Macroinvertebrate action plan workshop

Prepared for DairyNZ

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Executive summary

The National Policy Statement for Freshwater Management 2020 (NPS-FM 2020) provides a management framework where regional councils are required to set target states for the region's rivers for a range of attributes (measurable characteristics) that are indicators of aquatic ecosystem health; ecosystem health is a compulsory value in the NPS-FM. The NPS-FM identifies three approaches to meet target states of specified, compulsory attributes:

- limits on resource use and nutrient application,
- conditions on resource consents, and
- action plans.

Among the attributes to be used to assess ecosystem health, three are based on benthic macroinvertebrates: the Macroinvertebrate Community Index (MCI), based on presence and absence of macroinvertebrate taxa assigned tolerance scores to organic pollution; its quantitative variant (QMCI); and the Average Score Per Metric (ASPM), which is a combination of the MCI and the number and percentage abundance of sensitive Ephemeroptera, Plecoptera and Trichoptera taxa. Although the MCI indicates overall ecosystem health, the complicated pathways through which stressors impact macroinvertebrate communities makes it difficult to separate the impacts of individual stressors on MCI values.

The macroinvertebrate attributes are to be managed through action plans. Under the NPS-FM, action plans can include restoration actions, such as creation of riparian buffers or implementation of constructed wetlands, in addition to setting limits to resource use. Action plans require a target attribute value to be set and a timeframe within which it is to be achieved. Action plans are developed to improve stream health (attribute state) and this requires identification of key stressors causing degradation, actions to improve attribute state, and a plan to monitor the effectiveness of the mitigations.

Action plans are a new requirement, so there is little guidance (beyond that stated in the NPS-FM) about how they can be implemented. DairyNZ seeks to better understand how action plans could be developed to respond to degraded or degrading macroinvertebrate attributes in pastoral catchments where multiple stressors are likely to be in effect. DairyNZ contracted NIWA to assemble a group of macroinvertebrate experts from councils and other organisations at a workshop to provide guidance. This report summarises the workshop outcomes and provides a brief literature review.

At the time of writing this report, selected Regional council participants (Canterbury, Waikato, Horizons and Taranaki) indicated that they have prioritised other requirements under the NPS-FM (e.g., ensuring monitoring networks are representative of the region and setting target attribute states), and that considering action plan requirements remains to be done.

We provide recommendations for three key steps of action plans developed to improve macroinvertebrate attribute values as identified in the NPS-FM below. The three steps are: 1) identification of key stressors causing degradation 2) identifying and implementing actions to improve attribute state, and 3) monitoring the effectiveness of the mitigations.

Identifying key stressors

The potential stressors in pastoral catchments include: a lack of shade leading to increased water temperature and periphyton growth, deposited and suspended fine sediment, increased nutrient concentrations impacting periphyton growth or having direct toxic effects on macroinvertebrates, a lack of instream habitat or channelisation, instream channel works and altered flow regimes due to abstraction. We did not consider flow changes directly in this report. The NPS-FM requires that environmental flows are set to achieve environmental outcomes. Although potential stressors can be readily identified for macroinvertebrate communities, as indicated above, multiple stressor situations can make identifying causative stressors and choosing appropriate mitigation actions to improve macroinvertebrate attribute states challenging.

We considered that two methods would be useful for identifying the stressors that affect macroinvertebrates at broad and small scales. Correlative studies of stressors and macroinvertebrate response metrics using space-for-time substitution assist in identifying broad-scale patterns in stressor predominance and identifying potential causative factors across a region, which helps in setting regional plans by answering questions such as 'how big and widespread are the problems in a region? and 'what are the major causes of the problems?'

Identifying key stressors at sites with degraded macroinvertebrate attributes is a prerequisite for implementing effective mitigation strategies. We recommend that the identification process have three steps:

1. Use of macroinvertebrate data (metrics and raw taxonomic data) to validate the poor state and investigate changes in community structure and function.

2. Using stressor-response relationships and critical stressor thresholds known to impact macroinvertebrate communities (e.g., toxic concentrations of nitrate, or deposited sediment cover over 20-30% cover) and the bands in the NPS-FM for other attributes likely to contribute to poor macroinvertebrate state (e.g., periphyton, dissolved oxygen, suspended sediment) to identify any likely impacts.

3. Undertaking a catchment investigation to look for potential causes of degradation and constraints to the ability of macroinvertebrate communities to respond to mitigation actions (for example, distance to a source of macroinvertebrates able to recolonise the impacted river reach).

Potential mitigation actions

Mitigation actions designed to improve macroinvertebrate communities can be broadly grouped into terrestrial and in-stream mitigations. Terrestrial mitigations include actions to reduce nutrient or sediment inputs, such as stock exclusion, changes to farm management to minimise contaminant loss into waterways, and riparian planting. Examples of in-stream mitigation actions include removal of deposited sediment or restoration of instream habitat such as engineering riffles or adding wood or boulders as substrate.

As with most studies of stream restoration projects, we found mixed evidence for beneficial effects of mitigation actions on macroinvertebrate communities. Lack of success was commonly attributed to constraints such as a lack of macroinvertebrate recolonisation, mitigation actions that either targeted the wrong stressor or did not work as expected, mismatches between the scale of restoration and the scale of degradation, and inadequate or unsuitable monitoring. Restoration success occurred when clear restoration goals were set, the right stressors were targeted at appropriate scales, and constraining factors such as a lack of colonists were either not present or were mitigated in some way. The importance of integrated management and having regard for ki uta ki tai was highlighted, where mitigation plans must consider the entire catchment.

Monitoring mitigation actions

Monitoring the success of mitigation actions in reducing stressors and in improving macroinvertebrate communities is a crucial aspect of adaptive management. Over time, the records of outcomes of multiple restoration projects, will help in deciding which mitigation measures work best given different river types, levels of degradation and restoration strategies. Unfortunately, monitoring in restoration projects is often lacking or inadequate. Ideally, monitoring should follow a Before-After-Control-Impact (BACI) design, with control and impact sites monitored before and after mitigation actions for an adequate length of time. However, identifying suitable control sites can be challenging and creating additional monitoring locations was raised as a potential financial challenge by regional council staff at the workshop. We recommend sharing of data and information derived from mitigation monitoring, both within and between councils, as this would help enable adaptive management and expedite improvement in the effectiveness of mitigation actions. In addition to applying an effective monitoring design, careful consideration needs to be given to the variables being measured and the methods used to make sure that changes in relevant stressors as well as in macroinvertebrate communities are identified.

Topics for further investigation

The workshop discussion raised several topics that were outside the scope of this project, but that warrant further investigation or development of guidance:

1. Identifying the magnitude, degree of uncertainty, ecological impact and causes of deteriorating trends in attributes necessitating action plans is required by the NPS-FM but is very challenging.
2. Identifying appropriate target attribute states for developed catchments is challenging because few suitable reference sites exist, and our understanding of what is possible in terms of restoring already degraded sites is limited.
3. It is important to ensure that a council's monitoring network is representative of the region and individual Freshwater Management Units (FMUs) because monitoring of these sites will be used to set limits and actions for the FMU.
4. Trade-offs between the cost of additional monitoring of restored reaches and the requirements of the NPS-FM will likely be necessary.
5. We have considered macroinvertebrates in this report – in practice, multiple attributes will need to be considered simultaneously. Awareness that action plans will be developed for multiple attributes (e.g., fish, macroinvertebrates, periphyton, deposited sediment) is important.

Conclusions

The nature of macroinvertebrate attributes and communities means that we must accept complicated relationships with potential stressors. While these complex stressor-response relationships make the task of improving degraded macroinvertebrate conditions in multiple stressor environments difficult, we do not need perfect knowledge to make progress. Making decisions with the best knowledge available can lead to great gains if paired with effective post-mitigation monitoring that allows for adaptive management by learning from mitigation successes and failures.

1 Background

The National Policy Statement for Freshwater Management (NPS-FM, New Zealand Government 2020) provides a management framework where regional councils are required to set environmental outcomes for their Freshwater Management Units (FMUs) for the compulsory ecosystem health value (and other values). From these environmental outcomes, councils must develop target states for at least the compulsory attributes (measurable characteristics) in the National Objectives Framework (NOF). As a minimum, target attribute states must be set at the national bottom line or current state for each attribute. In the 2020 update of the NPS-FM, new attributes were added, and the distinction was made between attributes requiring limit setting and attributes requiring action plans (see full list of compulsory attributes for rivers in Table 1-1). Once limits on resource use have been set, action plans and resource consents (including consent conditions) can be used to achieve the target states.

Macroinvertebrate metrics were added as attributes requiring action plans for the ecosystem health value. These metrics are:

- the Quantitative Macroinvertebrate Community Index (QMCI),
- the Macroinvertebrate Community Index (MCI, Stark and Maxted 2007b), and
- Average Score Per Metric (ASPM) (Collier 2008).

Table 1-1: Compulsory attributes for rivers that require either limits or action plans under the NPS-FM. Regional councils, in consultation with communities and tangata whenua, will identify other relevant attributes as required.

Attributes requiring limits	Attributes requiring action plans
Periphyton	Macroinvertebrates
Ammonia	Deposited fine sediment
Nitrate	Dissolved oxygen
Dissolved oxygen (below point sources)	Fish
Suspended fine sediment	Dissolved reactive phosphorus
E. coli (year-round)	Ecosystem metabolism
	E. coli (primary contact sites during the bathing season)

Action plans can be implemented in two scenarios:

1. When councils set target attribute states, an action plan can be used to outline how they will meet identified attribute targets within specified timeframes.
2. Under clause 3.20 of the NPS-FM, if monitoring identifies either that individual, multiple or component parts of FMUs are 'degraded' (i.e., not meeting national

bottom-line or target attribute states) or are 'degrading' (i.e., a deteriorating trend is detected that is due to a non-natural process), an action plan can be used to identify how the attribute state will be improved. The alternative to an action plan is changes to the regional plan.

In general, establishing an action plan in response to not meeting freshwater objectives must include methods to identify the cause of the degradation, actions to address those causes and a plan to monitor the effectiveness of any mitigation actions. The specific relevant guidance for how to develop an action plan is set out in clauses 3.15 (Preparing action plans) and 3.20 (Responding to degradation) of the NPS-FM. Requirements include:

- Clause 3.15.2 - an action plan may describe both regulatory measures and non-regulatory measures;
- Clause 3.20.2 - any action taken in response to a deteriorating trend must be proportionate to the likelihood and magnitude of the trend, the risk of adverse effects on the environment, and the risk of not achieving target attribute states;
- Clause 3.20.3 - every action plan prepared in response to degradation must include actions to identify the causes of the deterioration, methods to address those causes, and an evaluation of the effectiveness of the methods.

The MCI has been widely used to assess freshwater ecosystem health in New Zealand. It is commonly correlated with the proportion of native landcover upstream (Death and Collier 2010; Clapcott and Goodwin 2014) and with broad gradients in nutrient enrichment, organic pollution and sedimentation (e.g., Clapcott and Goodwin 2014). However, causative relationships linking changes in MCI (and its variants) to variation in individual stressors can be difficult to identify where multiple stressors are present (Clapcott and Goodwin 2014; Collier et al. 2014; Clapcott et al. 2017b). This means that identifying the cause of degradation of macroinvertebrate communities and actions that could address the degradation (as required by action plans) is challenging, particularly where multiple stressors are in effect.

Development of action plans is a recent requirement and guidance regarding preparation of action plans in response to degradation is limited. DairyNZ is interested in understanding how action plans could be prepared in response to degraded or degrading macroinvertebrate attributes in pastoral catchments, where typically multiple stressors are in effect. DairyNZ contracted NIWA to 1) organise a workshop with macroinvertebrate experts from councils and other organisations aimed at collating existing knowledge and discussing the challenges and potential solutions for identifying causes of degradation and applying actions to improve macroinvertebrate community health as required under clause 3.20 of the NPS-FM, and 2) provide a written report that summarises the learnings from the workshops and briefly review the literature to provide guidance[1].

1.1 Scope

The goal of this report is to provide recommendations for developing action plans in response to degraded macroinvertebrate attribute states (under clause 3.20) in pastoral rivers where multiple stressors are likely to operate.

[1] While individual participants did not agree on all points, this report summarises the issues discussed and the majority consensus reached.

The guidance is focused on three keys points of clause 3.20.3 in the NPS-FM, particularly:

1. potential methods that could be used to identify causes of degradation (i.e., causative stressors) in agricultural catchments,
2. mitigation actions that can be used to address the causes of degradation, and that are likely to improve macroinvertebrate community state, and
3. methods to evaluate the effectiveness of the mitigation actions used to improve macroinvertebrate communities

As requested by DairyNZ, the scope of the project was limited to agricultural catchments where the land use was predominantly pastoral. Furthermore, the impacts of water abstraction are not directly considered in this report as the NPS-FM requires that environmental flows be set at a level that meets environmental outcomes. The contract between DairyNZ and NIWA specified the scope of this report to be focused on addressing the following specific questions:

1. What are the potential stressors of macroinvertebrate communities in pastoral catchments?
2. In order to identify the causes of degradation (i.e., causative stressors) of macroinvertebrate communities in pastoral catchments:
   i. what quantitative and qualitative statistical and inferential methods can be used?
   ii. what quantitative and qualitative information about stressors and invertebrate responses is needed?
3. What mitigation options are available for reducing the impact of key stressors on macroinvertebrate communities?
4. What evidence is there that common mitigations benefit macroinvertebrate communities?
5. What should be considered when monitoring the effectiveness of mitigation actions?

1.2 Assumptions and observations

We make the assumptions and observations described below in providing the guidance in this report around developing action plans based on our best understanding of the requirements outlined in the NPS-FM.

1.2.1 Detecting trends

Action plans can be implemented if non-natural causes result in attribute values to be degraded or degrading where:

> Degraded: the attribute state is below the national bottom line or other target state.
>
> Degrading: the attribute value is demonstrating an anthropogenically driven deteriorating trend.

Clause 3.20.2 of the NPS-FM states that any action taken in response to a deteriorating trend must be proportionate to the likelihood and magnitude of the trend, the risk of adverse effects on the environment and the risk of not achieving target attribute states.

Meeting these requirements of the NPS-FM may be challenging for several reasons. First of all, the annual frequency of monitoring means that >10 years of data are generally required to detect trends with confidence (Larned et al. 2018). Secondly, identifying the cause of trends in macroinvertebrate data is likely to be challenging for several reasons. Multiple stressors are likely to be in effect causing degrading trends but often there is a shortage of adequate temporal monitoring data for both the potential stressors and for macroinvertebrate metrics. Furthermore, separating the influence of anthropogenic causes (e.g., landcover change) from natural climate variability such as the El Niño Southern Oscillation may also be challenging (Scarsbrook et al. 2003).

The expert panel identified trend detection and the excluding of the influence of natural climatic variation and climate change as significant challenges. For the purposes of this report, we will assume that the magnitude, likelihood and the risk of adverse effects on the environment due to deteriorating trends in macroinvertebrate attributes have been previously identified.

1.2.2 Action plan development

The methods used to develop action plans and their targeted outcomes will vary between councils. However, we assume that the methods to identify stressors and the actions taken to improve macroinvertebrate communities that will be included in action plans developed in response to degraded attributes will have commonalities across the regions. We aim to provide general guidance about the challenges and potential solutions for developing action plans for macroinvertebrates which councils can use to suit their regional context.

Action plans are likely to be prepared for multiple attributes at once for an FMU, parts of an FMU or multiple FMUs (see compulsory attributes that require action plans in Table 1-1). The priority order for dealing with individual attributes will likely depend on data availability. Here we present guidance around developing action plans for macroinvertebrates, while recognising that some of the methods and actions presented may also be useful for other attributes.

2 Methods

A combined workshop and desktop-based approach was used to identify potential stressors, methods to identify causative stressors and mitigations actions that could be included in actions plans developed in response to degraded attributes. This approach comprised:

1. Assembling a panel of experts including scientists from regional councils and other science organisations with macroinvertebrate expertise (See Table 2-1).
2. Sharing of information by the expert panel using an online collaboration tool (Miro) to:
   i. create a strawman diagram of the likely stressors impacting macroinvertebrate communities in agricultural catchments
   ii. identify potential methods to determine key stressors in multiple stressor environments and
   iii. collate evidence for potential mitigation actions that benefit macroinvertebrates
3. Conducting a 4-hour virtual workshop with the expert panel to discuss and supplement the information generated in point 2
4. Prepare a report summarising the workshop combined with a brief review of recent literature relevant to the scope.

2.1 Expert panel

The panel of macroinvertebrate experts from councils and other organisations was assembled in discussion with DairyNZ. Attendees are provided in Table 2-1.

Table 2-1: List of workshop attendees and their area of expertise.

Attendee*	Organisation	Relevant expertise
Michelle Greenwood (convener)	NIWA Christchurch	Macroinvertebrates Drivers of macroinvertebrate communities Development of macroinvertebrate indices
Elizabeth Graham	NIWA Hamilton	Macroinvertebrates Drivers of macroinvertebrate communities Riparian restoration to improve macroinvertebrate communities
Joanne Clapcott	Cawthron Institute	Macroinvertebrates Drivers of macroinvertebrate communities Development of macroinvertebrate indices

Attendee*	Organisation	Relevant expertise
Annika Wagenhoff	Cawthron Institute	Macroinvertebrates Modelling stressor-response relationships in multiple-stressor environments Development of stressor-specific macroinvertebrate indices and setting of thresholds for management
Duncan Gray	Environment Canterbury	Macroinvertebrates Drivers of macroinvertebrate communities Development of macroinvertebrate indices RMA plan development
Maree Patterson	Horizons Regional Council	Sources of stressors and pathways Science input to policy development and implementation
Fiza Hafiz	Taranaki Regional Council	State of the Environment monitoring and reporting Strategic planning of SEM programmes NRP policy and plan development (Natural Resources Plan and Regional Policy Statement)
Darin Sutherland	Taranaki Regional Council	Macroinvertebrates Drivers of macroinvertebrate communities Monitoring and reporting of ecosystem health, especially in regard to macroinvertebrates and cyanobacteria
Michael Pingram	Waikato Regional Council	Monitoring and reporting of ecosystem health, especially macroinvertebrates, fish and aquatic habitats Drivers of macroinvertebrate communities
Justin Kitto	DairyNZ	Macroinvertebrates Drivers of macroinvertebrate communities Land and farm management
Karwin Perez	Ministry for the Environment	Present as an observer
Amy Whitehead	NIWA Christchurch	Assisted with workshop logistics / technology Involved in Our Land and Water project on mitigation effectiveness

*Jon Harding, University of Canterbury, was invited and added notes into the online collaboration space but was unable to attend the workshop.

2.2 Online collaboration and virtual workshop

Prior to the workshop a virtual whiteboard was created using the online collaboration software program Miro. Workshop participants were asked to visit the online whiteboard prior to the workshop to complete several tasks (where individual input was recorded):

1. Comment on a straw-man flow diagram of key stressors of macroinvertebrates in agriculturally dominated catchments

2. Add any information to a table of methods that could be used to identify stressors in multiple stressor environments

3. Add examples of studies where macroinvertebrate responses to potential mitigation methods had been observed.

The online workshop (comprising two 2-hour Zoom sessions), was convened on 7th April 2021.

Further information was added to the whiteboard by participants as virtual notes during the workshop, with Elizabeth Graham adding additional notes as required. These notes formed a record of the meeting outcomes. The final collaboration whiteboard, text of Zoom chats and full Zoom recording were saved at the end of the workshop to a NIWA project folder. Overview images of the online whiteboard are provided in Appendix A.

2.3 Report

This report summarises the information from the workshop, supplemented by additional references/literature where relevant. We use the term 'mitigation' or mitigation actions to mean actions that both prevent stressors entering a waterway and those that aim to restore degraded conditions.

3 NPS-FM requirements and council implementation progress

3.1 Te Mana o te Wai and ki uta ki tai

The NPS-FM requires that freshwater be managed in a way that gives effect to Te Mana o te Wai, which recognises the fundamental importance of protecting the mauri of the wai in order to be able to support healthy people and thriving communities (New Zealand Government 2020).

Te Mana o te Wai imposes a hierarchy of obligations. This hierarchy means prioritising the health and well-being of the water first. The second priority is the health needs of people (such as drinking water) and the third is the ability of people and communities to provide for their social, economic and cultural well-being currently and into the future. Te Mana o te Wai also requires an integrated approach to freshwater management, ki uta ki tai, which recognises the connections of the freshwater from the mountains and lakes to the sea and between the waterbodies and surrounding land. Management of freshwater, land use and development in catchments must be done in a sustainable way to avoid, remedy or mitigate adverse effects, including cumulative effects on freshwater ecosystems and receiving environments (clause 3.5 NPS-FM).

This concept of integrated management and consideration of the entire catchment is highly relevant to understanding and mitigating causes of degraded macroinvertebrate attributes identified at a particular monitoring site, as invertebrate communities reflect both site scale and upstream influences (e.g., Allan et al. 1997).

The specific details of how Te Mana o te Wai is to be applied must be developed by councils in conjunction with tangata whenua and communities in their region (see clauses 1.3, 3.2 and 3.4 of the NPS-FM for further details). Action plans are also to be developed in partnership with tangata whenua and local communities.

3.2 National Objectives Framework requirements

The National Objectives Framework (NOF) in the NPS-FM requires that councils:

1. Identify Freshwater Management Units (FMUs) for their region (clause 3.8).
2. Identify values for each FMU (clause 3.9). The four compulsory values are ecosystem health, human health for recreation, threatened species, mahinga kai. Additional values can be identified.
3. Set environmental outcomes for each value and include them as objectives in regional plans (clause 3.9).
4. Based on the environmental outcomes identify attributes for each value and set baseline states for those attributes (clause 3.10). These measure how well the values are being provided for and include the macroinvertebrate attributes as compulsory attributes for the ecosystem health value.
5. Set target attribute states, environmental flows and levels and other criteria to support the achievement of environmental outcomes (clauses 3.11, 3.13. 3.16). These must be set at or above national the bottom lines and at or above the current state.
6. Use limits and action plans to achieve target attribute states (clauses 3.12, 3.15, 3.17) by:

- limiting resource use (e.g., discharges, water abstraction)

- setting out other actions to improve freshwater (e.g., restoration methods such as riparian planting).

The NOF also requires that regional councils:

A. monitor water bodies and freshwater ecosystems (clauses 3.18 and 3.19); and

B. take action if degradation is detected (clause 3.20).

3.3 Council progress implementing the NOF

Scientists from Environment Canterbury and Horizons, Waikato and Taranaki Regional Councils were present at the workshop. In these regions, implementation of the NOF is in early stages, generally within steps 1 to 4 of the list in the previous section; specifically defining FMUs, identifying regional baseline states and trends and reviewing existing planning frameworks and monitoring networks.

Macroinvertebrate monitoring is already part of most council operations and some of the data needed to identify State of the Environment (SoE) monitoring sites breaching attribute bands are currently available. However, many councils are working to ensure their current monitoring networks are representative of their region and meet the NPS-FM requirements, which may involve relocating sites or adding new ones. The work required to identify FMUs and relevant attributes beyond the compulsory ones has meant that councils have not considered development of action plans in detail. Several common challenges were identified in the workshop:

1. **How to identify appropriate target attribute states?** The descriptions and associated numeric thresholds of the attribute bands for macroinvertebrate metrics in Tables 14 and 15 (the macroinvertebrate attribute tables) of the NPS-FM provide a guide for identifying target attribute states for wadeable rivers and in particular a lower boundary (target attribute states must be above the national bottom line). However, the setting of attribute states is a challenging task. First, it requires the knowledge of reference state (pristine or near-pristine state). Prediction of reference state has shown that application of benchmarks specific to particular stream types is more appropriate than using universal benchmarks (Clapcott et al. 2017a). These predictions indicate that perhaps even under reference conditions not all sites may achieve Band A (MCI ≥ 130). For example, median predictions of reference MCI values in Clapcott et al. 2017a generated using a boosted regression tree model varied between REC combined climate/source of flow groups from a minimum of 113 (Warm-Dry / Lake), which is within Band B in the NPS-FM, to a maximum of 139 (Cool-extremely wet / Hill), which is within Band A.

   A lack of suitable reference sites is also a common issue, particularly in developed lowland areas. In addition to the challenge of finding what benchmarks (attribute bands) to apply to rivers or catchments that naturally differ in their environmental characteristics, the second challenge is of a different type. This challenge relates to what improvement is achievable and within what timeframe given the large changes that streams/catchments have undergone. Many developed catchments are likely to have multiple constraints limiting improvement of macroinvertebrate communities, such as a legacy of fine deposited sediment or a lack of sources of taxa to recolonise a site (See Section 5 of this report for more details). Achieving target attribute states considerably above current state (e.g., target states close to reference condition) are likely to require large-scale mitigations, interventions or broad-scale land-use change in many pastoral catchments. Consideration will be required of achievable target attribute states above the national bottom line and current state for many FMUs, including those with largely pastoral land use.

2. **How to ensure that the monitoring network appropriately represents the region and FMUs?** It was identified that trade-offs between making sure a sampling network is representative of the region while also targeting sites that may experience increasing stressor impacts over time can be challenging. Financial constraints will likely limit addition of new monitoring sites and require a trade-off between relocating existing sites to increase network representativeness and maintaining sites with long-term datasets.

3. **How to define the magnitude and certainty of deteriorating trends in macroinvertebrate attributes and to separate non-natural causes from natural climatic variability?** This is important as under the NPS-FM, actions in response to degrading macroinvertebrate attributes are required to be proportional to the likelihood and magnitude of the trend, the risk of adverse effects on the environment, and the risk of not achieving target attribute states. Given macroinvertebrate sampling is annual, there were questions around "how long is long enough to detect a trend?", and "how confident can we be (about an apparent trend)?" Although addressing these questions is beyond the scope of this report, they indicate that further guidance is likely to be required.

4. **Awareness that significant river length in most regions will breach the national bottom line for one or more macroinvertebrate attributes and will require action plans.** Pingram et al. (2019) identified that QMCI scores indicated 'poor' condition for approximately 49% of the wadeable streams on developed land in the Waikato region (approximately 15, 000 km or 41% of the regional river network). Poor condition was defined as QMCI <4, which is slightly less stringent than the national bottom line of 4.5. This indicates that perhaps an even higher percentage of stream length on developed land in the Waikato than 49% is likely to exceed the national bottom line for QMCI, a situation likely to occur in other regions. For example, analyses of the national state of MCI using data ending in 2017 identified that, of the 464 sites with predominant upstream pastoral land cover (according to REC), approximately 25% had MCI values below the national bottom line (MCI < 90) (Larned et al. 2018). Similarly, the Land, Air, Water Aotearoa website (LAWA; www.lawa.org.nz) shows that just over 25% of sites in pasture land cover had MCI values below the national bottom line (<90) using values calculated over a 5 year period ending in December 2019. Many of the sites currently likely to fall under the national bottom lines for macroinvertebrate attributes have been historically degraded, and therefore may be more difficult to shift above the bottom line.

3.4 Requirements for action plans in response to degraded attribute values

Under clause 3.20 of the NPS-FM, if monitoring identifies either that individual, multiple or component parts of FMUs are 'degraded' (i.e., not meeting bottom-line or target attribute states) or are 'degrading' (i.e., a deteriorating trend is detected that is due to a non-natural process) an action plan can be used to identify how the attribute state will be improved. Alternatives to an action plan in this situation is changes to the council's regional plan or consenting. In this report we focus on action plans developed in response to degraded or degraded attribute states.

The relevant guidance for how to develop an action plan is set out in clauses 3.15 (Preparing action plans) and 3.20 (Responding to degradation) of the NPS-FM. In particular, every action plan prepared in response to degradation must include actions to identify the causes of the deterioration, methods to address those causes, and an evaluation of the effectiveness of the methods (clause 3.20.3).

Action plans identify a target attribute state and a plan for achieving the state within a specified timeframe. Target attribute states must be set at or above the national bottom line. If the current attribute state is above the national bottom line then the minimum target attribute state is the current state, i.e., the current state must be maintained or improved. In accordance with ki uta ki tai, target attribute states must be set with regard to potential impacts on any receiving environments. Target attribute states can be set in a staged approach with lower shorter-term goals than the final target attribute state. Action plans can be developed at the scale of individual, multiple or part of FMUs.

For actions plans developed in response to an anthropogenic deteriorating trend, the actions taken must be proportionate to the likelihood and magnitude of the trend and risks to environment and of not achieving target attribute state.

Tangata whenua and communities must be consulted during the development of action plans, or when doing more than minor amendments. The plans are to be reviewed after 5 years.

An action plan may describe both regulatory measures (such as proposals to amend regional policy statements and plans, and actions taken under the Biosecurity Act 1993 or other legislation) and non-regulatory measures (such as work plans and partnership arrangements with tangata whenua and community groups). They may include actions directed at restoration, target critical areas using farm plans and use limits on resource use to meet the target states. In addition to action plans councils may identify limits on resource use and include them as rules in regional plans and may impose conditions on resource consents to achieve target attribute states.

Action plans do not have a regulatory effect themselves. They describe a regional council's commitments and planned actions in relation to relevant attributes in relevant FMUs. Action plans can be 'prepared' by adding to or amending an existing action plan.

3.5 How are macroinvertebrate attributes monitored?

3.5.1 The attributes

The macroinvertebrate metrics added as compulsory attributes of the ecosystem health value for rivers in the NPS-FM in 2020 are:

1. The Macroinvertebrate Community Index (MCI; Stark and Maxted 2007b), based on the presence or absence of macroinvertebrate taxa, which have assigned tolerance scores depending on their sensitivity to organic pollution.

2. The MCI's quantitative variant (QMCI; Stark and Maxted 2007b), which also accounts for the abundance of taxa.

3. The Average Score Per Metric (ASPM, Collier 2008). ASPM is a combination of the MCI, the richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa and the percentage of EPT individuals present (%EPT abundance). Hydroptilidae caddisflies are excluded from the EPT counts. The metrics are normalised before combining to calculate the overall ASPM score. Details of the method are provided in Collier (2008) with the following minima and maxima used to normalise the scores: MCI (0-200), % EPT abundance (0-100), EPT richness (0-29).

The three attribute scores are calculated from samples collected between December and March (inclusive) annually, which are processed using either full counts of all individuals or fixed counts of at least 200 individuals.

3.5.2 Hard-bottom and soft-bottom tolerance scores

The MCI is based on tolerance values[2] assigned to taxa depending on their sensitivity to organic pollution. There are two sets of tolerance values. One set is used in hard-bottomed streams where samples are generally collected from stony, fast-flowing, wadeable riffle or run habitats; the other set of tolerance scores are designed for use in soft-bottomed streams where the bed is largely composed of fine sediments; in these habitats, invertebrates are collected from macrophytes and hard substrates such as wood, and stream edges (see Stark and Maxted 2007a).

In the NPS-FM, there seems to be some inconsistency with regards to when one or the other set of tolerance values should be used for calculation of the MCI and QMCI. Our understanding is that MCI and QMCI are to be calculated using the hard-bottom tolerance values, except for sites for which the deposited sediment attribute does not apply (see below) or because they require the use of alternate habitat monitoring, in which case MCI and QMCI are to be calculated using the soft-bottom tolerance values and taxonomic resolution defined in table A1.1 in Clapcott et al. (2017b). More specifically, sites that require the use of the soft-bottom tolerance values are those that either:

1. Fall within River Environment Classification (REC) classes (as defined in the River Environment Classification user guide; Snelder et al. 2004) defined as naturally soft-bottomed (Table 25 in the NPS-FM):

    i. WD_Low_Al; warm-dry climate + lowland topography + alluvium geology

    ii. WD_Low_VA; warm-dry climate + lowland topography + volcanic geology

    iii. WD_Low_SS; warm-dry climate + lowland topography + soft sedimentary geology

    iv. WD_Lake_Any; warm-dry climate + lakefed topography + any geology

    v. WW_Low_Al; warm-wet climate + lowland geology + alluvial geology

2. Or require alternate habitat monitoring (under clause 3.25) because it is currently soft-bottomed, which is defined by >50% coverage of deposited fine sediment (grain size <2 mm).

Note that clause 3.25 specifies what steps councils have to take if a site to which a target attribute state for deposited fine sediment applies (because it falls within REC classes specified for 'REC-defined' hard-bottomed sites according to Tables 24 and 26 in the NPS, i.e., not falling within one of the above five REC classes) but is soft-bottomed when assessed in the field (>50% coverage of deposited fine sediment). These steps include that the council must determine whether the site is naturally soft-bottomed or naturally hard-bottomed and if it is found to be naturally hard-bottomed the council must assess whether it is appropriate to return the site to a hard-bottomed state. However, we found it unclear from reading the NPS-FM whether the soft-bottom tolerance values should be used for MCI/QMCI calculation for soft-bottom sites (>50% coverage of deposited fine sediment) regardless of whether the site is naturally soft-bottom or naturally hard-bottom and

[2] For the MCI, the terms 'tolerance values or scores' and 'sensitivity values or scores' are used interchangeably in the literature.

regardless of whether the council determines that it should be returned to a hard-bottom state or not.

3.5.3 Spatial and temporal resolution of attribute states

The current macroinvertebrate attribute state is determined as the rolling five-year median of annual monitoring, which dampens some of the natural climatic and environmental variability in attribute values (e.g., Collier et al. 2014).

Attribute target states can be set for individual, component parts or for multiple FMUs. The minimum target state that can be set is the national bottom line (Table 3-1), or the current attribute state if higher than the national bottom line. Target attribute states may be expressed in a way that accounts for natural variability and sampling error. Consideration of the potential magnitude of variability in attribute states due to these factors would be beneficial when both setting target attribute states and when determining whether management actions (including action plans) should be implemented in response to changing attribute states.

Table 3-1: National bottom line values for macroinvertebrate attributes. Descriptive states are for band D (or below the national bottom line).

Invertebrate metric	Band D (< national bottom line)	
	Description	Numeric state
Quantitative Macroinvertebrate Community Index (QMCI)	Macroinvertebrate community indicative of severe organic pollution or nutrient enrichment. Communities are largely composed of taxa insensitive to inorganic pollution/nutrient enrichment	<4.5
Macroinvertebrate Community Index (MCI)	Macroinvertebrate community indicative of severe organic pollution or nutrient enrichment. Communities are largely composed of taxa insensitive to inorganic pollution/nutrient enrichment	<90
Average Score Per Metric (ASPM)	Macroinvertebrate communities have severe loss of ecological integrity	<0.3

4 Identifying stressors causing degraded macroinvertebrate attribute state

4.1 Key stressors for macroinvertebrates in developed catchments

The potential stressors for macroinvertebrate communities in developed catchments, including those with largely pastoral land use, are relatively readily identified. However, the mechanisms through which they impact macroinvertebrate communities and the resulting attribute scores are complex. A diagram from Collier et al. (2014), modified to be more specific to pastoral catchments, was discussed and modified further during the online workshop (see Figure 4-1 for the final figure).

Among workshop participants, the stressors highlighted in orange were found to be the most likely causes for degradation in pastoral streams that also could be addressed through commonly applied mitigation methods such as riparian restoration. Below is a short description of these stressors. Note that water abstraction was identified as a potentially important stressor in streams in pastoral catchments, but its impacts on ecosystem health are managed through the setting of environmental flows and hence it is not the focus of this report.

Fine sediment is a common stressor of macroinvertebrate communities in developed catchments (e.g., Townsend et al. 2008). Deposited fine sediment smothers invertebrate habitat and periphyton food sources. Suspended sediment can abrade soft body structures such as gills. Marked negative responses of macroinvertebrate metrics, including the MCI score, have been observed at a threshold of around 20 – 30 % coverage of the stream bed in fine sediment (Niyogi et al. 2007; Burdon et al. 2013; Franklin et al. 2019). Fine sediment enters streams via many mechanisms including eroding stream banks caused by stock access or a lack of stabilising plants, or via overland flow or tile drain run-off from land use activities. Instream channel works is highlighted as a separate key stressor in the diagram in Figure 4-1, however the main impacts will likely also be via an increase in sediment input from disturbance of the streambed, banks or macrophyte beds.

Nutrients (nitrogen and phosphorus) are other common stressors affecting macroinvertebrate communities in developed catchments. Elevated instream nutrient concentrations can impact macroinvertebrate communities, even at levels not much above reference condition (Wagenhoff et al. 2017a; Wagenhoff et al. 2017b). At the lower end of the spectrum of increased nutrient concentrations, indirect impacts on macroinvertebrates can occur through a change in periphyton or macrophyte composition or an increase in plant biomass leading to low oxygen concentrations. Forms of nitrogen can be directly toxic to macroinvertebrates at higher concentrations and could also be a cause of low macroinvertebrate metrics scores, however the indirect pathway is more likely to be the main cause for degradation in many pastoral streams.

Removal of riparian vegetation impacts macroinvertebrates through several mechanisms. **Reduced shade** contributes to warmer temperatures and high light levels, which, when combined with non-limiting levels of nutrients, can promote excessive periphyton or macrophyte growth. **Increased water temperatures** or **excessive plant growth** contribute to reduced dissolved oxygen (DO) concentrations. Elevated water temperatures and **reduced DO** concentrations have shown to negatively affect sensitive taxa (often belonging to the EPT orders) once tolerance limits are exceeded (e.g., Quinn et al. 1994; Cox and Rutherford 2000), hence affecting metrics of the macroinvertebrate attributes.

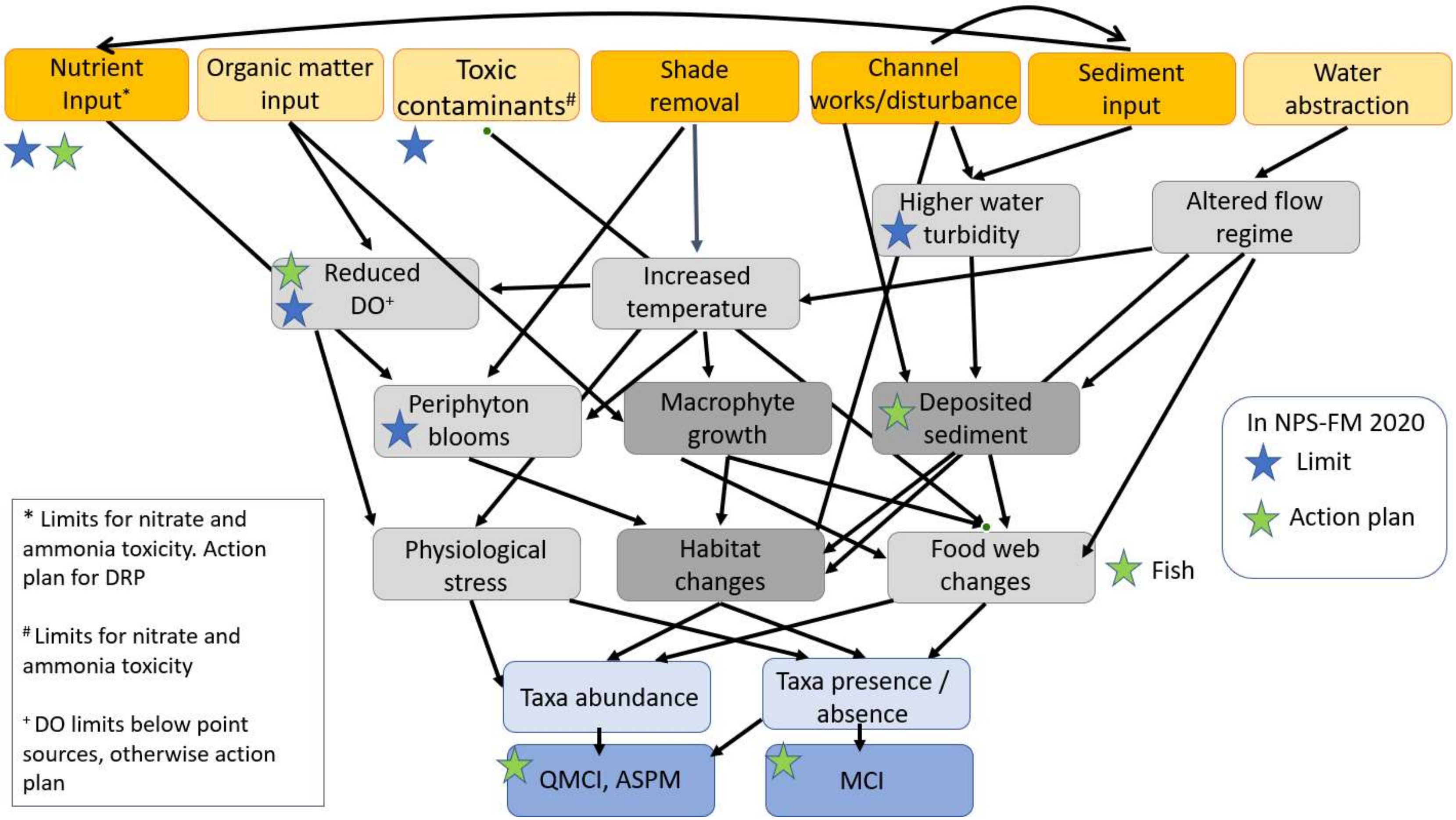

Figure 4-1: Diagram of potential stressors (upper boxes) and relationships with macroinvertebrate communities in agricultural catchments. Modified from Collier et al 2014. Note that the ASPM combines three component metrics: the MCI, EPT richness, and %EPT abundance (see text for details on all metrics relevant for macroinvertebrate attributes in the NPS-FM). The diagram relies on the key assumption that potential colonists are not limiting. Among workshop participants, the stressors highlighted in orange were found to be the most likely causes for degradation that could be addressed through commonly applied mitigation methods such as riparian restoration.

4.2 The complexity of multiple-stressor impacts

However, in general, deposited fine sediment seems to have more pervasive impacts on macroinvertebrate communities than nutrients, at least below toxic nutrient concentrations (Matthaei et al. 2010; Wagenhoff et al. 2012; Juvigny-Khenafou et al. 2021). When both nutrient and fine sediment levels are elevated, field surveys and experimental approaches have shown that the combined effects on macroinvertebrates can be of an additive or complex synergistic nature (Wagenhoff et al. 2011; Wagenhoff et al. 2012; Davis et al. 2018).

In pastoral catchments, particularly at the more degraded sites, many stressors co-occur (e.g., Pingram et al. 2019), which have complex causal impacts on macroinvertebrates and on the metrics that we use in management to assess their impacts (see Figure 4-1 for a conceptual diagram, and Clapcott and Goodwin (2014) where some of these causal links were tested using structural equation modelling). For example, the MCI was developed as an indicator of nutrient/organic enrichment (Stark 1985) but has shown to respond to other stressors also (e.g., sedimentation) and hence has been used widely by regional councils in State of the Environment reporting (Stark and Maxted 2007b). Further work has established that the MCI (and other metrics) shows consistently negative response patterns as the percentage cover of native vegetation in the catchment decreases (Death and Collier 2010; Clapcott and Goodwin 2014), and thereby provides further evidence for use of these metrics in the assessment of ecosystem health. However, based on the assessment of the MCI (and QMCI and EPT/ASPM) alone, it is impossible to know the relative impacts of individual stressors at a specific site or within a specific catchment. This makes targeting stressors difficult, and potentially renders mitigation methods less efficient (or inefficient) if they do not address the underlying causes of degradation appropriately.

Complex synergistic or antagonistic interactions between two or more stressors further contribute to the complexity of predicting macroinvertebrate responses to degradation because responses to combined stressors cannot be predicted based on the knowledge of single-stressor effects (Townsend et al. 2008). Several outdoor mesocosm experiments testing different combinations of key stressors (listed under section 4.1) have shown that complex multiple-stressor effects on macroinvertebrate communities are likely to be common (Matthaei et al. 2010; Piggott et al. 2012; Wagenhoff et al. 2012; Juvigny-Khenafou et al. 2021). These studies have also shown that sediment is a pervasive stressor that can have overall larger effects on macroinvertebrate communities than the other stressors tested (nutrients, reduced water velocity, increased water temperature), at least over the range of stressor concentrations/levels included in the experiments.

Field survey approaches to studying multiple-stressor effects (using space-for-time substitution) have largely confirmed the findings of experimental studies. Field surveys have the advantage of establishing stressor-response relationships between two or more stressors and macroinvertebrate response, although the correlation between stressor gradients and natural variation in the datasets can affect the ability to accurately describe these relationships. In New Zealand, such relationships have been mainly established for nutrients (or periphyton biomass) and fine sediment using both regional and national datasets and different statistical approaches (Wagenhoff et al. 2011; Clapcott et al. 2017b; Wagenhoff et al. 2017b; Davis et al. 2018).

Overall, while further research could improve identifying stressor-response relationships in multi-stressor scenarios, existing research has advanced our understanding of multiple-stressor impacts, especially for nutrients and sediment stressors, that could help in identifying causes of macroinvertebrate attribute degradation provided we know current state of nutrients and fine sediment and other stressors. Under the NPS-FM, councils are required to act to improve freshwater ecosystem health if attributes are degraded relative to the target state. This will require using the best knowledge available at the time to make decisions.

The relative impact of different stressors is likely to vary with catchment size (e.g., Leps et al. 2015) and stream type (e.g., slow-flowing, low-gradient springs compared to higher gradient hill-slope fed streams). For example, lack of shade and abundant nutrients may lead to periphyton blooms impacting macroinvertebrates in a small, shallow stream. However, in deeper or naturally tannin-stained rivers, high light levels due to lack of shade are unlikely to be a major stressor.

4.3 Methods to identify causes of macroinvertebrate attribute degradation

Identifying potential causes of macroinvertebrate degradation is likely to be useful for councils at two broad-scales. Firstly, identifying predominant stressors across a region or multiple FMUs will assist in the development of long-term and large-scale management plans (Pingram et al. 2019). Secondly, for a particular degraded FMU or part of an FMU, knowing the likely causal factors will help identify mitigations likely to improve macroinvertebrate communities.

Table 4-1 provides a summary of quantitative or qualitative methods to identify stressor impact that can be used at a range of spatial scales and includes a brief discussion of their advantages and disadvantages. Among those, we elaborate on a couple of approaches that may provide relevant insights without requiring additional data to be collected.

For example, recently stressor-specific macroinvertebrate metrics have been developed that can be calculated from the same data required to calculate the macroinvertebrate attribute scores (Wagenhoff et al. 2018). These nutrient and sediment stressor-specific metrics are currently based on relatively few indicator taxa and have yet to be fully tested for their diagnostic power. Initial analyses seem promising, for example, the Sediment MCI is more closely related to increasing deposited fine sediment than the MCI (Wagenhoff et al. 2018; Davis et al. 2021). Macroinvertebrate traits have also been investigated as potentially stressor-specific metrics (Wagenhoff et al. 2018) and suggested to be useful in potentially disentangling multiple-stressor effects (Lange et al. 2014) or improving our understanding of multiple-stressor effects (Juvigny-Khenafou et al. 2021). Calculation of trait scores is relatively complex however and generally require a higher taxonomic resolution than that required for the MCI or stress-specific MCI. Finally, community compositional turnover (Wagenhoff et al. 2017a; Graham and Quinn 2020) can also potentially provide additional information about the mechanisms causing observed patterns. Community turnover, trait and stressor-specific metrics can be used across multiple spatial scales.

Frameworks to structure decision making can also be useful. The United States Environmental Protection Agency online application CADDIS (Causal Analysis/Diagnostic Information System) is an example of a framework developed to help users identify potential stressors and their sources, describe potential stressor-impact relationships, and assess stressors likely to cause poor ecosystem state (see Table 4-1 for more information). Reviews of published literature can also benefit from structured methods to allow evidence to be collated, weighed and examined in a repeatable way. The Eco Evidence method (See Table 4-1) is one way to do this – it assists when assessing the likelihood of causality between stressors and response (e.g., Webb et al. 2013).

4.3.1 Stressor predominance across broad scales

Identifying the relative importance of different stressors across a region or large spatial area can be conducted using multiple methods (Table 4-1). Generally, these methods are used to correlate macroinvertebrate metrics with stressor states collected from many sites and assume that patterns observed between sites are relevant to temporal changes in response to stressors within a site. Data requirements include stressor levels and macroinvertebrate data from multiple sites across a region that span a gradient of stressor impacts. Although these studies do not indicate causal mechanisms, they can give a broad overview of patterns in stressor state and macroinvertebrate responses. Examples of methods used to investigate spatial patterns in stressor-macroinvertebrate relationships include the machine learning techniques of boosted regression trees, random forests and generalised linear mixed effects models (See Table 4-1). Tools such as Eco Evidence can also be used to assess the likelihood of cause and effect relationships using existing published literature.

A sampling network that is representative of the wider region is needed to allow extrapolation to provide an informative assessment of biological state at a broader scale. For example, Pingram et al. (2019) used a sampling network of wadeable streams on developed land in the Waikato that had been developed using a probability based, spatially balanced design to estimate ecological condition and relative importance of key stressors across the region. This monitoring network and analysis method allowed them to estimate the length of stream across the region in ‘poor’ ecological condition, based on macroinvertebrate and fish metrics, and to assess co-occurrence of poor ecological conditions with elevated stressor levels.

Table 4-1: The scale of use, advantages and disadvantages of selected methods that could potentially be used to identify causes of degraded macroinvertebrate communities. This table is not an exhaustive list of all possible methods.

Method	Likely scale of use	Data needs	Advantages	Disadvantages	References
Probability survey design and risk analysis	Region/ multiple catchments	Well-designed representative monitoring network. Quantified stressors	Quantification of large-scale patterns in stressor and stream ecological health (i.e., provides extent estimates of ecological condition within a region or FMU, including estimates of uncertainty). Identifies best stressors to target to improve MCI across broad scales.	Needs appropriately designed sampling network	Pingram et al. (2019)
Correlative methods such as random forests, boosted regression trees, generalised linear models	Region/ multiple catchments	Quantified stressors (monitored or modelled)	Indication of region-wide patterns and relative stressor explanatory power.	Not predictive at a site/reach scale. Correlative so not direct causative mechanism may not be identified	For example, (Clapcott et al. 2012; Leps et al. 2015; Kath et al. 2018; Franklin et al. 2019)
Cumulative stressors approach	Catchments	Quantified stressors. Need to be able to quantify stressor impact.	Semi-quantifiable way of estimating stressor impact cumulatively down a catchment	Doesn't seem to account for stressor interactions Need to be able to semi-quantitatively assign stressor impacts to categories– not sure how sensitive results are to these	de Vries et al. (2019)
Eco-Evidence type approach	Region/ multiple catchments	A good range of published studies in area of interest	summarises evidence in the literature in standardised way. Evidence is weighted, classified and combined according to a set of rules	Relies on published datasets so requires good coverage of area of interest	For example, Webb et al. (2013). Eco Evidence at: https://toolkit.ewater.org.au/tools/eco-evidenceer Toolkit

Method	Likely scale of use	Data needs	Advantages	Disadvantages	References
Use of macroinvertebrate traits or species turnover as response variables	multiple	For traits a database of macroinvertebrate traits, no additional data for species turnover, stressors quantified	May identify mechanistic relationships for stressors such as sedimentation better	Traits often described at species or genus level but MCI level identification often to coarser taxonomic level. Therefore, often needs expert knowledge to assign traits categories	For example, traits: Wagenhoff et al. (2018) Species turnover: (Wagenhoff et al. 2017a; Graham, S. E. and Quinn 2020)
Expert opinion and assessment of stressors at a site	Site / catchment	Stressors quantified and/or in-depth local knowledge	Can be used when quantified data is lacking, can capture data not easily quantified and local knowledge of the site. Could be included in statistical methods such as Bayesian networks	Needs experienced freshwater ecologist with good local knowledge. Hard to quantify uncertainty and accuracy	Drake et al. (2011)
Stressor-specific metrics as response variables (nutrients, sediment)	multiple	MCI-level taxonomic resolution i.e., same as for MCI	Can easily be calculated for existing macroinvertebrate data, could potentially use them as surrogates for sediment and nutrient data, more correlated with individual stressor than MCI	Not been extensively tested for diagnostic power, rely on a small number of indicator taxa (49 taxa), difficult to extract additive or synergistic effects of multiple stressors	Wagenhoff et al. (2018) Testing: Davis, N. G. et al. (2021)
CADDIS Causal Analysis/Diagnosis Decision Information System	Largely site	Combines expert opinion and quantified relationships	A decision support framework to help identify stressors. Combines multiple lines and types of data in a repeatable way	Based on best data available at the time	United State Environmental Protection Agency website: https://www.epa.gov/causal-analysisdiagnosis-decision-information-system-caddis/caddis-basic-information

4.3.2 Identifying causative stressors in degraded or degrading FMUs

In degraded or degrading FMUs, experienced freshwater ecologists should be able to identify key stressors, from the list of potential stressors listed under section 4.1, through a detailed investigation of site and upstream catchment conditions. We propose the following three steps to achieve this:

1. Validate the identified decrease or low state in macroinvertebrate attributes.

Investigate the macroinvertebrate data for the site further while considering the following questions:

- Is this a recent change or persistent long-term degradation?
- Current state is based on a 5-year median so the annual attribute values should be looked at to investigate temporal trends more thoroughly.
- Are all three macroinvertebrate attributes showing the same pattern?
- Are there any obvious patterns in presence/absence or abundances of particular taxa that can give insight into what is causing the low MCI, QMCI and/or ASPM values?
- Do any other invertebrate metrics provide further insight?
- Calculate other invertebrate metrics such as stressor specific metrics, community turnover, or trait abundances. These metrics will be correlated with the macroinvertebrate attributes but in some cases can provide additional diagnostic information (see recommendations in Clapcott et al. 2017b). Stressor-specific invertebrate metrics designed to respond to nutrients and fine sediment individually (Wagenhoff et al. 2018) have shown promise in providing additional information to MCI (Davis, N. G. et al. 2021), but are yet to be rigorously tested for their diagnostic power. Community turnover or beta diversity can provide a more complete assessment of change in community composition in response to degradation or restoration than metrics such as the MCI (Graham, S. E. and Quinn 2020). Traits may also be a useful complement to MCI type metrics (Juvigny-Khenafou et al. 2021).

2. Investigate potential stressors

Investigate values of other environmental variables to identify potential stressors. Data will be available for at least the other compulsory ecosystem health attributes (periphyton, nutrients, deposited sediment, fish, and dissolved oxygen if near a point source discharge). Collate any other available environmental data relevant to the site, for example any data on river flows, temperature, potential toxic contaminants. Use the data available to consider the following questions:

- Is there any natural reason for degradation? e.g., large scouring flood recently.
- Are the other attributes in degraded states? Have they changed recently? From the available data collated assess as many of the following questions:
  - If the stream is hard-bottomed - is the periphyton biomass high?
  - If the stream is soft-bottomed – which invertebrate taxa are present and is their biomass high?

- Are dissolved oxygen minima likely to create stress? (See Table 17, NPS-FM for guidelines)
- Is nitrate toxicity an issue? i.e., is the annual median concentration greater than the national bottom line value of 2.4 mg NO_3-N/L (See Table 6, NPS-FM for further guidelines)
- Is deposited sediment likely to be an issue? The national bottom line is >50 % coverage by fines <2 mm (see Section 3.5.2 for the REC classes identified as naturally soft-bottomed). Was the site likely to be hard-bottomed historically? Are there signs of bank erosion?
- Is suspended sediment possibly an issue? (See Table 8 in the NPS-FM for guidance for different suspended sediment classes).
- Is the site subjected to intermittent or persistent low flows? If so, is this a natural occurrence or exacerbated by water abstraction?
- Are high stream temperatures likely to be causing stress? (see Davies-Colley et al. 2013 for guidance).

This assessment should allow practitioners to identify the key environmental parameters that are likely to be acting as stressors on macroinvertebrate communities, which can then guide choices of different mitigation options.

3. Identify upstream constraints and impacts via a stream walk or virtual catchment investigation

Recognition that ecological health in a stream reach is influenced by local and catchment processes is bound up in the concept of ki uta ki tai. A landscape-scale approach is required to maintain ecosystem health. Once key environmental stressors are identified at the site with the degraded environmental condition, then locations in the upstream catchment contributing to poor stressor state can be identified. Likewise, potential constraints to macroinvertebrate response to mitigation actions should be investigated, such as the distance to potential colonists. This could be done via a catchment walk or using aerial imagery (e.g., recent Google Earth images). Conversations with landowners and local communities and tangata whenua are also likely to be valuable.

The goal of this knowledge collection is to identify potential causes of downstream degradation, any constraints that may limit the efficacy of chosen mitigation actions and existing mitigation or restoration actions that could be extended. Consideration should be given to:

- What is the current and historic land use?
- Identifying areas of potential concern, e.g., stock access or crossing points.
- Are there any current or proposed mitigation activities?
- Identifying and mapping distances to potential sources of colonists or barriers for dispersal.
- Identifying any areas where new or increasing stressors could be originating, for example clearance of forestry may create sediment issues.

- Perhaps consider a cumulative stressors-effects assessment as outlined in de Vries et al. (2019)

5 Potential mitigation actions

In this section we provide an overview of potential mitigation options, the evidence for their effectiveness for macroinvertebrate communities and a discussion of considerations when choosing mitigation actions.

5.1 Overview of mitigation actions

Detailed discussion of the best practice for mitigation options is beyond the scope of this report and can be found in Ausseil et al. (2021). Our overview of mitigation actions is a broad summary of those most relevant to macroinvertebrates (Table 5-1).

Actions that may reduce the effects of stressors of macroinvertebrate communities and improve attribute scores in pastoral catchments were previously identified (e.g., Collier et al. 2014). They can be divided into actions undertaken on the land or within the stream-channel. Some mitigations reduce the input or the impact of stressors (often termed interventions), some attempt to mitigate or restore degraded habitat conditions (often termed restoration), and some mitigations act as both intervention and restoration methods. For example, riparian plantings can intercept nutrients and fine sediment, reducing input to a waterway, and rehabilitate habitat by providing shade, terrestrial leaf litter inputs and terrestrial habitat for adult aquatic insects. Here we use the terms mitigation or mitigation actions to encompass both intervention and restoration actions.

Examples of mitigations that reduce the input of stressors such as organic matter, nutrients and fine sediment into waterways include fencing, planting of riparian margins, protection or development of wetlands, and farm management plans that reduce fertiliser, effluent and sediment run-off into waterways (Table 5-1). Mitigation of high in-stream nutrient and suspended sediment concentrations are more challenging because fewer studies investigating the benefits of such mitigations for macroinvertebrates have been undertaken. In many locations, high in-stream nutrient concentrations may occur at spatial or temporal scales (i.e., time lag) beyond which management actions could impact. We do not consider methods to reduce in-stream nutrient concentrations here.

Mitigation actions to remove deposited sediment include manual removal by diggers or modified vacuum systems (e.g., the sand wand). Addition of boulders or coarse woody debris can be used to improve instream habitat, and channel re-meandering may reduce the impacts of channelisation.

Macrophyte beds can be shaded or removed manually, although disturbance of fine sediment that accumulates around their bases may have adverse effects. Management of nuisance periphyton may include limiting nutrient concentrations, increased shading and changes to flow regimes to try to flush accumulated biomass downstream.

We did not directly consider flow regime alterations in this report as the NPS-FM requires that environmental flows are managed to support environmental outcomes, however we note that flushing flows are a potential management option for excess periphyton growth and potentially for deposited fine sediment. Under the NPS-FM any mitigation action chosen must take into consideration the impacts on receiving environments, which is likely for actions such as altering flow regimes to flush sediment downstream.

5.2 Evidence for mitigation actions benefiting macroinvertebrate communities

Our brief literature search found 48 papers summarising evidence from 377 reaches or rivers in which macroinvertebrate communities were monitored in response to different mitigation actions (See Table 5-1). The mitigation actions were both terrestrial and in-stream and designed to address a range of stressors including sediment and nutrient inputs, deposited fine sediment, channelisation (and associated loss of in-stream habitat diversity), and deforestation. At least three published papers described macroinvertebrate community change in response to mitigation methods such as: riparian planting, farm best management practices, channel reconstruction, channel stabilisation, wood addition, boulder addition and increases in substrate heterogeneity, removal of deposited sediment and creation of artificial riffles (Table 5-1). The published evidence for all mitigation actions showed mixed effects. Only three of the eight different mitigation actions led to improvement in at least 50% of studies (Table 5-1, methods: riparian planting, farm best management practice, channel reconstruction, channel stabilisation, wood addition, boulder addition/increased substrate heterogeneity, deposited sediment removal and artificial riffle construction). The three more successful mitigations were all in-stream habitat restoration approaches (channel reconstruction, channel stabilisation and installation of artificial riffles). However, we found relatively few studies testing each method (8, 3 and 4 studies, respectively). A more extensive literature search for these methods may lead to different conclusions about their efficacy. Mixed success is a common finding for many restoration projects (e.g., Parkyn et al. 2003; Bernhardt et al. 2005; Roni et al. 2018).

Commonly cited reasons for limited benefit from restoration projects include:

- Legacy effects from historical land-use was limiting macroinvertebrate recovery. For example, deposits of fine sediment limiting response to habitat restoration (Harding et al. 1998).
- Larger scale degradation was overwhelming local mitigation actions. For example, small-scale habitat additions in degraded waterways do not often result in improvement in macroinvertebrate condition (Collier 2017) due to a lack of colonists, and poor water quality (Roni et al. 2018). Catchment land-use can be a stronger driver of macroinvertebrate communities compared to riparian land use (Death and Collier 2010; Leps et al. 2015), indicating that riparian plantings may struggle to prevent or improve degradation associated with land use change. However, riparian plantings at a landscape scale can positively impact macroinvertebrate communities in areas with upstream sources of colonists (Graham et al. 2018).
- Inefficient placement of mitigation actions along the river network (Parkyn et al. 2010). For example, if the goal of mitigation is to improve shading and reduce stream temperature, then riparian planting is less effective in larger waterways (Leps et al. 2015).
- Failure of the mitigation action to improve stressors. For example, re-meandering improved the aesthetic appeal of a river reach but did not increase habitat diversity for macroinvertebrates (Al-Zankana et al. 2020). In addition, the right mitigation action may have been chosen but failed to reduce the effect of the stressor adequately. For some stressors, for example high nutrient concentrations in groundwater, temporal

lags between reduction in nutrient inputs and decreased in-stream concentrations mean that stressors are likely to exert an undesirable effect for long time periods.

- Absence of a source of recolonists able to reach the site to improve macroinvertebrate communities (Parkyn et al. 2010).
- Improvement happening at a time scale slower than expected. Recovery of macroinvertebrate communities after riparian planting can take up to two decades or longer, and even then the community may still be different to reference streams (Parkyn et al. 2003).
- The wrong stressors have been targeted by mitigation efforts, or the limiting stressor(s) may not have been addressed adequately.
- Incorrect assumptions about what restored macroinvertebrate communities will look like and the wrong metrics to quantify responses can mean that benefits from restoration are not identified. For example, mitigation actions have improved macroinvertebrate communities, but the wrong macroinvertebrate response metric has been investigated. For example, metrics such as diversity or taxa richness are likely to be slower to respond than metrics that include abundance or biomass or more functional measures of macroinvertebrate communities (Clapcott et al. 2017b). Degraded invertebrate communities often comprise taxa that are resilient and resistant to change. It may take a perturbation to allow new colonist taxa to establish, and recovery of stream community composition may follow a different pathway to that which led to degradation.
- Poor study design, particularly post-restoration monitoring can make detecting restoration benefits challenging. For example, Brooks and Lake (2007) found that only 14 % of records from 2247 restoration projects across Victoria, Australia showed that some form of monitoring was carried out. See section 6 for further details of post-mitigation monitoring.

Although many studies have documented mitigation efforts that show mixed or no significant beneficial effects on macroinvertebrate communities, there are also success stories. Successes occur when mitigations are done in the right location, at the right spatial scale and where few constraints limit the macroinvertebrate community ability to respond. Appropriate monitoring conducted over the right temporal time scales is also required to quantify these benefits. For example, Graham et al. (2018) reported that metrics including the MCI, EPT richness and EPT abundance responded positively to restoration at 59 sites within the Taranaki region. This was an extensive land-scape scale riparian planting project where approximately 70% of all 13, 000 km of stream length outside the national park on the Taranaki ring plain is planted and 84 % is fenced. The Riparian Management Plan co-ordinating the planting has been in place since the early 1990s and all streams are connected to upstream sources of colonists (the national park). This riparian planting project provides evidence that riparian mitigations can improve macroinvertebrate communities.

5.3 Considerations when choosing mitigation actions

To improve macroinvertebrate attribute values in sites or catchments not meeting target attribute states the main question is likely to become not which is the main stressor, but what can we change to provide the greatest improvement in macroinvertebrate attribute scores? For example, deposited sediment may be a historical legacy in a site or catchment but returning a site to a hard-bottomed state may be logistically or financially impossible. In this case alternative mitigations that may improve stream health will need to be investigated. Likewise, mitigation actions will likely be ineffective if constraints preventing macroinvertebrate response are not identified and incorporated into the mitigation plan and goals. Absence of local recolonists may mean new taxa cannot be added to a site, unless physically relocated there. Increasing the abundance of any sensitive taxa already presence may be a more achievable goal if relocation is unlikely to be successful.

The following questions would be beneficial to explore when deciding on appropriate mitigation strategies in pastoral catchments:

- **What is the goal of the mitigation?** The goals for action plans prepared in response to macroinvertebrate attributes not meeting target states will be to improve MCI, QMCI and ASPM. QMCI and ASPM to some degree can be improved by increasing the relative abundance of taxa with high MCI tolerance values (i.e., those sensitive to organic pollution). However, additional sensitive taxa need to occur and/or currently present tolerant taxa need to be absent for MCI values to improve. Restoration actions are likely to be more challenging in degraded sites because most sensitive taxa may have been already lost and local sources of taxa to recolonise may not be present. In addition, recovery of macroinvertebrate communities following mitigation actions may not follow the same pathway as degradation due to the resilience and resistance of communities leading to a different type of community post-restoration. Alternative strategies or goals of restoration may need to be considered in these cases.

- **What constraints to mitigation are likely to hinder improvement to macroinvertebrate communities?** Are there local sources of recolonists? Is the site and upstream catchment soft-bottomed? If so, the habitat may not be suitable for some taxa unless modified. Is there anything that can be done to reduce the impacts of the constraints? Restoring streams to pristine condition is unlikely to be possible in many developed catchments so realistic restoration goals must be set carefully. Likewise, understanding constraints on macroinvertebrate responses can help inform timescales of expected success (Parkyn et al. 2010).

- **What are the causative stressors acting on macroinvertebrates?** If multiple stressors are present can causative stressors be prioritised for mitigation? Mitigation strategies that target multiple stressors may be beneficial in multiple stressor environments. For example, adding riparian vegetation is likely to be a good option as it can stabilise banks, provide shade, potentially reduce periphyton and macrophyte biomass (at least in smaller waterways), and perhaps improve dissolved oxygen levels.

- **What is the current state of degradation?** Extensively degraded sites, where stressors are significantly impacting macroinvertebrate communities, especially sites with multiple stressors, will be more difficult to improve through mitigation because stressors are likely to have acted over long time periods and source populations for recolonisation may be limited. The presence of threshold responses between macroinvertebrate communities and stressors also means that mitigations may seem to have little impact on macroinvertebrates until the stressor is reduced below the threshold value. For example, studies by Franklin et al. (2019), Burdon et al. (2013) and Niyogi et al. (2007) indicate that fine deposited sediment may need to be reduced to below ~ 20-30% coverage of the stream bed before macroinvertebrate communities respond. Moderately impacted sites may improve in response to mitigations fairly quickly, whereas in very degraded streams the same amount of mitigation or stressor reduction may show no benefit.

- **What is the spatial scale and network location of the degradation and proposed mitigation?** An integrated catchment approach to mitigation options is required both under ki uta ki tai and to ensure the best outcomes for the ecosystem health values. Identify the scale and location of any key areas of degradation identified in the stream walk / catchment assessment as described in section 4.3.2. What scale of mitigation is likely to be beneficial? Different strategies will be appropriate for headwater versus downstream reaches exposed to greater cumulative effect. For example, Parkyn et al. (2010) considered that at least 1 km of stream length is required to shade and decrease temperature in relatively small waterways. In larger waterways local riparian vegetation is unlikely to influence water temperature through shading. In general, targeting headwaters or specific degraded or impacted areas is likely to provide the most impact. Collier (2017) recommended that habitat restoration must be addressed at multiple scales to cater for the needs of different species and life stages, be carried out a scales relative to the spatial scale of degradation (i.e., often over relatively large scales) and include landscape-scale planning to ensure that recolonisation from local source areas can occur.

- **Are any mitigation actions already present in the upstream catchment?** For example, what is the extent of upstream riparian vegetation?

- **What timeframe for favourable response to mitigations is desired?** Riparian plantings generally lead to faster reductions in nutrients and sediment but can take decades to show improvements for macroinvertebrates. Likewise, the types of riparian plants used are important: how fast do they grow, do they prevent surface run-off well, are native plants more desirable? Expectations for timeframes of improvement by stakeholders may need to be managed.

- **What is the lifespan of the mitigation?** Some mitigation tools, such as sediment traps or denitrification walls may need maintenance or refurbishment to maintain efficiency. What establishment or on-going maintenance is required? For example, riparian plantings may need watering or weeding until plants are established, or wetland plants may need to be replaced in response to pukeko predation.

- **Which mitigation will be beneficial for multiple attributes?** Action plans will be prepared for multiple attributes in combination (e.g., fish, invertebrates, periphyton and/or deposited sediment). Mitigation actions that are beneficial to multiple attributes will likely be more cost effective. An example of such a mitigation action is riparian planting on small waterways as it can provide shade and reduce stream water temperature, potentially reducing periphyton biomass, intercept overland sediment and nutrient inputs, which may improve habitat suitability and water quality for invertebrates and fish and provide leaf litter and terrestrial insects inputs as food resources for fish and invertebrates.

- **Is river flow affecting macroinvertebrate communities?** Although we have not considered flow alterations within this report, consideration should be given to the impacts of changes in flow due to abstraction or other mechanisms. The NPS-FM requires that environmental flows are set to achieve environmental outcomes, but low flow events or lack of flushing flows could limit macroinvertebrate communities in some locations.

- Financial considerations are likely to be important. The potential benefits of different mitigation options will have to be weighed against cost on a case-by case basis, with councils, tangata whenua and the community making trade-offs between cost-effectiveness and likely function and ability to protect the mauri of the wai.

Table 5-1: Summary of published evidence for the influences of terrestrial and in-stream mitigations on macroinvertebrate communities. Note this is not an exhaustive list, but indicative of the literature. Actions that mitigate flow alterations were not included as the **NPS-FM** requires that environmental flows are set that enable values to be protected. Most of the literature search focuses on fine sediment as that was identified as a predominant stressor of macroinvertebrate communities in pastoral catchments. See Appendix B for references in this table.

Mitigation	Stressors targeted	Scale of mitigation	Invertebrate impact	Notes and citation
Terrestrial mitigation: Riparian planting				
Improve: 4 / 11 studies 82 / 134 reaches None: 5 / 11 studies 44 / 134 reaches Mixed: 2 /11 studies 8 / 134 reaches	Sediment Nutrients Shade removal (smaller waterways) Land use change (can provide terrestrial litter inputs and terrestrial habitat for adult insects	Reach Sub-catchment if well co-ordinated and extensive	Composition shifted to become more similar to forested sites over 10 years	2 NZ pastoral streams; (Jowett et al. 2009)
			Invertebrate metrics positively correlated with restoration	59 sites draining Mt Taranaki NZ (Graham, E. et al. 2018)
			Improved community composition 15 years after planting, no restoration of hydrology or water quality	3 urban streams Melbourne, Australia (Thompson and Parkinson 2011)
			Improved community composition	18 Finnish streams; (Turunen et al. 2018)
			No temporal improvement over =/ <30 years	20 Australian streams (Giling et al. 2015
			Diversity / composition limited by recolonists	9 NZ streams; (Parkyn et al. 2003)
			Tolerant taxa remained dominant	9 agricultural streams in central US (Effert-Fanta et al. 2019)
			No response of invertebrates over 6 years post-restoration	1 urban NZ stream; (Winterbourn et al. 2007)
			Weak response to restoration	5 NZ urban streams (Suren and McMurtrie 2005)
			Mixed results for MCI	4 NZ reaches (Collins et al. 2013)
			Some shift in macroinvertebrate composition towards reference conditions	4 NZ rivers; (Quinn et al 2009)

Mitigation	Stressors targeted	Scale of mitigation	Invertebrate impact	Notes and citation
Terrestrial mitigation: Farm Best Management Practices (BMPs)				
Improve: 1 /3 studies 15 / 21 reaches None: 1 / 3 studies 1 / 21 reaches Mixed: 1 / 3 studies 5 / 21 reaches	Sediment Nutrients	Sub-catchment	Density of sensitive taxa lower and tolerant taxa more abundant in conventional farms than in integrated management or organic farms	15 agricultural NZ streams (Magbanua et al. 2010)
			Little improvement in MCI in over 5 years with reduced effluent discharge, P fertiliser application and riparian planting	1 Taranaki NZ stream; (Wilcock et al. 2009)
			Mixed effects, communities still distinct from reference up to 13 years post-restoration	5 NZ dairy streams (Wright-Stow and Wilcock 2017)
In-stream mitigations: Channel reconstruction *(e.g., re-meandering)*				
Improve: 4 /8 studies 13 / 142 reaches None: 4 / 8 studies 129 / 142 reaches	Channelisation	Generally reach	Improvement in community composition, also included boulder and substrate additions	9 Finnish streams, (Muotka and Syrjanen 2007)
			Lower invertebrate abundance and biomass 6-7 years post-restoration	1 restored reach in California (Albertson et al. 2010)
			Increased EPT in restored reach 2 years post-restoration, also included substrate additions	1 California rangeland stream; (Herbst and Kane 2009)
			Improved diversity and taxa richness, also included substrate and wood additions	2 German rivers, (Lorenz et al. 2009)
			Non-significant increase in richness and density	meta-analysis of 24 global studies (Miller et al. 2010)
			No effect reported	review of 78 global restoration studies (Palmer et al. 2010)
			No effects on invertebrate metrics	meta-analysis of 26 European river restoration projects (Jahnig et al. 2010)

Mitigation	Stressors targeted	Scale of mitigation	Invertebrate impact	Notes and citation
			No effect on diversity after 11 years	1.8 km restored reach of a large river in Denmark; Friberg et al. 2014)
In-stream mitigations: Channel stabilisation				
Improve: 2 / 3 studies 5 / 10 reaches None: 1 / 3 studies 5 / 10 reaches			Slight improvement of EPT	1 Virginia urban stream (Selvakumar et al. 2010)
			Small improvements in taxa richness and overall biomass	4 Georgia urban streams, (Sudduth and Meyer 2006)
			No change in invertebrate metrics following natural channel design restoration	5 Catskill Mountain (New York, USA) streams (Ernst et al. 2011)
In-stream mitigations: Wood addition				
Improve: 5 / 13 studies 41 / 238 reaches Mixed: 3 / 13 studies 30 / 238 reaches None: 5 / 13 studies 167 / 238 reaches	Deforestation, channelisation	Reach	Improved diversity and taxa richness	2 restored German rivers, (Lorenz et al. 2009)
			Improved community composition and more sensitive taxa	6 Swedish streams (Pilotto et al. 2018)
			Increased richness and improved community composition	8 agricultural streams in Australia (Lester et al. 2007)
			Increases in invert density, biomass, and taxa richness	1 English headwater stream (Al-Zankana et al. 2021)
			Significant increases in richness and density	meta-analysis of 24 global studies (Miller et al. 2010)
			Positive, but limited by poor water quality and lack of recolonists, included re-meandering and substrate additions	15 Australian reaches (Lester and Boulton 2008)
			Large wood additions enhanced diversity and biomass in summer but opposite in winter	4 headwater streams in Spain (Flores et al. 2017)

Mitigation	Stressors targeted	Scale of mitigation	Invertebrate impact	Notes and citation
			Improvements in richness or diversity reported for 11 of 49 global studies	11 of 49 global studies (review in Al-Zankana et al. 2021)
			No effect reported	review of 78 global restoration studies (Palmer et al. 2010)
			No effects on invertebrate metrics	meta-analysis of 26 European river restoration projects (Jahnig et al. 2010)
			No change in invertebrate IBI scores following wood addition	6 Washington state urban streams (Larson et al. 2001)
			No effect on abundance or family richness	1 Mississippi creek (Testa III et al. 2010)
			No consistent differences in abundance, diversity, or biomass	18 restored boreal streams (Nilsson et al. 2015)
In-stream mitigations: Boulder addition and/or improved substrate heterogeneity				
Improve: 6 / 19 studies 62 / 288 reaches Mixed: 1 / 19 studies 1 / 288 reaches None: 12 / 19 studies 223 / 288 reaches	channelisation, sediment	reach	Significant increases in richness, non-significant increases in density	meta-analysis of 24 global studies (Miller et al. 2010)
			Improvement in community composition, also included channel reshaping	9 Finnish streams (Muotka and Syrjanen 2007)
			Increased EPT in restored reach 2 years post-restoration, also included channel reshaping	1 California rangeland stream (Herbst and Kane 2009)
			Improved diversity and taxa richness, also included re-meandering and wood additions	2 restored German rivers (Lorenz et al. 2009)
			Shift in community composition in restored reaches, greater improvement in sites with larger changes in substrate composition	20 European river restoration projects (Hering et al. 2015)

Mitigation	Stressors targeted	Scale of mitigation	Invertebrate impact	Notes and citation
			Improved community composition and more sensitive taxa	6 Swedish streams restored with boulders and large wood (Pilotto et al. 2018)
			Increased abundance but not richness after boulder addition	1 small Canadian stream (Negishi and Richardson 2003)
			No effect reported	review of 78 global restoration studies (Palmer et al. 2010)
			No effects on invertebrate metrics	meta-analysis of 26 European river restoration projects (Jahnig et al. 2010)
			No effect on invert diversity	7 restored Swedish streams (Lepori et al. 2005)
			No consistent differences in abundance, diversity, or biomass	18 restored boreal streams (Nilsson et al. 2015)
			No increase in diversity after 20 years	29 Finnish streams (Louhi et al. 2011)
			No improvements in richness, abundance, or other biotic metrics, also included bank restructuring	19 restored streams in Germany, (Lorenz et al. 2018)
			No improvement detected after 1 – 12 years	24 river sites in Germany (Haase et al. 2013)
			No improvement in invertebrate diversity	7 streams in Sweden (Lepori et al. 2005)
			No consistent patterns in richness, diversity, density, or evenness following gravel addition	1 North Carolina river (McManamay et al. 2013)

Mitigation	Stressors targeted	Scale of mitigation	Invertebrate impact	Notes and citation
			No consistent patterns in richness, diversity, density, or evenness following gravel addition	1 French headwater stream (Sarriquet et al. 2007)
			No change in abundance or diversity following boulder weir placement	13 Oregon streams (Roni et al. 2006)
In-stream mitigations: Sediment removal				
Improve: 1 / 3 studies 2 / 5 reaches Mixed: 1 / 3 studies 1 / 5 reaches None: 1 / 3 studies 2 / 5 reaches	Sediment	Reach	Increased invertebrate richness and density of caddisflies following water blasting to remove sediment	2 NZ farmland streams (Ramezani et al. 2014)
			Mixed effects of sand wand, increase in sensitive EPT taxa but inconclusive due to high overall variability	1 urban NZ stream (Gray et al. 2013)
			No invertebrate response following fine sediment removal via sand wand 2 years post-restoration	2 Idaho streams (Sepulveda et al. 2015)
In-stream mitigations: Artificial riffles				
Improve: 3 / 4 studies 15 / 93 reaches None: 1 / 4 studies 78 / 93 reaches	Channelisation	Reach	EPT higher on installed rock weirs than streambed	Reaches of Cache River, Illinois (Walther and Whiles 2008)
			Shallow artificial riffles increased diversity to levels similar to natural riffle	1 English lowland alluvial river (Ebrahimnezhad and Harper 1997)
			Invertebrate diversity similar in rehabilitated reaches with artificial riffles and reference reaches	13 lowland UK rivers (Harrison et al. 2004
			No effect reported	review of 78 global restoration studies (Palmer et al. 2010)

6 How to monitor mitigation effectiveness – some considerations

Monitoring the effectiveness of mitigation or restoration projects is crucial for several reasons. Firstly, it is required by the NPS-FM as part of action plans prepared in response to degraded attributes. Secondly, effective monitoring improves our understanding of why mitigations succeed or fail and allows for adaptive management (Parkyn et al. 2010). Without accurate information we cannot improve the effectiveness of mitigations and are likely to spend money undertaking actions that are ineffective and/or in the wrong location. However, monitoring the effectiveness of mitigation actions is often not done well or at all. For example, Bernhardt et al. (2005) reported that of >37,000 river restoration projects undertaken, only 10% of projects had some form of monitoring or assessment after restoration, and that in most cases post-mitigation monitoring was not well designed, making it difficult to assess effectiveness.

The mixed success of restoration projects identified in Table 5-1 is likely in part to be an artefact of poor post-restoration monitoring. Effective post-mitigation monitoring is hindered for several reasons, including insufficient funding and a lack of appropriate tools and methods. Interviews with 317 stream restoration project managers across the United States revealed that many were frustrated by the lack of funding or limited emphasis given to project monitoring (Bernhardt et al. 2007).

In a review of 379 global restoration projects targeted at improving macroinvertebrates, Al-Zankana et al. (2020) identified the most common reasons why effectiveness of the restoration couldn't be assessed appropriately as:

- A lack of comprehensive and robust comparisons with unrestored controls reaches, and before and after restoration monitoring (Before-After-Control-Impact (BACI) study design) meant that changes due to restoration efforts couldn't be separated from natural temporal changes.
- Limited temporal sampling after restoration made it difficult to separate changes due to restoration efforts from natural seasonal changes within the restored reaches.
- Inappropriate measures of restoration success showed little response to mitigation efforts when other indicators may have showed changes. For example, taxa richness and diversity were commonly used whereas more functional metrics such as the percentage EPT taxa or density may have better quantified responses.

Resources such as the Restoration Indicator Toolkit (Parkyn et al. 2010) and books such as "Monitoring stream and watershed restoration" (Roni 2005) provide detailed advice regarding effective monitoring of restoration projects, so we summarise the main points below.

6.1 What is the restoration goal?

Mitigation or restoration projects must have clear goals against which to measure success. Target attribute states and the timeline for reaching them are required as part of action plans and will form the primary goals for mitigation actions. However, defining realistic target states and timeframes is likely to be challenging and will require a good understanding of the constraints on the macroinvertebrate communities likely to limit their response to mitigation actions.

Additional restoration goals against which mitigation actions may be measured are also likely to be useful for councils. These may also indicate desired values beyond those measured by the MCI, QMCI and ASPM. For example, restoring the presence of mayflies to a particular stream reach may be a desirable goal or improving emergent boulders or vegetation as oviposition habitat to enable the return of taxa that require it.

6.2 What to monitor

It is recommended that monitoring includes assessment of:

1. The ongoing presence of the mitigation action. For example, to ensure that riparian plants become established, grow and maintain adequate density over time, or that in-channel habitat modifications survive high flow events.

2. The ongoing efficacy of the mitigation or restoration at reducing stressors. For example, this may include monitoring water temperature, fine sediment deposition and periphyton growth in a reach that has had riparian planting installed.

3. The macroinvertebrate response to the mitigation action. Macroinvertebrate data will be available at routine monitoring sites. Metrics other than the macroinvertebrate attributes (MCI, QMCI and ASPM), such as %EPT or species turnover are likely to be valuable indicators of mitigation success as they can be better show early signs of improvement (Graham and Quinn 2020). The MCI may be particularly slow to respond to mitigations as it requires either the addition or loss of taxa before score values can improve. Reductions in stressors identified in point 2 above will likely be better early signs that mitigations are likely to be beneficial. Information is inevitably lost from the raw data (taxa lists and abundances) when metrics are calculated. Therefore, biotic indices should not be the only means of analysing biological data (Boothroyd and Stark 2000) and the raw macroinvertebrate data should be investigated to see if changes in the abundance of particular taxa or groups of taxa provide additional information about potential stressors (e.g., a loss of snails may indicate pH changes).

6.3 How long to monitor

Monitoring must occur over appropriate timescales to quantify whether the mitigation is meeting the set goals. Table 2-1 in Parkyn et al. 2010 has suggested monitoring times and frequencies for various parameters (e.g., macroinvertebrates, water chemistry, periphyton[3]). Factors that constrain macroinvertebrates responses to mitigation efforts need to be considered when determining the length of time to monitor. For example, the proximity of sources of taxa potentially available to recolonise a location will influence the rate of change of macroinvertebrate communities. Macroinvertebrate metrics may show threshold responses to some stressors (Wagenhoff et al. 2017b). In these cases, macroinvertebrates may show no or very limited response to stressor reduction for quite some time and then respond more rapidly once a critical threshold is achieved. Monitoring needs to occur over a sufficiently long period to capture and quantify this improvement. Monitoring stressor reduction in response to mitigations can also be used as early indicators of the likely success of the mitigation for macroinvertebrates, assuming constraints to their ability to respond have been appropriately identified.

[3] freely available here: https://niwa.co.nz/sites/niwa.co.nz/files/import/attachments/Restoration-Indicators-4-WEB.pdf

6.4 Where to monitor

Monitoring should be conducted before and after mitigation actions at the same location. If mitigations are conducted at or near current monitoring sites this should be easily achieved. However, if mitigations actions occur at a location other than a monitoring site the location of monitoring will need to be considered (see point below). Monitoring of mitigations conducted under action plans is likely to be conducted at existing monitoring sites due to financial constraints. However, if mitigations are undertaken in reaches away from a current monitoring site, it would be beneficial to undertake additional monitoring in that location to demonstrate and quantify the effectiveness of mitigation actions.

Ideally a reference site would be included to compare trajectories of change in the mitigated to an unimpacted or un-mitigated site. It may be possible to identify an existing monitoring site that could be used as the control site for a BACI experimental design.

6.5 What to do with monitoring data

It is crucial that monitoring data are stored appropriately and analysed periodically to determine whether restoration goals are being met. If goals are not being met, we recommend that an investigation is undertaken to determine the reasons why performance is lower than anticipated. Obtaining such information during the post-implementation period will allow stakeholders and regulators to improve the effectiveness of mitigation actions through adaptive management. Ideally such knowledge would be published or made publicly available so that councils, other agencies and farmers can learn from the successes and failures of others.

7 Further considerations

During the workshop several points were raised about the wider implications of action plan development. We summarise those points below:

1. In this report we discuss factors that should be considered when developing action plans in response to degraded macroinvertebrate attributes. However, action plans are likely to be prepared for multiple attributes, for example: fish, macroinvertebrates, periphyton, nutrients and/or deposited sediment. In developed catchments it is plausible that several attributes will be degraded. In these circumstances, an assessment of the best mitigation will have to consider the potential benefits, costs and limitations for multiple attributes at once. Mitigation actions that improve multiple stressors at once are desirable, but it would need to be established that the overall effectiveness will be adequate.

2. Financial constraints may limit the ability of councils to undertake additional monitoring to determine efficacy at sites where mitigations are installed, and they may need to rely on monitoring at existing SoE monitoring sites. Monitoring site locations should be representative of the upstream catchment because they need to provide specific information in response to catchment limit setting and about mitigation actions. Post-mitigation monitoring at existing downstream standard monitoring sites may not be ideal because it may not detect cause-effect relationships or early change in stressors or macroinvertebrates. Wherever possible, monitoring should be undertaken at the actual site of mitigation actions.

3. The three macroinvertebrate attributes may classify sites into attribute bands differently. For example, Wright-Stow and Winterbourn (2003) found inconsistencies in the classification of sites using the MCI and QMCI. We assume that should one of the three attributes provide

attribute values below the national bottom line or target attribute states, this score will trigger the need for an action plan.

4. Further guidance is likely to be required around determining appropriate target attribute states and timeframes for detecting change in response to mitigation actions.

5. Further guidance is also likely to be required around assessing the magnitude and uncertainty around temporal trends in attribute states.

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9 Glossary of abbreviations and terms

These definitions have largely been taken from the NPS-FM 2020 to maintain consistency with that document.

Attribute	A measurable characteristic that can be used to assess the extent to which a particular value is provided for
BACI	Before-After-Control-Impact study design. Two sites are monitored before and after mitigation is undertaken at the impact site. This allows comparison of trajectories of change at the two sites.
Degraded	In relation to an FMU or part of an FMU, "degraded" means that as a result of something other than a naturally occurring process: (a) a site or sites in the FMU or part of the FMU to which a target attribute state applies: (i) is below a national bottom line; or (ii) is not achieving or is not likely to achieve a target attribute state; or (b) the FMU or part of the FMU is not achieving or is not likely to achieve an environmental flow and level set for it; or (c) the FMU or part of the FMU is less able (when compared to 7 September 2017) to provide for any value identified for it under the NOF
Degrading	In relation to an FMU or part of an FMU, "degrading" means that any site or sites to which a target attribute state applies is experiencing, or is likely to experience, a deteriorating trend (as assessed under clause 3.19 in the NPS-FM)
Environmental outcome	In relation to a value that applies to an FMU or part of an FMU, a desired outcome that a regional council identifies and then includes as an objective in its regional plan(s) (see clause 3.9 in the NPS-FM)
EPT	Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly) taxa. Often sensitive to stressors such as organic pollution, sedimentation and increased water temperature
FMU	Freshwater management unit – all or any part of a water body or water bodies, and their related catchments, that a regional council determines under clause 3.8 is an appropriate unit for freshwater management and accounting purposes; and part of an FMUNational Policy Statement for Freshwater Management 2020 7 means any part of an FMU including, but not limited to, a specific site, river reach, water body, or part of a water bod
Limit on resource use	The maximum amount of a resource use that is permissible while still achieving a relevant target attribute state (see clauses 3.12 and 3.14)
National bottom line	An attribute state identified as such in Appendix 2A or 2B in the NPS-FM; for macroinvertebrate attributes, this is the state defined below the band C/D boundary
NOF	National Objectives Framework in the NPS-FM

SoE	State of the Environment. Usually in relation to the current monitoring network that councils have in place for State of the Environment reporting.

10 References

Al-Zankana, A.F.A., Matheson, T., Harper, D.M. (2020) How strong is the evidence - based on macroinvertebrate community responses - that river restoration works? *Ecohydrology & Hydrobiology*, 20(2): 196-214. 10.1016/j.ecohyd.2019.11.001

Allan, J.D., Erickson, D.L., Fay, J. (1997) The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology*, 37: 149-161.

Ausseil, O., Clapcott, J.E., Etheridge, Z., Hamilton, D., Linke, S., Matheson, F., Ramsden, M., Ruru, I., Selbie, D., Tanner, C., Whitehead, A., Bradley, A. (2021) Measuring the benefits of management actions. Mitigation effectiveness monitoring design. Proof of Concept development phase.: Prepared for Our Land and Water National Science Challenge.,

Bernhardt, E.S., Palmer, M.A., Allan, J.D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G.M., Lake, P.S., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Powell, B., Sudduth, E. (2005) Ecology - Synthesizing US river restoration efforts. *Science*, 308(5722): 636-637. DOI 10.1126/science.1109769

Bernhardt, E.S., Sudduth, E.B., Palmer, M.A., Allan, J.D., Meyer, J.L., Alexander, G., Follastad-Shah, J., Hassett, B., Jenkinson, R., Lave, R., Rumps, J., Pagano, L. (2007) Restoring rivers one reach at a time: Results from a survey of US river restoration practitioners. *Restoration Ecology*, 15(3): 482-493. DOI 10.1111/j.1526-100X.2007.00244.x

Boothroyd, I.K.G., Stark, J.D. (2000) Use of invertebrates in monitoring. In: K. Collier & M.J. Winterbourn (Eds). *New Zealand stream invertebrates: ecology and implications for management*. New Zealand Limnological Society, Christchurch: 344-373.

Brooks, S.S., Lake, P.S. (2007) River restoration in Victoria, Australia: Change is in the wind, and none too soon. *Restoration Ecology*, 15(3): 584-591. DOI 10.1111/j.1526-100X.2007.00253.x

Burdon, F.J., McIntosh, A.R., Harding, J.S. (2013) Habitat loss drives threshold response of benthic invertebrate communities to deposited sediment in agricultural streams. *Ecological Applications*, 23: 1036-1047.

Clapcott, J.E., Collier, K.J., Death, R.G., Goodwin, E.O., Harding, J.S., Kelly, D., Leathwick, J.R., Young, R.G. (2012) Quantifying relationships between land-use gradients and structural and functional indicators of stream ecological integrity. *Freshwater Biology*, 57(1): 74-90. DOI 10.1111/j.1365-2427.2011.02696.x

Clapcott, J.E., Goodwin, E. (2014) Relationships between MCI and environmental drivers: Prepared for Ministry for the Environment. Cawthron Report No. 2507.

Clapcott, J.E., Goodwin, E.O., Snelder, T.H., Collier, K.J., Neale, M.W., Greenfield, S. (2017a) 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. 10.1080/00288330.2016.1265994

Clapcott, J.E., Wagenhoff, A., Neale, M., Storey, R., Smith, B., Death, R.G., Harding, J.S., Matthaei, C.D., Quinn, J., Collier, K., Atalah, J., Goodwin, E., Rabel, H., Mackman, J., Young, R. (2017b) Macroinvertebrate metrics for the National Policy Statement for Freshwater Management: Prepared for the Ministry for the Environment, Cawthron report No. 3073.

Collier, K., Clapcott, J.E., Neale, M. (2014) A macroinvertebrate attribute to assess ecosystem health of New Zealand waterways for the National Objectives Framework: issues and options: Prepared for the Ministry for the Environment, Environmental Research Institute report no 36.

Collier, K.J. (2008) Average score per metric: An alternative metric aggregation method for assessing wadeable stream health. *New Zealand Journal of Marine and Freshwater Research*, 42: 367-378.

Collier, K.J. (2017) Editorial: Measuring river restoration success: Are we missing the boat? *Aquatic Conservation-Marine and Freshwater Ecosystems*, 27(3): 572-577. 10.1002/aqc.2802

Cox, T.J., Rutherford, C. (2000) Thermal tolerances of two stream invertebrates exposed to diurnally varying temperature. *New Zealand Journal of Marine and Freshwater Research*, 34: 203-208.

Davies-Colley, R., P. Franklin, P. R. Wilcock, S. Clearwater, and C. W. Hickey. 2013. National Objectives Framework - Temperature, dissolved oxygen and pH: proposed thresholds for discussion. Prepared for Ministry for the Environment. NIWA client report.

Davis, N.G., Hodson, R., Matthaei, C.D. (2021) Long-term variability in deposited fine sediment and macroinvertebrate communities across different land-use intensities in a regional set of New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research*. 10.1080/00288330.2021.1884097

Davis, S.J., Huallachain, D.O., Mellander, P.E., Kelly, A.M., Matthaei, C.D., Piggott, J.J., Kelly-Quinn, M. (2018) Multiple-stressor effects of sediment, phosphorus and nitrogen on stream macroinvertebrate communities. *Science of the Total Environment*, 637: 577-587. 10.1016/j.scitotenv.2018.05.052

de Vries, J., Kraak, M.H.S., Verdonschot, R.C.M., Verdonschot, P.F.M. (2019) Quantifying cumulative stress acting on macroinvertebrate assemblages in lowland streams. *Science of the Total Environment*, 694. ARTN 133630 10.1016/j.scitotenv.2019.133630

Death, R.G., Collier, K.J. (2010) Measuring stream macroinvertebrate responses to gradients of vegetation cover: when is enough enough? *Freshwater Biology*, 55(7): 1447-1464. DOI 10.1111/j.1365-2427.2009.02233.x

Drake, D.C., Kelly, D., Schallenberg, M. (2011) Shallow coastal lakes in New Zealand: current conditions, catchment-scale human disturbance, and determination of ecological integrity. *Hydrobiologia*, 658(1): 87-101. 10.1007/s10750-010-0452-z

Franklin, P., Stoffels, R.J., Clapcott, J.E., Booker, D.J., Wagenhoff, A., Hickey, C.W. (2019) Deriving potential fine sediment attribute thresholds for the National Objectives Framework: Prepared for Ministry for the Environment, NIWA report 2019039CH.

Graham, E., Jones-Todd, C.M., Wadhwa, S., Storey, R. (2018) Analysis of stream responses to riparian management on the Taranaki ring plain: Prepared for Taranaki Regional Council, NIWA report No. 2018051HN.

Graham, S.E., Quinn, J.M. (2020) Community turnover provides insight into variable invertebrate recovery between restored streams with different integrated catchment management plans. *New Zealand Journal of Marine and Freshwater Research*, 54(3): 467-489. 10.1080/00288330.2020.1764595

Harding, J.S., Benfield, E.F., Bolstad, P.V., Helfman, G.S., Jones III, E.B.D. (1998) Stream biodiversity: the ghost of land use past. *Proceedings of the National Academy of Sciences (USA)*, 95: 14843-14847.

Juvigny-Khenafou, N.P.D., Piggott, J.J., Atkinson, D., Zhang, Y.X., Macaulay, S.J., Wu, N.C., Matthaei, C.D. (2021) Impacts of multiple anthropogenic stressors on stream macroinvertebrate community composition and functional diversity. *Ecology and Evolution*, 11(1): 133-152. 10.1002/ece3.6979

Kath, J., Thomson, J.R., Thompson, R.M., Kefford, B.J., Dyer, F.J., Mac Nally, R. (2018) Interactions among stressors may be weak: Implications for management of freshwater macroinvertebrate communities. *Diversity and Distributions*, 24(7): 939-950. 10.1111/ddi.12737

Lange, K., Townsend, C.R., Matthaei, C.D. (2014) Can biological traits of stream invertebrates help disentangle the effects of multiple stressors in an agricultural catchment? *Freshwater Biology*, 59(12): 2431-2446. 10.1111/fwb.12437

Larned, S.T., Whitehead, A., Fraser, C., Snelder, T.H., Yang, J. (2018) Water quality state and trends in New Zealand rivers: analyses of national data ending in 2017: Prepared for Ministry for the Environment, NIWA report 2018347CH.

Leps, M., Tonkin, J.D., Dahm, V., Haase, P., Sundermann, A. (2015) Disentangling environmental drivers of benthic invertebrate assemblages: The role of spatial scale and riverscape heterogeneity in a multiple stressor environment. *Science of the Total Environment*, 536: 546-556. 10.1016/j.scitotenv.2015.07.083

Matthaei, C.D., Piggott, J.J., Townsend, C.R. (2010) Multiple stressors in agricultural streams: interactions among sediment addition, nutrient enrichment and water abstraction. *Journal of Applied Ecology*, 47(3): 639-649. DOI 10.1111/j.1365-2664.2010.01809.x

New Zealand Government (2020) National Policy Statement for Freshwater Management 2020: Available here: https://environment.govt.nz/assets/Publications/Files/national-policy-statement-for-freshwater-management-2020.pdf.

Niyogi, D.K., Koren, M., Arbuckle, C.J., Townsend, C.R. (2007) Stream communities along a catchment land-use gradient: subsidy stress responses to pastoral development. *Environmental Management*, 39: 213-225.

Parkyn, S.M., Collier, K., Clapcott, J.E., David, B., Davies-Colley, R., Matheson, F., Quinn, J., Shaw, W., Storey, R. (2010) The restoration indicator toolkit: Indicators for monitoring the ecological success of stream restoration: National Institute of Water and Atmospheric Research.

Parkyn, S.M., Davies-Colley, R.J., Halliday, N.J., Costley, K.J., Croker, G.F. (2003) Planted riparian buffer zones in New Zealand: do they live up to expectations? *Restoration Ecology*, 11(4): 436-447.

Piggott, J.J., Lange, K., Townsend, C.R., Matthaei, C.D. (2012) Multiple Stressors in Agricultural Streams: A Mesocosm Study of Interactions among Raised Water Temperature, Sediment Addition and Nutrient Enrichment. *Plos One*, 7(11). ARTN e4987310.1371/journal.pone.0049873

Pingram, M.A., Collier, K.J., Hamer, M.P., David, B.O., Catlin, A.K., Smith, J.P. (2019) Improving region-wide ecological condition of wadeable streams: Risk analyses highlight key stressors for policy and management. *Environmental Science & Policy*, 92: 170-181. 10.1016/j.envsci.2018.11.028

Quinn, J.M., Steele, G.L., Hickey, C.W., Vickers, M.L. (1994) Upper thermal tolerances of twelve New Zealand stream invertebrate species. *New Zealand Journal of Marine and Freshwater Research*, 28: 391-397.

Roni, P. (2005) *Monitoring stream and watershed restoration* American Fisheries Society.

Roni, P., Aberg, U., Weber, C. (2018) A Review of Approaches for Monitoring the Effectiveness of Regional River Habitat Restoration Programs. *North American Journal of Fisheries Management*, 38(5): 1170-1186. 10.1002/nafm.10222

Scarsbrook, M.R., McBride, C.G., McBride, G.B., Bryers, G.G. (2003) Effects of climate variability on rivers: Consequences for long term water quality analysis. *Journal of the American Water Resources Association*, 39(6): 1435-1447. DOI 10.1111/j.1752-1688.2003.tb04429.x

Snelder, T.H., Biggs, B., Weatherhead, M. (2004) New Zealand River Environment Classification user guide: Prepared for the Ministry for the Environment. NIWA report.

Stark, J.D. (1985) A macroinvertebrate community index of water quality for stony streams. *Water & Soil miscellaneous publication*, 87: 1-52.

Stark, J.D., Maxted, J.R. (2007a) A biotic index for New Zealand's soft-bottomed streams. *New Zealand Journal of Marine and Freshwater Research*, 41(1): 43-61. Doi 10.1080/00288330709509895

Stark, J.D., Maxted, J.R. (2007b) A user guide for the Macroinvertebrate Community Index. Cawthron Report No. 1166.

Townsend, C.R., Uhlmann, S.S., Matthaei, C.D. (2008) Individual and combined responses of stream ecosystems to multiple stressors. *Journal of Applied Ecology*, 45(6): 1810-1819. DOI 10.1111/j.1365-2664.2008.01548.x

Wagenhoff, A., Clapcott, J.E., Lau, K.E.M., Lewis, G.D., Young, R.G. (2017a) Identifying congruence in stream assemblage thresholds in response to nutrient and sediment gradients for limit setting. *Ecological Applications*, 27(2): 469-484. 10.1002/eap.1457

Wagenhoff, A., Goodwin, E., Atalah, J., Smith, B., Harding, J.S. (2018) Development and validation of stressor-specific macroinvertebrate metrics: Prepared for Ministry for the Environment, Cawthron report no. 3197.

Wagenhoff, A., Liess, A., Pastor, J., Clapcott, J.E., Goodwin, E., Young, R. (2017b) Thresholds in ecosystem structural and functional responses to agricultural stressors can inform limit setting in streams. *Freshwater Science*, 36(1): 178–194.

Wagenhoff, A., Townsend, C.R., Matthaei, C.D. (2012) Macroinvertebrate responses along broad stressor gradients of deposited fine sediment and dissolved nutrients: a stream mesocosm experiment. *Journal of Applied Ecology*, 49(4): 892-902. DOI 10.1111/j.1365-2664.2012.02162.x

Wagenhoff, A., Townsend, C.R., Phillips, N., Matthaei, C.D. (2011) Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. *Freshwater Biology*, 56(9): 1916-1936. 10.1111/j.1365-2427.2011.02619.x

Webb, J.A., Miller, K.A., King, E.L., de Little, S.C., Stewardson, M.J., Zimmerman, J.K.H., Poff, N.L. (2013) Squeezing the most out of existing literature: a systematic re-analysis of published evidence on ecological responses to altered flows. *Freshwater Biology*. doi:10.1111/fwb.12234

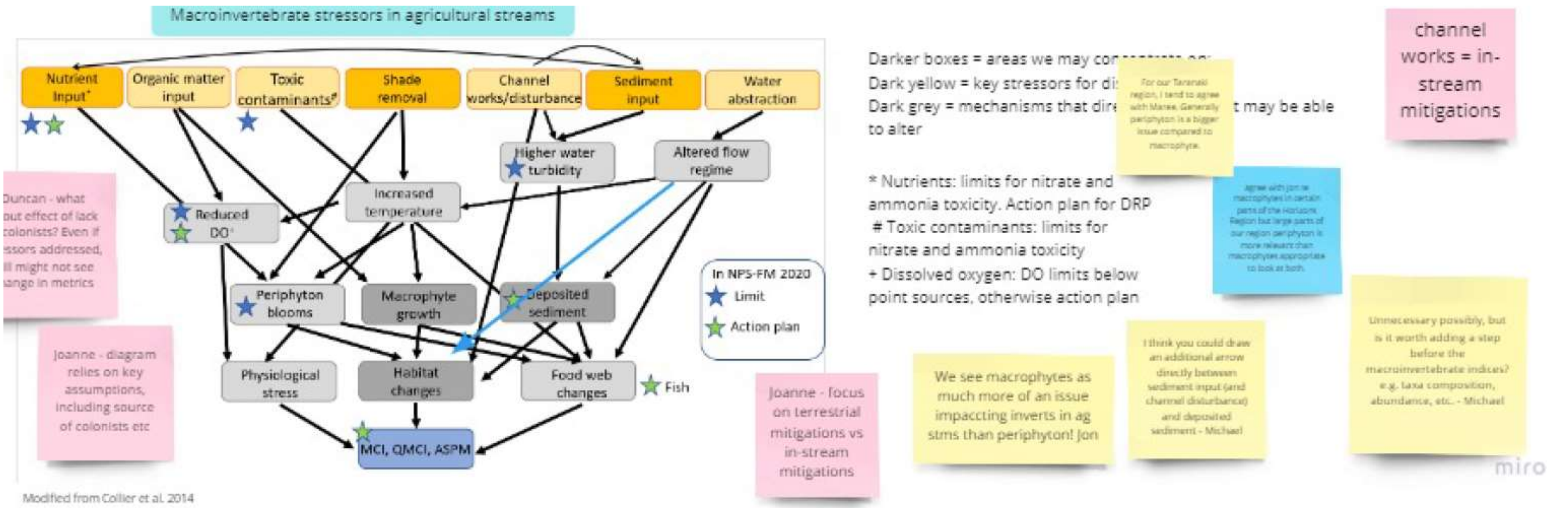
Wright-Stow, A.E., Winterbourn, M.J. (2003) How well do New Zealand's stream-monitoring indicators, the Macroinvertebrate Community Index and its quantitative variant, correspond? *New Zealand Journal of Marine and Freshwater Research*, 37(2): 461-470. Doi 10.1080/00288330.2003.9517180

Appendix A Images of virtual whiteboard

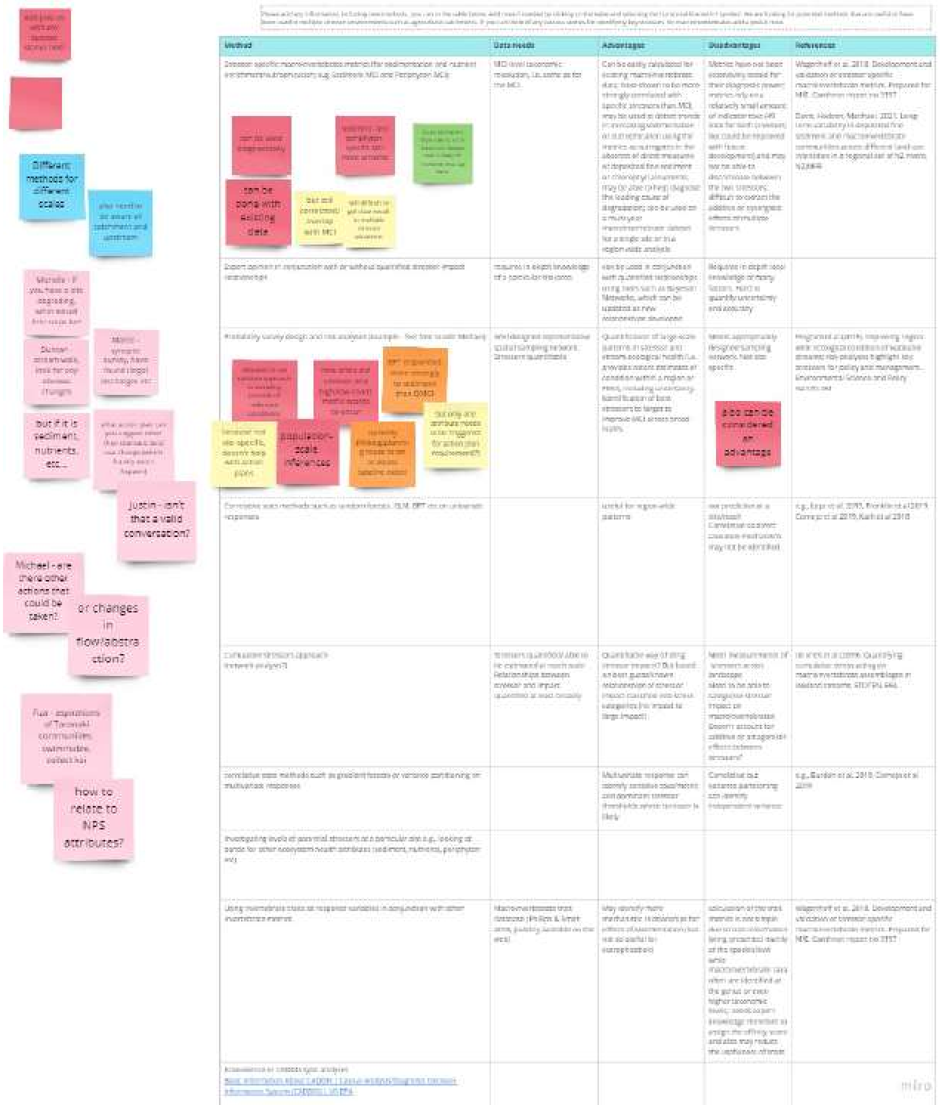
Exported images of the virtual whiteboard showing the layout. The software exports low-resolution images of the whiteboard.

Welcome mat

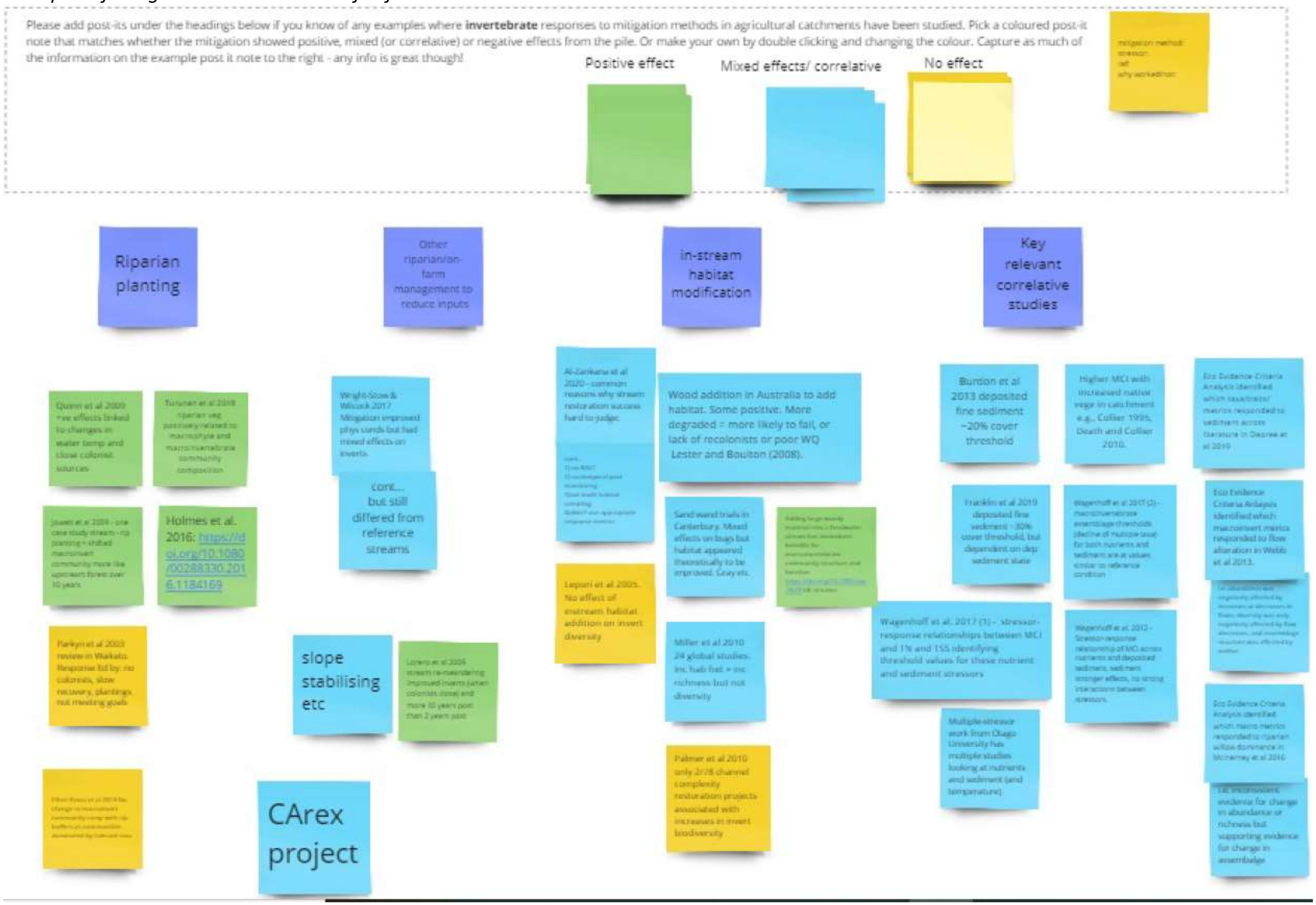
Stressors in agricultural streams diagram



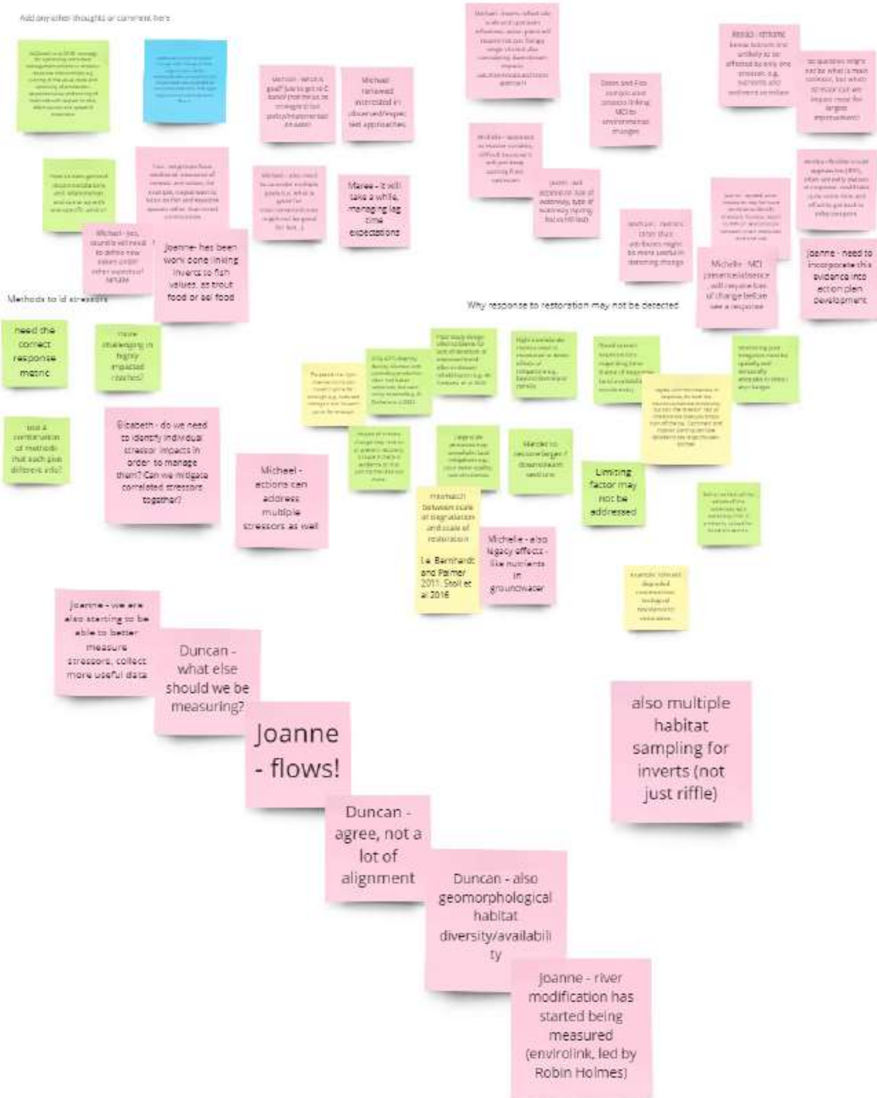
Methods to identify stressors



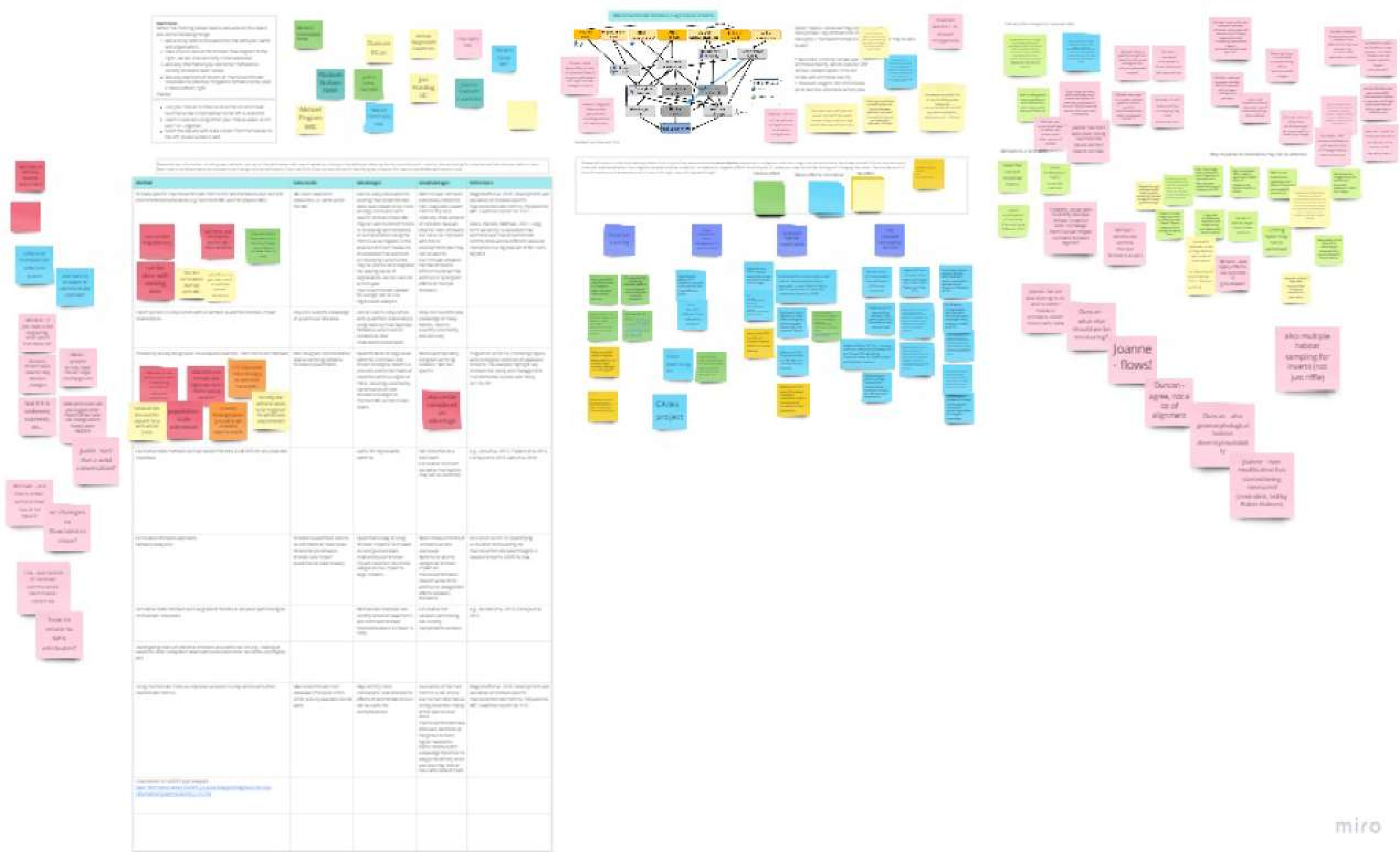
Examples of mitigations that show benefits for macroinvertebrates



Other comments



Overview of online whiteboard



Appendix B References for Table 5-1

Albertson, L.K., Cardinale ,B.J., Zeug SC, Harrison, L.R., Lenihan, H,S., Wydzga, M.A. (2011) Impacts of channel reconstruction on invertebrate assemblages in a restored river. *Restoration Ecology*, 19: 627-638.

Zankana, A.L., Matheson, A., Harper, T.D. (2021) Adding large woody material into a headwater stream has immediate benefits for macroinvertebrate community structure and function. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 31: 930-947.

Collins, K.E., Doscher, C., Rennie, H.G., Ross, J.G. (2013) The effectiveness of riparian 'restoration' on water quality - a case study of lowland streams in Canterbury, New Zealand. *Restoration Ecology*, 21: 40-48.

Ebrahimnezhad, M., Harper, D.M., (1997) The biological effectiveness of artificial riffles in river rehabilitation. Aquatic Conservation: Marine and Freshwater Ecosystems, 7: 187-197.

Effert-Fanta, E.L., Fischer, R.U., Wahl, D.H. (2019) Effects of riparian forest buffers and agricultural land use on macroinvertebrate and fish community structure. *Hydrobiologia*, 841: 45-64.

Ernst, A.G., Warren ,D.R., Baldigo ,B.P. (2012) Natural-Channel-Design restorations that changed geomorphology have little effect on macroinvertebrate communities in headwater streams. *Restoration Ecology*, 20: 532-540.

Flore,s L., Giorg,i A., González, J.M., Larrañaga, A,. Díez, J.R., Elosegi, A. (2017) Effects of wood addition on stream benthic invertebrates differed among seasons at both habitat and reach scales. *Ecological Engineering*, 106(A): 116-123.

Friberg, N., Baattrup-Pedersen, A., Kristensen, E.A., Kronvang ,B., Larsen, S.E., Pedersen, M.L., Skriver, J,. Thodsen, H,. Wiberg-Larsen, P. (2014) The River Gelså restoration revisited: Habitat specific assemblages and persistence of the macroinvertebrate community over an 11-year period. Ecological Engineering, 66: 150-157.

Giling, D.P., Mac Nally, R., Thompson, R.M., (2015) How sensitive are invertebrates to riparian-zone replanting in stream ecosystems? *Marine and Freshwater Research,* **67:** 1500-1511.

Gray, D., Taylor, M., Moore, E., Pohe, S., Barbour, S. (2013) A trial of fine sediment removal using the Sand WandTM: efficacy and impacts. Environment Canterbury Report R13/96: 16 p.

Haase, P., Hering, D,. Jähnig, S.C., Lorenz, A.W., Sudermann, A. (2013) The impact of hydromorphological restoration on river ecological status: a comparison of fish, benthic invertebrates, and macrophytes. *Hydrobiologia*, 704: 475-488.

Harrison, S.S.C,. Pretty, J.L., Shepherd, D., Hildrew, A.G., Smith, C., Hey, R.D. (2004) The effect of instream rehabilitation structures on macroinvertebrates in lowland rivers. *Journal of Applied Ecology*, 41: 1140-1154.

Herbst, D., Kane , J. (2009). Responses of aquatic macroinvertebrates to stream channel reconstruction in a degraded rangeland creek in the Sierra Nevada. *Ecological Restoration,* 27(1): 76-88.

Hering, D., Aroviita, J., Baattrup-Pedersen, A,. Brabec, K., Buijse, T,. Ecke, F., Friberg, N., Gielczewski, M., Januschke ,K., Köhler, J., Kupilas, B., Lorenz, A.W,. Muhar, S,. Paillex, A., Poppe, M., Schmidt, T., Schmutz ,S., Vermaat, J., Verdonschot ,P.F.M., Verdonschot, R.C.M., Wolter, C., Kail, J. (2015) Contrasting the roles of section length and instream habitat enhancement for river restoration success: a field study of 20 European restoration projects. *Journal of Applied Ecology*, 52: 1518-1527.

Jähnig, S.C., Brabec ,K., Buffagni, A., Erba, S., Lorenz, A.W., Ofenböck, T., Verdonschot, P.F.M., Hering, D. (2010) A comparative analysis of restoration measures and their effects on hydromorphology and benthic invertebrates in 26 central and southern European rivers. *Journal of Applied Ecology*, 47: 671-680.

Jowett, I.G., Richardson, J., Boubée, J.A.T. (2009) Effects of riparian manipulation on stream communities in small streams: two case studies. *New Zealand Journal of Marine and Freshwater Research*, 43(3): 763-774.

Larson, M.G., Booth, D.B., Morley, S.A. (2001) Effectiveness of large woody debris in stream rehabilitation projects in urban basins. *Ecological Engineering*, 18(2): 211-226.

Lepori, F., Palm ,D., Brännäs, E., Malmqvist, B. (2005) Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? *Ecological Applications*, 15: 2060-2071.

Lester, R.E., Boulton, A.J. (2008) Rehabilitating agricultural streams in Australia with wood: a review. *Environmental Management*, 42: 310-326.

Lester, R.E., Wright, W., Jones-Lennon, M. (2007) Does adding wood to agricultural streams enhance biodiversity? An experimental approach. *Marine and Freshwater Research,* **58:** 687-698.

Lorenz, A.W., Haase, P., Januschke, K., Sundermann, A., Hering, D. (2018) Revisiting restored river reaches - assessing change of aquatic and riparian communities after five years. *Science of The Total Environment*, 613-614: 1185-1195.

Lorenz, A.W., Jähnig, S.C., Hering, D. Re-meandering German lowland streams: qualitative and quantitative effects of restoration measures on hydromorphology and macroinvertebrates. *Environmental Management*, 44: 745-754.

Louhi, P., Mykrä, H., Paavola, R., Huusko, A., Vehanen, T., Mäki-Petäys, A., Muotka, T. (2011) Twenty years of stream restoration in Finland: little response by benthic macroinvertebrate communities. *Ecological Applications,* 21(6): 1950-1961.

Magbanua, F.S., Townsend, C.R., Blackwell, G.L., Phillips, N., Matthaei, C.D. (2010) Responses of stream macroinvertebrates and ecosystem function to conventional, integrated and organic farming. *Journal of Applied Ecology*, 47: 1014-1025.

McManamay, R., Orth, D., Dolloff,C. (2013) Macroinvertebrate Community Responses to Gravel Addition in a Southeastern Regulated River. *Southeastern Naturalist,* 12(3): 599-618.

Miller, S.W,. Budy, P., Schmidt, J.C. (2010) Quantifying macroinvertebrate responses to in-stream habitat restoration: applications of meta-analysis to river restoration. *Restoration Ecology*, 18: 8-19.

Muotka, T., Syrjänen, J. (2007) Changes in habitat structure, benthic invertebrate diversity, trout populations and ecosystem processes in restored forest streams: a boreal perspective. *Freshwater Biology*, 52: 724-737.

Negishi, J.N., Richardson, J.S. (2003) Responses of organic matter and macroinvertebrates to placements of boulder clusters in a small stream of southwestern British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, 60(3): 247-258.

Nilsson, C., Polvi, L.E., Gardeström, J., Hasselquist, E.M., Lind, L., Sarneel, J.M. (2015) Riparian and in-stream restoration of boreal streams and rivers: success or failure? *Ecohydrology*, 8: 753-764.

Palmer, M.A., Menninger ,H.L., Bernhardt, E. (2010) River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? *Freshwater Biology*, 55: 205-222.

Parkyn, S.M., Davies-Colley, R.J., Halliday, N.J., Costley, K.J., Croker, G.F. (2003) Planted riparian buffer zones in New Zealand: do they live up to expectations? *Restoration Ecology*, 11: 436-447.

Pilotto, F., Nilsson, C., Polvi, L.E., McKie, B.G. (2018) First signs of macroinvertebrate recovery following enhanced restoration of boreal streams used for timber floating. *Ecological Applications*, 28: 587-597.

Quinn, J.M., Croker, G.F., Smith, B.J., Bellingham, M.A. (2009) Integrated catchment management effects on flow, habitat, instream vegetation and macroinvertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research*, 43(3): 775-802.

Ramezani, J., Rennebeck, L., Closs, G.P., Matthaei, C.D. (2014) Effects of fine sediment addition and removal on stream invertebrates and fish: a reach-scale experiment. *Freshwater Biology*, 59: 2584-2604.

Roni, P., Bennett, T., Morley, S., Pess, G.R., Hanson, K., Slyke, D.V., Olmstead, P. (2006) Rehabilitation of bedrock stream channels: the effects of boulder weir placement on aquatic habitat and biota. *River Research and Applications*, 22: 967-980.

Sarriquet, P.E., Bordenave, P., Marmonier, P. (2007) Effects of bottom sediment restoration on interstitial habitat characteristics and benthic macroinvertebrate assemblages in a headwater stream. *River Research and Applications*, 23: 815-828.

Selvakumar, A., O'Connor, T.P., Struck, S,D. (2010) Role of stream restoration on improving benthic macroinvertebrates and in-stream water quality in an urban watershed: case study. Journal of Environmental Engineering, 136(1): 127-139.

Sepulveda, A.J., Layhee ,M., Sutphin, Z.A., Sechrist, J.D. (2015) Evaluation of a fine sediment removal tool in spring-fed and snowmelt driven streams. *Ecological Restoration*, 33: 303-315.

Sudduth, E.B., Meyer, J.L. (2006) Effects of bioengineered streambank stabilization on bank habitat and macroinvertebrates in urban streams. *Environmental Management*, 38: 218-226.

Suren, A.M., McMurtrie, S. (2005) Assessing the effectiveness of enhancement activities in urban streams: II. Responses of invertebrate communities. *River Research and Applications*, 21: 439-453.

Testa, S. III, Shields ,D.F. Jr., Cooper, C.M. (2011) Macroinvertebrate response to stream restoration by large wood addition. *Ecohydrology*, 4: 631-643.

Thompson ,R., Parkinson, S. (2011) Assessing the local effects of riparian restoration on urban streams. *New Zealand Journal of Marine and Freshwater Research*, 45(4): 625-636.

Turunen J, Markkula J, Rajakallio M, Aroviita J. 2018. Riparian forests mitigate harmful ecological effects of agricultural diffuse pollution in medium-sized streams. *Science of The Total Environment*, 649: 495-503.

Walther, D.A., Whiles, M.R. (2008) Macroinvertebrate responses to constructed riffles in the Cache River, Illinois, USA. *Environmental Management*, 41(4): 516-27.

Wilcock, R.J., Betteridge, K., Shearman, D., Fowles, C.R., Scarsbrook, M.R., Thorrold ,B.S., Costall, D. (2009) Riparian protection and on-farm best management practices for restoration of a lowland stream in an intensive dairy farming catchment: a case study. *New Zealand Journal of Marine and Freshwater Research,* 43(3): 803-818.

Winterbourn, M.J., Harding, J.S., McIntosh, A.R. (2007) Response of the benthic fauna of an urban stream during six years of restoration. *New Zealand Natural Sciences*, 32: 1-12.

Wright-Stow, A.E., Wilcock, R.J. (2017) Responses of stream macroinvertebrate communities and water quality of five dairy farming streams following adoption of mitigation practices. *New Zealand Journal of Marine and Freshwater Research*, 51(1): 127-145.