BEFORE WAIKATO REGIONAL COUNCIL
HEARINGS PANEL

UNDER the Resource Management Act 1991 (**RMA**)

IN THE MATTER OF Proposed Plan Change 1 to the Waikato Regional Plan and Variation 1 to that Proposed Plan Change: Waikato and Waipa River Catchments

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Adam Douglas Canning

PRIMARY EVIDENCE ON BEHALF OF THE AUCKLAND/WAIKATO & EASTERN REGION FISH AND GAME COUNCILS ("FISH & GAME")

SUBMITTER ID: 74985

Hearing Block 1

Dated: 15 February 2019

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1. QUALIFICATIONS AND EXPERIENCE

1.1 My full name is Adam Douglas Canning.

1.2 I am employed as a Research Scientist & Technical Advisor at Fish & Game

1.3 I have a BSc (Hons) and a PhD (Ecology) from Massey University. I am a member of the New Zealand Ecological Society, the New Zealand Freshwater Sciences Society, the International Society for Ecological Modelling, the Australasian Society for Fish Biology, and the Society for Ecological Restoration. I have published papers on freshwater ecology in peer-reviewed journals. My research is focussed on understanding community and ecosystem thresholds to ensure ecosystem health (life supporting capacity) of freshwater systems in New Zealand. I am very familiar with literature relating to ecological community stability, environmental thresholds, modelling thresholds, and nutrient and environmental determinants of New Zealand freshwater ecosystem health. I am a member of the Government's Science and Technical Advisory Group that is informing the development of new national objectives for freshwater as part of its *Essential Freshwaters* package.

1.4 I have read the Environment Court's Code of Conduct for Expert Witnesses, and I agree to comply with it. I confirm that the issues addressed in this brief of evidence are within my area of expertise.

1.5 I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed. I have specified where my opinion is based on limited or partial information and identified any assumptions I have made in forming my opinions.

2 SUMMARY STATEMENT

2.1 To manage ecosystem health there is a need to manage the main factors driving ecosystem health. These primarily include nutrients, sediment, habitat and flow. Clear numeric objectives that <u>measure</u> ecosystem health in its entirety (i.e. structure (species diversity and composition), function (ecological processes) and resilience)) are also needed. These should reflect the precautionary principle, be naturally achievable and not result in poor ecosystem health.

2.2 The current attributes in Table 3.11-1 are not sufficient to determine whether ecosystem health will be achieved.

2.3 I recommend that the MCI be used as a numeric objective at all wadeble monitoring sites, with a bottom-line no more than 20% less than expected in reference condition, and no more stringent than expected in reference condition. I also recommend:

2.3.1 That nitrate-nitrogen and dissolved reactive phosphorus concentrations numerics be applied at all tributaries, with no site having greater concentrations than 0.89 mg/L and 0.038 mg/L respectively.

2.3.2 That no naturally hard-bottomed sites should have a deposited fine sediment cover greater than 20%.

2.3.3 That all sites have a numeric objective for the Waikato Q-IBI of no less than 27.

2.3.4 That the NPSFM bottom-line for dissolved oxygen (5.0 mg/L for 7-day minimum and 4.0 mg/L for a 1-day minimum) be applied to all sites, regardless of whether they are downstream of a point source discharge.

2.3.5 For water clarity, I support the evidence of Dr Daniel for Fish & Game, which includes recommendations on water clarity bottom lines for nationally significant streams, regionally significant streams and significant spawning streams, for management of the trout fishery (Dr Daniel's Table 1).

2.3.6 That all numerics at a single site are within the same band, such that the desired ecosystem health state is consistent across all attributes. The relevant bands are 'A' (Excellent), 'B' (Good) and C ('Fair').

2.4 I recommend a replacement for Table 3.11-1, containing a full range of attributes to measure and manage ecosystem health, for mainstem and tributary sites. This is set out in Table A4 of my evidence. Tables A1, A2 and A3 show the basis upon which Table A4 has been developed. In addition to representing attribute states necessary for the purposes of adequate reflection of Scenario 1, Table A4 contains attribute states for certain significant sites for the trout fishery (subcatchments) that reflect the habitat requirements of trout, drawing upon Dr Daniels' evidence.

3 ECOSYSTEM HEALTH

3.1 Waterways are akin to the lymphatic system and kidneys of the land, in that they drain and process chemicals and material leaving the land. Like lymphatic systems and kidneys, if excessively stressed the health of the entire system deteriorates.

3.2 If humans are unwell they will usually see a physician who will assess their 'health' with a range of physical, psychological and biochemical indicators. Likewise, good environmental management practices often require that the health of an ecosystem is measured and maintained using multiple indicators (Rapport *et al.*, 2009, Kundzewicz *et al.*, 2007, Steedman, 1994), as do the National Policy Statement on Freshwater Management (NPSFM), the Vision & Strategy for the Waikato River and the Healthy Rivers/Wai Ora committee.

3.3 The Waikato River Authority is custodian for a Vision where: [1]

> "*…a <u>healthy Waikato river</u> sustains abundant life and prosperous communities who, in turn, are all responsible for restoring and protecting the health and wellbeing of the Waikato river, and all it embraces, for generations to come*."
> (My emphasis)

3.4 The Healthy Rivers/Wai Ora Committee supported the Scenario 1 proposed by the Collaborative Stakeholder Group ("CSG"), which seeks:[2]

> *"Substantial improvement in water quality for swimming, taking food, and healthy biodiversity.This means: Swimmable in all seasons for microbes and clarity. Water quality supports <u>ecological health</u>. Some improvement in all parameters."*
> (My emphasis)

3.5 The components of Scenario 1, proposed by the CSG, and subsequently accepted by the HRWO Subcommittee were set out for *e coli*, clarity, algae and nutrients respectively, with reference to NPSFM bands.[3] I refer to this again below in my evidence. I agree with Ms Marr's evidence for Fish & Game, that PC 1 does not take a 'spatial approach' to defining values. In PC1, the values upon which freshwater objectives are based, are generally stated for all catchments, with no differentiation for example for trout spawning sites or other special values. This is reflected in PC1 Table 3.11-1.

What do we mean by 'ecosystem health' and what drives it?

3.6 The NPSFM Appendix 1 contains "*National values and uses for fresh water*". It contains two "Compulsory national values" being "*ecosystem health*" and "*human health for recreation*".

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[1] Waikato River Authority. (2008). *Restoring and protecting the health and wellbeing of the Waikato river.* Waikato River Authority: Hamilton, NZ.
[2] Doole, G., Elliott, S., & McDonald, G. (2015). *Evaluation of scenarios for water-quality improvement in the Waikato and Waipa River catchments.* Healthy Rivers/Wai Ora project: Hamilton, NZ (Document 3564910).
[3] Table 1, page 15 above-cited.

3.7 The NPS-FM defines ecosystem health is:

> "*Ecosystem health – The freshwater management unit supports a healthy ecosystem appropriate to that freshwater body type (river, lake, wetland, or aquifer).*
> *In a healthy freshwater ecosystem ecological processes are maintained, there is a range and diversity of indigenous flora and fauna, and there is resilience to change.*
> *Matters to take into account for a healthy freshwater ecosystem include the management of adverse effects on flora and fauna of contaminants, changes in freshwater chemistry, excessive nutrients, algal blooms, high sediment levels, high temperatures, low oxygen, invasive species, and changes in flow regime. Other matters to take into account include the essential habitat needs of flora and fauna and the connections between water bodies."*

3.8 Within rivers and streams there is algae, detritus, terrestrial plant and animal matter, aquatic invertebrates and fish:

3.8.1 Algae can be either free-floating (phytoplankton) or be attached to substrate (periphyton - coating of slightly furry green or brown algae on rocks). Along with detritus (both in-stream and terrestrial derived plant matter, e.g. leaves) they form the basis of the stream food web.

3.8.2 Some periphyton is required as food for many aquatic invertebrates; however, too much algal growth can dramatically change the ecology and habitat conditions of a river.

3.8.3 Aquatic invertebrates consume the periphyton and plant matter either directly (along with other organic sources) or by predating the smaller grazing invertebrates.

3.8.4 Native and sport fish eat these invertebrates and some terrestrial inputs.

3.9 In the Appendix 2 to my evidence I discuss some of these biological components in more detail (macroinvertebrates, sediment and nutrients). The ecological community composition is determined by a range of factors as summarised in Figure 1:

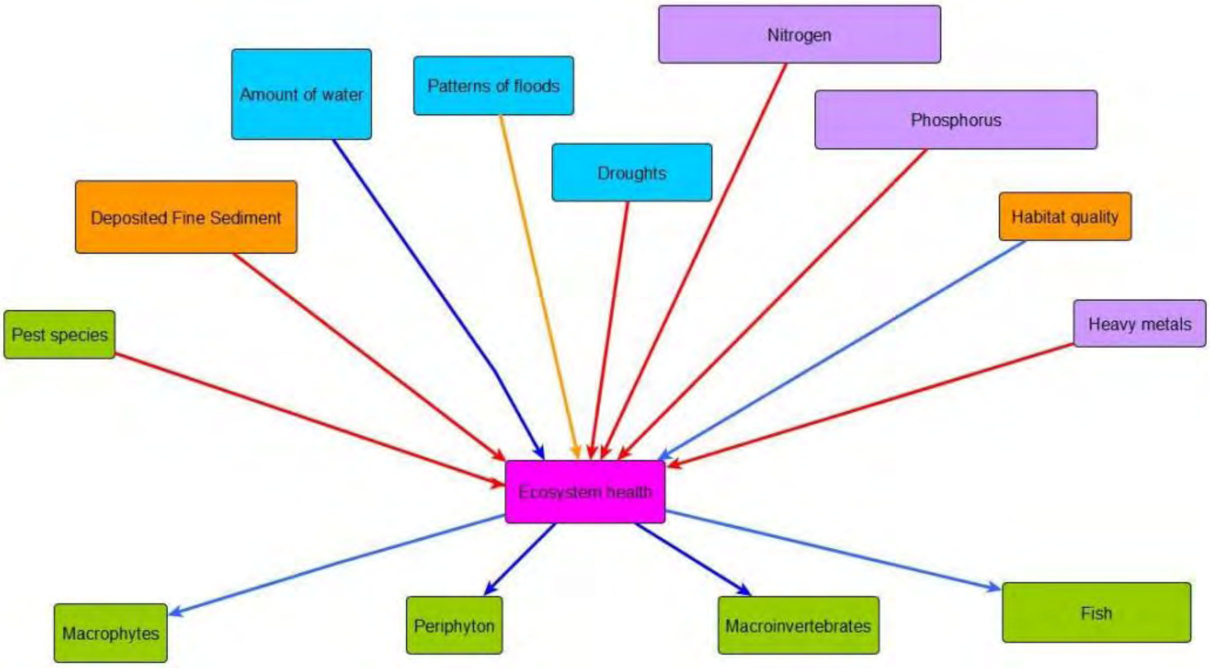


Figure 1. An overview of the main drivers of ecosystem health and the main biological compartments that can measure ecosystem health.

3.10 All of the biological components of a river food web require the correct habitat, water quantity and water quality in order to maintain healthy populations and functioning ecosystems. A change in a single constituent can have cascading impacts that alter the entire community composition.

What should the 'ecosystem health' objectives be?

3.11 Before the desired outcomes for the drivers of ecosystem health can be defined, we first need to know what level of ecosystem health we are aspiring for.

3.12 To manage ecosystem health, there is a need to manage the main factors driving ecosystem health. In my opinion there is also a need to <u>measure</u> health in its entirety (i.e., structure (species diversity and composition), function (ecological processes) and resilience).

3.13 PC1 is focussed on reducing nitrogen, phosphorus, sediment and *E coli* (related to human health). Whilst nutrients and sediment are important drivers of ecosystem health, and I strongly support their management, PC1 does not have any objectives that describe the ecological community itself (i.e., the fish, bugs and algae) leaving substantial ambiguity in what is meant by “sustains abundant life” and “healthy biodiversity”.

3.14 The NPSFM also describes the likely factors driving ecosystem health, all of which I deem necessary to manage.[4]

3.15 In agreement with the Technical Leaders Group (TLG), I support the application of the NPSFM criteria for lakes, for total nitrogen (TN), total phosphorus (TP) and chlorophyll *a*, being applied to the <u>mainstem</u> of the Waikato River. However, other attributes should be included for all tributaries.

3.16 In the next section of my evidence I recommend numeric objectives for the Waikato River <u>tributaries</u> that cover the range of ecosystem health components (discussed earlier) based on the following variables:

- Macroinvertebrate Community Index;
- Fish Index of Biotic Integrity;
- Dissolved Oxygen;
- Gross Primary Production; and
- Ecosystem Respiration.

3.17 As the NPSFM already has Chlorophyll *a* as a compulsory attribute, I do not cover addition of a periphyton attribute here. However, I strongly support the adoption of the NPSFM Chlorophyll *a* attribute at all naturally hard-bottomed streams.

3.18 I also suggest an attribute based on Estuarine Trophic Index for the estuary.

3.19 Although I have used the term “attributes”, as stated in Ms Marr’s evidence for Fish & Game, some numerics in Table 3.11-1 are also

[4] In the definition of Ecosystem Health, which includes: “…contaminants, changes in freshwater chemistry, excessive nutrients, algal blooms, high sediment levels, high temperatures, low oxygen, invasive species, and changes in flow regime … essential habitat needs of flora and fauna and the connections between water bodies.”

appropriate "limits", and may form "targets" in locations where they are currently not met (within the meaning of the NPSFM). Ms Marr has recommended differentiations in her evidence.

TLG Attribute Selection Criteria

3.20 The TLG assessed a range of potential attributes for inclusion in the plan against a modified version of the criteria used for the NPSFM objective development.[5] The criteria applied were:

1. *Does the attribute provide a measure of the value?*
2. *Measurement and band thresholds:*
    - *Are there established protocols for measurement of the attribute?*
    - *Do experts agree on the summary statistic and associated time period?*
    - *Do experts agree on thresholds for the numerical bands and associated band descriptors?*
3. *Management and limits:*
    - *Do we know what to do to manage this attribute?*
    - *Are the four contaminants (N, P, sediment & faecal microbes) direct drivers of this attribute?*
    - *Do quantitative relationships link the attribute state to limits and/or management interventions to control N, P, sediment and faecal microbes?*
4. *Evaluation of current state:*
    - *Is there data of sufficient quality, quantity and representativeness to assess the current state of the attribute within Waikato FMUs?*
5. *Implications:*
    - *Can the social, cultural, economic and environmental implications of setting limits be assessed?*
    - *Are we able to model scenarios for these attributes within the Healthy Rivers: Wai ora timeframe?*

[5] Pages 9-10 Scarsbrook (2016) Water Quality Attributes for Health Rivers: Wai Ora Plan Change.

3.21 Of all the attributes considered, many failed to meet the criteria, such that there were no measures of actual ecosystem health recommended at all.

3.22 I disagree with the appropriateness of the criteria used by the TLG. It is my view that any criteria used should:

3.22.1 adopt the precautionary principle; and

3.22.2 not seek outcomes that represent poor ecological health or conversley be unachievable even in pristine conditions.

3.23 Criteria 3 and 4 seek that certain matters are 'well understood', including links between management interventions and limits, and also the current state. More often than not we do not know that a desired outcome will be achieved by manipulating x, y and z. But we know it will drive improvement in the right direction.

3.24 Ms Marr's evidence addresses criterion 5. Of relevance, central Government is currently reforming the NPS as part of its *Essential Freshwaters* package. I am a member of the Science and Technical Advisory Group that is informing the development of new national objectives. The Group considered the previous NOF attribute criteria (which the TLG criteria was adapted slightly from); however, it was deemed that economic implications are inappropriate for the Group to be considering (except in directly implementing the policy e.g. cost to council monitoring teams). Remaining the criteria were taken as aspects to consider and comment on but not decision gates. There is also strong recognition of the need to consider the precautionary principle and links between attributes and other components of the ecosystem.

3.25 Ecological reality is that ecosystems are complex networks where indirect interactions are typically more dominant than direct interactions (Salas and Borrett, 2011). Given that we are seeking healthy ecosystems, to ignore *indirect* links is fraught with risk. The risks of excluding measures of ecosystem health are that there will be inadequate measures, resulting in a plan without strong direction of outcome. Tools may therefore be insufficient in safeguarding ecosystem health.

Macroinvertebrate Community Index

3.26 In New Zealand the MCI is a popular and simple index of macroinvertebrate community health (Stark, 1993). It was primarily designed to indicate how invertebrate communities change with organic enrichment, though has since been well established as an indicator of ecosystem health. Each species is assigned a value between 1 and 10 depending on their sensitivity/tolerance. Depending on the species present within a stream/river an overall score of sensitivity is derived. High scores indicate a community with many sensitive species, which only persist when environmental conditions are optimum; whereas low scores indicate a community with low sensitivity which occur when environmental conditions are poor. Figure 2 contrasts several macroinvertebrate species typically found in clean waters versus those in poor water quality.

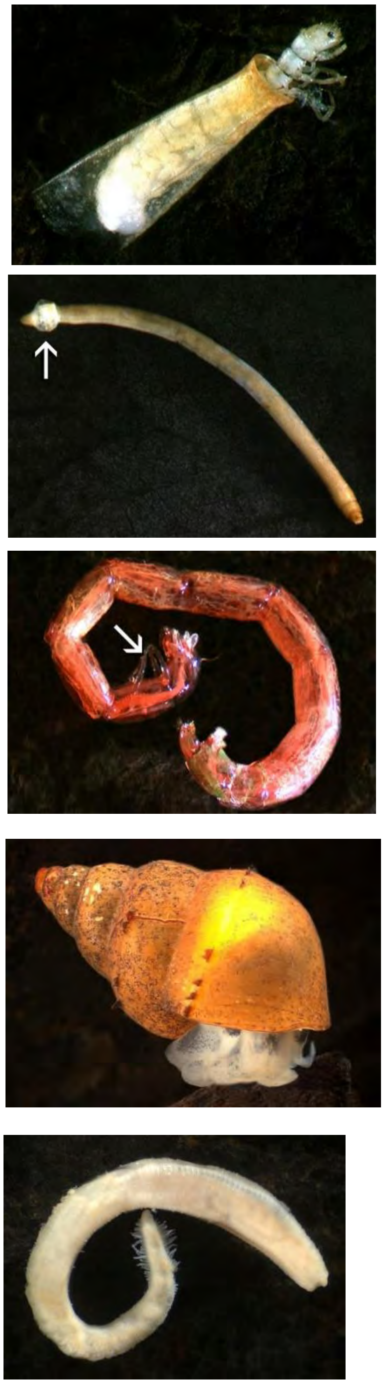
Good water quality	Poor water quality
	

Figure 2. Example bugs indicating good and bad water quality. Images sourced from: http://www.landcareresearch.co.nz/resources/identification/animals/freshwater-invertebrates/species-list

3.27 The TLG considered that there were too many drivers influencing the MCI and that understanding these drivers would be too complex for assessing implications[6]. Though, they did express support the MCI as an indicator of ecosystem health, stating[1]:

> *"Indices such as MCI provide good indicators of land use impacts…"*

and

> *"…the value of MCI as an integrating measure of overall Ecosystem Health should not be ignored and it is recommended that MCI (and other macroinvertebrate indices) should continue to be monitored by WRC"*

3.28 I disagree with TLG's recommendation to reject MCI as an attribute. I support MCI as an attribute (numerical objective), for the reasons set out above. Other regional councils (e.g., Manawatu-Whanganui, Greater Wellington and Canterbury) also manage water quality using MCI (or variant) numerics.

3.29 I disagree that the MCI is too complex to model and predict effectiveness of controls. There will always be uncertainty in modelling ecological communities, but it is still possible to derive useful models to guide effective management. For example, Death *et al.* (2015) has demonstrated how modelling can be useful and informative in understanding the complex interactions driving the Q-MCI (the quantitative variation of the MCI) throughout the lower North Island. Their Bayesian Belief Network (BBN) example (Figure 3) had a typically acceptable performance with an area under the receiver operating characteristic curve of 0.76 (a measure of how good the model is) and was published in an independently peer-reviewed international journal (*Freshwater Biology*). They were able to conclude that:

> *"The BBN suggested management of habitat quality, such as riparian planting, along with the current management focus on limiting nutrient leaching from agricultural land may be most*

[6] Scarsbrook, M. (2016) Water Quality Attributes for Health Rivers: Wai Ora Plan Change. Waikato Regional Council: Hamilton, NZ.

> *effective in improving ecological condition." - (Death et al., 2015)*

3.30 Therefore, modelling exercises can be undertaken to inform the potential effectiveness of management actions, even although modelling may not be perfect.

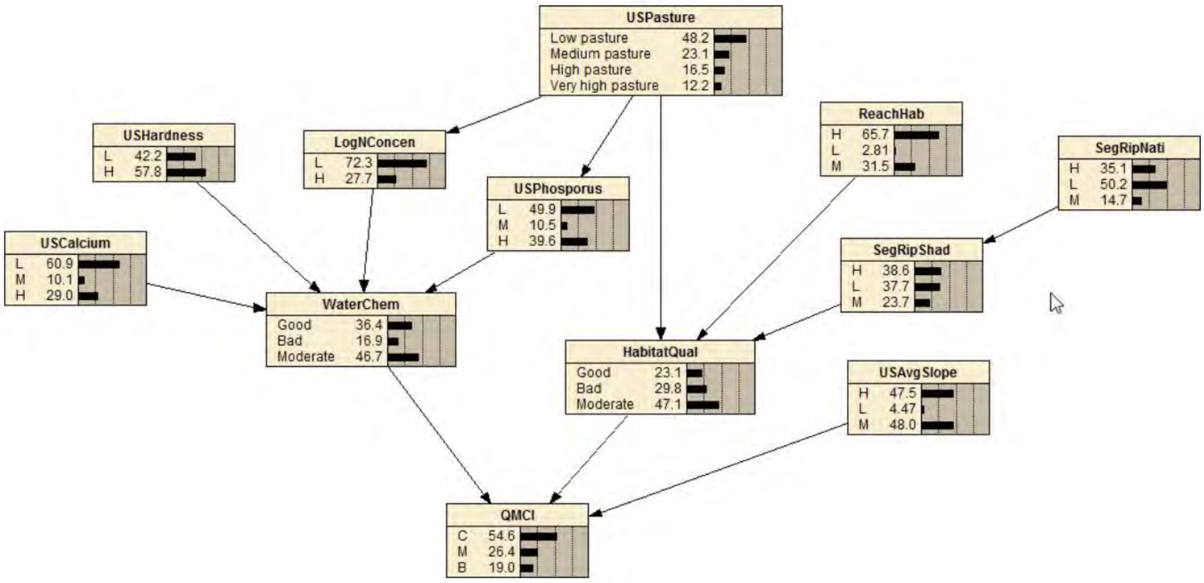


Figure 3. The BBN used by Death *et al.* (2015) to model QMCI in the lower North Island. Reproduced from:

Death, R. G., Death, F., Stubbington, R., Joy, M. K. & van den Belt, M. 2015. How good are Bayesian belief networks for environmental management? A test with data from an agricultural river catchment. *Freshwater Biology*, 60 (11), 2297-2309.

3.31 In setting MCI objectives, typically four quality classes are used to denote 'Excellent' (MCI >119), 'Good' (100–119), 'Fair' (80–99) or 'Poor' (<80) ecological condition (Stark and Maxted, 2007). I do not recommend using these interpretations universally throughout Waikato as many river reaches may never reach 'Excellent' or 'Good' grades even if they were in human-absent conditions. It is not that they are naturally 'Fair' or 'Poor', they are simply different. Therefore, the extent to which an ecosystem is degraded should be relative to the state it would be in human-absent or reference conditions (Clapcott *et al.*, 2017). Failure to recognize this could result in ecologically unachievable MCI objectives being set. Furthermore, to safeguard ecosystem health there should be, at a maximum, no more than 20% deviation in MCI from reference condition. Clapcott *et al.* (2017) modelled both current MCI for all rivers throughout New Zealand as well as the MCI likely to occur under reference conditions (i.e. 100% native forest cover etc – not pre-human conditions). Figure 4 shows the likely MCI predicted to occur in reference conditions (a), the predicted MCI in current conditions (b), and the minimum MCI scores required for Waikato rivers if a degradation is limited to no more than 20% reduction from reference state (c) (Clapcott *et al.*, 2017). Broadly, the upper Waikato tributaries typically require a minimum MCI of 100, the middle tributaries a minimum MCI of 90 and lower tributaries a minimum MCI of 80.

3.32 Recommendation: That the MCI be used as a numeric objective at all wadeble monitoring sites, with a bottom-line no more than 20% less than expected in reference condition, and no more stringent than expected in reference condition.

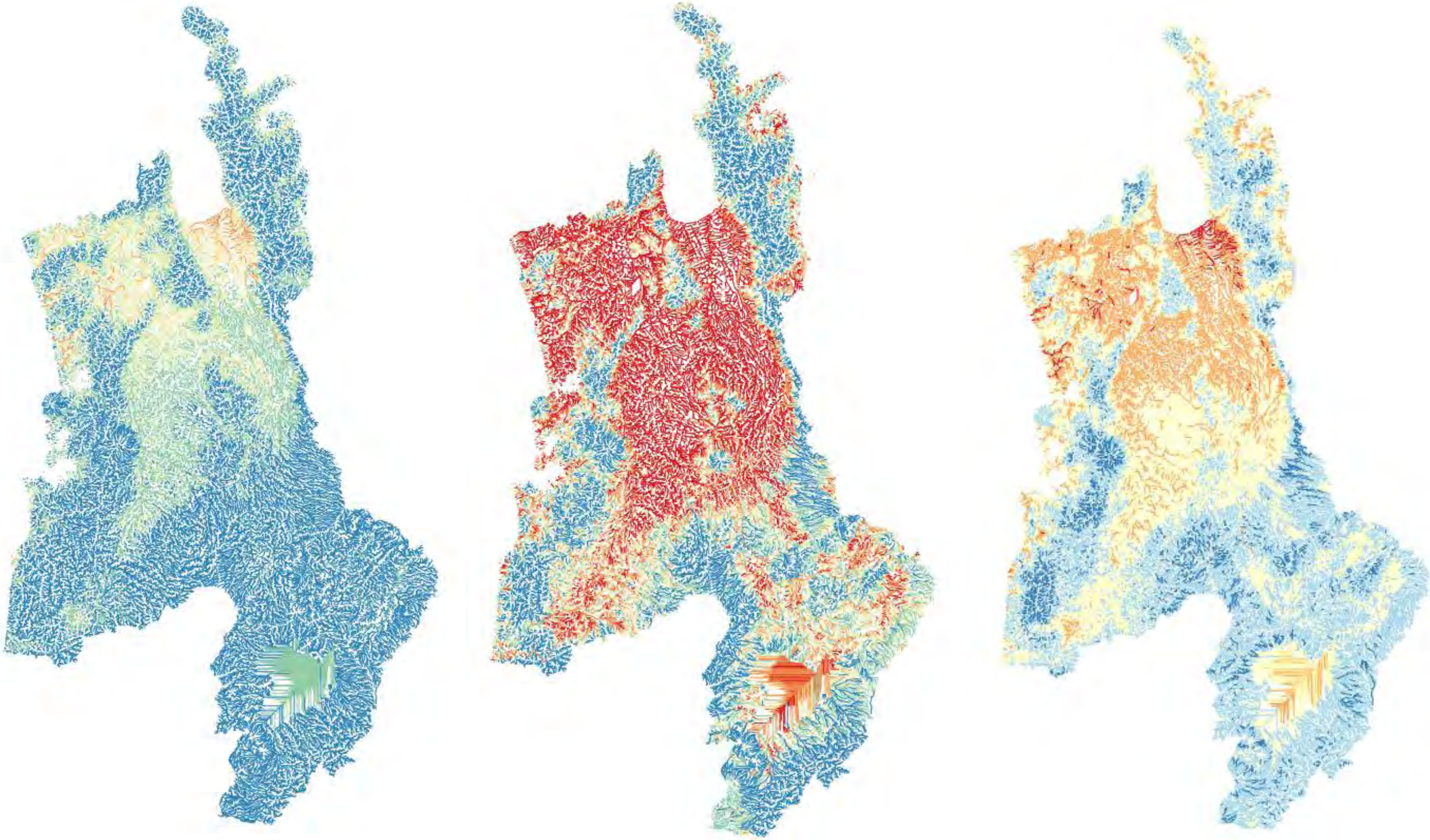


Figure 4. The likely MCI predicted to occur in reference conditions (a), the predicted MCI in current conditions (b), and the minimum MCI scores required for Waikato rivers if a degradation is limited to no more than 20% reduction from reference state (c). Data sourced from Clapcott *et al.* (2017). Dark blue >110, light blue 100-110, yellow 90-100, orange 80-90 and red <80.

Nutrients

3.33 In the absence of specific river-reach data, it is possible to use *modelled* data to set desired nutrient concentrations. In this section of my evidence I recommend annual median Nitrate-nitrogen (N) and Dissolved reactive phosphorus (DRP) levels to assist in meeting the desired ecosystem health states based on modelling.

3.34 In recommending suitable nutrient concentrations, I present nutrient bands for N and DRP as related to ecosystem health levels based on the attached paper *"Clean but not green: a weight-of-evidence approach for setting nutrient criteria in New Zealand rivers"* Death *et al.* (Submitted), Appendix 3. This research produced a four-band grading system consistent with the A, B, C and D approach from the NPSFM. The authors state however:

> *"Perhaps the only concern we have in using this approach is that the established bottom line for MCI/QMCI of 80/4 appears to be very low. Once ecological health reached that point the long flat tail of the relationship (e.g. Fig. 2) along the right of the nutrient axis meant there could be large increases in nutrient levels with only a very small decline in health. In other words, once the ecological health is at the bottom line, condition is relatively unaffected no matter how many more nutrients are added. This suggests the bottom line for the MCI/QMCI may be better at a slightly higher level (e.g., 90 or 4.5 for the MCI and QMCI, respectively)."*

3.35 I present here a slightly adapted version that has a fifth band splitting the C-band in this Paper, along with narrative grades for easier interpretation (Table1).

Table 1. Proposed nutrient criteria for Waikato River tributaries		
Value	Ecosystem health	
Freshwater Body Type	Rivers	
Attributes	Nitrate-nitrogen and dissolved reactive phosphorus. Annual median (mg/L)	
Attribute State	**Numeric Attribute State**	
	Dissolved reactive phosphorus	**Nitrate-nitrogen**
Excellent (A)	≤ 0.006	≤ 0.10
Good (B)	> 0.006 and ≤ 0.019	> 0.10 and ≤0.46
Fair (C)	> 0.019 and ≤ 0.038	> 0.46 and ≤ 0.74
Regional Bottom Line	**0.038**	**0.74**
Poor (D)	> 0.038 and ≤ 0.057	> 0.74 and ≤ 1.32
Very poor (E)	>0.057	>1.32

3.36 To explain further, in Death *et al.* (Submitted), we compiled several datasets and bodies of evidence on links between nutrients and invertebrates, links between fish and nutrients and links between periphyton and nutrients as well as the statistical distribution of nutrient levels in New Zealand waterways. This included findings from New Zealand National Network Monitoring data (Unwin and Larned, 2013), published reports and papers (e.g., (Biggs, 2000, Matheson *et al.*, 2016, Joy, 2009b), Professor Russell Death's data from 964 streams (Death *et al.*, 2015) and the ANZECC guidelines (Davies-Colley, 2000).

3.37 The multiple lines of evidence were combined in a weight-of-evidence approach.[7] The weight of evidence approach involves transparent application of individual weights to individual results/lines of evidence. Weighted averaging was based on whether linkages between nutrients and a given ecosystem health metric were direct or indirect. Direct linkages were allocated twice the weight of purely statistical or less direct linkages. Only numbers from significant relationships were included in the final assessment.

3.38 Given that many catchments have long lag times for nitrogen (time between nitrogen leaching soil to reaching the river), in these catchments the final targets for nitrogen loads leaving the root-zone will need to be achieved much sooner than the 80 years instream objectives need to be met. For example, suppose a catchment has a 60 year lag time, yet the desired quantum of nitrogen leaching from soil within the catchment is not achieved for 50 years, then it will take approximately 110 years for the instream targets/objectives to be met. Likewise, many catchments have short lag times for nitrogen, in these places targets will be achieved much sooner after management changes are put in place to reduce nitrogen leaching an 80-year target would not be needed if root-zone leaching targets are achieved well before the 80-years. Semadeni-Davies et al. (2015) report for 121 sites on nutrient loads to come, lag times and attenuation capacity.For clarity, in Tables A2 and A3 I have quoted from Semadeni-Davies et al. (2015) the lag time description given by the expert panel caucused by NIWA.

[7] Smith and Tran (2010) *"A weight-of-evidence approach to define nutrient criteria protective of aquatic life in large rivers".*

3.39 The above numerics for Nitrogen and Phosphorus are expressed as mg/L, which is a measure of the *concentration* of the contaminant. I note, for completeness, that desired loads of DRP and Nitrate-Nitrogen (N-N) can be calculated from the desired concentrations, and flows. A load represents the total mass of a contaminant which passes a point over a defined period. Mathematically it is the integral of flux over time (Equation 1):

$$Load = \int flux(t)dt \quad (1)$$

3.40 Numerous methodologies exist to calculate loads where concentration data is collected discretely. While no methodology is perfect, previously I have estimated nutrient loads using the average of three methodologies (the numeric integration method, the regression method, and the stratified ratio method).[8]

3.41 Recommendations:

3.41.1 That nitrate-nitrogen and dissolved reactive phosphorus concentrations numerics be applied at all tributaries, with no site having greater concentrations than the suggested regional bottom-lines (Table A1).

3.41.2 That all numerics at a single site are within the same band of Table A1 (so for example, if MCI is set at B Band all other numerics would also be set at B Band).

Deposited Sediment

3.42 In recommending sediment attributes, I support Fish & Game's request for a deposited sediment attribute. As explained in Appendix 2, deposited fine sediment in areas naturally low in fine sediment can have profound impacts on ecosystem health. For naturally hard-bottomed streams, following the Clapcott *et al.* (2011a) recommended guidelines for the

[8] Evidence to the Panel hearing submissions on the Greater Wellington Proposed Natural Resources Plan (Hearing Stream 1).

protection of biodiversity and amenity values, deposited fine sediment should not exceed 20% cover.

3.43 The TLG rejected adding deposited sediment on the basis that there was insufficient monitoring data and that the attribute was in development stage. This is despite the acknowledgement that: [9]

> *"…the deposition of fine sediment can have significant adverse effects on ecosystem health and other values (e.g., trout fishery)."*

3.44 Ms Marr's evidence discusses issues regarding setting a freshwater objective where there is poor information on the current state, and the ability to adjust levels upwards if it is found that existing water quality is higher than the level imposed. I note that deposited fine sediment cover is very easy and inexpensive to measure at each site – it has long been routine by many regional councils. The rejection based on development stage is also inappropriate. The Clapcott *et al.* (2011a) guidelines have been around for some time. All environmental guidelines are consistently being developed and they represent the best information we currently have. I also do not believe that the criteria recommended for hard-bottomed streams would change considerably even with further development.

3.45 <u>Recommendation: That no naturally hard-bottomed sites should have a deposited fine sediment cover greater than 20%.</u>

Fish Index of Biotic Integrity

3.46 Whilst the NPSFM has a national bottom-lines on periphyton and a direction based on macroinvertebrates, it does not have any attributes covering the health of fish – a large and integral component of the ecological community. The New Zealand Freshwater Fish Index of Biotic Integrity (IBI) provides a suitable measure of fish community health (Joy and Death, 2004). The Fish IBI scores a site based of the number and type of fish actually present at a site relative to what should be there under

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[9] Scarsbrook, M. (2016) Water Quality Attributes for Health Rivers: Wai Ora Plan Change. Waikato Regional Council: Hamilton, NZ.

ideal conditions. The IBI provides a value between 0 and 60, with 0 indicating no fish community at all (when there should be one) and 60 represents an extremely healthy fish community with all species expected being present. Fish-IBIs, and similar indices based on predictive models, are common place in most developed countries around the world.

3.47 An attribute for fish, separate from macroinvertebrates and periphyton, is needed because fish respond to different pressures. For example, fish require greater interstitial spaces than invertebrates, have different sensitivity thresholds than macroinvertebrates, and are heavily impacted by migration barriers (Jowett and Davey, 2007, Joy and Death, 2004, Canning, 2018a, Leathwick *et al.*, 2005). In the past few decades, Fish IBI scores nationally have declined substantially, primarily driven by land use change and migration barriers, with 74% of native fish listed as threatened. If these trends continue then it is expected that by 2050 or potentially before then all native fish in New Zealand will be extinct (Joy, 2014, Joy, 2009a). Of relevance to PC1, Canning (2018b) showed that nutrients and sediment collectively explained over half the difference between the fish communities predicted to currently occur versus those expected in reference conditions (the remainder largely explained by dams and riparian cover).

3.48 Joy and Henderson (2007) further developed a Waikato-specific Fish IBI using Quantile Regression. They recommend five bands of IBI scores, I support using these bands and suggest a regional bottom-line of 27 as this represents the boundary between ‘Moderate’ and ‘Poor’ integrity. These same bands are reflected in Table A1.

3.49 Recommendation: That all sites have a numeric objective for the Waikato Q-IBI of no less than 27.

Figure 5. The QIBI for 2269 sites throughout the Waikato region. Image reproduced from:

Joy, M. & Henderson, I. 2007. *A New Fish Index of Biotic Integrity using Quantile Regressions: the Fish QIBI for the Waikato Region*. Hamilton, New Zealand: Environment Waikato.

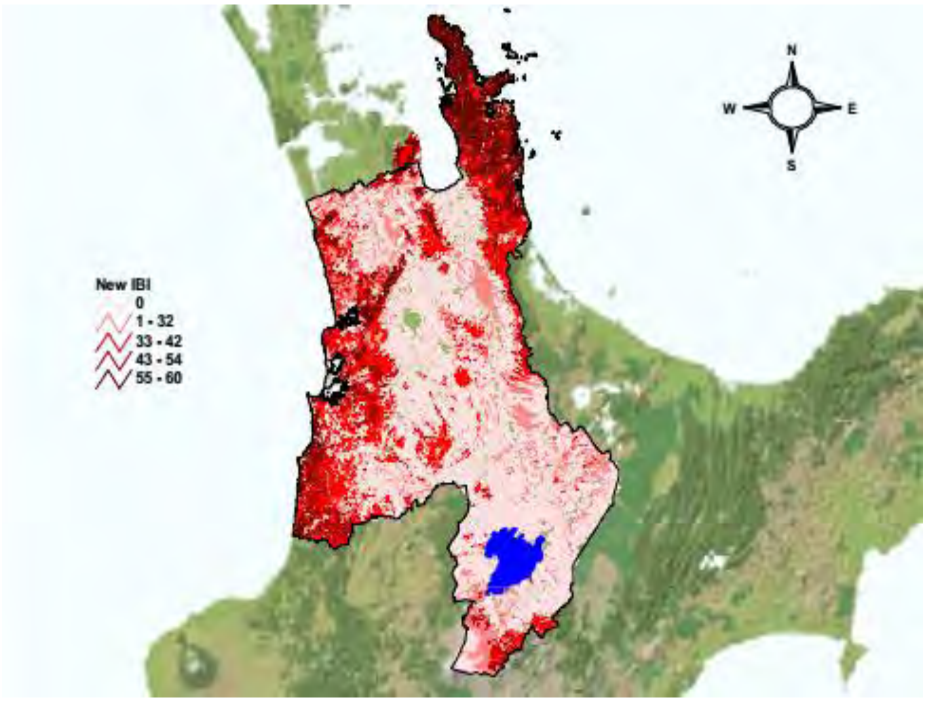


Figure 6. The predicted QIBI across the Waikato region. Image reproduced from:

Joy, M. & Henderson, I. 2007. *A New Fish Index of Biotic Integrity using Quantile Regressions: the Fish QIBI for the Waikato Region*. Hamilton, New Zealand: Environment Waikato.

Dissolved Oxygen

3.50 Almost all life requires Oxygen to survive. As discussed in Appendix 2, diurnal fluctuations in dissolved oxygen (DO) mean that at night concentrations can drop to stressful or even deadly levels. At present the NPSFM only applies DO bottom-lines below point source discharges as this is where continuous DO monitoring mostly occurred at the time of attribute development.

3.51 Despite being fundamental for life, the TLG rejected DO as an attribute to apply across waterways because of the monitoring costs and the indirect link to the four contaminants being managed by PC1. Firstly, there is a wealth of international and local knowledge supporting the NPSFM bottom-lines. This has been reviewed by Franklin (2013). Secondly, it should not have been the concern of the TLG whether monitoring costs are too much – this is a political decision and the TLG should have simply advised decision makers of the costs. The cost of continuous DO meters have also been dropping considerably with increasing durability. Thirdly, as explained with the MCI, indirect links are a defining feature of ecosystems, failing to recognise this risks failing to manage ecosystems adequately.

3.52 Recommendation: That the NPS-FM bottom-line for dissolved oxygen be applied to all sites, regardless of whether they are downstream of a point source discharge.

Estuarine Trophic Index

3.53 The current NPS does not have any compulsory attributes for estuaries, despite often being sensitive downstream environments that are heavily influenced by incoming river loads. Up until recently there was no suitable metric for assessing the trophic condition of estuaries. In 2015, regional council coastal scientists used Envirolink funding to develop a nationally consistent assessment of estuary eutrophication, called the NZ Estuary Trophic Index (ETI). The ETI is a composite multi-metric indicator that accounts for the most relevant indicators depending on estuary type. Indicators used for the ETI score primarily include measures of algae and macrophyte composition and abundance, and in some instances sediment redox potential and composition, nutrients and macroinvertebrates. Following the bands in ETI, as a minimum I recommend a regional bottomline of 0.75, or maintained if above. A suggested ETI attribute table is in Table 2. Furthermore, the NPS requires that nutrient loads in rivers are set to ensure the desired state of the most sensitive downstream environment is achieved. The ETI tools provide guidance on setting suitable nutrient loads to achieve the ETI outcomes.

Table 2. Proposed attribute table for Waikato estuaries

Value	Ecosystem health	
Freshwater Body Type	Estuaries	
Attribute	NZ Estuary Trophic Index (ETI)[1]	
Attribute Unit	NZ Estuary Trophic Index (between 0-1)	
Attribute State	**Numeric Attribute State**	**Narrative Attribute State**
	ETI	**Description**
Excellent (A)	≤0.25	Ecological communities (e.g., birds, fish, seagrass, and macroinvertebrates) are healthy and resilient. Algal cover and biomass is very low. Algal blooms are opportunistic, small and infrequent. Sediment quality is high.
Good (B)	>0.25 and ≤0.5	Ecological communities (e.g., birds, fish, seagrass, and macroinvertebrates) are slightly impacted by algae. There is limited algal cover and low biomass; blooms are opportunistic. Sediment quality is transitional.
Fair (C)	>0.5 and ≤0.75	Ecological communities (e.g., birds, fish, seagrass, and macroinvertebrates) are moderately impacted by algae. There is persistent and moderate algal cover and/or biomass; blooms are semi-frequent. Sediment quality is moderately degraded.
Regional Bottom Line	0.75	
Poor (D)	>0.75 and ≤1.0	Ecological communities (e.g., birds, fish, seagrass, and macroinvertebrates) are moderately to strongly impacted by algae. There is persistent and high algal cover and/or biomass; blooms are frequent. Sediment quality is degraded.

4 CURRENT VERSUS DESIRED STATE

4.1 In Table A1 I have shown numerics for the six[10] ecosystem health attributes discussed in my evidence. This shows the attribute states that would achieve Excellent (A), Good (B), Fair (C), Poor (D) and Very poor (E) (the ‘bands’). Table A1 also shows the Regional Bottom Line, as has been recommended in the above sections of my evidence.

[10] DRP, N-N, % MCI reduction, Fish Q-IBI, Dissolved Oxygen and Deposited fine sediment.

4.2 Tables A2 and A3 show the following, for the Waikato River Tributares and the Waikato mainstem sites respectively:

4.2.1 the annual median *concentrations* for TN and TP (mg/L), along with the percentage reductions in concentrations required to achieve the A, B or C bands; and

4.2.2 the corresponding desired instream nutrient *load* (T/y) required to achieve the A, B or C bands. (As I have explained, a load represents the total mass of a contaminant which passes a point over a defined period);

4.2.3 Lag times (reflecting attenuation capacity) times taken from Semadeni-Davies *et al.* (2015) report for 121 sites.

4.3 For the Waikato River Tributaries, Table A2 also shows the MCI scores required to meet the desired band (this is not relevant for the Waikato main stem sites, which are based on the NPSFM attributes for lakes).

4.4 The Auckland/Waikato and Eastern Fish & Game Regions then provided me with their desired levels of ecosystem health (as an A, B or C band) for each of the Waikato River Tributary (subcatchment) sites based on values. This was based on desired states for ecosystem health consistent with Scenario 1 (requiring water quality which supports ecological health). The Scenario 1 descriptions are generally at least a B band or higher.[11] Auckland/Waikato and Eastern Fish & Game Regions also provided me with higher values required for rivers and streams significant for the trout fishery. These are listed in Table 1 of the evidence of Dr. Daniel and are streams of regional or national significance and spawning streams.[12] I translated those into numerics and present these in Table A4. The desired clarity has been sourced from Dr Daniels' evidence.

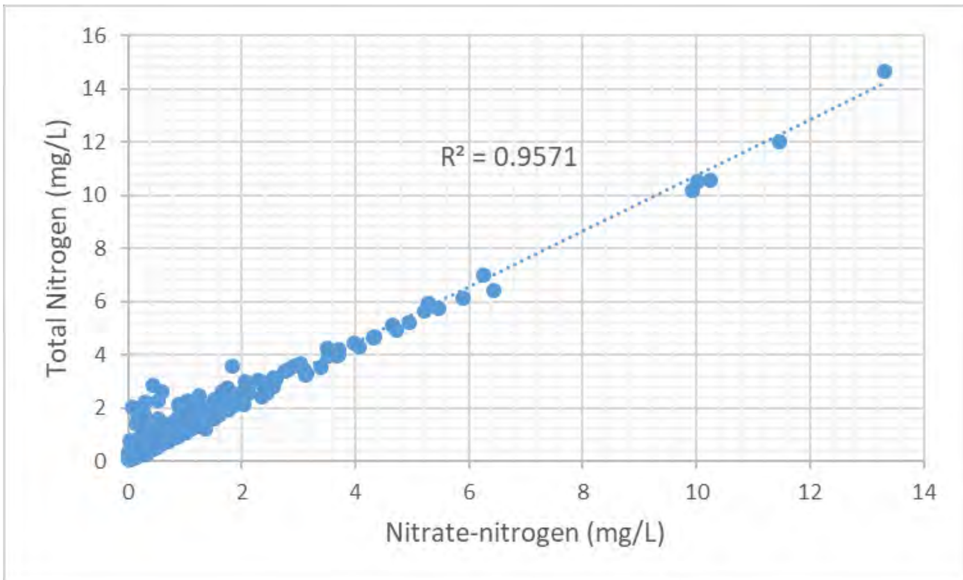
[11] A bottom line for ammonia is not specified. Clarity includes some C bands in the lower Waikato and lower Waipā This attribute links to a Waikato Objective Framework for clarity which is for the value 'swimmability' rather than ecosystem health (Scarsbrook, M (2016) Water quality attributes for Healthy Rivers: Wai ora Plan Change, at Table 2)

[12] I understand that higher values have been sought to reflect the restoration and national significance of the Whangamarino Wetland.

4.5 The existing in-stream nutrient loads were sourced from Semadeni-Davies et al. (2015), and are calculated as Total Nitrogen (TN) and Total Phosphorus (TP), thus represent both organic and inorganic forms of each nutrient. I calculated the percentage reductions that would be required to desired states (Tables A2 A3. As stated, my desired concentrations use Nitrate-Nitrogen (N-N) and dissolved reactive phosphorus (DRP). These are different measures of nitrogen and phosphorus. However across New Zealand NO3-N is highly correlated with TN (r2=0.96, Figure 7(a)) and DRP is well correlated with TP (r2=0.85, Figure 7(b)). Therefore I consider this is a reasonable approach. I have applied the same percentage reduction to the *loads* as to the *concentrations*. That is, if a site requires a 30% reduction in NO3-N *concentration* then a 30% reduction in TN *load* is also suggested. Loads assume the flow regimes remain the same.

4.6 In summary, based on my evidence and that of Dr Daniel, Table A4 represents attributes for Table in 3.11 of PC 1 for the purposes of adequate reflection of Scenario 1 (necessary to achieve the Vision & Strategy), together with values for sites of significance for the trout fishery, at specific subcatchment sites.

A)



B)

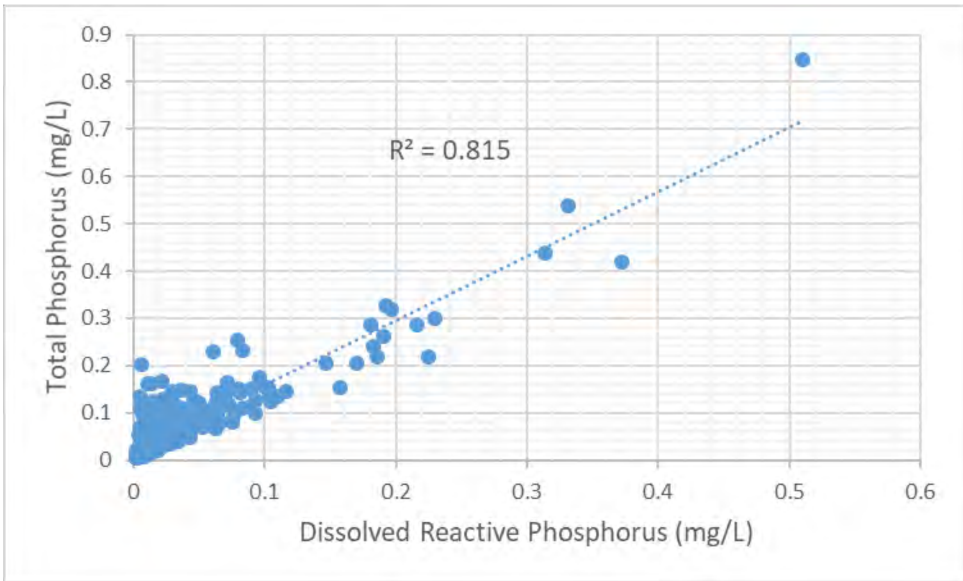


Figure 7. Correlations of average annual Total Nitrogen versus Nitrate-nitrogen (a), and Total Phosphorus versus Dissolved Reactive Phosphorus (b) for 833 monitoring sites throughout New Zealand between 2006-2015.

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APPENDIX 1

Table A1. Proposed ecosystem health attributes for the Waikato region

Value	Ecosystem health						
Freshwater Body Type	Rivers						
Attributes	Nitrate-nitrogen, dissolved reactive phosphorus, % reduction of MCI from reference condition, and fish Q-IBI						
Attribute State	**Numeric Attribute State**						
	Dissolved reactive phosphorus (DRP) - Annual median	**Nitrate-nitrogen (NO_3-N) – Annual median**	**% MCI reduction**	**Waikato Fish Q-IBI**	**Dissolved Oxygen (mg/L)**		**Deposited fine sediment (% cover)**
					7-day mean minimum	1-day minimum	
Excellent (A)	≤ 0.006	≤ 0.10	≤ 5%	47-60	≥8.0	≥7.5	≤20%
Good (B)	> 0.006 and ≤ 0.019	> 0.10 and ≤0.46	> 5% & ≤ 15%	36-46	≥7.0 and <8.0	≥5.0 and <7.5	
Fair (C)	> 0.019 and ≤ 0.038	> 0.46 and ≤ 0.89	>15% & ≤20%	27-35	≥5.0 and <7.0	≥4.0 and <5.0	≤20%
Regional Bottom Line	**0.038**	**0.89**	**20%**	**27**	**5.0**	**4.0**	**20%**
Poor (D)	> 0.038 and ≤ 0.057	> 0.89 and ≤ 1.32	>20% & ≤25%	6-26	<5.0	<4.0	>20%
Very poor (E)	>0.057	>1.32	>25%	0-6	N/A	N/A	N/A

1. Applies only to wadable streams and is calculated as the five-year rolling average annual MCI divided by the predicted reference MCI from: Clapcott, J. E., Goodwin, E. O., Snelder, T. H., Collier, K. J., Neale, M. W., & Greenfield, S. (2017). Finding reference: a comparison of modelling approaches for predicting macroinvertebrate community index benchmarks. New Zealand Journal of Marine and Freshwater Research, 51(1), 44-59.

Table A2. The annual median concentrations for nitrate-nitrogen and DRP (mg/L) at Waikato River Tributaries, along with the percent reductions in concentrations needed to achieve either an A, B or C band, and the corresponding desired instream nutrient load (T/y) to achieve the desired nutrient concentration band. Also provided are the MCI grades required to meet either an A, B or C band for each tributary site, and estimated lag time from Semadeni-Davies *et al.* (2015).

River site		Current median concentrations (mg/L)		Current annual in-stream loads (T)		NO3-N reduction required to meet desired band (%)			TN annual in-stream load required to meet desired band (T)			DRP reduction required to meet desired band (%)			TP annual in-stream load required to meet desired band (T)			MCI scores to meet desired band		
Upper Waikato	Lag time?	NO3-N	DRP	TN	TP	A-band	B-band	C-band	A-band	B-band	C-band	A-band	B-band	C-band	A-band	B-band	C-band	A-band	B-band	C-band
Pueto Stm Broadlands Rd Br	?	0.45	0.072	96	11.7	78	0	0	21	N/A	N/A	92	74	47	1.0	3.1	6.2	125	110	105
Torepatutahi Stm Vaile Rd Br	?	0.48	0.084	79	12.1	79	3	0	17	77	N/A	93	77	55	0.9	2.7	5.5	115	105	95
Waiotapu Stm Homestead Rd Br	Short	1.33	0.034	299	40.9	92	65	44	22	103	166	82	44	0	7.2	22.9	N/A	115	100	95
Mangakara Stm (Reporoa) SH5	Moderate	1.29	0.048	24	2.0	92	64	43	2	9	14	88	60	21	0.3	0.8	1.6	120	105	100
Kawaunui St SH5 Br	?	2.60	0.052	12	2.1	96	82	72	0	2	3	88	63	27	0.2	0.8	1.5	120	105	100
Waiotapu Stm Campbell Rd Br	Moderately long	0.93	0.004	102	5.7	89	51	20	11	51	81	0	0	0	N/A	N/A	N/A	110	100	90
Otamakokore Stm Hossack Rd	Likely long	0.74	0.152	49	9.7	86	38	0	7	30	N/A	96	87	75	0.4	1.2	2.4	115	105	95
Whirinaki Stm Corbett Rd	Long	0.78	0.061	12	0.9	87	41	5	1	7	11	90	69	38	0.1	0.3	0.6	120	105	100
Tahunaatara Stm Ohakuri Rd	Moderately long	0.57	0.034	169	15.6	82	19	0	30	137	N/A	82	44	0	2.8	8.7	N/A	115	105	95
Mangaharakeke Stm SH30 (Off Jct SH1)	Moderately long	0.51	0.032	30	2.2	80	10	0	6	27	N/A	81	41	0	0.4	1.3	N/A	115	100	95
Waipapa Stm (Mokai) Tirohanga Rd Br	?	1.21	0.089	60	7.8	92	62	39	5	23	37	93	79	57	0.5	1.7	3.3	120	110	100
Mangakino Stm Sandel Rd	?	0.66	0.038	212	12.2	85	30	0	32	147	N/A	84	50	0	1.9	6.1	N/A	125	115	105
Whakauru stm SH1 Br	Moderately long	0.37	0.025	5	1.4	73	0	0	1	N/A	N/A	76	22	0	0.3	1.1	N/A	115	100	95
Mangamingi Stm Paraonui Rd Br		2.60	0.265	274	27.8	96	82	72	11	49	78	98	93	86	0.6	2.0	4.0	115	100	95
Pokaiwhenua St Arapuni – Putaruru Rd	Moderately long	1.77	0.092	379	19.1	94	74	58	21	99	159	93	79	59	1.2	3.9	7.9	115	100	95
Little Waipa Stm Arapuni Putaruru Rd	Long lags	1.62	0.056	154	5.3	94	72	54	9	44	70	89	66	32	0.6	1.8	3.6	115	105	100
Mid-Waikato																				
Karapiro Stm Hickey Rd Bridge	Moderate	0.52	0.049	ND	ND	81	12	0	ND	ND	ND	88	61	22	ND	ND	ND	100	90	85
Mangawhero Stm Cambridge-Ohaupo Rd	Moderately short	1.99	0.0365	45	8.7	95	77	63	2	10	17	84	48	0	1.4	4.5	N/A	105	95	90
Mangaonua Stm Hoeka Rd	Moderately short	1.46	0.0125	78	3.8	93	68	49	5	25	40	52	0	0	1.8	N/A	N/A	105	95	90
Mangaone St Annebrooke Rd Br	Moderately short	2.50	0.063	96	5.2	96	82	70	4	18	29	90	70	40	0.5	1.6	3.1	110	95	90

Mangakotukutuku Stm Peacockes Rd	Short	0.81	0.169	30	8.7	88	43	8	4	17	27	96	89	78	0.3	1.0	2.0	105	95	90
Waitawhiriwhiri Stm Edgecumbe Street	Moderately short	0.84	0.025	29	1.4	88	45	12	3	16	26	76	24	0	0.3	1.1	N/A	105	95	90
Kirikiriroa Stm Tauhara Dr	Moderately short	0.74	0.012	12	0.6	86	38	0	2	7	N/A	50	0	0	0.3	N/A	N/A	105	95	85
Lower Waikato																				
Komakorau Stream Henry Road	Short	1.34	0.0085	241	10.4	93	66	45	18	83	133	29	0	0	7.3	N/A	N/A	100	90	85
Mangawara Stm Rutherford Rd Br	Moderately short	0.79	0.0465	620	82.9	87	42	6	79	361	581	87	59	18	10.7	33.9	67.7	95	85	80
Awaroa Stm (Rotowaro) Sansons Br @ Rotowaro-Huntly Road	Short to moderate	0.64	0.004	73	5.5	84	28	0	11	52	N/A	0	0	0	N/A	N/A	N/A	100	90	85
Matahuru Stm Waiterimu Road Below Confluence	?	0.74	0.0235	108	9.3	86	38	0	15	67	N/A	74	19	0	2.4	7.5	N/A	100	90	85
Whangape Stm Rangiriri- Glen Murray Rd	?	0.00	0.004	9	1.9	0	0	0	N/A	N/A	N/A	0	0	0	N/A	N/A	N/A	100	90	85
Waerenga Stm Taniwha Rd	?	0.82	0.02	9	1.9	88	44	10	1	5	8	70	5	0	0.6	1.8	N/A	110	95	90
Whangamarino River Jefferies Rd Br	Short	0.63	0.029	152	15.0	84	26	0	24	112	N/A	79	34	0	3.1	9.8	N/A	100	90	85
Mangatangi River SH2 Maramarua	Moderately short	0.12	0.021	116	13.1	17	0	0	96	N/A	N/A	71	10	0	3.7	11.9	N/A	100	90	80
Mangatawhiri River Lyons Road Buckingham Br	Short	0.03	0.012	18	1.6	0	0	0	N/A	N/A	N/A	50	0	0	0.8	N/A	N/A	110	100	90
Whangamarino River Island Block Rd	?	0.13	0.006	655	54.9	23	0	0	505	N/A	N/A	0	0	0	N/A	N/A	N/A	95	85	80
Whakapipi Stm SH 22 Br	Moderately short	3.45	0.028	121	5.0	97	87	79	4	16	26	79	32	0	1.1	3.4	N/A	95	85	80
Ohaeroa Stm SH22 Br	Short	1.54	0.008	17	0.4	93	70	52	1	5	8	25	0	0	0.3	N/A	N/A	100	90	85
Opuatia Stm Ponganui Rd	Moderately short	0.73	0.006	81	5.1	86	37	0	11	51	N/A	0	0	0	N/A	N/A	N/A	105	95	90
Awaroa River (Waiuku) Otaua Rd Br Moseley Rd	Moderate	1.37	0.004	36	0.9	93	66	46	3	12	20	0	0	0	N/A	N/A	N/A	95	85	80
Waipa																				
Waipa River Mangokewa Rd	Moderately short	0.33	0.0055	25	0.6	70	0	0	7	N/A	N/A	0	0	0	N/A	N/A	N/A	125	110	105
Waipa River Otewa	Moderate to short	0.25	0.008	242	30.5	60	0	0	96	N/A	N/A	25	0	0	22.9	N/A	N/A	115	100	95

Waipa River SH3 Otorohanga	Moderately short	0.41	0.008	121	8.2	76	0	0	30	N/A	N/A	25	0	0	6.2	N/A	N/A	110	100	95
Waipa River Pirongia-Ngutunui Rd Br	Short	0.58	0.014	2968	150.5	83	20	0	516	2374	N/A	57	0	0	64.5	N/A	N/A	110	100	90
Waipa River Whatawhata Br	Moderately short	0.70	0.017	3986	284.6	86	34	0	571	2627	N/A	65	0	0	100.4	N/A	N/A	110	95	90
Ohote Stm Whatawhata/Horotiu Rd	Short	0.46	0.02	35	2.2	78	0	0	8	N/A	N/A	70	5	0	0.7	2.1	N/A	105	90	85
Kaniwhaniwha Stm Wright Rd	Short	0.39	0.007	106	9.2	74	0	0	27	N/A	N/A	14	0	0	7.9	N/A	N/A	110	100	95
Mangapiko Bowman Rd Stm	Moderately short	1.50	0.118	429	76.5	93	69	51	29	131	211	95	84	68	3.9	12.3	24.6	100	90	85
Mangaohoi Stm South Branch Maru Rd	Moderately short	0.23	0.041	1	0.1	56	0	0	0	N/A	N/A	85	54	7	0.0	0.0	0.1	120	110	100
Mangauika Stm Te Awamutu Borough W/S Intake	Short	0.21	0.004	4	0.2	52	0	0	2	N/A	N/A	0	0	0	N/A	N/A	N/A	135	120	115
Puniu River Bartons corner Rd Br	?	0.65	0.022	ND	ND	85	29	0	ND	ND	ND	73	14	0	ND	ND	ND	110	95	90
Mangatutu Stm Walker Rd Br	Moderately short	0.33	0.009	ND	ND	70	0	0	ND	ND	ND	33	0	0	ND	ND	ND	110	100	95
Waitomo Stm SH31 Otorohanga	Short	0.53	0.027	ND	ND	81	13	0	ND	ND	ND	78	30	0	ND	ND	ND	110	100	95
Mangapu River Otorohanga	?	0.81	0.019	ND	ND	88	43	9	ND	ND	ND	68	0	0	ND	ND	ND	105	95	90
Waitomo Stm Tumutumu Road	Moderately short	0.62	0.01	ND	ND	84	26	0	ND	ND	ND	40	0	0	ND	ND	ND	110	100	95
Mangaokewa Stm Lawrence street bridge	?	0.57	0.015	ND	ND	82	19	0	ND	ND	ND	60	0	0	ND	ND	ND	115	100	95

Table A3. The current annual median concentrations for TN and TP (mg/L) for Waikato mainstem sites, along with the percent reductions in concentrations needed to achieve either an A, B or C band (based on NPS lake criteria), the corresponding desired instream nutrient load (T/y) to achieve the desired nutrient concentration band, and estimated lag time from Semadeni-Davies *et al.* (2015).

	Lag time?	Current median concentrations (mg/L)		Current annual in-stream loads (T)		TN reduction required to meet desired band (%)			TN annual in-stream load required to meet desired band (T)			TP reduction required to meet desired band (%)			TP annual in-stream load required to meet desired band (T)		
Upper Waikato		TN	TP	TN	TP	A-band	B-band	C-band	A-band	B-band	C-band	A-band	B-band	C-band	A-band	B-band	C-band
Waikato River - Ohaaki Br	Moderate to long	0.14	801	0.010	58.5	0	0	0	N/A	N/A	N/A	0	0	0	N/A	N/A	N/A
Waikato River Ohakuri Tailrace Br	Moderately long	0.22	1520	0.020	135.4	27	0	0	1105	N/A	N/A	50	0	0	67.7	N/A	N/A
Waikato River Whakamaru Tailrace	Moderately long	0.27	2059	0.020	160.3	41	0	0	1220	N/A	N/A	50	0	0	80.2	N/A	N/A
Waikato River Waipapa Tailrace	Moderately short	1.36	2654	0.140	218.8	88	74	45	312	683	1463	93	86	64	15.6	31.3	78.1
Mid-Waikato																	
Waikato River Narrows Boat Ramp	Moderately short	0.41	4414	0.030	301.5	61	15	0	1723	3768	N/A	67	33	0	100.5	201.0	N/A
Waikato River Horotiu Br	Moderately short	0.44	4385	0.040	353.2	64	20	0	1594	3488	N/A	75	50	0	88.3	176.6	N/A
Lower Waikato																	
Waikato River Huntly-Tainui Br	Moderately short	0.59	10301	0.05	719.8	73	41	0	2793	6111	N/A	80	60	0	144.0	287.9	N/A
Waikato River – Mercer Br	Moderately short	0.66	13706	0.05	960.5	76	47	0	3323	7268	N/A	80	60	0	192.1	384.2	N/A
Waikato River Tuakau Br	Moderately short	0.60	13191	0.06	958.7	73	42	0	3518	7695	N/A	83	67	17	159.8	319.6	798.9

Table A4. The final states desired by Fish & Game at Waikato River Tributaries.

River site	Nutrients		Biological		Dissolved Oxygen		Sediment	
Upper Waikato	Annual Median Nitrate (mg/L)	DRP Annual Median (mg/L)	MCI	Fish Q-IBI	7-day mean minimum (mg/L)	1-day minimum (mg/L)	Deposited sediment (% cover)	Clarity (m)
Pueto Stm Broadlands Rd Br	0.46	0.019	110	36	7.0	5.0		3.0
Torepatutahi Stm Vaile Rd Br	0.46	0.019	105	36	7.0	5.0		
Waiotapu Stm Homestead Rd Br	0.46	0.019	100	36	7.0	5.0	20	
Mangakara Stm (Reporoa) SH5	0.46	0.019	105	36	7.0	5.0		1.0
Kawaunui St SH5 Br	0.46	0.019	105	36	7.0	5.0	20	1.6
Waiotapu Stm Campbell Rd Br	0.46	0.019	100	36	7.0	5.0		1.6
Otamakokore Stm Hossack Rd	0.46	0.019	105	36	7.0	5.0	20	1.6
Whirinaki Stm Corbett Rd	0.46	0.019	105	36	7.0	5.0	20	3.0
Tahunaatara Stm Ohakuri Rd	0.46	0.019	105	36	7.0	5.0	20	1.6
Mangaharakeke Stm SH30 (Off Jct SH1)	0.46	0.019	100	36	7.0	5.0		1.6
Waipapa Stm (Mokai) Tirohanga Rd Br	0.46	0.019	110	36	7.0	5.0		2.2
Mangakino Stm Sandel Rd	0.46	0.019	115	36	7.0	5.0	20	3.0
Whakauru stm SH1 Br	0.46	0.019	100	36	7.0	5.0	20	1.0
Mangamingi Stm Paraonui Rd Br	0.46	0.019	100	36	7.0	5.0		1.0
Pokaiwhenua St Arapuni – Putaruru Rd	0.1	0.006	115	47	8.0	7.5	20	1.8
Little Waipa Stm Arapuni Putaruru Rd	0.46	0.019	105	36	7.0	5.0	20	1.8
Mid-Waikato								
Karapiro Stm Hickey Rd Bridge	0.46	0.019	90	36	7.0	5.0		1.0
Mangawhero Stm Cambridge-Ohaupo Rd	0.46	0.019	95	36	7.0	5.0	20	1.0
Mangaonua Stm Hoeka Rd	0.46	0.019	95	36	7.0	5.0	20	1.0
Mangaone St Annebrooke Rd Br	0.46	0.019	95	36	7.0	5.0		1.0

Mangakotukutuku Stm Peacockes Rd	0.46	0.019	95	36	7.0	5.0		1.0
Waitawhiriwhiri Stm Edgecumbe Street	0.46	0.019	95	36	7.0	5.0		1.0
Kirikiriroa Stm Tauhara Dr	0.46	0.019	95	36	7.0	5.0		1.0
Lower Waikato								
Komakorau Stream Henry Road	0.46	0.019	90	36	7.0	5.0		1.0
Mangawara Stm Rutherford Rd Br	0.46	0.019	85	36	7.0	5.0		1.0
Awaroa Stm (Rotowaro) Sansons Br @ Rotowaro-Huntly Road	0.46	0.019	90	36	7.0	5.0		1.0
Matahuru Stm Waiterimu Road Below Confluence	0.46	0.019	90	36	7.0	5.0		1.0
Whangape Stm Rangiriri-Glen Murray Rd	0.1	0.006	100	47				1.0
Waerenga Stm Taniwha Rd	0.46	0.019	95	36	7.0	5.0		1.0
Whangamarino River Jefferies Rd Br	0.46	0.019	90	36	7.0	5.0		1.0
Mangatangi River SH2 Maramarua	0.1	0.006	100	47	8.0	7.5		1.0
Mangatawhiri River Lyons Road Buckingham Br	0.1	0.006	110	47	8.0	7.5	20	2.0
Whangamarino River Island Block Rd	0.1	0.006	95	47	8.0	7.5		1.0
Whakapipi Stm SH 22 Br	0.46	0.019	85	36	7.0	5.0	20	1.1
Ohaeroa Stm SH22 Br	0.46	0.019	90	36	7.0	5.0		1.0
Opuatia Stm Ponganui Rd	0.46	0.019	95	36	7.0	5.0	20	1.0
Awaroa River (Waiuku) Otaua Rd Br Moseley Rd	0.46	0.019	85	36	7.0	5.0		1.0
Waipa								
Waipa River Mangokewa Rd	0.1	0.006	125	47	8.0	7.5	20	2.0
Waipa River Otewa	0.1	0.006	115	47	8.0	7.5	20	2.1
Waipa River SH3 Otorohanga	0.1	0.006	110	47	8.0	7.5	20	2.0
Waipa River Pirongia-Ngutunui Rd Br	0.46	0.019	100	36	7.0	5.0		1.0
Waipa River Whatawhata Br	0.46	0.019	95	36	7.0	5.0		1.0

Ohote Stm Whatawhata/Horotiu Rd	0.46	0.019	90	36	7.0	5.0		1.0
Kaniwhaniwha Stm Wright Rd	0.1	0.006	110	47	8.0	7.5		1.8
Mangapiko Bowman Rd Stm	0.46	0.019	90	36	7.0	5.0		1.0
Mangaohoi Stm South Branch Maru Rd	0.46	0.019	110	36	7.0	5.0	20	1.6
Mangauika Stm Te Awamutu Borough W/S Intake	0.46	0.019	120	36	7.0	5.0	20	3.3
Puniu River Bartons corner Rd Br	0.1	0.006	110	47	8.0	7.5		1.8
Mangatutu Stm Walker Rd Br	0.46	0.019	100	36	7.0	5.0		1.6
Waitomo Stm SH31 Otorohanga	0.46	0.019	100	36	7.0	5.0		1.0
Mangapu River Otorohanga	0.46	0.019	95	36	7.0	5.0		1.0
Waitomo Stm Tumutumu Road	0.46	0.019	100	36	7.0	5.0		1.6
Mangaokewa Stm Lawrence street bridge	0.46	0.019	100	36	7.0	5.0		1.6

APPENDIX 2: Macroinvertebrates, Sediment and Nutrients

Macroinvertebrates

Macroinvertebrates are important contributors to a river food web's functioning and stability (important aspects that comprise ecosystem health). However, not all macroinvertebrates are equal contributors. Some invertebrates are more energetically rewarding with lower foraging costs for fish. Maintaining the abundance and diversity of these energetically rewarding invertebrates is important for the stability of fish diet. Large grazers are also important for down-cutting periphyton. Rivers with good water quality are dominated by mayflies, stoneflies and caddisflies, whereas rivers with poor water quality are dominated by worms, snails and midges and do not support the same abundance, biomass or diversity of fish that the former communities do. Fish that feed on poor invertebrate communities become stressed, susceptible to disease and develop poor condition as a result of undesirable dietary changes (Dean and Richardson, 1999, Franklin, 2013).

At a broader level, the large, high energy invertebrates maintain the flow of energy from lower trophic levels through to higher trophic levels, maintain nutrient cycling, thus preventing "stock-piling" of energy and nutrients, which are all crucial aspects for ecological community resilience (the ability of a community to recover following disturbance).

Sediment

Sediment is a natural component of aquatic systems, which is transported as suspended and bedload sediment, mostly at times of high river flows and floods (Neverman *et al.*, submitted, Clapcott *et al.*, 2011b). Small particles (< 2 mm), such as clay and silt, are generally transported in suspension, whereas larger particles, such as sand and gravel, are usually transported close to the riverbed during high flow events (Death, 2008, Schwendel *et al.*, 2011). Erosion from land use activities greatly enhances sediment supply both during low and high flow events (Lyons *et al.*, 2000, Scheurer *et al.*, 2009, Fahey and Marden, 2006). Sediment levels during floods are also considerably higher in agricultural catchments than similar catchments with native vegetation (Burcher and Benfield, 2006).

Excessive deposited sediment can smother animals directly (Figure A1) and/or motivate them to leave. It can also smother and bind with the epilithon on rock surfaces that is the food for many aquatic invertebrates and lower the nutritional quality of this food. It fills in the interstitial spaces between rocks (Figure A1) where benthic fish and invertebrates reside or seek refuge during flood events. Stream invertebrates and many fish (e.g., eels) can live at least up to a metre under the stream bed if there are suitable interstitial spaces – all of which can be easily clogged and lost by excessive deposited sediment (Stanford and Ward, 1988, Williams and Hynes, 1974, Boulton *et al.*, 1997, McEwan, 2009). The majority of New Zealand freshwater fish and organisms are benthic species and live in the interstitial spaces between substrate rocks (Jowett and Boustead, 2001, McEwan and Joy, 2013, McEwan and Joy, 2014b, McEwan and Joy, 2014a, Richardson and Jowett, 2002, Suren and Jowett, 2001). Excessive deposited sediment can also change the invertebrate community from one dominated by highly mobile, large invertebrates to one with sedentary, small invertebrates that require more foraging effort with reduced energetic reward for fish (Burdon *et al.*, 2013, Harrison *et al.*, 2007, Jowett and Boustead, 2001, Lenat *et al.*, 1981, Ramezani *et al.*, 2014, Richardson and Jowett, 2002, Ryan, 1991, Suren and Jowett, 2001, Wood and Armitage, 1997).

Direct impacts of excessive suspended sediment on fish include: mechanical abrasion to the body of the fish and more significantly its gill structures, death, reductions in growth rate, lowered resistance to disease, prevention of successful egg and larval development, and impediments to migration. Indirect impacts include displacing macroinvertebrate communities that provide food, and reducing visual clarity so finding prey is more difficult (Scheurer et al., 2009, Fudge et al., 2008, Herbst et al., 2012, Sternecker and Geist, 2010, Peters, 1967, Argent and Flebbe, 1999, Suttle et al., 2004, Hartman and Hakala, 2006, Collins et al., 2011, Acornley and Sear, 1999). Furthermore, freshwater fish have been shown to exhibit preference for waterways with low turbidity and avoid those with high suspended sediment (Boubée *et al.*, 1997). See Kemp *et al.* (2011) for a comprehensive review of the impacts of sediment on riverine communities.

Figure A1. New Zealand Freshwater Crayfish (*Paranephrops planifrons*) (top) and New Zealand Banded Kokopu (*Galaxias fasciatus*) (middle) smothered in fine sediment. Bottom - stream substrate with interstitial spaces partly clogged with deposited sediment.

Nutrients

Nutrient concentrations (among other factors) can have strong indirect influence on the macroinvertebrate and fish community compositions via algal growth. Nutrients are often a factor limiting algal growth. Algal growth can change invertebrate community composition in two ways:

- Increased periphyton changes the relative ratios of primary producers. Therefore, more periphyton leads to relatively more invertebrates that graze on periphyton relative to those that feed on vegetation/particulate organic matter (POM). The increase in periphyton grazers increases the habitat competition with those grazing on vegetation/POM.
- When periphyton biomass builds to high levels the lower layers start to rot. This can dramatically reduce the oxygen levels and change the pH of the water leading to significant adverse effects on many invertebrates and fish. Whilst oxygen concentration may be very high during the day time from high rates of photosynthesis, at night the lack of light prevents oxygen from being released into the water and oxygen levels can plummet to lethal levels with increased bacterial activity (Dean and Richardson, 1999, Franklin, 2013). By way of comparison, moderate reductions in fish and invertebrate production occur when dissolved oxygen is <5mg/L and 50% of common bullies will not survive an hour below 3mg/L (Dean and Richardson, 1999, Franklin, 2013), salmonids will also suffer mortality. The most tolerant invertebrates are typically small bodied with low metabolic demand and consequently undesirable for fish (Landman *et al.*, 2005). Thus many fish and invertebrate species are unable to survive, regardless of high oxygen concentrations that are recorded from daytime measurements, leading to differences in community composition. During the day, if DO saturation gets too high (supersaturated) then fish can suffer from Gas Bubble Disease. This is a condition similar to decompression illness that SCUBA divers get, whereby air embolisms occur in tissue and vessels (Espmark *et al.*, 2010, Geist *et al.*, 2013, Mesa *et al.*, 2000, Doulos and Kindschi, 1990). When oxygen saturation is high, fish will try swim deeper as the added water pressure compresses air bubbles (Boyles Law); however, if water levels are also low and pools are missing then fish can suffer blistering (Figure A2) and struggle maintaining bouyancy (Shrimpton *et al.*, 1990).

Figure A2. A Rainbow Trout with gas embolism blisters. Image courtesy of David Palmer.

The two key nutrients often driving excessive periphyton growth (when they are the limiting factor) are Dissolved Inorganic Nitrogen (primarily nitrate-nitrogen) and Dissolved Reactive Phosphorus (DRP). Both nutrients need to be managed to prevent excessive periphyton as flow, temperature, pH and nutrient fluxes can easily switch a DRP limited stream to a nitrogen limited stream, and vice versa (Briand 1983; Wilcock et al. 2007); different algae species thrive in and are composed of different N:P ratios (Biggs 1990; Biggs and Price 1987; Milner 1953); and two recent reviews of an extensive array of studies (237 and 382 studies, respectively) have found Redfield ratios (the molar N:P ratio) are inaccurate for determining nutrient limitation (Francoeur 2001; Keck and Lepori 2012).

APPENDIX 3

Clean but not green: a weight-of-evidence approach for setting nutrient criteria in New Zealand rivers.

(Death, R. G., Magierowski, R., Tonkin, J. & Canning, A. D.)

Clean But Not Green: A Weight-of-Evidence Approach for Setting Nutrient Criteria in New Zealand Rivers

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Right running head: Nutrient criteria for New Zealand rivers

Abstract

Eutrophication of waterbodies is a major stress on freshwater ecosystems globally, and New Zealand is no exception. Expanding agricultural intensification is increasing nutrient levels in rivers throughout the country and, as a response, the New Zealand Government has established a policy of freshwater management where waterbodies are managed within four states ranging from high to low ecosystem health. We compiled a large range of data sources, used a weight-of-evidence approach to determine nitrate, and dissolved reactive phosphorus (DRP) limits objectively to categorise rivers and streams into these four states. The compiled evidence establishes nutrient concentrations differentiating rivers into each of these states at 0.10, 0.46 and 1.32 mg/l for nitrate and 0.006, 0.019 and 0.057 mg/l for DRP. While a wide range of interacting stressors affect the ecological health of rivers, nutrients are among the most important stressors and we believe the evidence supports managing to these nutrient criteria will provide for better ecological condition in New Zealand's rivers and streams.

Keywords Ecological health · Eutrophication · New Zealand · Multiple lines of evidence · Nutrient criteria · Nutrients · River management

Introduction

Globally freshwater biodiversity is under considerable threat from a wide variety of anthropogenic stressors (Dudgeon 2010; Dudgeon et al. 2006; Vorosmarty et al. 2010). This decline in biodiversity has resulted from multiple interacting stressors (Leps et al. 2015; Matthaei et al. 2010; Piggott et al. 2012; Wagenhoff et al. 2011) including water abstraction for consumptive and agricultural needs (Dewson et al. 2007; McDowell et al. 2011; Poff and Zimmerman 2010), invasive species (Collier and Grainger 2015; Olden et al. 2010), channelization, sedimentation, eutrophication (Allan 2004; Carpenter et al. 1998b) and changing climate regimes (Death et al. 2015b; Heino et al. 2009; Palmer et al. 2008). Eutrophication is among the most widespread and problematic stressors: high nutrient levels are associated with the loss of biodiversity, reduced recreational and property values, and increased costs for drinking water treatment (Foote et al. 2015). Eutrophication of freshwaters, therefore, not only comes with a cost to the organisms that inhabit these systems but also financially to the agencies managing them (Dodds et al. 2009; Jarvie et al. 2013; Pretty et al. 2003). The main culprits of eutrophication requiring the greatest attention for management and policy development are nitrogen and phosphorus (Carpenter et al. 1998a; Elser et al. 2007).

As in most developed countries, there has been considerable concern over the declining water quality, ecological health and biodiversity of many of New Zealand's freshwater bodies (Ballantine and Davies-Colley 2010; Foote et al. 2015; Joy 2015; Joy and Death 2014; Larned et al. 2016; Ministry for the Environment & Stats NZ 2017; Parlimentary Commisioner for the Environment 2013; Verburg et al. 2010). Over the last 25 years many measures of water quality have declined at monitored sites throughout the country, particularly in lowland rivers with catchments dominated by agriculture (Ballantine and Davies-Colley 2010; Davies-Colley and Nagels 2002; Foote et al. 2015; Ministry for the

Environment & Stats NZ 2017; Unwin and Larned 2013). Most sites in lowland pastoral catchments and all sites in urban catchments exceed safe swimming standards for pathogens, and 55% and 25% of monitored sites have increasing nitrate-nitrogen and dissolved reactive phosphorus (DRP) levels, respectively (Larned et al. 2004; Ministry for the Environment and Statistics New Zealand 2015). Thirty-two percent of monitored lakes are now classed as polluted with nutrients as are 84% of lakes in pastoral catchments (Verburg et al. 2010). Groundwater ecosystems are less well monitored, but at 39% of monitored sites nitrate levels are rising and at 21% pathogen levels exceed human drinking standards (Daughney and Wall 2007).

The condition of New Zealand's freshwater has become such an issue that both national and regional government have responded with a large variety of regulatory, non-regulatory or funding initiatives in an attempt to improve water quality (Cullen et al. 2006; Hughey et al. 2010; Joy 2015; Ministry for the Environment 2004; Ministry for the Environment 2014). However, regulation and/or limit setting with respect to waterbody nutrient levels has become one of the most contentious issues in improving New Zealand's water quality (Chisholm et al. 2014; Rutherford 2013; Wilcock et al. 2007). This is undoubtedly because of the perceived negative economic consequences associated with constrained nutrient discharge to waterbodies, particularly by the dairy farming industry, although the cost of preventing nutrients reaching waterways is considerably less than trying to remove them once they are there (Foote et al. 2015; Joy 2015; USEPA 2015). The government has established total nitrogen and total phosphorus criteria for lakes, but in the case of bioavailable nutrient forms in rivers, the government has only established criteria associated with toxic endpoints (i.e., nitrate and ammonia) not to manage ecological health (Ministry for the Environment 2010; Ministry for the Environment 2014). There are guidelines for nutrient management for particular river types (e.g., ANZECC 2000) and/or taxa (e.g., Biggs 2000b). However, despite the obvious and extensively documented links between high nutrient levels in rivers and declines in ecological health (Biggs 1996; Biggs 2000a; Clapcott et al. 2012; Collier et al. 2013; Death et al. 2007; Death et al. 2015a), current government policy does not provide mechanisms to manage nutrients to safeguard overall ecological health.

Many countries have established nutrient criteria or thresholds to protect aquatic life in their waterways (Camargo and Alonso 2006; Dodds and Welch 2000; Heiskary and Bouchard 2015; Jarvie et al. 2013; Smith and Tran 2010). There are four broad approaches, ecological, statistical and expert-opinion, that can be used alone or in combination (Birk et al. 2012). The ecological approach establishes critical levels of a potential stressor at which ecological condition shifts markedly. Statistical approaches partition all available records of a stressor into *a priori* determined numerical groups (e.g., 25^{th}, 50^{th} 75^{th} percentile). Expert-opinion uses the knowledge of a range of experts to determine the critical levels of a stressor where ecological change occurs. In setting the current numerical thresholds for toxicity, the New Zealand Ministry for the Environment appears to have relied predominantly on expert opinion (e.g., Snelder et al. 2013b). While this approach can be useful when there is insufficient data to make more objective decisions, this is not the case in New Zealand where multiple parameters of river water quality and ecological health have been monitored for nearly three decades (e.g., Clapcott et al. 2012; Larned et al. 2004; Scarsbrook et al. 2000; Smith and Maasdam 1994; Smith and McBride 1990; Unwin and Larned 2013).

In this study we adopt the weight-of-evidence approach of Smith and Tran (2010) to develop nitrogen and phosphorus nutrient limits for New Zealand rivers and streams to protect ecosystem health. We adopt the New Zealand Ministry for the Environment approach detailed in the ‘National Policy Statement for Freshwater Management (NPS-FM)’ whereby a number of measures (termed attributes: nitrogen and phosphorus in this case) are identified by numerical thresholds into one of four states (from A to D). State D is termed the ‘National

Bottom Line' or 'minimum acceptable state' (actually an unacceptable condition of impairment), with the intention that waterbodies will need to be improved to at least above the national bottom lines over time (Ministry for the Environment 2014). This approach differs from that in the USA where nutrient limits are derived for impaired / not-impaired waterways (Dodds and Welch 2000; USEPA 2000), but is similar to that of the European Union Water Framework Directive, which also characterises water bodies as belonging to one of five states of ecological status from bad to high (Birk et al. 2012; European Commission 2000; Poikane et al. 2014). Our work improves on the existing nutrient guidelines for New Zealand's rivers with multiple lines of evidence from empirical and/or modelled data rather than expert opinion, and, by defining states to safeguard ecological health for periphyton, macroinvertebrates and fish rather than a few key taxa. Our approach is the first we know of where the ecological requirements of all riverine food web components are considered concurrently in developing in-stream nutrient concentrations.

Materials and Methods

Methods for Nutrient Identifying Criteria

There are four established methods for identifying nutrient limits (Smith and Tran 2010; USEPA 2000). These are 1) division of known nutrient measures into equal classes (percentile analysis); 2) identification of significant thresholds in the relationship between nutrient values and ecosystem health metrics (Baker and King 2010; King and Richardson 2003; Nelson and Shober 2012; Smith and Tran 2010); 3) identification of signification relationships between nutrient values and ecosystem health metrics at predetermined points; and 4) experimental manipulation of the effect of nutrient values on ecosystem health metrics. Classification and Regression Tree analysis of the data did identify some thresholds of change (option 2 above), but these thresholds had low accuracy (only 30% of cases were correctly classified). Furthermore, they were often binary splits more in line with impaired/non-impaired waterway classification, than degrees of impairment implicit in the New Zealand policy framework. Therefore, to be consistent with the derivation of existing NPS-FM attribute criteria, we used approaches one and three to define potential criteria for both nitrate-nitrogen and dissolved reactive phosphorus (DRP) (Davies-Colley et al. 2013; Hickey 2014; National Objectives Framework Reference Group 2012; Snelder et al. 2013a). A combination of empirical and modelled data sourced from a variety of publications and agencies (Table 1) were used to determine biological or percentile variables. Some data sets allowed the derivation of multiple metrics for determining criteria; so to avoid potential non-independence of these metrics we averaged the nutrient criteria derived from metrics from a single data source and used them as a single piece of evidence. The contribution of each piece of evidence to an overall threshold was determined by weighted averaging of the 10 numerics based on whether linkages were direct or indirect.

Data Sets and Preparatory Analyses

Percentile Analysis of Modelled Nutrient Data for National Environmental Monitoring and Reporting

Collection of data on water chemistry in New Zealand rivers is relatively extensive, but highly variable in space and time, with proportionally more sites in lowland areas than higher altitude conservation land (Ballantine and Davies-Colley 2010; Larned and Unwin 2012; Larned et al. 2004; McDowell et al. 2009; Unwin and Larned 2013). Unwin and Larned (2013) have compiled data, from 786 water quality sites, monitored from 2006 to 2011, around New Zealand (Table 1: dataset 1). They modelled nitrate-nitrogen and dissolved reactive phosphorus (DRP) using random forests and 28 site-specific catchment descriptors as predictors. The models explained 66% and 57% of the variation in the data; for nitrate and

DRP, respectively, and provided predicted median nitrate and DRP values for every river reach in New Zealand (n = 566,563). The predicted medians were strongly correlated with independent measures (r=0.64 and r=0.83, for nitrate and DRP, respectively) made at 22 Manawatu rivers and streams (R Death, unpublished) and at 77 National River Water Quality Network (NRWQN) sites (r=0.86 and r=0.73, for nitrate and DRP, respectively). Although it might have been better to have actual nutrient data for all sites, it requires several years of monthly collection to estimate accurate medians for nutrients. Furthermore, sites where such records are available are highly skewed to large lowland sites of particular interest to environment agencies, not the smaller streams that collectively represent a longer length of stream. Modelled data also has the advantage of removing the considerable 'white noise' that occurs with actual nutrient measures (Özkundakci et al. 2018). As the modelled data gave a more extensive, consistent and spatially unbiased measure of nitrate and DRP, the use of this data is appropriate and the modelled medians from Unwin and Larned (2013) were used for the percentile analysis. Modelled data are increasingly being used for practical, planning and legal resource management decisions because of their many advantages (Özkundakci et al. 2018; Schmolke et al. 2010)

To assign sites into percentile groups, based on their nitrate and DRP values, we used the percentile analysis approach of Smith and Tran (2010) and the USEPA (2000). The USEPA recommend the 25th percentile when all sites (pristine and impaired) are combined; and the 75th percentile for pristine sites only. We used the 25^{th}, 50^{th} and 75^{th} percentiles for the modelled medians to yield A, B, C and D thresholds for nitrate and DRP. For reaches in Conservation land like National Parks (n = 242,521) that are relatively pristine we used the 95^{th}, 99^{th} and 99.9^{th} percentiles. These sites will reflect natural geographic and geological variation in nitrate and DRP levels but have little or no anthropogenic nutrient influences (Fig. 1); thus, our pre-defined values were at the high extremes of what can occur. Even the A state allows for minimal degradation, while B, C and D allow for increasing degradation levels.

Nutrient - Ecosystem Health Metric Relationships

Several data sources were used to examine the relationship between nutrient concentrations and metrics of ecosystem health (Table 1: datasets 2-8). New Zealand has well established biological indicator criteria for benthic invertebrates: the Macroinvertebrate Community Index (MCI) and its quantitative variant (QMCI) (Quantitative Macroinvertebrate Community Index) (Boothroyd and Stark 2000; Stark 1985; Stark and Maxted 2007). These have been in place since 1985 and are now widely used in all environmental assessment in New Zealand (Boothroyd and Stark 2000; Ministry for the Environment and Statistics New Zealand 2015). Although there is some suggestion they may respond to a variety of stressors in New Zealand waterways, they were specifically developed to assess organic enrichment and eutrophication (Stark 1985) and have been shown to be insensitive to heavy metals, acid mine drainage and deposited sediment (Death and Death 2014; Gray and Harding 2012; Hickey and Clements 1998). The standard MCI and QMCI states (120, 100 and 80, and 6, 5 and 4, for MCI and QMCI, respectively) provide ideal criteria against which to assess A, B, C and D criteria for nutrients.

There are no similar criteria for other potential invertebrate metrics like the proportion of Ephemeroptera, Plecoptera and Trichoptera (EPT). We, therefore, derived criteria for determining nutrient thresholds for these metrics by examining the distribution of EPT(taxa) (percent of taxa that are EPT at a site) and EPT(animals) (percent of animals that are EPT individuals at a site) in 513 streams sampled in conservation land. The A, B and C/D attribute classes for percent EPT(taxa) and EPT(animals) were set at values for the 10^{th}, 1 and 0.1% of these sites. For the metrics EPT(taxa) these were 46, 37 and 22%, respectively and for EPT(animals) 26, 11 and 1% for A, B and C/D, respectively.

The datasets used to explore the relationship between nutrient concentration and ecosystem health metrics (Table 1) are independent and were derived using different methodologies including modelled metric and nutrient values, measured metric and modelled nutrient values at a reach-scale, and measured metric and nutrient values. Each dataset and the approach used to describe the relationship with nutrients is outlined below and in Table 1. Where multiple metrics were averaged for a single dataset, the individual regressions are presented in the Supplementary Material and the averages in Table 1.

Modelled Nutrient - Modelled Ecosystem Health Metric Relationships (Table 1: datasets 1 vs. 2)

Clapcott et al. (2013) modelled MCI values calculated from invertebrate collections in 1033 unique stream segments between 2007 and 2011 using Random Forests to yield predictions of MCI scores for all river reaches in New Zealand (r=0.83 between observed and predicted MCI). We regressed these modelled MCI values against the modelled nutrient values from Unwin and Larned (2013) for each reach in New Zealand. QMCI was calculated for the Clapcott et al (2013) MCI predictions by deriving a regression equation between measured MCI and QMCI from 963 North Island sites (Death et al. 2015a) ($F_{1,961}$ =1761 $p<0.001$; r^2=0.65). These QMCI values for each river reach in New Zealand were also regressed against the modelled nutrient values from Unwin and Larned (2013). Finally, predicted MCI (in the absence of landuse change) and observed MCI expressed as a ratio of Observed/Expected (O/E) (Clapcott et al. 2017) were regressed against the same modelled nutrient values from Unwin and Larned (2013). Thresholds for A, B and C/D for the O/E were determined at 0.9, 0.85 and 0.8 following Clarke and Murphy (2006).

Modelled Nutrient – Measured Metric Relationships (Table 1: datasets 1 vs. 3 and 6)

Biological indices calculated for invertebrate data were collected at 962 sites sampled in the lower North Island between 1994 and 2007 were used for the regression (Death et al. 2015a). Most of these sampling occasions involved 5 replicate 0.1 m^2 Surber samples from riffles, although some collections comprised a single 1-minute kick-net sample (see Death et al. (2015a) for more details). Samples were filtered through a 500 µm mesh sieve and identified to the lowest possible taxonomic level (usually genera) using Winterbourn et al. (2006). Where repeat samples were collected from a site in multiple years, only the most recent sample was used in the analysis. The MCI and QMCI is relatively independent of sampling effort and season (Duggan et al. 2002), thus we are confident that the measures of biological water quality used are an accurate representation of ecological condition, even though data were collected for a variety of reasons. MCI, QMCI, EPT(taxa) and EPT(animals) were regressed against the modelled nutrient values from Unwin and Larned (2013).

The Index of Biotic Integrity (IBI) (Joy and Death 2004), a bioassessment metric used for fish assemblages in New Zealand, was calculated for data collected nationally but irregularly (New Zealand Freshwater Fish Database https://www.niwa.co.nz/our-services/online-services/freshwater-fish-database (Jowett 1996)) between 1970 and 2007 (Joy 2009). These measures were regressed against the modelled nutrient values from Unwin and Larned (2013) for the corresponding reach. IBI thresholds for A, B, C and D were set at 42, 32 and 24 following Joy (2009).

Measured Nutrient – Measured Metric Relationships (Table 1: datasets 4 and 5)

Median metrics calculated from collected invertebrates and nutrients were regressed against each other for two datasets. One collected at 24 Manawatu streams and rivers (Death 2013) and the other at 64 nationwide NIWA monitoring rivers (Larned and Unwin 2012; Unwin and

Larned 2013). Samples were collected on multiple occasions (monthly for nutrients, yearly for invertebrates) between 1999 to 2011 and 1989 to 2014, for Death (2013) and NIWA, respectively.

Relationships between biological metrics and nutrient measures were assessed with linear regression using the lm function in R (R Development Core Team 2015). Regressions of y=x, y=ln(x), ln(y) = x and ln(y) = ln(x) were analysed for the best fit. Nutrient thresholds were determined by back calculating from the regression equation at y= 120, 100 and 80 for MCI, y= 6, 5 and 4 for the QMCI, y= 46%, 37% and 22% for EPT(taxa), and y = 26%, 11% and 1% for EPT(animals).

Previously Published Numerics and Ecosystem Health Metric Relationships

Several previous publications have investigated nitrate-nitrogen and DRP thresholds for water management in New Zealand. The ANZECC (ANZECC 2000) guidelines derived nitrate and DRP thresholds for upland and lowland rivers in New Zealand (Table 3.3.10 (ANZECC 2000)) based on monitoring data collected by Davies-Colley (2000) (Table 1: datasets 9 and 10). These have been used widely in New Zealand over the last two decades for management decisions around water quality (e.g., Manawatu Wanganui Regional Plan). Biggs (2000a) collected a variety of periphyton and nutrient measures from 30 rivers throughout New Zealand and derived regression equations for maximum chlorophyll *a* and nitrate / DRP (Table 1: dataset 7). This information has also been used in management recommendations on water quality in New Zealand (Biggs 2000b; Biggs and Kilroy 2000). The current National Policy Statement for Freshwater Management 2014 lists A, B, C and D thresholds for periphyton of 50, 120 and 200 mg chlorophyll *a* m^2, so these were used with the Biggs' equations to derive nitrate and DRP numerics (Ministry for the Environment 2014). Matheson et al. (2016) have also used quantile regression on data from several regions

(Wellington, Manawatu Wanganui, Canterbury and Hawkes Bay) to derive nutrient guidelines to achieve the NPS periphyton attribute states above (Table 1-3 in report). These derived numerics were also included as lines of evidence (Table 1: dataset 8).

Weighting Lines of Evidence

Thresholds of change between the above ecological classes were derived from each nutrient ecosystem health metric relationship regression and combined with percentiles or previously published limits in Table 2 (see also Supplementary Material). The final nutrient limits were determined by calculating a weighted average of those 10 nutrient limits for each dataset / line of evidence multiplied by their allocated weighting. Following Smith and Tran (2010), direct linkage relationships between ecosystem health measures and nutrients were allocated twice the weight in the analysis of purely statistical or less direct linkages (e.g. percentile analysis and Fish IBI). Where relationships were not significant they were not included as a line of evidence i.e. they were allocated a weighted value of 0. To evaluate the influence of a single piece of evidence (i.e. sensitivity) the weighted criteria were recalculated by removing one line of evidence in turn, for all lines of evidence.

Results

Are National or Regional Criteria More Appropriate?

New Zealand is geologically active with high mountains, frequent earthquakes, geothermally active areas and volcanoes. This geological activity in turn results in a spatially variable geology that might suggest regional nutrient criteria will be necessary to account for the natural differences in 'pristine' environmental conditions. However, a plot of the median and range of nutrient values from Unwin and Larned (2013) in catchments with predominantly (>80%) native vegetation (Fig. 1) indicates that although the median is lower and range greater as one moves south, there are no dramatic regional differences. For nitrate, all regions have 75% of 'pristine' reaches well below the A band upper nutrient threshold (see below for derivation), and all reaches are well below the B band upper threshold, except for a few outlying points in the South Island (Fig. 1). There are more distinct differences between the North and South Islands in DRP because of the preponderance of volcanic activity in the former. A different threshold for category A in the North and South Islands may be warranted, but given the greater simplicity and understanding associated with one set of national criteria, rather than multiple regional criteria, we have opted for the former.

Ecosystem Health Metric Relationships

The relationships between the health metrics and nutrient concentrations were predominantly exponential (Supplementary Material) with health declining more rapidly for increasing nutrient concentrations at low levels and plateauing as ecological health approached poor condition (e.g., Fig. 2). That is, once low health was achieved, further increasing nutrient levels had little additional detrimental effect. As variables other than nutrients will also potentially be affecting ecosystem health it is not surprising that there is a large spread in the data. Only numbers from significant relationships were included in the final assessment.

Numerical Nutrient Thresholds

Table 2 presents the numerical nutrient thresholds for the A, B, C and D states derived from each line of evidence. The weighted evidence yielded nitrate concentrations of 0.10, 0.46 and 1.32 mg/l, and DRP concentrations of 0.006, 0.019 and 0.057 mg/l for the A, B, C and D states (Table 2). Criteria from each individual line of evidence (where these were significant) were remarkably consistent across all the lines of evidence (Table 2, Supplementary

Material). The only real exception was that criteria derived from the percentile analysis were generally lower than those from the regression analysis.

Sensitivity analysis (i.e., removing one line of evidence in turn and recalculating weighted criteria) had very minor effects on the final weighted criteria. For example, in this sensitivity analysis the nitrate criteria ranged from 0.10-0.15, 0.43-0.81 and 1.35-1.93 for the A/B, B/C and C/D criteria, respectively. The DRP criteria ranged from 0.005-0.006, 0.017-0.022 and 0.039-0.064 for the A/B, B/C and C/D criteria, respectively. There was also no indication of differences in criteria derived from regionally focused data (e.g. Manawatu (FAT) data) or those from more geographically spread data.

A small percentage of New Zealand river reaches, based on modelled median nitrate or DRP levels from Unwin and Larned (2013), would be classified as below the bottom line for ecosystem health (Table 3). The majority of river reaches would be classed as A for nitrate (58.2%) and B for DRP (52%).

Discussion

Although the ecological health of rivers and streams is determined by a wide range of potentially interacting stressors, nutrients are one of the most pervasive and detrimental stressors for the fauna and flora of rivers globally (Allan 2004; Carpenter et al. 1998a; Stevenson and Sabater 2010). Environmental stress from excess nutrients is particularly detrimental to river health in New Zealand where the dominant business and land use is agriculture (Foote et al. 2015; Joy 2015; Weeks et al. 2016). Our weight-of-evidence assessment produced the following nutrient criteria: 0.10, 0.46 and 1.32 mg/l for nitrate, and 0.006, 0.019 and 0.057 mg/l for DRP. These criteria represent objective, data-driven numbers for use in policy tools to maintain or improve the ecological health of rivers in good, moderate or poor condition. Additionally, Wagenhoff et al. (2017) in a study of 58

Manawatu, New Zealand rivers, published subsequent to our data compilation, have also found a threshold for impact on macroinvertebrate metrics at total N = ~ 0.5 mg/l.

Although there can be many situations where expert opinion, rather than data, are necessary to establish management objectives, this is not the case in the nutrient management of rivers and streams for ecological health in New Zealand. There is a large amount of data available to draw on to make decisions; the only issue can be how to draw all that information together into some firm conclusions. The weight-of-evidence approach offers an objective, scientifically rigorous, multiple lines of evidence method to compile a variety of data sources to set nutrient thresholds to meet the four attribute states of ecological health adopted by current New Zealand Government policy. Given the large environmental, economic and social costs these limits may create (Foote et al. 2015; Hughey et al. 2010; Weeks et al. 2016), it is important that they are objectively determined from as wide a range of data and in as robust a manner as possible.

This is the first example we are aware of where fish have been included with periphyton and macroinvertebrates in such an assessment, despite their obvious public interest. Interestingly, the derived nutrient criteria for fish (IBI) were very similar to those for the other taxa. Perhaps one of the impediments has been that a range of variables, besides nutrients, will also affect river health and thus it is not always easy to determine rigorous relationships between nutrients and indices of ecological health. This is clear in the large amount of data scatter in the relationships used in this study. It may also explain why some of the national datasets used, such as that collected by NIWA (Supplementary Material) did not yield significant relationships between the biological indices and nutrient levels. These NIWA sites are predominantly on larger rivers that are more likely to be influenced by multiple stressors than those from a wider range of stream sizes and more limited land uses (e.g., Death 2013, Death *et al.* 2015a). However, it is reassuring that all the data sets yielded numerics within the same small range. Furthermore, in a Boosted Regression Tree analysis of the Death *et al.* (2015a) data, nutrients explained 51% (n=962, cross-validated correlation coefficient = 0.65) and 50% (cross-validated correlation coefficient = 0.76), of the modelled MCI and QMCI, respectively, from 15 potential geographic, geomorphological and catchment predictor variables.

As with any freshwater resource management, adhering to these nutrient limits will not provide a panacea for maintaining good ecological health. Many other factors may interact with, or override the effects of nutrients on river health. However, as a well-established determinant of river food web structure, managing below these nutrient concentrations will certainly be a step in the right direction (Clapcott et al. 2012; Matthaei et al. 2010; Wagenhoff et al. 2012; Wagenhoff et al. 2011). Similarly, establishing limits for only nitrate-nitrogen or dissolved reactive phosphorus will not serve to limit adverse environmental effects, as when and where the respective nutrients become limiting changes and is thus often hard to establish (Death et al. 2007; Dodds and Welch 2000; Jarvie et al. 2013; Keck and Lepori 2012).

Previous studies using the weight-of-evidence approach to establish nutrient thresholds have applied nonparametric changepoint analysis to identify significant biological transition thresholds (e.g., King et al. 2005; King and Richardson 2003; Smith and Tran 2010). However, there was weak evidence for thresholds in our ecological metric nutrient relationships examined in the compiled data. Rather than any particular threshold response there seemed to be an almost continuous, although log-linear change in declining ecological condition with increasing stressor concentration. Therefore, in line with the approach adopted in Government policy, criteria were determined *a priori* for each of the four attribute states using pre-established biological index criteria (e.g., MCI, QMCI). Although, somewhat subjective these thresholds have been in use for a long time in river management (Stark 1985;

Stark 1993; Wright-Stow and Winterbourn 2003), are familiar to all river managers and fit the model of four category attribute states adopted by government policy (Ministry for the Environment 2014).

Perhaps the only concern we have in using this approach is that the established bottom line for MCI/QMCI of 80/4 appears to be very low. Once ecological health reached that point the long flat tail of the relationship (e.g. Fig. 2) along the right of the nutrient axis meant there could be large increases in nutrient levels with only a very small decline in health. In other words, once the ecological health is at the bottom line, condition is relatively unaffected no matter how many more nutrients are added. This suggests the bottom line for the MCI/QMCI may be better at a slightly higher level (e.g., 90 or 4.5 for the MCI and QMCI, respectively).

It is extremely difficult to put the nutrient criteria established in this study for New Zealand in a global context, as differing countries and regions use different chemical species (e.g., total nitrogen and total phosphorus vs nitrate and DRP), they have differing numbers of classes (e.g., the USA has two and Europe five) and many also divide criteria between upland and lowland sites (ANZECC 2000; European Commission 2000; Smith and Tran 2010; USEPA 2000). Table 4 provides a cross-section of those criteria for Australia, USA, England and Wales. Although ranges of nutrient criteria for most of these countries are much larger, reflecting their greater area and geological variability, they do not suggest those developed for New Zealand are incorrect. Those for South Eastern Australia, perhaps the most similar to New Zealand geologically, are very similar.

In conclusion, we derived the nitrate concentrations of 0.10, 0.46 and 1.32 mg/l, and DRP concentrations of 0.006, 0.019 and 0.057 mg/l, which correspond with numerical threshold states A to D (high to low ecological health). We believe these provide rigorous and objective levels at which to set instream nutrient concentrations to protect New Zealand river ecological health. These have been compiled across a range of studies over the full length of New Zealand without any indication of regional differences that might affect the efficacy of these limits in protecting and maintaining the desired ecological state of rivers or streams. Given the pervasive and ever-increasing eutrophication of waterbodies worldwide, we hope these limits will be adopted by New Zealand freshwater managers as one more tool in the arsenal of techniques to better protect and manage freshwater.

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Table 1. Data sources compiled and/or used for analysis. Reference numbers are used to link with Table 2.

Data	Number of reaches	Weight of evidence category	Time interval	Variables used	Reference
Modelled data for National Environmental Monitoring and Reporting	All river reaches in NZ	Percentile analysis	2006-2011	Nitrate, DRP	1 (Unwin and Larned 2013)
Modelled data for National Environmental Monitoring and Reporting	All river reaches in NZ	Metric relationship	2007-2011	MCI, QMCI[A]	2 (Clapcott et al. 2103)
Russell Death private data collection	962 streams and rivers in lower half North Island	Metric relationship	1994-2007	MCI, QMCI, EPT(animals), EPT(taxa)	3 (Death et al. 2015a)
Russell Death Freshwater Animal Targets (FAT) model[B]	24 Manawatu streams multiple temporal measures (inverts yearly, nutrients monthly)	Metric relationship	1999-2011	Nitrate, DRP, MCI, QMCI	4 (Death 2013)

NIWA data	64 rivers multiple temporal measures (inverts yearly, nutrients monthly)	Metric relationship	1989-2014	Nitrate, DRP, MCI, QMCI	5 (Unwin and Larned 2013)
Mike Joy IBI fish model	All river reaches in NZ	Metric relationship	1970-2007	IBI	6 (Joy 2009)
Biggs (2000) model	30 rivers throughout New Zealand	Regression equations	1995-1998	Periphyton measured as chlorophyll *a*	7 (Biggs 2000a)
Matheson et al. 2016	64+ rivers NRWQN and Regional Council data from throughout New Zealand	Summary table 1-3 from regression analysis.	Not stated	Periphyton measured as chlorophyll *a*	8 (Matheson et al. 2016)
ANZEC guidelines	Table 3.3.10		Not stated	Nutrient measures	9, 10 (Davies-Colley 2000)

[A] QMCI was calculated for the Clapcott et al (2013) MCI predictions by deriving a regression equation between measured MCI and QMCI from 962 North Island sites (Death et al. 2015a) ($F_{1,961}$ =1761 $p<0.001$; r^2=0.65).

[B] Median values of all temporal replicates were used (i.e. one value per site).

Table 2 Numerical nutrient thresholds (mg/l) for each freshwater state (A-D) derived from multiple lines of evidence (weighted according to whether it is a direct (2) or indirect (1) relationship). See Table 1 for details on source data. See Supplementary material for derivation of evidence for multiple metrics from the same data source. Columns shaded in grey involve at least some data derived from models. PCL = public conservation land.

Source or Source nutrient dataset	1	1 PCL only	1	1	4	5	1	9,10	7	8				
Source ecological dataset	n/a	n/a	2	3	4	5	6	n/a	7	8				
Ecological metric	n/a	n/a	MCI/QMCI/ OE	MCI/QMCI/ EPT	MCI/QMCI	MCI	IBI	n/a	Chl a	Chl a	Weight. Mean	Std. Err.	Min.	Max.
Nitrate														
Weight of evidence	1	1	2	2	2	2	1	2	2	2				
A/B threshold	0.03	0.08	0.02	0.28	0.08	0.00	0.00	0.17	0.12	0.10	0.10	0.03	0.00	0.28
B/C threshold	0.06	0.12	0.29	0.84	0.43	0.60	0.21		0.43	0.63	0.46	0.09	0.06	0.84
C/D threshold	0.28	0.20	0.79	2.58	2.78	1.60	1.10	0.44	0.90	1.10	1.32	0.29	0.20	2.78
DRP														
A/B threshold	0.004	0.011	0.004	0.011	0.007		0.002	0.009	0.002		0.006	0.001	0.002	0.011
B/C threshold	0.008	0.014	0.014	0.021	0.031		0.007		0.007	0.110	0.019	0.003	0.007	0.031
C/D threshold	0.012	0.021	0.025	0.039	0.177		0.014	0.100	0.014	0.018	0.057	0.019	0.012	0.177

Table 3. Percentage of river reaches in each nutrient attribute state. NPS state = New Zealand National Policy Statement for freshwater state. Nutrient data for all New Zealand river reaches are derived from the modelling of Unwin & Larned (2013).

NPS state	NO_3-N (mg/l)	Percent	DRP (mg/l)	Percent
A	< 0.10	58.2	< 0.006	37.4
B	$0.10 \leq x < 0.46$	25.2	$0.006 \leq x < 0.019$	52.0
C	$0.46 \leq x < 1.32$	14.1	$0.019 \leq x < 0.057$	10.5
D	> 1.32	2.5	> 0.057	0.03

Table 4. Nutrient criteria developed for other countries

	USA[1]		South Eastern Australia[2]		Rest of Australia[2]		England and Wales[3]		
			Upland	Lowland	Upland	Lowland	DRP (mg/l)	Upland	Lowland
Total phosphorus (mg/l)	0.01-0.076*	Filterable reactive phosphorus (mg/l)	0.015	0.02	0.005-0.01	0.01-0.04	High	0.013-0.024	0.019-0.036
Total nitrogen (mg/l)	0.12-2.18	NOx (mg/l)	0.015	0.4	0.15-0.20	0.15-1.00	Good	0.028-0.048	0.040-0.069
							Moderate	0.087-0.132	0.114-0.173
							Poor	0.752-0.898	0.842-1.003

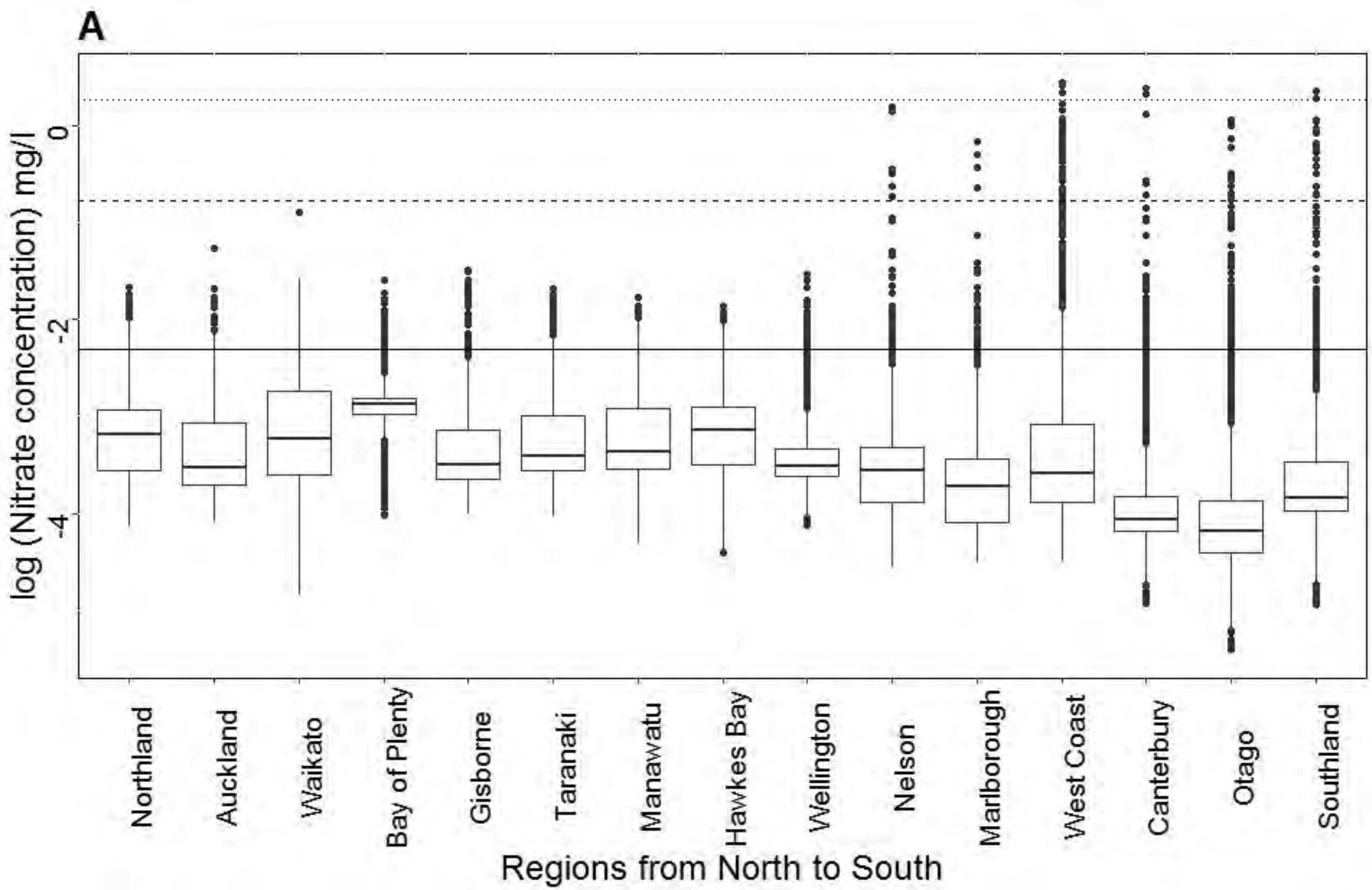
[1] https://www.epa.gov/sites/production/files/2014-08/documents/criteria-nutrient-ecoregions-sumtable.pdf

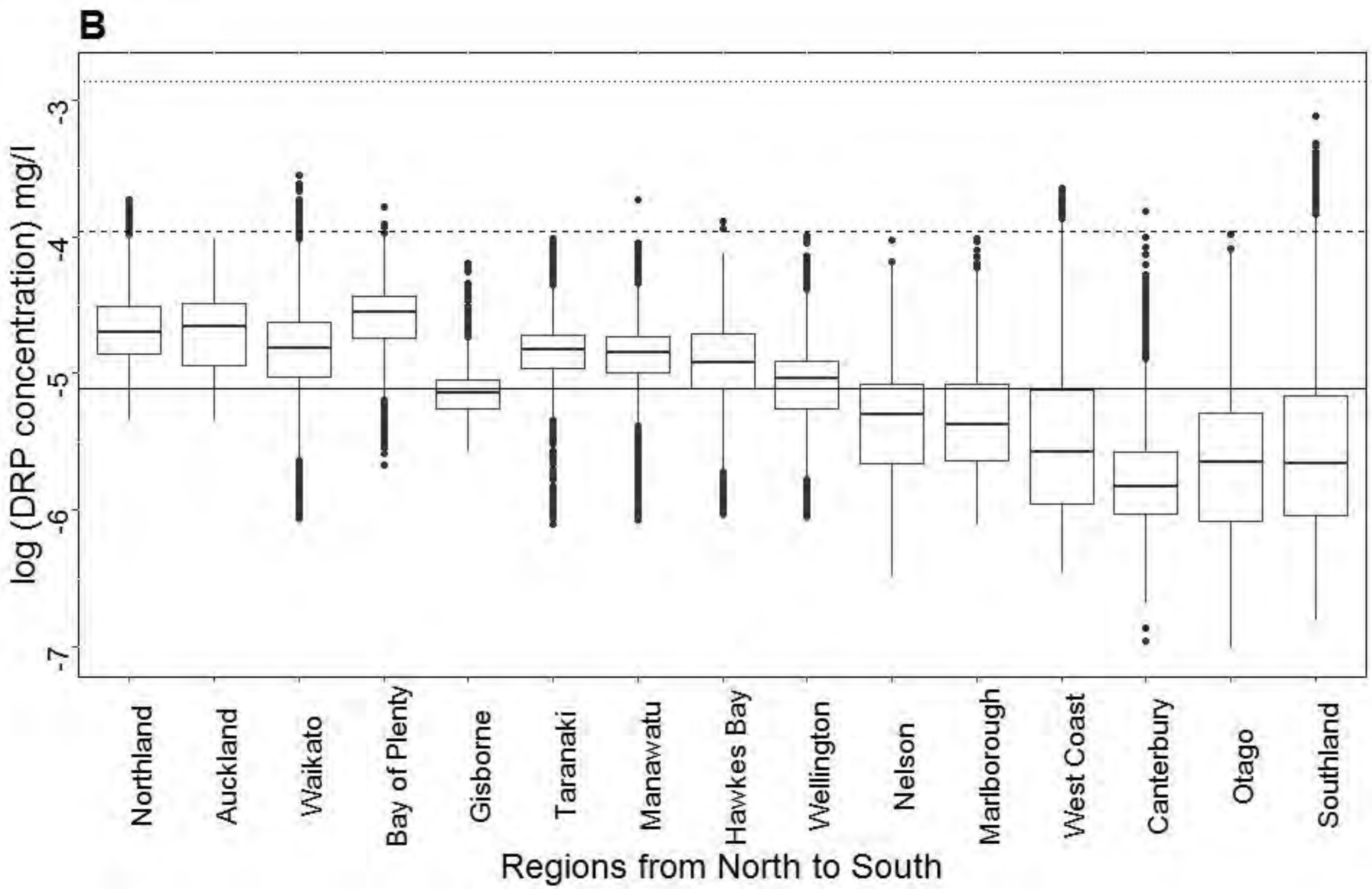
[*] there is one value higher in the report but document implies it is likely to be incorrect

[2] (ANZECC 2000)

[3] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/307788/river-basin-planning-standards.pdf

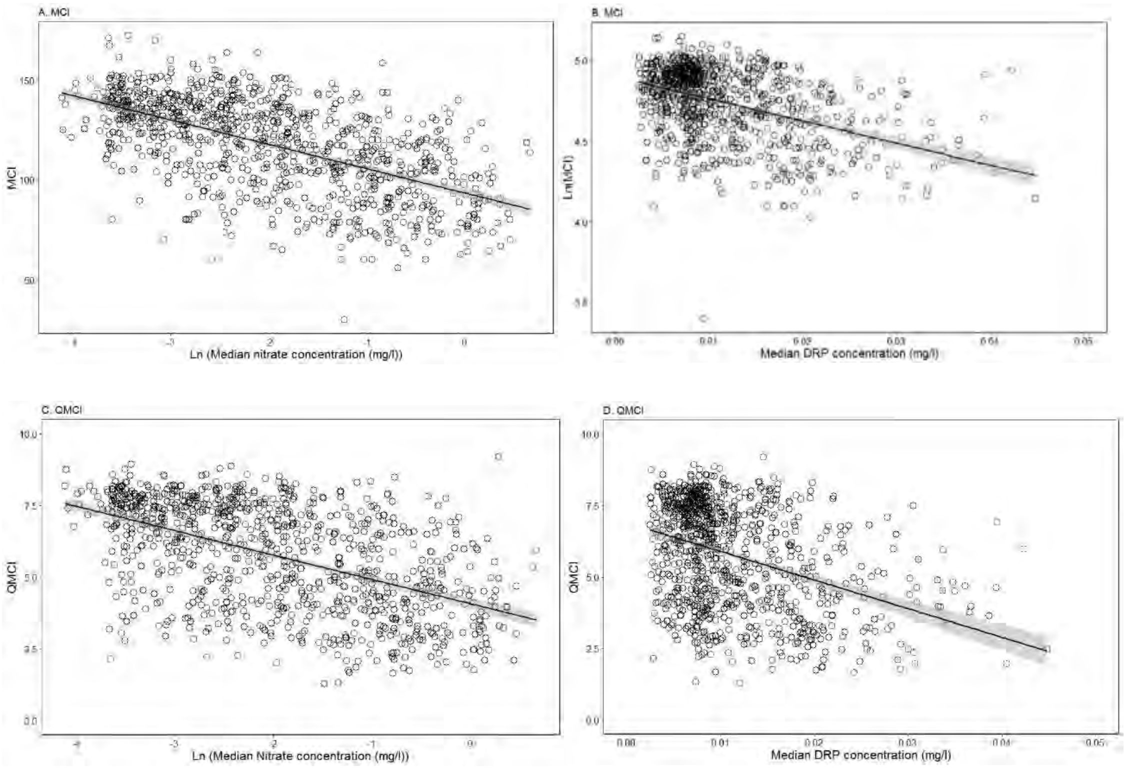
Figure 1 Boxplots of modelled median A) nitrate and B) DRP concentrations from river reaches in the conservation estate in each region of New Zealand from Unwin and Larned (2013). Nutrient thresholds are plotted as solid, dashed and dotted straight lines for nitrate concentrations of 0.10, 0.46 and 1.32 mg/l, respectively and for DRP concentrations of 0.006, 0.019 and 0.057 mg/l, respectively.





B
log (DRP concentration) mg/l
-3
-4
-5
-6
-7
Northland
Auckland
Waikato
Bay of Plenty
Gisborne
Taranaki
Manawatu
Hawkes Bay
Wellington
Nelson
Marlborough
West Coast
Canterbury
Otago
Southland
Regions from North to South

Figure 2 MCI and QMCI measured at 962 North Island rivers and streams as a function of median modelled nitrate and DRP from Unwin and Larned (2013).



Supplementary Material

Numerical nutrient thresholds (mg/l) for each freshwater state (A-D) derived from multiple metrics from a single data source. Average nutrient thresholds (in bold) were used in Table 1. Regression statistics (F statistic, degrees of freedom, probability and r^2) for relationships are provided along with the data source used from Table 1.

Source nutrient dataset	1	1	1		1	1	1	1		4	4		5	5	1
Source ecological dataset	2	2	2		3	3	3	3		4	4		5	5	6
Ecological metric	MCI	QMCI	O/E		MCI	QMCI	EPT animals	EPT taxa		MCI	QMCI		MCI	QMCI	IBI
Nitrate															
Equation	ln y = ln (x+1)	ln y = ln (x+1)	y = ln x		y = ln x	y = ln x	y = ln x	y = ln x		y=lnx	y=lnx		y=x	y=lnx	y=lnx
A/B threshold	0.02	0.00	0.05	**0.02**	0.11	0.10	0.20	0.71	**0.28**	0.06	0.09	**0.08**	0.00	0.00	0.00
B/C threshold	0.45	0.29	0.14	**0.29**	0.58	0.34	0.52	1.92	**0.84**	0.53	0.33	**0.43**	0.60	0.13	0.21

C/D threshold	1.22	0.77	0.39	**0.79**	3.01	1.09	2.51	3.71	**2.58**	4.36	1.20	**2.78**	1.60	9.10	1.54
r^2	0.53	0.54	0.51		0.35	0.27	0.28	0.29		0.37	0.27		0.08	0.04	0.09
F	632224	653084	588600		513	363	377.6	390.6		51.72	32.66		6.78	3.85	3775
df	1,566548	1,566548	1,566548		1,961	1,961	1,961	1,961		1,86	1,86		1,62	1,62	1,392543
p	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001		0.01	0.05	<0.0001
DRP															
Equation	ln y =x	ln y =x	ln y =x		ln y = x	ln y = x	ln y = x	y=x		y=lnx	y = lnx		y=x	Y=lnx	lny=lnx
A/B threshold	0.004	0.003	0.006	**0.004**	0.008	0.006	0.014	0.015	**0.011**	0.005	0.008	**0.007**	0.000	0.000	0.002
B/C threshold	0.016	0.012	0.013	**0.014**	0.022	0.015	0.025	0.022	**0.021**	0.038	0.025	**0.031**	0.023	0.008	0.007
C/D threshold	0.032	0.024	0.019	**0.025**	0.040	0.027	0.055	0.035	**0.039**	0.275	0.079	**0.177**	0.066	0.024	0.014
r^2	0.38	0.39	0.32		0.18	0.15	0.18	0.18		0.54	0.420		0.02	0.04	0.04
F	349187	357979	265000		210.3	165	217.80	211.10		99.83	63.89		2.16	3.61	15770
df	1,566548	1,566548	1,566548		1,961	1,961	1,961	1,961		1.86	1,86		1,62	1,62	1,392543
P	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.001		0.15	0.06	<0.0001