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Physical and chemical attributes affecting survival and collection of freshwater mahinga kai species

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Cover photo

Top Row: Tuna and kōura (photos by S. Moore)
Bottom row: Watercress (K. Collier) and post-larval whitebait (K. Gorski)

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EXECUTIVE SUMMARY

Mahinga kai is one of a number of significant Māori values identified within the National Objectives Framework (NOF) for freshwater management. The Ngā Tohu o Te Taiao (NToTT) project aimed to develop knowledge, tools and processes for setting freshwater limits for mahinga kai within the NOF. Māori have raised issues and concerns about mahinga kai species due to: (i) declines in abundance, size and quality; and (ii) potential contamination from anthropogenic activities. This review provides information about the contaminants and environmental stressors likely to be affecting some important freshwater mahinga kai, with a focus on tuna (eel), īnanga (whitebait), kākahi (freshwater mussel), kōura (freshwater crayfish) and wātakirihi (watercress). In this report, we provide guidance on how to relate existing guidelines and regulations to freshwater invertebrate and fish species traditionally used for food gathering. The guidance covered includes: (i) the ANZECC (2000) water quality guidelines for physical and chemical attributes of aquatic life, which are in the process of being updated; (ii) selected international water quality guidelines (e.g., USEPA, Environment Canada, OECD) which can be used to support and supplement ANZECC water quality guidelines; (iii) human health information for collection and consumption of aquatic foods; and (iv) the National Policy Statement for Freshwater Management (NPS-FM) and the NOF (which is also under further development). It is envisaged this report will support discussion on food abundance and safety of mahinga kai, and promote steps to ensure appropriate standards are set for clean waterways and customary resources under the NPS-FM and ANZECC (2000). We highlight the complexity of issues affecting abundance and suitability of five commonly-used mahinga kai species: tuna, īnanga, kōura, kākahi and wātakirihi. Information from this report should also be of use in future freshwater habitat and species restoration projects, especially where mahinga kai species are at risk and the goal is to maintain or enhance customary resource use, and species state and condition.

ACKNOWLEDGEMENTS

The study was funded by the Ministry of Business, Innovation and Employment as part of the programme *Nga Tohu o te Taiao: Sustaining and Enhancing Wai Māori and Mahinga Kai* (contract no. UOWX1304). We thank John Quinn (NIWA) for contributions to the mahinga kai species knowledge network diagrams, Rebecca Stott (NIWA) for guidance on current microbiological standards in New Zealand (although any interpretation inaccuracies are our own), Maui Hudson (UoW), and the Waikato-Tainui College of Research and Development for involvement in the programme.

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1. Introduction

The *Ngā Tohu o te Taiao: Sustaining and Enhancing Wai Māori and Mahinga Kai* (NToTT) project has been developing tools and processes for supporting conversations involving regional, tribal and national environmental management of freshwaters for mahinga kai. Mahinga kai is one of a number of significant Māori values identified within the National Objectives Framework (NOF) for freshwater management. The term mahinga kai is commonly used to describe the activity of, and the place for, harvesting, collection, hunting and gathering of food resources. Mahinga is derived from the word mahi. As a verb this is; "*to work, be occupied with, perform, procure*", and as a noun; "*work, occupation, function, abundance*". The term *kai* refers to the activity of consuming or eating food and is also the noun for food (Coffin 2015; Williams 1992a,b). Therefore *mahinga kai*, literally means *garden, cultivation, food-gathering place*. The NToTT project aimed to develop knowledge, tools and processes for setting freshwater limits for mahinga kai within the NOF, notably regarding:

- the extent to which mahinga kai represents a key proxy for the state of, and pressures on, freshwater catchments;
- how synergising mātauranga Māori and contemporary science can enhance credibility and acceptability of limit-setting to sustain mahinga kai objectives.

Hauanga kai is the term used by Waikato-Tainui and refers to customary and contemporary gathering and use of naturally occurring and cultivated foods (Waikato-Tainui Te Kauhanganui Inc. 2013).

The strong relationship with taonga and mahinga kai stems from Māori cosmology where every part of the natural world has a whakapapa or genealogical connection to Atua (gods, deities) from the primal parents Ranginui (sky father) and Papatūānuku (earth mother) (Buck (Te Rangi Hiroa) 1950; Coffin 2015). The importance of water and food for sustenance of the individual, family, community, and ultimately the iwi is paramount. In a subsistence economy, such as pre-1860, the survival of communities depended on a sustainable and secure water and food supply from a range of sources. This provided immediate day-to-day nutrition but also, through preserving, fermenting, drying, smoking and other techniques, medium-term storage for periods where harvesting was not possible (poor weather, cold seasons) and large events (feasts, celebrations). Fish and shellfish from rivers, streams, lakes and coastal areas, birds from forests, waterfowl, forest fruits, berries, roots and macrophytes, fungi and mushrooms, insect larvae and in more recent times watercress all contributed to the diet of river iwi (Buck (Te Rangi Hiroa) 1950; Waitangi Tribunal 2011; Waikato-Tainui Te Kauhanganui Inc. 2013; Coffin 2015).

Today, whilst iwi/hapū/whānau/marae do not rely as much on mahinga kai for survival, it is still an important part of the identity of an iwi, and comprises a large body of knowledge and a range of activities that connect people to their ancestors and the environment. Iwi/hapū have expressed the view that kai species are culturally significant as an integral part of the environment and through whakapapa (ancestral lineage), and many have listed these mahinga kai as taonga species in claims and in environmental management plans (e.g., (Waitangi Tribunal 2011; Wai 262 claim). Another traditional key value still highly regarded today, which is associated with mahinga kai, is manaakitanga: the ability for an iwi to display their generosity and wealth from the natural provisions harvested from their mahinga kai sites. The more abundant and generous the display of provision, the more mana (prestige, authority, status) is associated with a specific iwi/hapu/whanau (Marsden 2003; Mead 2003; Ratana et al. 2016).

The emphasis on fisheries in iwi planning documents related to mahinga kai likely reflects late-20th century emphasis on fisheries management legislation and competing cultural, commercial and recreational users (Coffin 2015), but there are references to many other types of kai in the literature, including watercress, shellfish, kōura, birds, potatoes and puha. Pressures and factors which have degraded mahinga kai abundance and condition include hydro-dams, sedimentation, disconnection and fragmentation of habitat, reduced wetland area, agricultural and urban pollution, poor water quality, point and diffuse discharges, discharges and contaminants from intensive agriculture, commercial fishing, pest plants, pest fish such as koi carp and catfish, commercial fishing, gravel extraction, channel modification, and alterations to flow (Rainforth 2008; NIWA 2010; Coffin 2015). Accordingly, Māori have raised a number of recent concerns that may limit the harvest, collection and consumption of aquatic mahinga kai due to:

- declines in their abundance, size and quality;
- potential contamination from anthropogenic activities; and
- concerns about food safety for consumption.

As part of the NToTT project, a number of tools have been developed with iwi to provide a perspective based on kaupapa Māori values for assessing the state and condition of mahinga kai and to help define environmental limits for survival and collection (Awatere et al. 2017; Taura et al. 2017; this report). These tools have drawn on scientific biophysical knowledge and mātauranga-a-iwi to provide complementary information and understandings of freshwater values and how limits can be set to sustain mahinga kai as part of the NOF. The tools have included: (i) a whakapapa framework for mātauranga data collection and capture, conceptual-mapping, and representation in tables and logic wheels that summarise and express values; (ii) a kaupapa Māori assessment tool to provide a pathway for iwi to assess and articulate freshwater resource condition and pressures, particularly for mahinga kai, grounded in a mātauranga approach that is complementary to the NOF by defining attributes and measures; (iii) lake water quality modelling that uses water colour as a key output that resonates with tangata whenua; and (iv) empirical models for three mahinga kai species based on biophysical parameters that can be used to map distribution and abundance in waterways at the regional scale and potentially predict generalised changes in land use on these species.

Collectively, these tools provide a means of interfacing mātauranga- and science-based approaches within the operating context of the NOF value for mahinga kai, as well as other NOF values that affect Māori aspirations for freshwater. To support the application of these tools, this report summarises available information on physical and chemical attributes affecting survival and collection of freshwater mahinga kai species. This need was identified by Harmsworth et al. (2016) in their assessment of how science information, in particular modelling, can interface with mātauranga to meet the needs of Māori. Many mahinga kai sites, both current and historical, are in lowland settings where freshwater environments are often in a degraded state and values are correspondingly compromised, with limited availability of sites in good condition within rohe to help define desired states for mahinga kai.

The review that follows provides information about the contaminants and environmental stressors likely to be affecting some important freshwater mahinga kai species with a focus on tuna, īnanga, kōura, kākahi, and wātakirihi. We provide guidance on how to relate existing guidelines to freshwater invertebrate and fish species traditionally used for food gathering, including: (a) the ANZECC (2000) water quality and sediment toxicity guidelines (which are in the process of being updated); (b) the NPS-FW and the NOF (which is also under development), and; (c) selected international water quality guidelines (e.g., USEPA, Environment Canada, OECD) which can be used to support and supplement ANZECC guidelines. Our review is focussed on key physical and chemical parameters required to support aquatic life (e.g., water temperature, dissolved oxygen, suspended sediment), and commonly encountered toxicants that are often present in water and sediment due to factors such as natural or modified geothermal inputs (e.g., As, Hg), urban stormwater (e.g., Cu, Zn), and agricultural activities (Cd, Cu, Zn, As). We also summarise selected food safety information and guidelines relating to mahinga kai collection and consumption, and provide information on the biology and stressors affecting the focal species. Based on currently available information, we treat these contaminants individually but acknowledge the additive or synergistic effects of multiple stressors acting together, forming complex effect pathways. We have attempted to illustrate this complexity for contaminant pathways and focal mahinga kai species through the use of conceptual models.

2. Key Physical and Chemical Stressors Affecting Mahinga Kai Species

2.1 Approach

For the purposes of this work, two thresholds were identified for physical and chemical stressors that directly affect mahinga kai species through toxicity or water quality changes (see Figure 1), to help define conditions under which species were expected to survive or thrive, as follows:

- **Chronic threshold** beyond which long-term survival and reproduction of the species was likely to be compromised based on: (i) recent reviews that define thresholds for moderate or occasional stress which may affect sensitive organisms; (ii) ANZECC guidelines for protection of 95% of aquatic species; and/or (iii) relevant international water quality guidelines (e.g., USEPA, Environment Canada).
- **No observed adverse effects** on aquatic organisms based on: (i) recent reviews that define thresholds for minor stress that may affect sensitive organisms for short periods; or (ii) ANZECC guidelines for protection of 99% of aquatic species.

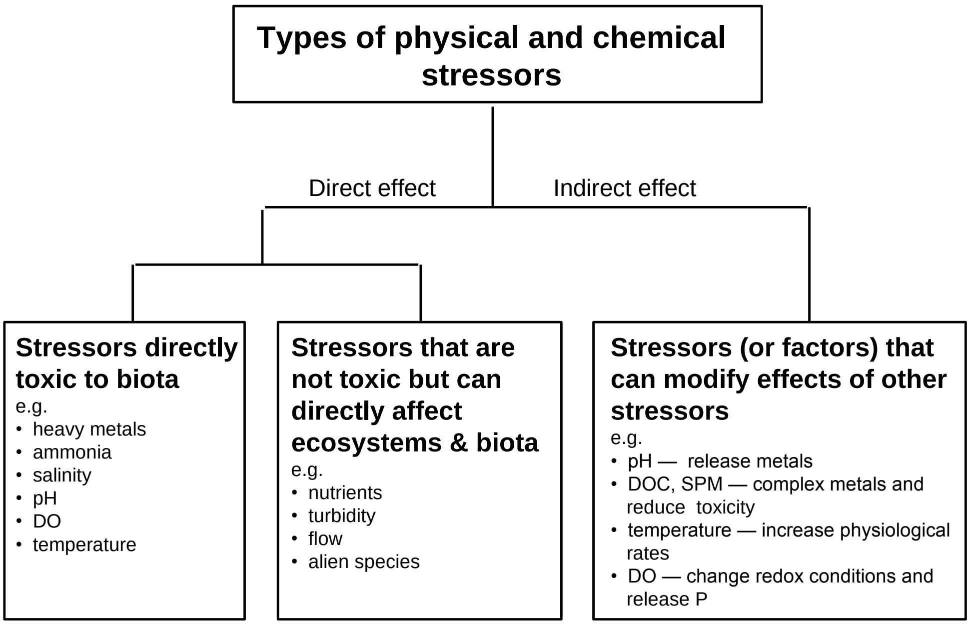

Figure 1: Types of physical and chemical stressors from ANZECC (2000)

It should be noted that the physical and chemical trigger values in the ANZECC (2000) guidelines are not designed to be used as 'magic numbers' or threshold values at which an environmental problem is inferred if they are exceeded. Rather, they are designed to be used in conjunction with professional judgement, to provide an initial assessment of the state of a waterbody regarding the issue in question. The trigger values for toxicants were derived using a statistical distribution method to calculate four different protection levels, 99%, 95%, 90% and 80%, that signify the percentage of species expected to be protected. The ANZECC (2000) guidelines state that, in most cases, the 95% protection level trigger values should apply to ecosystems that could be classified as slightly–moderately disturbed, although a higher protection level could be applied to slightly disturbed ecosystems where the management goal is no change in biodiversity. The highest protection level (99%) is used as the default value for ecosystems with high conservation value, pending collection of local chemical and biological monitoring data. The 99% protection level can also be used as default values for slightly–moderately disturbed systems where local data are lacking on bioaccumulation effects or where it is considered that the 95% protection level fails to protect key species. It should be noted that the ANZECC guidelines are currently under review but updates were not available at the time of writing[1].

A 95% ANZECC trigger value should provide for all except the most sensitive species, and therefore is considered a conservative approach for addressing the long-term survival of mahinga kai species, while a 99% trigger value should ensure populations thrive within the constraints of other factors operating at particular sites. Thresholds that indicate acute or critical effects (e.g., mortality, immobility, loss of equilibrium) were considered too harsh for the purposes intended here. Species-specific data were collated from published information where this was available. Species-specific LC_{50} thresholds, which define the level of a stressor at which half the test population survives in laboratory conditions, were considered inappropriate because of the potential long-term effect on recruitment and ensuing population decline that would result from persistent pressure.

In terms of direct non-toxic water quality stressors (e.g., temperature, dissolved oxygen, pH, suspended sediment), the ANZECC (2000) guidelines recognise three levels of "ecosystem condition", each with an associated level of protection. However, for New Zealand waters these levels were based on limited sets of data and so are not used here. Rather, to infer suitable conditions for mahinga kai species we use recent reviews that define thresholds for moderate or occasional stress for particular species or biota generally, or relevant international water quality guidelines.

Sediment quality can also be a key factor for species associated with benthic environments, such as kākahi. The most recent guidelines by Simpson et al. (2013) are updates of the ANZECC (2000) Sediment Quality Guidelines (SQG) (see Section 2.3). The general principle behind these guidelines is to measure the total concentration of each contaminant in the sediments. If concentrations are lower than the SQG value, they are considered low risk for toxicity to biota. If contaminant concentrations exceed the SQG value then further analysis is conducted to determine what fraction of the contaminants is bioavailable and likely to be toxic. Multiple

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[1] Updates will be available at http://www.mfe.govt.nz/fresh-water/technical-guidance-and-guidelines/anzecc-2000-guidelines and/or http://www.agriculture.gov.au/water/quality/guidelines

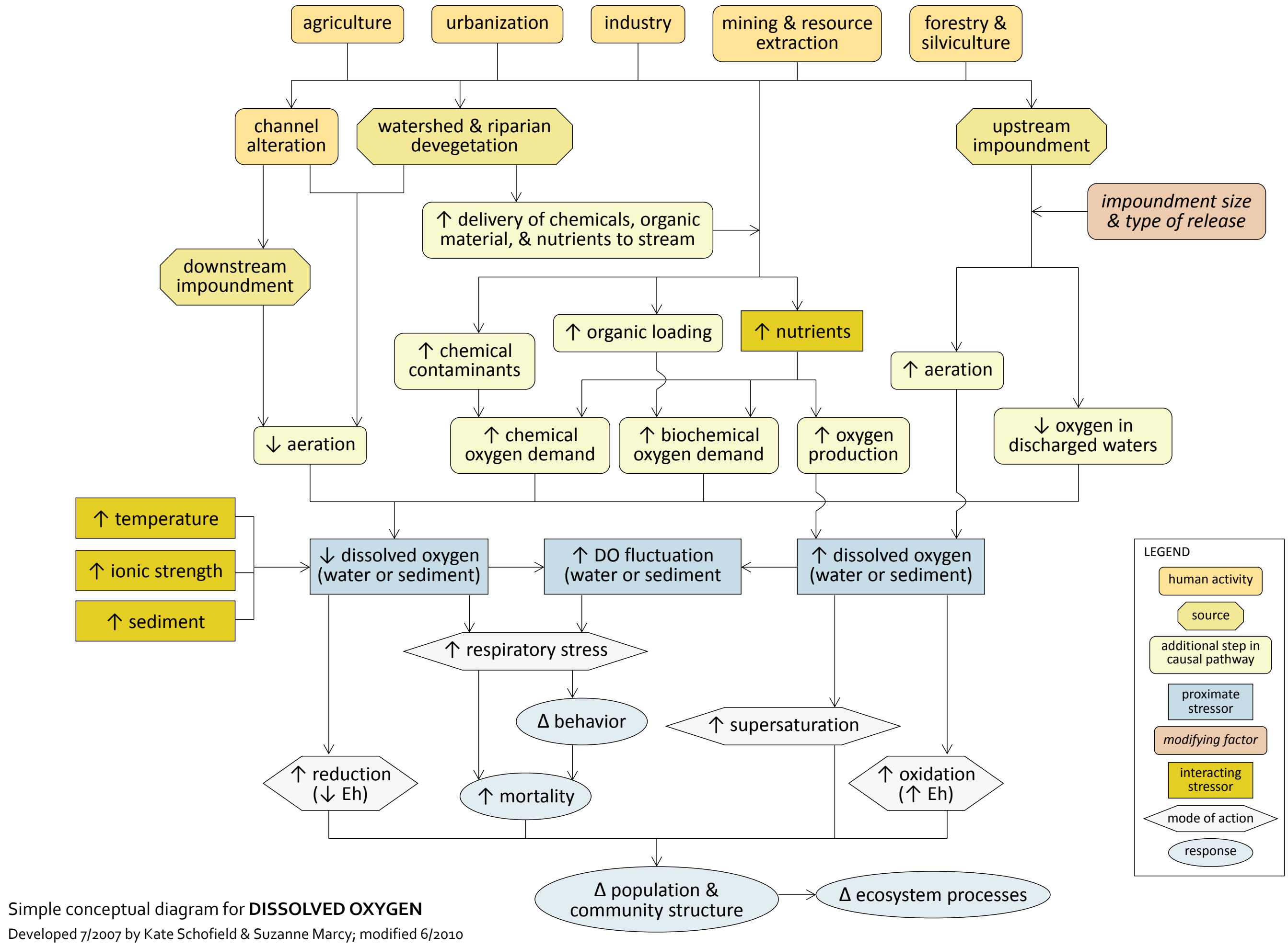
lines of evidence can be used in this process to determine the site-specific risk to their ability to survive and thrive (see Appendix 2 for further information).

2.2 Water quality parameters

2.2.1 Physicochemical pressures

Dissolved oxygen: Dissolved oxygen is a key life-supporting parameter for all aquatic animals, with some species more sensitive than others to low dissolved oxygen, and some life-stages (e.g., eggs) requiring higher oxygen levels than others. Mobile species such as fish can temporarily avoid low dissolved oxygen levels for short periods by gulping air or moving to locations with higher levels such as tributary inflows. However, less mobile species, such as kākahi, are slow to respond behaviourally to low levels of oxygen. Dissolved oxygen can be expressed as mg/L or % saturation. Concentrations are affected by temperature with higher temperatures reducing the oxygen carrying capacity of the water. For example, 80% saturation (equivalent to Class A waters under the Resource Management Act (1991)) is equivalent to 9.02 mg/L at 10^{o}C, 7.5 mg/L at 18^{o}C and 6.6 mg/L at 25^{o}C (Davies-Colley et al. 2013; Franklin 2014).

Dissolved oxygen concentrations can vary during the course of a day due in part to change in temperature, but also as a result of the balance between respiration and photosynthesis by plants that both use and produce oxygen. In other words, this means that dissolved oxygen concentrations can decrease to zero at night in dense aquatic plant beds when the plants are only respiring (using oxygen) and not photosynthesising. There are other situations where dissolved oxygen levels can become naturally low, in geothermally-influenced waters, and where flow in rivers is dominated by poorly-oxygenated groundwater (Davies-Colley et al. 2013). A diagrammatic representation of factors affecting dissolved oxygen levels in aquatic environments is provided in Figure 2, and guideline values relevant to New Zealand are shown in Table 1.



Simple conceptual diagram for **DISSOLVED OXYGEN**
Developed 7/2007 by Kate Schofield & Suzanne Marcy; modified 6/2010

Figure 2: Conceptual model for dissolved oxygen effects on aquatic animals
(From: https://www3.epa.gov/caddis/)

Table 1: **New Zealand guideline values that have been proposed for dissolved oxygen. The original documents should be referred to for a comprehensive understanding of their application**

Guideline	DO (mg/L)	Comments
Franklin (2014):		
7-day mean		Fish only
Guideline*	8.0	
Imperative**	7.0	
7-day mean daily minimum		
Guideline*	6.0	
Imperative**	5.0	
Instantaneous minimum		
Guideline*	5.0	
Imperative**	3.5	
Davies- Colley et al. (2013):		
as for NOF below plus:		Rivers
7-day mean*** A (no stress)	9.0	
7-day mean*** B (minor stress on sensitive organisms for short periods – reduced abundance)	8.0	
7 day mean*** C (moderate stress – risk of sensitive fish and invertebrates being lost)	6.5	
NOF (2017):		
A-band – No stress		Rivers below point sources only
7-d mean minimum (summer)	≥8.0	
1-d minimum (summer)	≥7.5	
B-band – Occasional minor stress:		“
7-d mean minimum (summer)	≥7.0 and <8.0	
1-d minimum (summer)	≥5.0 and <7.5	
C-band – Moderate stress:		“
7-d mean minimum (summer)	≥5.0 and <7.0	
1-d minimum (summer)	≥4.0 and <5.0	
National bottom line (Moderate stress):	5.0 4.0	“
D-Band (Significant, persistent stress):		“
7-d mean minimum (summer)	<5.0	
1-d minimum (summer)	<4.0	

*Guideline protection = target protection level or minimum for salmonids and early life stages of all species.

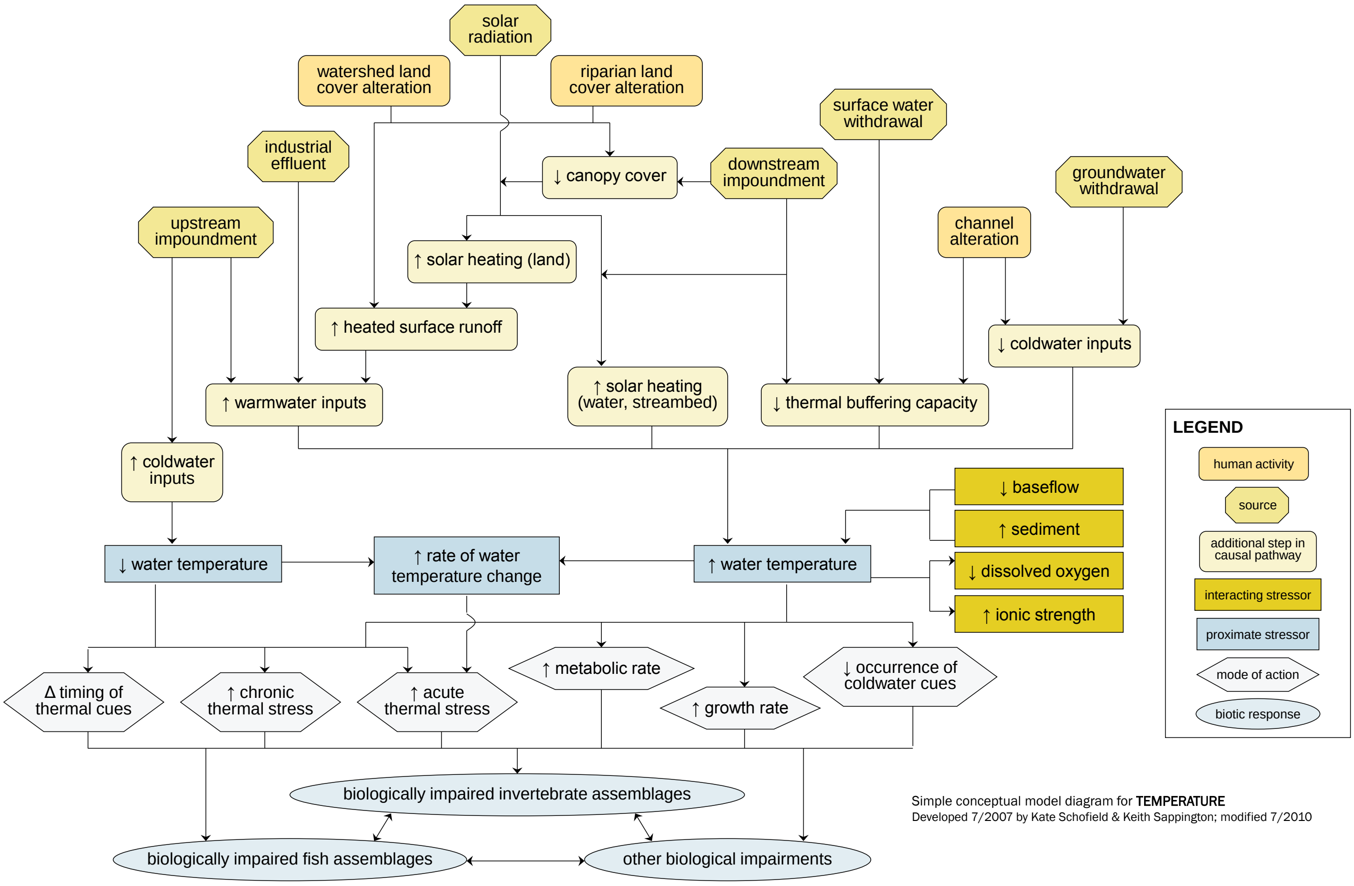
**Imperative protection = minimum recommended protection for adult fish.

***7-day duration alone is insufficient to avoid chronic impacts. It is intended that in any continuous 7-day period throughout the year, this threshold will be met (i.e., this is the annual minimum 7-day mean).

Temperature: Aquatic ecosystem processes, such as oxygen solubility and metabolic rates, are sensitive to temperature changes, and consequently species survival is closely linked to water temperature. Temperature changes occur as part of normal diurnal (daily) and seasonal cycles, while discharges of excess heat or cold can constitute forms of thermal pollution (e.g., discharges of cooling water from power plants, or heated stormwater runoff from sun-baked roads suddenly entering a small stream). Loss of shading by riparian vegetation may also lead to temperature increases in streams, while discharges of bottom waters from storage reservoirs (e.g., hydro-electric power dams) can decrease downstream bottom water temperatures. Water temperature can also affect the toxicity of some contaminants (e.g., ammonia and aluminium toxicities increase at higher temperatures).

A diagrammatic representation of factors affecting water temperature in aquatic environments is provided in Figure 3, and proposed guideline values relevant to New Zealand are shown in Table 2. At the request of the Ministry for the Environment (MfE), Davies-Colley et al. (2013) proposed temperature guidelines for consideration in the NOF. It is recognised that several metrics/statistics may need to be applied to account for various features of the thermal regime that aquatic organisms experience. Given that high summertime temperatures are usually the most adverse thermal conditions experienced in degraded New Zealand waterways, Davies-Colley et al. (2013) proposed using the Cox-Rutherford Index (CRI) calculated from the five hottest days in summer. The CRI is simply the mean (or average) of the maximum temperature and the mean temperature on a single day—it tends to represent the upper end of the temperature regime experienced by aquatic organisms on the hottest days of the year. The proposed guidelines also recognised that certain eastern and lowland regions of New Zealand (e.g., Bay of Plenty, Canterbury) tend to experience naturally warmer summertime conditions than the rest of New Zealand. Finally the proposed guidelines also provide for other locations that do not fit the generalised criteria (e.g., a geothermal- or glacier-fed stream supporting unique species) by allowing for comparison against a suitable reference site.

Olsen et al. (2012) had earlier summarised available thermal criteria for several New Zealand freshwater species, although they noted the lack of confidence in making species-specific conclusions (see Table 3). It is difficult to simply define a species thermal tolerance or optimum because a species usually tolerates a range of temperatures (depending on the season), and that temperature range is affected by multiple factors, such as the rate of temperature change, any preceding acclimation (e.g., fast or slow (perhaps 0.5^{o}C/day) increase), the duration of exposure to extremes, and the life stage being exposed. Also, the non-lethal metabolic processes affected, particularly reproductive and early life stage development, may not be evident for some time after the exposure. Olsen et al. (2012) provide an excellent discussion of the various thermal tolerance indices that have been developed and how they can be interpreted and applied.



Simple conceptual model diagram for **TEMPERATURE**
Developed 7/2007 by Kate Schofield & Keith Sappington; modified 7/2010

Figure 3: Conceptual model for temperature effects on aquatic animals
(From: https://www3.epa.gov/caddis/)

Table 2: **Generalised New Zealand guideline values proposed for water temperature in rivers only from Davies-Colley et al. (2013). To be calculated from the mean Cox-Rutherford Index (CRI) averaged over the five hottest days (from inspection of a continuous temperature record) in the summer period. Davies-Colley et al. (2013) provide background information *<u>required</u>* for full interpretation of these proposed guidelines (exclusions, cautions etc). CRI = average of the mean and maximum temperature on a single day; summer is defined as the period from 1 December to 21 March. “Site-specific approach” provides for temperature change relative to a reference site**

Guideline	**CRI Temperature (°C)**	**Comments**
Band boundary:		**Narrative descriptor of the bands A to D:**
A/B	≤18°C	A: No thermal stress on any aquatic organisms that are present at matched references (near-pristine sites).
B/C	≤20°C	B: Minor thermal stress on occasion (clear days in summer) on particularly sensitive organisms such as certain insects and fish.
C/D	≤24°C	C: Some thermal stress on occasion, with elimination of certain sensitive insects and absence of certain sensitive fish.
D (unacceptable/does not provide for value)	>24°C	D: Significant thermal stress on a range of aquatic organisms. Risk of local elimination of keystone species with loss of ecological integrity.
Eastern, dry zones:		**Narrative descriptor of the bands A to D:**
Eastern dry climate A/B	≤19°C	As above for all bands
Eastern dry climate B/C	≤21°C	“
Eastern dry climate C/D	≤25°C	“
Eastern dry climate D (unacceptable/does not provide for value)	>25°C	“
Site-specific approach:		**Narrative descriptor of the bands A to D:**
A/B	≤1°C*	As above for all bands
B/C	≤2°C*	“
C/D	≤3°C*	“
D (unacceptable/does not provide for value)	>3°C*	“

*increment compared to reference site.

Table 3: **Predicted thermal growth optima and preferences (low-moderate confidence from Olsen et al. (2012)). Values indicated will be partly related to the temperature to which fish are acclimated, and do not account for other life-stages or non-lethal behavioural responses to temperature and related physicochemical and physiological changes. nd = no data**

Species	Māori names can include…	Life stage	Predicted growth optimum** (°C)	Temperature preferenda*** (°C)
Shortfin eel	Tuna	Elver	29.0	26.9
Longfin eel	Tuna	Elver	27.8	24.4
Crans bully	Titikura	Mixed	22.6	21.0
Upland bully		Juvenile	25.1	nd
Common bully	Toitoi	Mixed	nd	20.2
Torrentfish	Mokomoko	Adult	21.4	21.8
Īnanga*	īnanga	Adult	22.5	18.1
Banded kōkopu*	Kōkopu	Adult	nd	17.3
Giant kōkopu*	Kōkopu	Whitebait	21.4	nd
Shortjaw kōkopu*	Kōkopu	Juvenile	21.4	nd
Kōaro*	Kōaro	Juvenile	18.8	nd
Common smelt	Pōrohe, paraki	Adult	19.2	16.1

*whitebait species.
**temperature at which maximum growth is observed (estimated from an equation).
***temperature at which acclimation and preferred temperature are equal.

pH: pH is a measure of the acidity or alkalinity of water and has a scale from 0 (extremely acidic) to 7 (neutral), through to 14 (extremely alkaline). Most waters have some capacity to buffer or resist changes in pH (measured in terms of the alkalinity). pH can affect aquatic ecosystems through acid or alkaline conditions causing direct adverse physiological effects on fish and aquatic insects, and through changes resulting in increased toxicity of pollutants such as aluminium (from reduced pH) and ammonia (through elevated pH). Most natural freshwaters have a pH in the range 6.5–8.0, but naturally acidic conditions can occur due to geothermal activities and leaching of organic acids from thick layers of decomposing organic matter on adjacent land. Human influences on pH can stem from acid mine drainage and acidification of soils by agriculture (see Figure 4). Guideline values relevant to New Zealand are shown in Table 4.

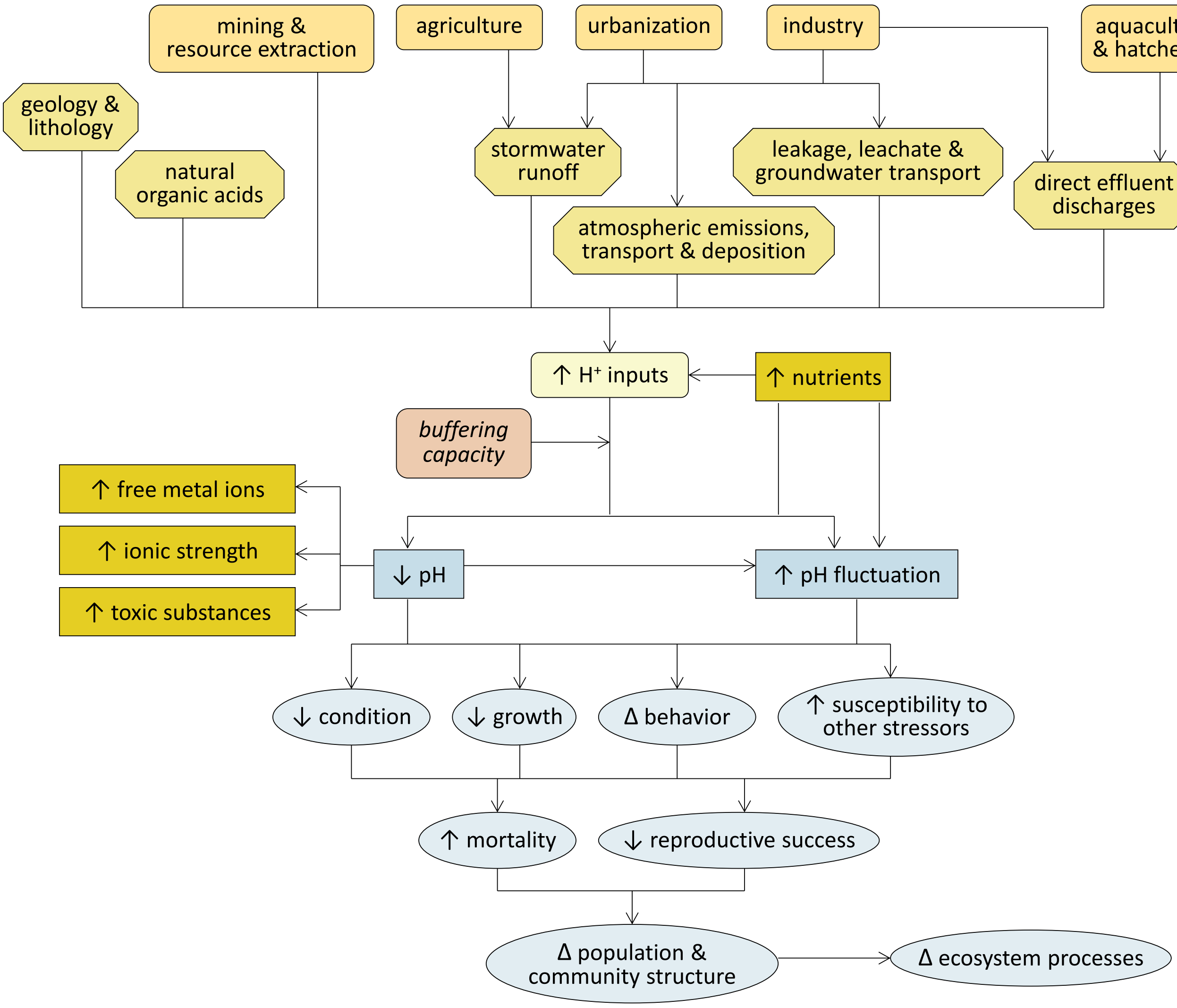


Figure 4: **Conceptual model for pH effects on aquatic animals**
(From: https://www3.epa.gov/caddis/)

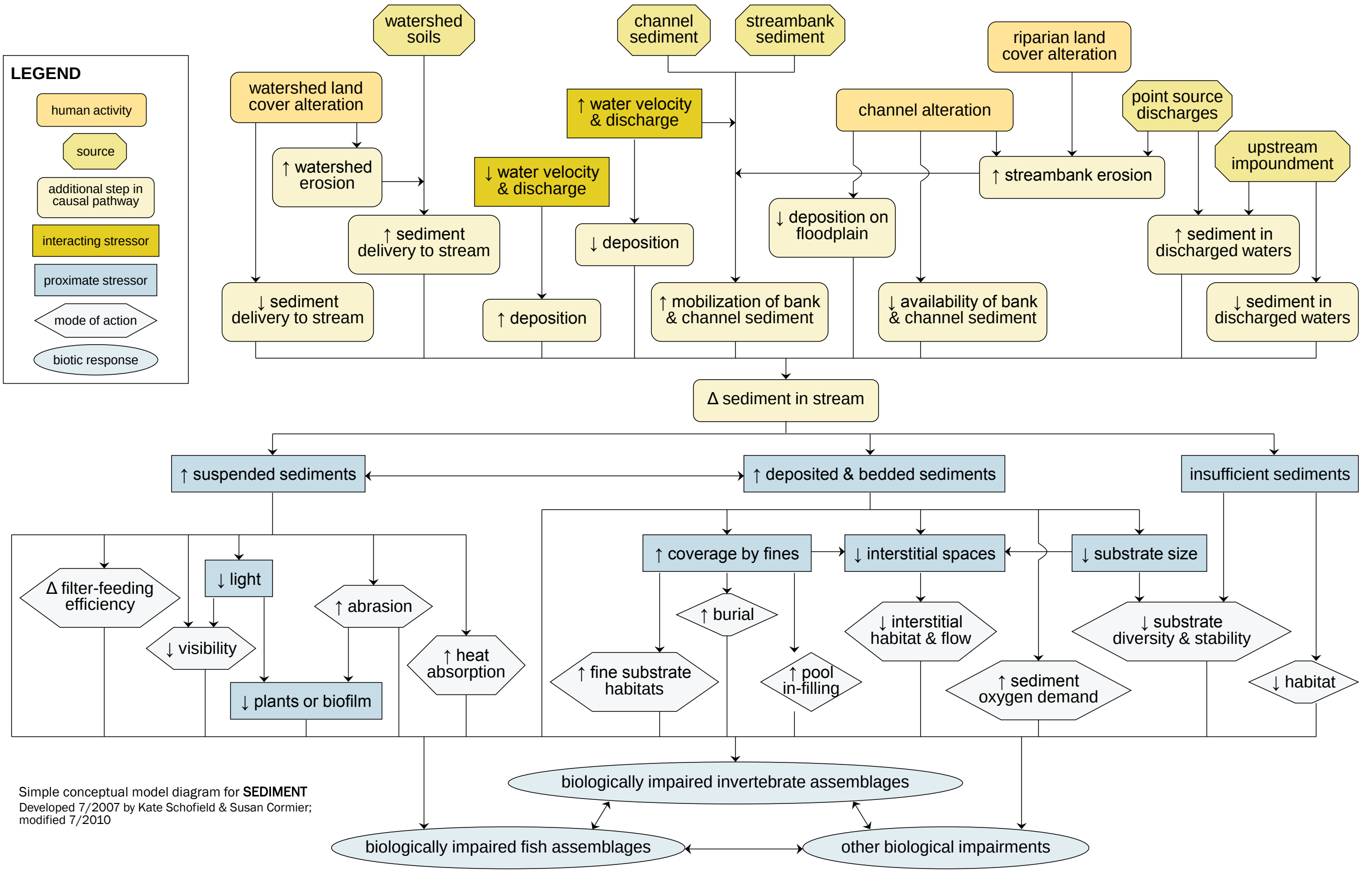
Table 4: **New Zealand guideline values proposed for pH from Davies-Colley et al. (2013)**

Guideline	**Summer pH***	**Comments**
A/B – no stress	6.5 < pH < 8.0	
B/C – occasional minor stress on particularly sensitive organisms	6.5 < pH < 8.5	Rivers only
C/D – stress caused on occasion by pH exceeding preference levels for sensitive insects and fish	6.0 < pH < 9.0	
D – significant persistent stress	< 6 or > 9	

*upper 95th-%ile.

Suspended sediment: Suspended sediment can affect aquatic biota through direct abrasion, clogging of gills which affects oxygen exchange, impairment of feeding whether by lowering the quality of food or impairing visual clarity, and by making water less attractive as a migration route. Settling of suspended sediment on the bed of lakes and rivers can also smother habitat for bottom-dwelling species such as kākahi (especially the juveniles), or degrade food supplies. A recent review of the effects of suspended sediment on New Zealand freshwater fish is available (Cavanagh et al. 2014).

Suspended sediment is measured either directly by quantifying the mass of particles in a water sample, or indirectly by measuring turbidity in nephlometric turbidity units (NTU) with a meter or using a black disc viewer to record visual clarity. There are ANZECC (2000) guidelines for suspended sediment in relation to ecosystem health (see below) but not as trigger values. A diagrammatic representation of factors affecting sediment levels in aquatic environments is provided in Figure 5, and selected guideline values are shown in Table 5.



Simple conceptual model diagram for **SEDIMENT**
Developed 7/2007 by Kate Schofield & Susan Cormier; modified 7/2010

Figure 5: Conceptual model for sediment effects on aquatic animals
(From: https://www3.epa.gov/caddis/)

Table 5: **Guideline values proposed for suspended sediment effects**

	Suspended sediment (mg/L or % change)	Turbidity (NTU)	Visual clarity (m)
ANZECC (2000): Slightly disturbed ecosystems (NZ)			
Upland rivers	-	4.1	0.6
Lowland rivers	-	5.6	0.8
USEPA (2007)*	10%	-	-
Canada**	5	2	-
European Union***	25	-	-

*Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life.
**Chronic exposure criteria used in table (from CCME 2007):
Clear flow: maximum increase of 8 NTU or 25 mg/L above background levels for short-term exposure (e.g. 24 h). Maximum average increase of 2 NTU or 5 mg/L for any long-term exposure (e.g. 24 h – 30 days).
High flow: maximum increase of 8 NTU or 25 mg/L above background levels at any time when background levels are between 8 and 80 NTU or 25 and 250 mg/L, respectively. Should not increase more than 10% of background levels when background is >80 NTU or ≥250 mg/L.
***25 mg/L should not be exceeded, with the exception of floods or droughts, for both salmonids and cyprinids (European Parliament and Council - Freshwater Fish Directive 2006/44/EC).

2.2.2 Selected toxicants

Nitrate: Nitrate is produced and consumed as part of the nitrogen cycle, and is also produced by humans for agricultural use as a fertiliser. Consequently, the major anthropogenic sources of nitrate to surface waters are from agricultural runoff, municipal and industrial wastewaters, urban runoff and groundwater inputs (Hickey & Martin 2009; Hickey 2013). Physiological effects of nitrate include damage to gills and kidneys affecting osmoregulatory ability, and disruptions to the immune system. Nitrate toxicity can be affected by water hardness (the amount of calcium and magnesium salts in the water). Available guideline values are shown in Table 6. Trigger values originally listed in ANZECC (2000) were retracted in an Erratum in 2002, which should now be superseded by NOF (2017).

Total ammoniacal nitrogen (TAN): Ammonia (known as total ammoniacal-nitrogen or TAN) is produced and consumed as part of the nitrogen cycle through the microbial transformation of organic nitrogen from organic matter and animal waste. In terms of human influences, it is normally associated with waste from animal farming operations, sewage disposal and landfill leachates, but can also become elevated in aquatic environments due to high densities of aquatic animals such as pest fish. Aquatic invertebrates are generally more sensitive than native fish to TAN, and this is particularly true for freshwater mussels which have highly sensitive larval (glochidial) and juvenile stages (Clearwater et al. 2014a). TAN toxicity increases with increasing water pH and temperature because the percentage of ammonia in its more toxic form increases (see Appendix 1 for TAN relationship relative to pH and temperature).

A diagrammatic representation of factors affecting ammonia levels in aquatic environments is provided in Figure 6, and available guideline values are shown in Table 7. These guideline values compare with recent modifications to the USEPA guidelines for a 30-day chronic rolling average of 0.78 mg/L (pH 8.0, 20°C), with guideline values not to be exceeded more than once in three years (USEPA 2013).

Table 6: **New Zealand guideline values proposed for nitrate**

	Nitrate (mg/L)	**Comments**
Hickey 2013* (see also Hickey & Martin 2009):	Annual median values	
Chronic – high conservation value (99% protection)	1.0	Pristine
Chronic – slightly-to-moderately disturbed systems (95% protection) – annual median grading conc.	2.4	Minor effects
Chronic – highly disturbed systems (90% protection)	3.8	Elevated concs. for 1-3 months
Chronic – highly disturbed systems (80% protection) – annual median grading conc.	6.9	Elevated concs. for 1-3 months
Acute**	20	Chronic effects on multiple species
NOF:		
A-band		Unlikely to affect sensitive spp.
Annual median	1.0	
Annual maximum	1.5	
B-band		
Annual median	2.4	Some growth effects on up to 5% of species
Annual maximum	3.5	
C-band		Growth effects on up to 20% of species, esp. fish; no acute effects
Annual median	6.9	
Annual maximum	9.8	

*values used in NOF.

**48-240 hours LC_{50} endpoint.

Table 7: Generalised New Zealand guideline values proposed for ammonia (TAN) in lakes and rivers. Refer to the original documents for a comprehensive description of how these guidelines should be applied

	TAN (mg/L)	**Comments**
ANZECC (2000) toxicant trigger value: 80%-ile protection 95%-ile protection 99%-ile	 2.3 0.9 0.32	 pH 8.0 “ “
NOF: A-band Annual median Annual maximum	 0.03 0.05	 No observed effect pH 8.0, 20°C
B-band Annual median Annual maximum	 0.24 0.40	Occasional impacts on 5% most sensitive spp. pH 8.0, 20°C
C-band Annual median Annual maximum	 1.30 2.20	Regular impacts on 20% most sensitive spp. pH 8.0, 20°C

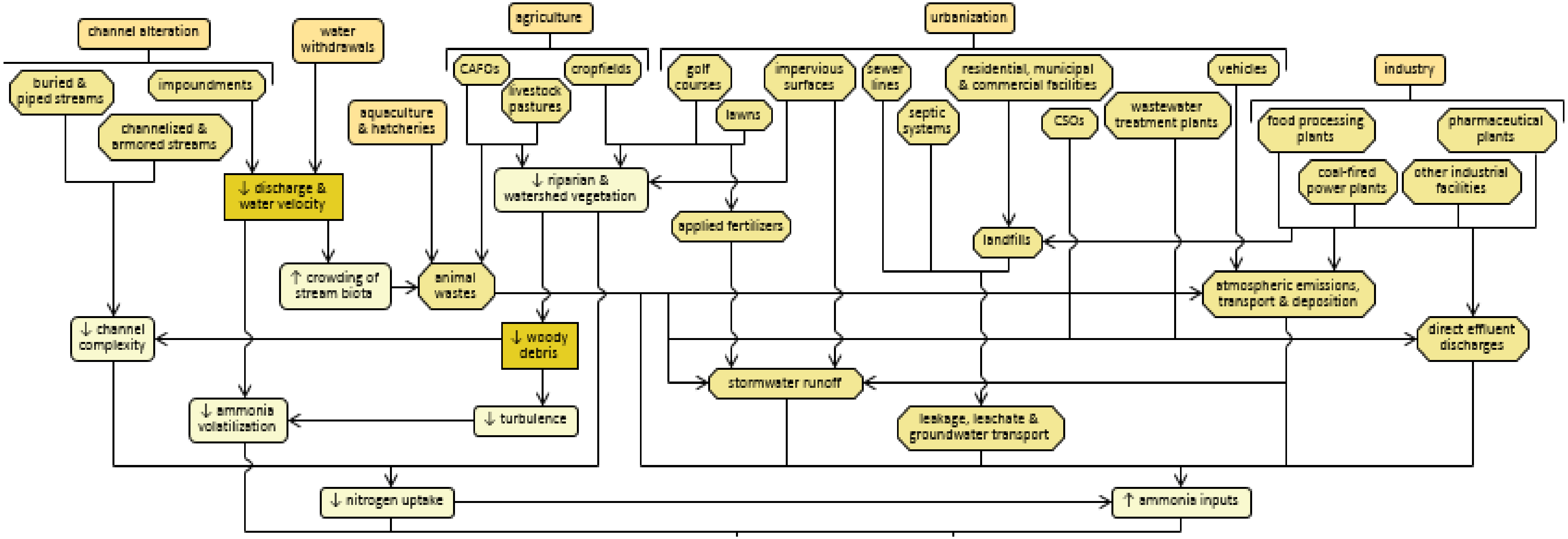


Figure 6: **Conceptual model describing sources of ammonia input to aquatic ecosystems. CAFO = concentrated animal feeding operation; CSOs = combined sewer overflows**
(Edited from: https://www3.epa.gov/caddis/)

Metals and metalloids: Metals and metalloids, including arsenic (As), copper (Cu), cadmium (Cd), mercury (Hg), nickel (Ni) and zinc (Zn), are common aquatic contaminants associated with point-source discharges such as stormwater, wastewater and industrial effluents (e.g., mining), as well as diffuse source inputs such as agricultural run-off and landfill leachate. In New Zealand, Cu and Zn are important nutritional supplements for livestock (e.g., Zn is used to prevent facial eczema) that enter the environment through agricultural waste (point-source inputs or diffuse run-off). Copper and other metals are also important active ingredients in many pesticides, such that loadings to horticultural soils can be predicted by crop type (e.g., onions 6 kg Cu/ha/year and 2.4 kg Zn/ha/year; Land Monitoring Forum 2009). Cadmium naturally occurs in phosphate rock and consequently concentrations can be high in phosphatic fertilisers, some of which may leach into freshwaters (Williams & David 1972).

Zinc and Cu enter urban stormwater from sources such as galvanised iron roofing and road runoff (e.g., particles from tires and brake pads), while lead (Pb) used to be a petrol additive and is associated with historic stormwater contamination. New Zealand also has many active geothermal areas where As, boron and Hg concentrations are often naturally high in geothermal waters. Arsenic was an important ingredient in pesticides used in sheep-dips and is therefore a common contaminant of agricultural soils and leachate. Arsenic and Hg in particular tend to bioaccumulate in aquatic organisms.

Metals and metalloids tend to be toxic to aquatic life primarily through interactions with gill tissues and secondarily through dietary uptake. Often the element will interfere with the normal transport mechanisms of the gill or gut tissue, and thereby disrupt metabolism. Once inside an organism, metals and metalloids often accumulate in and affect the liver and kidneys of fish, or the equivalent organ such as the hepatopancreas in kōura and kākahi. Copper, for example, affects sodium uptake and accumulates first in the liver or hepatopancreas.

The toxicity of metals and metalloids is significantly affected by water chemistry (e.g., increased hardness decreases Cd toxicity) and temperature. To take this into account, ANZECC trigger values are often expressed in terms of allowable concentrations at a certain pH, hardness, and/or temperature (and conversion tables are provided). There are also different trigger values for freshwater and marine environments. As a rule of thumb, metal and metalloid toxicity is often highest at low pH, low hardness and high temperatures. As a result of its geology, New Zealand surface waters tend to be relatively soft (i.e., low in calcium and magnesium), thus increasing the susceptibility of aquatic biota to metal and metalloid toxicity.

The ANZECC water quality guidelines include the use of metal speciation models, such as the Biotic Ligand Model, so that local water chemistry can be taken into account to evaluate the toxicity of a particular element. In other words, local water chemistry can be "plugged into" a modelling programme to determine locally-relevant trigger values to ensure the protection of aquatic organisms. Also, many metals and metalloids are found as different "species" or valency states in natural environments (e.g., As can be found as As(III) or As(V)), and this will markedly affect the toxicity of the element.

ANZECC (2000) includes summary information about each contaminant, and guidance on how to apply the trigger values correctly. These guidelines are continually being updated and improved based on the latest research (updates available at http://www.mfe.govt.nz/fresh-water/tools-and-guidelines/anzecc-2000-guidelines). Major revisions of the ANZECC (2000) guidelines are underway and a new website should become live in 2018. A diagrammatic representation of factors affecting metal input levels in aquatic environments is provided in Figure 7, and available guideline values are shown in Table 8.

Table 8: **Trigger values for some metals and metalloids at pH 8.0 from ANZECC (2000)**[2] **(ID = insufficient data available to provide a "high reliability" trigger value, therefore users must check ANZECC (2000) Vol 2, section 8.3.7. for low reliability values and further guidance)**

Element	Hardness adjustment (H) or Bioaccumulation (B) must be taken into account*	Trigger values for freshwater (µg/L)		Trigger values for marine water (µg/L)	
		Level of protection (% species)			
		99%	95%	99%	95%
Arsenic (III)	-	1	24	ID	ID
Arsenic (V)	-	0.8	13	ID	ID
Boron	-	90	370	ID	ID
Cadmium	H	0.06	0.2	0.7	5.5
Copper	H	1.0	1.4	0.3	1.3
Lead	H	1.0	3.4	2.2	4.4
Mercury (inorganic)	B	0.06	0.6	0.1	0.4
Mercury (methyl)	B	ID	ID	ID	ID
Nickel	H	8	11	7	70
Zinc	H	2.4	8.0	ID	ID

*Users must check ANZECC (2000) Vol 2, section 8.3.7 for hardness adjustment equations or tables and/or guidance about bioaccumulation or secondary poisoning effects.

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[2] ANZECC (2000) Volume 2. Table 3.4.1

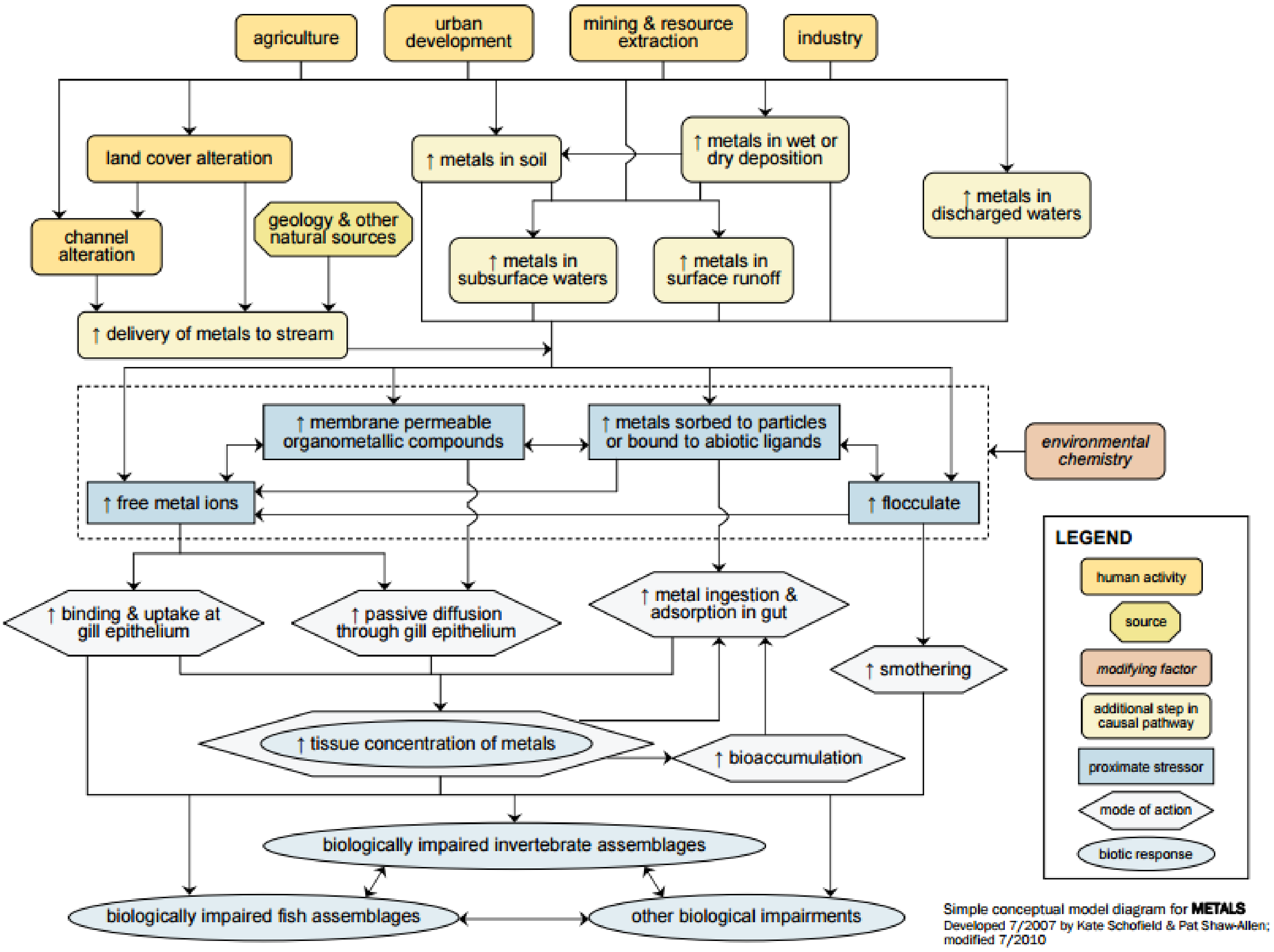

Figure 7: Conceptual model describing sources of metal inputs, such as copper and zinc, to aquatic ecosystems and their effects on aquatic animals
(From: https://www3.epa.gov/caddis/)

2.3 Sediment quality parameters

2.3.1 Sediments and aquatic biota

Sediments have an important influence on aquatic biota both in terms of: (i) their composition and the physical habitat they provide (e.g., sediment grain size, density, oxygenation); and (ii) the nutrients and contaminants they may contain. The nutrients or contaminants can be found in either the sediment particles or the sub-surface pore water between the particles. Some aquatic biota interact directly with sediments, for example by burrowing or feeding on or in sediments. The sediment in the gut contents of prey organisms can then indirectly affect predatory species such as fish. Other indirect interactions are also important, for example under certain conditions (e.g., deoxygenation) nutrients and toxicants can be mobilised from sediments into the water and affect species utilising the water column above sediments. This can occur on a massive scale in stratified lakes[3].

Some species used for food gathering are closely associated with sediments, for example kākahi and kōura (James 1985; Hollows et al. 2002), As well as taking up contaminants directly from the sediments and overlying water (Hickey et al. 1995, 1997; Clearwater et al. 2014b), these species can in turn significantly influence sediment composition and habitat through their movement (bioturbation) and excretion (biodeposition) (Parkyn et al. 1997; Cyr et al. 2016; Collier et al. 2017). Such effects on food-webs can have influences on higher trophic levels such as fish which feed on invertebrates living on and within sediments. The implications of these food-web bioaccumulation processes for food safety are discussed in Section 3.1.

Contaminants can build up in sediments either from point-source or diffuse inputs. Point source inputs include wastewater outfalls which are usually easier to manage (e.g., through resource consent conditions and treatment plants) than diffuse inputs. Diffuse sources include aerial deposition and contaminants that have entered the groundwater (e.g., through fertiliser application), and are subsequently introduced to an aquatic environment through groundwater movement. Alternative diffuse inputs include sedimentation from erosion, or from overland stormwater or agricultural runoff.

2.3.2 Sediment composition

There are many different classification systems for aquatic sediments, and one used frequently in aquatic toxicology divides sediment particles into sizes from <63 µm to 2 mm (Table 9). Understanding the proportion of particles in the clay, silt, and sand grain sizes (for example) helps characterise sediments in terms of their physical suitability for certain species.

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[3] Nutrient release from sediments in stratified lakes can also cause algal blooms when the deoxygenated bottom water mixes (i.e., during lake destratification) with surface waters.

Particles >2 mm diameter (e.g., rocks, shells, wood fragments) are not considered in sediment chemistry evaluation as they are not usually a source of bioavailable contaminants.

Table 9: Particle size classes commonly used in sediment evaluation. Particle sizes <63 µm are indicated in bold (referred to hereafter as fine sediments) and are those most relevant to sediment toxicity

Size Fraction	Size range
Gravel	>2 mm
Sand	0.5-2 mm
Medium sand	250-500 µm
Fine sand	63-250 µm
Silt	**47-63 µm**
Clay	**<47 µm**

Fine sediments are composed of different types of inorganic particles (e.g., quartz sand, carbonates, oxides of aluminium or iron) and organic particles (e.g., degraded vegetation, decaying organisms, microbial biofilms). The proportion of organic particles in sediment is important because sediments are often a "sink" for aquatic contaminants, with both metals and organic contaminants (e.g., pesticides) and their break-down products accumulating in, or on, fine organic particles. As well as readily adsorbing metals and hydrophobic[4] organic contaminants, these particles have large surface areas relative to their mass and therefore concentrate certain contaminants. Contaminants can be incorporated into sediments from dissolved forms in the overlying water adsorbing onto sediment particles, as particulates such as soot or antifouling paint particles, or by chemical processes such as flocculation and precipitation. The silt and clay fractions (i.e., <63 µm) are particularly important in terms of their effects of aquatic life because their surface chemistry makes them chemically "attractive" to or adsorbant of metals and some organic contaminants.

Many aquatic organisms feed either directly or indirectly (e.g., via accidental ingestion with other food items) on sediments, thereby exposing them to contaminants via the digestive system. Depending on the species (e.g., fish versus crayfish), the digestion process can release sediment-borne contaminants, particularly from fine particles, making them more bioavailable and toxic to the consumer. Some species (e.g., carnivorous fish) have an acid-digestion stage that will release metals from fine sediments, while other species will have more alkaline digestive processes making them less susceptible to metal exposure.

The nutrient content of sediments is also important, and in turn this affects the chemistry of the sediments at different depths, because the combination of changes in oxygen content of

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[4] Hydrophobic compounds have chemical and physical properties that prevent them from dissolving in water, and therefore they tend to sorb onto or into organic matter instead.

the sediments and their nutrient content will drive the degradation processes of the sediment microbial community. A typical aquatic sediment profile includes an oxygenated (oxic) surface layer, and a sub-surface oxygen-poor (anoxic) layer that progresses from a zone of denitrification, to sulphate reduction followed by methane formation. Many aquatic invertebrates prefer the habitat provided by the oxygenated layer. Well-oxygenated sediments will tend to have a low proportion of silt and clay particles, and the oxygenated layer will be relatively deep (e.g., >1 cm). As the proportion of these very fine particles increases, and/or water-movement decreases (e.g. stream velocity or up-welling ground water), the sediments will become progressively more deoxygenated (or anoxic) and the depth of the surface oxygenated layer will decrease.

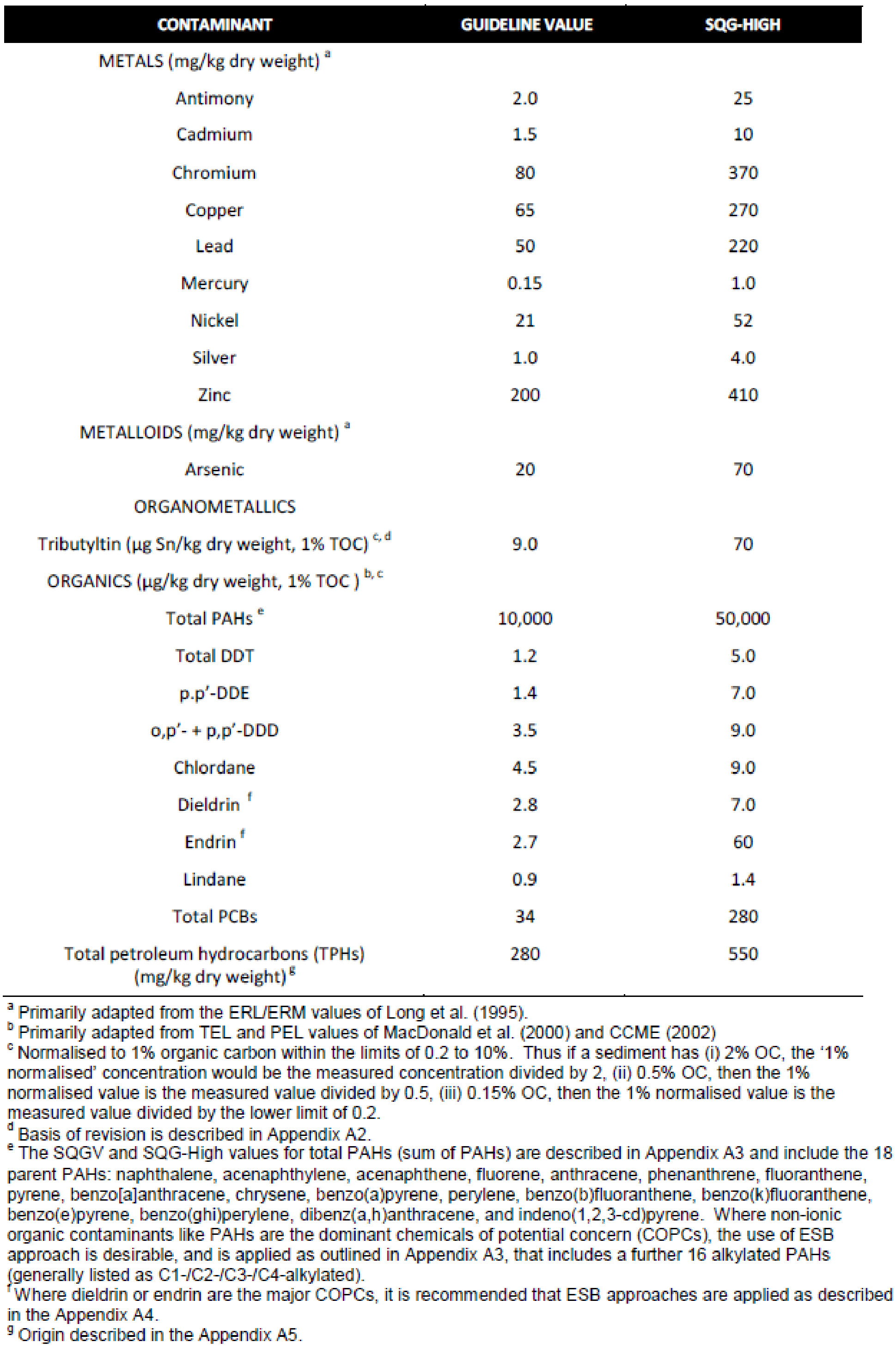
Because oxygen concentrations tend to decrease with increasing sediment depth, the pore water chemistry changes with depth and contaminants can be released from, or absorbed onto, sediment particles. If contaminants are released from sediment particles and dissolved in sediment pore water they can then become bioavailable and toxic to aquatic biota. Pore-water contaminant concentrations can be compared to surface water quality guidelines to determine whether they are likely to be toxic to biota. There are, however, exceptions because sediment-dwelling organisms are often adapted to sub-surface conditions like elevated pore water ammonia. These organisms may be physiologically adapted to high ammonia exposure, or have behavioural adaptations such as building burrows that they irrigate with surface water that reduces their pore-water exposure. The risk of elevated concentrations of ammonia or sulphide in pore water generally increases as sediments become more anoxic and nutrient-rich.

In aquatic environments affected by peat bogs it is common to observe areas of red-stained fine sediments or seeps, for example in the margins of small streams. This is caused by oxygen-poor, peat-influenced acidic ground water that has a high iron (Fe) content contacting aerated (or oxic) surface waters. The subsequent chemical reactions and microbial activity result in the Fe coming out of solution (i.e., the opposite of dissolving) and coating the sediments in a fine Fe-rich precipitate (or solid) or microbial mat which appears bright tallow-orange, sometimes with a cotton-wool appearance. These chemical processes tend to decrease the local oxygen concentration, and/or coat aquatic organisms with fine particles that can choke their gills (or other respiratory organs). Iron precipitates or Fe flocculates (fine particles joining together and settling of suspended material), while not particularly toxic, generally have a localised negative affect on aquatic biodiversity. Other geological processes can also cause iron precipitation in surface waters.

2.3.3 Sediment quality guidelines

The sediment quality guidelines (SQG) for Australia and New Zealand have recently been updated (Simpson et al. 2013) from ANZECC (2000) and they take into account the influence of the multiple factors described above on aquatic organisms. Sediment evaluation requires a tiered approach. The first level of screening measures contaminant concentrations in "whole" sediments (e.g., without separating silt/clay fractions from large sizes). If contaminant concentrations fall below recommended sediment quality guideline values (SQGV) in Simpson et al. (2013), then the sediments are considered low risk (Table 10).

Table 10: Recommended sediment quality guidelines (SQG) (Table 2 in Simpson et al. 2013)



CONTAMINANT	GUIDELINE VALUE	SQG-HIGH
METALS (mg/kg dry weight) [a]		
Antimony	2.0	25
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1.0
Nickel	21	52
Silver	1.0	4.0
Zinc	200	410
METALLOIDS (mg/kg dry weight) [a]		
Arsenic	20	70
ORGANOMETALLICS		
Tributyltin (µg Sn/kg dry weight, 1% TOC) [c, d]	9.0	70
ORGANICS (µg/kg dry weight, 1% TOC) [b, c]		
Total PAHs [e]	10,000	50,000
Total DDT	1.2	5.0
p.p'-DDE	1.4	7.0
o,p'- + p,p'-DDD	3.5	9.0
Chlordane	4.5	9.0
Dieldrin [f]	2.8	7.0
Endrin [f]	2.7	60
Lindane	0.9	1.4
Total PCBs	34	280
Total petroleum hydrocarbons (TPHs) (mg/kg dry weight) [g]	280	550

[a] Primarily adapted from the ERL/ERM values of Long et al. (1995).

[b] Primarily adapted from TEL and PEL values of MacDonald et al. (2000) and CCME (2002)

[c] Normalised to 1% organic carbon within the limits of 0.2 to 10%. Thus if a sediment has (i) 2% OC, the '1% normalised' concentration would be the measured concentration divided by 2, (ii) 0.5% OC, then the 1% normalised value is the measured value divided by 0.5, (iii) 0.15% OC, then the 1% normalised value is the measured value divided by the lower limit of 0.2.

[d] Basis of revision is described in Appendix A2.

[e] The SQGV and SQG-High values for total PAHs (sum of PAHs) are described in Appendix A3 and include the 18 parent PAHs: naphthalene, acenaphthylene, acenaphthene, fluorene, anthracene, phenanthrene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo(a)pyrene, perylene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(e)pyrene, benzo(ghi)perylene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene. Where non-ionic organic contaminants like PAHs are the dominant chemicals of potential concern (COPCs), the use of ESB approach is desirable, and is applied as outlined in Appendix A3, that includes a further 16 alkylated PAHs (generally listed as C1-/C2-/C3-/C4-alkylated).

[f] Where dieldrin or endrin are the major COPCs, it is recommended that ESB approaches are applied as described in the Appendix A4.

[g] Origin described in the Appendix A5.

If, however, sediment contaminant concentrations are higher than the SQG value, then a next level of screening is applied to determine the contaminant fraction that is bioavailable and potentially toxic (Figure 8). Often expert advice is required to guide this process and its interpretation, as multiple approaches can be taken depending on the contaminants involved and the biological community being investigated. For example, the metal content of only the <63 µm silt and clay fraction can be measured by using a "mild acid digestion" that mimics the digestive processes of some aquatic organisms. The principle is that metals released by this process will be the fraction that is most bioavailable and potentially toxic to aquatic life[5]. A conventional chemical analysis would use a strong acid digestion to release a much greater proportion of the metals for measurement but in many cases this is likely to overestimate the contaminant risk posed to aquatic organisms through ingestion.

It is worth noting that the SQG values do not include all possible contaminants and, if it is thought that there are significant concentrations of sediment contaminants present for which there are no SQG value, then the investigation can proceed immediately to other lines of evidence (e.g., by omitting analysis of contaminants in whole sediments and proceeding straight to chemical analysis of certain sediment fractions plus toxicity testing). The SQG are specifically designed to allow site-specific examination of contaminant risk, rather than locking evaluators into a particular set of tests. Methods for collecting sediment samples are described in Appendix 2.

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[5] There are important exceptions to this, for example copper and mercury may require additional evaluation to fully characterise their toxicity.

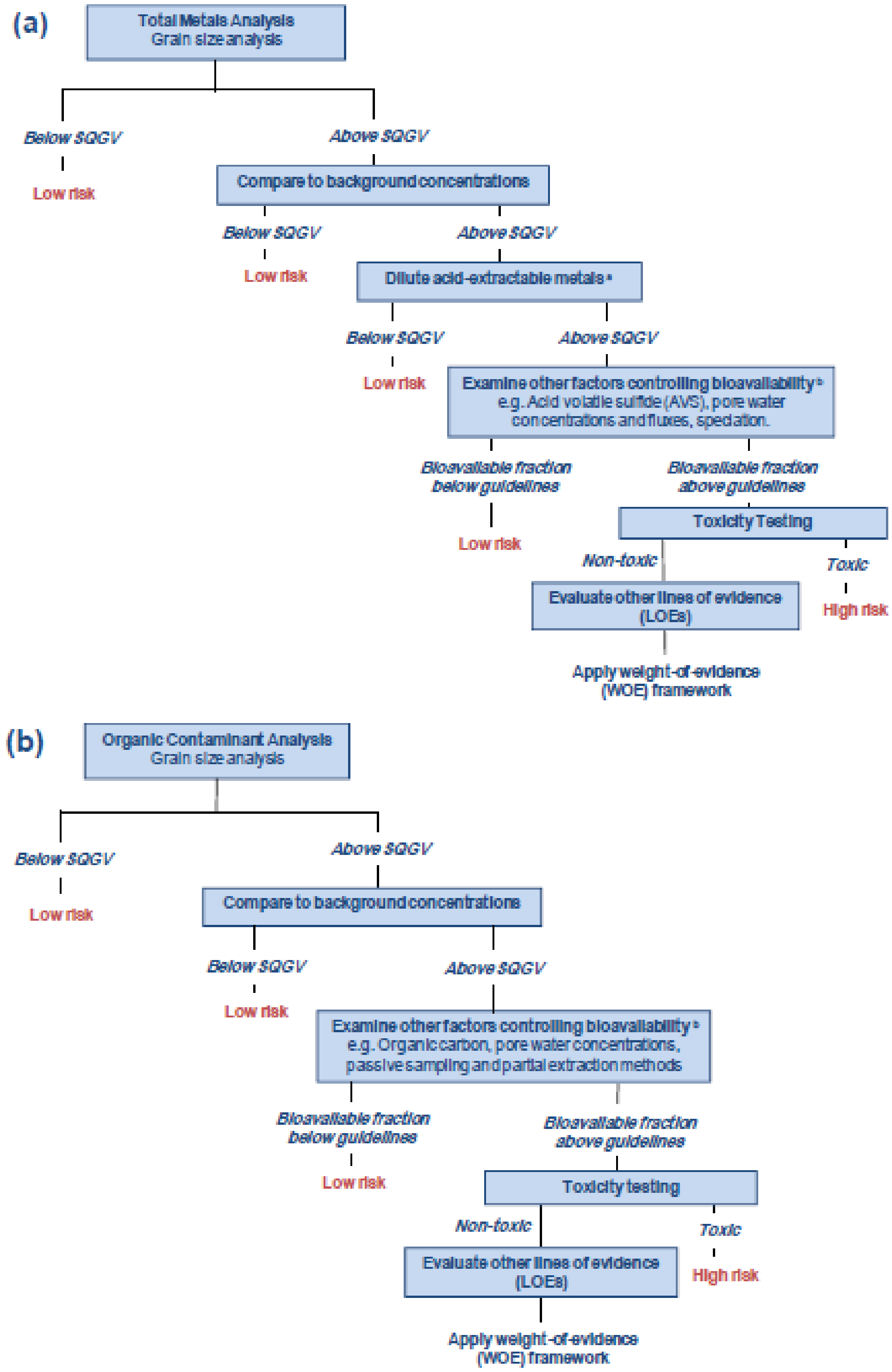


Figure 8: The tiered framework (decision tree) for the assessment of contaminated sediments according to ANZECC guidance for a) metals and b) organics. SQGV = Sediment quality guideline value.

Notes: [a]This step may not be applicable to metalloids (As, Se) and mercury (Hg). [b]See specific methods on how bioavailability test results are used. Other “Lines of Evidence” or investigative pathways that can be followed include toxicity, bioaccumulation, ecology, and biomarkers. Copied without modification from Simpson et al. (2013).

3. Key Contaminants Affecting Collection and Consumption

It is our understanding that apart from sustainability, one of the main concerns for iwi collecting mahinga kai is potential contamination of this food supply. To some extent there are also concerns about direct exposure to water contaminated with microorganisms (e.g., from wastewater or stormwater inputs) or agrichemicals while collecting. This could occur through activities such as being splashed while collecting, swimming, by eating later without washing hands after collection, or not sufficiently rinsing them in clean or chlorinated potable water. The reality is that there is scant specific information available about this issue, but a couple of recent attempts have been made to address these concerns in New Zealand. We review this information below and also attempt to answer some key questions from a science point-of-view, namely:

- What are the most likely key contaminants of mahinga kai?
- What are the most likely sources and situations of concern?
- What are the resources available to evaluate these contaminants?

3.1 Information required to evaluate risk from contaminants in kai

Several strands of information are required to fully understand the risk posed by contaminants in mahinga kai. The intent is to understand not only what concentrations of contaminants are in the food, but how much people are actually consuming, and then compare this “dose” to recommended safe doses. The information required includes:

- How much and what types of mahinga kai are collected and eaten, and how often;
- Where is the mahinga kai collected from;
- What are the concentrations of contaminants in the mahinga kai at these locations;
- What concentrations of contaminants in food are considered acceptable?

For many reasons, this information is not readily available. In addition, concentrations of contaminants in kai species are expensive to measure and vary with season, species, life stage and age of fish/shellfish collected. These issues illustrate why it is difficult to characterise the risk of contaminants in mahinga kai.

3.1.1 What are the most likely key contaminants of mahinga kai?

Likely contaminants or toxins can be split into four main classes: (i) metals and metalloids; (ii) organics; (iii) biotoxins; and (iv) microorganisms (Table 11–refer to Section 3.2). Metals, metalloids, and organics in particular are known to be persistent and to have negative health effects (see Section 2.2.2). Biotoxins can be produced by marine or freshwater microalgae (phytoplankton) and blue-green algae (Cyanobacteria) which are important in the diet of shellfish. The biotoxins most relevant to freshwater environments are cyanotoxins from Cyanobacteria (see Section 3.1.2). Microorganisms include bacteria, viruses and other microbes that can cause disease in humans. Thorough cooking can destroy many microorganisms but does not reduce the toxicity of many contaminants or biotoxins, including some produced by high concentrations of microorganisms proliferating in poorly-stored food.

Some mahinga kai may be at risk of contamination by several different classes of toxins simultaneously. It is not practical to analyse mahinga kai for all possible contaminants so a useful approach is to measure some of the most likely substances and use these as an indicator of probable risk. Another factor to consider is what is known about the history of the site, and current activities where mahinga kai are being collected–especially upstream industrial sites, wastewater discharges, intensive agriculture, and geothermal activity in the catchment. Good examples of this approach are two collaborative studies completed in Rotorua and South Canterbury that examined the most likely contaminants in those regions based on an understanding of historic land use and the presence or absence of geothermal activity (Stewart et al. 2011; Phillips et al. 2014). According to the wishes of local iwi, only small numbers of a few mahinga kai species were sampled and analysed for these contaminants. Iwi members participated in a consumption survey to establish eating patterns and therefore the likely “doses” of contaminants. In summary, the studies found that there was some cause for concern about exposure to contaminants from mahinga kai. Both studies suggest that although iwi consumption rates were relatively low, and this reduced their contaminant exposure risk, risks from exposure to mercury or arsenic remained. On the other hand, less than 20 people were interviewed to establish consumption rates for each iwi so it is possible that higher consumption scenarios should apply in which case risks increase, particularly from eating eels and from organic contaminants. Eels are long-lived predators and scavengers that tend to have a high fat content, and these characteristics mean that they are likely to accumulate both heavy metals and organic contaminants. Further detail is provided in Appendix 3 about these studies and the risk analysis methodology applied to mahinga kai consumption.

Table 11: Examples (not all) of the contaminants likely in freshwater mahinga kai in New Zealand, and likely to cause potential health problems in consumers at unsafe levels. Information has been collected from a wide range of sources (e.g., Ahrens 2008; ANZECC 2000; CAE 2000; Depree & Ahrens 2007; Hickey 2000; Kim & Rochford 2008; Meyer et al. 2007; Phillips et al. 2014; Stewart et al. 2011; Wood et al. 2006)

Class	Contaminant	Sources	Main health risks
Metals/ metalloids	As	Geothermal, timber treatment, pulp & paper, old sheep dip sites, horticulture, mining	Cancer, non-cancer, liver, kidneys
	Cd	Fertiliser, mining, stormwater	Non-cancer risks, kidneys, liver, neural
	Hg (methyl Hg)	Geothermal, coal combustion, mining, industrial processes, landfill leachate	Cancer, neurological damage, other non-cancer
	Pb	Stormwater, landfill leachate, mining	Neurological damage, liver
Organics	PAHs	Stormwater (soot), landfill leachate	Cancer
	PCBs	Landfill leachate, wastewater	Cancer
	Pesticides	Agriculture, horticulture	Cancer
	Organochlorines and breakdown products	Agriculture, horticulture, pulp & paper manufacture, industrial discharges, wastewater	Cancer
	Dioxins	Degradation products of combustion (e.g., volcanoes, forest fires, incineration, combustion engines), organochlorine use (e.g., pulp & paper bleaching) & other industrial processes	Cancer
Biotoxins	Cyanotoxins	Cyanobacterial blooms of drifting cells (pelagic) or “algal” mats (benthic)	Liver, kidneys, neural, lungs, gastroenteritis, skin, possibly carcinogenic

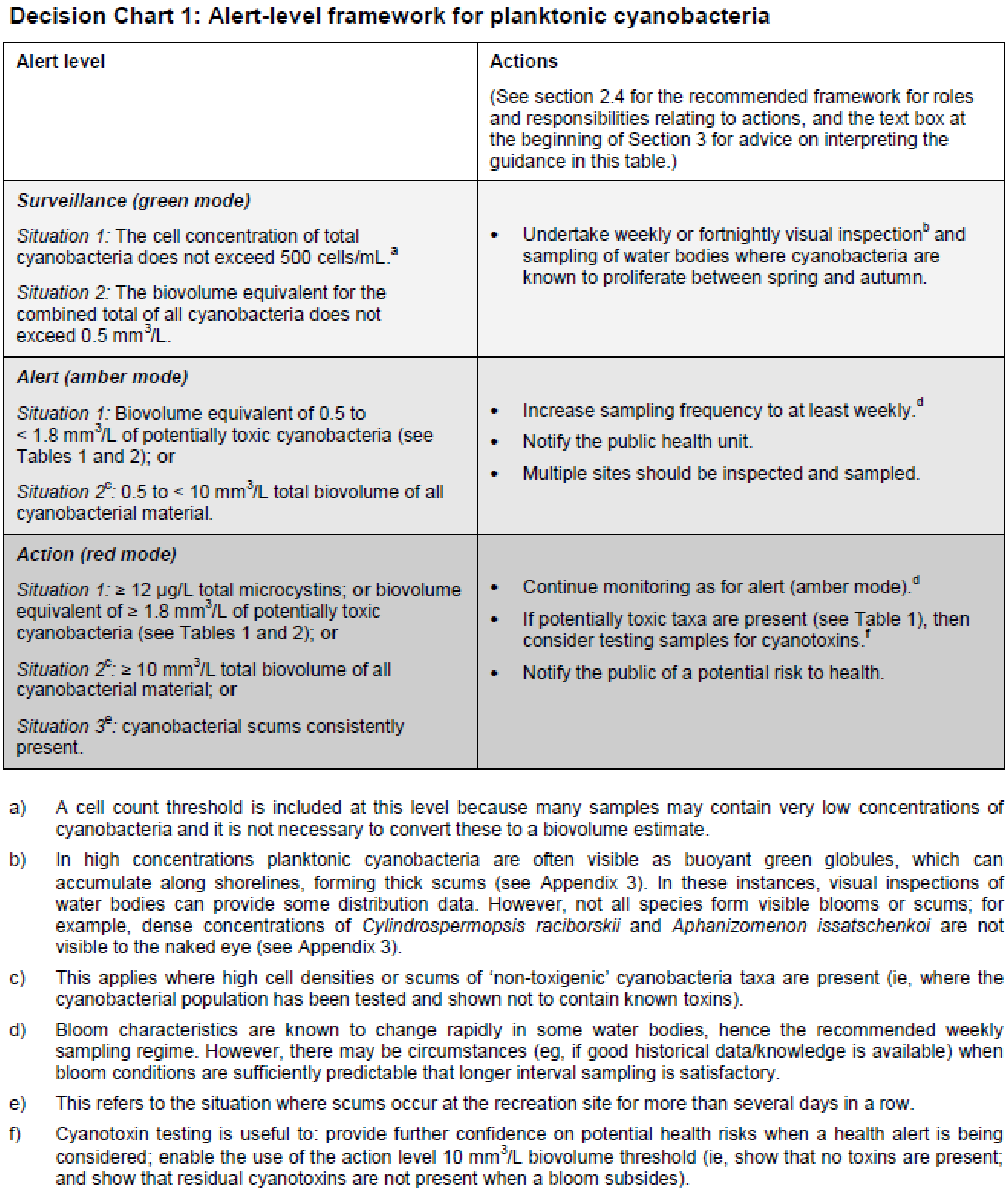
3.1.2 Toxic cyanobacterial blooms

Most Cyanobacteria, unlike most other aquatic algae, are able to fix nitrogen from the atmosphere and can therefore bloom in phosphorus-rich environments (e.g., downstream of wastewater inputs) where other photosynthetic organisms do not because of the lack of accessible dissolved nitrogen. There is some evidence that cyanobacterial blooms are increasing in freshwater aquatic environments across New Zealand, possibly associated with increased nutrient concentrations (Wood et al. 2006; Harke et al. 2016). This evidence includes development of cyanobacterial mats on top of sediments in lakes, rivers or streams (i.e., benthic mats; Wood et al. 2015). Some, but not all cyanobacterial species, can produce toxins but even the toxin-producing species do not produce toxins all the time. Also, the cyanotoxins can either remain contained within the cyanobacterial cell, be released by the intact living cell (cell-free), or be released by a dying cyanobacterial cell (e.g., when large blooms concentrate on a lake shore, become anoxic and die).

When present at high levels, the toxins can be deadly, affecting aquatic life, birds and mammals including notably dogs and humans. Cyanotoxins often affect the liver and kidneys, and/or are neurotoxic, but they can also directly affect skin, for example causing rashes. If inhaled (e.g., by swimmers breathing in moist air), they can damage lung tissue as well as causing non-specific symptoms such as nausea and diarrhoea. Cyanotoxins can also have significant impacts on humans collecting mahinga kai species and/or drinking lake water, and dogs are often badly affected by cyanotoxins because they forage along the waterline, actively seek out cyanobacterial mats for consumption, and will swim in water despite its appearance and smell (MfE/MoH 2009).

Many councils have monitoring programmes in place to detect when cyanobacterial blooms are occurring, and to inform the public of these risks. Monitoring and management should be based on the MfE/MoH (2009) guidelines for cyanobacteria in recreational freshwaters (Figures 9, 10) and the NPS (2014). These guidelines specify threshold concentrations of cyanobacteria biovolumes at which different management actions should be taken (e.g., notify the public of potential risk to health). The thresholds are to be interpreted along with knowledge of other factors that may indicate increased risk. Councils monitor a selection of sites where there is both a risk of blooms and known recreational activity.

Cyanotoxins are directly relevant to mahinga kai because they can accumulate from waterborne or dietary exposure of kōura, kākahi, tuna and trout (Wood et al. 2006; Clearwater et al. 2014b; Dolamore et al. 2017). The cyanotoxin accumulation measured in the flesh of these species sometimes exceeded human health guidelines, but the data gathered so far indicate that risk can be markedly reduced by removing the liver or hepatopancreas (crayfish), and gut tissues (including those of kākahi) prior to consumption. Given the potential health impacts of cyanotoxin exposure it would be prudent to exercise caution in the presence of obvious blooms and refrain from collecting. Significant cyanotoxin exposure can also occur by sourcing drinking water directly from lakes or rivers affected by blooms and this would be additive to any dietary exposure from mahinga kai. Cyanotoxin exposure can affect the behaviour, growth and survival of juvenile kākahi and kōura (Clearwater et al. 2014b), and therefore significant or recurring blooms may potentially impact on the sustainability of harvesting these species.



Decision Chart 1: Alert-level framework for planktonic cyanobacteria

Alert level	Actions (See section 2.4 for the recommended framework for roles and responsibilities relating to actions, and the text box at the beginning of Section 3 for advice on interpreting the guidance in this table.)
Surveillance (green mode) *Situation 1:* The cell concentration of total cyanobacteria does not exceed 500 cells/mL.[a] *Situation 2:* The biovolume equivalent for the combined total of all cyanobacteria does not exceed 0.5 mm^3/L.	- Undertake weekly or fortnightly visual inspection[b] and sampling of water bodies where cyanobacteria are known to proliferate between spring and autumn.
Alert (amber mode) *Situation 1:* Biovolume equivalent of 0.5 to < 1.8 mm^3/L of potentially toxic cyanobacteria (see Tables 1 and 2); or *Situation 2*[c]*:* 0.5 to < 10 mm^3/L total biovolume of all cyanobacterial material.	- Increase sampling frequency to at least weekly.[d] - Notify the public health unit. - Multiple sites should be inspected and sampled.
Action (red mode) *Situation 1:* ≥ 12 µg/L total microcystins; or biovolume equivalent of ≥ 1.8 mm^3/L of potentially toxic cyanobacteria (see Tables 1 and 2); or *Situation 2*[c]*:* ≥ 10 mm^3/L total biovolume of all cyanobacterial material; or *Situation 3*[e]*:* cyanobacterial scums consistently present.	- Continue monitoring as for alert (amber mode).[d] - If potentially toxic taxa are present (see Table 1), then consider testing samples for cyanotoxins.[f] - Notify the public of a potential risk to health.

a) A cell count threshold is included at this level because many samples may contain very low concentrations of cyanobacteria and it is not necessary to convert these to a biovolume estimate.

b) In high concentrations planktonic cyanobacteria are often visible as buoyant green globules, which can accumulate along shorelines, forming thick scums (see Appendix 3). In these instances, visual inspections of water bodies can provide some distribution data. However, not all species form visible blooms or scums; for example, dense concentrations of *Cylindrospermopsis raciborskii* and *Aphanizomenon issatschenkoi* are not visible to the naked eye (see Appendix 3).

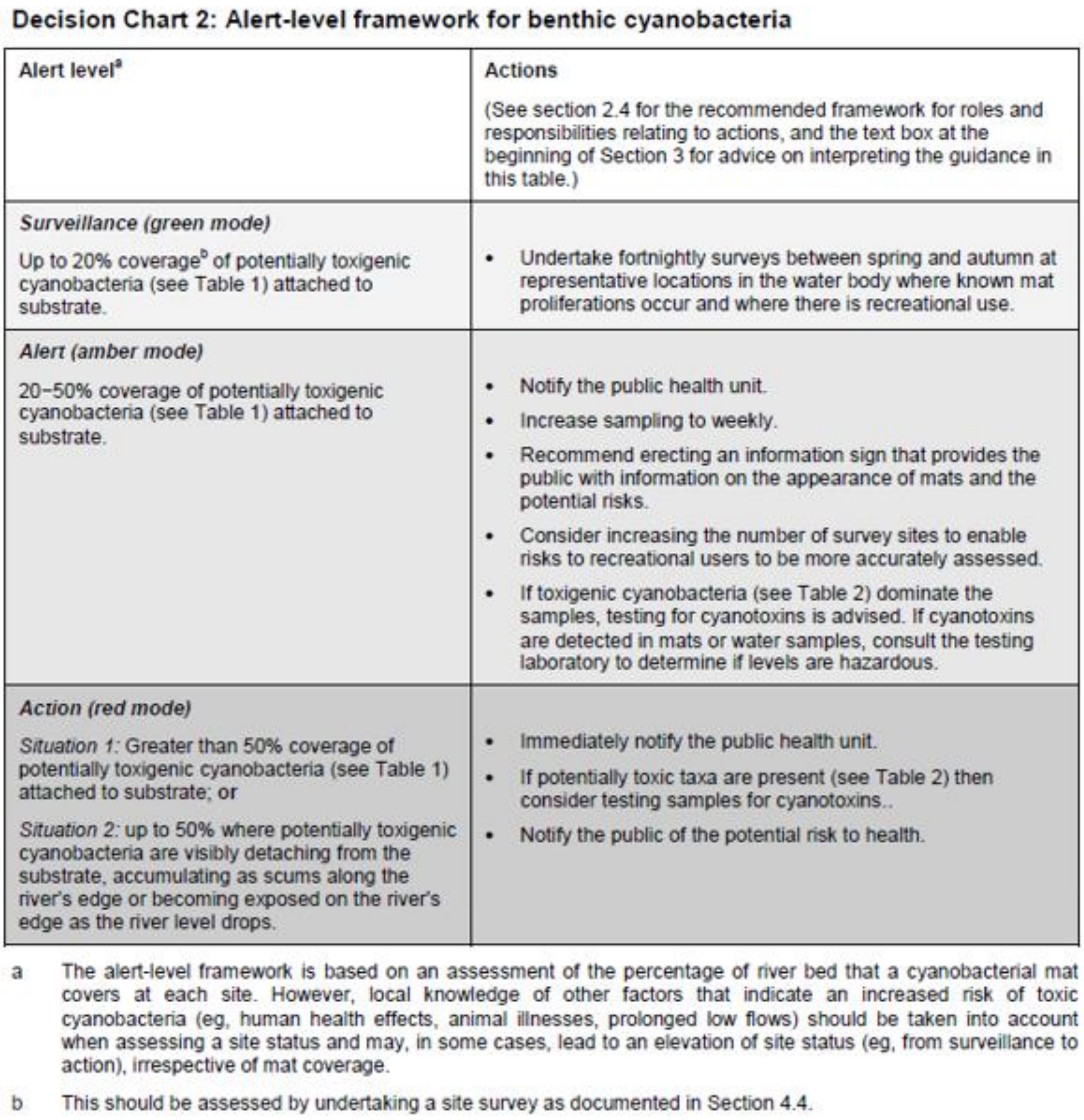
c) This applies where high cell densities or scums of 'non-toxigenic' cyanobacteria taxa are present (ie, where the cyanobacterial population has been tested and shown not to contain known toxins).

d) Bloom characteristics are known to change rapidly in some water bodies, hence the recommended weekly sampling regime. However, there may be circumstances (eg, if good historical data/knowledge is available) when bloom conditions are sufficiently predictable that longer interval sampling is satisfactory.

e) This refers to the situation where scums occur at the recreation site for more than several days in a row.

f) Cyanotoxin testing is useful to: provide further confidence on potential health risks when a health alert is being considered; enable the use of the action level 10 mm^3/L biovolume threshold (ie, show that no toxins are present; and show that residual cyanotoxins are not present when a bloom subsides).

Figure 9: Extract of the framework for planktonic Cyanobacteria monitoring and management activities from MfE/MoH (2009). This is an extract and should only be used with a thorough understanding of the MfE/MoH (2009) guideline for Cyanobacteria in recreational guidelines



Decision Chart 2: Alert-level framework for benthic cyanobacteria

Alert level[a]	Actions (See section 2.4 for the recommended framework for roles and responsibilities relating to actions, and the text box at the beginning of Section 3 for advice on interpreting the guidance in this table.)
Surveillance (green mode) Up to 20% coverage[b] of potentially toxigenic cyanobacteria (see Table 1) attached to substrate.	• Undertake fortnightly surveys between spring and autumn at representative locations in the water body where known mat proliferations occur and where there is recreational use.
Alert (amber mode) 20–50% coverage of potentially toxigenic cyanobacteria (see Table 1) attached to substrate.	• Notify the public health unit. • Increase sampling to weekly. • Recommend erecting an information sign that provides the public with information on the appearance of mats and the potential risks. • Consider increasing the number of survey sites to enable risks to recreational users to be more accurately assessed. • If toxigenic cyanobacteria (see Table 2) dominate the samples, testing for cyanotoxins is advised. If cyanotoxins are detected in mats or water samples, consult the testing laboratory to determine if levels are hazardous.
Action (red mode) *Situation 1:* Greater than 50% coverage of potentially toxigenic cyanobacteria (see Table 1) attached to substrate; or *Situation 2:* up to 50% where potentially toxigenic cyanobacteria are visibly detaching from the substrate, accumulating as scums along the river's edge or becoming exposed on the river's edge as the river level drops.	• Immediately notify the public health unit. • If potentially toxic taxa are present (see Table 2) then consider testing samples for cyanotoxins.. • Notify the public of the potential risk to health.

a The alert-level framework is based on an assessment of the percentage of river bed that a cyanobacterial mat covers at each site. However, local knowledge of other factors that indicate an increased risk of toxic cyanobacteria (eg, human health effects, animal illnesses, prolonged low flows) should be taken into account when assessing a site status and may, in some cases, lead to an elevation of site status (eg, from surveillance to action), irrespective of mat coverage.

b This should be assessed by undertaking a site survey as documented in Section 4.4.

Figure 10: Extract of the framework for benthic Cyanobacteria monitoring and management activities from MfE/MoH (2009). This is an extract and should only be used with a thorough understanding of the MfE/MoH (2009) guideline for Cyanobacteria in recreational guidelines; for example these guidelines are not protective of dogs

3.2 Microbiological risks and safe collection practices

3.2.1 Background information

Humans can be exposed to disease-causing microorganisms (pathogens) either during the act of collecting mahinga kai or by consuming contaminated kai (Edmonds & Hawke 2007). Contamination with disease-causing microorganisms can occur via wastewater discharges, stormwater or agricultural run-off, among other sources. The presence and type of discharges or activities upstream in the catchment of the collection site is an indicator of increased risk.

For example, watercress collected from agricultural land has been shown to be contaminated with *Escherichia coli*[6], while watercress from urban sites was contaminated with the pathogen *Campylobacter* (Edmonds & Hawke 2007).

In freshwater, the bacterium *E. coli* is often used as an indicator organism to characterise the risk of exposure to a much larger suite of disease-causing microorganisms associated with faecal contamination. The presence of high concentrations of *E. coli* at a site does usually indicate a higher risk of faecal contamination, but it is very important to know that low concentrations of *E. coli* doesn't always mean low risk. This is because *E. coli* are only indicators of the likelihood of other microorganisms being present. For example, sometimes the factors driving the removal of bacteria (e.g., certain types of wastewater treatment) will not act on viruses, so *E. coli* counts could be low while high concentrations of viruses are still present.

Different activities in freshwater are classified as either 'primary' or 'secondary' recreational contact. Primary contact includes swimming, diving and other activities where participants are highly likely to drink water and/or aspirate (or breathe in) water droplets. Secondary contact includes activities like boating or fishing where participants are much less likely to drink the water. There are different guidelines available for primary and secondary contact with water; the line between primary and secondary contact is not always clear, however.

At present (2017), there are several guidelines and regulatory tools available in New Zealand that together can be used to help determine whether a site is safe in terms of microbial contamination for collection of mahinga kai (Table 12). These rules and guidelines do not however, deal with other types of contamination (e.g., metals, cyanotoxins and biotoxins). Also, none of the guidelines are specifically tailored for the collection of freshwater mahinga kai, but together they provide a good starting point for evaluating a site. Also, as of early 2017, new microbial guidelines have been proposed for freshwater recreation (swimmability) to update the NPS (2014). In order to place the new guidelines in context, and help understand the discussion around them, we provide information on the 2003 guidelines that are currently in place in the following section.

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[6] A type of bacteria found in the gut of mammals, and therefore associated with faecal contamination.

Table 12: Summary of microbial standards and guidelines available in New Zealand. '-' indicates no information available or not relevant

General activity	Classification	Guideline(s)	What is measured?	Site survey (Sanitary Inspection) also required?	How is measurement interpreted?
Swimming, wading or boating	Primary or secondary contact recreation	MfE/MoH (2003)	*E. coli* in water	Yes	Need site survey and historical data to interpret measurements.
Marine shellfish gathering	Recreational shellfish gathering (marine)	MfE/MoH (2003)	Faecal coliform in water	Yes	Need site survey and historical data to interpret measurements.
Swimming	Human health for recreation	NPS (2014)	*E. coli* in water	No	Need long term data as thresholds are annual medians and 95th-iles. No guidance provided regarding site surveys.
Swimming	Human health for recreation	NPS (2017) proposal	*E. coli* in water	Not sure, as no detail provided yet.	Need long term data to provide percentages of samples above/below thresholds.
Marine shellfish harvesting	Commercial harvesting	NZFSA (2006)	Faecal coliform in water & *E. coli* in flesh.	Yes	Need site survey and classification to interpret measurements.
Fish, Crustacea or shellfish	Manufacture – not applicable to wild gathering	ANZFA (2001)	Microorganisms in food.	Not relevant	Compare to standards and pass/fail.
Freshwater shellfish, crustacean or fish gathering	-	No guideline available	-	-	-
Collecting freshwater mahinga kai for marae	-	MPI (2013) Te Kai Manawa Ora Marae	-	Guidance is for a site evaluation similar to a sanitary inspection.	-
Watercress/puha gathering	-	MPI (2013) Te Kai Manawa Ora Marae	-	Guidance is for a site evaluation similar to a sanitary inspection and for plant washing & cooking before eating.	
Swimming – lakes and lake-fed rivers ONLY[A]	Human health for recreation[A]	MfE/MoH (2009)	Cyanobacteria biovolume in water	No - not relevant for cyanotoxins, other factors would be considered.	Interpret according to sample programme design, local/ historical knowledge, guidelines.
Swimming – lakes and lake-fed rivers	Human health for recreation	NOF 2014 (unchanged in NPS 2017 proposal)	Cyanobacteria biovolume in water	No - not relevant for cyanotoxins, other factors would be considered.	Need minimum of 12 samples collected over 3 years to interpret.

[A] Not applicable to food gathering

3.2.2 Current microbial guidelines and regulations in New Zealand

From 2003, the Ministry for the Environment and Ministry of Health "*Microbiological water quality guidelines for marine and freshwater recreational areas*" have been in place in New Zealand. Guidelines are provided for 'primary' or 'secondary' recreational contact and for recreational (not commercial) shellfish gathering in marine waters (MfE/MoH 2003). These guidelines take a two part approach to evaluating a site for microbial safety that accounts for weaknesses in using *E. coli* as an indicator organism on a day-to-day basis. The process requires:

1. A freshwater site is graded for susceptibility to microbial contamination; and
2. Local authorities undertake surveillance to measure *E. coli* (especially during times of high risk) to determine if *E.* coli concentrations currently meet standards, and/or if there are current problems that need to be addressed.

The grading process includes both a "Sanitary Inspection" to examine the many factors, particularly those upstream, that may cause microbial contamination, and a "Microbial Assessment Category" that examines historical microbiological results. The Sanitary Inspection asks questions such as, "*Is there intensive livestock grazing immediately upstream?*", and "*Are there stormwater discharges in the upstream catchment?*". Local factors must be taken into account, such as whether there is a wastewater treatment plant in the area, even if it is downstream. The historical data and the Sanitary Inspection results are combined to generate a "Suitability for Recreation Grade" (Table 13–upper).

Also, on an ongoing basis, surveillance data gathered as part of a monitoring programme (guidance is provided on how to do this) are interpreted according to freshwater guidelines (Table 13–lower) to indicate what action and monitoring must be undertaken to address likely issues. There are conditions that must be applied to the interpretation of the guidelines–for example, if there is a major outbreak of a potentially waterborne disease in the community upstream of the site then these guidelines may not be sufficient to protect users of the site. It is recommended that MfE/MoH (2003) is consulted for a full description of the guidelines.

Table 13: Table E2 (upper) and Box 2 (lower) from MfE/MoH (2003) showing Suitability for recreation grade for freshwater sites and Surveillance, Alert and Action levels, respectively

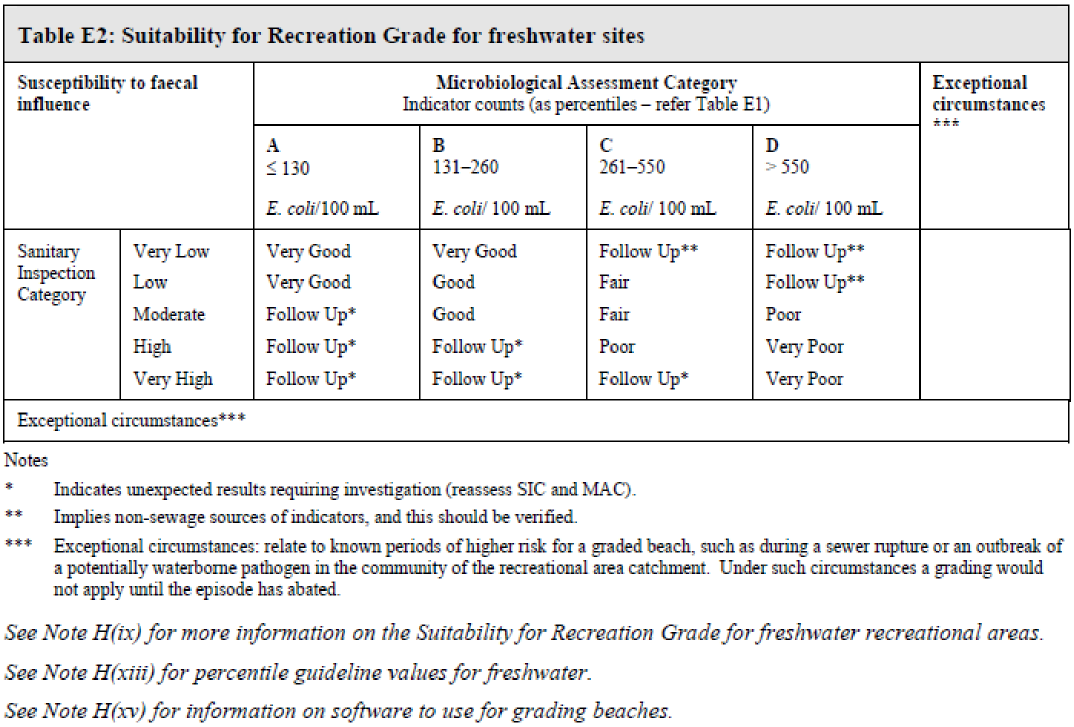


Table E2: Suitability for Recreation Grade for freshwater sites

Susceptibility to faecal influence		Microbiological Assessment Category Indicator counts (as percentiles – refer Table E1)				**Exceptional circumstances** ***
		A ≤ 130 *E. coli*/100 mL	B 131–260 *E. coli*/ 100 mL	C 261–550 *E. coli*/ 100 mL	D > 550 *E. coli*/ 100 mL	
Sanitary Inspection Category	Very Low	Very Good	Very Good	Follow Up**	Follow Up**	
	Low	Very Good	Good	Fair	Follow Up**	
	Moderate	Follow Up*	Good	Fair	Poor	
	High	Follow Up*	Follow Up*	Poor	Very Poor	
	Very High	Follow Up*	Follow Up*	Follow Up*	Very Poor	
Exceptional circumstances***						

Notes

* Indicates unexpected results requiring investigation (reassess SIC and MAC).

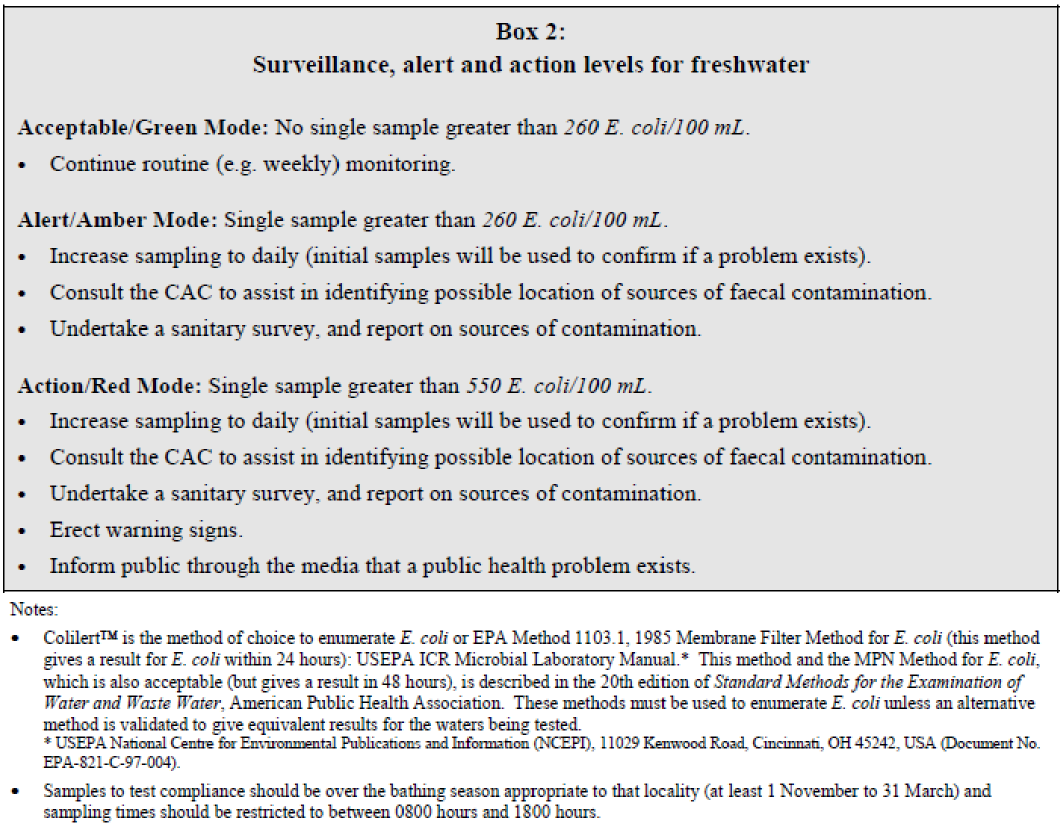
** Implies non-sewage sources of indicators, and this should be verified.

*** Exceptional circumstances: relate to known periods of higher risk for a graded beach, such as during a sewer rupture or an outbreak of a potentially waterborne pathogen in the community of the recreational area catchment. Under such circumstances a grading would not apply until the episode has abated.

See Note H(ix) for more information on the Suitability for Recreation Grade for freshwater recreational areas.

See Note H(xiii) for percentile guideline values for freshwater.

See Note H(xv) for information on software to use for grading beaches.



Box 2:
Surveillance, alert and action levels for freshwater

Acceptable/Green Mode: No single sample greater than *260 E. coli/100 mL*.

- Continue routine (e.g. weekly) monitoring.

Alert/Amber Mode: Single sample greater than *260 E. coli/100 mL*.

- Increase sampling to daily (initial samples will be used to confirm if a problem exists).
- Consult the CAC to assist in identifying possible location of sources of faecal contamination.
- Undertake a sanitary survey, and report on sources of contamination.

Action/Red Mode: Single sample greater than *550 E. coli/100 mL*.

- Increase sampling to daily (initial samples will be used to confirm if a problem exists).
- Consult the CAC to assist in identifying possible location of sources of faecal contamination.
- Undertake a sanitary survey, and report on sources of contamination.
- Erect warning signs.
- Inform public through the media that a public health problem exists.

Notes:

- Colilert™ is the method of choice to enumerate *E. coli* or EPA Method 1103.1, 1985 Membrane Filter Method for *E. coli* (this method gives a result for *E. coli* within 24 hours): USEPA ICR Microbial Laboratory Manual.* This method and the MPN Method for *E. coli*, which is also acceptable (but gives a result in 48 hours), is described in the 20th edition of *Standard Methods for the Examination of Water and Waste Water*, American Public Health Association. These methods must be used to enumerate *E. coli* unless an alternative method is validated to give equivalent results for the waters being tested.
  * USEPA National Centre for Environmental Publications and Information (NCEPI), 11029 Kenwood Road, Cincinnati, OH 45242, USA (Document No. EPA-821-C-97-004).
- Samples to test compliance should be over the bathing season appropriate to that locality (at least 1 November to 31 March) and sampling times should be restricted to between 0800 hours and 1800 hours.

Shellfish filter large quantities of water (e.g., typical filtration rates for individual kākahi are 1 L/hr) and therefore are particularly susceptible to accumulating bacteria, viruses and other microorganisms. The microbial water quality guidelines for shellfish gathering are therefore even more stringent than those for primary contact. However, these guidelines have been developed for gathering marine shellfish in New Zealand, and may not be directly applicable to freshwater shellfish gathering.

In addition to the MfE/MoH (2003) guidelines described above, there are the standards for the protection of human health for recreation in lakes and rivers in the 2014 National Policy Statement for Freshwater. An update to these standards was proposed in early 2017. Both standards are based on *E. coli* concentrations in water samples, but the 2017 version uses a different combination of measurements to evaluate risk for swimming. As yet, neither standard includes site evaluation processes to place the microbiological results in a context of site-specific risk. Other microbiological guidelines available for commercial harvesting and food manufacture (of fish, shellfish and crustaceans) are not strictly applicable to mahinga kai. These resources may, however, be useful for the development of future mahinga kai guidelines.

The NZFSA (2006) guidelines for commercial harvesting/farmed bivalve shellfish (e.g., mussels, oysters) are based on faecal coliforms in water and *E. coli* counts in shellfish flesh. A site survey and historical data are required as part of the process to interpret the measurements. The Australia New Zealand Food Authority (ANZFA) (2001) microbiological standards for food must be met by the nominated foods or classes of foods at any stage of their manufacture– those possibly relevant to mahinga kai are “Crustacea, cooked and raw”, “Ready-to-eat finfish” (does not include sushi or other raw fish foods), “Molluscs, other than scallops without the gut” and “Processed molluscs”. The standards are based on concentrations of different microorganisms (e.g., *Staphylococci*, *Salmonella*) enumerated according to sampling protocols included in the standard. The ANZFA (2001) include microbiological guideline criteria for various foods that are not mandatory.

3.2.3 Guidance on collection of mahinga kai

The Te Kai Manawa Ora Marae Food Safety Guide provides excellent information on many aspects of food on the marae, including some mahinga kai (MPI 2013). The following tips for gathering kaimoana are relevant to freshwater mahinga kai (MPI 2013):

- “*respect rāhui if one has been placed on an area where kaimoana is gathered;*
- *kaumātua, whānau, hapū, and iwi and local experts/kaitiaki will be able to provide advice on appropriate areas to collect kaimoana;*
- *follow the advice on any warning signs advising not to gather kaimoana from an area;*
- *when collecting kaimoana, avoid the following areas to lower the risk of illness:*
    - *where pipes or culverts run down to the beach;*
    - *where sewage or stormwater is discharged;*
    - *if farm animals are grazing nearby;*
    - *anywhere showing signs of industrial pollution;*
    - *coastal areas with houses nearby;*
    - *near wharves or marinas where boats might have discharged sewage or chemicals (such as anti-fouling paint or diesel);*
    - *near rivers or estuaries after heavy rain. Wait until the water has run clear for several days. Storms might flush sewage overflow or farm run-off downstream.*”

Watercress (wātakirihi) collected from popular sites in the Wellington region was shown to be significantly contaminated with *E. coli* and *Campylobacter*, as well as the heavy metal lead at concentrations above the FSANZ standards (Edmonds & Hawke 2007). To manage this risk, Edmonds & Hawke (2007) recommended washing then boiling watercress before consumption and only collecting from sites that have not been affected by significant industrial or urban discharges. In 2000, in response to the preliminary result of the Edmonds & Hawke study, both the regional and the national health authorities issued statements recommending that the public “*should not eat or serve watercress harvested from creeks, rivers or streams unless it was washed and cooked thoroughly in boiling water*”. In addition the statements also “*advised people selling watercress to inform their customers of this safety warning*”.

For collecting pūha or watercress the following safety tips are provided by MPI (2013):

- avoid collecting from beside the road–especially near high traffic density areas–as plants found near roads could contain high levels of heavy metals from car exhaust;
- seek advice from kaumātua or your local Health Protection Officer if contemplating collecting plants in geothermal areas because they may contain high concentrations of arsenic (not destroyed by cooking);
- wash plants thoroughly with drinking-quality water before using them;
- cook all plants thoroughly in boiling water to kill microbes; or, if you are to use plants raw (e.g., in salads or garnishes) make sure to get them from a reputable source (guidance is provided on such sources).

Another study was carried out to determine the food safety status of watercress (*Nasturtium officinale*) harvested from rural streams under Māori protocol (Donnison et al. 2009). Two streams were within reserves and the other two flowed through pastoral farms. To assess faecal contamination status, both *E. coli* and thermo-tolerant *Campylobacter* were measured on watercress as collected, and *E. coli* counts were assessed against the New Zealand guideline for ready-to-eat foods (satisfactory: <3 *E. coli* per g). To determine whether washing would ensure the watercress met food safety standards, an additional 6 bunches were collected and washed in running tap water (household regime). A further 15 bunches were washed by a simulated commercial triple washing regime. At harvest, 16 of 17 watercress samples collected from one reserve site and 11 of 22 from the other reserve site met the satisfactory criterion for ready-to-eat food, but only 1 of 17 and none of nine were satisfactory for the two pastoral sites. No *Campylobacter* was recovered from any sample of watercress collected from the four sites. After washing in running tap water, *E. coli* numbers still exceeded the satisfactory criterion. Commercial triple washing was more effective in ensuring satisfactory watercress, but of the 15 samples subjected to this regime, only 6 met the satisfactory criterion. *Escherichia coli* remained firmly attached to watercress leaves after both washing regimes (presumably in biofilms). Overall, these findings suggest that it is not advisable to use watercress harvested from rural streams as a raw salad vegetable, particularly from those affected by pastoral farming.

Dixon (2006) studied the microbiological quality of toroi, which is a fermented food prepared from puha or watercress and fish or meat, and provides a discussion of the relationship between traditional mahinga kai practices and concerns about contamination (Dixon 2006, 2017). For example, it was noted Māori consider many traditional mahinga kai sources to be degraded, particularly by the discharge of waste, especially human waste, into waterbodies. Traditional collection practices now include consideration of the impacts of feral animals and stock at collection sites: "*Māori will not harvest watercress, puha or mussels when there is evidence of animals and their dung as this is considered as a direct violation of mana kai*" (Dixon 2006). The main environmental concerns for Māori around mahinga kai were listed as: (i) access to mahinga kai sites; (ii) unknown pollutants at these locations; (iii) black market of Māori kai; and (iv) desecration of wāhi tapu sites.

3.2.4 Links to useful resources

Te Kai Manawa Ora Marae

- http://www.foodsafety.govt.nz/elibrary/manawa-marae-food-safety-guide/

Te Reo o Te Repo: The voice of the wetland

- http://www.landcareresearch.co.nz/publications/books/te-reo-o-te-repo

Collecting shellfish and keeping it safe

- http://www.foodsafety.govt.nz/elibrary/collecting_shellfish_keeping.htm

4. Selected Mahinga Kai Species Summaries

4.1 Species summaries

The following section summarises information of the 5 mahinga kai taonga species that were the focus of the NToTT programme:

- Tuna – freshwater eels
- Īnanga – whitebait
- Kōura – freshwater crayfish
- Kākahi – freshwater mussels
- Wātakirihi - watercress

The summaries include information of traditional mahinga kai values and collection practices, information on their habitat and use, and factors known to affect their distribution and abundance. Conceptual diagrams are used to illustrate the complex interacting issues affecting mahinga kai abundance and suitability.

Tuna

Other name(s)

Longfin eel, shortfin eel, spotted eel

Scientific name(s)

Anguilla australis, Anguilla dieffenbachii, Anguilla reinhardtii

Distribution

Throughout New Zealand except *A. reinhardtii* known mostly from Waikato

Photo: Steve Moore

Traditional use

Māori use a range of names for tuna that reflect appearance, colouration, season of the year, size, behaviour, locality, and palatability. Tuna kuwharuwharu (longfin eels) are of great significance culturally, spiritually, nutritionally and economically. Traditional harvesting methods involve setting of baited hīnaki, with the catch prepared by drying and smoking. Sometimes pā tuna (weirs) are used to capture downstream migrating tuna heke.

Habitat and biology

Longfin eels are the largest freshwater eel in the world, some living for many decades and reaching more than 25 kg in weight. Shortfin eels are smaller, have shorter life spans and are more abundant, whereas the spotted eel is a recent colonist with a limited distribution. Adults tend to live in places where they can hide during the day, such as amongst living or dead plant material, and often in areas of slow flow. Once mature, tuna migrate out to sea to spawn in the Pacific Ocean, and the eggs and larvae then drift back towards New Zealand, arriving as glass eels which migrate up streams and rivers. Adults breed only once at the end of their life.

Factors affecting abundance and use

Because tuna are migratory, their distribution is significantly affected by major barriers such as dams where trap and transfer is sometimes used to move elvers upstream. Longfin eels are better climbers and therefore penetrate further inland than shortfin eels which are more common in lowland environments. Other pressures include loss of habitat and wetlands including the disconnection of the river from the surrounding waterways and natural floodplains due to flood control structures, discharges/pollution, commercial fishing, and pest plants and fish. Downstream migrating mature eels can experience significant mortality in flood pumps and hydro-turbines. Commercial eel fishing is included in the Quota Management System (QMS) which set limits on the minimum and maximum size (220 grams and 4 kg) and a Total Allowable Catch which has not been reached in any fishing season since the QMS implementation. In recognition of the traditional significance of longfin eels, Māori have a 20 percent allocation of fishery stocks. The capture and export of glass eels in New Zealand has been prohibited.

Key online information sources

https://www.niwa.co.nz/te-kuwaha/tools-and-resources/tuna-information-resource
http://www.doc.govt.nz/nature/native-animals/freshwater-fish/eels/

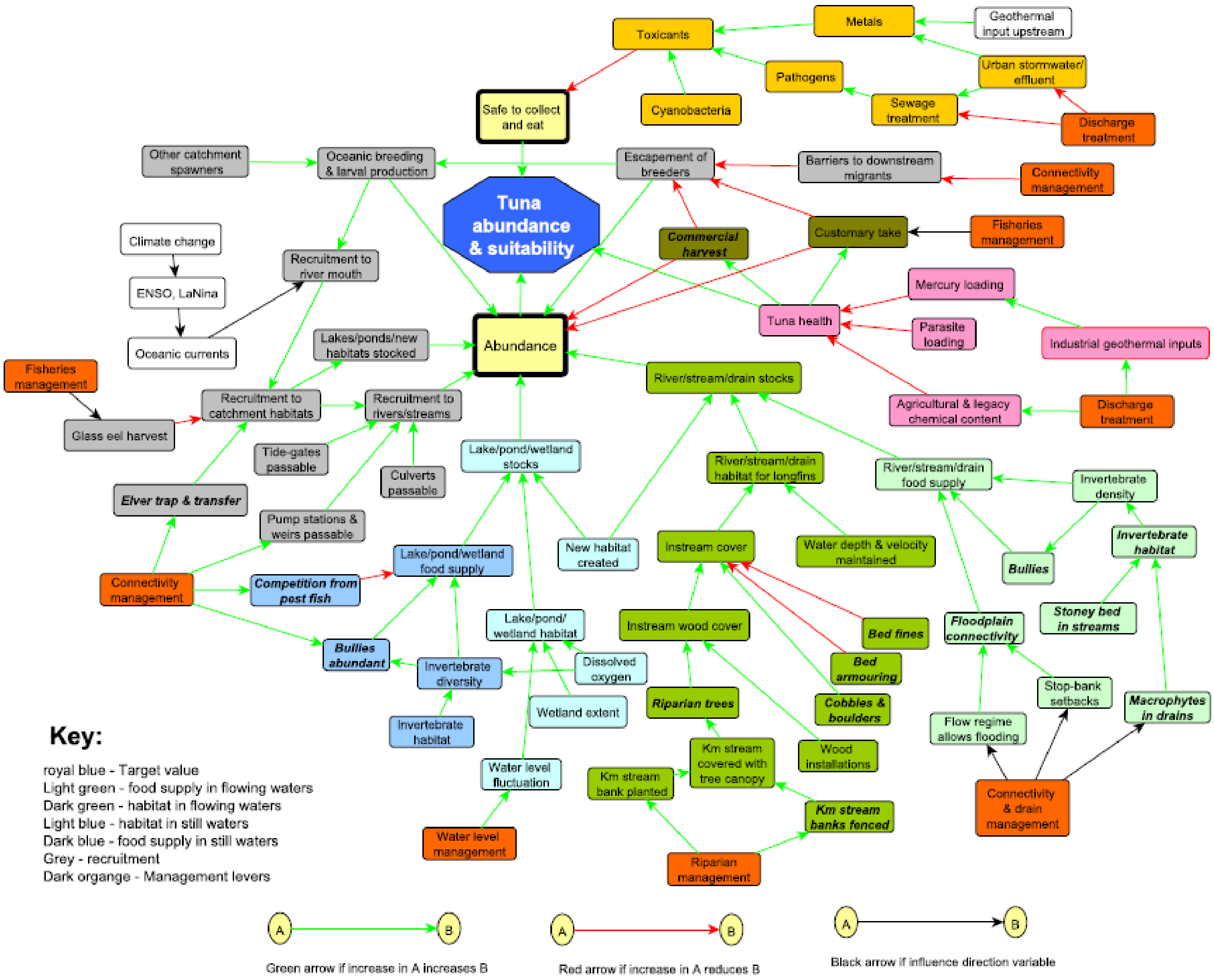


Figure 11: Conceptual model highlighting interconnections between factors affecting tuna abundance and suitability to collect and eat (modified from Quinn, unpubl.)

Additional information:

Tuna remains a significant taonga for most Māori tribes throughout Aotearoa New Zealand and a very important mahinga kai species. Māori have in-depth and extensive local and generic knowledge (mātauranga Māori) of tuna based on traditional knowledge and belief systems (held by whānau, hapū and iwi). There exist many stories, artefacts, and songs dedicated to eels that reinforce their importance to Māori. The protection and sustainable management of tuna as a resource and spiritual entity is central to many iwi management plans and Waitangi Tribunal claims. Longfin eels in particular are a significant traditional food source. Tuna used to be caught in abundance with relative ease and Māori have long had extensive knowledge of the timing of their upstream and downstream migrations. The stories of tuna and their special physical and spiritual relationship to the environment (taiao) e.g., landscapes, wetlands, lakes, rivers, streams etc, differs from place-to-place, but tuna were traditionally regarded as very important kaitiaki (guardians) over resources and people in many tribal rohe and regions and this remains the case. They were also a vehicle for knowledge transmission and were used as an ecological/cultural health indicator to assess water and habitat health and vitality. However, dwindling numbers of tuna in many areas have seriously impacted the use of tuna as a staple part of the food diet and nutrition. Tuna were one of the main sources of protein in the diets of tūpuna (ancestors) and a rich source of essential fats and oils. Traditionally and historically, tuna were heavily relied upon as a source of kai and important events were often scheduled around the harvesting of tuna. Because tuna come in many different sizes, they are a very versatile food. Tuna can be stored live in 'pataka tuna' for over twelve months and eaten as required. They can also be preserved or dried and kept for months. Easy storage of tuna provided tūpuna with a good source of protein at a time when conventional refrigeration was not available. There are over 100 different tribal names for freshwater eels, based on the subtle variations in their characteristics, which is representative of the extensive mātauranga (knowledge/science) that still exists. This knowledge emerged from intense observation and interactions to determine the life cycle, habitat needs and migration patterns, which guided Māori to a sustainable take of the population in different areas. Tuna would be harvested at "*specific times of the year according to tikanga (protocols) which determine sustainable utilisation of the species*". Māori developed sophisticated trapping methods, such as hīnaki (eel pots), pā-tuna (eel weirs), patu tuna (eel striking), toi (eel bobbing without hooks), koumu (eel trenches), korapa (hand netting) and mata rau (spearing). Eel weirs were commonly used, however, the arrival of settlers and their desire to make waterways more navigable saw the interruption of the use of eel weirs. At present Māori have customary harvest rights for events such as hui and tangi, as well as a portion (20%) of the commercial take.

Selection of relevant publications:

Best, E. (1929). Fishing Methods and devices of the Maori. Dominion Museum Bulletin No 12. 92 p.

Chisnall, B.L. (2000). The Australian longfinned eel, *Anguilla reinhardtii*, in New Zealand. Conservation Advisory Science Notes No. 302. Department of Conservation. 14 p. http://www.doc.govt.nz/upload/documents/science-and-technical/casn302.pdf

Jellyman, D.J., Chisnall, B.L., Dijkstra, L.H., Boubée, J.A.T. (1996). The first record of the Australian longfinned eel, *Anguilla reinhardtii*, in New Zealand. Australian Journal of Marine and Freshwater Research 47:1037-1040. http://www.publish.csiro.au/nid/126/paper/MF9961037.htm

McDowall, R.M. (2011). Ikawai: Freshwater fishes in Māori culture and economy. Christchurch, N.Z., Canterbury University Press. 872 p. http://www.cup.canterbury.ac.nz/catalogue/ikawai.shtml

McDowall, R.M., Jellyman, D.J., Dijkstra, L.H. (1998). Arrival of an Australian anguillid eel in New Zealand: an example of transoceanic dispersal. Environmental Biology of Fishes 51(1): 1-6. http://www.springerlink.com/content/j634k38l2l041j77/

Potangaroa, J. (2010). Tuna kuwharuwharu, the longfin eel. An educational resource: facts, threats and how to help. 26 p. http://www.rangitane.iwi.nz/education/attachments/169_tuna_vweb.pdf

Strickland, R.R. (1990). Nga tini a Tangaroa. A Maori-English, English-Maori dictionary of fish names. New Zealand Fisheries Occasional Publication No. 5. MAF Fisheries, Wellington. http://www.cawthron.org.nz/coastal-freshwater-resources/downloads/nga-tini-a-tangaroa.pdf

Īnanga

Other name(s)

Whitebait, matamata

Scientific name(s)

Galaxias spp. (*G. maculatus, G. brevipinnis, G. fasciatus, G. argenteus, G. postvectis*)

Distribution

Throughout New Zealand

Photo: Konrad Gorski

Traditional use

The annual whitebait migration is an important mahinga kai resource for Māori and specific iwi have local names for īnanga. Traditionally Māori caught īnanga/whitebait in woven flax nets, sometimes called kaka, with frames made from aka aka (native vine supplejack) attached to a long pole handle. An ariari board of white bark was used so that fish could be seen swimming upstream. After drying in the sun or over a fire, they were steamed in baskets in an earth oven. Adult īnanga were often taken during downstream migration when they were full of eggs. Captured fish were either dried in the sun or on rocks. Preservation in this manner meant that the fish could be kept in an edible state for months.

Habitat and biology

Whitebait comprise the translucent migrating larvae (4-5 cm long) of īnanga, kōaro, banded kōkopu, giant kōkopu, and shortjaw kōkopu which move upstream from the sea during spring/summer. In many places the catch is dominated by one species–īnanga–although kōaro and banded kōkopu can sometimes also make up significant proportions of the catch. Larvae of all species are born in freshwater or tidal waters, although the spawning sites vary between species and some are poorly known. Īnanga spawn on moist, marginal vegetation in the tidal areas of rivers; eggs stay out of the water for several weeks and hatch when re-immersed by spring tides when larvae are washed out to sea. Larvae of other whitebait species are believed to hatch from eggs laid in marginal vegetation and be washed out to sea during floods. Sea-run larvae spend several months out at sea feeding on plankton before returning to rivers as whitebait.

Factors affecting abundance and use

All whitebait species are migratory and therefore barriers to upstream passage are a major factor affecting the distribution and abundance of species which have different climbing abilities–kōaro are impressive climbers able to scale wet vertical surfaces many metres high, while īnanga are poor climbers and most common in lowland areas. Other factors include poor water quality, disturbance of spawning habitats, wetland drainage, invasive species impacts, and fishing pressure. Whitebaiting is regulated with the season from August to November for all areas of the country except the West Coast where it is September to November (see http://www.doc.govt.nz/whitebaiting)

Key online information sources

http://www.landcareresearch.co.nz/__data/assets/pdf_file/0007/134944/5-5-Fauna_Matamata.pdf
http://www.doc.govt.nz/nature/native-animals/freshwater-fish/whitebait-migratory-galaxiids/
https://www.sciencelearn.org.nz/resources/425-whitebaiting

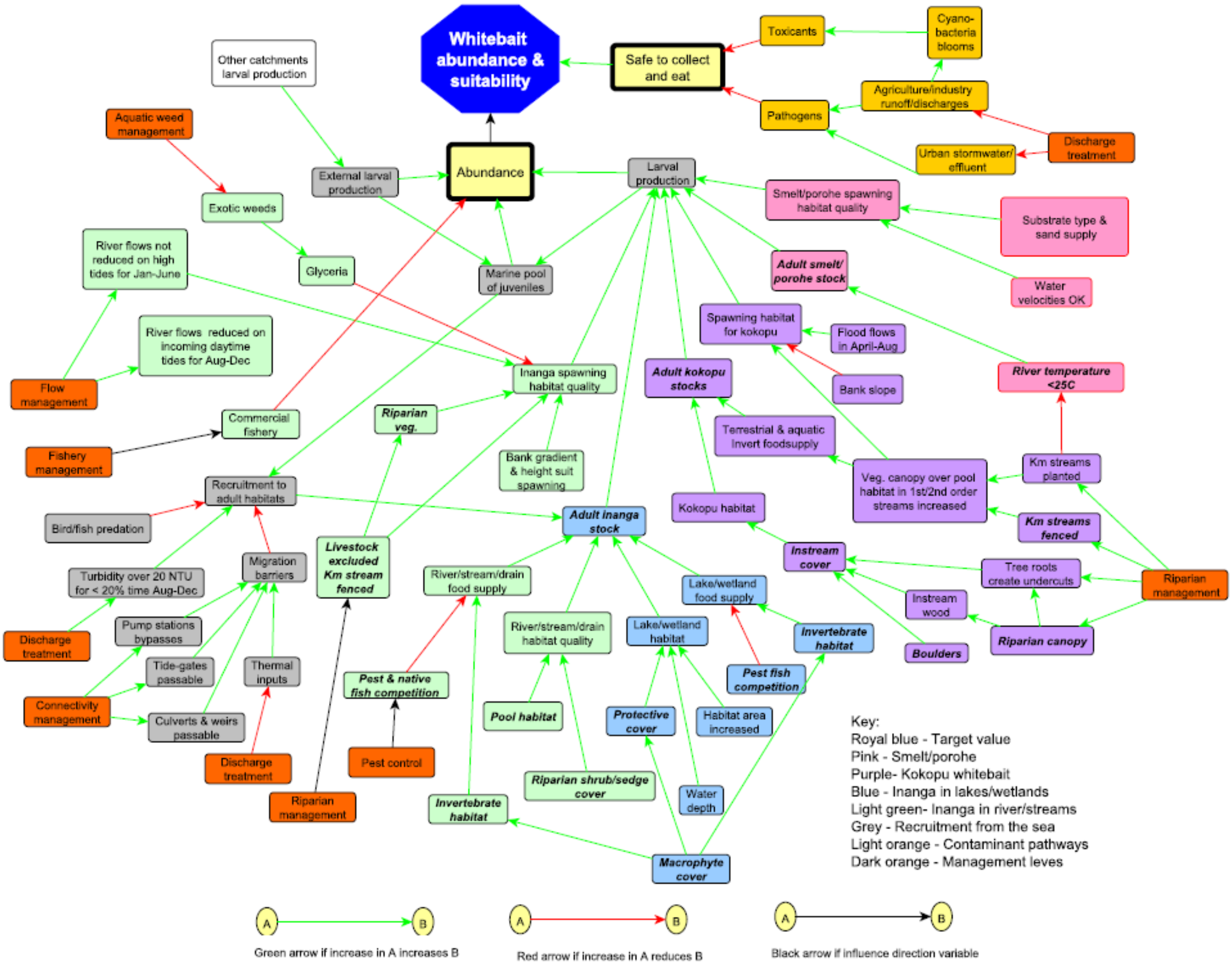


Figure 12: Conceptual model highlighting interconnections between factors affecting whitebait abundance and suitability to collect and eat (modified from Quinn, unpubl.)

Selection of relevant publications:

Mahuta R, van Schravendijk-Goodman C, Baker C 2017. Matamata – eating with our tupuna. In: Taura Y, van Schravendijk-Goodman C, Clarkson B eds. 2017. Te reo o te repo, the voice of the wetland. Hamilton, Manaaki Whenua – Landcare Research and Waikato Raupatu River Trust. Pp. 107–117.

Kōura, Kewai

Photo: Steve Moore

Other name(s)

Freshwater crayfish

Scientific name(s)

Paranephrops planifrons, Paranephrops zealandicus

Distribution

P. planifrons–North Island/West Coast of South Island; *P. zealandicus*–east and south of South Island

Traditional use

Historically, kōura was an important food for Māori in specific regions and locations, and was harvested in large numbers for consumption and trading. Today, kōura are considered a 'taonga' species and support important customary fisheries, particularly in central North Island lakes. Traditional harvesting methods have included the use of bundles of ponga fronds or bracken (whakaweku) within which kōura seek shelter, enabling them to be easily harvested (a method referred to as tau kōura). Other methods used include pouraka (baited traps), hīnaki (fyke nets), pae pae (dredge nets) and rama kōura (hand nets). Limited information on kōura abundance and ecology makes it difficult for iwi and others to manage kōura in their lakes and rivers. The tau koura have been verified as a useful tool for monitoring in lakes and are currently being examined for their utility for monitoring streams and rivers.

Habitat and biology

Kōura live in streams, lakes, ponds and swamps where substrates and water quality, particularly dissolved oxygen, are suitable. Their diet is varied and can include plants (living and dead), other invertebrates, terrestrial insects, fish, decaying organic matter, and can even extend to cannibalism. Females can carry berry-like eggs under their abdomens from 4-5 months of the year, depending on the species and location, where they hatch and go through two moults before dropping off as miniature crayfish. It is thought that kōura typically live for 3-4 years dependent on water temperature. They can perform important ecosystem functions by breaking down plant material and by mobilising fine silt in streams, in turn positively affecting other aquatic invertebrates. They are predated on by birds, eels and introduced fish such as trout, catfish and perch.

Factors affecting abundance and use

Historical and recent anecdotal evidence from iwi/hapū indicates a declining trend in kōura abundance in many lakes. Removal of native forest, loss of habitat, declining water quality, sedimentation and pest species are all factors affecting kōura abundance. They require good water quality and typically become stressed when dissolved oxygen falls below 5 g/m^3, water temperatures exceed 16^{o}C (based on laboratory experiments), and levels of calcium are low (needed for synthesis of their outer shell after moulting).

Key online information sources

http://www.landcareresearch.co.nz/__data/assets/pdf_file/0004/134941/5-2-Fauna_Koura.pdf
https://www.niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/species/koura
http://www.doc.govt.nz/nature/native-animals/invertebrates/crayfish-koura/
http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Fresh%20water/tau-koura.aspx

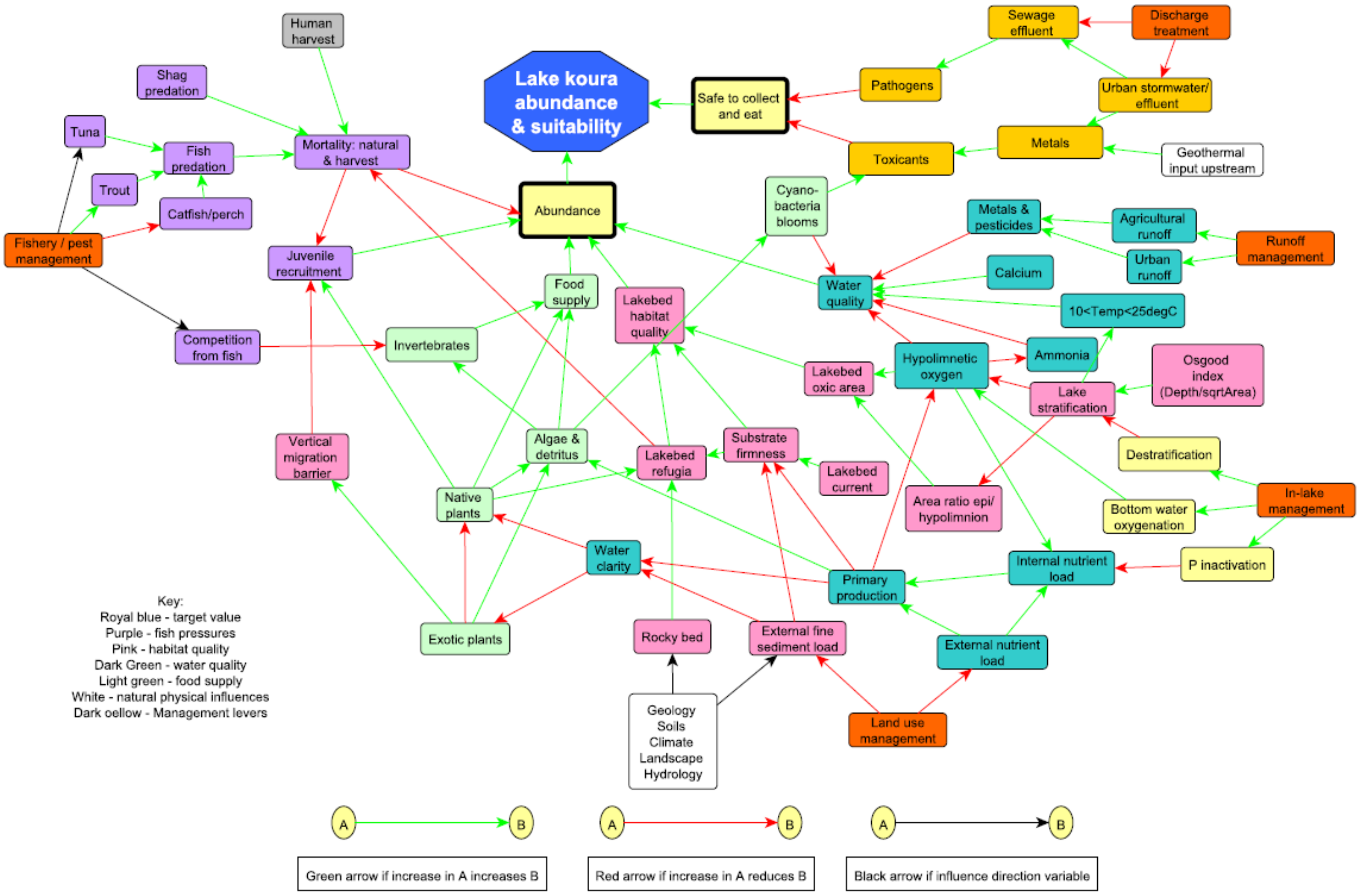


Figure 13: Conceptual model highlighting interconnections between factors affecting lake kōura abundance and suitability to collect and eat (modified from Quinn, unpubl.)

Selection of relevant publications:

Clearwater S.J, Kusabs IA, Budd R, Bowman E. 2014. Strategic evaluation of kōura populations in the upper Waikato River. NIWA Client Report No. HAM2014-086 prepared for the Waikato River Authority, Project No. WRA14204.

Hiroa TR. 1921. Maori food-supplies of Lake Rotorua, with methods of obtaining them, and usages and customs appertaining thereto. Transactions of the Royal Society of New Zealand 52: 433-451.

Kusabs IA, Quinn JM, Hamilton DP. 2015a. Effects of benthic substrate, nutrient enrichment and predatory fish on freshwater crayfish (kōura, *Paranephrops planifrons*) population characteristics in seven Te Arawa (Rotorua) lakes, North Island, New Zealand. Marine and Freshwater Research 66: 631-643.

Kusabs IA, Hicks BJ, Quinn JM, Hamilton DP. 2015b. Sustainable management of freshwater crayfish (kōura, *Paranephrops planifrons*) in Te Arawa (Rotorua) lakes, North Island, New Zealand. Fisheries Research 168: 35-46.

Kusabs I. 2017. Kōura – the ancient survivor. In: Taura Y, van Schravendijk-Goodman C, Clarkson B eds. 2017. Te reo o te repo, the voice of the wetland. Hamilton, Manaaki Whenua – Landcare Research and Waikato Raupatu River Trust. Pp 89–93.

Kākahi, Kāeo, Torewai

Other name(s)

Freshwater mussel

Scientific name(s)

Echyridella menziesii, E. aucklandica, E. onekaka

Distribution

E. menziesii - throughout NZ;
E. aucklandica - most commonly encountered in northern NZ but also in some southern lakes;
E. onekaka - north-west Nelson

Photo: Mark Hamer

Traditional use

The traditional value of kākahi reflects the great skill required for collection, their role in historical Māori diet, and their value as tools such as for cutting and scraping. They were also used as part of spiritual practices and for medicinal purposes (rongoā). Traditional harvesting methods usually involved use of a kapu/mangakino or mussel dredge to scoop mussels from the bottom of lakes and rivers. Many Treaty claims processes aim to protect and manage kākahi numbers and habitats (e.g., Whanganui, Wairarapa, Ngāti Kahungungu).

Habitat and biology:

Kākahi densities can be extremely high in some lakes, streams and rivers, reaching over several hundred per square meter. At these densities the mussel bed can play an important role filtering water and turning over the sediment (bioturbation). Eggs develop inside females and males discharge sperm which is then taken in through the female's inhalant siphon to fertilise the eggs held in a specialised brood pouch in the female's gill. Fertilised eggs grow into larvae called glochidia which are discharged during summer into the water column where they have 2-3 days to find a fish host to provide nutrients for the transformation into juveniles. Following approximately 2 weeks attached to a fish, the juvenile mussel falls off and is thought to settle into the sediment. Juvenile kākahi (<0.5 mm length) are extremely hard to find and possibly live in the spaces between sediment grains within the beds of rivers and lakes, but once they are 20 to 30 mm long they are found at the sediment surface with adult kākahi. As juveniles they have the unusual habit of feeding with their ciliated foot which is thought to capture small algae, bacteria and organic particles. An astounding feature of kākahi is their longevity, with *E. menziesii* possibly living for an estimated 40-50 years based on annual growth rings laid down in their shells. *E. aucklandica* is larger and may live even longer.

Factors affecting abundance and use:

The larvae and juveniles of kākahi are very sensitive to contaminants such as ammonia and copper–both common in urban and agricultural pollution. This sensitivity might explain why kākahi have low reproduction in small streams and in eutrophic lakes, leaving only populations of older adults that will slowly die out. Pressures such as changes towards flashy flow regimes, predation, sedimentation, deoxygenation in eutrophic lakes and loss of their preferred larval hosts are probably also contributing to a decline in kākahi.

Key online information sources:

https://www.niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/species/kakahi
https://www.niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/species/kakahi

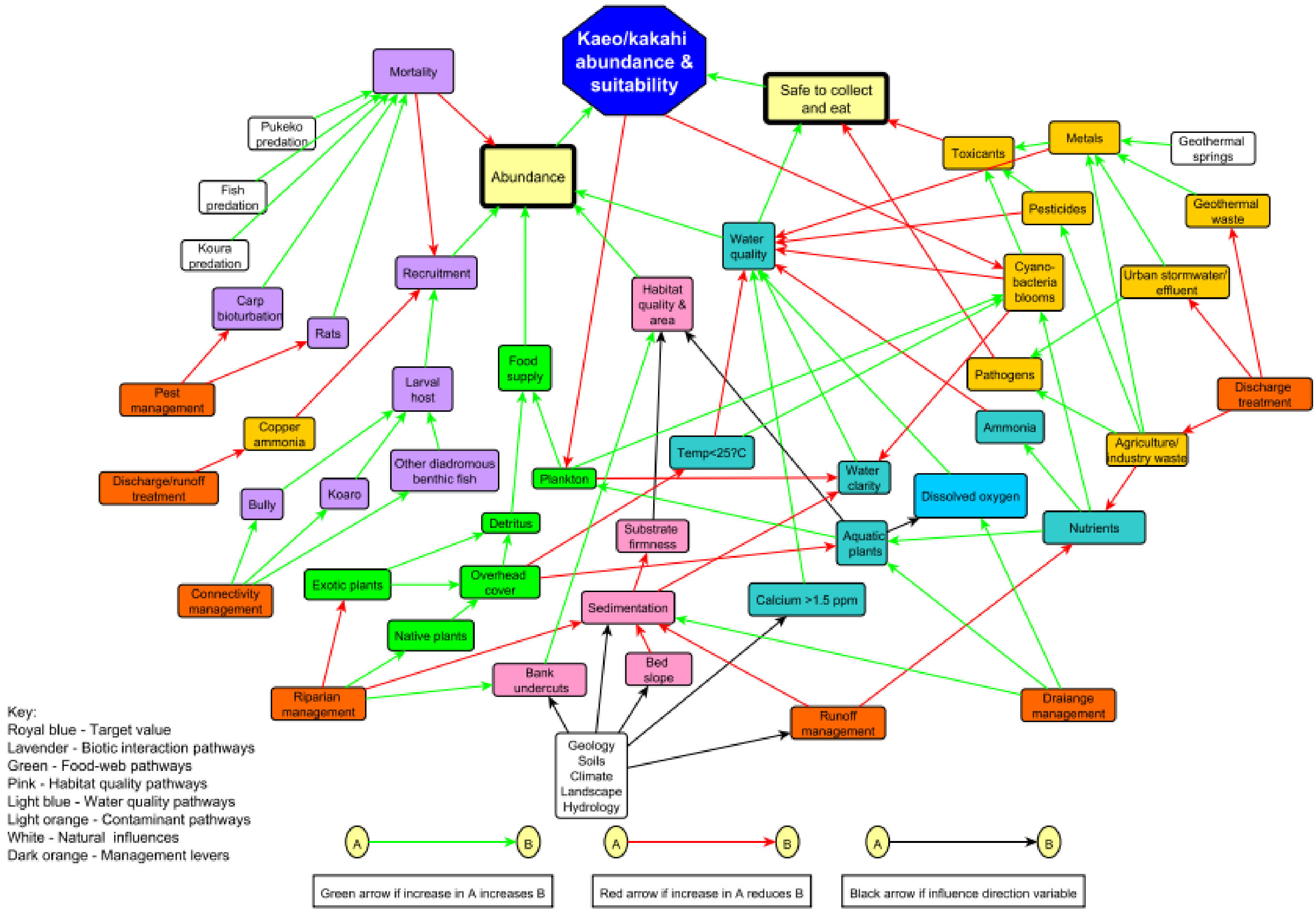


Figure 14: Conceptual model highlighting interconnections between factors affecting kākahi/kāeo abundance and suitability to collect and eat

Selection of relevant publications:

McDowall R. 2002. Decline of the kakahi - identifying cause and effect. https://www.niwa.co.nz/publications/wa/vol10-no4-december-2002/decline-of-the-kakahi-identifying-cause-and-effect

Rainforth J. 2008. Tiakina Kia ora – Protecting our Freshwater Mussels. A thesis submitted to Victoria University of Wellington in fulfilment of the requirements for the degree of Masters in Ecological Restoration. Victoria University of Wellington.

Walker KF, Byrne M, Hickey CW, Roper DS 2001. Freshwater mussels (Hyriidae) of Australasia. In: Bauer G, Wächtler K. (eds). Evolution of the freshwater mussels Unionoida, pp. 5–31. Ecological Studies Vol. 145. Springer-Verlag, Berlin, Heidelberg.

Wātakirihi, Kōwhitiwhiti, Kirihi wai, Poniu

Other name(s)

Watercress

Scientific name(s)

Nasturtium officinale, Nasturtium microphyllum

Distribution

Throughout New Zealand

Traditional use

Watercress forms a major component of many traditional dishes and is eaten raw or cooked as a very nutritious vegetable high in iron, calcium, vitamins C and A, folic acid and antioxidants. It has a mild mustard flavour and is often used as an alternative to puha; the milky sap was used as chewing gum. Usually it is boiled up with protein-based foods such as meat or fish, and is also used extensively in hangi to wrap food. Harvest sites are highly coveted and sometimes known only to whānau. Historically there was a 'native cress' – probably *Rorippa palustris* and *R. divaricata* (now a threatened plant), possibly also known as panapana, ponui, and matangaoa. These native cresses have been replaced in many areas by introduced *Nasturtium* species.

Habitat and biology

Watercress is typically associated with drains, puna (springs), small streams, wetlands, and the calmer edges of rivers and lakes. It is found in open, unshaded settings. It is very efficient at removing nutrients from water, absorbing as much as 40% of the nitrate and phosphate from a Rotorua stream in an experimental trial.

Factors affecting abundance and use

Watercress is highly susceptible to the effects of swamp and wetland drainage, water extraction, spraying, sedimentation, and pugging and grazing by large animals. Pugging caused by the movement of stock along riparian margins can create small slips that fall onto watercress beds and smother them. Sediment deposits, in particular, can affect photosynthesis by smothering leaves and blocking sunlight. Watercress can accumulate metals and metalloids, particularly arsenic, which is a concern for human consumption. For example, geothermal waters are often metal-enriched, and therefore local guidance should be sought before consumption. Also, watercress is often abundant in nutrient-rich, unshaded lowland waterways accessed by farm animals that are vectors of pathogenic microorganisms such as bacteria and viruses. Bacteria such as *E. coli* and other pathogens such as *Campylobacter* can affect the suitability of watercress for safe human consumption, and precautionary measures are recommended (e.g., seeking local advice, washing thoroughly with drinking water and cooking before eating).

Key online information sources:

http://www.landcareresearch.co.nz/__data/assets/pdf_file/0008/134936/4-1-Flora_Watakirihi.pdf
https://www.niwa.co.nz/freshwater-and-estuaries/freshwater-and-estuaries-update/no28-2008/watercress-one-step-to-cleaner-waterways
http://www.hrc.govt.nz/sites/default/files/Kai%20contamination_Te%20Arawa_Summary%20Report_25%20Aug%5B1%5D.pdf

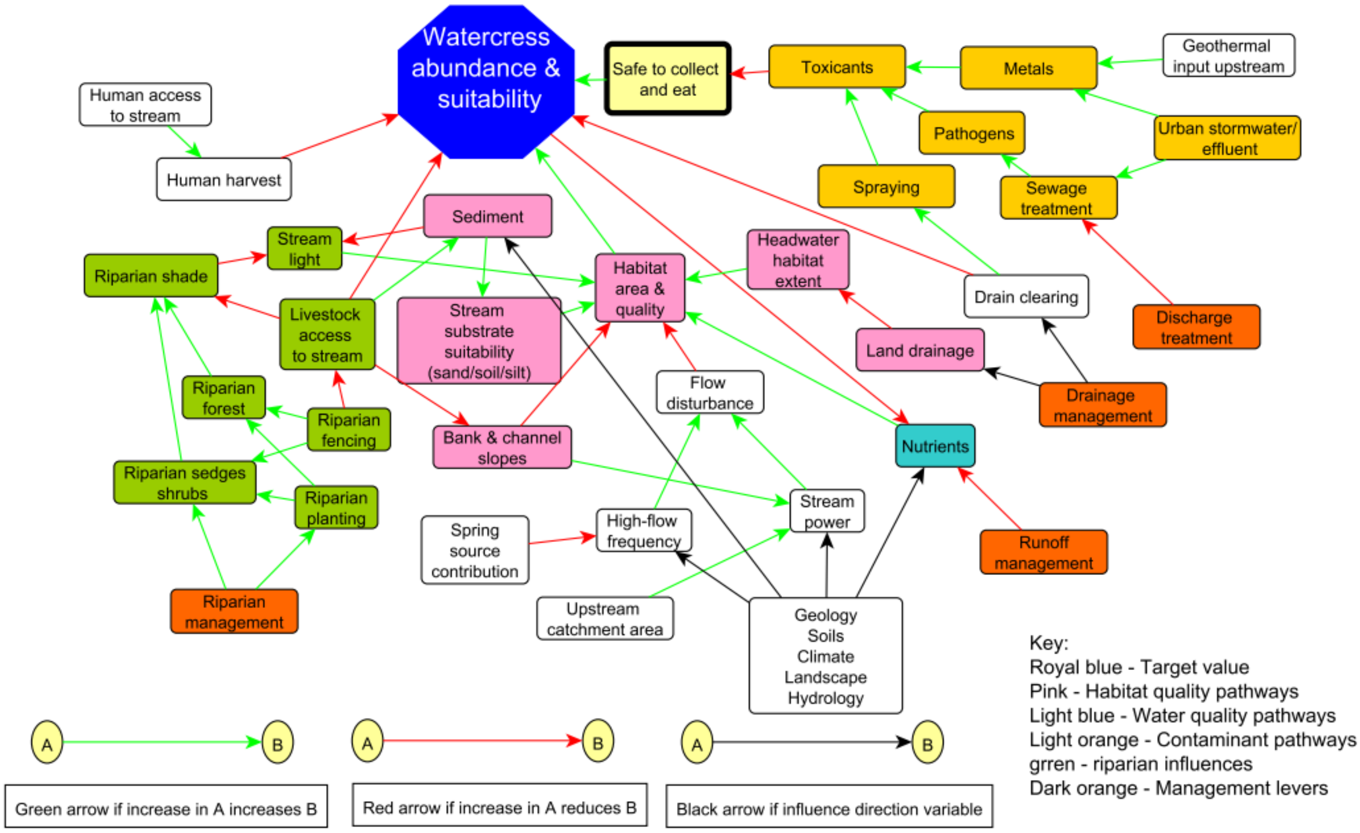


Figure 15: Conceptual model highlighting interconnections between factors affecting watercress abundance and suitability to collect and eat (modified from Quinn, unpubl.)

Selection of relevant publications:

Best E. 1942. Forest lore of the Māori. Dominion Museum Bulletin 14.

Dixon LLB. 2006. Microbiological quality of toroi: a Māori food delicacy. University of Waikato, Hamilton.

Dixon L. 2017. Wātakirihi – te huakita o te wātakirihi – bacterial quality of the watercress. In: Taura Y, van Schravendijk-Goodman C, Clarkson B eds. 2017. Te reo o te repo, the voice of the wetland. Hamilton, Manaaki Whenua – Landcare Research and Waikato Raupatu River Trust. Pp. 57–64.

Donnison A, Ross C, Dixon L. 2009. Faecal microbial contamination of watercress (*Nasturtium officinale*) gathered by a Maori protocol in New Zealand streams. New Zealand Journal of Marine and Freshwater Research 43: 901-910.

4.2 Supporting Mahinga Kai Species Documents

Taura Y, Reihana K, Awatere S, Harmsworth G, Forrest E. 2017. Wai Ora Wai Maori–a kaupapa Maori assessment tool for Ngati Tahu-Ngati Whaoa. Hamilton, Manaaki Whenua - Landcare Research. Ngā Tohu o te Taiao: Sustaining and Enhancing Wai Māori and Mahinga Kai. MBIE contract number UOWX1304. 8p.

Awatere S, Robb M, Taura Y, Reihana K, Harmsworth G, Te Maru J, Watene-Rawiri E. 2017. Wai Ora Wai Māori – a kaupapa Māori assessment tool. Policy Brief No. 19 (ISSN: 2357-1713). Hamilton, Manaaki Whenua - Landcare Research. 7p.

- http://www.landcareresearch.co.nz/__data/assets/pdf_file/0019/145108/policy-brief-19-Wai-Ora-Wai-Maori.pdf

Taura Y, van Schravendijk-Goodman C, Clarkson B eds. 2017. Te reo o te repo, the voice of the wetland. Hamilton, Manaaki Whenua - Landcare Research and Waikato Raupatu River Trust.

- http://www.landcareresearch.co.nz/publications/books/te-reo-o-te-repo

Harmsworth G. 2017. Indicators for cultural resources. In: Taura Y, van Schravendijk-Goodman C, Clarkson B eds. 2017. Te reo o te repo, the voice of the wetland. Hamilton, Manaaki Whenua – Landcare Research and Waikato Raupatu River Trust. Pp. 51–55.

- http://www.landcareresearch.co.nz/__data/assets/pdf_file/0007/134935/4-Indicators-for-Cultural-resources.pdf

Wetland Posters:

- http://www.landcareresearch.co.nz/__data/assets/pdf_file/0004/135085/Poster-1-maori-values.pdf
- http://www.landcareresearch.co.nz/__data/assets/pdf_file/0005/135086/Poster-2-maori-environmental-monitoring.pdf
- http://www.landcareresearch.co.nz/__data/assets/pdf_file/0006/135087/Poster-3-taonga-species.pdf

5. Conclusions

Mahinga kai is one of a number of significant Māori values identified within the National Objectives Framework (NOF) for freshwater management. A large number of Māori groups have raised issues and concerns about mahinga kai species largely due to: (i) declines in abundance and quality; and (ii) potential contamination from anthropogenic activities. The *Ngā Tohu o te Taiao: Sustaining and Enhancing Wai Māori and Mahinga Kai* (NToTT) research project has responded to these concerns and developed frameworks, methods, tools and processes to inform and support conversations on mahinga/hauanga kai for the management of freshwater at national, regional, catchment, tribal and local scales.

One of these tools was a kaupapa Māori assessment method Wai Ora Wai Māori which, based on specific and local iwi/hapū values and principles, can be used to assess and measure the present state and condition of mahinga/hauanga kai as a customary resource or taonga from an iwi/hapū Māori perspective, and articulate and align this assessment to the National Policy Statement and National Objective Framework bands and limits. The tool can help any group assess and monitor progress towards, or away from, desired mahinga kai restoration/remediation goals and outcomes, often within the wider context of the catchment or freshwater management unit. It also introduces central concepts such as whakapapa, whānaungatanga, kaitiakitanga, oranga, mauri, wairua and Te Mana o Te Wai within a mātauranga Māori and tikanga based framework.

This report extends the conversations around mahinga kai by identifying physical and chemical attributes affecting the survival and collection of important selected freshwater mahinga kai species from a much longer list of species usually presented by each iwi/hapū. It has been important to illustrate the connections between mahinga kai and contaminants especially where contaminants may limit or threaten the survival of key mahinga kai species and constrain desired goals and outcomes of many iwi/hapū groups to increase the populations, habitats and condition of these key species.

6. References

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Cyr H, Collier KJ, Clearwater SJ, Hicks BJ, Stewart S. 2016. Feeding and nutrient excretion of the New Zealand freshwater mussel *Echyridella menziesii* (Hyriidae, Unionida): Implications for nearshore nutrient budgets in lakes and reservoirs. Aquatic Sciences 79: 557-571.

Davies-Colley R, Franklin P, Wilcock R, Clearwater S, Hickey C. 2013. National objectives framework – temperature, dissolved oxygen and pH. Proposed thresholds for discussion. Prepared for Ministry for the Environment. NIWA, Hamilton.

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Dixon L. 2017. Wātakirihi Te Huakita O Te Wātakirihi Bacterial quality of watercress. In Taura, Y., C. Schravendijk-Goodman & B. Clarkson (eds) Te Reo o Te Repo The Voice of the Wetland: Connections, understandings and learnings for the restoration of our wetlands. Manaaki Whenua Landcare Research and Waikato Raupatu River Trust, Hamilton, New Zealand, pp 57-64.

Dolamore B, Puddick J, Wood SA. 2017. Accumulation of nodularin in New Zealand shortfin eel (*Anguilla australis*): potential consequences for human consumption. New Zealand Journal of Marine and Freshwater Research 51:321-332.

Donnison A, Ross C, Dixon L. 2009. Faecal microbial contamination of watercress (*Nasturtium officinale*) gathered by a Maori protocol in New Zealand streams. New Zealand Journal of Marine and Freshwater Research 43:901-910.

Edmonds C, Hawke R. 2007. Microbiological and metal contamination of watercress in the Wellington regioni, New Zealand - 2000 survey. Australian and New Zealand Journal of Public Health 28:20-26.

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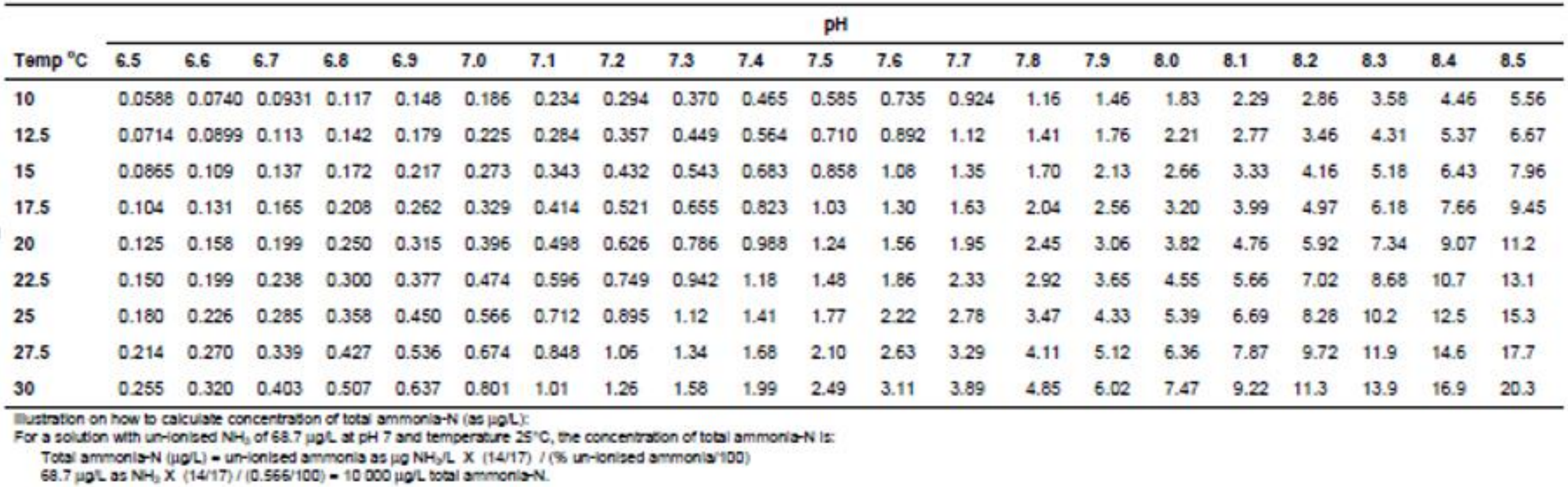
Appendix 1

Percentage of unionised ammonia at differing pH and temperature (from ANZECC (2000))



	pH																				
Temp °C	**6.5**	**6.6**	**6.7**	**6.8**	**6.9**	**7.0**	**7.1**	**7.2**	**7.3**	**7.4**	**7.5**	**7.6**	**7.7**	**7.8**	**7.9**	**8.0**	**8.1**	**8.2**	**8.3**	**8.4**	**8.5**
10	0.0588	0.0740	0.0931	0.117	0.148	0.186	0.234	0.294	0.370	0.465	0.585	0.735	0.924	1.16	1.46	1.83	2.29	2.86	3.58	4.46	5.56
12.5	0.0714	0.0899	0.113	0.142	0.179	0.225	0.284	0.357	0.449	0.564	0.710	0.892	1.12	1.41	1.76	2.21	2.77	3.46	4.31	5.37	6.67
15	0.0865	0.109	0.137	0.172	0.217	0.273	0.343	0.432	0.543	0.683	0.858	1.08	1.35	1.70	2.13	2.66	3.33	4.16	5.18	6.43	7.96
17.5	0.104	0.131	0.165	0.208	0.262	0.329	0.414	0.521	0.655	0.823	1.03	1.30	1.63	2.04	2.56	3.20	3.99	4.97	6.18	7.66	9.45
20	0.125	0.158	0.199	0.250	0.315	0.396	0.498	0.626	0.786	0.988	1.24	1.56	1.95	2.45	3.06	3.82	4.76	5.92	7.34	9.07	11.2
22.5	0.150	0.199	0.238	0.300	0.377	0.474	0.596	0.749	0.942	1.18	1.48	1.86	2.33	2.92	3.65	4.55	5.66	7.02	8.68	10.7	13.1
25	0.180	0.226	0.285	0.358	0.450	0.566	0.712	0.895	1.12	1.41	1.77	2.22	2.78	3.47	4.33	5.39	6.69	8.28	10.2	12.5	15.3
27.5	0.214	0.270	0.339	0.427	0.536	0.674	0.848	1.06	1.34	1.68	2.10	2.63	3.29	4.11	5.12	6.36	7.87	9.72	11.9	14.6	17.7
30	0.255	0.320	0.403	0.507	0.637	0.801	1.01	1.26	1.58	1.99	2.49	3.11	3.89	4.85	6.02	7.47	9.22	11.3	13.9	16.9	20.3

Illustration on how to calculate concentration of total ammonia-N (as µg/L):

For a solution with un-ionised NH_3 of 68.7 µg/L at pH 7 and temperature 25°C, the concentration of total ammonia-N is:

Total ammonia-N (µg/L) = un-ionised ammonia as µg NH_3/L X (14/17) / (% un-ionised ammonia/100)

68.7 µg/L as NH_3 X (14/17) / (0.566/100) = 10 000 µg/L total ammonia-N.

Appendix 2

Collection and chemical analysis of sediments

Measurement of sediment-associated contaminants, especially organic contaminants, is relatively expensive and so a strategic approach must be taken to site investigations. Consideration should be given to the historic and current activities that may have influenced sediment composition. For example if pastoral agriculture was the only historic upstream land use and there is no known geothermal influence on the site then sediment analyses might include As, Cd, Cu, Zn and persistent pesticides associated with the particular stock or crops farmed upstream. If there is, or was, a pulp and paper mill upstream then the list of contaminants should include chlorinated organics including dioxins and pentachlorophenol. Stormwater inputs would indicate the inclusion of particular metals (i.e., Cu, Ni, Pb and Zn) and organics, in particular polycyclic aromatic hydrocarbons (PAH's) which are the breakdown products of the combustion of fossil fuels. If there is, or has been, local geothermal activity then sediment analyses should include As, B, F and Hg.

A "first tier" investigation of a site for a suite of likely metals will indicate which further analyses can be undertaken to target specific issues. If for example, it is thought that significant concentrations of mercury are likely to be present – analyses for methyl-mercury can be undertaken. Methyl-mercury is the most bioavailable and neurotoxic form of mercury in aquatic environments. Hg tends to biomagnify in top predators (i.e., concentrate in consumers at the top of the food web) such as humans consuming freshwater fish.

It is relatively straight-forward to collect sediment samples, but the key is that the sampling is part of a well-thought out sampling design that has clear monitoring objectives. Good design guidance is available in the ANZECC (2000) guidelines and in Simpson et al. (2005). For example, sediments should be collected from representative areas. Generally, when the health of the aquatic community is being investigated, it is most relevant to only collect the top 10 centimetres of aquatic sediments. Sometimes it is useful to separate the top 1 to 2 cm of the oxic layers from deeper sediments. Samples should be collected (i) using uncontaminated equipment and containers, (ii) with minimal water content. Once collected, sediment samples should be kept chilled (or sometimes frozen) until they can be processed by the analytical laboratory. Depending on the objectives of the sampling it may be important to retain the "structure" (e.g., layering and anoxic state) of the sediments in order to avoid over- or under-estimating contaminant toxicity.

Pore waters (or interstitial waters)

Collection of pore waters can be done either by (i) collecting sediments with minimal overlying water and then extracting the pore water prior to processing the sediments for particle-associated contaminants, or (ii) using specialised devices that can be inserted into sediments to absorb contaminants from the pore water at the site. These devices are sometimes called "peepers" and usually consist of some kind of porous frame (or container) containing an organic substance that absorbs contaminants in a manner similar to aquatic organisms. They can be left at a site for varying durations (e.g., days to months) then collected, and analysed for their contaminant content. They are sometimes considered bio-mimics because if well-designed they will provide information on the contaminants that aquatic organisms are most likely to absorb.

Toxicity testing of sediments and pore waters

Another approach to evaluating sediments is to bring samples into the laboratory and expose the sediments to sensitive aquatic organisms (e.g., algae, small crustaceans, snails, or worms) in a standardised manner. For example sediment tests are usually conducted at a constant temperature and in aerated water with a known water chemistry (e.g., pH and hardness). A control sediment known to be non-toxic to aquatic biota (and sometimes a "positive control" containing a known contaminant) must be included in such toxicity tests. Sediment toxicity tests are usually conducted for periods of 10 to 28 days, depending on the objectives of the study. The advantage of such tests includes (i) that many sediments can be compared to one another to examine their relative toxicity, (ii) the combined effect of multiple contaminants can be evaluated, and (iii) sensitive organisms can be exposed to the sediments to evaluate effects on the most vulnerable species and life-stages present in an aquatic community. The disadvantages of sediment toxicity tests include (i) sampling sediments and preparing them for a toxicity test (e.g., by sieving out predatory organisms) inevitably disrupts their physical structure in a manner that means the laboratory test is less relevant to the natural environment, (ii) the effects of the sediments on a community of organisms cannot be replicated in a laboratory, (iii) it is often difficult to ensure that the test organism feeds on and interacts with the sediments in a manner that replicates the natural environment, and (iv) available test organisms are not always relevant to the environment of interest. Sometimes preparation of sediments for a toxicity test can artificially increase or decrease their toxicity to aquatic organisms.

At present the best approach to toxicity testing of sediments or pore waters is to follow standardised protocols that are relevant to the environment of interest[7]. The relative advantages and disadvantages of these protocols are usually well-understood and can be taken into account in the interpretation of the results. In some cases, additional sampling or analyses can be conducted to provide supporting information to address these issues.

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[7] There are also standardised protocols to collect "elutriates" from sediments by adding measured amounts of water and shaking or rolling the sediments for set time periods (e.g., 4 h). Elutriate extraction is a harsher method of extraction that will characterize the water quality created by significantly disturbing sediments. For this reason elutriate extraction is usually applied to evaluation of the effects of dredging.

Appendix 3

Contaminants in kai in South Canterbury and the Rotorua Lakes region

Two recent collaborative studies examined collection and consumption, followed by contaminant analysis of key food species (Stewart et al. 2011; Phillips et al. 2014). This information was then used in a risk analysis to attempt to understand the likely contaminant exposure from mahinga kai. The studies examined contaminant concentrations in mahinga kai species collected by tribe members in the Rotorua lakes region and in South Canterbury. The studies were conducted by the same team of researchers and were exploratory in nature. Surveys of mahinga kai collection patterns and consumption rates were conducted with 12 or 19 volunteers and the results guided collection of samples for contaminant analysis. Only a relatively small number of biota samples were taken and analysed because (i) locals wished to limit collection of some species (e.g., long fin eel), and (ii) because of the prohibitive costs of some analyses, particularly organic contaminants (e.g., dioxins). In South Canterbury, eels, flounder, rainbow trout, watercress and sediments were sampled. In the Te Arawa study eels, rainbow trout, smelt, whitebait, freshwater crayfish, pipi, marine mussels, and sediments were sampled. Contaminants were selected for analysis based on past and current use or presence in the region (e.g., mercury from geothermal inputs) and known human health risks. A suite of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn), selected organochlorines (OC's), and polychlorinated biphenyls (PCB's) were measured in both studies (only metals were measured in watercress).

Contaminant concentrations in the biota were examined against the relatively few contaminant limits recommended by Food Standards Australia New Zealand[8] for mercury, arsenic, cadmium and lead (Table A3-1) or organic contaminants (Table A3-2). Median mercury concentrations in trout and eels in the Rotorua region exceeded recommended concentrations, while only the most contaminated kōura exceeded Hg recommendations (Table A3-4). Arsenic guidelines were not exceeded in the limited number of shellfish or fish samples analysed. In South Canterbury, only the most contaminated trout or eels had mercury concentrations at or exceeding the FSANZ (2017) guidelines (0.5 mg/kg wet weight). Organic contaminants were detected in some of the biota samples (particularly eels), but there are few recommended food concentrations to simply compare them against. Instead a risk assessment had to be undertaken to understand the implications for human consumers.

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[8] http://www.foodstandards.govt.nz/publications/pages/dioxinsinfood/Default.aspx

Table A3-1: **Concentrations of metals or metalloids considered acceptable in different types of food according to FSANZ or the European Commission. As = arsenic, Cd = cadmium, Hg = mercury, Pb = lead. mg/kg = parts per million in wet weight**

Food type	As (inorganic)[A] (mg/kg)	Cd (mg/kg)	Hg (mg/kg)	Pb (mg/kg)	Source
Crustacea (e.g., kōura)	2	0.05	0.5 (mean) 1.0-1.5 (max)[B]	0.5	Cd, Pb-European Commission (2017); FSANZ (2017)
Fish	2	0.1 (eels), 0.05 other fish	0.5 (mean) 1.0-1.5 (max)[B]	0.5	Cd-European Commission (2017); others FSANZ (2017)
Molluscs (shellfish)	1	2	0.5 (mean) 1.0-1.5 (max)[B]	2	FSANZ (2017)
Seaweed (apply to watercress)	1	-	-	-	FSANZ (2017)
Vegetables (apply to watercress)	-	0.1	-	0.1	FSANZ (2017)

[A] Inorganic arsenic is usually about 10% of the total arsenic in freshwater fish and probably also in crustaceans and shellfish. A higher proportion is likely to be inorganic in plants; [B] See details in FSANZ (2017).

Table A3-2: **Concentrations of organic contaminants considered acceptable in different types of food according to FSANZ or the European Commission**

Food type	Sum of dioxins	Sum dioxins & dioxin-like PCBs (pg/g ww)	BaP (a PAH) ug/kg ww	Source
Crustacea (e.g., kōura)	-	-	2.0 (smoked)	European Commission (2017); FSANZ (2017)
Fish	3.5	6.5 (10 eels)	2.0 (smoked)	European Commission (2017); others FSANZ (2017)
Molluscs (shellfish)	-	-	5.0 (6.0 smoked)	FSANZ (2017)
Seaweed (apply to watercress)	-	-	-	FSANZ (2017)
Vegetables (apply to watercress)	-	-	-	FSANZ (2017)

Table A3-3: A simplified summary of the findings of the two studies on contaminants in kai indicating which contaminants either exceeded FSANZ guidelines for concentrations in food or exceeded acceptable cancer (C) or non-cancer (Non-C) risk under conservative scenarios (e.g., low consumption rate, median concentrations) or worst-case scenarios (e.g., large meal size, highest contaminant concentration). As =arsenic, C = cancer risk, Cd= cadmium, Hg = mercury, –M indicates median concentration, Non-C = non-cancer health risk, OCx = organochlorine metabolites, PCB = polychlorinated biphenyls; –W indicates highest concentrations (i.e., worst-case)

Region	**Kai**	**Hg, As, Cd, Pb concentration exceeding guidelines?**	**Low consumption/ conservative scenario**		**High consumption/ worst-case scenario**	
			C	Non-C	C	Non-C
Rotorua	Tuna	Hg-M	-	-	-	-
	Trout	Hg-M	-	Hg	-	-
	Smelt	-	-	-	-	-
	Whitebait	-	-	-	-	-
	Kōura	Hg-W	-	-	-	-
	Pipi	-	As	-	-	-
	Mussels (marine)	-	As	-	-	-
South Canterbury	Tuna	Hg-W	-	-	Dieldrin, As, PCB, OCx	Hg, PCB
	Rainbow trout	Hg-W	-	-	As	Hg
	Flounder	-	-	-	As	-
	Watercress	-	-	-	As	-

The two studies took a slightly different approach to the risk assessment–the salient points are summarised below. The risk assessments took into account factors such as meal size and the fact that multiple contaminants (e.g., mercury and arsenic) could be present in a single meal. The investigators examined both “worst-case scenarios” (e.g., only the most contaminated food consumed and in large meal sizes) and more conservative scenarios (e.g., median contaminant concentrations and relatively low local consumption rates of wild-collected food). The risk of cancer and non-cancer toxicity (e.g., neurological effects) was evaluated separately. Internationally accepted definitions of health risks were applied. For example, internationally a 1-in-a-million (i.e., 1:1,000,000 (or 10^{-6})) lifetime risk of cancer is considered acceptable, therefore a 1-in-100,000 (or 10^{-5}) lifetime risk of cancer is used as the threshold for exceedance (WHO 2009).

The local mahinga kai surveys found that for both the consumption of wild-caught species was only a small proportion of the total food of that type consumed (e.g., wild fish eaten was a small proportion of total fish consumed including store-bought). Similarly the consumption rates of wild-collected species was relatively low in comparison to national average total consumption rates of comparable species (i.e., including store-bought and wild-caught sources). These findings are, however, limited by the fact that less than twenty people participated in the surveys for each group.

Once local consumption rates for the Rotorua region were taken into account it became apparent that although arsenic concentrations were below FSANZ standards in pipi and mussel from an estuarine site, consumption rates of these species exceed that recommended for acceptable cancer risk (i.e., 3.5 meals per month are consumed of each species, whereas only 2.6 and 2.9 meals/month of pipi and mussels are recommended), while mercury contamination of trout exceeded limits for non-cancer health risks (i.e., 1.5 meals per month eaten locally in comparison to 0.4 meals per month recommended for non-cancer health risks). Some of the exceedance is caused by taking into account that there were multiple contaminants in these food sources.

In South Canterbury, a risk assessment using low consumption rates of locals and median contaminant concentrations found in the mahinga kai species eel, trout and flounder and watercress found that there was no significant lifetime cancer or non-cancer risk. But, once a “worst-case” scenario was applied using the highest measured concentrations (i.e., 95th percentiles) then exposure to the organochlorine dieldrin in eels became significant for cancer risk even for low local consumption rates. If “average” to “high energy” diet consumption rates were applied to the 95th-percentile concentrations then arsenic, PCB, and organochlorine metabolite exposure also presented a significant cancer risk. Arsenic presented a significant lifetime cancer risk once New Zealand average consumption rates were applied to median contaminant concentrations in South Canterbury biota.

When fish and watercress in South Canterbury were evaluated against non-cancer risk information, both mercury and PCB exposure was significant for eel at all consumption rates except the very low local consumption rates. Mercury contamination of trout also presented a non-cancer risk for high energy consumption rates or average-to-high consumption rates if the 95th-percentile contaminant concentrations were considered.

Watercress was analysed in the South Canterbury study as it is a known hyperaccumulator of arsenic. When consumed at the low rates reported by locals, arsenic presented no significant lifetime cancer risk even if the 95th percentile concentrations were considered.

In summary, these exploratory studies indicate that there is some cause for concern about exposure to contaminants from mahinga kai. Both studies indicate that reported consumption rates were relatively low and this reduces their contaminant exposure risk, but risks from exposure to Hg or As remain. On the other hand, less than 20 people were interviewed to establish consumption rates for each group so it is possible that the higher consumption scenarios should apply in which case risks increase, particularly from eating eels. Eels are long-lived predators and scavengers that tend to have a high fat content and these characteristics mean that they are likely to accumulate both heavy metals and organic contaminants.