risks of Emerging Organic Contaminants and Potential Impacts to Hawkes Bay*. Cawthron Report No. 1973, 39 pp.

Turner, S. and Schwarz, A.M. (2006) *Management and Conservation of Seagrass in New Zealand: An Introduction*. Science for Conservation 264, Department of Conservation, Wellington, ISSN 1173-2946.

U.S. Environmental Protection Agency. (2002) *List of Contaminants and Their MCLs*. EPA 816-F-02-013, July 2002. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency (2012) *Recreational Water Quality Criteria*. Office of Water 820-F-12-058, Health and Ecological Criteria Division, Office of Science and Technology, U.S. Environmental Protection Agency.

Vaquer-Sunyer, R. and Duarte, C.M. (2008) Thresholds of hypoxia for marine biodiversity. *Proceedings of the National Academy of Science of the USA*, 105: 15452–15457. Retrieved from http://www.pnas.org/content/early/2008/09/26/0803833105.full.pdf

Williamson, R.B., Hickey, C.W. and Robertson, B.M. (2015) *Preliminary Assessment of Limits and Guidelines Available for Classifying Coastal Waters*. Report for Auckland Council by Diffuse Sources, NIWA and Wriggle - Coastal Management, 129 pp.

Wriggle Coastal Management. (2012) *Preliminary Guidance Document: Nutrient Load Criteria to Limit Eutrophication in Typical NZ Estuary Types – Tidal Lagoon and Tidal River Estuaries*. Prepared by Wriggle Coastal Management for Environment Southland. Retrieved from http://www.es.govt.nz/media/26710/nutrient_criteria_nz_shallow_estuaries_leigh_copy.pdf