BEFORE THE ENVIRONMENT COURT OF NEW ZEALAND
CHRISTCHURCH REGISTRY
I MUA I TE KŌTI TAIAO O AOTEAROA
KI ŌTAUUTAHI

ENV-2018-CHC-0037
ENV-2018-CHC-0050

UNDER	the Resource Management Act 1991
IN THE MATTER OF	an appeal under clause 14 of Schedule 1 of the RMA in relation to decisions on the Proposed Southland Water and Land Plan
BETWEEN	ROYAL FOREST AND BIRD PROTECTION SOCIETY OF NEW ZEALAND INC **Appellant**
AND	SOUTHLAND FISH AND GAME COUNCIL **Appellant**

REPLY EVIDENCE OF ADAM CANNING

Dated 22 February 2022

AND	SOUTHLAND REGIONAL COUNCIL **Respondent**

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INTRODUCTION

1. My full name is Adam Douglas Canning. I am a Research Scientist, specialising in freshwater ecosystems and water quality, at James Cook University, Queensland, Australia.

2. I hold a Bachelor of Science (First Class Honours) and a Doctor of Philosophy (Ecology) from Massey University. I have published 14 peer-reviewed scientific publications related to freshwater ecology, along with over 30 technical reports and expert evidence on freshwater ecology and water quality. Prior to moving to Australia, I was also a member of the Essential Freshwater Science and Technical Advisory Group (STAG) that advised the Minister for the Environment on New Zealand's recent freshwater policy reforms.

CODE OF CONDUCT

3. I confirm that I have read the code of conduct for expert witnesses as contained in the Environment Court's Practice Note 2014. I have complied with the Code when preparing this written statement and will do so when I give oral evidence before the Court. The data, information, facts, and assumptions I have considered in forming my opinions are set out in this statement to follow. The reasons for the opinions expressed are also set out in the statement to follow. Unless I state otherwise, this evidence is within my sphere of expertise, and I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

4. I was previously employed by Wellington Fish & Game Council as a Research Scientist/Technical Advisor from 2015 to 2019. I do not consider that this gives rise to any conflict of interest. During that employment, and in all my roles, I act as an independent expert.

SCOPE

5. I have been asked by the Royal Forest and Bird Protection Society of New Zealand Inc (Forest & Bird) and the Southland Fish and Game Council

(Fish and Game) to provide evidence in relation to water quality and ecosystem health with respect to the Topic B provisions of the proposed Southland Water and Land Plan (pSWLP). In particular, I have been asked to provide evidence in relation to identification and mapping of degraded water bodies in the Southland Region.

6. My evidence is by way of reply to:

   a. Evidence in chief of Craig Depree for Dairy NZ and Fonterra dated 20 December 2021.

   b. Section 274 party evidence of Craig Depree for Dairy NZ and Fonterra dated 4 February 2022.

   c. Evidence in chief of Antonius Snelder dated 11 February 2022.

7. My evidence draws on the water quality Joint Witness Statement dated 20-22 November 2019. I provided evidence in relation to Topic A of the pSWLP appeals, and I participated in the subsequent joint witness conferencing. Mr Justin Kitto appeared as a witness for Dairy NZ and Fonterra in Topic A and subsequent conferencing, but I am advised that those parties have not subsequently called evidence from Mr Kitto and have substituted Dr Depree. The need for me to give evidence in reply arises as a direct result of Dr Depree's evidence, which departs from the 2019 JWS.

EXECUTIVE SUMMARY

8. My evidence responds to Dr Depree's evidence, which centres around a proposal to only indicate riverine ecosystem health / degradation using the Macroinvertebrate Community Index (MCI). While he also suggests using *E. coli*, this is to indicate human health concerns, rather than ecological.

9. While the MCI is a useful ecological indicator, it is not a sufficiently comprehensive metric to be the only indicator of ecosystem health. Not

only does its derivation result in a substantial loss of information, but it only focuses on one aspect of an ecosystem.

10. Freshwater ecosystems are complex. Using only one indicator, as recommended by Dr Depree, is highly reductionist and 'one size fits all', and an approach I do not support. The approach presented in the JWS is more robust and holistic as it assesses ecosystems using multiple indicators and is in better keeping with the National Policy Statement for Freshwater Management 2020 (NPSFM).

11. I have reviewed the mapping produced in Dr Snelder's evidence and consider this a much more robust alternative to Dr Depree's. Unlike Dr Depree's approach, Dr Snelder's approach is also in line with the JWS.

12. With respect to references in the JWS (November 2021) and some witnesses' evidence to predicted load reductions derived from nutrient criteria to support periphyton targets, I disagree with Dr Depree's criticisms. I reviewed the documentation describing the derivation of these nutrient criteria and concluded that the "nutrient criteria to support periphyton targets are the most robust and defensible currently available" - (Canning, 2021). That remains my opinion.

DR DEPREE'S REDUCTIONIST APPROACH AND THE JWS HOLISTIC APPROACH

13. The NPSFM directs Regional Councils to manage waterbodies and freshwater ecosystems in a way that prioritises their health and well-being and improves where degraded, or otherwise maintains or improves, their ecological health. Improvement is to occur where waterbodies and freshwater ecosystems when they do not meet national bottom-line standards or the community's expectations. The NPS-FM seeks a holistic approach to the assessment and management of ecosystem health. While the NPS-FM (2020) does not use the term 'holistic', holism is demonstrated by requiring that managers consider the five broad components of ecosystem health, being (in no particular order) water quality, water quantity, habitat, aquatic life, and ecological processes. It also prescribes attribute assessments, including national bottom-line

standards, for numerous metrics that each indicate a component of ecosystem health.

14. The NPSFM requires the management of multiple components and multiple assessment attributes because there is no single metric that can possibly indicate the health of an entire ecosystem.

15. Following the Topic A hearing, the Court directed the expert freshwater science witnesses to conference. Conferencing occurred on 14-16 October 2019, and again on 20-22 November 2019. The purpose of the conferencing that occurred on 20-22 November 2019 was:

    a. To finalise attributes and thresholds to be used as the basis of defining degradation on an interim basis.

    b. To identify which of Southland's waterbodies are degraded and by which attributes.

    c. To consider possible linkages to cultural indicators and Ki Uta Ki Tai and Te Mana o Te Wai, based on currently available information from cultural experts.

16. The experts that participated in conferencing to develop the Joint Witness Statement on Water Quality dated 20-22 November 2019 were of the view that, consistent with the NPSFM, multiple metrics are required to indicate the health of a freshwater ecosystem. That view was retained throughout the group's assessment in identifying 'degraded' water bodies. We considered a site as being 'degraded' if it breached at least one of 11 different standards that we considered likely to be generally unacceptable. The use of multiple indicators and standards was guided by what we considered to be the intent of the NPSFM. The standards that we preferred included (but were not limited to) dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP).

17. While Dr Depree expresses an aversion to the phrase 'degraded' on grounds of perception, I use the term as it is accurate in the context that

we (expert witnesses from 2019 conferencing) defined and judged sites as ‘degraded’ if they fell below any standard that we defined.

18. Dr Depree proposes in his evidence that the macroinvertebrate community index (MCI) should be the only attribute by which the need to improve the ecosystem health of a waterbody is assessed. While he claims that this would represent a holistic approach, in my view, *reducing* the number of attributes used in assessing the numerous components of ecosystem health from 11 to one is a highly *reductionistic* approach, not a holistic approach.

19. While the MCI is a useful indicator of ecosystem health, it does not indicate all components of riverine ecosystem health. For example:

    a. It is not uncommon for a stream to have little to no fish life but have an acceptable MCI score. Fish life may be absent for a wide variety of reasons that may not be, or are unlikely to be, impacting macroinvertebrates and reflected in the MCI score, such as migration barriers or the lack of suitable fish habitat.

    b. Habitat required for macroinvertebrates differs from that required for fish, and within both taxonomic groups, habitat will also differ between species and life stages. Not all the species that inform an index will be responding to the potential stressor in the same way, or at the same threshold.

    c. Any index, including the MCI, by its very nature will result in a substantial loss of information as the multiple responses of multiple taxa are condensed into a single number. Figure 1 of Dr Depree’s evidence also shows how numerous responses are collapsed into a single number – it is not possible for a single number to accurately reflect all the information that informed it. It is a useful step for conceptualising a complex ecosystem, but the substantial loss of information needs to be kept in mind when interpreting scores, and multiple indicators assessing multiple different aspects of an ecosystem should be considered when assessing an ecosystem. This loss of information is a key reason why direct correlations between indices and abiotic components, such as nutrient concentrations, are usually weak.

20. Dr Depree states:

"*While it may be useful to divide 'ecosystem health' into 5 components, aquatic life, in my opinion, effectively integrates (i.e. the response to) the other 4 components which can be viewed as 'stressors'."*

21. I disagree with Dr Depree's opinion as it demonstrates a misunderstanding of what an 'ecosystem' is. The term 'ecosystem', coined in 1935, referred to "an integrated system composed of a biotic community, its abiotic environment, and their dynamic interactions" (Salomon, 2008). An ecosystem is also described by Salomon (2008) as "…a biological community, its physical and chemical environment, and the dynamic interactions that link them. Ecosystems can also be thought of as energy transformers and nutrient processors." Clearly, while aquatic life (or the biotic community) is an important aspect, it is not the only aspect., By definition, an ecosystem also includes the physical and chemical environment (abiotic environment), and the interactions between all components (ecological processes). Hydrology (including water quantity), water chemistry (including its quality) and habitat are all key parts of the abiotic environment. Ecological processes are the dynamic interactions, which often show emergent properties - being more than the sum of their parts. They are, by definition, components of an ecosystem, and are not stressors of an ecosystem. Ecosystems are dynamic and often structured by natural disturbances (such as natural floods and droughts), as a part of that, abiotic components will change and that will usually affect biotic components (aquatic life), and the biotic components will change and affect the abiotic components (e.g., habitat and water quality). Being dynamic, ecosystems often fluctuate within the bounds of viability, a balance between having efficiency and having resilience – some have termed this the 'window of vitality (or viability)' (Figure 1; A. Canning & Death, 2018; Jørgensen et al., 2011; Ulanowicz, 2009). Thinking of aquatic life as being separate from an ecosystem is a misinterpretation of what an 'ecosystem' is and, therefore, a misinterpretation of the term as used in the NPSFM.

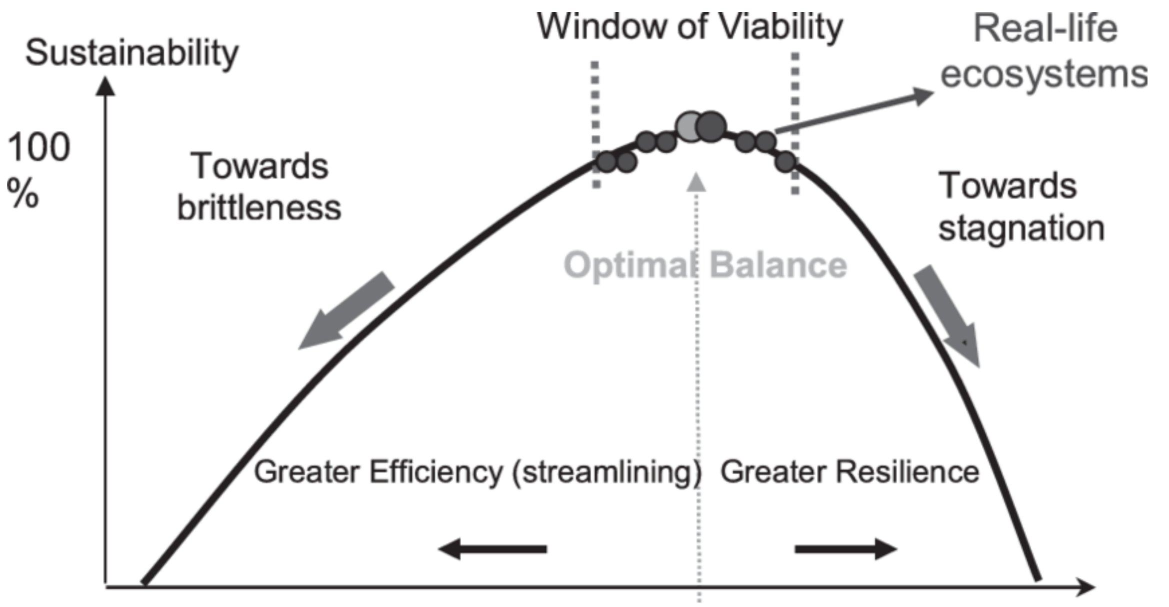

Figure 1. Ecological network analyses have demonstrated that the Relative Ascendency (metric network size and efficiency) of real-world food webs almost always exists within a narrow range, indicating a balance between ecosystem efficiency and ecosystem resilience for long-term sustainability. Healthy ecosystems will naturally fluctuate within this range (Zorach and Ulanowicz, 2003; Belgrano *et al.*, 2004; Ulanowicz, 2009).

22. Dr Depree states:

Macroinvertebrates are reliable indicators of biological health, because they are relatively stationary and respond predictably to a variety of environmental stressors (e.g. water quantity, water quality and habitat quality)."

23. This statement, again, represents a misunderstanding of stream ecology. In addition to the discussion above about abiotic components of an ecosystem not necessarily being 'stressors', the claim that macroinvertebrates are "stationary and respond predictably" is also incorrect. While macroinvertebrates do not migrate in the same way migratory fish do, they do move considerably through drifting down a catchment, adult flight migrations, and within the substrate movement (hyporheic zone, where surface and shallow waters mix within the substrate) (Jacobsen *et al.*, 2008; Mackay, 2011; Johnson *et al.*, 2012). In

addition to macroinvertebrate movements, assemblages can vary substantially with both space and time, due to influences including (but not limited to) life cycle patterns, predator-prey cycles, changes in flow, temperature, substrate distribution and movement, biogeography patterns, nutrient variability, and natural genetic variability. This multitude of interacting factors makes macroinvertebrates difficult to reliably predict. Ecosystems should not be thought of like engineered mechanical systems that are highly deterministic, rather indeterminism is the rule as variation is natural and prevails.

24. That is not to say that macroinvertebrates are not useful, that they cannot be modelled, or that we should not bother managing anthropogenic stressors upon them. Rather, focusing solely on one aspect of an ecosystem is risky and could give an entirely misleading perception of an ecosystem's health. Managing ecosystems requires an appreciation of natural variability and the extent to which it occurs. Adopting a precautionary approach where ecosystems are assessed using multiple metrics covering multiple components of the ecosystem would be best practice, and this is the approach adopted by the experts in preparing the JWS, which I continue to support (Boulton, 1999; Karr, 1999; O'Brien *et al.*, 2016). This is also in keeping with that of the broader scientific community, including a review by O'Brien et al (2016) stating:

"*We suggest indicators used in ecosystem health assessments include at least one biological indicator species or group plus other chemical and/or physical indicators chosen to reflect the key ecological linkages of the system (identified by conceptual model), the spatial scales over which they operate, and the objectives of the assessment, such as, to detect early warning signs of degradation, or assess and diagnose compliance*."

25. Dr Depree states:

"*Although I am not a stream ecologist, I believe there would be general consensus that macroinvertebrates are the most widely used indicator of stream ecosystem health.*"

26. While Dr Depree states that he is “not a stream ecologist”, much of his evidence comprises his opinions on matters that require stream ecology expertise, including all the discussion on the MCI and macroinvertebrates. As a stream ecologist, I disagree with Dr Depree’s assumption and make several points in response:

   a. Macroinvertebrates are a biological taxonomic group, not a single indicator. Indicators are derived by ecologists from information, such as presence and abundance, garnered from surveying macroinvertebrates, and are collated into an indicator that has been designed for a particular purpose. There are many indicators that use information from macroinvertebrate surveys. The MCI is just one macroinvertebrate indicator. For context, Clapcott et al (2017) identified 30 macroinvertebrate-based indicators for consideration in the NPSFM, all indicating different aspects of ecosystem health, with the NPSFM ultimately adopting three macroinvertebrate-based indicators (not one as proposed by Dr Depree). A University of Otago report provided to Environment Southland by prominent freshwater ecologists on assessing stream health in Southland also recommending using multiple metrics, and simply stated:

      “*It would be unwise only to rely on MCI and EPT estimations...”* (Wagenhoff, Matthaei and Townsend, 2008)

   b. In New Zealand, water quality-based indicators of ecosystem health are assessed at many more sites and more frequently than macroinvertebrates. That is not to say that macroinvertebrates are unimportant, they certainly are, but they only constitute one aspect of the ecosystem.

27. Paragraphs 4.7-4.15 of Dr Depree’s evidence downplays the idea that management of nutrients is important in improving or maintaining freshwater quality. This minimisation of the impact of nutrients on freshwater health is made more convenient and simpler if water bodies are only assessed using the MCI, which some may argue have a weaker relationship with nutrient concentrations than periphyton. If the view is

taken that nutrients should only be set to achieve aquatic life objectives, reducing from multiple aquatic life objectives to only one then reduces the perceived need for nutrient limits. If an argument is then made that nutrients poorly correlate with the chosen aquatic life metric, then some may argue that nutrient criteria are not necessary at all. However, nutrients would still be having ecological impacts, rather they may not be readily detected by the chosen assessment metric. Nutrients can affect aquatic ecosystems in ways that are often not easily measured, and noise in relationships will arise.

28. Briefly, nutrient inputs can increase algal and microbial production directly, which can cause a range of cascading impacts that are difficult to reliably predict. Increased algal and microbial growth can promote the growth of primary consumers, such as invertebrates, either by increasing food supply for algivores, or through conditioning nutrient-poor organic matter for detritivores (Elser *et al.*, 2000; Ferreira *et al.*, 2015; Dodds and Smith, 2016). The increased metabolic activity and decomposition can increase hypoxic conditions; alter the availability of course and fine particulate organic matter for microbes, invertebrates and downstream ecosystems (Stelzer, Heffernan and Likens, 2003; Benstead *et al.*, 2009; Davis *et al.*, 2010); and alter greenhouse gas emissions and carbon storage in aquatic environments (Macreadie *et al.*, 2017). At very high concentrations, nutrients can be directly toxic to invertebrates and fish by disrupting numerous metabolic pathways (Camargo and Alonso, 2006; Romano and Zeng, 2013). Nutrient enrichment can also alter the intensity and incidence of pathogenic infections, often by exacerbating infections of generalist parasites with direct or simple lifecycles (Frost, Ebert and Smith, 2008; Johnson *et al.*, 2010). As a result, nutrients can adversely impact, directly or indirectly entire ecological communities, including their overall predator-prey cycles and network stability. Nutrient criteria are typically adopted to reduce the prevalence of adverse impacts.

29. While it is true that direct correlations between MCI and nutrients are weak, that does not mean nutrients and their management are unimportant. Dr Depree emphasises the need for improvements in habitat quality, which I also agree with, but habitat quality is also likely to have weak correlations with MCI. Habitat improvements should not be thought

of as an alternative to reducing nutrient inputs to waterbodies, but complementary. Stressors should be reduced on numerous fronts to maximise the probability of improving MCI scores and freshwater ecosystem health.

30. Management of nitrogen, in particular, is critical in managing freshwater quality. While multiple factors can affect MCI scores, and while direct correlations between MCI and nutrients are weak, when other factors are accounted for the influence of nutrients becomes more apparent. When modelling a large MCI dataset for STAG using random forests, a cross-validated correlation of 0.80 was achieved (indicating a well-performing model) with nitrate-nitrogen (often the dominant form of DIN) concentrations being the most influential factor in predicting MCI scores by a considerable margin. This was followed by flow variability, temperature, slope and riparian cover (Canning, 2020). This is also in accordance with other analysis (Wagenhoff *et al.*, 2011, 2017).

31. Dr Depree uses a quote from five of the 19 scientists on the STAG to support his opinion downplaying the rule of nutrients in freshwater health. His implication is that the STAG, or at least some of its members, did not support management of nitrogen through the NOF. Dr Depree was not a member of the STAG. As a member of the STAG that was directly involved in all discussions related to the NOF nutrient attributes, I make several points in response:

    a. The majority of the STAG (14 out of 19 members) stated that:

       "…the methodologies and data sets used to derive the proposed criteria, bottom lines and thresholds for DIN and DRP for rivers are scientifically rigorous, well explained and well justified, have been discussed at length by the STAG and peer reviewed independently by Professor David Hamilton who generally supported the approach adopted." (Essential Freshwater Science and Technical Advisory Group, 2019b).

    b. The five members who expressed any reservations about inclusion of a DIN attribute in the NOF had different views from each other.

> Some were of the view that the proposed national bottom lines were not sufficiently *stringent* to warrant their support, and were concerned that they would lead to inadequate protection for many rivers. They sought tighter and more spatially nuanced numerics and were concerned that a single national bottom-line *"…could have the effect of not triggering a management response in rivers where this is necessary to protect ecosystem health*" (Essential Freshwater Science and Technical Advisory Group, 2019b). That opinion is distinctly different from not supporting "the introduction of DIN and DRP thresholds".

32. Since the STAG discussions, I have published further work, in an international, independently peer-reviewed academic journal, that derived DIN and DRP limits to support the achievement of the NPSFM macroinvertebrate (MCI) objectives nationally (Canning, Joy and Death, 2021). While there are many different approaches available for establishing nutrient criteria, the approach I used - 'minimisation of mismatch' - is one recommended by the EU Best Practice document for establishing nutrient concentrations (Phillips *et al.*, 2018) and has been used abroad (Phillips *et al.*, 2019; Poikane *et al.*, 2019, 2021). The minimisation-of-mismatch approach seeks to identify nutrient criteria that are most likely to pass or fail when the ecological indicators also pass or fail respectively. Essentially it aimed to identify concentrations that maximised achieving a desired macroinvertebrate target, while minimising the probability of being too stringent or too weak. That analysis revealed nutrient criteria with a high probability of achieving desired macroinvertebrate objectives, with mismatch rates typically ranging 10-20% (Canning, Joy and Death, 2021).

33. The median DIN concentration I identified for supporting the MCI bottom-line of 90 was 1.07 mg/L (range: 0.93-1.21 mg/L), which is very similar to the DIN concentration of 1 mg/L used to define "degraded" in the 2019 JWS, and that recommended by STAG (Essential Freshwater Science and Technical Advisory Group, 2019a, 2019b; Canning, 2020).

34. In conclusion, freshwater ecosystems are complex and I do not support the highly reductionist, one size fits all, approach recommended by Dr

Depree which relies only on MCI to assess whether a waterbody is degraded in terms of ecosystem health.

35. Dr Depree objects (paragrapsh 5, 6.1 to 6.10 and Appendix 1) to witnesses referring to the modelled contaminant load reductions produced as part of the preparation of Plan Change Tuatahi (referred to in the Science JWS (November 2021) and some evidence). Dr Depree did not participate in that expert conferencing either. Dr Snelder was the lead author in deriving the nutrient criteria to support periphyton objectives in Southland, which is the basis for the indicative load reductions. I recently reviewed the documentation describing the derivation of these nutrient criteria, and concluded that the "nutrient criteria to support periphyton targets are the most robust and defensible currently available" - (Canning, 2021 – Attached as **Appendix 1**). That remains my opinion, and I disagree with Dr Depree's criticisms.

EVIDENCE BY DR ANTONIUS SNELDER

36. I agree with Dr Snelder that the term 'degraded' invokes a value judgement that goes beyond science, and I am also comfortable with approach to define 'degraded' generally adopting the 'national bottom-line' approach[1]. I am also comfortable with the nutrient criteria used in the analysis as I, in agreement with Dr Snelder, consider the DIN and DRP concentrations generally consistent with the levels required to manage periphyton at the national bottom-line threshold.

37. I consider Dr Snelder's approach to mapping degraded catchments, using multiple metrics that have been modelled reliably and thresholds from the 2019 JWS, and using estuarine thresholds, as a much more robust approach than that adopted by Dr Depree. The approach is consistent with that outlined in the JWS, and in accordance with the precautionary principle and generally accepted recommended practice for assessing ecosystem health.

[1] Except where some experts, including myself, preferred to use the A-band for nutrient toxicity (as a precautionary approach) given the substantial lack of data available to inform the NPS toxicity thresholds.

Adam Canning

22 February 2022

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Appendix 1

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21st of December 2021

Ref: Setting nutrients to support the Southland periphyton targets

MEMORANDUM

To whom it may concern,

In this memorandum, I provide my views on the debate between Southland Regional Council and DairyNZ on the appropriate derivation of nutrient criteria to support achieving Southland's periphyton targets for rivers. I do not comment on the appropriateness of the chosen periphyton objectives nor the appropriateness of the derived nutrient criteria to support ecosystem health objectives other than periphyton, such as for macroinvertebrates and fish.

In my opinion, nutrient criteria to support periphyton targets that are based on Snelder, Moore and Kilroy (2019), as recalibrated in Ministry for the Environment (Ministry for the Environment, 2020), are the most robust and defensible currently available. While the methodology is sound, the final nutrient criteria adopted would be dependent on (a) the level of risk of periphyton target exceedance that decision makers are willing to accept, and (b) the nutrient criteria needs to support other ecosystem health objectives (e.g., macroinvertebrates and downstream environments).

Snelder, Moore and Kilroy (2019) is a published, internationally peer reviewed, journal article that presents total nitrogen (TN) and dissolved reactive phosphorus (DRP) target concentrations to support achieving desired periphyton objectives across New Zealand. The authors used a national dataset of monthly nutrient concentrations and periphyton biomass, temperature, flow, flood frequency, substrate size, solar radiation and absorption, water clarity and riparian shade to model and validate the probability of achieving (and risk of not achieving) desired periphyton targets. The models were then used to derive nutrient criteria look-up tables to identify suitable nutrient criteria, dependent on the desired periphyton target, the river class (groups rivers based on like climatic and topographical characteristics), and the level of risk of not achieving the desired periphyton targets that decision makers are willing to accept. As periphyton communities are biological they have inherent uncertainty, that means they cannot be modelled in a deterministic (or mechanistic) way to reliably predict a guaranteed

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outcome in response to management actions, such as nutrient reductions. Modelling the probability of outcome is a sensible, pragmatic way of deriving nutrient criteria, though it also relies on decision makers making a socio-political judgement on the acceptable level of precaution. More stringent nutrient criteria have lower risks of periphyton non-compliance.

In doing so, I have reviewed the following relevant items:

- Norton, N. & Wilson, K. (2019). *Developing draft freshwater objectives for Southland*. Environment Southland Regional Council. Invercargill, New Zealand.
- Wilson, K., McLachlan, S., & Davie, T. (2020). *Community values for Southland's freshwater management units*. Environment Southland Regional Council. Invercargill, New Zealand.
- Depree, C. & Thiange, C. (2021). *Technical review of work undertaken to inform nutrient reduction requirements to achieve freshwater objectives in Southland catchments.* DairyNZ. Hamilton, New Zealand.
- De Silva, N., & Hodson, R. (2020). *Drivers of periphyton in the Southland region.* Environment Southland Regional Council. Invercargill, New Zealand.
- Ministry for the Environment (2020) Action for healthy waterways: Guidance on look-up tables for setting nutrient targets for periphyton. Wellington, New Zealand.
- Snelder, T. H., Moore, C. & Kilroy, C. (2019) 'Nutrient Concentration Targets to Achieve Periphyton Biomass Objectives Incorporating Uncertainties', JAWRA Journal of the American Water Resources Association. John Wiley & Sons, Ltd (10.1111), 0(0). doi: 10.1111/1752-1688.12794.
- Snelder, T. (2020). *Assessment of nutrient load reductions to achieve freshwater objectives in the rivers, lakes and estuaries of Southland: To inform the Southland Regional Forum process.* Land Water People. Lyttleton, New Zealand.
- Zoom meeting recording discussing DairyNZ's feedback on Southland's proposed nutrient criteria to support periphyton. File: "Zoom_peripyton_20201113.mp3".
- Cox, T., Kerr, T., Snelder, T., Rodway, E., & Wilson, K. (2020). *Southland region catchment nutrient models: Supporting the Southland Regional Forum process*. LWP. Lyttleton, New Zealand.
- Wilson, K. & Norton, N. (2021). *Memorandum: Recommended actions arising from stakeholder feedback on science reports estimating nutrient load reductions to achieve freshwater objectives.* Environment Southland Regional Council. Invercargill, New Zealand.

I outline the main arguments presented by DairyNZ and my response:

Issue one: Nutrient criteria for periphyton should not be applied to lowland soft-bed streams

There is an increasing view that nutrient criteria should not exist for soft-bed streams as periphyton requires a hard substrate to grow on, effectively seen as a "get out of jail free card" for those opposed to nutrient regulation. This view, however, demonstrates a misunderstanding of what periphyton is and where it grows. Periphyton is defined as "the microfloral community living attached to the surfaces of submerged objects in water" (Wetzel, 2001; Azim *et al.*, 2005). Periphyton can be sub-classified depending where it grows: termed 'epiphyton' if it is attached to aquatic plants, 'epipelon' if attached to sedment/mud/silt, 'epixylon' if attached to wood, 'epilithon' if attached to rock or 'epipsammon' if attached to sand (Wetzel, 2001; Azim *et al.*, 2005). The argument here incorrectly assumes that periphyton and epilithon are exactly the same, rather epilithon is a category periphyton. Furthermore, although state of environment monitoring typically uses a method that measures epilithon, it does not negate the presence of other categories that are unmeasured. Periphyton is present in all rivers, regardless of whether it is bound to rocks, plants, mud or other substrates. The National Policy Statement for Freshwater Management (NPS-FM) 2020 also does not make the distinction soft and hard bottomed rivers.

While the nutrient criteria derived use only data from epilithon surveys, it is the only periphyton-nutrient relationship to date, and should be used as a precaution and alongside nutrient criteria for other objectives (such as for the estuary, dissolved oxygen, ecosystem metabolism and macroinvertebrates).

Issue two: Models have poor predictive performance and require regional validation

The models provided by Snelder, Moore and Kilroy (2019) have already been validated nationally including data from Southland. Overall, the models performed well. If further work were to be undertaken to improve the models, then this work could: (1) incorporate new data from across the country as it collected; (2) examine different nutrient summary statistics, beyond the median; (3) use more nuanced hydrological data, accounting for the days of accrual; and (4) use data collected from all forms of periphyton, not just that growing on rocks. Some may be of the view that only data from the Southland region should be used, however, I do not share that view. When modelling it is best use data across the spectrum of environmental conditions where the model will be used. If only regional data is used, then it is probable that some river classes will not have periphyton survey data collected at numerous sites across the nutrient gradient. As a result, there would be low confidence in a model that was required to extrapolate nutrient criteria beyond the range of the data that informed it. If the right climatic, geological and hydrological variables are included in the model, then national datasets allow for more data to be included and more environmental gradients to be captured, minimising the need for gross extrapolation.

Issue three: Nutrient criteria for a broader range of risk levels for periphyton non-compliance should be considered

Deciding the level of risk for periphyton non-compliance is ultimately a normative decision that depends on the values being managed for and the ambition of objectives. It can and should, however, be informed by science as the risk of non-compliance needs to be weighed against the ecological impacts of non-compliance. Furthermore, choosing a high-risk level may, given the logarithmic relationship between periphyton and nutrients, lead to nutrient criteria that are ineffectual at driving improvements in periphyton biomass. In my view, nutrient criteria should rely on multiple lines of evidence, considering all the objectives that could be affected by nutrients. Nutrient criteria for other objectives may need to be more stringent than those required for periphyton and/or have parity with an acceptable risk of periphyton non-compliance. For example, suitable nutrient criteria for an MCI score of 100 would be ~0.4 mg DIN/L (Canning, Joy and Death, 2021), which is slightly more stringent than (but very close to), the ~0.5 mg N/L required to support achieving a 20% risk of periphyton non-compliance using a chlorophyll *a* objective of 200 mg/m^2 at the 92nd percentile, in a cool dry lowland river (such as the Oreti). If a 30% risk of non-compliance was chosen, then ~1.5 mg N/L would be adopted, grossly exceeding that required for a healthy macroinvertebrate community. Choosing a risk-level that gives nutrient criteria on par with those needed for other components of the ecosystem can give confidence that protection is adequate.

In addition to being a normative decision, I have low confidence in the predictions for high risk levels because the nutrient criteria derived at a 30% non-compliance level have very high concentrations that indicate extrapolations beyond the range of most of the data.

Issue four: The random forest model by Kilroy et al (2019) *should be considered for setting nutrient criteria*

Even with the inclusion of many potential explanatory variables, the random forest models by Kilroy et al (2019) performed poorly in predicting the chlorophyll *a* biomass at the 92nd percentile, having R^2 values at 0.37, and random forests are unable to predict outside the range of data use to inform the models (the authors highlight the biases in the dataset used and suggest alternative methods). The report by Kilroy et al (2019) has also not calculated nutrient criteria from their random forests, so values are not readily available and would require further work. Given the uncertainty in predicting periphyton, the approach already adopted allows for uncertainty in periphyton compliance to be considered in decision making.

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Literature cited

Azim, M.E. *et al.* (2005) *Periphyton: ecology, exploitation and management*. CABI.
Canning, A.D., Joy, M.K. and Death, R.G. (2021) "Nutrient criteria to achieve New Zealand's riverine macroinvertebrate targets," *PeerJ*, 9, p. e11556. doi:10.7717/peerj.11556.
Kilroy, C. *et al.* (2019) *Modelling periphyton in New Zealand rivers. 1. An analysis of current data and development of national predictions*. Christchurch, New Zealand.
Ministry for the Environment (2020) *Action for healthy waterways: Guidance on look-up tables for setting nutrient targets for periphyton*. Wellington, New Zealand.
Snelder, T.H., Moore, C. and Kilroy, C. (2019) "Nutrient Concentration Targets to Achieve Periphyton Biomass Objectives Incorporating Uncertainties," *JAWRA Journal of the American Water Resources Association*, 0(0). doi:10.1111/1752-1688.12794.
Wetzel, R.G. (2001) *Limnology: lake and river ecosystems*. Gulf Professional Publishing.