Manaaki Whenua
Landcare Research

Freshwater interventions literature review

Impact of Jobs for Nature projects on freshwater ecosystems

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Contents

Executive summary 6

Background 12

Review methodology 12

  Information gathering and prioritisation exercise 14
  Quasi-systematic literature review 16

Frameworks 17

  Kaupapa Māori framing for evaluation of environmental projects 17
  Ecosystem Services Framework 23

Literature measuring the intervention-domain relationship 28

Gap and literature quality analysis 60

  Process 60
  Findings 60

Discussion 62

  Context matters 62
  Timescales 62
  Outcomes should determine interventions and metrics 63
  People are a part of the ecosystem 63
  Restoration is not a one-and-done situation 64
  Gaps in knowledge 64

Recommendations 66

Appendix 1 – Ecosystem service definitions and examples 68

Appendix 2 – Detailed intervention-domain relationship tables 71

Appendix 3 – Empirical representation of literature quality 131

Glossary 137

  Te reo Māori 137

References 139

  Literature used to inform Kaupapa Māori framework 139
  Intervention-domain relationship references 142

Tables

Table 1. Prioritised interventions and qualifiers of those interventions 13

Table 2. Prioritised domains and qualifiers of those domains 14

Table 3. Subject expert groupings, number of researchers involved in each grouping and method of engagement 15

Table 4. Search terms used to identify supplementary literature for the quasi-systematic literature review 17

Table 5. Te ao Māori worldview assessment framework 20

Table 6. Relationships between ecosystem services and interventions using an Ecosystem Services Framework 24

Table 7. Observed (O), reviewed (R) or modelled (M) change in sediments, clarity, nutrients and *E. coli* 29

Table 8. Observed (O), reviewed (R) or modelled (M) change in bank erosion 35

Table 9. Observed (O), reviewed (R) or modelled (M) change in freshwater biodiversity 38

Table 10. Observed (O), reviewed (R) or modelled (M) change in terrestrial biodiversity 44

Table 11. Observed (O), reviewed (R) or modelled (M) change in carbon sequestration and GHG emissions mitigation 56

Table 12. Observed (O), reviewed (R) or modelled (M) change in flood and drought resilience 58

Table 13. Observed (O), reviewed (R) or modelled (M) change in ethical and spiritual values, social relationships, community and well-being 59

Table 14. Summarised indication of quality of literature to measure intervention-domain relationships 61

Figures

Figure 1. Ecosystem service classification (Source: Millennium Ecosystem Assessment, 2005) 23

Executive summary

Background

The five-year NZ$1.219 billion Jobs for Nature programme was established in 2020 by the New Zealand Government to co-support the economic, social and environmental recovery from the impacts of the Covid-19 pandemic. The programme was delivered through the Department of Conservation (DOC), the Ministry for the Environment (MfE), the Ministry for Primary Industries (MPI), the Ministry for Business Innovation and Employment (MBIE) and Land Information New Zealand (LINZ) with strategic oversight by the 'Sustainable Land Use' Ministers and supported by a Ministerial appointed Reference Group.

With programme funding ceasing June 2025, the Ministry for the Environment contracted Manaaki Whenua – Landcare Research (MWLR) and the National Institute of Water and Atmospheric Research (NIWA) to conduct a literature review (Phase 1) and modelling (Phase 2) of the expected impacts of their catchment management projects on freshwater-focused environmental and social domains. This report serves to fulfil the requirement of Phase 1. Decisions on commencement of Phase 2 will take place after this report has been finalised.

Scope and approach

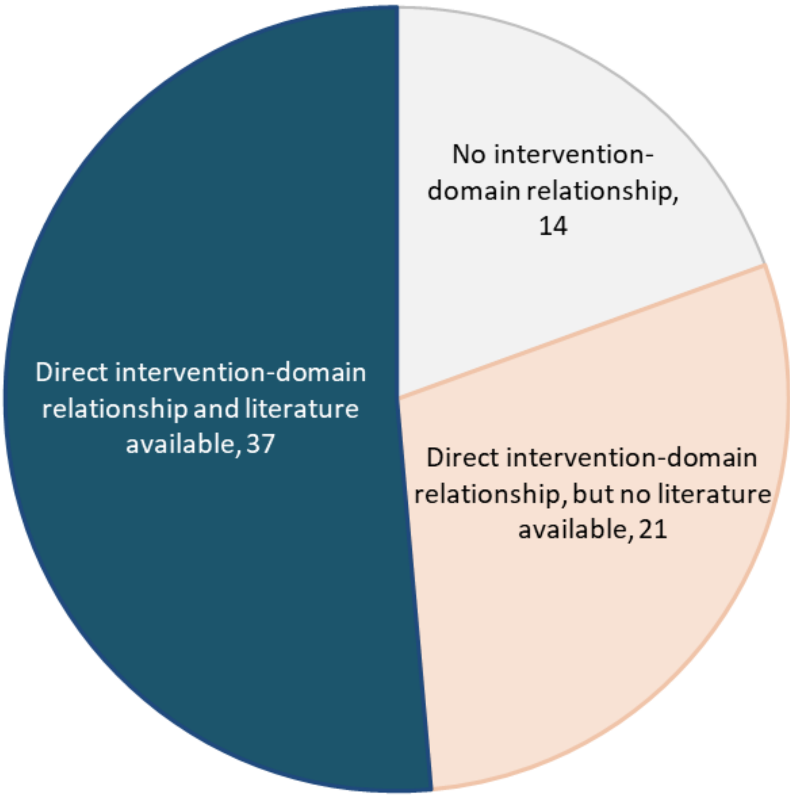
The literature review sought to find the best publicly available quantitative and qualitative information in New Zealand on the impact of catchment management interventions on environmental and social domains in a freshwater riparian and wetland context. For completeness of representing the intervention–domain relationships and available literature to measure those relationships, we used an Ecosystem Services Framework and Kaupapa Māori–based framing to identify and consider additional domains, and/or identify suitable aspects of each domain to consider in the assessment. Informed by those frameworks, the literature review was conducted in two stages:

- Stage 1 consisted of a scoping and information gathering exercise with subject experts to define the intervention(s)–environmental domain relationships, identify appropriate indicators for those relationships and to collate relevant peer-reviewed and grey literature. Facilitated discussions with subject experts took place between 27th May and 7th June 2024. Written responses were collected from subject experts between mid-May and 30th June.
- Stage 2 was a quasi-systematic literature review of the New Zealand-based peer-reviewed and grey literature. Our review approach was directly informed by our subject experts to efficiently identify and appropriately narrow the breadth of literature across the intervention–domain relationships in lieu of a fully systematic and exhaustive literature search. Documents, articles, papers, and reports sourced from experts were the primary source of literature followed by review of relevant articles from the reference lists of the literature identified by the subject experts. Additional literature was sourced from on-line databases using search terms identified through conversations with our subject experts. Stage 2 took place concurrent to Stage 1 discussions and written responses.

Summary of literature

The knowledge gathering process with subject experts identified direct relationships between 58 of a possible 72 intervention–domain relationships. Eighty-two studies were identified as suitable for providing quantitative and qualitive information to inform the modelling for only 37 out of the 58 direct intervention–domain relationships. Our literature review process did not find sufficient literature to assess 21 intervention–domain relationships. Nearly all studies were published within the last 25 years and half of the sourced studies were published since 2017 (figure S1).

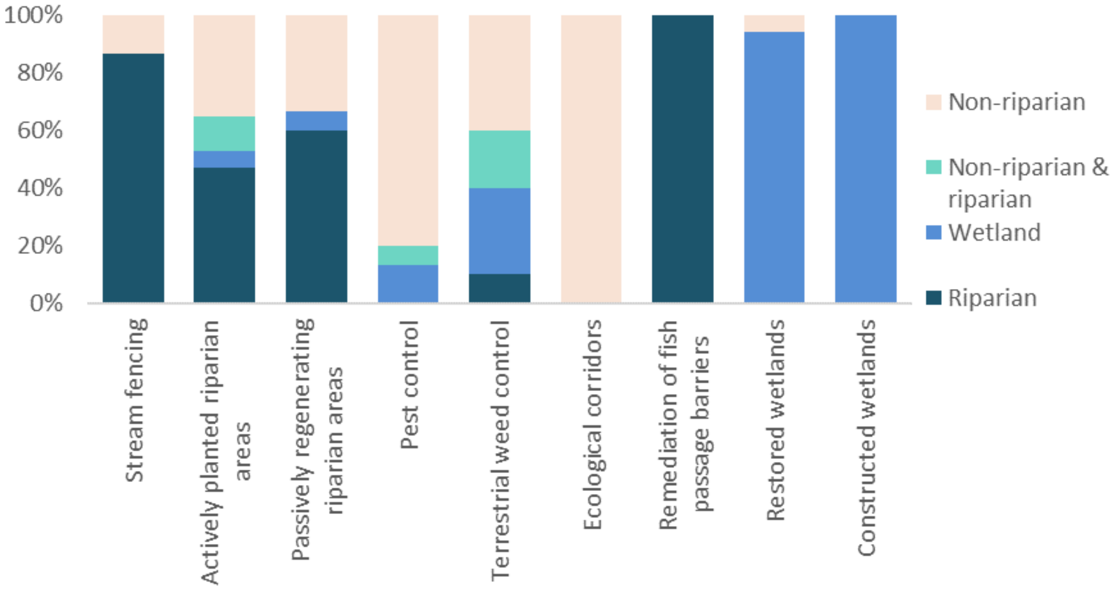
Figure S1. **Distribution of the 72 intervention–domain relationships and availability of studies to model those relationships**



The majority of the literature identified as suitable was New Zealand-based. Ninety percent of studies were only New Zealand-based, 7% of studies used data from New Zealand and other countries and 3% of studies only used data from other countries. Of these international studies, two were field experiments/models (USA and UK), one was a meta-analysis that included a New Zealand study, four were reviews that included New Zealand studies and one was a review that did not include a New Zealand study.

The most challenging aspect of the literature review was identifying studies that took place in freshwater riparian and wetland environments. While the vast majority of studies that investigate the impacts of stream fencing, riparian buffers, fish barrier remediation and wetlands on our domains took place in freshwater riparian and wetland environments, nearly all studies investigating the impact of pest control, weed control and ecological corridors took place in non-freshwater riparian/wetland environments (figure S2).

Figure S2. Proportion (%) of studies that investigated intervention impacts in freshwater riparian and wetland environments



Knowledge gaps

Through the process of identifying and collating the empirical literature on the impacts of restoration interventions on environmental domains, common themes, gaps and challenges emerged. To summarise these themes, we created a literature gap and quality index to indicate the overall suitability of literature available to model the intervention–domain relation. Three applicability indicators measured the (1) country of study, (2) landscape in which the study took place, and (3) relevance of study to the specific intervention–domain relationship. An applicability weight was created from the arithmetic mean of these three indicators. Four study quality indicators measured the objective and subjective quality of available literature based on (1) type of study, (2) empirical rigor of study, (3) impact found in study and (4) certainty and generalisability of the study. The four quality indicators were averaged and then weighted by the applicability weight to create the index.

The literature gap and quality index was represented on a 0–5 scale where 0 represents no available information and 5 represents a New Zealand–based study that directly measures the impact of the intervention on the domain in a freshwater ecosystem using a highly generalisable before-after-control experimental design or meta-analysis methodology. We have shaded the scores from very light turquoise (lowest quality literature) to dark turquoise (highest quality literature).

One limitation of this index is that is reflects the literature identified through the quasi-systematic approach as suitable for the purposes of modelling the intervention–domain relationship in a freshwater ecosystem. The index may change with additional literature or if the literature was applied to different ecosystems (eg, terrestrial). However, within the scope of the literature review and reliant on the institutional knowledge of our subject experts we believe the index reflects the current state of knowledge as it relates to modelling the in-scope intervention–domain relationships in a freshwater ecosystem.

We found very strong evidence that improving riparian area vegetation and constructing wetlands attenuates nutrients, *E. coli*, and sediments in surface water runoff (table S1). We also find strong evidence that stream fencing attenuates nutrients, *E. coli*, and sediments in surface runoff and stream bank erosion; improving riparian area vegetation reduces stream bank erosion; removing, replacing or remediating fish passage barriers and improving riparian area vegetation has a positive impact on freshwater biodiversity; and restoring wetlands attenuates nutrients and *E. coli* in surface water flows.

We find some evidence to suggest that carbon sequestration and flood/drought resilience is enhanced by improving riparian area vegetation, and restoring wetlands, however there is a lack of studies that investigate the impact of the interventions explicitly.

We find significant gaps in literature assessing the impact of terrestrial weed control, ecological corridors, remediation of fish passage barriers and constructed wetlands on nearly all domains, and limited literature that assessed the impact of wetland restoration on nearly all domains or the impact of catchment management interventions on terrestrial biodiversity and ethical and spiritual values.

The index reflected many of the gaps and challenges that our subject experts identified in our discussions. For instance, literature assessing the impact of pest control or ecological corridors on domains or literature assessing the impact of interventions on terrestrial biodiversity were not located in freshwater ecosystems (figure S2). Our terrestrial biodiversity experts indicated that all the studies that they were aware of that assessed the impact of interventions on indigenous flora and fauna took place in forested environments. Similarly, these experts were unsure if the impacts of ecological corridors specially along streams and rivers had been assessed in a New Zealand context. (table S1).

Table S1. Summarised indication of availability and quality of literature to measure the 72 intervention–domain relationships in a freshwater riparian and wetland context

Ecosystem service (aspect)	Stream fencing	Actively planted riparian areas	Passively regenerating riparian areas	Restored wetlands	Constructed wetlands	Remediation of fish barriers	Pest control	Terrestrial weed control	Ecological corridors
Water purification (Nutrients, E. coli)	2.97	3.50	4.19	3.91	4.25	0.00		0.00	0.00
Water purification (Sediments, clarity)	3.37	4.06	3.94	2.56	4.28	0.00		0.00	0.00
Erosion control (Stream bank erosion)	3.43	3.17	2.91			0.00		0.00	0.00
Habitat (Freshwater biodiversity)	2.94	2.97	2.90	2.64	1.90	3.96	1.72	0.00	0.00
Habitat (Terrestrial biodiversity)	1.61	2.27	1.16	2.97	1.94		2.04	2.49	1.70
Climate regulation (Carbon sequestration and mitigation of GHG emissions)		1.97	2.58	2.75	0.00			0.00	0.00
Natural hazard regulation (Flood and drought resilience)		1.98	0.00	2.95	0.00	0.00		0.00	0.00
Ethical and spiritual values (Social connection, well-being, Kaitiakitanga)		2.21		1.41	1.41	0.24	2.17	0.00	0.00

Legend:						
	Index value	0 to 0.99	1 to 1.99	2 to 2.99	3 to 3.99	4 to 5
	Index value colour					

Recommendations from subject experts for future impact assessments of catchment management projects

Based on the literature, discussions with experts and the authors own experience, our recommendations for improving the ability to assess the impacts of project activities are listed below.

Ensure the desired outcome(s) of the project are clearly defined alongside the benefits of the associated intervention(s) at the beginning of the project. Outcomes should be aligned with community aspirations. Collaborating with the people/organisations within the community (eg, general public, traditional knowledge holders, scientists, iwi, local government, etc) during the project can broaden the impact of the project (eg, increase social benefits or encourage other restoration activities beyond those being undertaken through the project).

Select metric(s) of impact, and design evaluation monitoring to measure progress toward the desired outcomes. Metrics and design should accommodate all biophysical and social outcomes. Collect information, from a community perspective, on the project's broader social and economic impacts on the community before, during and after the project undertaking.

Design the data collection and monitoring schedule to account for the expected and unexpected dynamic changes in the domain and surrounding ecosystem. Environmental and social domains and their aspects do not always follow a linear change process (eg, trees ability to sequester carbon changes over its growth cycle) while natural experiments exist within a wider landscape where other interventions and land use changes may influence the expected benefits of the project. As a result, monitoring schedules should be designed over longer time periods and at appropriate intervals to measure anticipated project impacts, capture any interactions of the project with other activities in the catchment and the dynamic changes within the project site.

Engage the community, where possible, in the monitoring and data collection process to enhance well-being, social cohesion and spiritual connection with nature. This engagement is also an excellent opportunity to build broader skills and knowledge capacity within the community.

Develop targeted and sustained long-term monitoring post-project completion to understand expected and unexpected outcomes of typical management practices on the environment. Supporting in-going research into these outcomes provides invaluable knowledge of emerging relationships that will be publicly available. Study sites can be representative across regions and landscapes for the national benefit.

Background

The Jobs for Nature (J4N) programme was established in 2020 by the New Zealand Government in response to the economic and community impacts of the Covid-19 pandemic. The five-year, $1.219 billion programme was designed to create 11,000 conservation jobs, enhance the country's freshwater and biodiversity, and support sustainable land use. The programme was delivered through the Department of Conservation (DOC), the Ministry for the Environment (MfE), the Ministry for Primary Industries (MPI), the Ministry for Business Innovation and Employment (MBIE) and Land Information New Zealand (LINZ) with strategic oversight by the 'Sustainable Land Use' Ministers and supported by a Ministerial appointed Reference Group (Ministry for the Environment, 2021).

The Ministry for the Environment's J4N programme sought to support the implementation of the National Policy Statement on Freshwater Management. With the J4N programme funding ceasing in June 2025, the MfE contracted Manaaki Whenua – Landcare Research (MWLR) and the National Institute of Water and Atmospheric Research (NIWA) to conduct a literature review (Phase 1) and modelling (Phase 2) of the expected impacts of these catchment management projects on freshwater ecosystems, indigenous biodiversity, climate change mitigation and adaptation, and other environmental and community benefits (social and cultural, and economic impacts). This report serves to fulfil the requirement of Phase 1.

Our literature review sought to provide the best publicly available quantitative information on the relationship between the catchment management interventions and several environmental and social domains in a freshwater riparian and wetland context. In the absence of quantitative information, qualitative narratives were sought to understand the impacts. Absence of publicly available quantitative and qualitative studies are also noted in this report.

Following discussions between the MfE, MWLR and NIWA, it was decided to create a stop gate between Phase 1 and Phase 2 to assess the feasibility of a modelling exercise dependent on the quality and quantity of available literature.

Review methodology

Phase 1 was divided into two stages. The first stage consisted of an information gathering exercise with subject experts to define the intervention(s)–domain relationships, identify appropriate indicators for those relationships and to collate relevant peer-reviewed and grey literature. The second stage was a quasi-systematic review of the peer-reviewed and grey literature collected during and informed by the findings in Stage 1.

Stage 1 sought to answer the following questions.

1. What is the relationship between the interventions and environmental domains of interest?
2. How are the impacts of the interventions on the environmental domains of interest measured?
3. What are the factors that influence the success of interventions and the appropriate mitigations to those hindrances?

Stage 2 sought to answer the following questions.

1. What literature/modelling is available to quantify the impact of the intervention on each of the domains?

2. If no literature exists to quantify the impact, what other forms of knowledge are available to qualify the impact?

Scoping and prioritisation

A scoping meeting between the MfE, MWLR and NIWA took place on 1 May 2024. The outcome of this meeting prioritised the interventions, domains and intervention(s)-environmental domain relationships for the purpose of this project (table 1, table 2). The key environmental domains of interest to MfE were freshwater and the adjacent terrestrial ecosystems, particularly streams, riparian zones and wetlands.

Table 1. Prioritised interventions and qualifiers of those interventions

Intervention areas	Definition and attributes of interventions relevant to the review
Stream fencing	Stream fencing that is constructed of timber, wire, post-batten, or something similar and designed to restrict access to a fluvial stream or river by cattle, sheep, goats, deer or other stock. No specified setbacks from stream bank; Fencing can be at the top of the stream bank with or without any area of passively or actively regenerating riparian buffer.
Passively regenerating and actively planted riparian zones	Riparian areas that are the transitional zones extending in-land from a fluvial stream/river. No specified width for intervention but is usually between 3m and 5 m. These zones are usually, but not always, protected from stock grazing by stream fencing. Riparian areas may have been allowed to regenerate with or without intentional seeding and/or plantings. Actively planted riparian areas require intentional plantings with known vegetation types. Local seed recruitment may occur but is not assumed. Passively regenerating riparian areas reseed with seedlings from the surrounding vegetation. Active and passive revegetation may or may not involve terrestrial weed control.
Pest animal control	Animal pests that are controlled or managed in riparian zones. Method of control may or may not target specific pest species, be designed to improve specific indigenous biodiversity or target pest species that impact other interventions such as riparian plantings.
Terrestrial weed control	Invasive weeds in the riparian areas may be controlled through physical, chemical and/or biocontrol methods. These weeds may be managed and/or supressed prior to other interventions such as riparian area plantings, and/or continuously managed or supressed to reduce competition (with plantings or revegetation through natural recruitment/passive revegetation).
Fish passage barrier removal, replacement or remediation	Fish passage barriers along fluvial streams/rivers such as culverts, weirs, dams, fords and flood gates may be removed, replaced and/or remediated to increase access to upstream/downstream habitat by various aquatic species (eg, tuna). Removed, replaced and/or remediated fish passages may impact on habitat quantity and quality and on different types of fish populations in different ways.
Development of ecological corridors along stream riparian areas	Islands of habitat along the riparian area may be connected to other islands of habitat along the riparian area through physical habitat creation to support the natural dispersal of indigenous fauna. Habitat may be created through active plantings or by allowing riparian areas to passively revegetate and may also involve fencing of riparian zones to support the establishment of vegetation. Habitat along the riparian area may be connected to habitat across the wide landscape as well, however, for the purposes of this report this intervention focuses only on connecting pockets of riparian habitat to each other along streams and rivers.
Constructed and restored wetlands	Restored wetlands: Drained, dry, damaged and/or degraded historic and current freshwater wetlands may be restored to through rewetting and/or intentional or passive revegetation. Part or all of the historic wetland may be restored. Constructed wetlands: Freshwater wetlands may also be constructed in areas where historic wetlands may or may not have existed but where land use and hydrology has changed to such an extent that restoration is not applicable. Constructed wetlands are usually built for the purpose of water retention, nutrient filtration and/or sediment settling in an agricultural or urban landscape.

Table 2. Prioritised domains and qualifiers of those domains

Domains	Aspect(s)	Notes
ECOSYSTEM SERVICES FRAMING		
Habitat	Terrestrial indigenous biodiversity Freshwater indigenous biodiversity	Impacts of interventions on terrestrial and freshwater habitats that affect indigenous flora and fauna biodiversity.
Water purification	Sediments and water clarity Nutrients and *E. coli*	Ability of interventions to reduce in-stream nutrients (i.e., phosphorus, nitrogen), *E. coli* and sediments.
Erosion control	Stream bank erosion	Ability of interventions to reduce erosion from stream banks entering the water.
Climate regulation	Carbon sequestration and mitigation of greenhouse gas (GHG) emission	As it relates to freshwater ecosystems and riparian plantings. Ability of interventions to sequester carbon, mitigate GHG emissions and adapt to climate change. Resilience of interventions to the effects of climate change.
Natural hazard regulation	Flood and drought resilience	Ability of interventions to mitigate flooding and drought.
Wild foods	Mahinga kai	Enhancement of traditional foods sourced from freshwater systems.
Ethics and spiritual values / Social connections	Well-being Kaitiakitanga/Stewardship Community relationships	Impact of the intervention and/or programme on participants' sense of place, aesthetic, spiritual, religious, and cultural heritage values, social cohesion and relations, cultural diversity that people attach to ecosystems, landscapes or species, and connection within the community and community resilience.
KAUPAPA MĀORI FRAMING		
Mātauranga Māori		Impact of the interventions and/or whole programme on development of and support for Mātauranga Māori (Māori knowledge).

Information gathering and prioritisation exercise

The MfE's J4N programme supported various interventions with the intention of enhancing freshwater quality. However, these interventions and investments in the community may have enriched, supported and improved other environmental, economic and social domains. To ensure our list of affected domains was comprehensive, appropriate and, importantly, quantifiable we used an Ecosystem Services Framework and Kaupapa Māori-based framing to identify and consider additional domains, and/or identify suitable aspects of each domain to consider in the assessment. Using an Ecosystem Services Framework allowed us to determine systematically which ecosystem services to include and the complementary Kaupapa Māori-based framing allowing us to identify the key metrics/indicators within the cultural domains to reflect the Māori worldview.

Information on the intervention–domain relationships was gathered from facilitated discussions with, and written responses from, subject experts. The findings of this stage directed the Stage 2 quasi-systematic literature review and was intended to directly feed into the proposed Phase 2 modelling assessment (not done in this report). We undertook this process to ensure that the

Phase 2 modelling assessment focused on those intervention–domain relationships that can be supported by robust evidence, while also highlighting those potentially important relationships where less (or no) information exists.

Subject experts

From the scoping and prioritisation exercise, subject groupings were created to extract relevant literature and knowledge from subject experts (table 3). The subject expert discussions and written responses were used to:

- identify the appropriate and measurable aspects of the impact of the interventions on each domain, and where possible identify suitable metrics to systematically assess the impact of interventions on the different aspects of each domain
- identify factors that influence the effectiveness of each intervention on each domain and/or aspect of a domain
- collate relevant literature to underpin the intervention impact assessment
- identify key knowledge gaps in the relationship between interventions and domains to highlight where it will not be possible to quantify an impact, but where an impact exists, and more research is needed.

We draw on the extensive knowledge derived from research that MWLR and NIWA have undertaken on freshwater ecosystems, indigenous biodiversity, climate change mitigation and/or adaptation, other ecosystem service benefits, and Māori values to refine the domains, aspects of domains and metrics/interventions for the literature review and impact assessment. Expert groups were created from the breadth of knowledge across MWLR and NIWA with four cross-organisation groups, three MWLR groups, and three NIWA groups. Given availability, experts were given the option to contribute through facilitated online discussion or through written responses to specific questions. Online discussions took place between 27th May and 7th June 2024. Written responses were gathered through May and June.

Table 3. Subject expert groupings, number of researchers involved in each grouping and method of engagement

Subject groupings	No. of researchers	Organisation(s)	Method of engagement
Wetlands	3	MWLR; NIWA	Discussion
Erosion/sediment interventions	6	MWLR; NIWA	Discussion
Weed management / biological control	1	MWLR	Discussion
Animal pest management	1	MWLR	Discussion (w/ Terrestrial biodiversity group)
Greenhouse gas mitigation / Carbon sequestration	3	MWLR; NIWA	Written response
Terrestrial biodiversity	2	MWLR	Discussion
Nutrients and *E. coli*	3	NIWA	Discussion
Freshwater biodiversity	4	NIWA	Written response
Flooding/drought resilience	2	NIWA	Written response
Mātauranga Māori	2	MWLR; NIWA (review only)	Discussion and review of report section

This knowledge-gathering process (based on Ausseil et al, 2022, 2023) asked our subject experts to consider the nature of any impacts of an intervention on each aspect of the domains included in the scope. To do this we used the following series of targeted questions.

- Is there a relationship between the intervention and a domain (or more broadly ecosystem service(s))?
- If there is a relationship, what would be an appropriate indicator(s) for that relationship?
- For each of these indicator(s)-interventions, is there sufficient evidence to measure that relationship (and how reliably)?
- If so, what evidence exists for each indicator to quantify the impact/effectiveness of the interventions?
- What papers exist that measure the impact/effectiveness of the interventions using the identified indicators?

Experts who responded in writing were provided with the above questions and list of interventions of interest. These groups were also told which domain(s) of interest to consider, informed of the premise of the project, and encouraged to consider the impact of the interventions through their unique research lens. Experts who participated in the discussions were provided with the list of interventions and a brief on the purpose of the project. They were guided through the above questions with discussion-specific follow-up questions but were also encouraged to voice their expert opinions on the known knowledge gaps, barriers to knowledge improvement, and assumptions associated with any quantitative measures/studies on an intervention–domain relationship.

Literature review

We conducted a review of the New Zealand –based peer-reviewed and grey literature to directly inform and support the development of the modelling assessment planned for Phase 2. For some interventions and domains, we extended our review to international literature for relationships that were not expected to be spatially/context dependent. The decision to include international literature was informed by our subject experts. The review approach is directly informed by our subject experts to efficiently identify and appropriately narrow the literature review search across the 72 intervention–domain relationships. The high reliance on subject expert knowledge of limitations, best practices, typical methodological, and current state of knowledge guided our literature review and search process towards the best available literature to model the intervention–domain relationships.

The literature review used a quasi-systematic process where key peer-reviewed literature and search terms were first identified by subject experts. Documents, articles, papers, and reports sourced from experts were the primary source of literature followed by review of relevant articles from the reference of the literature identified by the subject experts. For some domains, on-line databases such as Google, Google Scholar and Web of Science were searched using identified search terms (Table 4) to corroborate the literature provided and to supplement literature not provided or identified through the reference lists in the provided literature. These search terms were informed by our subject expert workshops and literature provided by our subject experts.

Table 4. Search terms used to identify supplementary literature for the literature review

Domain / intervention area	Search terms
Weed management / biological control:	'Himalayan balsam', 'Impatiens glandulifera', 'Lagarosiphon major', 'Alligator weed', 'Purple loosestrife', , 'willow aphids', 'terrestrial weed management and freshwater', 'bio-control of aquatic weeds', 'weed management impact on freshwater quality', 'impact of weed control on native plants'
Social connection	'Urban eel project', 'Well-being and ecological restoration'
Pest control	'Palatability of weeds', 'eco-sanctuary', 'deer fencing', 'animal pest management', 'biophysical benefits from animal pest control', 'terrestrial pest control and water quality'
Wetlands	'Wetland restoration', 'restored wetlands and biodiversity', 'wetlands and nutrients', 'carbon sequestration and wetlands', 'constructed wetlands and nutrients', 'Whangamarino wetland'
Terrestrial biodiversity	'habitat fragmentation', 'habitat and microclimate', 'habitat edge effects', 'scattered trees', 'bird gap crossing', 'habitat preferences of birds'
Riparian plantings	'impact of riparian planting on indigenous biodiversity', 'indigenous biodiversity and riparian areas', 'passively regenerating riparian areas and biodiversity',
Nutrients, *C. coli*	'Dairy best practice catchments', 'plant response to nutrient additions'
Stream fencing	'fencing riparian areas and pest control', 'fencing and biodiversity'

Frameworks

Kaupapa Māori framing for evaluation of environmental projects

No attempt was made to identify quantifiable relationships between interventions and domains from a Kaupapa Māori perspective. Instead, we have provided a Kaupapa Māori framework to facilitate the evaluation of J4N projects or future nature-focused projects. We provide a series of potential metrics in table 5, but which to apply would depend on the outcomes being sought from a specific project.

A Kaupapa Māori framing for project evaluation considers the impact of a project from a holistic–nature, people, and community perspective and is driven by five broad themes (Table 5). This framework was developed by Garth Harmsworth (Te Arawa, Waikato-Tainui, Ngāti Tūwharetoa, Tūhourangi, Ngāti Raukawa) based on his decades of knowledge and experience of cultural monitoring as it relates to freshwater systems and was supported by similar work in Kaupapa Māori programme evaluation (eg, Barnes, 2009; McKegg et al, 2017)[1]. In recognition of the need to accommodate a range of Māori aspirations, objectives and approaches, some key components to evaluate are listed below. A glossary of te reo Māori kupu/terms and of biophysical terms is provided at the end of this report.

[1] Kaupapa Māori framework references are listed in a separate reference list. See p 125.

Kawatau tukunga iho (outcome)

The community aspirations and goals decided and defined at the beginning of a project guide the evaluative criteria for the biophysical outcomes. Being outcome driven as opposed to input driven for metrics and measures of success means that a project has a clear path connecting activities to meaningful improvements for the environment, as determined by Māori.

For example, a specific te ao Māori objective for a project could be to restore or enhance the mauri of the river/awa/whenua. Criteria by which outcomes may be evaluated could include fence lines constructed (m/km), eroded areas planted/reduced (extent/area), taonga fish identified (abundance), and/or cultural monitoring programmes in place (Y/N). By meeting these criteria, the project would be expected to lead to sustained/strengthened mauri (an outcome which can only be assessed/determined by Māori), halt the decline of habitat/biodiversity, reduce in-stream nutrient levels and/or improve cultural/environmental flows.

Te Anga Pūkenga (skills/capacity)

Through a project, there is an opportunity to build resilience, capacity and empower the community. This is through capacity and skills building such as training, education, job creation and courses integrated into a project. If community capacity building is a specified outcome of the project, then capturing people/community impacts is a necessary component for the evaluation of the whole project. Criteria by which te anga pūkenga could be evaluated includes number of field days/hui/wānanga, number and type of training days, or number of people trained/employed.

Mātauranga Māori (Māori knowledge)

During a project knowledge can be created, generated, and enhanced. However, what type of knowledge and to whom that knowledge accrued has the potential to affect relationships across the broader community and the sustainability of the project beyond its completion. The community may neither have the capacity nor the interest to maintain a project's activities if they have not been fairly engaged. In evaluating the generation of knowledge, it is important to understand how well the project embraced and strengthened mātauranga Māori, where relevant, alongside western science, to strengthen the Māori intergenerational capability and capacity, education outcomes and cultural continuity, as well as bringing the community along the project journey. Criteria by which this domain could be evaluated includes evidence of mātauranga Māori being presented and used, number of wānanga and hui at which mātauranga Māori was shared, or mātauranga Māori-based monitoring and indicators developed.

Whakapapa/tūhononga (relationships/connections)

Environmental activities are an active representation of the connection that people have with the land (Papatūānuku), nature (taiao) and wider community networks. Project activities have the capability to create, strengthen and enhance these relationships for a more resilient community and environment. Criteria by which this domain may be evaluated includes mapping of wāhi tapu (sacred areas), protection strategies for wāhi tapu, networks/connections established/strengthened, eg, through hui/wānanga, and/or co-developed resources/ documents disseminated via hui/wānanga/field activities.

Tūhononga te hapori (connections with community)

Projects have the capability to bring together different people, organisations and groups to undertake the project. This bringing together of the entire community (starting with Māori and then extending to farmers, other land holders, urban residents, scientists, council staff, government organisations, etc) has the capability to develop and strengthen the network of whanaungatanga (relationships). The building and strengthening of these networks enhance resilience and generates trusting relationships with the community. Criteria by which this domain could be evaluated includes evidence of partnerships to working towards common or shared goal(s), and/or map of the number of partner connections or relationships formed (number, strength).

Table 5. Te ao Māori worldview assessment framework

Te Ao Māori Domain	Description	Outcome dependent metrics / indicators examples	Expected impact(s)
Kawatau tukunga iho (outcome) Did the project achieve Māori aspirations and goals?	Project outcomes are defined and described at the beginning of the project to reflect the aspirations, goals, and broad vision of the community with the aim for te puāwaitanga o te taiao/whenua (flourishing of nature/land). Project activities and evaluative criteria reflect those outcomes for the community. Central themes: • Ngā wawata Māori (aspirations) • Matawhānui Māori (broad vision) • Moemoeā (dream, vision) • Uara (desire, value) • Rangatiratanga and tino rangatiratanga Example - Specific te ao Māori objectives and goals are developed and described at the beginning of the project. eg, to restore or enhance the mauri of the river/awa/whenua	Criteria by which outcome could be evaluated: • Māori values (uara) described and presented • Plan consistent with kaitiaki/iwi/hapū management plans • Trees/plants planted (number, % area planted, hectares, etc) • Taonga plants/trees (number, % area planted, hectares, etc) • Fencelines (m/km) • Eroded areas planted/reduced (extent/area) • Sediment reduced/mitigated (% erosion reduction) • Taonga fish and biota identified (presence, abundance, distribution) • Monitoring programmes in place • Active and capable governance and management established • Formal management structures established	Iwi/hapū/kaitiaki goals/objectives met Mauri sustained/strengthened Mauri enhanced/restored Halt the decline of habitat/biodiversity Reduce habitat loss (extent and condition) Nutrient reduction Water flow improvements Water quality improvements (N, P, *E. Coli*, sediment) Less sediment in rivers (awa). Target planting/management of critical source areas Greater stability of riverbanks (eg, less riverbank erosion) Riparian planting activities Greater area of habitat (extent and condition) for taonga species and communities to thrive Increased fish and biota (eg, tuna, kākahi) Greater indigenous biodiversity (extent and condition) Active and capable governance and management Increased employment opportunities
Te anga pūkenga (skill/capacity) Did it build Māori community capacity, share knowledge, collaboration,	Through the aims and/or process of the project, there is an opportunity to build resilience, capacity and empowerment of the community through training, education, job creation and courses. Central themes: • Waihanga te whakamana (empowerment) • Hāpaitia raukaha (strength/resilience)	Criteria by which outcome could be evaluated: • Training (type, hours, days, no. of people, etc.) • Education (ako, ākona) • Instruction, teaching, and advising (type, hours, etc) • Jobs created (type/ momo)	Community/kaitiaki training, skills and capacity is developed, built up and/or carried out Community is empowered through enhanced confidence and esteem Management plans developed and operationalised/implemented Increased whānau/marae capability

Te Ao Māori Domain	Description	Outcome dependent metrics / indicators examples	Expected impact(s)
learning, well-being / resilience?	• kahapupuri o Māori (Māori power) • hapori/kaitiaki (society/guardian) • Pūkenga (skills) Māori • Whakawhanake (development) Māori • Whaiora te whānau ora/hapori ora	• Skills, abilities (pūkenga, āheinga,mātanga) • Courses • Field days/hui/wānanga (number) • Training days (number) • People trained (number)	
Mātauranga Māori (Māori knowledge) What knowledge was created, generated, and/or enhanced?	During a project knowledge can be created, generated, and enhanced. However, what type of knowledge and to whom did that knowledge accrue makes a difference to the impact of the project on the community in the short and longer term. Central themes: • Te kupenga o mātauranga Māori (network of knowledge) • Te māramatanga (understanding) • Te mātauranga (knowledge) • Te mohiotanga (comprehension) • Te Pūnaha Hihiko (dynamic system) • Kia kaha te ao Māori, te mātauranga Māori me tikanga Māori (to strengthen the Māori world, education and culture)	Criteria by which outcome could be evaluated: • Evidence of mātauranga Māori being presented and used • No. of wānanga and hui at which mātauranga Māori was shared • Mātauranga Māori documented • Mātauranga Māori-based monitoring and indicators developed	Mātauranga Māori (Māori knowledge) strengthened, shared, understood, and used Wānanga held and research conducted (eg, pūrakau, customary practices, maramataka, plants identified, nurseries, rongoā, taonga species) Pepeha (tribal saying, connection) Pūrakau (story, narrative, legend) Pakiwaitara (legend, story, narrative) Kōrero tuku iho Taonga tuku iho Mōteatea (lament, chant) Waiata Karakia Tauparapara (incantation, chant) Whakataukī (proverb – anonymous) Wahakatauākī (proverb)
Whakapapa / tūhononga (relationships / connections) Has the project reinforced connection	Environmental activities are an active representation of the connection that people have with the land (Papatūānuku), nature (taiao) and community (whenua). These activities have the capability to create, strength and enhance these relationships for a more resilient community and environment. Central themes:	Criteria by which outcome could be evaluated: • Links to whenua/taiao • Evidence of strengthened connections with whenua/taiao • Connections presented and established at hui/wānanga,	Relationships with taiao/whenua strengthened and enhanced Community Māori wellbeing/resilience is built Whakapapa presented and strengthened Kaitiakitanga Ahi kā

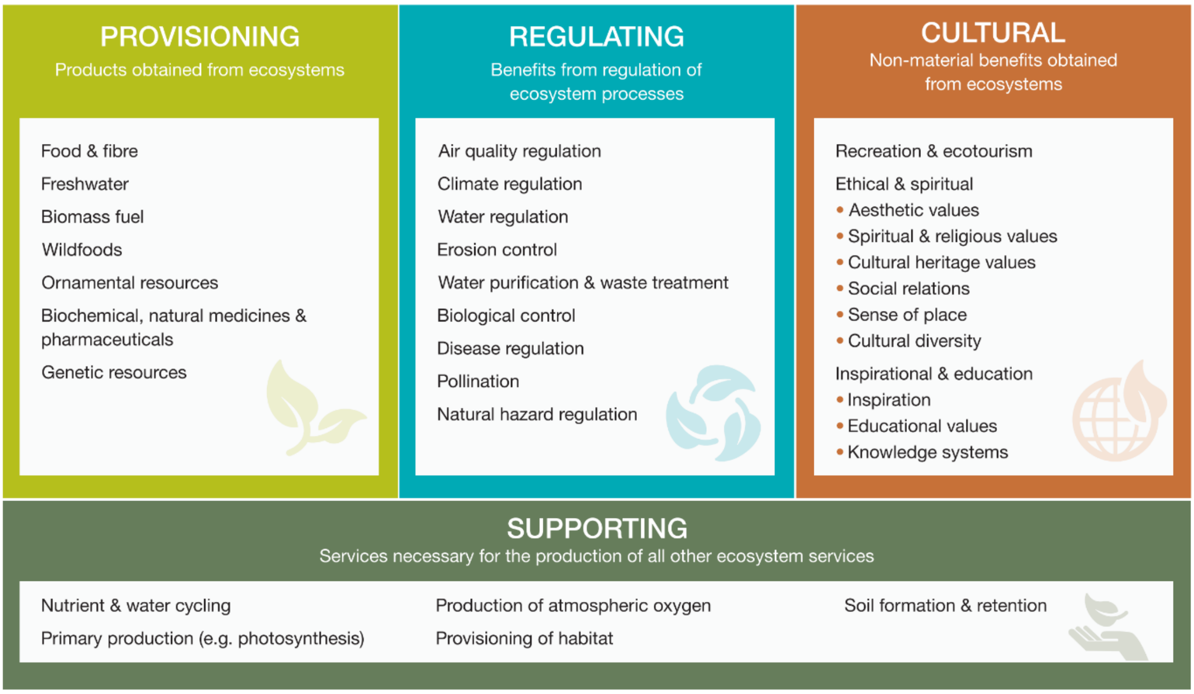
Te Ao Māori Domain	Description	Outcome dependent metrics / indicators examples	Expected impact(s)
or links to Papatūānuku / Taiao / whenua?	• Papatūānuku/taiao/whenua • Tūhonongatanga i te taiao • Connection	• Shared in documents and at hui/wānanga/field • Demonstrate connections to Papatūānuku/taiao/whenua through metrics • List activities/active programmes to demonstrate benefit (tau utuutu) to the natural environment/taiao • Mapping of wāhi tapu (sacred areas) • Protection strategies for wāhi tapu	Turangawaewae Kaitiakitanga responsibilities being met Safeguarding and protection of cultural heritage, customary practice, and scared sites (wāhi tapu)
Tūhononga te hapori (connect the community) How has the project created and/or strengthened the connection across the wider community?	Projects have the capability to bring together different people, organisations and groups for the purpose of the project's execution. This bringing together of the entire community (starting with Māori and then extending to farmers, other land holds, urban residents, scientists, government organisations, etc) has the capability to develop and strengthen the network of whanaungatanga (relationships). Central themes: • Tūhononga te tangata (connect people) • Te whakapiki i te Tūhonongatanga (increasing connectivity) • Kotahitanga, collaboration, mahi tahi, ngātahi • Relationships/whanaungatanga	Criteria by which outcome could be evaluated: • Evidence of partnerships to work towards common or shared goals • Map the number of partner connections • Relationships formed (number, strength)	Relationships with all parts of the community strengthened and enhanced Relationships with partner organisations established

Ecosystem Services Framework

Ecosystem services are the direct and indirect benefits provided to humans by nature (see Figure 1). An Ecosystem Services Framework provides a structured, comprehensive and holistic approach for decision making that puts a strong emphasis on the flow of benefits people receive from ecosystems and can provide arguments for their conservation, rehabilitation and/or enhancement. An ecosystem service framing is used in this review to identify the wider impacts/benefits to consider for each intervention. The key ecosystem services of interest to MfE for J4N projects are providing habitat (indigenous biodiversity), water purification, erosion control, natural hazard regulation, climate regulation, wildfoods and ethical and spiritual values. A high-level overview of the potential relationship between the interventions and the full range of ecosystem services is outlined in Table 6.

A definition of each ecosystem service and some examples of the service is provided in Appendix 1.

Figure 1. Ecosystem service classification



Source: Millennium Ecosystem Assessment 2005, modified by Landcare Research

Table 6. Relationships between ecosystem services and interventions using an Ecosystem Services Framework

	Stream fencing	Active / passive riparian areas	Pest control	Terrestrial weed control	Remediation of fish barriers	Ecological corridors	Restored / constructed wetlands
PROVISIONING SERVICES							
Food & fibre	Reduced meat, milk or wool production if fencing leads to land being taken out of pasture production; change (positive or negative) depends on characteristics and area of land.	Reduced meat, milk or wool production where riparian areas means land is taken out of pasture production; change (positive or negative) depends on characteristics and area of land.	Production may be enhanced if pests are reservoirs of disease (possums, cats), consume pasture (deer/goats) or predate stock (eg, feral pigs).	As weed control is in riparian areas, the effect on meat, milk or wool production relates to area taken out of pasture; reduction depends on characteristics and area of land.	N/A	Reduced meat, milk or wool production if land for ecological corridors mean land is taken out of pasture production; change (positive or negative) depends on characteristics and area of land.	Reduced meat, milk or wool production if wetland areas is no longer able to be used for grazing; change (positive or negative) depends on characteristics and area of land.
Freshwater	Reduction in access to freshwater for stock purposes.	Depending on species there could be some reduction in the quantity of freshwater given tree species use water but they also provide shade which may reduce evaporation.	N/A	N/A	N/A	Depending on species there could be some reduction in the quantity of freshwater given tree species use water but they also provide shade which may reduce evaporation.	Could be an increase in freshwater availability depending on use of wetland area prior to restoration.
Biomass fuel	N/A	Depends on species and if any timber is used for fuel	N/A	Depends on species, eg, use of willows or poplars and if these species were used for fuel before control/removal.	N/A	Depends on species and if any timber is used for fuel	N/A
Wild foods	Potential increase in certain wild food species as a result of improved water quality from the interventions.	Potential increase in certain wild food species as a result of improved water quality from the interventions.	Potential increase in certain wild food species as a result of improved water quality from the interventions.	Potential increase in certain wild food species as a result of greater habitat and improved	Potential increase in certain wild food species as a result of improved water quality from the	Potential increase in certain wild food species as a result of improved water quality from the	Depending on restoration practices, there may be an increase in wild foods associated with wetlands.

	Stream fencing	Active / passive riparian areas	Pest control	Terrestrial weed control	Remediation of fish barriers	Ecological corridors	Restored / constructed wetlands
				water quality from the interventions.	interventions. See tableTable A2. 7	interventions. See tableTable A2.8	
Ornamental resources	N/A	Potential increase in ornamental resources depending on species in riparian areas (eg, flax used for weaving)	N/A	N/A	N/A	N/A	N/A
Biochemical, natural medicines & pharmaceuticals	N/A	Potential increase in medicinal species; depends on planting or regenerating species.	Depends on recovery of species suppressed/ browsed by pest animals.	Depends on recovery of species suppressed by pest plants.	N/A	Potential increase in medicinal species; depends on planting or regenerating species.	Potential increase in medicinal species; depends on planting or regenerating species.
Genetic resources	N/A	N/A	N/A	N/A	N/A	N/A	N/A
REGULATING SERVICES							
Air quality regulation	N/A	Trees can improve air quality by reducing air temperature and directly removing pollutants and altering particles and gases from the atmosphere or reduce air quality through generating pollen and volatile organic compounds; improvement depends on species.	N/A	Depends on weeds being controlled. Some weeds, eg, privet, can be allergenic. Plants with larger leaf area tends to provide greater air quality.	N/A	Depends on species, leaf area and level of pollutants. Plants with higher leaf area tend to provide greater air quality.	Depends on species, leaf area and level of pollutants. Plants with higher leaf area tend to provide greater air quality.

	Stream fencing	Active / passive riparian areas	Pest control	Terrestrial weed control	Remediation of fish barriers	Ecological corridors	Restored / constructed wetlands
Climate regulation	N/A	See tableTable A2.2, Table A2.3	N/A	See tableTable A2.6, Table A2.11	N/A	See tableTable A2.8	See tableTable A2.9, tableTable A2. 10, tableTable A2.11
Water regulation	N/A	Depending on riparian species water regulation may improve.	N/A	Depending on species being controlled, water regulation may change.	N/A	N/A	Depending on the restoration activities water regulation may improve.
Erosion control	See tableTable A2.1	See tableTable A2.2, tableTable A2.3	See tableTable A2.4, table Table A2. 5, tableTable A2.11	See tableTable A2.6, table Table A2.11	See tableTable A2. 7	See tableTable A2.8	See tableTable A2.9, tableTable A2. 10, tableTable A2.11
Water purification & waste treatment	See tableTable A2.1	See tableTable A2.2, tableTable A2.3	N/A	See tableTable A2.6, table Table A2.11	See tableTable A2. 7	See tableTable A2.8	See tableTable A2.9, table Table A2. 10, tableTable A2.11
Biological control	N/A	Depending on the species, there may be more habitat for certain biological control species.	Depending on control activities, biological control may decline.	Depending on control activities, biological control may decline.	N/A	Depending on the species, there may be more habitat for certain biological control species.	Depending on the species, there may be more habitat for certain biological control species.
Disease regulation	N/A	Likely small, if any impact	N/A	N/A	N/A	Likely small, if any impact	Likely small, if any impact
Pollination	N/A	May see an increase in pollination services; plant and pollinator species dependent	N/A	N/A	N/A	May see an increase in pollination services; plant and pollinator species dependent	May see an increase in pollination services; plant and pollinator species dependent
Natural hazard regulation	See table**Error! Reference source not found.**	See tableTable A2.2, tableTable A2.3	N/A	See tableTable A2.6, tableTable A2.11	See tableTable A2. 7	See tableTable A2.8	See tableTable A2.9, table Table A2. 10, tableTable A2.11
CULTURAL SERVICES							

	Stream fencing	Active / passive riparian areas	Pest control	Terrestrial weed control	Remediation of fish barriers	Ecological corridors	Restored / constructed wetlands
Recreation & eco-tourism	N/A	Any improvement in water quality due to intervention may lead to improved recreation and eco-tourism. Consider alongside access (which many be reduced)	Probably small, if any impact	Changes that increase safe access to may lead to improved recreation and eco-tourism (eg, willow or blackberry removal).	Any improvement in fish passage and spawning due to intervention may lead to improved recreation and eco-tourism (eg, fishing).	Any improvement in water quality due to intervention may lead to improved recreation and eco-tourism. Consider alongside access (which many be reduced).	Any improvement in water quality due to intervention may lead to improved recreation and eco-tourism. Consider alongside access (which many be reduced).
Ethical & spiritual values	N/A	Depending on species, several cultural services may improve. See tableTable A2.2, tableTable A2.3	Several cultural services may improve as native ecosystems improve. See Table A2.4,Table A2. 5, Table A2.11.	Several cultural services may improve as native ecosystems improve. See Table A2.6,Table A2.11	Several cultural services may improve as native ecosystems improve. SeeTable A2. 7	Depending on species, several cultural services may improve	Depending on species, several cultural services may improve. See tableTable A2.9, tableTable A2. 10, tableTable A2.11
Inspiration & education	N/A	Likely small, if any impact	Likely small, if any impact	Likely small, if any impact	Likely small, if any impact	Likely small, if any impact	Likely small, if any impact
SUPPORTING SERVICE							
Provision of habitat	See tableTable A2.1	Depending on species, habitat may improve. See tableTable A2.2, tableTable A2.3	See table Table A2.4, tableTable A2. 5, tableTable A2.11**Error! Reference source not found.**	See tableTable A2.6,Table A2.11	See tableTable A2. 7	Depending on species, habitat may improve. See Table A2.8	Depending on species, habitat may improve. See Table A2.9, tableTable A2. 10, tableTable A2.11

Literature measuring the intervention–domain relationship

The knowledge gathering process (based on Ausseil et al, 2022, 2023) from our subject experts identified direct relationships between 58 of the possible 72 intervention–domain relationships (see Appendix 2). Our literature review identified 82 studies as suitable for providing quantitative and qualitive information to inform the modelling for these 58 direct intervention–domain relationships. Twenty-one of these studies provided information on more than one intervention–domain relationship.

Table 7–Table 13 summarise, where possible, quantitative and qualitative information relating the impact of each intervention on each domain. The domains are those identified by MfE as the key focus areas for the assessment. The relationships are organised by domain with rows indicating the intervention of interest and columns indicating the available indicators for that relationship. We include notation for type of study findings to account for the diversity of methodological approaches. Where the finding was observed or collected as part of an experiment, we precede the metric with an “O” for observed. Where the finding was a predicted or modelled estimate we precede the metric with a “M” for modelled. Where the finding was summarised in a literature review, in a best practice guide or as values to calibrate models we precede the metric with a “R” for review.

Where no empirical example or literature is available to measure/estimate the relationship for freshwater ecosystems quantitatively, we relied on discussions with subject experts and studies in other terrestrial area (eg, studies of birds in forests) to describe the relationship and indicator(s) that would best measure/estimate the relationship. These caveats and context-specific details are included in these summary tables.

There are two pieces of information about the intervention–domain relationships that are not presented in these summary tables. First, there are several expected intervention–domain relations for which no publicly available studies were found. Second, indicators described in these summaries are those presented in the available literature but other indicators which have not been assessed in the literature may be more appropriate. Table A2.1–Table A2.11 (in Appendix 2) describe in more detail the assessed quality of data of the intervention–domain relationships and appropriate indicators. Our subject experts provided information relevant to the detail of these relationships.

Domain: Water purification

Table 7. Observed (O), reviewed (R) or modelled (M) change in sediments, clarity, nutrients and *E. coli*

Intervention	Sediment	*E. coli*	Nitrogen	Phosphorus	Reference(s)	Context of study	Notes
Stream fencing	(O) Suspended sediment decreased by 0.21-0.89g m^{-3} yr^{-1}				Wright-Stow and Wilcock (2017)	Trend of suspended sediment improvement with improved effluent disposal and riparian fencing and/or planting in all five Dairy Best Practice catchments over 13 years. Pastoral landscape in Toenepi, Waiokura, Inchbonnie, Waikakahi and Bog Burn catchments.	Study was not able to separate out fencing, riparian planting, and effluent disposal interventions. Difficult to prove conclusively that these interventions are responsible for improvements as other changes may have occurred in the catchment over the same time period and influenced these suspended sediment responses.
Stream fencing		(O) peak concentration of 50,000 cfu/100 ml			Davies-Colley et al (2004)	Study measured the change in of *E. coli*, sediment, and total nitrogen directly downstream of 246 cows crossing a stream (2x in one day) during the period of crossing activity. Pastoral landscape in the Wangapeka River catchment, Tasman.	Changes in concentrations can be reliable if there is no change in flow over study duration or concentrations are flow-weighted as was the case in this study and studies by Wright-Stow and Wilcock (2017) and Graham et al (2018).
Stream fencing		(M) concentration decreases from 1500 to 300 cfu/100 ml			Graham et al (2018)	In Taranaki regional riparian analysis improvement in *E. coli* concentrations were inversely correlated to upstream stream length fenced and/or planted. As upstream stream length fenced and/or planted increased from 0% to 100%. Interventions were put in place 14–23 years before study.	Authors found that weighting for age and shade did not improve the relationships which suggests that fencing may have had more influence than planting on the responses observed.

Intervention	Sediment	*E. coli*	Nitrogen	Phosphorus	Reference(s)	Context of study	Notes
Stream fencing				(M) Pre-CREP: 4,100 kg Phosphorus (P) yr^{-1} deposited in-stream. (M) Post-CREP: 2,800 kg P yr^{-1} deposited in-stream; 5,800kg P yr^{-1} deposited near-stream.	James et al (2007)	Modelled in-stream and near-stream (within 10 m) phosphorus deposition from faeces pastured dairy cattle across the whole watershed. Modelled impact of cattle exclusion interventions from Conservation Reserve Enhancement Program (CREP) in the US.	Four reference sites in Cannonsville Watershed, New York, USA used to inform modelling. Observations taken 4x during 2003. Pastoral landscape.
Stream fencing		(O) load decrease of 0%–98%[1] (M) load reduced 15%, 62%, and 85% depending on fencing condition[2] (O) load reduced (NNI) 13%, 53% and 73%; 11%, 44% and 61% (SNI); 10%, 40% and 55% (SI).[3]			Muirhead (2016)	Systematic review and analysis of 16 suitable NZ and international studies. Studies included i) modelling, ii) paired catchments, iii) up- and down-stream sampling, and iii) pre- and post-treatment sampling approaches Results drawn from pastoral landscapes in the USA, NZ, UK and Canada.	[1]Range of values from beef cattle, deer and dairy studies. [2]Poor, Most likely effective and Highly effective fencing for cattle on dairy farms. [3]Cattle on sheep and beef farms in Northern North Island (NNI), Southern North Island (SNI), and South Island (SI) with poor, most likely effective and highly effective fencing, respectively.
Stream fencing Actively planted riparian areas	(O) Sediment load reduced by 98%		(O) 78% lower NO_3-N load (O) 91% lower NH_4-N load	(O) 86% lower TP load	McDowell (2008)	Fencing off and planting a 300 m^2 area of stream channel that also contained a deer wallow in a small 4 ha headwater catchment. Concentrations and loads of Suspended sediment, Total phosphorus (TP), Nitrate-Nitrogen (NO_3-N) and ammonium (NH_4-N) measured at the outlet.	Effect of fencing not separated from effects of riparian planting.

Intervention	Sediment	*E. coli*	Nitrogen	Phosphorus	Reference(s)	Context of study	Notes
						Study compared 2 years after intervention to 2-year period before fencing/plantings. Deer farm in Mosgiel, Otago, New Zealand.	
Actively planted riparian areas		(O) *L. scoparium* and *K. robusta* facilitated 90% reduction in *E. coli* cfu after 5 and 7 days compared to *Lolium perenne* [2,3]	(O) NO_3-N leaching rates of *L. scoparium, K. robusta* was 2kg ha^{-1} compared to 53kg ha^{-1} for *P. radiata*[1]		Esperschuetz et al (2017)[1] Prosser et al (2016)[2]	[1]Lab experiment comparing the abilities of *L. scoparium, K. robusta,* and *P. radiata* to reduce nitrate leaching from soil through plant uptake and by facilitating denitrification. [2]Lab experiment comparing the ability of *L. scoparium* and *K. robusta* to reduce *E. coli* concentration in soil compared to *Lolium perenne*.	[1]Plants were grown in a greenhouse lysimeter experiment, with controlled irrigation and temperature. Plants were treated with 200kg ha^{-1} per week of N for 15 weeks followed by a one-off 800kg ha^{-1} N. Leaching rates were compared to plots not treated with N. [2] Pots inoculated with 1x109 cfu *Escherichia coli* in 100ml sterile phosphate buffered saline. Plants harvested on day 1, 3 and 7 and soil E.coli concentrations measured at time of harvest. Control plots were planted with perrenial ryegrass *Lolium perenne* to simulate a typical pasture. [3]See figure 2 in paper for linear trend of *E. coli* concentration reduction over time.
Passively regenerative riparian areas	(O) 50% to 99% (median 59%) reduction in sediment load		(O) 49 to 94% (median 57%) reduction in TN (O) 0 to 100 % (median 87%)	(O) 80% to 95%, (median 36%) reduction in TP	McKergow et al (2020, 2022)	Systematic analysis of 19 suitable NZ and international literature studies to derive transferable relationships.	Magnitude of reduction was related to width of filter strip relative to hillslope length, soil type (% clay content) and land slope.

Intervention	Sediment	*E. coli*	Nitrogen	Phosphorus	Reference(s)	Context of study	Notes
			reduction in nitrate-N			Studies measuring changes in sediment load with passage through riparian filter strips	Suspended sediment attenuation was positively correlated with inflow load and %silt, and negatively correlated with %clay and filter age. Total phosphorous (TP) attenuation was negatively correlated with filter age and %clay. Total nitrogen (TN) attenuation was negatively correlated with %clay and positively correlated with incoming load. Mean buffer width of 6 m for studies examined. Filter width to hillslope length ratio better indicator of attenuation ability than filter width alone because hillslope length is a surrogate for incoming load.
Restored wetlands	(M) restored wetland exported 771 ± 468 t of sediment $ha^{-1}\ yr^{-1}$ (M) unrestored wetland exported 775 ± 468 t of sediment $ha^{-1}\ yr^{-1}$		(O) restored wetland exported 148 ± 43 kg N $ha^{-1}\ yr^{-1}$ (O) unrestored wetland exported 166 ± 48 kg N $ha^{-1}\ yr^{-1}$	(O) restored wetland exported 711 ± 268 g P $ha^{-1}\ yr^{-1}$ (O) unrestored wetland exported 1,347 ± 366 g P $ha^{-1}\ yr^{-1}$	Tomscha et al (2021)	Study on wetland restoration in Wairarapa was trying to measure the ecosystem services contribution of wetland restoration. Comparison of restored wetlands to unrestored paired reference sites (for Total nitrogen (TN), Total phosphorous (TP) and Olsen phosphorous). Sediment changes were modelled where unrestored wetlands were assumed to be conditions under agricultural land use.	Restored portions of wetlands only a small proportion of larger historical extent. 18 sites with restored areas ranging from 0.4 ha to 33.7 ha. Sites restored between <1 year ago up to 42 years ago. Modelling used land cover, DEM, rainfall, soils, rivers/streams and evapotranspiration GIS layers.

Intervention	Sediment	*E. coli*	Nitrogen	Phosphorus	Reference(s)	Context of study	Notes
Restored wetlands			(M) Median load removal efficiency of TN is 28%–39%	(M) Median load removal efficiency of TP is –16% to +36%	Land et al (2016)	Meta-analysis of the efficacy of constructed (n = 28) and restored (n= 9) wetland studies to remove Total nitrogen (TN) and Total phosphorus (TP). 93 studies from US, Europe, Turkey China, South Korea, Japan, and New Zealand.	Formally drained land, restored to wetland. Median wetland age at the start/end of study periods was 1 year/3 years. TP leaching of restored wetland could be the result of short-term washing of P from previously cropland.
Constructed wetlands			(M) Median load removal efficiency of TN is 36-39%	(M) Median load removal efficiency of TP is 50-55%	Land et al (2016)	Meta-analysis of the efficacy of constructed (n = 28) and restored n = (9) wetland studies to Total nitrogen (TN) and Total phosphorus (TP). 93 studies from US, Europe, Turkey China, South Korea, Japan, and New Zealand.	Formerly other land uses, converted to constructed wetlands. Median wetland age at the start/end of study periods was 1 year/3 years. TP leaching of restored wetland could be the result of short-term washing of phosphorous from soils within wetland that were previously cropland.
Constructed wetlands	(M) Median TSS removal of 88% (Interquartile range (IQR): 83%-89%)		(M) Median TN removal of 22% (IQR: 16%–30%) (M) TN removal for subsurface drainage waters: 30% median (IQR: 22%–38%)	(M) Median TP removal of 41% (IQR: 20%-59%) (M) TP removal for subsurface drainage waters: –52% median (IQR: -105% to +1%)	Woodward et al (2020)	Systematic analysis of 16 suitable NZ and international literature to derive transferable relationships. Studies measured attenuation efficiency of net Total nitrogen (TN), nitrate, Total phosphorous (TP) and Total suspended sediment (TSS) with passage through constructed wetlands.	Magnitude of TN, nitrate, TP and sediment load reduction was related to size of wetland as percentage of contributing catchment area. For TN and nitrate removal it was also related to air temperature and TP removal also depends on soil clay content. Net exports of *E. coli* from constructed wetlands could be due to prolonged survival, probable multiplication, and subsequent entrainment of environmentally adapted strains of resident *E. coli* as evidenced at the Toenepi wetland, Waikato (Stott et al, 2023).

Intervention	Sediment	*E. coli*	Nitrogen	Phosphorus	Reference(s)	Context of study	Notes
Constructed wetlands	(M) TSS reduced by 50% to 90% with %wetland area increase from 1% to 5%		(O) TN reduced by 25% to 50% with %wetland area increase from 1% to 5% (warm climate) (O) TN reduced by 20% to 40% with %wetland area increase from 1% to 5% (cool climate).	(O) TP reduced by 25% to 50% with %wetland area increase from 1% to 5%	Tanner et al (2022)	Best practice guide for constructed wetlands. Shows relationship between attenuation efficiency of Total suspended sediment (TSS), Total nitrogen (TN), and Total phosphorous (TP) and wetland area as percentage of catchment area. Estimates based on work in Woodward et al (2020).	TSS and TP estimates only applicable in catchments with soils having < 35% clay content. TP estimates do not cover subsurface drainage water. Recommends constructing wetland using soils with low potential P release.

Domain: Erosion control

Table 8. Observed (O), reviewed (R) or modelled (M) change in bank erosion

Intervention	Sediment yield / Suspended sediment	Suspended Sediment Concentration	Bank erosion / Channel damage	Reference(s)	Context of study	Notes
Stream fencing	(O) TSS in hillslope runoff were 90% lower at treated sites[1] (M) 80% reduction in sediment yield from stream banks[2]		(O) Actively eroding banks reduced from 30% to 4%	Phillips et al (2020)	Review of studies in New Zealand that measure streambank erosion are limited to pastoral landscapes.	Report includes international literature as well, but identifies NZ vs international. [1] Fenced and grass riparian buffers. [2]'Conservative' adjustment of the Australian SedNet model parameter. [3] % length of eroding bank 1–7 years after riparian buffers were established.
Stream fencing		(M) 30% reduction in SSC[1] (M) 50% reduction in SSC[2]		Monaghan and Quinn (2010)	Development of model for eight farm archetypes to identify what actions could be taken to reduce input of farm containment into a river in a representative Waikato catchment. Suspended sediment concentration (SSC) estimates are pulled from a literature review of selected studies. E. coli, Total nitrogen (TN) and Total phosphorous (TP) reduction ranges also available in table 3 in paper.	Median estimates derived from unpublished data for use in a modelling exercise. Reduction in SSC that can be attributed to stream bank erosion. [1] Fencing cattle out. [2] Fencing all stock out.
Stream fencing	(O) 40% reduction in sediment yield from pastures[1] (O) 60% reduction in TSS[2] (O) 82%-93% reduction in TSS[3]			O'Callaghan et al (2018)	Review of New Zealand and international studies to assess the impact of cattle exclusion interventions on morphology, sediment, nutrients, invertebrates and biology of streams. Table 1 in paper summarise the findings of review papers.	[1]Following fencing. [2]After fencing and nutrient management plan. [3]Following fencing and planting of riparian zones.

Intervention	Sediment yield / Suspended sediment	Suspended Sediment Concentration	Bank erosion / Channel damage	Reference(s)	Context of study	Notes
Stream fencing	(M) assumes 30%-90% reduction in TSS at catchment scale			McKergow et al (2007)	Review (stocktake) of New Zealand and international studies.	Assumes 2 m fenced margin. Total suspended sediment (TSS) includes all sources (bank erosion, hillslope erosion).
Stream fencing Passively regenerating riparian areas	(O) TSS in hillslope runoff were 90% lower at treated sites[1] (M) 80% reduction in sediment yield from stream banks[2]		(O) Actively eroding banks reduced from 30% to 4%[3]	Phillips et al (2020)	Review of studies in New Zealand that measure streambank erosion are limited to pastoral landscapes.	Report includes international literature as well, but identifies NZ vs. international. [1] Fenced and grass riparian buffers. [2] 'Conservative' adjustment of the Australian SedNet model parameter. [3] % length of eroding bank 1–7 years after riparian buffers were established.
Stream fencing Passively regenerating riparian areas		(M) 30%–90% reduction in SSC		Monaghan and Quinn (2010)	Development of model for eight farm archetypes to identify what actions could be taken to reduce input of farm containment into a river in a representative Waikato catchment. Suspended sediment concentration estimates are pulled from a literature review of selected studies. E. coli, TN and TP reduction ranges also available in table 3 in paper.	Median estimates derived from unpublished data for use in a modelling exercise. Reduction in SSC that can be attributed to stream bank erosion. Fencing cattle out. Empirical analysis of unpublished data from PW3 site at Whatawhata collected over 3 years.
Stream fencing Passively regenerating riparian areas		(O) 0.21– 0.89 $g\ m^{-3}\ yr^{-1}$ reduction in SSC (c. 4%–11%)		Wilcock et al (2013)	Five streams in Waikato pastoral dairy farming catchments. Change in adoption of Best Management Practices (BMPs) over 7–16 years from 1995 to 2008 (Tables 1 and 2 has attributes of ΔBMPs by catchment).	Reduction in suspended sediment concentration (SSC) that can be attributed to stream bank erosion. Non-storm SSC. Multiple BMPs put in place at same time, but authors attribute sediment changes to fencing changes.

Intervention	Sediment yield / Suspended sediment	Suspended Sediment Concentration	Bank erosion / Channel damage	Reference(s)	Context of study	Notes
Stream fencing Actively planted riparian areas	(R) 85% reduction in sediment load[1]		(R) Actively eroding banks reduced from 30% to 4%[2] (R) >50% reduction in channel damage[3]	Phillips et al (2020)	Review of studies in New Zealand that measure streambank erosion are limited to pastoral landscapes.	Report includes international literature as well, but identifies NZ vs. international. [1] 1-7years after riparian buffers were established. Reduction in suspended load that can be attributed to stream bank erosion. [2] % length of eroding bank.1–7 years after riparian buffers were established. [3] % of bank eroded post Cyclone Bola. Space-planted trees along riparian zones in the Waihora, Whareama, and Waipa catchments. Assumed adequate condition of plantings.
Stream fencing Actively planted riparian areas		(R) 60% to 65% reduction in SSC[1] (R) 55% reduction in SSC[2]		Monaghan and Quinn (2010)	Development of model for eight farm archetypes to identify what actions could be taken to reduce input of farm containment into a river in a representative Waikato catchment. Suspended sediment concentration (SSC) estimates are pulled from a literature review of selected studies. *E. coli*, Total nitrogen (TN) and Total phosphorous (TP) reduction ranges also available in table 3 in paper.	Median estimates derived from unpublished data for use in a modelling exercise. Reduction in SSC that can be attributed to stream bank erosion. [1] Fencing, planting 5 m to 15 m riparian buffers. [2] Fencing cattle out, 6-8 years post planted poplars.

Domain: Habitat for freshwater biodiversity

Table 9. Observed (O), reviewed (R) or modelled (M) change in freshwater biodiversity

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Stream fencing Actively planted riparian areas	(M) Semi-Quantitative Macroinvertebrate Community Index (SQMCI) increase from 2 to 9 as upstream stream length fenced and/or planted increased from 0 to 100%	Graham et al (2018)	An analysis of macroinvertebrate indices and riparian effort data for the Taranaki region. Indices were correlated at regional scale to upstream stream length fenced and/or planted.	Authors found that weighting for age and shade did not improve the relationships which suggests that fencing may have had more influence than planting on the responses observed. SQMCI is derived from coded abundance scores for macroinvertebrate taxa (rare, common, abundant, very abundant, very very abundant). In comparison the QMCI is derived from quantitative count data for macroinvertebrate taxa. SQMCI score >5.99 = excellent (clean water), 5.00-5.99 = good (possible mild pollution) 4.00-4.99 = fair (probably moderate pollution) and <4.00 = poor (probable severe pollution)
Actively planted riparian buffers Passively regenerating riparian areas	(O) Periphyton weighted composite cover constrained to <30% [1] (O) Aquatic macrophyte channel clogginess reduced to <50%[1]	Matheson et al (2017) Mouton et al (2019)	Regional analyses of data for Waikato streams relating riparian vegetation to nuisance growth of periphyton and aquatic macrophytes in streams and the relative abundance of native macrophytes in streams.	[1] With 65% to 70% shade. Shade was measured as overhead canopy cover with a densiometer.
Passively regenerating riparian areas	(O) Egg density increased from 0 to maximum of c. 800/0.01 m^2 (O) Egg survival positively correlated with stem density and thickness of the aerial root mat.	Hickford et al (2010)	Laboratory and field experiment to test the impact of riparian vegetation and density on the survival of developing *Galaxias maculatus* eggs in three Banks Peninsula riparian zones. Spawning areas adjacent to urban area and riparian vegetation was a mixture of grass, native rushes/sedges and invasive exotic plants.	With riparian stem density at ground level of c. 3-16/500 m^2 Type of vegetation does not particularly matter as long as it creates high stem density and thick aerial root-mat. These characteristics are directly tied to keeping ground temperatures consistently lower and humidity consistently higher.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Actively planted riparian areas	(O) Mean daily survival ranged from 91.0% ± 2.4% (*J. edgariae*) to 18.8% ± 18.8% (*Schedonorus phoenix*)[1] (O) More eggs found in exotic grass *Agrostis stolonifera* and in native rush *J. edgariae*[2] (O) More eggs found in exotic grass *A. stolonifera* and native sedge *C. virgata*[2.3]	Hickford et al (2017)	Laboratory and field experiments to test the impact of native versus exotic vegetation on the survival of developing *Galaxias maculatus* eggs in Barrys Bay stream, Banks Peninsula riparian zones. Lab 1: individual tanks for native vegetation (2 types), exotic vegetation (2 types), mixture of *J. edgariae* and *S. phoenix* and smooth river stones. Lab 2: 4 tanks with combination of 2 native and 2 exotic plants Field: All eight treatments from Lab 1, potted bank vegetation and uncut bank vegetation.	Tiller densities were at the higher end across all vegetation treatments. *Carex virgata* (native), *Juncus edgariae* (native), *Schedonorus phoenix* (exotic), and *Agrostis stolonifera* (exotic). [1] No significant difference between vegetation treatments due to high variability between replicates. However, all eggs in stone treatment died within 24 hours. [2] High proportion than would be expected by chance. [3] No difference in survivability between vegetation treatments.
Pest control	(O) Mean daily survival ranged from 91.0% ± 2.4% (*J. edgariae*) to 18.8% ± 18.8% (*Schedonorus phoenix*)[1]	Hickford et al (2010)	Laboratory and field experiment to test the impact of exotic slugs (*Milax gagates, Deroceras panormitanum* and *D. reticulatum*) and mice (*Mus musculus*) on the survival of developing *Galaxias maculatus* eggs in Avon River, Takamatua Stream and Barrys Bay Stream.	[1]Lab experiment. No impact of mice or slugs on egg survivability found in field experiments. Mice have been found to predate *G. maculatus* along the Mokau River (Baker 2006). However, insect and seedlings were highly abundant at field sites in the present study which may have satiated mice.
Fish passage barrier removal, replacement or remediation	(O) installation of ramp and spoiler baffles increased species richness (mean 80%) and total fish density (mean 45%) upstream (O) 27.1% of *G. maculatus* successfully passed ramp (0% prior) (O) 6.2% of *G. maculatus* successfully passed culvert with baffles (0% prior)	Franklin and Bartels (2012)	Before-after monitoring examined the efficacy of a fish ramp and spoiler baffles for restoring īnanga (*G. maculatus)* communities upstream of a culvert in Hamilton. Surveys over 6 years pre- and post-treatment. Passage trials with inanga were also carried out.	General note from subject matter experts in this area: Variation in efficacy likely reflects both the site-specific nature of interventions (ie, they are highly varied) and the significant range in quality of interventions. There is no relationship available at present that accounts for these factors. Investigations using a numerical tool have shown that spoiler baffles can reduce water velocities within culverts dramatically (Feurich et al, 2011). Installing a complex array of smaller spoiler baffles has been shown experimentally to increase passage of *G. maculatus* from 13.5 to 86% (MacDonald and

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
				Davies 2007). A recent machine learning assessment determined that using smaller baffles with medium spatial density provided more efficient upstream passage for *G. maculatus* (Magaju et al, 2023)
Fish passage barrier removal, replacement or remediation	(O) 0.79% successfully passed the ramp (O) 0% successfully passed the whole culvert	Baker et al (2024)	This study examined the passage efficiency of sea run juvenile īnanga (*Galaxias maculatus*) past a perched culvert fitted with spat ropes and a flexible rubber ramp in Nelson using a mark-recapture technique with stains Rhodamine B and Bismarck Brown. Trials carried out over 4-day period.	Culvert: 0.9-m-wide, 7.5-m-long perched pipe, c. 180 mm drop height at outlet. Retrofitted with a 440-mm-wide rubber ramp and two strands of mussel spat rope. Mark-recapture studies using Rhodamine B shown to produce more reliable estimates of fish passage for small bodied fish like *G. maculatus* than use of VIE-tags (Franklin et al, 2024).
Fish passage barrier removal, replacement or remediation	(O) increase in mean diadromous fish abundance from 5.5 to 15.43 fish $100m^{-2}$ (O) Redfin bullies and eels did not appear to respond to culvert remediation (abundance <5 fish $100m^{-2}$)	David and Hamer (2012)	Before and after control treatment design examined the effectiveness of mussel spat ropes for improving fish passage past perched culvert structures in two tributaries to the Waiwawa River, Coromandel Peninsula	Change driven by young of the year (<50 mm) banded kokopu (*Galaxias fasciatus*). Redfin bullies (*Gobiomorphus huttoni*), longfin eels (*Anguilla dieffenbachii*) and shortfin eels (*Anguilla australis*) also present.
Fish passage barrier removal, replacement or remediation	(O) Mean passage success for juvenile inanga was 3% (low flow) and 6% (high flow) for the 15° ramp. For the 30° ramp success was 2% for both flows. (O) For adult inanga mean passage success was 49% (low flow) and 23% (high flow) for the 15° ramp, and 8% (low flow) and 7% (high flow) for the 30° ramp. (O) Mean passage success for redfin bully was 44.6% (low flow) and 73.3% (high flow) for the 15° ramp, and 8.9% (low flow) and 9.9% (high flow) for the 30° ramp.	Franklin et al (2021)	The study compared passage efficiency of native and exotic fish species over an artificial baffled ramp designed for overcoming low-head (≤1.0 m) fish migration barriers. Two ramps with vertical fall height of 1 m were used, one with 15° slope and the other with 30° slope.	The ramps were 1.5 m wide and v-shaped with lengths of 3.86 and 2 m, respectively. Two flow velocities were tested of 29 $m^3 h^{-1}$ (high flow) and 23.8 $m^3 h^{-1}$ (low flow).

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
	(O) Mean passage success for juvenile rainbow trout was 49.8% (low flow) and 42% (high flow) for the 15° ramp and 3.9% (low flow) and 10.2% (high flow) for the 30° ramp. Rudd and koi carp could not pass the ramps.			
Fish passage barrier removal, replacement or remediation	(O) Passage of juvenile inanga and common bully prevented by fall height of 10 cm or greater. Passage of adult inanga was prevented by fall height of 20 cm or greater. (O) Common bully could more easily navigate a V-notch weir, than rectangular or circular weirs. Notch shape did not affect adult inanga passage, but juvenile inanga were restricted by a wide rectangular weir.	Baker (2003)	Trials were carried out using experimental weirs in outdoor experimental channels at Whatawhata, Waikato.	
Fish passage barrier removal, replacement or remediation	(O) Most ramps at 45° only allowed passage of redfin bullies except when using Miradrain surface for inanga. (O) The highest rates of passage for all species tested was at the lowest slope tested (15°). (O) Gravel, nylon brush, Cordrain and Miradrain provided high rates of fish passage for both species at slopes of 15° and 30°.	Baker and Boubee (2006)	Trials were carried out using artificial ramps to test effects of surface and slope. Species tested were the redfin bully *Gobiomorphus huttoni* and adult and juvenile inanga Galaxias maculatus.	
Fish passage barrier removal, replacement or remediation	(O) Of the 400 fish tested, 0% passed the perched culverts and 66% passed non-perched culverts without the ramp installed. With ramp installed passage of perched culverts improved to 44%.	Doehring et al (2011)	Installed a ramp at 13 replicate culverts around Nelson City to determine if passage of juvenile inanga *Galaxias maculatus* was improved.	The authors recommended that ramp length and angle should not exceed three metres and 20 degrees, respectively.
Fish passage barrier removal,	(O) At 15° slope both inanga and common bully could pass, most successfully with shorter ramp length of 3 m c.f. 4.5 or 6 m.	Baker (2014)	This study evaluated the effect of ramp length and slope on fish passage over experimental baffled ramps.	

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
replacement or remediation	(O) At 30° slope only inanga could pass the shortest ramp. Increasing slope reduced successful passage for redfin bully but increased length had no effect.			
Fish passage barrier removal, replacement or remediation	(O) For juvenile rainbow trout in 6-m culverts mean success increased from 5% (no rope) to 40% (rope). (O) For 3-m pipes mean success increased from 34% (no rope) to 50% (rope). (O) For inanga passage success increased from 23% without ropes to 83% with ropes present in the 3-m pipes and from 0 to 57% in the 6-m pipes. (O) For shrimp, passage success increased from 0% (no rope) to 14-54% (rope).	David et al (2013)	Study assessed passage success for two fish species, juvenile rainbow trout and adult inanga, and one migratory shrimp, through culverts of differing length (3 and 6 m), slope (1·5 and 3°) and flow (0·24 and 0·75 $L\ s^{-1}$)	
Fish passage barrier removal, replacement or remediation	(O) Mean >85% of individuals used the ropes to successfully negotiate the 0.5 m high simulated perched culvert. No difference in success between the two rope types tested.	David et al (2010)	Laboratory trials to evaluate two UV stabilised polypropylene spat rope types: “Russet Loop” and “Super Xmas Tree” to assist passage of banded kokopu through an experimental perched culvert. Four 3-hr trials conducted.	
Fish passage barrier removal, replacement or remediation	(O) The probability of successful passage of young-of-year Galaxias spp. through the culvert increased from 0.03 to 0.41 following the remediation works and was similar to levels observed at a control site (0.33).	Amtstaetter et al (2017)	A Before-After Control-Impact mark-recapture study was used to evaluate improvement in passage for Galaxias spp. Water velocity in a 70 m pipe culvert was reduced by installing a concrete weir downstream of the culvert. A lateral ridge rock-ramp fishway was installed to provide for the passage of fish over the weir, and baffles were installed in the upstream portion of the culvert to provide refuge from higher water velocity at this location.	Cone fishways have been developed as an alternative to rock-ramp designs for places where rock is difficult to source. These are a series of pre-fabricated cone-shaped concrete baffles installed laterally within a concrete channel. Early indications are that these cone fishways can provide passage for a broad range of the target size-classes of small-bodied fish and individuals as small as nine mm can ascend (Stuart and Marsden 2021).

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Restored wetlands	(O) Beetle community in restored locations close to unmined areas after 13 years (O) Poor-dispersing native taxa were less abundant in restored than in unmined after 13 years	Clarkson et al (2017)	Experimental study testing different restoration techniques in a peat mined lowland *Sporadanthus*-dominated wetland (Torehape bog, Waikato). Cultivation/water table regimes (raised, non-raised), fertilizer applications (nitrogen, phosphorus), and seed additions (Leptospermum, Sporadanthus).	Canopy density and height, and vegetation cover, strongly influenced beetle species composition.
Restored wetlands	(O) 42% native beetles in willow-dominated wetlands[1] (O) 37% native beetles in native wetlands undergoing willow invasion[1] (O) 79% native beetles in native wetlands[1] (O) 67% native beetles in restored native wetlands[1]	Watts et al (2012)	Effects of invasion by introduced grey willow (Salix cinerea) on beetle. communities within four wetland vegetation types: native vegetation, native vegetation following grey willow removal, native vegetation undergoing grey willow invasion and dense grey willow dominated vegetation.	Whangamarino (native and willow-dominated plots), Toreparu (native, willow-dominated, and invading willow plots), Lake Kaituna (restored native plots) and Lake Tunawhakapeka (willow-dominated plots). [1] % of all beetle species caught.
Constructed wetlands	(O) 18 aquatic species found at smallest wetland (<0.05ha), 31 found at largest wetland (0.3 ha) (O) 61% to 82% of aquatic species were native	Goeller et al (2023)	Survey of the vegetation and fauna assemblages in five established free-water surface flow wetlands in a lowland, pastoral landscape in the Waikato, New Zealand.	No before intervention or reference site comparison. Community composition correlated with wetland size. Aquatic invertebrates. Low degree of connectivity of free water surface flow wetlands to larger areas of forest or hydrology.

Domain: Habitat for terrestrial biodiversity

Table 10. Observed (O), reviewed (R) or modelled (M) change in terrestrial biodiversity

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Stream fencing	(O) 6.50 rats ha^{-1} in fenced grids compared to 0.48 rats ha^{-1} in unfenced grids in summer (*p<.02*). (O) 2.75 rats ha^{-1} in fenced grids compared to 2.36 rats ha^{-1} in unfenced grids in autumn (*p<.25).*	Innes et al (2010)	Empirical study of ship rat density in fenced versus non-fenced indigenous forest fragments in a grazed landscape conducted over a 6-month period in a lowland pastoral landscape in Waikato.	Fencing out stock leads to an increase in vegetation thereby improving habitat for ship rats. Analysis for eight indigenous forest fragments (4 fenced and 4 grazed) in pastoral farming areas of Waikato. Half of each type had vegetation that connected the fragments. Fencing creates the corridor across fragmentation. Grid-based tracking rates below 30% reliably correspond to c. 3–5 rats ha^{-1}. Rats above 30% are of conservation concern.
Stream fencing	(O) Sapling counts in unfenced plots were 3–10 times lower after 60 years of deer control compared with unfenced plots.	Husheer and Tanentzap (2023)	Study estimates the mountain beech tree growth, survival and recruitment in response to unrestricted sport hunting and commercial culling of deer over 20 years in Kaweka Forest Park. 40 experiment paired fenced and unfenced plots across 594 km^2.	Mountain beech forest plots in Kaweka Forest Park. 1958–1987, 1987–2008.
Actively planted riparian areas	(M) Local abundance of arthropods, vertebrates and woody plants was 60%–430% greater in areas with scattered trees compared to open areas. (M) Overall species richness was 50%–100% higher in areas with scattered trees compared to open areas. (M) Species richness of herbaceous plants was, on average, 43% lower in areas with scattered trees compared to open areas	Prevedello et al (2018)	Global meta-analysis of 62 suitable studies to quantify relationships between scattered trees and species richness, species abundance and composition of vertebrates, arthropods and plants.	Habitat patches: includes habitat fragments and/or continuous habitat areas, and occasionally habitat corridors. Native forests and non-forest environments. Ratios of scattered trees: open area and habitat patch: scattered trees shown in figure 1 of the paper. Community composition similarity shown in figure 2 of the paper.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
	(M) Species richness of epiphytes was, on average, 50% higher in habitat patches compared to open areas. (M) Communities inhabiting habitat patches were more similar in composition to the communities inhabiting areas with scattered trees, and less similar to the communities of open areas.			
Actively planted riparian areas	(R) North Island kōkako, pōpokotea, South Island tīeke, and North Island brown kiwi currently unknown to cross gaps larger than 500 m. (R) Mohua, tītitipounamu, pīpipi, weka, North Island tīeke, kakaruai, toutouwai, and miromiro not observed crossing a gap more than 5 km.	Innes et al (2022)	Review of New Zealand forest bird whole-year sociality and movement, natal dispersal, and pasture- and water-gap crossing behaviour studies. Data on 34 bird species available.	Inferences would need to be made about the impact of additional habitat or habitat corridors on different bird species. Table 1 of the paper shows all bird species and the environments where they have been observed. Tables 2, 3, 4 of the paper shows observed dispersal behaviour (land or water crossing, natal dispersal, whole-year range).
Actively planted riparian areas	(O) Plant species composition and planting density changed over the 4 years. (O) Abundance of native ground invertebrates increased 18 months after planting. (O) Distribution of invertebrate species in their trophic levels did not show a pyramidal trophic structure compared with remnant kahikatea forest sampled in the north side of the Lake (figure 13 of the paper).	Gutierrez Gines et al (2022)	Study reports on the water quality findings from a 4 ha, 40,000 plant experimental riparian planting plot along Lake Waikare, Waikato. Invertebrate surveys conducted before plantings and for 2 years following plantings.	Planted 1–1.9 plants m^{-2}. Reached full canopy cover and 3.3 m height after 3.5 years 30–50 m riparian band. Mix of 22 native species. At least 50% planted with local mānuka species. Act management first year with weed management.
Actively planted riparian areas	(M) Total species richness and abundance decline significantly when forest cover dropped below 5%-10%. (M) Total abundance and number of common indigenous bird species increased with forest	Ruffell and Didham (2017)	Study evaluated the influence of forest cover, pest control and interaction of forest cover and pest control on bird species richness and abundance across 195 sites in Auckland. Lowland forest sites around Auckland Forest cover ranges from 0% to 100%	Indigenous forest cover within 1 km of each sampling site Primary data comes from the Terrestrial Biodiversity Monitoring Programme from 2009–2014. Gaps in data quality and quantity were filled by selective surveying by authors.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
	fragment area in the Auckland area. Increase driven by tūī. (M) Tomtit preferred >25% forest cover. (M) Tūī populations would still be relatively high in high forest cover (>10%) without pest control, but would decline as forest cover approached 0% even with pest control.			5-minute bird counts between November and December. Abundance: total number of individuals recorded across all three counts. Species richness: number of native forest species recorded. Total relative abundance: total number of individuals recorded from all native forest species.
Passively regenerating riparian areas	(R) North Island kōkako, pōpokotea, South Island tīeke, and North Island brown kiwi currently unknown to cross gaps larger than 500m. (R) Mohua, tītitipounamu, pīpipi, weka, North Island tīeke, kakaruai, toutouwai, and miromiro not observed crossing a gap of more than 5km.	Innes et al (2022)	Review of New Zealand forest bird whole-year sociality and movement, natal dispersal, and pasture- and water-gap crossing behaviour studies. Data on 34 bird species available.	Inferences would need to be made about the impact of additional habitat or habitat corridors on different bird species. Table 1 of the paper shows all bird species and the environments where they have been observed. Tables 2, 3, 4 of the paper shows observed dispersal behaviour (land or water crossing, natal dispersal, whole-year range).
Passively regenerating riparian areas	(M) Indigenous-dominated regrowth from around year 20 after retirement and a return to near-natural state after 40 years. (M) Graph of change in indigenous species richness over time in figure 2 of the paper.	Smale et al (2005)	Case study of a Waikato dairy farm where fragmented indigenous forest was fenced to exclude cattle . Modelled revegetation of retired grazing land near a kahikatea-dominate forest fragment.	Locations close to urban invasive-dense locations showed higher variability for native revegetation dominance. Modelled 0-74 years after retirement.
Pest control	(M) Ground-based possum control has a small, but positive impact on invertebrates and mammal-sensitive vegetation while unfenced mainland islands have a small but positive impact on birds. (M) Plant palatability plays a role in magnitude of impact from pest control (eg, possums attracted by planting of kohekohe).	Binny et al (2021)	Meta-analysis of impact of different pest management regimes (eg, ring-fencing, unfenced, aerial etc.) on 145 species of bird, lizards, invertebrates and plants, largely in forested areas. Observational data from New Zealand studies.	Data in studies used for meta-analysis was observational and not specific to riparian areas. Pest control regime is based on overall approach and is not based on marginal changes in specific pest control methods. Effects size by control duration (0 to 20 years) in figure 1 of the paper.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Pest control	(M) If rat populations are continuously maintained below 10%, then robin populations are likely to increase 10% each year. (M) Once robin population variability is introduced into the model, rat populations must be kept near zero and breeding pairs will most likely need to be introduced for population recovery.	Armstrong et al (2006)	Simulation model of North Island robin population recovery after reintroduction into forest remnant Paengaroa Mainland Island (near Taihape) dependent on predator control activities. Ship rat and possum control in place until 1999, discontinued for 6 months, then stopped again in 2002.	The model started with 4 North Island robin breeding pairs after pest control ceased the second time which in the long run shows population collapse without additional breeding pairs.
Pest control	(R) Less than one fifth of relationships showed a linear impact function. (R) More than half of studies showed non-linear relationships with substantial benefits for indigenous species when pests were suppressed to low levels.	Norbury et al (2015)	Literature review and analysis to catalogue the relationship between pest density functions and indigenous flora and fauna recovery likelihood. Observational data from New Zealand studies.	Data in studies used for meta-analysis was observational and not specific to riparian areas. Table 1 of the paper summarises literature on pest density impact functions by indigenous response species and pest species.
Pest control	(O) No measurable response of rats and mice following stoat removal. (O) Removal of possums alone can increase ship rats while removal of ship rats can release mice (figure 2 of the paper).	Ruscoe et al (2011)	Replicated Before-After Control-Impact field experiment with a four-species assemblage across mixed podocarp – broadleaved forest sites in Whirinaki Forest Park, Mokaihana Ecological Area, Te Urewera National Park and Kaimai Ranges.	Stoat removal, possum removal, and possum and rat removal treatments. No indigenous response variables. Stoat: kill traps summer of 2007. Possum: 1080 bait traps spread by helicopter Sept–Oct 2006. Possum and rat: 1080 bait traps spread by helicopter followed up with mouse-unpalatable rodenticide (diphacinone) placed in bait stations Sept–Oct 2006.
Pest control	(M) No measurable impact on invertebrates or lizards. (M) Predator control, Predator and possum control, Predator and mouse control, and Predator, possum and mouse control: more rabbits, mice and birds, and less green pasture, and seed.	Ramsey and Norbury (2009)	Fuzzy logic neural network modelling of a dryland system to quality the interactions between (4) vegetation, (8) pests, and (3) indigenous fauna in response to different management regimes in New Zealand.	Generic predator control model was where cat, ferret, stoat and weasel abundances were held at 20%. Table 2 of the paper shows the relative interaction strength and direction among the flora/fauna. Table 3 of the paper shows the qualitative model responses to differing management models.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
	(M) Possum control: more fruit and browse. (M) Possum and mouse control: more fruit and birds.			
Pest control	(O) Significant improvement in bellbird, brown creeper, fantail, grey warbler, mohua, rifleman, tui and yellow-crowned parakeet over the 12-year period. Trends in bird counts in figure 4 of the paper.	O'Donnell and Hoare (2012)	Predicted the efficacy of pest control efforts in Landsborough Valley, New Zealand, during 1998–2009 to aid in the recovery of mohua (*Mohoua ochrocephala*) and other predator-sensitive hole-nesting birds and maintenance of numbers of South Island kaka (*Nestor meridionalis meridionalis*).	Pest control regime is based on overall approach and is not based on marginal changes in specific pest control methods. Continuous trapping to control mustelids plus 1080 toxin to control rats and brushtail possums. Point-count method: relative abundance of a population (indices of relative abundance). All bird species seen and heard within 5-min periods at 112 count sites.
Pest control	(R) 79% of studies reported positive responses of indigenous biodiversity from possum-focused control. (M) Plant palatability plays a role in magnitude of impact from pest control on vegetation. Possum control benefited vegetation by increasing foliage and fruit production, and by reducing tree mortality. (M) Controlling ship rats and possums together improved bird populations. Controlling of stoats and ferrets enhanced those benefits. (M) Benefits of pest control to Auckland wētā lasted 1–2 years or until ship rats reinvaded	Byrom et al (2016)	Meta-analysis of 35 New Zealand studies from DOC and TBfree on the response of native biota to possum control. Log response ratio: quantitative measure of the effect of treatment on a population relative to the effect of non-treatment.	Pest control regime is based on overall approach and is not based on marginal changes in specific pest control methods. 60% of studies quantified responses to aerial 1080 and the remainder were ground-based control methods. Land type: podocarp-broadleaved forests (77%) mixed beech/podocarp or pure beech forest (15%), exotic forest, shrubland or other successional communities (8%). See table 2 of the paper. Flora/fauna: vegetation (48%), birds (32%), invertebrates (15%), frogs (8%). See table 2 of the paper. Figure 1 of the paper shows mean effect size.
Pest control	(R) Widespread evidence of deer browsing on vegetation even at low to moderate population densities, especially understoreys.	Leathwick and Byrom (2023)	Review of New Zealand impact-outcome studies from management of wild ungulates, brushtail possums and predators.	Reviews the historical trends in pest control in New Zealand including knowledge of impacts of pests, gaps in knowledge and potential reasons for changes in pest management policies.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Pest control	(M) Kererū and tūī were significantly more abundance in pest controlled (E and HRP) landscapes. Tūī populations would still be relatively high in high forest cover (>10%) without pest control, but would decline as forest cover approached 0% even with pest control. (O) Pest control was correlated with forest cover so sensitivity of marginal changes in relationship was challenging to estimate.	Ruffell and Didham (2017)	Study evaluated the influence of forest cover, pest control and interaction of forest cover and pest control on bird species richness and abundance across 195 sites in Auckland. Lowland forest sites around Auckland. Forest cover ranges from 0% to 100%. Pest control intensity ranged from no control to eradication.	Indigenous forest cover within 1 km of each sampling site. Pest control scenarios: eradication (E), high-intensity rat and possum control (HRP), low-intensity rat and possum control (LRP), periodic possum control (PP), no pest control. Primary data comes from the Terrestrial Biodiversity Monitoring Programme from 2009-2014. Gaps in data quality and quantity were filled by selective surveying by authors. 5-minute bird counts between November and December. Abundance: total number of individuals recorded across all three counts. Species richness: number of native forest species recorded. Total relative abundance: total number of individuals recorded from all native forest species.
Pest control and stream fencing	(M) Ground-based possum control has a small, but positive impact on invertebrates and mammal-sensitive vegetation while unfenced mainland islands have a small but positive impact on birds. (M) Plant palatability plays a role in magnitude of impact from pest control (eg, possums attracted by planting of kohekohe).	Binny et al (2021)	Meta-analysis of impact of different pest management regimes (eg, ring-fencing, unfenced, aerial etc.) on 145 species of bird, lizards, invertebrates and plants, largely in forested areas. Observational data from New Zealand studies.	Data in studies used for meta-analysis was observational and not specific to riparian areas. Pest control regime is based on overall approach and is not based on marginal changes in specific pest control methods. Effects size by control duration (0 to 20 years) in figure 1 of the paper.
Pest control and stream fencing	(R) Positive impact on number of kohekohe, mahoe, pate, tūī, bellbirds, adult tree wētā, flower pollination, and fuchsia fruit dispersal from combining pest control and fencing.	Innes et al (2012, 2019)	Reviews of New Zealand literature on the response of indigenous flora and fauna to ecosanctuaries (eg, mainland ring-fenced,	Riparian fencing and pest control should be catalogued as a pest suppression method (not exclusion) requiring ongoing pest management.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
			mainland unfenced island, island sanctuaries, fenced peninsulas).	Supressed would also most likely also have lower a smaller magnitude of benefits.
Terrestrial weed control	(O) native dicots +7% cover in biocontrol plots over 5 years. (O) native monocots +5% cover in biocontrol plots and 11% cover in biocontrol & herbicide plot. (O) non-native dicots -3% cover in herbicide plots and +4% cover in biocontrol plots over 5 years. (O) non-native monocots +14% cover in biocontrol and herbicide plots, +19% in biocontrol & herbicide plot over 5 years.	Peterson et al (2020)	5-year field trial comparing bio-control agent to control methods to manage heather in Tongariro. Non-riparian environment.	Control method was a selective herbicide that was indiscriminate on which plants it killed. Figure 2 of the paper contains estimates over time Reinvasion of heather low after 5 years
Terrestrial weed control	(O) Native % cover and species richness in treatment plots near close to control plots (with no mist flower present). (O) Non-native species % cover and richness did not change as % mist flower decreased indicting that native species were able to recolonise in the absence of mist flowers.	Barton et al (2007)	Study of the impacts from multiple release sites of white smut fungus and gall fly in the North Island to control mist flower. Repeat observations over 1999 to 2001.	Waitakere Ranges are dominated by native cover, potentially explaining the low non-native colonisation post-mist flower removal. Streams present at study site, but not specific to target invasive species.
Terrestrial weed control	(O) Native fern *Hypolepis ambigua* second highest cover at 18.1% in plot 3 (alluvial) and 11.6% in plot 4 (river). See table 1 of the paper.[1] (O) No seedling of native species observed near dead dock. Pohuehue occupied some bare areas, but *Solanum chenopodioides* tended to grow in the open canopy spots. See table 2 of the paper.[2] (O) Partially sprayed plants didn't always die. No resurgence of woody natives and no seeding of other natives from adjacent areas. See table 4 of the paper.[3]	Williams et al (1998)	Experimental comparison of sites treated and not treated with different sprays for *Lonicera japonica* (1), *Rumex sagittatus* (2) and *Chrysanthemoides monilifera* (3). (1) Four plots treated with four types of sprays. Data collected over 2 years. (2) 16 individual plants. 1 m cleared around each plant to catalogue seeding growth. All plants sprayed. Measured over 2 years. (3) Two plots. Measured over 7 weeks.	[1] Plots roadside bank adjacent to the Takaka River. 2 plots next to river, 2 plots on alluvial soil. [2] Sand dunes at the base of Farewell Spit. [3] coastal shrubland in Queen Elizabeth Park. Native plants avoided. All sites had more than target weed present.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Terrestrial weed control	(O) Removing mature bone-seed plants had a positive effect on bone-seed regeneration (1.6 ±0.4 seedlings per plot after a year), and a negative effect on native regeneration (from 2.1 ± 0.5 seedlings per plot down to 0.3 ± 0.1 per plot after a year) (See figure 1 of the paper).	McAlpine et al (2009)	Experiment comparison of four sites n = 40 plots treated and not treated with physical removal (cut off at ground). Plots subdivided at 6-month mark with half receiving weeding treatment (exotic grasses, gorse, bracken, and fern physically removed).	All gorse removed at sites. Coastal Wellington New Zealand within 200 m of secondary forest. Sites had a mixture of target species, natives and other invasive species.
Terrestrial weed control	(O) Mean native and non-native species richness higher in plots where *Impatiens glandulifera* was removed than in plots where *Impatiens glandulifera* was present. (See table 1 of the paper). (O) Species accumulation curves suggested that extensive *Impatiens glandulifera* stands may reduce species richness by as much as 25%.	Hulme and Bremner (2006)	Experimental comparison of removal of *Impatiens glandulifera* on species richness, diversity and evenness in open riparian habitats in north-east England.	International study of a common riparian weed found in New Zealand. Experiment conducted over 4-months.
Terrestrial weed control	(O) Tradescantia biomass at biocontrol site (200 g m^{-2}) significantly lower than at control sites (300+ g m^{-2}; figure 3 of the paper) (O) Number of woody seedlings significantly higher at hand-cleared sites (c. 150) than biocontrol (~115) or control (~50) sites after 3 years (figure 4 of the paper)	Clarkson et al (2019)	Field experiment at two sites using beetle biocontrol and manual clearing over 3 years to manage *Tradescantia fluminensis.*	Forest remnants on the Hikurangi floodplain. No additional site details, type of woody seedlings and changes in vegetation community.
Terrestrial weed control	(O) Shading controlled weed growth while allowing natives to recolonise. Herbicides and hand weeding had reinvasion. (O) 2.5 years, 61% of the saplings planted had emerged from the surrounding tradescantia.	Standish (2002)	Experimental study of herbicide, shading and hand weeding of *Tradescantia fluminensis* in Awahuri (podocarp/broad-leaved forest remnant on a flood plain) and Monro's Bush (lowland podocarp/broad-leaved forest remnant).	Planted seedlings are not light –dependent so will thrive in shaded areas. Native sub-canopy species were planted into tradescantia to achieve natural shading
Ecological corridors	(O) 6.50 rats ha^{-1} in fenced grids compared to 0.48 rats ha^{-1} in unfenced grids in summer (*p<.02*). (O) 2.75 rats ha^{-1} in fenced grids compared to 2.36 rats ha^{-1} in unfenced grids in autumn (*p<.25).*	Innes et al (2010)	Empirical study of ship rat density in fenced versus non-fenced indigenous forest fragments in a grazed landscape conducted over a 6-month	Fencing out stock leads to an increase in vegetation thereby improving habitat for ship rats. Analysis for eight indigenous forest fragments (4 fenced and 4 grazed) in pastoral farming areas of

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
			period in a lowland pastoral landscape in Waikato.	Waikato. Half of each type had vegetation that connected the fragments. Fencing creates the corridor across fragmentation. Grid-based tracking rates below 30% reliably correspond to c. 3–5 rats ha^{-1}. Rats above 30% are of conservation concern.
Ecological corridors	(R) North Island kōkako, pōpokotea, South Island tīeke, and North Island brown kiwi currently unknown to cross gaps larger than 500 m. (R) Mohua, tītitipounamu, pīpipi, weka, North Island tīeke, kakaruai, toutouwai, and miromiro not observed crossing a gap of more than 5 km.	Innes et al (2022)	Review of New Zealand forest bird whole-year sociality and movement, natal dispersal, and pasture- and water-gap crossing behaviour studies. Data on 34 bird species available.	Inferences would need to be made about the impact of additional habitat or habitat corridors on different bird species. Table 1 of the paper shows all bird species and the environments where they have been observed. Tables 2, 3, 4 of the paper shows observed dispersal behaviour (land or water crossing, natal dispersal, whole-year range).
Restored wetlands	(O) Restored wetland plots have a mean native plant species richness of 17.9 species Unrestored wetland plots have a mean native plant species richness of 2.6 species.	Tomscha et al (2021)	Study on wetland restoration in Wairarapa was trying to measure the ecosystem services contribution of wetland restoration. Comparison of restored wetland to unrestored wetland paired reference sites.	Native species richness defined as total number of vascular plants (native or non-native) per plots. Restored portions of wetlands only a small proportion of larger historical extent. 18 sites with restored areas ranging from 0.4 ha to 33.7 ha. Sites restored between <1 year ago up to 42 years ago.
Restored wetlands	(R) Early successional *Leptospermum* was near 100% after 2 years when planted directly into soils, but late successional *Sporadamthus* did not survive. (R) Raised beds with a few *Leptospermum* resulted in more successful diversification of desirable flora as *Leptospermum* provided a nursey for late successional peat-forming plants *Sporadanthus ferrugineus, Empodisma robustum* blown in from surrounding seed sources.	Clarkson et al (2017)	Experimental study testing different restoration techniques in a peat mined lowland *Sporadanthus*-dominated wetland (Torehape bog, Waikato). Cultivation/water table regimes (raised, non-raised), fertiliser applications (nitrogen, phosphorus), and seed additions (Leptospermum, *Sporadanthus*).	*Sporadanthus*-dominated wetlands. Study appears to be more of a review of the relevant literature.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Restored wetlands	(O) Whangamarino: (table 2 of the paper) *Baumea teretifolia* and *Schoenus brevifolius* dominant until yr3 post fire, *Leptospermum* established early reaching peak coverage at yr5 post fire*, Empodisma* established after 10 months post fire then dominated after c. 4 years (Figures 3 and 4 of the paper) (O) Moanatuatua: (table 1 of the paper) Unburnt area: 34% *Empodism*a minus, 37% *Sporadanthus traversii* 2 yr post fire: 65% *Schoenus brevifolius* 4.5 yr post fire: 39% *Empodisma minus*, 20% *Gleichenis dicarpa* 11.5 yr post fire: 67% *Empodisma minus*, 32% *Sporadanthus traversii* 21 yr post fire: 41% *Empodisma minus*, 57% *Sporadanthus traversii.*	Clarkson (1997)	Observational study of the recovery trajectory of vegetation in Whangamarino and Moanatuatua wetlands after fires in 1984 and 1989.	No intervention. Study shows the progression of recovery of wetlands. Infer the potential benefits of restoration and the trajectory of the recovery without direct intervention. Whangamarino: dominated by *Baumea/Leptospermum*, *Baumea-Leptospermum*, and (*Leptospermum)-(Epacris)/Empodisma* before fire. Moanatuatua: dominated *by Sporadanthus/Empodisma, Leptospermum* and *Epacris, Gleichenis dicarpa, Baumea teretifolia*, and *Schoenus brevifolius* before fire.
Restored wetlands	(O) % native Coleoptera: 100% (intact) vs 97.4% (modified). (O) % native Lepidoptera: 89.4% (intact) vs 24.5% (modified). (O) % native Diptera: 35.9% (intact) vs 15.5% (modified). (O) % native Hymenoptera: 64.5% (intact) vs 60.6% (modified).	Watts et al (2020)	Observational study comparing terrestrial invertebrate communities in a remnant modified bog (Moanatuatua) isolated in an agricultural landscape to communities in an intact large bog (Kopuatai).	Infer the potential benefits of restoration.
Constructed wetlands	(O) Community composition correlated with wetland size. (O) 53% of terrestrial invertebrates were native. (O) 45% of birds were native. (O) 32% of plants were native.	Goeller et al (2023)	Survey of the vegetation and fauna assemblages in five established free-water surface flow wetlands in a lowland, pastoral landscape in the Waikato, New Zealand.	No before intervention or reference site comparison. Low degree of connectivity of free water surface flow wetlands to larger areas of forest or hydrology.

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Constructed wetlands	(R) Constructed wetlands lend toward a homogenous biodiversity structure due to emphasis on sediment retention and lack of connection with natural hydrology. (R) Most likely to support high diversity of birds, benthic invertebrates and macrophytes in the first few years, but there is a chance for declining diversity over time as constructed wetlands becomes more eutrophic. (R) Constructed wetlands are often dominated by nutrient tolerant species due to the placement of constructed wetlands in a usually agricultural landscape with high nutrient and sediment concentrations in runoff. (R) Mixed impact relationship between plant species richness and purification ability.	Zhang et al (2020)	Review of 19 international studies that measured the biodiversity benefits of constructed wetlands.	USA, Ireland, Sweden, Australia, Denmark, China, Italy, and Spain. Studies do not show the change in biodiversity as a response to the wetland being constructed. Table 1 of the paper shows studies of the presence/use of the wetlands by flora/faun. Table 2 of the paper shows studies that identify constructed wetlands as ecological traps (ie, animals preferring suboptimal habitat)
Constructed wetlands	(O) 6 months after construction: 106 shortfin eels counted. (O) 3 years after construction: 205 shortfin eels counted. (O) Kotare (kingfisher; *Todiramphus sanctus*), swans (*Cygnus atratus*), ducks (*Anas* spp.), smelt and bullies utilise constructed wetlands (3 yrs post construction)	Taura et al (2021)	Guide to wetland restoration using case studies of wetland restoration undertaken by whanau, marae, hapu and iwi. Case study: 10 wetlands were constructed along the Waipa and Waikato River catchment for the purpose of creating a safe habitat for tuna (eel) population recovery.	Unclear whether additional information on restoration project is publicly available. No pre-constructed numbers available for comparison.
Pest control in wetland environments	(R) Loss of 11 of 14 extinct wetland birds linked to predation. (R) 30 extant species, particularly ground-nesting species, are still under threat from mammalian predators. (R) All introduced mammalian predator species are abundant and/or widespread in wetlands. Most have been confirmed to prey upon freshwater bird species.	O'Donnell et al (2015)	Review of empirical studies in New Zealand that show the impacts of mammalian predators on freshwater birds and in particular species that are restricted to wetlands.	List and threat classification of indigenous birds that characteristically feed, breed, or shelter in freshwater palustrine, riverine and lacustrine wetlands (table 1 of the paper). List of known predators of these birds (table 2 of the paper) and case studies (table 4 of the paper).

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Terrestrial weed control in wetland environments	(O) Grey willow canopy cover was reduced to 44% ± 3.7%. (O) Light availability increased to 64% ± 15%. (O) Kahikatea grew an average of 44 cm ± 11.7 cm in 14 months. (O) No kahikatea in untreated sites.	Griffiths and McAlpine (2017)	Paired-site experiment of the response of kahikatea seedlings to different types of control of willows along the margins of Lake Ellesmere/Te Waihora.	Kahikatea seedlings planted into an intact stand of grey willow and into areas where the herbicides glyphosate or triclopyr had been aerially applied to control willow c. 1.5 years earlier. Compared to untreated sites.
Terrestrial weed control in wetland environments	(O) Willow canopy cover reduced to <5% on average for 20yrs post spraying (Figures 2 and 3 of the paper). (O) Negative long-term impact on *Dicksonia squarrosa* (O) Increased species richness in treated plots (O) Shift towards a native *Carex*-dominated sedgeland community.	Burge et al (2017)	Before–after control–impact experiment over 7.1 ha in Whangamarino Wetland, Waikato prior to spraying and 2 years after glyphosate application to control willows.	
Terrestrial weed control in wetland environments	(O) Saplings grew best in partial cleared plots. Estimated 24–26 years to reach height of surrounding willows. See table 1 of the paper for average height per year by treatment. Figures 3–5 of the paper show graphical comparisons.	Sukias et al (2023)	Testing methods to jumpstart revegetation of a willow-dominated Whangamarino wetland with native kahikatea (*Dacrycarpus dacrydioides)* podocarps.	Annual measurements from 2015 to 2020. Planted saplings after full herbicide clearance, partial herbicide clearance and manual cutting of willow canopy.

Domain: Climate regulation

Table 11. Observed (O), reviewed (R) or modelled (M) change in carbon sequestration and GHG emissions mitigation

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Actively planted riparian areas	See table 1 of Mander (2022) for a summary of carbon sequestration rates of planted indigenous woody vegetation. Rates ranges from 3 to 17 t CO_2e ha^{-1} yr^{-1} depending on species and context, with a riparian carbon sequestration estimate of 3.5 t CO_2e ha^{-1} yr^{-1}. The National GHG Inventory provides emissions factors and methods to estimate methane and nitrous oxide emissions from livestock and fertiliser and drained peatland. These emissions factors can be used to estimated the avoided emissions associated with converting some pastoral aera to riparian uses. The avoided emissions will depend on the reduction in stock numbers, if any, and the types of stock removed.	MfE (2024) Mander (2022)	The 2024 inventory contains the emissions and removals data from 1990 to 2022, major emissions trends, and methodology used by New Zealand for estimating its emissions and removals. See report for method details.	Burrows et al (2018a) in their comprehensive literature review of non-ETS compliant land, state that there are no known quantitative data sets for carbon sequestration for planted riparian strips in New Zealand, with the only data for riparian shrublands being dominated by mostly gorse, broom, grass, and mixed shrublands. Thus, the Mander (2022) summary of indigenous woody vegetation should be used with care. Methane reductions will depend on what livestock, if any, are removed. Nitrous oxide emissions reductions will depend on synthetic nitrogen or organic fertiliser is reduced. Soil carbon is an active area of on-going research into measurement and uncertainties related to measurement.
Passively regenerating riparian areas	For naturally regenerating forests, mostly kānuka and/or manuka: Nelson (4.1 ± 0.7 t CO_2e ha^{-1} y^{-1}.). Northland (3.7 ± 0.3 t CO_2e ha^{-1} yr^{-1}). Gisborne (3.7 ± 0.4 t CO_2e ha^{-1} yr^{-1}). Manawatu/Wanganui (3.6 ± 0.3 t CO_2e ha^{-1} yr^{-1}). West Coast (1.7 ± 0.2 t CO_2e ha^{-1} yr^{-1}). Otago (2.1 ± 0.3 t CO_2e ha^{-1} yr^{-1}).	Holdaway et al (2010) Payton et al (2010) Burrows et al (2018b)	An approximation of sequestration rates by region (based on 52 naturally regenerating forests, mostly dominated by kānuka and/or mānuka)	Carbon sequestration rates vary depending on the species planted, and factors such as age and environmental conditions. Payton et al (2010) suggested that sequestration rates should not be compromised so long as annual rainfall is > 700 mm (or mean water deficit < 200 mm), soils are not excessively infertile (eg, ultramafic) and mean temperature of the warmest month is ≥ 11°C (ie, some extent below treeline).
Restored wetland	(O) Net carbon stored ranged from 134.7 to 216.9 g C m^{-2} yr^{-1}	Goodrich et al (2017)	Estimated carbon exchange and storage from an unaltered peat bog (Kopuatai bog) over 4 years using the Global Warming Potential approach.	Unaltered peatland remnants that are dominated by the jointed wire rush, *Empodisma robustum.*

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
	(O) Extreme summer drought reduced net ecosystem carbon balance by 30-40%, but bog still remained a carbon sink (O) Annual methane fluxes ranged from 14.2 to 21.9 g CH_4–C m^{-2} yr^{-1}			
Restored wetland	Recommended approach for estimating emissions for wetland organic soils: See Tables 6.3, 6.4 and 6.5of the paper for recommended CO_2, N_2O and CH_4 emissions for New Zealand. Carbon dioxide emissions factors ranged from 2.6 to 7.9 t CO_2-C ha^{-1} yr^{-1}; nitrous oxide emissions factors ranged from 1.6 to 13 kg N_2O-N ha^{-1} yr^{-1} and methane emissions factors ranged from 0 to 39 kg CH_4 ha^{-1} yr. Emissions factors differed depending on the land use on the drained peat/wetland soils.	Pronger et al (2023)	Review of spatial data, approaches and emission factors relevant to organic soil carbon and methane sequestration for improved policy recommendations.	If wetland/peatland is restored then these emissions are avoided.
Restored wetland	(M) 1348t C ha^{-1} for organic soils through full peat depth (3.9 m). (M) 102t C ha^{-1} for organic soils through 0.3m depth. (M) 121t C ha^{-1} for mineral soils through 0.3m depth. (M) 11 ± 1 Mt in organic soil through 0.3m depth. (M) 144 ± 17 Mt in peat soil through full 3.9m depth. (M) 23 ± 1 Mt in mineral soils through 0.3 m depth. (M) Estimated 0.5 and 2 Mt CO2 released per year from conversion of organic soils wetlands to agriculture since early European settlement	Ausseil et al (2015)	Carbon (C) stock estimates for unaltered freshwater wetlands extrapolated to national scale from 126 current wetland sites across New Zealand covering organic and mineral soil types across fen, bog, swamp, marsh, pakihi and ephemeral wetland types.	Not enough sites to consider spatial or soil profile effects (assumed carbon density constant along depth). Does not consider temporal changes in carbon or the impact of land use change on carbon. Study is of current stock of wetlands and is therefore indicative of potential benefits of restoration. Pakihi is a type of wet heath characterised by very infertile soils.

Domain: Natural hazard regulation

Table 12. Observed (O), reviewed (R) or modelled (M) change in flood and drought resilience

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Actively planted riparian areas	Reductions were 30% for total stormflow, and 50% for peak flow associated with thinning. Pattern of reduced runoff, peak flows and total storm flows after pine afforestation.	Hughes et al (2020)	Whole catchment study of runoff, peak flows and total storm flows after pine afforestation in a Whatawhata, NZ. Pine afforested catchment was compared to a native forest catchment.	This study is a whole of catchment afforestation not riparian planting per se. Relies on assumption of native (control) and afforested (treatment) catchments being equivalent.
Restored wetland	(M) Flood management in Manawatū requires natural capital investment alongside built flood protection capital	van den Belt et al (2013)	Simulation modelling of flooding in the flood plain of the Manawatu River to assess the trade-offs of investing in natural capital and/or man-made capital for flood mitigation.	
Restored wetland	(R) Whangamarino wetland: NZ$5.2 million avoided flood damage costs from a 1-in-100-year flood event in 1998	Clarkson et al (2013)	Valuation study to quantify the ecosystem service benefits of wetlands in New Zealand using restoration case Whangamarino wetland.	General discussion of wetlands and their potential ecosystem services benefits in New Zealand.
Restored wetland	(O) Average saturated hydraulic conductivity of restored wetlands was 1.239 mm h^{-1}, whilst unrestored wetlands average saturated hydraulic conductivity was 0.97 mm h^{-1} (O) Restoration increased a wetland soil's saturated hydrologic conductivity by 27.3% ± 11% See figure 7 of the paper.	Tomscha et al (2021)	Study on wetland restoration in Wairarapa was trying to measure the ecosystem services contribution of wetland restoration. Comparison of restored wetlands to unrestored paired reference sites.	Bulk density, particle size measurements and soil organic carbon samples were used to estimate saturated hydraulic conductivity as an indicator of flood mitigation ability. Saturated hydraulic conductivity (Ks) estimated using samples from a restored wetland and paired unrestored wetland. Paired sampling design.

Domain: Cultural Values including ethical and spiritual values/social connections and educational and inspirational values

Table 13. Observed (O), reviewed (R) or modelled (M) change in ethical and spiritual values, social relationships, community and well-being

Intervention	Main finding(s)	Reference(s)	Context of study	Notes
Actively planted riparian areas	*Social connections:* There is some qualitative evidence such as the assessment of social relationships from being involved in community freshwater monitoring: • (O) Monitoring increased participants' awareness, knowledge and understanding of science process. • (O) Stimulated participants to reflect on their own, and society's, relationship with the environment.	Kin et al (2016)	9 volunteer groups participated in freshwater monitoring over 18-months in 2014/15 and then were interviewed post-project.	Proxy for being involved in other freshwater restoration activities. Participants received training in stream monitoring methods, and had face-to-face contact and dialogue with NIWA and regional councils during monitoring projects. Auckland, Nelson, Waikato (Taupo), Gisborne and Wellington. Results could be used as a proxy for other interventions.
Pest control	*Ethical and spiritual values:* (O) Participation in predator trapping groups was significantly inversely correlated with perceived depression, perceived stress and likelihood of taking blood pressure medicine and positively correlated with sense of social cohesion.	Shanahan (2020)	Representative quantitative survey of the impact of nature on mental, physical and social well-being in 2019 in Wellington.	City-wide and not specific to riparian zones. Duration in nature experiences and participation on community trapping networks measured.
Restored wetland	*Ethical and spiritual values:* (R) Loss of ingoa (names), whakapapa (connections), and tikanga (customary values and practices) associated with *Sporadanthus* has been lost as a result of draining, damage, and conversion of historical *Sporadanthus* wetlands across the North Island. [1] (R) Regular wānanga (workshops) and community planting days connected mana whenua and the wider community[2,3] *Educational and inspirational values:* (R) Kaimahi development by qualifications/experience[2,3] (R) Improved understanding of dune lake ecosystems and kaitiakitanga roles and responsibilities[2,3] (R) Schools now including the local lakes in their curriculum as places of learning[2,3]	Taura et al (2017, 2021)	Guide to wetland restoration using case studies of wetland restoration undertaken by whanau, marae, hapū and iwi. Guide lists lessons learned from restoration activities, how to improve relationship for a more successful project, the Ake Ake process of identifying project aims and aspirations, and development of appropriate indicators. Case studies describe the existence of projects, the successes and lessons learned from these projects and how to build successful restoration projects.	[1] Ecological considerations for designing restoration of different types of wetlands (gum lands, swamps, estuaries, peat bogs) that consider the types of flora and fauna that would naturally flourish in those different environments. [2] Toreparu wetland will be using a combination of wetland Cultural Health Index and science approaches to assess restoration impacts. Post-restoration assessment not available as project is in progress. [3] Dune lakes in Te Hiku; Lake Waiparera at Waiharara, Split Lake at Sweetwater Farm, Bulrush Lake and Waimahuru Lake

Literature gap and quality analysis

Process

Indicators were created to code intervention–domain relationship literature by country of study, landscape in which the study took place, relevance of study to the specific intervention–domain relationship, and four attributes of study quality. Country of study, landscape, and relevance are intended to be objective measures of the overall applicability of the study to the scope of the literature review. An applicability weight $\in [0,1]$ was created from the geometric mean of the country of study, landscape, and relevance indicators scaled to 1. See Appendix 3 for the codebook and average scores of intervention–domain relationships by indicator.

Study quality indicators measured the objective and subjective quality of available literature based on type of study, empirical rigor of study, impact found in study and certainty and generalisability of the study. As such, for each study the level of each indicator were assigned based on how well the study. Study attributes were then weighted by applicability before aggregation by each intervention–domain relationship.

For some intervention–domains there was an expected relationship, but no literature that explored that relationship (See Table A2.1–Table A2.11 in Appendix 2). In these instances, we coded a row of 0's across all indicators. These absent studies are included in the aggregate intervention–domain relationship scores.

We aggregated our four study quality indicators to quickly summarise the overall quality of empirical literature available to measure each intervention–domain relationship (table 14). Quality is represented on a scale of 0 to 5, where 0 represents no available information and 5 represents a New Zealand–based study that directly measures the impact of the intervention on the domain in a riparian landscape using a highly generalisable before-after-control experimental design or meta-analysis methodology. We have shaded the scores increasingly from very light turquoise to dark turquoise in accordance with increasing quality.

Findings

We find very strong evidence that improving riparian area vegetation and constructing wetlands attenuates nutrients, *E. coli*, and sediments in surface water runoff (table 14). We also find strong evidence that stream fencing attenuates nutrients, *E. coli*, and sediments in surface runoff and stream bank erosion; improving riparian area vegetation reduces stream bank erosion; removing, replacing or remediating fish passage barriers and improving riparian area vegetation has a positive impact on freshwater biodiversity; and restoring wetlands attenuates nutrients and *E. coli* in surface water flows.

We find some evidence to suggest that carbon sequestration and flood/drought resilience is enhanced by improving riparian area vegetation and restoring wetlands, but those findings are less reliable due to the lack of explicit investigation of the relationship. For example, to measure the impact of restored wetlands on carbon sequestration we used a methodologically rigorous modelling paper that found generalisable sequestration rates of wetland soil types but relied on input information from intact wetlands only. Data on restored wetlands was not available or not of sufficient quality for the model. We were also unaware of literature that either quantitatively or qualitatively explored the relationship between carbon sequestration and terrestrial weed control, ecological corridors or constructed wetlands and between flood/drought mitigation and passively regenerating riparian areas, terrestrial weed control, ecological corridors or constructed wetlands despite an expectation that these relationships exist.

Table 14. Summarised indication of availability and quality of literature to measure the 72 intervention–domain relationships in a freshwater riparian and wetland context

Ecosystem service (aspect)	Stream fencing	Actively planted riparian areas	Passively regenerating riparian areas	Restored wetlands	Constructed wetlands	Remediation of fish barriers	Pest control	Terrestrial weed control	Ecological corridors
Water purification (Nutrients, *E. coli*)	2.97	3.50	4.19	3.91	4.25	0.00		0.00	0.00
Water purification (Sediments, clarity)	3.37	4.06	3.94	2.56	4.28	0.00		0.00	0.00
Erosion control (Stream bank erosion)	3.43	3.17	2.91			0.00		0.00	0.00
Habitat (Freshwater biodiversity)	2.94	2.97	2.90	2.64	1.90	3.96	1.72	0.00	0.00
Habitat (Terrestrial biodiversity)	1.61	2.27	1.16	2.97	1.94		2.04	2.49	1.70
Climate regulation (Carbon sequestration and GHG emissions mitigation)		1.97	2.58	2.75	0.00			0.00	0.00
Natural hazard regulation (Flood and drought resilience)		1.98	0.00	2.95	0.00	0.00		0.00	0.00
Ethical and spiritual values / Social connection (Well-being, Kaitiakitanga)		2.21		1.41	1.41	0.24	2.17	0.00	0.00

Legend:						
	Index value	0 to 0.99	1.00 to 1.99	2.00 to 2.99	3.00 to 3.99	4.00 to 5.00
	Index value colour					

Discussion

Through the process of identifying and collating the empirical literature on the impacts of restoration interventions on environmental domains, common themes, gaps and challenges emerged. We discuss these themes here.

Context matters

Nature is dynamic, sometimes predictably and other times not. New Zealand also has many endemic species and these species have unique characteristics that require consideration (Walker et al, 2021). Geology, hydrology, geography, soil types, history of land modification activities, past land cover, climate, flora and fauna behaviours, human activities and time interact to influence the success of restoration interventions including erosion control activities (Hughes et al, 2012; McKergow et al, 2022; Neverman et al, 2023; Phillips et al, 2020), wetland restoration and construction (Johnson and Gerbeaux, 2004; Price et al, 2003), and pest control for biodiversity improvements (Binny et al, 2021; Byrom et al, 2016; Norbury et al, 2015). Sometimes other intervention activities are occurring in the watershed, which may interact with the intervention of interest and limit definitive conclusions on impacts (eg, Hickford et al, 2010; Wright-Stow and Wilcock, 2017). For each reference study we included details on the spatial context and study design so that scaling of the findings in future modelling/assessments can apply the appropriate assumptions and caveats. However, those assumptions are still limited by the contextual nature of the available literature.

We have also endeavoured to find New Zealand studies and only resorted to international literature when the New Zealand studies were limited. The applicability of international literature to the New Zealand context varies across domains and interventions. For example, weed management and bio-control literature relies heavily on the experiences of international colleagues when deciding how to approach managing invasive weeds here. Each invasive weed behaves slightly differently in a new environment, so New Zealand weed specialists take into account the experiences of those who have dealt with the weed for longer and are more familiar with the eccentricities of the weed. Feasibility studies, predictive modelling and experimental tests are conducted here to consider how the New Zealand context may differ. Sometimes the New Zealand context does make a difference to the relationships observed. For example, an international model that estimates the depth of a forest fragment that is impacted by warmer microclimate edge effects when applied to forest data from New Zealand significantly underestimated the quantity of habitat unaffected by these microclimate effects (Didham and Ewers, 2012). This was largely due to the spatial diversity of forest fragments and surrounding landscapes that exist across New Zealand.

Timescales

Ecosystems respond to interventions at different timescales. The benefits of some interventions may accrue in a very short period of time. For example, fencing prevents stock from directly degrading riverbanks and defecating in water ways. The intervention immediately removes the direct source of nutrients, *E. coli* and sediments that is degrading water quality, provided the intervention is as effective as intended (ie, the fencing is adequately constructed and maintained to keep stock out). However, many intervention–domain relationships are dynamic (eg, indigenous biota vulnerability and response to pest management mostly depends on the density of pests in a landscape, Norbury et al, 2015), some interventions require time to establish (eg, vegetation mirrored native bush plots 40 years after land was retired from grazing, Smale et al,

2005) and some ecological processes require time to recover (eg, restored wetlands may not support key flora for decades after rewetting, Price et al, 2003).

Monitoring of interventions, either continuously for a short period of time (6 months to 1 year) or by returning at intervals (eg, once a year for 5+ years) over long time frames, is uncommon in the literature. We only found a handful of examples measuring the long-term impacts of pest control on terrestrial biodiversity (Husheer and Tanentzap, 2023; Innes et al, 1999; O'Donnell and Hoare, 2012), impacts of land management practices on freshwater quantity, quality and biotic indices (e.g., McDowall 2008; Wright-Stow and Wilcock 2017, Graham et al. 2018, Hughes et al. 2020), trajectory of terrestrial and freshwater biodiversity change after wetland restoration (Clarkson 1997; Clarkson et al 2017; Goodrich et al, 2017) and impacts of fish barrier remediation on *G. maculatus* populations (Franklin and Bartels 2012). However, all areas of expertise agreed that repeated sampling (ie, monitoring) provides invaluable understanding of the success of interventions and the dynamic relationship between interventions and ecosystems. All areas of expertise also said that the monitoring of interventions is, more often than not, considered a 'nice to have' or an afterthought in project design. In the absence of empirical data, some studies turned to predictive modelling to estimate the outcomes over time. However, modelling requires educated assumptions which may or may not hold under climate change (Neverman et al, 2023), may depend on certain site characteristics (Pattison et al, 2019), or may only apply in the short-term (eg, Norbury et al, 2015). Modelling may be constrained if empirical data to support the relationships to be included does not exist. However, conceptual or physically-based models can be used in some cases, as alternatives to empirical models.

Outcomes should determine interventions and metrics

The outcomes sought by a project should be defined clearly and precisely at the beginning of the project. The outcomes sought will dictate what intervention activities are appropriate and what data to collect to demonstrate that the desired outcomes have been achieved. The relationship between an intervention (eg, fencing) and a metric of the degree to which that intervention has been applied (eg, length of fencing along a stream margin), and the anticipated benefits to some environmental domains (eg, improvement in stream *E. coli* concentration) can be difficult to demonstrate. This is especially evident for interventions that affect water quality aspects of the freshwater domain because of the cumulative nature of river flows and multiple pathways for water and contaminants to enter a stream. For example, measuring water quality in a stream adjacent to a stream bank that has been fenced to exclude livestock may not detect an improvement in the load of *E. coli* transported by the stream if the length of stream fencing is a small proportion of the upstream bank length and stock can access the water at other locations upstream. There might also be other sources of *E. coli* to the stream that increase over the time that monitoring is carried out. An appropriate monitoring plan to demonstrate that the outcomes sought are being achieved needs to take factors such as these into account.

In other cases, the relationship between an intervention activity, the selected metric and the desired outcomes sought for a project in a particular environmental domain can be weak because the intervention may not the most effective method to achieve the desired environmental outcome (eg, fencing and terrestrial biodiversity). Selecting suitable interventions and metrics around the desired outcomes leads to a) more accurate measures of impact and b) greater likelihood of achieving the desired ecological benefits.

People are a part of the ecosystem

Human activity has caused extensive remodelling of soil structure, hydrology, and vegetation and resulted in the loss of nearly 90% of historic wetland extent (Ausseil et al, 2015). However, people are both the solution to healing nature and are intrinsically linked with their surrounding environment. Anecdotal evidence (and a handful of qualitative-quantitative studies) suggests that community involvement in restoration activities has a significant positive effect on well-being, sense of place, social cohesion and cultural connection to tupuna (ancestors) through whakapapa. We also know that Māori feel a responsibility through kaitiakitanga to protect and care for the environment and damage to te taiao (natural environment) affects their ability to undertake those responsibilities. Restoration of the damaged ecological processes supports mana whenua to undertake kaitiakitanga for the future generations (Taura et al, 2017, 2021). Improved documentation of these relationships and the impact of restoration interventions on these domains through quantitative and qualitative means in future is just as important as the acquisition of further evidence to demonstrate the impacts of interventions on biophysical domains.

Restoration is not a one-and-done situation

Investment in the maintenance of assets and infrastructure is assumed when it comes to buildings, roads and other development. Investment in the environment through interventions should be thought of through the same common-sense lens. Fencing can degrade or be damaged over time reducing the structural benefits it provides to riparian banks through stock exclusion. Planting in riparian areas can also require maintenance to ensure that the planted vegetation flourishes root structures become well established, weeds are not smoothing newly planted or regenerating vegetation, and recruitment of other desired flora and fauna is occurring as expected.

The quality of vegetation is a key determinant of erosion mitigation efficacy (Phillips et al, 2020) while the diversity of native flora may influence the freshwater macroinvertebrate community structure in an adjacent stream (E. Graham unpublished data) and vegetation stem density and aerial root mat thickness of grass and native sedge vegetation in riparian areas has been positively correlated with īnanga *(Galaxias maculatus)* survival (Hickford et al, 2010). Planting vegetation without some ongoing maintenance (eg, weed control) in the immediate to short-term timescale limits or could negate benefits of such investments in the longer run. Lastly, pest control requires continuous investment. For example, Armstrong et al (2006) modelled the survival likelihood of a North Island robin *(Petroica longipes)* population after 3 years of pest control was ceased due to funding cuts. They found that despite the significant gains over those 3 years, the population was predicted to decline if pest control efforts were not reinstated and additional breeding pairs were not translocated to the area. These examples highlight the importance of changing the thinking that restoration activities are a one-and-done investment.

Gaps in knowledge

Through discussion with our experts and following survey of available empirical literature, several knowledge gaps were identified. These gaps are outlined and discussed in the headings below.

Intervention–domain relationships are complex, some more than others

The majority of the literature on the intervention–domain relationships are specific to location, landscape characteristics, vegetation characteristics, animal behaviours, timescales and intervention method. The complexity of these contexts creates a challenging environment in which to model and scale potential benefits to other spatial contexts and on different timescales. Identifying these complex relationships through the literature review and via discussion with our experts has also identified where modelling the gaps in knowledge is difficult and complicated even with assumptions. For example, each bird species has a different relationship with mammalian pests (and vice versa) dependent on landscape properties and other activities in the surrounding area. While several meta-analyses have identified trends in the available empirical data, there are empirical studies on only a few hundred out of the thousands of bird species that exist within New Zealand. As a result, any modelling that takes place must be within the context of the available data because extrapolation may be inappropriate, especially where intervention–domain relationships are complex.

We do not have the empirical evidence for all expected relationships

Some intervention–domain relationships are supported with anecdotal evidence, but insufficient empirical evidence exists to demonstrate the strength of the relationship. Ethical and spiritual values / Social relations and connection domain was one such area. For other relationships we found some indication that an intervention benefitted the domain, but that evidence was limited and/or poor-quality data was noted (eg, fish passage barrier removal, replacement, or remediation and freshwater biodiversity). Missing information was noticeable throughout our tables, indicating where further research is required.

Interventions need to be tested across different landscapes

Context matters and empirical evaluations of the effectiveness of ecological interventions are not always easily generalisable. For example, many erosion control studies have taken place in pastoral landscapes or adjacent to agricultural land uses. Human activity, however, has caused extensive remodelling of the soil structure, hydrology, and vegetation that influences the *a priori* conditions into which an intervention like fencing or planting of riparian areas is placed and then tested for effectiveness. The effectiveness of those interventions is therefore inherently linked to the condition of the land before the intervention. Applying effectiveness metrics for a particular study to a different landscape may not result in similar outcomes. Combining the results of multiple intervention–domain studies together in a systematic analysis (eg, McKergow et al, 2022; Tanner et al, 2022) can help to identify relationships that can be applied across different landscape types.

Interventions need to be implemented at the appropriate spatial scales

Intervention efforts need to be implemented at the spatial scale that matches the extent of degradation, size of the catchment, or characteristics of the target domain (eg, animal behaviours). Interventions may also only have an impact if they are sized to that appropriate spatial scale. For example, constructed wetlands are highly connected with the hydrology of the wider catchment and need to be designed and sized appropriately to achieve water quality benefits. A constructed wetland can be designed to intercept surface runoff, tile and surface drainage and even groundwater flows. However, to significantly reduce contaminant loads from the water sources that it's designed to intercept, a single constructed wetland, or series of constructed wetlands, usually need to cover an area equivalent to at least 1% and up to 5% of catchment land area (Tanner et al, 2022). If restoration activities are not scaled appropriately, then the likelihood of long-term success or measurable water quality improvement may not be evident. Weed management and pest control are other examples where the benefits of managing weeds or controlling pests on a small area may be negligible to non-existent because of the propensity of reinvasion from abundant, close proximity sources (Pearson et al, 2016) or as a result of animal pest behaviours (Ramsey and Norbury, 2009; Ruscoe et al, 2011). However, scaling the interventions to the spatial characteristics of the landscape may result in significant benefits to, for example, biodiversity (Innes et al, 1999).

Interventions need to be tested in isolation (or at least data needs to be collected prior to the intervention)

Identifying the direct impact of an intervention on a landscape is challenging when multiple interventions are implemented together in a scientific study or restoration project. For example, fencing has often been applied for livestock exclusion. However, if the fenced area is close to native seed sources and if there is low weed pressure then passive regeneration of the riparian areas may occur. Fencing and passive regeneration of riparian buffers are expected to have different relationships to domains. Disentangling the benefits of the passively regenerating riparian areas from those of fencing then becomes challenging and may require significant assumptions if project and studies do not design their monitoring and evaluation work to accommodate this. Identifying the distinct benefits of interventions become even more challenging when working in highly connected landscapes such as along rivers where unrelated upstream activities impact downstream domains of interest (see fencing and *E. coli* example earlier in our Discussion in the section entitled 'Outcomes should determine interventions and metrics').

Post-implementation analysis without a pre-implementation baseline or control data means that the impact of the intervention cannot be estimated with a high degree of certainty. Studies can be conducted using before-after-control-impact (BACI) type designs to isolate the intervention effect (see those that informed the guidelines and relationships presented in McKergow et al, 2022; Tanner et al, 2022 as examples), but those designs need to be integrated into projects from the beginning to robustly quantify the direct impact of the activities. These designs are usually best applied for monitoring purposes at the scale of a particular intervention as opposed to at catchment scales.

Recommendations

Based on the literature, discussions with experts and the authors own experience, our recommendations for improving the ability to assess the impacts of future project activities are listed below.

Ensure the desired outcome(s) of the project are clearly defined alongside the benefits of the associated intervention(s) at the beginning of the project. Outcomes should be aligned with community aspirations. Collaborating with the people/organisations within the community (eg, general public, traditional knowledge holders, scientists, iwi, local government, etc) during the project can broaden the impact of the project (eg, increase social benefits or encourage other restoration activities beyond those being undertaken through the project).

Select metric(s) of impact, and design evaluation monitoring to measure progress toward the desired outcomes. Metrics and design should accommodate all biophysical and social outcomes. Collect information, from a community perspective, on the project's broader social and economic impacts on the community before, during and after the project undertaking.

Design the data collection and monitoring schedule to account for the expected and unexpected dynamic changes in the domain and surrounding ecosystem. Environmental and social domains and their aspects do not always follow a linear change process (e.g., a trees' ability to sequester carbon changes over its growth cycle) while natural experiments exist within a wider landscape where other interventions and land use changes may influence the expected impacts of the project. As a result, monitoring schedules should be designed over longer time periods and at appropriate intervales to measure anticipated project impacts, capture any interactions of the project with other activities in the catchment and the dynamic changes within the project site.

Engage the community, where possible, in the monitoring and data collection process to enhance well-being, social cohesion and spiritual connection with nature. This engagement is also an excellent opportunity to build broader skills and knowledge capacity within the community.

Develop targeted and sustained long-term monitoring post-project completion to understand expected and unexpected outcomes of typical management practices on the environment. Supporting on-going research into these outcomes provides invaluable knowledge of emerging relationships that will be publicly available. Study sites can be representative across regions and landscapes for the national benefit.

Appendix 1 – Ecosystem service definitions and examples

Table A1.1. Regulating ecosystem service definitions

Service	Sub-category	Definition	Examples
Air quality regulation		Influence ecosystems have on air quality by either emitting chemicals to the atmosphere (reducing air quality) or extracting chemicals from the atmosphere (increasing air quality)	Weather, geography and vegetation all influence air quality (eg, vegetation can help filter air pollution in urban areas) Forest fires emit pollutants
Climate regulation	**Local and regional**	Influence ecosystems have on local and regional temperature, rain, winter, frost frequency and other climate factors	Vegetation temperature influence in urban areas Influence of vegetation on regional and local precipitation, wind, temperature and frost frequency
	Global	Influence ecosystems have on the global climate by emitting greenhouse gases or aerosols to the atmosphere, or by absorbing greenhouse gases or aerosols from the atmosphere	Livestock greenhouse gas emissions (methane) Nitrous oxide emissions from pastoral systems Soil capture of and storage (soil carbon) of carbon dioxide and methane Forest capture and storage of carbon dioxide
Water regulation (timing and volume of water flows)		Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge (particularly in terms of the water storage potential of the ecosystem or landscape)	Permeable soils facilitate aquifer recharge River floodplains, lakes, wetlands and forests have water storage capacity that ameliorate flood peaks
Erosion control		Role plants play in soil retention	Trees/forest on hills and mountains reduce mass-movement erosion Plants on dry-lands and agricultural lands reduce surface erosion
Water purification & waste treatment		Role ecosystems play in filtering nutrients, heavy metals and pollutants in water Role ecosystems play in decomposing organic wastes and recycling them (taking up and detoxifying compounds through soil and subsoil processes)	Soils absorb phosphorous and heavy metals, assimilate nitrogen, deactivate and decomposes endocrine disruptors Wetlands remove pollutants from water by trapping metals and organic materials Soils degrade organic waste such as animal dung and urine
Biological control		Influence ecosystems have on the amount of crop and livestock pests and diseases Bio control agents and pathogens limit the need for chemical interventions	Pest predators in natural ecosystems enhance pest control on nearby farms. For example, ladybugs prey on aphids

Service	Definition	Examples
Disease regulation	Influence that ecosystems have on the incidence and abundance of human pathogens Bio-control agents and pathogens limit the need for chemical interventions.	Plants, animals and soils can prevent agricultural runoff (eg, dung beetles), minimise spread of cattle-borne diseases such as campylobacter, salmonella, cryptospirosis, and *E. coli,* etc Undisturbed vegetation can minimise the abundance of disease carrying insects (eg, mosquitos and ticks carrying Ross River virus, dengue fever) by minimising breeding sites
Pollination	Role ecosystems play in transferring pollen between male and female plants	Managed bees are used to pollinate fruits and crops Many wild native pollinators (eg, bees, beetles, flies, butterflies, moths, bats, birds) pollinate crops and native species
Natural hazard regulation	Degree to which ecosystems reduce damage caused by natural hazards	Mangrove protection against tidal surges Riparian margins and green buffer areas protect against river floods Coastal dunes protect against coastal storms (erosion and flooding)

Table A1.2. Cultural ecosystem services definitions

Service	Definition	Examples
Recreation and ecotourism	Recreation undertaken in nature, including tourism sector business and tourist activities that rely on natural or managed ecosystems	Walking, tramping, hunting, biking, kayaking, camping, touring, fishing, surfing, boating etc
Ethical and spiritual values	Aesthetic, spiritual, religious, cultural heritage values, social relations, sense of place, cultural diversity – that people attach to ecosystems, landscapes or species	Sense of belonging by those people who associate themselves with a place, a landscape, or a natural feature (river, mountain) Spiritual connection and fulfilment derived from sacred lands and rivers
Inspirational & education values	Information people get from ecosystems that are used for intellectual development, culture, art, design and innovation. Includes inspiration, education and knowledge systems	The structure of tree leaves has inspired technological improvements in solar power cells School field trips to nature reserves help teach scientific and research skills

Table A1.3. Provisioning ecosystem services definitions

Service	Sub-category	Definition	Examples
Food	**Crops**	Cultivated plants for use by people or animals	Vegetables, fruits, grains
	Livestock	Animals raised for domestic or commercial consumption or use	Dairy cattle, beef cattle, sheep deer, pigs, chickens
	Capture fisheries	Wild fish captured through trawling and other non-farming methods	Hoki, mackerel, oreo, snapper
	Aquaculture	Fish, shellfish, and/or plants that are bred and reared in ponds, enclosures	Green lipped mussels, Pacific oysters, king salmon

Service	Sub-category	Definition	Examples
Fibre	**Timber and wood**	Products made from trees harvested from forest ecosystems, plantations, or non-forested lands	Wood/logs, wood pulp, paper
	Other fibres	Non-wood and non-fuel based fibres sourced from the environment	Wool, possum, alpaca, harakeke flax, leather, hemp
Freshwater		Inland bodies of water, groundwater, rainwater, and surface waters for household, industrial, and agricultural uses	Freshwater for drinking, cleaning, cooking, cooling, industrial processes, stock water, electricity production, or mode of transport
Biomass fuel		Sources of fuel derived from plants and animals	Wood (various) Biofuel production (eg, tallow and used vegetable oils)
Wild foods		Plant and animal food sources gathered or caught in the wild	Seafood (fish, whitebait, crayfish, shell fish), freshwater fish (trout, eels), deer, goat, pig, game birds, rabbits, tahr, water cress
Ornamental Resources		Products from nature that serve aesthetic purposes	Wood and stone used for carving Traditional Māori use of wood for production (eg, kauri for building canoes, weapons)
Biochemicals, natural medicines, and pharmaceuticals		Medicines, biocides, food additives, and other biological materials derived from ecosystems for commercial or domestic use	Fertiliser production; natural medicines (hemp seed oil, colostrum, enzogenol, deer velvet, etc) and Rongoa – Māori medicinal use of plants (eg, karaka, kawakawa, harakeke)
Genetic resources		Genes and genetic information used for animal breeding, plant improvement, and biotechnology	All animal and plant species and their diversity, represent the genetic resources of New Zealand (eg, potential for marine species to be developed for medicine) Introduced plant species have been bred to develop new horticultural crops
Biochemicals, natural medicines, and pharmaceuticals		Medicines, biocides, food additives, and other biological materials derived from ecosystems for commercial or domestic use	Fertiliser production; natural medicines (hemp seed oil, colostrum, enzogenol, deer velvet, etc) and Rongoa – Māori medicinal use of plants (eg, karaka, kawakawa, harakeke)

Appendix 2 – Detailed intervention–domain relationship tables

Intervention: Stream fencing

Table A2.1. Evidence of relationship between stream fencing and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Fencing to exclude stock is expected to improve terrestrial biodiversity by reducing herbivory and favour more palatable plant species (indigenous and exotic). Where areas are wide enough to prevent browsing (stock can reach over/through fences) these new conditions can promote succession to taller and denser vegetation and enable conditions favouring native encourage fauna.	Change in abundance of target indigenous species Avoided loss in target indigenous species	No known studies empirically analyse the impact of riparian fencing alone on indigenous flora or fauna biodiversity. Husheer and Tanentzap (2023) estimates the mountain beech tree growth, survival and recruitment in response to unrestricted sport hunting and commercial culling of deer over 20 years in Kaweka Forest Park using a paired site experiment over 40 years.	Analysis of fencing on terrestrial fauna has focused on eco-sanctuaries (see Table A2. 5) Sapling counts in unfenced plots were 3–10 times lower after 60 years of deer control compared with unfenced plots.	Husheer and Tanentzap (2023)	Fencing must be designed for target pest species. Deer, goats and pigs may be important pests for riparian areas that are not controlled by standard fences (except for cattle). The effect of fencing alone is highly site specific – depending on browsers, and what plant propagules are present (eg, crack willow upstream)

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
		Fencing to exclude stock may also have unintended consequences on terrestrial biodiversity. Reducing herbivory and favouring more palatable plant species changes the composition and density of exotic and indigenous vegetation.	Density of target species	Empirical study of ship rat density in fenced versus non-fenced forest fragments in a grazed landscape conducted over a 6-month period in a lowland pastoral landscape in Waikato. No measures of changes in indigenous or exotic bird life.	Ship rat density higher in fenced forest areas than in open grazed forest areas.	Innes et al (2010)	Fencing out stock leads to an increase in vegetation thereby improving habitat for ship rats. No pest control prior to study. Lowland pastoral landscape in Waikato.
	Freshwater indigenous biodiversity	Fencing is expected to benefit freshwater biodiversity by preventing livestock access to waterbodies and any associated degradation of instream habitat and water quality that results	Net gain in target species or community index or avoided loss Example indices include MCI, QMCI, SQMCI, %EPT, community dissimilarity to reference, trait-based metrics (macroinvertebrates), species richness, F-IBI, egg abundance and survival (fish), %channel clogginess (macrophytes), % weighted compositive cover (periphyton)	An analysis of macroinvertebrate indices and riparian effort data for the Taranaki region identified that MCI, QMCI and %EPT indices were correlated at regional scale to upstream stream length fenced and/or planted. Authors found that weighting for age and shade did not improve the relationships which suggests that fencing may have had more influence than	SQMCI was predicted to increase from c. 2 to 9 as upstream stream length fenced and/or planted increased from 0% to 100%	Graham et al (2018)	Width of riparian buffer and therefore potential for passive regeneration not considered. Difficult to prove conclusively that these interventions are responsible for improvements as it is possible that other changes may have occurred in the catchment over the same time period and therefore also influenced these freshwater biodiversity responses. SQMCI is derived

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				planting on the responses observed.			from coded abundance scores for macroinvertebrate taxa (rare, common, abundant, very abundant, very very abundant). In comparison the QMCI is derived from quantitative count data for macroinvertebrate taxa. SQMCI score >5.99 = excellent (clean water), 5.00-5.99 = good (possible mild pollution) 4.00-4.99 = fair (probably moderate pollution) and <4.00 = poor (probable severe pollution).
Water purification	Sediments / clarity	Fencing is expected to reduce waterbody bank damage and associated inputs of sediment into freshwater helping to improve sediment-related water quality	Riparian zone: Net reduction in bank soil loss. Freshwater: Decrease in suspended sediment load.	Trend of suspended sediment improvement with improved effluent disposal and riparian fencing and/or planting in all five Dairy Best Practice catchments over time.	Suspended sediment decreased by 0.21-0.89 g m^{-3} yr^{-1}.	Wright-Stow and Wilcock (2017)	Study was not able to separate out fencing, riparian planting, and effluent disposal interventions. Difficult to prove conclusively that these interventions are responsible for improvements as other changes may have occurred in the catchment over the same time period and influenced these suspended sediment responses.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				Fencing off and planting a 300 m^2 area of stream channel that also contained a deer wallow in a small 4 ha headwater catchment was found to result in decreased mean concentrations and loads of SS at the outlet	Loads of suspended sediment were 98% lower after fencing and riparian planting than in the 2-year period before this activity was undertaken.	McDowell (2008)	Effect of fencing not separated from effects of riparian planting.
	Nutrients, *E. coli*	Fencing is expected to reduce direct livestock access to waterbodies and associated inputs of nutrients and *E. coli* via direct defecation into the waterbody	Freshwater: Decrease in nitrate-N, ammoniacal-N, dissolved reactive-P, total-N, total-P, *E. coli* loads.	Stock crossing a stream resulted in increased concentrations of *E. coli*, sediment, and total nitrogen directly downstream during the period of crossing activity	246 cows increased *E. coli* to peak concentration of 50,000 cfu/100 ml.	Davies-Colley et al (2004)	Changes in concentrations can be reliable if there is no change in flow over study duration or concentrations are flow-weighted as was the case in both these studies.
				In Taranaki, riparian analysis improvement in *E. coli* concentrations (ie, decrease) were correlated to upstream stream length fenced and/or planted. Authors found that weighting for age and shade did not improve the relationships which suggests that fencing may have had more influence than	*E.coli* concentration was predicted to decrease from 1500 to 300 cfu/100 ml to as upstream stream length fenced and/or planted increased from 0% to 100%	Graham et al (2018)	

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				planting on the responses observed.			
				An observational study in New York, USA, was used to determine the in-stream and near-stream deposition of faeces of pastured dairy cattle. The amount of in-stream deposition of phosphorus that was avoided by fencing was estimated.	Current fencing was estimated to reduce the amount of instream phosphorus (P) deposition from the faeces of 11,000 dairy cattle by 2,800 kg (or 32%). In the near-stream zone, within 10 m of the stream, they estimated that a further 5, 800 kg of P was deposited.	James et al (2007)	Not a NZ study
				Fencing off and planting a 300 m^2 area of stream channel that also contained a deer wallow in a small 4 ha headwater catchment was found to result in decreased mean concentrations and loads of TP, NO_3-N and NH_4-N at the outlet	Loads of TP, NO_3-N and NH_4-N were 86, 78 and 91% lower, respectively, after fencing and riparian planting than in the 2-year period before this activity was undertaken.	McDowell (2008)	Effect of fencing not separated from effects of riparian planting.
				Percentage improvement in stream *E. coli* concentrations related to fencing were summarised	Percentage efficacy of *E. coli* concentrations reductions ranged from 0% to 96%. The authors	Muirhead (2016)	This study was a systematic review and analysis of 16 suitable NZ and international studies.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				for studies that employed a suitably robust experimental design. These included studies that employed i) modelling, ii) paired catchments, iii) up- and down-stream sampling, and iv) pre- and post-treatment sampling approaches	considered that the following *E. coli* load reductions 15%, 62% and 85% were representative of poor, most likely effective and highly effective fencing for cattle on dairy farms. For cattle on sheep and beef farms these values were 13%, 53% and 73% for Northern North Island, 11%, 44% and 61% for Southern North Island and 10%, 40% and 55% for South Island.		Beef cattle, deer and dairy studies.
Erosion control	Bank erosion	Fencing excludes stock from stream bank	Sediment load Non-storm suspended sediment concentration % length of eroding bank	Empirical studies come from pastoral land use case studies and are often in catchments with other interventions. Modelling uses calibrations from SedNet.	Structural exclusion of stock from riverbanks has significant positive impact on sediment entering rivers from the riverbank including: 30% to 90% reduction in Suspended sediment concentration attributed to reduced stream bank erosion following fencing cattle out (ii).	i. Phillips et al (2020) ii. Monaghan and Quinn (2010) iii. Wilcock et al (2013)	Intervention targets riparian bank erosion, but the main source of sediments entering the river could be different. Studies in New Zealand that measure streambank erosion are limited to pastoral landscapes (i). PW3 site at Whatawhata over 3 years. Median estimates derived from

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
					50% reduction in SSC attributed to reduced stream bank erosion following fencing all stock out (ii). 4% to 11% reduction in SSC that can be attributed to reduced bank erosion (iii).		unpublished data for use in a modelling exercise (ii). Five streams in pastoral dairy farming catchments of 7–16 years (iii).
			Total suspended solids	Various methodologies of studies reviewed. Process of review was descriptive.	60% reduction in TSS after fencing and NMP 82% to 93% reduction in TSS after fencing and planting of riparian zones 40% reduction in sediment yield from pastures following fencing	O'Callaghan et al (2018)	Review of NZ and international studies.
			Suspended sediment (SS) load	Before-and-after study designs. International studies only.	SS load reduction of 30% to 90% attributed to bank erosion	McKergow et al (2007)	Review of NZ and international studies for development of tool. No exclusively fencing studies available. All sites have combined BMPs.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
Climate regulation	Carbon sequestration and GHG emissions	Fencing is expected to reduce stream bank damage by retaining carbon and nitrogen in bank soils	No net loss of stocks of carbon and nitrogen held in stream banks	No known studies empirically analyse the impact of riparian fencing alone on carbon sequestration.		NA	
Natural hazard regulation	Flood and drought resilience	Unclear					
Ethical and spiritual values / Social relations and connection		Unclear					

Note on Erosion control: A review of international and the available NZ studies explicitly on the impact of stock exclusion on in-stream and stream bank conditions shows a consensus that fencing significantly reduces suspended sediment, bank erosion and E. coli and faecal coliform counts (O'Callaghan et al, 2018). The same review found that nutrient reduction due to fencing varied across studies in the USA, UK and Canada with some studies finding significant reductions in nitrogen and phosphorus indicators while other found no significant impact from fencing. Identifying the contributing influence of fencing for stock exclusion on water quality improvements and reduce bank erosion remains a challenge in New Zealand (McKergow et al, 2007) as all studies in the present review identified the presence of multiple best management practices including nutrient management plans, riparian plantings (actively planted and/or regenerating vegetation after fencing) and/or other effluent management practices.

Intervention: Passively regenerating and actively planted riparian buffers

Table A2.2. Evidence of relationship between actively planted riparian buffers and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Establishment and persistence of native planting in riparian areas increases the indigenous flora and habitat available for indigenous and non-indigenous fauna to occupy, assuming other attributes and conditions – eg, sources of immigrants, herbivory, predator numbers – are not limiting. Where areas are wide enough to prevent browsing (stock can reach over/through fences) these new conditions can promote succession to taller and denser vegetation and enable conditions favouring native encourage fauna.	Change in target indigenous species (presence, absence, abundance, fecundity). Native species dominance. Avoided loss in target indigenous species.	Few studies empirically analyse the impact of riparian plantings on terrestrial fauna biodiversity. Empirical knowledge of bird movement across landscapes is available for a handful for bird species for non-riparian areas. Analysis of habitat quantity and quality on terrestrial fauna has focused on non-riparian forest habitat (NZ based) and benefits to biodiversity of scattered trees compared to open areas (international, Australia). Some invertebrates are obligate to native plants; if the plants are absent the invertebrates are absent, and when suitable plants are present, invertebrates	Abundance and species richness of arthropods, vertebrates and woody plants was higher in scattered trees compared to open areas (i). Native bird species have varying ability to cross gaps and potentially colonise riparian buffers (ii). See Table A2.8. Abundance of native ground invertebrates increased 18 months after planting (iii). Total abundance and number of common indigenous bird species increased with forest fragment area in the Auckland area (iv). Relationship to riparian planting would have to be qualitative.	i. Prevedello et al (2018) ii. Innes et al (2022) iii. Gutierrez Gines et al (2022) iv. Ruffell and Didham (2017)	Relationship is based on the assumption that more habitat is better, but empirical evidence showing the impact of a marginal increase in habitat is lacking. Prevedello et al (2018) and Innes et al (2022) are on forest birds. Evidence of the impact of additional habitat for birds relates to Innes et al (2022) paper on gap crossing of native birds. Paper includes summation of known bird movement studies which could provide more nuanced evidence. Gutierrez Gines et al (2022) study is lake riparian areas.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				must be able to disperse to the plant to be present.			Some experts suggest that riparian buffers need to be 50 m wide (not c. 3 m) to get substantial biodiversity benefit.
	Freshwater indigenous biodiversity	Active planting of riparian buffers is expected to improve this domain and aspect if plantings increase shade and decrease water temperature, enhance spawning habitat, provide additional fish cover, or increase instream habitat as a result of leaf litter and wood inputs	Net gain in target species or community index or avoided loss. Example indices include MCI, QMCI, SQMCI, %EPT, community dissimilarity to reference, trait-based metrics (macroinvertebrates), species richness, F-IBI, egg abundance and survival (fish), %channel clogginess (macrophytes), % weighted compositive cover (periphyton)	Analyses of data for Waikato streams showed that the shade created by riparian vegetation (i) reduces the nuisance growth of periphyton and aquatic macrophytes in streams (i and ii) and improves the relative abundance of native macrophytes in streams	65% to 70% shade shown to constrain periphyton weighted composite cover to <30% and aquatic macrophyte channel clogginess to <50% in Waikato streams.	i. Matheson et al (2017) ii. Mouton et al (2019)	
			Survival rate of target species	Laboratory and field experiments to test the impact of native versus exotic vegetation on the survival of developing *Galaxias maculatus* eggs in Barrys Bay stream, Banks Peninsula riparian zones.	Mean daily survival ranged from 91.0% ± 2.4% (J. edgariae) to 18.8% ± 18.8% (Schedonorus phoenix) More eggs found in exotic grass *Agrostis*	Hickford et al (2017)	Tiller densities were at the higher end across all vegetation treatments. *Carex virgata* (native), *Juncus edgariae* (native), *Schedonorus phoenix* (exotic), and

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				Lab 1: individual tanks for native vegetation (2 types), exotic vegetation (2 types), mixture of *J. edgariae* and *S. phoenix* and smooth river stones. Lab 2: 4 tanks with combination of 2 native and 2 exotic plants Field: All eight treatments from Lab 1, potted bank vegetation and uncut bank vegetation.	*stolonifera* and in native rush *J. edgariae* More eggs found in exotic grass *A. stolonifera* and native sedge *C. virgata*		*Agrostis stolonifera* (exotic).
Water purification	Sediment / clarity	Active planting of riparian buffers is expected to improve this domain and aspect if species with superior root systems are planted in the area to stabilise banks and denser vegetation is created at ground level (eg, grasses) to increase filtration/deposition of surface runoff	Riparian zone and freshwater: Decrease in sediment load	There is evidence of net sediment deposition/filtration by riparian grass filters from studies measuring changes in load with passage through riparian filter strips	Sediment load carried by surface runoff decreases by -50% to 99% (median 59%) Magnitude was related to width of filter strip relative to hillslope length, soil type and land slope	McKergow et al (2020, 2022)	These studies are reviews and systematic analyses of suitable NZ and international literature to derive transferable relationships. (i) Reviewed and then re-analysed published datasets.
				Fencing off and planting a 300 m² area of stream channel that also contained a deer wallow in	Loads of suspended sediment were 98% lower after fencing and riparian planting than in	McDowell (2008)	Effect of fencing not separated from effects of riparian planting.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				a small 4 ha headwater catchment was found to result in decreased mean concentrations and loads of suspended sediment at the outlet	the 2-year period before this activity was undertaken.		The wallowing area was planted in a combination of 200 red tussock (*Chionochloa rubra* sp.) and 100 swamp sedge (*Carex virgata*) in and near the wallowing area and stream channel, and 100 mānuka (*Leptospermum scoparium* sp.), 50 tōtara (*Podocarpus totara* sp.) and 50 wineberry (*Aristotelia serrata* sp.) on the mid and high banks.
	Nutrients, *E. coli*	Active planting of riparian buffers is expected to improve this domain and aspect by enhancing biological processes that remove nutrients (ie, plant uptake, denitrification).	Riparian zone and freshwater: Reductions in nitrate-N, ammoniacal-N, dissolved reactive-P, total-N, total-P, *E. coli* loads	There is evidence of net nitrate-N by riparian buffers from studies measuring changes in load with passage through riparian buffers	Nitrate load carried by subsurface flow decreases by 0% to 100 % (median 87%). Magnitude was related to soil type, temperature and saturation	McKergow et al (2020, 2022)	These studies are reviews and systematic analyses of suitable NZ and international literature to derive transferable relationships.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				Fencing off and planting a 300 m^2 area of stream channel that also contained a deer wallow in a small 4 ha headwater catchment was found to result in decreased mean concentrations and loads of TP, NO_3-N and NH_4-N.	Loads of TP, NO_3-N and NH_4-N were 86, 78 and 91% lower, respectively, after fencing and riparian planting than in the 2-year period before this activity was undertaken.	McDowell (2008)	Effect of fencing not separated from effects of riparian planting. The wallowing area was planted in a combination of 200 red tussock (*Chionochloa rubra* sp.) and 100 swamp sedge (*Carex virgata*) in and near the wallowing area and stream channel, and 100 mānuka (*Leptospermum scoparium* sp.), 50 tōtara (*Podocarpus totara* sp.) and 50 wineberry (*Aristotelia serrata* sp.) on the mid and high banks
				(i) Lab experiment comparing the abilities of *L. scoparium, K. robusta,* and *P. radiata* to reduce nitrate leaching from soil through plant uptake and by facilitating denitrification.	NO_3-N leaching rates of *L. scoparium* and *K. robusta* were 2kg ha^{-1} compared to 53kg ha^{-1} for *P. radiata* (i) *L. scoparium* and *K. robusta* facilitated 90% reduction in *E. coli* cfu after 5 and 7 days	i. Esperschuetz et al (2017) ii. Prosser et al (2016)	(i) Plants were grown in a greenhouse lysimeter experiment, with controlled irrigation and temperature. Plants were treated with 200kg ha^{-1} of N per week for 15 weeks followed by a one off

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				(ii) Lab experiment comparing the ability or *L. scoparium* and *K. robusta* to reduce *E. coli* concentration in soil compared to *Lolium perenne*.	compared to *Lolium perenne.* (ii) See figure 2 in (ii) for linear trend of *E. coli* concentration reduction over time.		800kg ha^{-1} N. Leaching rates were compared to plots not treated with N. (ii) Pots inoculated with 1x109 cfu *Escherichia coli* in 100ml sterile phosphate buffered saline. Plants harvested on day 1, 3 and 7 and soil E.coli concentrations measured at time of harvest. Control plots were planted with perrenial ryegrass *Lolium perenne* to simulate a typical pasture.
Erosion control	Bank erosion	Planting the riparian bank with trees provides physical structure to the bank through root development and thereby reducing bank erosion.	Percentage of bank eroded.	Empirical assessments were done in three New Zealand catchments where pastoral farming occurs.	Channel damage was reduced by >50% where plantings were in adequate condition and 40% to 60% where plantings were in inadequate condition.	Phillips et al (2020)	Space planted trees along the riparian zone. Intervention targets riparian bank erosion but the main source of sediments entering the river could be different. Use of vegetation to control bank erosion is dependent on bank

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
							height (2-3 m high or less), age of tree, and cohesion of the bank material (Marden et al, 2005).
			Non-storm suspended sediment concentration (SSC).		55% reduction in SSC attributed to reduced stream bank erosion following fencing cattle out and 6-8 years post planted poplars. 60-65% reduction in SSC attributed to reduced stream bank erosion following 5 to 15 m wide planted buffer and fencing.	Monaghan and Quinn (2010)	PW3 site at Whatawhata over years. Treatment is inclusive of fencing for stock exclusion. However, fencing to exclude cattle or all stock reduced SSC by 30 to 50% so an assumption could be made that the additional reduction is due to plantings.
Climate regulation	Carbon sequestration and mitigation of GHG emissions	Active planting of riparian buffers is expected to increase carbon sequestration through both vegetation and soil organic matter. Rewetting of peat soils is expected to reduce emissions.	Carbon sequestered by plants and/or soil. Reduced methane emissions (associated with any reduction in stock number)/ Reduced GHG emissions from rewetting of drained peat soils.	Carbon sequestration: Carbon sequestration rates vary depending on the species planted, and factors such as age and environmental conditions. Payton et al (2010) suggested that sequestration rates should not be compromised so long as annual rainfall is	See table 1 of Mander (2022) for a summary of carbon sequestration rates of planted indigenous woody vegetation. Burrows et al (2018a) in their comprehensive literature review of non-ETS compliant land, state that there are no known	Mander (2022) Burrows et al (2018a)	Relevant discussion on forest vegetation and soil carbon stocks in Dickinson et al (2023).

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
			Reduced nitrous oxide emissions (associated with any reduction in nitrogen fertiliser application).	>700 mm (or mean water deficit <200 mm), soils are not excessively infertile (eg, ultramafic) and mean temperature of the warmest month is ≥11°C (ie, some extent below treeline). Methane and nitrous oxide emissions: methane reductions will depend on what livestock, if any, are removed. Nitrous oxide emissions reductions will depend on synthetic nitrogen or organic fertiliser is reduced. Soil carbon is an active area of on-going research into measurement and uncertainties related to measurement.	quantitative data sets for carbon sequestration for planted riparian strips in New Zealand, with the only data for riparian shrublands being dominated by mostly gorse, broom, grass, and mixed shrublands. Thus, the Mander (2022) summary of indigenous woody vegetation should be used with care. The National GHG Inventory provides emissions factors and methods to estimate methane and nitrous oxide emissions from livestock and fertiliser and drained peatland.	MfE (2024)	
Natural hazard regulation	Flood and drought resilience	Active planting of riparian buffers is expected to improve interception of rainfall and enhance infiltration of water into soil and groundwater leading to reduction in	Riparian zone: Net increase in underlying soil water. Net increase in underlying groundwater.	There was a pattern of reduced runoff, peak flows and total storm flows after pine afforestation in a native forest vs pine-afforested paired catchment study at	Reductions were 30% for total stormflow, and 50% for peak flow associated with thinning.	Hughes et al (2020)	This study is a whole of catchment afforestation not riparian planting per se. Also, pine afforestation appeared to reduce low flows by 30%.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
		downstream flood frequency and lessening drought risk	Ex-riparian zone: Reduction in downstream flood frequency and intensity.	Whatawhata, NZ. Relies on assumption of native (control) and afforested (treatment) catchments being equivalent			
Ethical and spiritual values / Social connections	Community relationships	Engagement in community environmental restoration project creates and strengthens bonds in community.	Sense of comradery Network of relationships across a community	Limited studies available	There is some qualitative evidence such as the assessment of social relationships from being involved in community freshwater monitoring. This could be a proxy for being involved in project activities.	Kin et al (2016)	

Table A2.3. Evidence of relationship between passively regenerating riparian buffers and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Passively regenerating riparian areas may provide opportunities for indigenous and non-indigenous flora to recolonise thereby creating additional habitat for indigenous and non-indigenous fauna. Riparian area to be recolonised by new vegetation could be bare because of weed control, newly fenced to exclude stock thereby reducing herbivory, or retired from other land uses (eg, grazing). The type of flora that recolonises the area depends on suitable seed sources nearby, seedlings that are dispersed by birds and condition of the current vegetation. Where areas are wide enough to prevent browsing (stock can reach	Change in target indigenous fauna species (presence/absence, abundance, fecundity). Native species dominance (plant, invertebrate). Change in plant community diversity. Avoided loss in target indigenous species.	No known studies empirically analyse the impact of passively regenerating riparian areas alone on indigenous terrestrial fauna. Empirical knowledge of bird movement across landscapes is available for a handful for bird species.	Best evidence of the impact of additional habitat for birds relates to Innes et al (2022) paper on gap crossing of native birds. Paper includes summation of known bird movement studies which could provide more nuanced evidence. See Table A2.8.	Innes et al (2022)	
			Plant species richness (of indigenous flora) species per 100 m^2. % of area covered in target species by vegetation tier. Native plant dominance by vegetation tier. Native seedling density per 5 m^2 plots.	Weed management literature suggests that in an invasive-dominated landscape invasives may be the main recoloniser while in a native-dominated landscape natives may be the main recoloniser.	See Table A2.6 for examples of the impact of biocontrol and control on flora recolonisation behaviours.	NA	Weed control method (eg, biocontrol agent, targeted herbicide to stumps or foliar spray) is applied to area first.
			Ship rat tracking rate.	Specific to ship rats in Waikato forest fragments, however ship rats are a	Ship rat density is higher in fenced and passively regenerating areas compared with	Gillies et al (2013)	Fencing allows passive regeneration of denser vegetation. Norway rats (cf ship rats)

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
		over/through fences) these new conditions can promote succession to taller and denser vegetation and enable conditions favouring native encourage fauna.		common predator across New Zealand	non-fenced grazed areas due to greater cover and food supply. See Table A2.8.		prefer streamside habitat and are likely to be more common in riparian areas.
			Indigenous species dominance. Density of target plant species. Relative density and relative dominance of key flora.	Case study of a dairy farm where fragmented indigenous forest was fenced to exclude cattle . Model considered the long-term impact of continued grazing retirement practices.	Modelled revegetation of retired grazing land near a kahikatea-dominate forest fragment showed indigenous-dominated regrowth from around year 20 after retirement and a return to near-natural state after 40 years.	Smale et al (2005)	Locations close to urban invasive-dense locations showed higher variability for native revegetation dominance. Model was for a non-riparian environment.
	Freshwater indigenous biodiversity	Passive regeneration of riparian buffers is expected to increase the amount of bankside vegetation which creates more shade and regulates water temperature, enhances riparian spawning habitat for fish, stream edge fish cover and provides leaf litter and wood as instream habitat	Net gain in target species or community index or avoided loss Example indices include MCI, QMCI, SQMCI, %EPT, community dissimilarity to reference, trait-based metrics (macroinvertebrates), species richness, F-IBI, egg abundance and survival (fish), %channel	Analyses of data for Waikato streams showed that the level of stream shade, which is created by riparian vegetation and banks (i) reduces the nuisance growth of periphyton and aquatic macrophytes in streams (i and ii) and improves the relative abundance of native macrophytes in streams	65% to 70% shade of stream shown to constrain periphyton weighted composite cover to <30% and aquatic macrophyte channel clogginess to <50% in Waikato streams	i. Matheson et al (2017) ii. Mouton et al (2019)	May take longer than active riparian planting to establish canopy for shade

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
			clogginess (macrophytes), % weighted compositive cover (periphyton)	The number and survival of īnanga (*Galaxias maculatus*) eggs was positively correlated to riparian vegetation stem density and aerial root mat thickness at ground level in three Banks Peninsula riparian zones	Initial egg density increased from 0 to maximum of c. 800/0.01 m^2 with riparian stem density at ground level of c. 3-16/500 m^2	Hickford et al (2010)	Riparian vegetation was a mix of pasture grasses and native sedges/rushes. This type of vegetation is what might be expected in a passively regenerating buffer. Subsequent work by Hickford et al (2017) found no clear differences in spawning preference at high stem/tiller density (2–12 stems or tillers per cm^2) when testing several different types of native versus exotic plant species
Water purification	Sediment, clarity	Passive regeneration of riparian buffers is expected to improve bank stabilisation if species with superior root systems colonise the area and denser vegetation is created at ground level (eg, grasses) to increase	Riparian zone: Deposition/filtration of sediment. Freshwater: Decrease in total suspended sediment, increase in visual clarity.	There is evidence of net sediment deposition/filtration by riparian grass filters from studies measuring changes in load with passage through riparian filter strips	Sediment load carried by surface runoff decreases by –50% to +99% (median 59%). Magnitude related to width of filter strip relative to hillslope length, soil type and land slope	McKergow et al (2020, 2022)	McKergow et al 2020, 2022 publications did not separate out active and passive riparian plantings, but we might assume similar relationships. This study is a review and systematic

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
		filtration/deposition of surface runoff.					analysis of suitable NZ and international literature to derive transferable relationships.
	Nutrients, *E. coli*	Passive regeneration of riparian buffers is expected to increase nutrient removal as a result of enhancement of biological removal processes associated with the plants and soil. *E. coli* removal expected as a result of enhanced deposition	Freshwater: Reductions in nitrate-N, ammoniacal-N, dissolved reactive-P, total-N, total-P, *E. coli.*	There is evidence of net nitrate-N removal by riparian buffers from studies measuring changes in load with passage through riparian buffers	Nitrate load carried by subsurface flow decreases by 0% to 100% (median 87%). Magnitude related to soil type, temperature, and saturation	McKergow et al (2020, 2022)	McKergow et al publications did not separate out active and passive riparian plantings, but we might assume similar relationships. This study is a review and systematic analysis of suitable NZ and international literature to derive transferable relationships.
Erosion control	Bank erosion	Riparian vegetation captures sediments in surface water runoff. Once rooted vegetation establishes, soils along the bank are stabilised reducing erosion from the bank.	Non-storm suspended sediment concentration. Mean annual sediment yield (tons km^{-2} yr.$^{-1}$). % bank eroded.	There is insufficient empirical data that separates the impact of passive planting from active plantings and/or exclusion fencing interventions. However, there are case studies with stock exclusion fencing that most likely	Channel damage was reduced by >50% where plantings were in adequate condition and 40% to 60% where plantings were in inadequate condition (i). 55% to 65% reduction in bank erosion	i. Phillips et al (2020) ii. Monaghan and Quinn (2010)	Assumes fencing occurred first to exclude stock from riverbank. Intervention targets surface erosion but can evolve into also targeting bank erosion

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
				captured the impacts of passive revegetation on erosion.	(depending on type of planting and buffer width). See table 3 for details (ii).		as roots stabilise the soils. Estimated impacts are high and unsure if they can be allocated to passive revegetation, active plantings and/or fencing with any certainty.
				Five streams in Waikato pastoral dairy farming catchments. Change in adoption of Best Management Practices (BMPs) over 7–16 years from 1995 to 2008 (Tables 1 and 2 has attributes of ΔBMPs by catchment).	0.21– 0.89 g/m3/yr reduction in SSC (c. 4%–11%)	Wilcock et al (2013)	Reduction in suspended sediment concentration (SSC) that can be attributed to stream bank erosion. Non-storm SSC. Multiple BMPs put in place at same time, but authors attribute sediment changes to fencing changes.
Climate regulation	Carbon sequestration and GHG emissions	Passive regeneration of riparian buffers is expected to increase carbon sequestration through both vegetation and soil organic matter.	Carbon sequestered by plants and/or soil. Reduced methane emissions (associated with any reduction in stock number).	Carbon sequestration: Carbon sequestration rates vary depending on the species planted, and factors such as age and environmental conditions.	Carbon sequestration: An approximation of sequestration rates by region (based on 52 naturally regenerating forests, mostly dominated by kānuka	i. Holdaway et al (2010) ii. Payton et al (2010) iii. Burrows et al (2018b)	Relevant discussion on forest vegetation and soil carbon stocks in Dickinson et al (2023)

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
		Rewetting of peat soils is expected to reduce emissions.	Reduced GHG emissions from rewetting of drained peat soils. Reduced nitrous oxide emissions (associated with any reduction in nitrogen fertiliser application).	Payton et al (2010) suggested that sequestration rates should not be compromised so long as annual rainfall is > 700 mm (or mean water deficit < 200 mm), soils are not excessively infertile (eg, ultramafic) and mean temperature of the warmest month is ≥ 11°C (ie, some extent below treeline). Methane and nitrous oxide emissions: methane reductions will depend on what livestock, if any, are removed. Nitrous oxide emissions reductions will depend on synthetic nitrogen or organic fertiliser is reduced. Soil carbon is an active area of on-going research into measurement and uncertainties related to measurement.	and/or mānuka indicated some of the fastest rates occur in Nelson (4.1 ± 0.7 t CO2e/ha/yr.), Northland (3.7 ± 0.3 t CO2e/ha/yr.), Gisborne (3.7 ± 0.4 t CO2e/ha/yr.), and Manawatu/Wanganui (3.6 ± 0.3 t CO2e/ha/yr.), whereas the slowest correspond to the West Coast (1.7 ± 0.2 t CO2e/ha/yr.) and Otago (2.1 ± 0.3 t CO2e/ha/yr.) (i). The National GHG Inventory provides emissions factors and methods to estimate methane and nitrous oxide emissions from livestock and fertiliser and drained peatland.	MfE (2024)	

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
Natural hazard regulation	Flood and drought resilience	Passive regeneration of riparian buffers is expected to increase the interception of rainfall and enhance infiltration of water into soil and groundwater leading to reduction in downstream flood frequency and lessening drought risk	Riparian zone: Net increase in underlying soil water . Net increase in underlying groundwater. Ex-riparian zone: Reduction in downstream flood frequency and intensity.	No known studies empirically analyse the impact of passively regenerating riparian areas alone on flood and drought resilience.		NA	
Ethical and spiritual values / Social connections	Community relationships	Engagement in community environmental restoration project creates and strengthens bonds in community.	Sense of comradery Network of relationships across a community	Limited studies available.	There is some qualitative evidence such as the assessment of social relationships from being involved in community freshwater monitoring. This could be a proxy for being involved in project activities.	Kin et al (2016)	

Intervention: Pest control

Table A2.4. Evidence of relationship between pest control and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Mammalian pest predation and browsing negatively impacts indigenous terrestrial flora and fauna. Pest control methods which reduce or eliminate these pests from habitats can (but not always) allow indigenous flora and fauna to survive.	Native species richness (ie, number of native species). Indigenous dominance (extent of influence of indigenous species in an ecosystem). Abundance of browse-sensitive plants or predator-sensitive indigenous fauna species.	Meta-analysis of impact of different pest management regimes (eg, ring-fencing, unfenced, aerial etc.) on 145 species of bird, lizards, invertebrates and plants, largely in forested areas (i). Data in studies used for meta-analysis (i and iii) was observational and not specific to riparian areas. Literature review and analysis to catalogue the relationship between pest density and indigenous flora and fauna (iii)	Pest control can be an effective approach to ecological restoration, but empirical evidence and modelling shows required ongoing control is required. Ground-based possum control has a small, but positive impact on invertebrates and mammal-sensitive vegetation while unfenced mainland islands have a small but positive impact on bird (figure 4 in i). If rat populations are continuously maintained below 10%, then robin populations are likely to increase 10% each year (figure 2 and 3 in ii).	i. Binny et al (2021) ii. Armstrong et al (2006) iii. Norbury et al (2015)	Effectiveness and intensity of required pest control methods depend on the target beneficiary indigenous fauna. Meta analyses by (iii) and (i) provide generalised findings and the best sources of studies relating pest management to fauna/flora response. The model started with 4 robin breeding pairs after pest control ceased the second time which in the long run shows population collapse without additional breeding pairs (ii) The impact of the type of pest control influences the likelihood of

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
							reinvasion of ship rats post-control and subsequent sustainable impact of pest control on indigenous flora/fauna (Innes et al, 2023).
		Control of one or a few predator and pest species can release others with unintended negative consequences. Some predator management interventions will fail to protect fauna and have unintended negative consequences.	Native species richness (ie, number of native species). Indigenous dominance (extent of influence of indigenous species in an ecosystem). Abundance of browse-sensitive plants or predator-sensitive indigenous fauna species.	Replicated Before-After Control-Impact field experiment with a four-species assemblage across four sites (i). Fuzzy logic neural network modelling of a dryland system including (4) vegetation, (8) pests, and (3) fauna (ii).	Removal of possums alone can increase ship rats while removal of ship rats can release mice (Fig. 2 in i). Table 2 in (ii) shows the relative interaction strength and direction among the flora/fauna. Table 3 in (ii) shows the qualitative model responses to differing management models. Nearly every type of management resulted in a positive impact on bird, but no measurable impact on invertebrates or lizards. This is possible because most pest control often leads to an increase in mice, which prefer lizards,	i. Ruscoe et al (2011) ii. Ramsey and Norbury (2009)	(i) does not have flora/fauna information, only the pest responses. Generic predator control model was where cat, ferret, stoat and weasel abundances were held at 20% (ii). In dryland systems, control of carnivores in an attempt to protect lizards will release mice - which are lizard and invertebrate predators - and also lead to more rabbits, which impact vegetation (ii).

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
		Mammalian pest predation and browsing negatively impacts indigenous terrestrial flora and fauna. Pest control methods which reduce or eliminate these pests from habitats can (but not always) allow indigenous flora and fauna to survive.	Annual counts of target bird species.	Pest control efforts in Landsborough Valley, New Zealand, during 1998–2009 Continuous trapping to control mustelids plus 1080 toxin to control rats and brushtail possums	Significant improvement in bellbird, brown creeper, fantail, grey warbler, mohua, rifleman, tui and yellow-crowned parakeet.	O'Donnell and Hoare (2012)	Forest birds. There are diverse mammal pests that between them eat seeds, fruits, leaves and seedlings. Pest impact varies by site across NZ.
			Abundance: total number of individuals recorded across all three counts. Species richness: number of native forest species recorded. Total relative abundance: total number of individuals recorded from all native forest species.	Study evaluated the influence of forest cover, pest control and interaction of forest cover and pest control on bird species richness and abundance across 195 sites in Auckland. Lowland forest sites around Auckland. Forest cover ranges from 0% to 100%. Pest control intensity ranged from no control to eradication.	Kererū and tūī were significantly more abundance in pest controlled (E and HRP) landscapes. Tūī populations would still be relatively high in high forest cover (>10%) without pest control, but would decline as forest cover approached 0% even with pest control.	Ruffell and Didham (2017)	Pest control was correlated with forest cover so sensitivity of marginal changes in relationship was challenging to estimate. Pest control scenarios: eradication (E), high-intensity rat and possum control (HRP), low-intensity rat and possum control (LRP), periodic possum control (PP), no pest control.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
		Mammalian pest browsing and trampling negatively impacts indigenous flora. Controlling these pests removes the cause of damage.	Changes in the presence or dominance of palatable species.	Meta analysis of impact of different pest management regimes (eg, ring-fencing, unfenced, aerial etc.) on a 145 species of bird, lizards, invertebrates and plants. Data in studies used for this meta-analysis is observational and not restricted to riparian areas.	(i) and (ii) Plant palatability plays a role in magnitude of impact from pest control (eg, possums attracted by planting of kohekohe, (ii)).	i.Binny et al (2021) ii. Byrom et al (2016)	Pest control regime is based on overall approach and is not based on marginal changes in specific pest control methods.
			Survival of planted seedlings.	20 years of mountain beech tree growth, survival and recruitment from 40 paired fenced and unfenced plots (i). Review of impact-outcomes from management of wild ungulates, brushtail possums and predators (ii)	Sapling counts in unfenced plots were 3–10 times lower after 60 years of deer control compared with unfenced plots (i). Widespread evidence of deer browsing on vegetation even at low to moderate population densities, especially understoreys (ii).	i. Husheer and Tanentzap (2023) ii. Leathwick and Byrom (2023)	(i) Unrestricted sport hunting of deer across 594 km^2 landscape in North Island. Mountain beech forest plots in Kaweka Forest Park. 1958-1987, 1987-2008.
	Freshwater indigenous biodiversity			Laboratory and field experiment to test the impact of exotic slugs (*Milax gagates, Deroceras panormitanum* and *D. reticulatum*) and mice	Exotic slugs (*M. gagates and D. panormitanum*) reduced the survival of eggs in laboratory experiments	Hickford et al (2010)	Drains coastal plains and steep pastoral valleys. Spawning areas adjacent to urban areas.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
				(Mus musculus) on the survival of developing *Galaxias maculatus* eggs in Avon River, Takamatua Stream and Barrys Bay Stream. Mice: exclusion cage, open cage, or no cage at Avon and Takamatua. Slugs: exclusion cage or no cage at Avon and Barrys Bay.	(c. 5% to 30%) compared to control (53%) after 15 days. Higher density of mice at Avon, but no difference in egg survivability between treatments or between sites after 28 days.		Mice have bene found to predate on *G.* maculatus along the Mokau River (Baker 2006). However, insect and seedings were highly abundant at field sites in the present study which may have satiated mice.
Water purification	Sediment, clarity	Unclear					
	Nutrients, *E. coli*	Unclear					
Erosion control	Bank erosion	Relationship is through the impact of pests on quality and quantity of vegetation available to stabilise banks and/or capture sediments trapped in surface water		No studies empirically analyse the impact of mammalian (ie, rats, stoats) pest control on riparian bank erosion.	See discussion of bank stabilisation in Table A2.1.	NA	Could use cattle as a proxy for ungulates (eg, deer, pigs) being removed. Phillps and Davie (2007) related animal pest control with biophysical benefits, however this analysis was not focused on riparian plantings.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
Climate regulation	Carbon sequestration and GHG emissions	Unclear					
Natural hazard regulation	Flood and drought resilience	Unclear					
Ethical and spiritual values / Social connections	Well-being	Time in nature has a positive impact on mental, physical and social health.	Sense of mental well-being (eg, depression). Blood pressure. Social cohesion (eg, trust.)	Representative quantitative survey in 2019 in Wellington. Included those who participate in local predator trapping groups	Participating in trapping groups inversely correlated with rates of depression and likelihood of blood pressure medicine and positively correlated with sense of social cohesion.	Shanahan (2020)	City-wide and not specific to riparian zones.
	Community relationships	Engagement in community environmental restoration project creates and strengthens bonds in community.	Network and strength of community relationship	Limited studies available	There is some qualitative evidence such as the assessment of social relationships from being involved in community freshwater monitoring. This could be a proxy for being involved in project activities.	Kin et al (2016)	

Table A2. 5. Evidence of relationship between pest control, fencing and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial biodiversity	Pest control and pest fencing can be concurrently applied to an enclosable environment for a pest exclusion then eradication approach. Pest eradication is not cost effective within a linear fenced riparian area, however. Terrestrial pest removal in riparian areas must generally be part of a wider landscape treatment to be effective.	Change in target indigenous species. Avoided loss in target indigenous species. Counts of predator-sensitive bird species.	Meta-analysis of impact of different pest management regimes (eg, ring-fencing, unfenced, aerial) on 145 species of bird, lizards invertebrates and plants. Data in studies used for this meta-analysis is observational (iii).	Positive impact on number of kohekohe, mahoe, pate, tūī, bellbirds, adult tree wētā, flower pollination and fuchsia fruit dispersal from a combining pest control and fencing (i and ii). This intervention could also be considered an eradication method as opposed to suppression with pest control alone.	i. Innes et al (2012) ii. Innes et al (2019) iii. Binny et al (2021)	Innes et al (2012) notes that fencing of peninsula sanctuaries is less effective as pests can walk and/or swim around the fence and reinhabit the exclusionary zone. This suggests that riparian fencing and pest control should be catalogued as a pest suppression method (not exclusion) requiring ongoing pest management. Innes et al (2012, 2019) are reviews.
	Freshwater biodiversity	Unclear					
Water purification	Sediment, clarity	Unclear					
	Nutrients, *E. coli*	Unclear					

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
Erosion control		Relationship is through the impact of pests on quality and quantity of vegetation available to stabilise banks and/or capture sediments trapped in surface water		No studies empirically analyse the impact of mammalian (ie, rats, stoats) pest control on riparian bank erosion.	See discussion of bank stabilisation in Table A2.1	NA	Could use cattle as a proxy for ungulates (eg, deer, pigs) being removed. Phillps and Davie (2007) related animal pest control with biophysical benefits, however this analysis was not focused on riparian plantings.
Climate regulation	Carbon sequestration and GHG emissions	Unclear					
Natural hazard regulation	Flood and drought resilience	Unclear					
Ethical and spiritual values / Social connections		Unclear if addition of fencing to pest control would change the relationship.			See studies in Table A2.4		

Note on terrestrial biodiversity: The relationship between native fauna, mammalian pest and active management of native fauna and mammalian pest is complex and not always generalisable to different fauna, mammalian pests or landscapes. Research of impacts of mammalian pest control on indigenous biodiversity is limited (Leathwick and Byrom, 2023) to case-specific flora, fauna and pest species relationships (see Binny et al, 2021 and Norbury et al, 2015) and rarely utilises robust experimental assessment methods (Allen et al, 2023). Methods to control pests and improve indigenous biodiversity depends on several factors, for example, which pest is impacting the target species, how is that pest is impacting the target species, and how responsive the target species is to reduction in predation likelihood. However, both the target pests and target indigenous species exist within a landscape and may change their behaviours based on different landscape attributes (eg, rats avoid grazed forest fragments, Boulton, 2006), changes in availability of preferred prey (Norbury et al, 1998), pest control in neighbouring landscapes (Ramsey and Norbury, 2009) or may move across landscapes seeking habitat for different purposes (eg, breeding – Innes et al, 2022). Measuring the impact of pest control efforts on biodiversity outcomes therefore requires understanding population dynamics across a landscape, clearly defining the desired outcomes for biodiversity success and designing pest control regimes to achieve those outcomes. An unfocussed approach to pest control may or may not result in long-term biodiversity outcomes (eg, Day and MacGibbon, 2007; Norbury et al, 2015; Ramsey and Norbury, 2009; O'Donnell and Hoare, 2012).

Intervention: Terrestrial weed control

Table A2.6. Evidence of relationship between weed control and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Controlling weeds can (but not always) allow for indigenous flora to replace the invasive flora in the ecosystem. Depends on weeds and duration of control, as some riparian weeds reinvade from upstream catchment. Weeds spread by birds can establish once a canopy is present; landscape control is often required for effective control. For early seral weeds such as broom and gorse leaving the vegetation cover was beneficial to the germination and survival of indigenous woody seedlings (Burrows et al, 2015).	Appropriate abundance measure for the target indigenous specie Target native species cover (in tiers) Numbers (for trees/shrubs)	Studies are species specific, but empirical. 5-year field trial comparing bio-control agent to control methods to manage heather in Tongariro. Non-riparian environment.	% of plots covered in native dicots and monocots by treatment type (eg, herbicide, bio-control, herbicide-biocontrol, control) over the 5-year period (see figure 2 of the paper).	Peterson et al (2020)	Comparing bio-control to control method in Tongariro. Control method was a selective herbicide that was indiscriminate as to which plants it killed.
				Study is species specific, but empirical. Multiple release sites in the North Island to control mist	Native % cover and species richness in treatment plots near close to control plots (with no mist flower present).	Barton et al (2007)	Bio-control study, not control weed management techniques.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
				flower. Repeat observations over 1999 to 2001. Streams present at study site, but not specific to target invasive species.	Non-native species % cover and richness did not change as % mist flower decreased indicting that native species were able to recolonise in the absence of mist flowers.		Waitakere Ranges are dominated by native cover, potentially explaining the low non-native colonisation post-mist flower removal.
				Experimental comparison of sites treated and not treated with different sprays for *Lonicera japonica* (i), *Rumex sagittatus* (ii) and *Chrysanthemoides monilifera* (iii). (i) Four plots treated with four types of sprays. Data collected over 2 years. (ii) 16 individual plants. 1 m cleared around each plant to catalogue seeding growth. All plants sprayed. Measured over 2 years. (iii) Two plots. Measured over 7 weeks.	(i) Native fern *Hypolepis ambigua* second highest cover at 18.1% in plot 3 (alluvial) and 11.6% in plot 4 (river). See table 1 of the paper. (ii) No seedling of native species observed near dead dock. Pohuehue occupied some bare areas, but *Solanum chenopodioides* tended to grow in the open canopy spots. See table 2 of the paper. (iii) Partially sprayed plants didn't always die. No resurgence of woody natives and no seeding of other natives from adjacent areas. See table 4 of the paper.	Williams et al (1998)	(i) Plots roadside bank adjacent to the Takaka River. 2 plots next to river, 2 plots on alluvial soil. (ii) Sand dunes at the base of Farewell Spit. (iii) coastal shrubland in Queen Elizabeth Park. Native plants avoided. All sites had more than target weed present.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
			Numbers (for trees/shrubs)	Experiment comparison of four sites (40 plots) treated and not treated with physical removal (cut off at ground). Plots subdivided at 6-month mark with half receiving weeding treatment (exotic grasses, gorse, bracken, fern physically removed).	Removing mature bone-seed plants had a positive effect on bone-seed regeneration (1.6 ±0.4 per plot after a year), and a negative effect on native regeneration (from 2.1 ± 0.5 per plot down to 0.3 ± 0.1 per plot after a year) (See figure 1 of the paper).	McAlpine et al (2009)	All gorse removed at sites. Coastal Wellington NZ within 200 m of secondary forest. Sites had a mixture of target species, natives and other invasive species.
				Experimental comparison of removal of *Impatiens glandulifera* on species richness, diversity and evenness in open riparian habitats in north-east England.	Proportion of non-native species in removal plots was higher than in invaded plots (See table 2 of the paper). Species accumulation curves suggested that extensive Impatiens stands may reduce species richness by as much as 25%.	Hulme and Bremner (2006)	International study of a common riparian weed found in New Zealand.
			Growth of *Tradescantia fluminensis.* Number of native flora.	Field experiment at two sites using beetle biocontrol and manual clearing over 3 years to manage *Tradescantia fluminensis.*	Tradescantia biomass at biocontrol site significantly higher than at control sites (figure 3 of the paper) No. woody seedlings significantly higher at hand-cleared than biocontrol or control after 3 years (figure 4 of the paper)	Clarkson et al (2019)	Forest remnants on the Hikurangi floodplain. No additional site details, type of woody seedlings and changes in vegetation community.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
				Experimental study of herbicide, shading and hand weeding of *Tradescantia fluminensis* in Awahuri (podocarp/broad-leaved forest remnant on a flood plain) and Monro's Bush (lowland podocarp/broad-leaved forest remnant).	Shading controlled weed growth while allowing natives to recolonise. Herbicides and hand weeding had reinvasion. 2.5 years, 61% of the saplings planted had emerged from the surrounding tradescantia	Standish (2002)	Planted seedlings are not light – dependent so will thrive in shaded areas. Native sub-canopy species were planted into tradescantia to achieve natural shading.
	Freshwater indigenous biodiversity	Change in riparian zone flora structure may positively or negatively impact macroinvertebrate communities.				NA	see Table A2.2 and Table A2.3
Water purification	Sediment, clarity	Change in riparian zone flora structure may positive or negatively impact sedimentation in-stream.		No empirical studies available measuring the direct impact of terrestrial weed control.		NA	see Table A2.2 and Table A2.3
	Nutrients, *E. coli*	Change in riparian zone flora structure may positive or negatively impact water quality. Possible relationship between type of control method (eg, spray) and water quality.		No empirical studies available measuring the direct impact of terrestrial weed control.		NA	see Table A2.2 and Table A2.3

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of the impact?	What key papers provide the quantitative evidence?	Notes / assumption
Erosion control	Bank erosion	Relationship is through the impact of weeds on quality and quantity of vegetation available to stabilise banks and/or capture sediments trapped in surface water		No known empirical studies assessing the impact of terrestrial weed control alone on bank and/or surface erosion.		NA	see Table A2.2 and Table A2.3
Climate regulation	Carbon sequestration and GHG emissions	Relationship is through the C sequestration ability of plants along the riparian area. If the weeds removed sequester C better than natives, then there may be an impact.		No known empirical studies assessing the impact of terrestrial weed control on carbon sequestration/ghg emissions.		NA	see Table A2.2 and Table A2.3
Natural hazard regulation	Flood and drought resilience	Relationship is through the impact of weeds on quality and quantity of riparian vegetation to manage water flows.		No known empirical studies assessing the impact of terrestrial weed control on flood and drought resilience.		NA	see Table A2.2 and Table A2.3
Ethical and spiritual values / Social connections	Community relationships	Engagement in community environmental restoration project creates and strengthens bonds in community.		Limited studies available	There is some qualitative evidence such as the assessment of social relationships from being involved in community freshwater monitoring. This could be a proxy for being involved in project activities.	Kin et al (2016)	

Note on terrestrial biodiversity: There is a major assumption in weed and bio-control methods when it comes to the impacts on biodiversity: by removing the invasive plant there will be a positive impact on indigenous biodiversity. However, the likelihood of indigenous plants colonising a created bare area is not guaranteed (Standish et al, 2009; eg, fennel in the UK, Erskine

Ogden and Rejmanek, 2005, and Himalayan balsam in the UK, Hulme and Bremner, 2006) . In addition, weeds interact with the ecosystem differently suggesting that management approaches should be tailored to the target weed species (eg, stream riparian areas, Pattison et al, 2019). For example, riparian areas, riverbanks and open water areas are more sensitive to intensive invasion by Himalayan balsam (*I. glandulifera*), most likely because of the limited shading that these areas provide (Coakley and Petti, 2021). In addition, Pattison et al (2019) found that riparian areas with low indigenous plant abundance favoured I. glandulifera through lack of competition. Together these findings suggest that successful management of I. glandulifera in riparian zones requires both removal of the weed and intensive reseeding with native plants that are capable of providing shade quickly. Similarly, control of willows (as openings or complete canopy removal) can stimulate light-demanding native podocarps otherwise excluded but 'once-only' treatment is unlikely to be successful due to reinvasion (Sukias et al, 2023). Intentional re-establishment of native kahikatea canopy, however, after willow invasion would require interventions over decades to centuries for successful dominance of the native tree.

Note on terrestrial biodiversity: Burrows et al (2015) found that germination and survival of seedlings of indigenous tree species within areas of scotch broom invasion in Canterbury was significantly higher in untreated control plots compared to four different weed control treatments. They note that weed control can be both far more expensive and considerably less effective than doing nothing. For example, "For any mechanical-disturbance treatments to be effective in removing broom cover, follow-up control of regenerating broom would be required over many years (Downey and Smith, 2000). While this might be effective in slowing broom regeneration, it inevitably causes additional disturbance, which in turn can result in other opportunistic introduced species colonising the disturbed areas, providing increased competition for the indigenous species (Buckley et al, 2007). Moreover, chemical or mechanical broom control removes other woody seedlings and saplings from a site, including indigenous species, eliminating the potential of these self-established seedlings to contribute to the succession towards an indigenous-dominated woody cover, and resets the broom invasion. This provides an additional incentive for retaining the standing broom cover in areas where natural seed sources are available and regeneration is occurring."

Intervention: Fish passage barrier removal, replacement, or remediation

Table A2. 7. Evidence of relationship between fish passage barrier removal, replacement or remediation and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Unclear					
	Freshwater indigenous biodiversity	Fish passage barrier intervention is expected to improve freshwater biodiversity by reinstating access to suitable habitat for migrating native freshwater fish species	Percentage of fish arriving at a structure that pass (passage efficiency), changes in the number of species upstream of a structure pre vs post intervention, changes in the abundance of a particular species upstream of the structure pre vs post intervention, changes in the size of fish upstream of a structure pre vs post intervention, decrease in the time taken to pass a structure pre vs post intervention, reductions in injury/mortality of fish passing downstream through the structure (eg, dam, turbine) pre vs post intervention.	Data on the effectiveness of fish passage interventions in NZ are generally poor quality. This is largely due to poor/confounded sampling design and confirmation bias. However, there are two main types of study design that can provide reliable evidence. These are before-after (control-impact) monitoring and mark-recapture studies.	Results have shown passage efficiency estimates of different interventions ranging from 0% to >90% (i). Variation in efficacy likely reflects both the site-specific nature of interventions (ie, they are highly varied) and the significant range in quality of interventions. There is no relationship available at present that accounts for these factors.	i. Franklin and Bartels (2012) ii. David and Hamer (2012) iii. Baker et al (2024) iv. Franklin et al. (2021) v. Baker (2003) vi. Baker and Boubee (2006) vii. Doehring et al. (2011) viii. Baker (2014) ix. David et al. (2013) x. David et al. (2010) xi. Amtstaetter et al. (2017)	Barrier removal, replacement or remediation has the potential to enhance passage for problematic pest fish species as well as desirable native species but these interventions have potential to be designed as selective migration barriers (Franklin et al, 2021)
Water purification	Sediment, clarity	Change in fish barriers could have				NA	Depends on the action taken.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
		an impact on in-stream sediment movement.					
	Nutrients, *E. coli*	Change in fish barriers could have an impact on in-stream nutrient dispersal or movement of nutrients through sediment movements.				NA	Depends on the action taken.
Erosion control	Bank erosion	Change in fish barriers could have an impact on the structure of the stream bank.				NA	Depends on the structural relationship of the fish barrier with the bank (eg, dams).
Climate regulation	Carbon sequestration and GHG	Unclear					
Natural hazard regulation	Flood and drought resilience	Change in fish barriers could have an impact on the structure of the stream bank impacting water				NA	Depends on extent of hydrological changes.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers the provide the quantitative evidence?	Notes / assumption
		quantity and timing.					
Ethical and spiritual values / Social connections	Wild foods	Remediation or removal of barriers would increase habitat connectivity of culturally significant aquatic species	Indicator(s) would have to be decided on by the community and may be narrative in nature	Anecdotal Urban Eel project in Manawatū-Wanganui	Unsure if impact assessment was done post project, however decline in eel population had a significant negative impact on community.	Gordon et al (2018)	Urban Eel project included multiple water quality and connectivity actions.
Wild foods	Mahinga kai	Remediation or removal of barriers would increase habitat connectivity of culturally significant aquatic species	Indicator(s) would have to be decided on by the community and may be narrative in nature	Anecdotal Urban Eel project in Manawatū-Wanganui	Unsure if impact assessment was done post project, however decline in eel population had a significant negative impact on community.	Gordon et al (2018)	Urban Eel project included multiple water quality and connectivity actions.

Intervention: Development of ecological corridors

Table A2.8. Evidence of relationship between development of ecological corridors and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Connecting fragmented habitats eases indigenous birds' travel to new habitats for settlement or genetic exchange purposes. Depending on the ability of birds to move across gaps, new habitat may be out of reach if the pockets of habitat are too far away. Whether connectivity has a net beneficial effect on a population is dependent on the habitat created in the corridor, including (and in New Zealand perhaps especially) predation risk. Contrary to the wide perception that corridors and connectivity have positive effects, higher connectivity will have negative consequences for species in predator-managed areas, if it encourages and enable s fauna species to move into unsafe habitats.	Abundance or occupancy by species of interest within new corridors and within predator managed core areas	Strong empirical data on forest bird movement behaviour is limited to a handful of species. Natal dispersal distances are unknown for half the species reviewed. Limited data on species ability to cross gaps between fragmented forests and over pastures, but more is known about the movement over water. Available data is on bird movement behaviour, not nests within an area.	North Island kōkako, pōpokotea, South Island tīeke, and North Island brown kiwi currently unknown to cross gaps larger than 500m. Mohua, tītitipounamu, pīpipi, weka, North Island tīeke, kakaruai, toutouwai, and miromiro not observed crossing a more than 5km. Qualitative.	Innes et al (2022)	Studies focused on non-riparian bird movement and preferences. Inferences would need to be made about the impact of corridors on different bird species.
		Connecting fragmented habitats allows mammalian pests to travel more easily across a landscape.	Rat density (50m x 50m detection device grid)	Specific to ship rats in Waikato forest fragments, however ship rats are a common predator across New	Rat density higher in fenced (higher vegetation) than in	Innes et al (2010)	Analysis for eight indigenous forest fragments (4 fenced and 4 grazed) in pastoral farming areas

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				Zealand. Does not measure impact on native biodiversity, but it is assumed that reduction in ship rats will help bird populations.	grazed (low vegetation) areas.		of Waikato. Half of each type had vegetation that connected the fragments. Fencing creates the corridor across fragmentation.
	Freshwater indigenous biodiversity	Extending riparian plantings would increase the length of vegetation along a river that provides benefits to in-stream biota.				NA	See Table A2.2 and Table A2.3
Water purification	Sediment, clarity	Extending riparian plantings would increase the length of vegetation along a river to capture sediments in surface flow.				NA	See Table A2.2 and Table A2.3
	Nutrients, *E. coli*	Extending riparian plantings would increase the length of vegetation along a river to capture nutrients in surface flow.				NA	See Table A2.2 and Table A2.3
Erosion control	Bank erosion	Extending riparian plantings would increase the length along a river bank that is stabilised.				NA	See Table A2.2 and Table A2.3
Climate regulation	Carbon sequestration and mitigation	Extending riparian plantings would increase the extent of vegetation that could sequester C.				NA	See Table A2.2 and Table A2.3

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
	of GHG emissions						
Natural hazard regulation	Flood and drought resilience	Extending riparian plantings would increase the extent of vegetation that could mitigate food impacts.				NA	See Table A2.2 and Table A2.3
Ethical and spiritual values / Social connections		Unclear if extension of riparian corridors would provide additional impact on Ethical and spiritual values other the impacts identified in riparian buffers or fish passages remediation				NA	See Table A2.2 and Table A2.3 See Table A2. 7

Intervention: Restored and constructed wetlands

Table A2.9. Evidence of relationship between restored wetlands and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
Habitat	Terrestrial indigenous biodiversity	Restoring the hydrological processes of drained or damaged wetlands to their natural state encourages recolonisation of native flora and fauna. Many New Zealand wetlands supported native forest prior to land use change.	Appropriate measures of abundance of target wetland species	Study on wetland restoration in Wairarapa was trying to measure the ecosystem services contribution of wetland restoration. Comparison of restored wetlands to unrestored paired reference sites.	Restored plots have a mean native plant species richness of 17.9 species Unrestored plots have a mean native plant species richness of 2.6 species	Tomscha et al (2021)	Wairarapa Native species richness not clearly defined in paper. Indigenous dominance is suggested as better indicator for wetlands. Restored portions of wetlands only a small proportion of larger historical extent. 18 sites with restored areas ranging from 0.4 ha to 33.7 ha. Sites restored between <1 year ago up to 42 years ago.
			Indigenous dominance	Experimental study testing different restoration techniques in a peat mined lowland *Sporadanthus*-	Table 1 of the paper shows method used, recovery time, and transferability of information (qualitative).	Clarkson et al (2017)	Torehape pet mining (lowland). *Sporadanthus*-dominated wetlands.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				dominated wetland (Torehape bog, Waikato). Recovery of vegetation community was related to recovery of successional plantings on raised beds.	Early successional *Leptospermum* was near 100% after 2 years when planted directly into soils, but late successional *Sporadamthus* did not survive. Raised beds with a few *Leptospermum* resulted in more successful diversification of desirable flora as *Leptospermum* provided a nursey for late successional peat-forming plants *Sporadanthus ferrugineus, Empodisma robustum* blown in from surrounding seed sources.		
		Trajectory of flora recovery in a wetland environment is dependent on the surviving flora and flora surrounding the recovery wetland. However, that trajectory is not always direct nor expected.	% coverage by vegetation types	Observational study of the recovery trajectory of vegetation in Whangamarino and Moanatuatua wetlands after fires in 1984 and 1989.	Whangamarino: Baumea teretifolia and Schoenus brevifolius dominant until yr3, Leptospermum established early reaching peak coverage at yr5, Empodisma established after 10 m then dominated after c. 4 years Moanatuatua: *Schoenus brevifolius* dominated first	Clarkson (1997)	No intervention. Study shows the progression of recovery of wetlands. Infer the potential benefits of restoration and the trajectory of the recovery without direct intervention.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
					2 years, *Empodisma minus*, dominated by around year 11, by year 21 *Empodisma minus* and *Sporadanthus traversii* coverage similar to unburnt areas.		Whangamarino: dominated by *Baumea /Leptospermum, Baumea-Leptospermum, and (Leptospermum)-(Epacris)/Empodisma* before fire. Moanatuatua: dominated by *Sporadanthus/ Empodisma, Leptospermum and Epacris, Gleichenia dicarpa, Baumea teretifolia*, and *Schoenus brevifolius* before fire.
	Freshwater indigenous biodiversity	Restoring the hydrological processes of drained or damaged wetlands to their natural state encourages recolonisation of native flora and fauna.	Dependent on target species (ii) [% total vegetation cover,% total grey willow cover, no. of vascular plant species, canopy height, canopy density, litter depth, litter biomass, amount of	Quantitative evidence of stock and richness of biodiversity in wetlands exists, however there are limited studies show the change in biodiversity from restoration activities.	Qualitative discussion of native invertebrate community recovery. Near undisturbed beetle community after 13 years, but still not able to fully recover (i). New genus and species of *Houdinia flexilissima* moth found (i)	i. Clarkson et al (2017) ii. Watts et al (2012)	*Sporadanthus*-dominated Torehape peat mine (lowland) wetland (i). Canopy density and height, and vegetation cover, strongly influenced beetle species composition (i).

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
			CWD, pH and moisture content		Native beetle species and abundance in restored to native wetland was closest to undisturbed nature wetland communities (ii).		
Water purification	Sediment, clarity	Restoring wetlands restores the natural filtration ability of the landscape	Sediment load	Sediment loading into restored and unrestored wetland land uses estimated using soil, climate, topography and land management. Sediment export at end of watershed estimated for restored vs unrestored.	See figure 6 and 7 Restored wetlands exported a mean of 771 ± 468 t ha^{-1} yr^{-1} Unrestored wetlands exported a mean of 775 ± 468 t ha^{-1} yr^{-1}	Tomscha et al (2021)	Wairarapa 'Unrestored' wetlands in modelling were assumed to be conditions under agricultural land use.
	Nutrients, *E. coli*	Restoring wetlands restores the natural filtration ability of the landscape	Total nitrogen Total phosphorus Olsen P	TN, TP loading into restored and unrestored wetland land uses estimated using soil, climate, topography and land management. TN, TP export at end of watershed estimated for restored vs unrestored. Olsen P measured through soil samples at restored and matching unrestored wetlands. Paired sampling design	See figure 6, 7 and 8 Restored wetlands exported a mean of 148 ± 43 kg N ha−1 yr−1 and 711 ± 268 g P ha−1 yr−1 Unrestored wetlands exported a mean of 166 ± 48 kg N ha−1 yr−1 and 1347 ± 366 g P ha−1 yr−1 Restored wetlands contained 6 to 62.5 µg P cm-3 dry soil Unrestored wetlands contained 11 to 51.5 µg P cm-3 dry soil of Olsen P	Tomscha et al (2021)	Wairarapa All restored wetlands were fenced and planted with native and exotic species. Other interventions present dependent on wetland. Years since restoration range from 6 to 42 years.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
		Restoring wetlands restores the natural filtration ability of the landscape	Total nitrogen Total phosphorus	Meta-analysis of the efficacy of constructed (28) and restored (9) wetland studies to remove nitrogen and phosphorus. 93 studies from US, Europe, Turkey China, South Korea, Japan, and New Zealand.	Median removal efficiency of TN is 28-39% Median load removal efficiency of TP is -16-36%	Land et al (2016)	Formally drained land, restored to wetland Median wetland age at the start/end of study periods was 1 year/3 years. TP leaching of restored wetland could be the result of short term washing of P from previously cropland.
Erosion control	Bank erosion	See references under Sediment, clarity					
Climate regulation	Carbon sequestration and mitigation of GHG emissions	Peat soils capture and store carbon when wet but release their stored carbon when dry or drained.	Net ecosystem carbon balance	Estimated from an unaltered peat bog (Kopuatai bog) over 4 years using the Global Warming Potential approach. Drained organic soil (wetland) emissions: Recommendation to move from IPCC 2006 methods to 2013 methods. Also, research proposed to further refine methods to	Net carbon stored ranged from 134.7 to 216.9 gCm-2 yr-1 (i). Extreme summer drought reduced NECB by 30-40%, but bog still remained a carbon sink (i). Recommended approach for estimating emissions for wetland organic soils: See tables 6.3 and 6.4 for recommended CO_2 and N_2O emissions for New Zealand (ii).	i. Goodrich et al (2017) ii. Pronger et al (2023)	Lower water tables increased ecosystem respiration, but *E. robustum* mitigates evaporation rates. Recommended update to emissions factors is based on 2013 IPCC Wetland supplement for drained inland organic soils.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
				reduce uncertainty of estimates.			
		Permanently or intermittently wet terrestrial areas (ie, freshwater wetlands) act as C sinks when their organic matter is stored under anaerobic conditions	Carbon density (t C ha-1) Carbon stock (ton)	Carbon stock estimates for unaltered freshwater wetlands extrapolated to national scale from 126 current wetland sites across New Zealand covering organic and mineral soil types across fen, bog, swamp, marsh, pakihi and ephemeral wetland types.	1348t C ha-1 for organic soils through full peat depth (3.9 m) 102t C ha-1 for organic soils through 0.3m depth 121t C ha-1 for mineral soils through 0.3m depth 11 ± 1 Mt in organic soil through 0.3m depth 144 ± 17 Mt in peat soil through full 3.9m depth 23 ± 1 Mt in mineral soils through 0.3 m depth Estimated 0.5 and 2 Mt CO_2 released per year from conversion of organic soils wetlands to agriculture since early European settlement	Ausseil et al (2015)	Not enough sites to consider spatial or soil profile effects (assumed C density constant along depth). Does not consider temporal changes in C or the impact of land use change on C.
Natural hazard regulation	Flood and drought resilience	Restoring the hydrological processes of drained or damaged wetlands provide a more cost-effective method of flood mitigation in floodplains		Modelling of flooding in the flood plain of the Manawatu River (i). Modelling of flood-prone areas in Bay of Plenty coincided with historic	Flood management in Manawatū requires natural capital investment alongside built flood protection capital (i).	i. van den Belt et al (2013) ii. Clarkson et al (2013)	Depends on location of the wetland is in the landscape and the type of wetland. Floodplain wetlands tend to reduce or

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
		than man-made engineering.		locations of wetlands (now drained) (ii). Economic benefits to restoring case studies: Whangamarino wetland, Torehape Bog (iii).	Whangamarino wetland: NZ$5.2 million avoided flood damage costs from a 1-in-100-year flood event in 1998 (ii). Economic values of damage avoided from restoration		delay flooding. Headwater wetlands may increase flood peaks. Location of wetlands influences the effectiveness of flood attenuation benefits from wetlands (van den Belt et al, 2013)
			Saturated hydraulic conductivity (Ks)	Bulk density, particle size measurements and soil organic carbon samples were used to estimate saturated hydraulic conductivity as an indicator of flood mitigation ability. Ks estimated using samples from a restored wetland and paired unrestored wetland. Paired sampling design	Average Ks of restored wetlands was 1.239 mm hr−1, whilst unrestored wetlands average Ks was 0.97 mm hr−1 Restoration increased a wetland soil's saturated hydrologic conductivity by 27.3% ± 11% See figure 7 of the paper.	Tomscha et al (2021)	Wairarapa All restored wetlands were fenced and planted with native and exotic species. Other interventions present dependent on wetland. Years since restoration range from 6 to 42 years.
Ethical and spiritual values /	Kaitiakitanga /Stewardship Community relationships	Reconnecting wetlands to the hydrologic processes of the landscape supports mana whenua	Appropriate metrics would have to be determined by the community	Case studies of wetland restoration undertaken by whanau, marae, hapu and iwi.	Some quantitative comparisons.	Taura et al (2017, 2021)	

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumption
Social connections		responsibility, as kaitiaki, to protect the whenua for future generations. Māori have a whakapapa connection with the whenua as such that damage to te taiao (natural environment) impacts their ability to undertake kaitiaki responsibilities. Repo have historical, cultural, and economical importance (eg, mahinga kai, wāhi tapu, repository of mātauranga) for Māori.					

Note on carbon sequestration and mitigation of GHG emissions: Peat soils in the North Island are estimated to lose 1 to 3.7 t C ha^{-1} $year^{-1}$ once drained (for conversion to other land uses) (Schipper and McLeod, 2002; Nieveen et al, 2005) depending on the length of time since drained and method of estimating the C loss. However, scaling those changes in C storage to areas of historic conversion across New Zealand, between 0.5 and 2 Mt CO_2 could be released per year from farmed organic soils (Ausseil et al, 2015). Restoration of these soils to their naturally wetted state could reduce or halt these loses, however, it may take decades before a drained peatland regains its function as a carbon sink after restoration (Ausseil et al, 2015; Price et al, 2003). Therefore, preservation of, in particular organic-soil (ie, peat soils), wetlands optimise carbon storage better than restoration of drained wetlands and construction of wetlands.

Table A2. 10. Evidence of relationship between constructed wetlands and environmental domains

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumptions
Habitat	Terrestrial indigenous biodiversity	Constructing a wetland can improve terrestrial biodiversity by providing additional habitat for fauna depending on species present, their characteristics; and management of the constructed wetland (eg, for treatment of stormwater runoff or effluent.	Proportion of species that are native Abundance of wetland species specialists Number of threatened indigenous species	Study sought to observe the flora and fauna present in five constructed wetlands adjacent to pastoral landscape in Waikato. Bird sound counts, invertebrate pitfall traps,	53% of terrestrial invertebrates were native 45% of birds were native 32% of plants were natives See figure 2, table 1 and table 2 of the paper for statistics.	Goeller et al (2023)	Mineral and organic soils. <0.5ha, drying classification assigned Fenced to exclude stock 3+ year prior to study.
			Metric depends on the target species being measured	19 international studies that measured the biodiversity benefits of constructed wetlands.	See table 1 of the paper for characteristics and main findings of studies (eg, taxa diversity, species richness) used in meta-analysis.	Zhang et al (2020)	Species richness is not an appropriate indicator for indigenous biodiversity as it is indiscriminate to indigenous and non-indigenous species.
	Freshwater indigenous biodiversity	Constructing a wetland is expected to improve this domain and aspect by providing new created wetland habitat for native freshwater biota to use	Net gain in target species or community	A study of five constructed wetlands in Waikato determined total species, proportion of native species, number of wetland specialists, or threatened species.	96% of freshwater biota identified were native species, no. of species identified increased with wetland size	Goeller et al (2023)	

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumptions
Water purification	Sediment, clarity	Constructing a wetland is expected to improve this domain and aspect by trapping sediment that enters the created wetland in runoff	Wetland and freshwater: Decrease in suspended sediment load	A systematic analysis of studies measuring changes in load with passage through constructed wetlands showed net sediment removal on average	Magnitude of sediment load reduction was related to size of wetland as percentage of contributing catchment area. For constructed wetlands intercepting runoff and a mixture of runoff and drainage waters the median SS removal was 88% with interquartile range of 83-89%. SS removal is not applicable for constructed wetlands intercepting (subsurface) drainage waters.	Woodward et al (2020) Tanner et al (2022)	This study is a review and systematic analysis of suitable NZ and international literature to derive transferable relationships.
	Nutrients, *E. coli*	Constructing a wetland is expected to improve this domain and aspect by biological processes in the wetland remove nutrients, ie, plant uptake, denitrification	Wetland and freshwater: Reductions in nitrate-N, ammoniacal-N, dissolved reactive-P, total-N, total-P, *E. coli* loads	A systematic analysis of studies measuring changes in load with passage through constructed wetlands showed net TN, nitrate, and TP removal on average	Magnitude of TN, nitrate and TP reduction was related to the size of size of wetland as percentage of contributing catchment area. For TN and nitrate removal it was also related to air temperature and TP removal also depends on soil clay content. For constructed wetlands intercepting runoff and a mixture of runoff and	Woodward et al (2020) Tanner et al (2022)	This study is a review and systematic analysis of suitable NZ and international literature to derive transferable relationships. Net exports of *E. coli* from constructed

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumptions
					drainage waters the median TN and TP removal (with interquartile ranges) were 22% (16-30%) and 41% (20-59%), respectively. For constructed wetlands intercepting (subsurface) drainage waters only the median TN and TP removal (with interquartile ranges) were 30% (22-38%) and –52% (-105 to 1%), respectively.		wetlands could be due to prolonged survival, probable multiplication, and subsequent entrainment of environmentally adapted strains of resident *E. coli* as evidenced at the Toenepi wetland, Waikato (Stott et al, 2023)
			Total nitrogen Total phosphorus	Meta-analysis of the efficacy of constructed (28) and restored (9) wetland studies to remove nitrogen and phosphorus. 93 studies from US, Europe, Turkey China, South Korea, Japan, and New Zealand.	Median load removal efficiency of TN is 36-39% Median load removal efficiency of TP is 50-55%	Land et al (2016)	Formally other land uses, now constructed wetland Median wetland age at the start/end of study periods was 1 year/3 years. TP leaching of restored wetland could be the result of short term washing of P from previously cropland.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumptions
Erosion control	Bank erosion	See references under Sediment, clarity					
Climate regulation	Carbon sequestration and mitigation of GHG emissions	Constructing a wetland is expected to improve this domain and aspect as a result of increased biomass of vegetation and soil organic matter				NA	See Table A2.9
Natural hazard regulation	Flood and drought resilience	Constructing a wetland is expected to improve by storing water thereby reducing downstream flood peaks and recharging underlying soil water and groundwater	Wetland: Water retention capacity Base permeability Ex-wetland: Net increase in underlying soil water Net increase in underlying groundwater Improvement in downstream flood frequency and intensity			NA	Effectiveness at catchment scale depends on their location, and individual and cumulative storage capacity (Griffiths et al, 2024) relative to the flows being received and current state of soil water and groundwater aquifers
Ethical and spiritual values / Social connections	Kaitiakitanga/ Stewardship Community relationships	Reconnecting wetlands to the hydrologic processes of the landscape supports mana whenua responsibility, as kaitiaki, to	Appropriate metrics would have to be determined by the community	Case studies of wetland restoration undertaken by whanau, marae, hapu and iwi.	6 m after construction: 106 shortfin eels counted. 3 years after construction: 205 shortfin eels counted.	Taura et al (2017, 2021)	Unclear whether additional information on restoration project is publicly available. No pre-

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumptions
		protect the whenua for future generations. Māori have a whakapapa connection with the whenua as such that damage to te taiao (natural environment) impacts their ability to undertake kaitiaki responsibilities. Repo have historical, cultural, and economical importance (eg, mahinga kai, wāhi tapu, repository of mātauranga) for Māori.			Kotare (kingfisher; Todiramphus sanctus), swans (Cygnus atratus), ducks (Anas spp.), smelt and bullies utilise constructed wetlands (3 yr post construction)		constructed numbers available for comparison. Wetland constructed examples were part of a wider river restoration project. Examples could be considered under wetland restoration or constructed wetlands.

Note on terrestrial biodiversity: The hydrologic processes of constructed wetlands differ from that of existing and restored wetlands. While wetlands may be constructed to replace existing wetlands for the purpose of supporting biodiversity, the primary purpose of most constructed wetlands is to purify nutrient-dense surface runoff usually from agricultural land-uses. These differences in purposes influence the type of flora and fauna that establish themselves in the landscape, either by design during the construction process or through natural recruitment. Not only do nutrified water bodies attract and support different communities of flora and fauna, but constructed wetlands are often dredged to maintain the desired water purification properties (ie, sediment and nutrient settling). As a result, constructed wetlands are often simplified versions of natural wetlands that do not provide the most optimal habitat for terrestrial biodiversity compared with habitat provided by natural and restored wetlands (Zhang et al, 2020).

Table A2.11. Evidence of relationship pest control, weed control and terrestrial biodiversity in wetland environments.

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumptions
Habitat	Terrestrial indigenous biodiversity	Controlling pests within the wetland landscape may support the survival of indigenous fauna. Control of one or a few predator and pest species can release others with unintended negative consequences. See Pest control.	Abundance and diversity of wetland bird species	List and threat classification of indigenous birds that characteristically feed, breed, or shelter in freshwater palustrine, riverine and lacustrine wetlands (table 1 of the paper). List of known predators of these birds (table 2 of the paper) and case studies (table 4 of the paper).	Qualitative, review of studies showing the impact of mammalian pests on various bird species. Vulnerability classification of wetland bird species.	O'Donnell et al (2015)	Assumes that reducing predator pressures would positively impact wetland bird species. Specific to wetland environments.
Habitat	Terrestrial indigenous biodiversity	Controlling weeds within the wetland landscapes may support the establishment and growth of indigenous flora	Canopy cover Light availability Growth of planted native seedlings	Kahikatea seedlings planted into an intact stand of grey willow and into areas where the herbicides glyphosate or triclopyr had been aerially applied to control willow ~1.5 years earlier. Compared to untreated sites.	Grey willow canopy cover was reduced to 44% ± 3.7% Light availability increased to 64% ± 15% Kahikatea grew an average of 44 cm ± 11.7 cm in 14 months No kahikatea in untreated sites.	Griffiths and McAlpine (2017)	
			Grey willow cover Canopy light interception Non-target damage Species richness	Before–after control–impact experiment over 7.1 ha prior to spraying and 2 years after glyphosate application	Willow canopy cover reduced to <5% on average Negative LT impact on *Dicksonia squarrosa* Increased species richness in treated plots	Burge et al (2017)	Whangamarino Wetland, Waikato Over 2 years

Domain/ ecosystem service	Aspect	Is there a relationship between the intervention and the domain?	What would be an appropriate indicator of the relationship?	What is the evidence of the relationship and how reliable is it?	What is the quantitative evidence of impact or effectiveness?	What key papers provide the quantitative evidence?	Notes / assumptions
					Shift towards a native *Carex*-dominated sedgeland community		
		Control of weed trees can stimulate light-demanding native podocarps otherwise excluded	Seedling growth rates	Testing methods to jumpstart revegetation of a willow-dominated wetland with native kahikatea (*Dacrycarpus dacrydioides)* podocarps. Annual measurements from 2015 to 2020 Planted saplings after full herbicide clearance, partial herbicide clearance and manual cutting of willow canopy.	Saplings grew best in partial cleared plots. Estimated 24-26 years to reach height of surrounding willows. See table 1 of the paper for average height per year by treatment. Figures 3-5 show graphical comparisons.	Sukias et al (2023)	'Once-only' treatment is unlikely to be successful. Whangamarino wetland, Waikato

Appendix 3 – Empirical representation of literature quality

Step 1: Code each study by country, landscape and relevance of study, type of study, rigor of study, impact found in study and certainty and generalisability using the definitions in table A3.1 and table A 3.2.

Step 2: Calculate the applicability weight ($Applicability_i$) for each study i using the following equation:

$$Applicability_i = \frac{\sum Country_i + Landscape_i + Relevance_i}{9}$$

Applicability indicators are of studies referenced in this report are averaged and reported in Table A3.3.

Step 3: Study quality scores can be calculated by individual indicator as defined in table A 3.2 or as a single summary value.

To calculate an individual indicator quality scores, for each study i multiply the raw indicator score by the applicability weight. Summarise by indicator as desired. Individual indicators of studies referenced in this report are averaged and reported in table A3.4

To calculate a single summary value, the raw quality indicators for types of study and rigour of study need to first be rescaled to a five-point scale before being averaged across all four raw quality indicators ($Quality_i$).

$$Quality_i = \frac{\frac{5}{4}(Study_i) + \frac{5}{4}(Generalise_i) + Rigour_i + Impact_i}{4}$$

The averaged raw score is then multiplied by the applicability weight to correct for misalignment with the scope of the project.

Aggregate the weighted individual or summary scores by domain, intervention and/or each domain-intervention intersection as desired.

Table A3.1. Gap analysis applicability indicator definitions and numerical representations

Numeric representation	Country of study	Landscape of study	Relevance of study
0	No data	No data	No data
1	International sites only	Non-riparian / non-terrestrial wetland sites	Study indirectly related to / measures intervention impact
2	International and New Zealand sites	Non-riparian / non-terrestrial wetland sites and riparian / terrestrial wetland sites	Study related to /measures intervention impact, but requires significant assumptions
3	New Zealand sites only	Riparian / terrestrial wetland sites	Study directly related to / measures intervention impact

Table A3.2. Gap analysis study quality indicator definitions and numerical representations

Numeric representation	Type of study	Rigor of study	Impact found in study	Certainty and generalisability
0	No data	No data	No data	No data
1	Qualitative, description, and/or no empirical analysis	Descriptive analysis	All negative outcomes for domain	High uncertainty in strength of findings and findings are not generalisable to other landscapes
2	Single site / time period quantitative study with empirical analysis	Single point in time (<1 year) with single statistical analysis	Mostly negative outcomes for domain	Relative certainty in strength of findings, but findings are most likely not generalisable to other landscapes
3	Multiple sites / time period quantitative study with empirical analysis	Study crosses multiple time periods (>1 year) and/or multiple locations with trend analysis	Some negative, some positive outcomes for domain	Certainty in strength of findings, but findings are context dependent to other landscapes
4	Meta-analysis or review with empirical analysis	Paired-reference-control experiment or predictive modelling	Mostly positive outcomes for domain	High consensus on strength and generalisability of findings to other landscapes
5	-	Before-after-control experimental design or meta-analysis	All positive outcomes for domain	-

Table A3.3. Average study applicability indicators

Ecosystem service (aspect)	Indicator	Stream fencing	Actively planted riparian areas	Passively regenerating riparian areas	Restored wetlands	Constructed wetlands	Remediation of fish passage barrier	Pest control	Terrestrial weed control	Ecological corridors
Water purification (Nutrients, *E. coli*)	New Zealand study	2.4	3.0	3.0	2.5	2.7	0.0		0.0	0.0
	Direct relationship	2.2	2.5	3.0	3.0	3.0	0.0		0.0	0.0
	Riparian environment	3.0	3.0	3.0	3.0	3.0	0.0		0.0	0.0
Water purification (Sediments, clarity)	New Zealand study	3.0	3.0	3.0	3.0	3.0	0.0		0.0	0.0
	Direct relationship	2.5	3.0	3.0	3.0	3.0	0.0		0.0	0.0
	Riparian environment	3.0	3.0	3.0	3.0	3.0	0.0		0.0	0.0
Erosion control (stream bank erosion)	New Zealand study	2.6	2.5	2.7			0.0		0.0	0.0
	Direct relationship	2.8	3.0	2.7			0.0		0.0	0.0
	Riparian environment	3.0	3.0	3.0			0.0		0.0	0.0
Habitat (Freshwater biodiversity)	New Zealand study	3.0	3.0	3.0	3.0	3.0	3.0	3.0	0.0	0.0
	Direct relationship	2.0	1.5	1.3	1.5	1.0	3.0	2.0	0.0	0.0
	Riparian environment	3.0	3.0	3.0	3.0	3.0	3.0	3.0	0.0	0.0
Habitat (Terrestrial biodiversity)	New Zealand study	2.3	3.0	2.0	3.0	2.3		3.0	2.8	3.0
	Direct relationship	0.8	1.3	0.7	2.3	1.0		1.0	2.0	1.0
	Riparian environment	0.8	1.3	0.7	3.0	3.0		1.3	1.9	1.0
Climate regulation (Carbon sequestration and GHG emissions mitigation)	New Zealand study		3.0	3.0	3.0	0.0			0.0	0.0
	Direct relationship		1.0	2.0	1.0	0.0			0.0	0.0
	Riparian environment		1.0	1.0	3.0	0.0			0.0	0.0

Ecosystem service (aspect)	Indicator	Stream fencing	Actively planted riparian areas	Passively regenerating riparian areas	Restored wetlands	Constructed wetlands	Remediation of fish passage barrier	Pest control	Terrestrial weed control	Ecological corridors
Natural hazard regulation (Flood and drought resilience)	New Zealand study		3.0	0.0	3.0	0.0	0.0		0.0	0.0
	Direct relationship		1.0	0.0	2.0	0.0	0.0		0.0	0.0
	Riparian environment		1.0	0.0	2.3	0.0	0.0		0.0	0.0
Ethical and spiritual values/ Social connection (Well-being, Kaitiakitanga)	New Zealand study		3.0		3.0	3.0	3.0	3.0	0.0	0.0
	Direct relationship		1.0		1.0	1.0	1.0	2.0	0.0	0.0
	Riparian environment		2.0		3.0	3.0	3.0	1.0	0.0	0.0

Table A3.4. Weighted average study attributes indicators

Ecosystem service (aspect)	Indicator	Stream fencing	Actively planted riparian areas	Passively regenerating riparian areas	Restored wetlands	Constructed wetlands	Remediation of fish passage barrier	Pest control	Terrestrial weed control	Ecological corridors
Water purification (Nutrients, *E. coli*)	Avg. type of study	1.9	1.9	3.0	2.8	3.2	0.0		0.0	0.0
	Avg. rigor of study	3.1	3.8	4.0	4.2	4.1	0.0		0.0	0.0
	Avg. impact found in study	3.5	4.3	4.0	3.8	4.5	0.0		0.0	0.0
	Avg. generalisability	2.4	2.8	4.0	3.3	3.5	0.0		0.0	0.0
Water purification (Sediments, clarity)	Avg. type of study	1.9	2.0	3.0	2.0	3.0	0.0		0.0	0.0
	Avg. rigor of study	3.8	5.0	4.0	4.0	4.0	0.0		0.0	0.0
	Avg. impact found in study	4.3	5.0	3.0	0.0	5.0	0.0		0.0	0.0
	Avg. generalisability	2.4	3.0	4.0	3.0	3.5	0.0		0.0	0.0
Erosion control (Stream bank erosion)	Avg. type of study	2.6	2.8	2.5			0.0		0.0	0.0
	Avg. rigor of study	2.5	2.4	2.5			0.0		0.0	0.0
	Avg. impact found in study	4.5	3.8	3.7			0.0		0.0	0.0
	Avg. generalisability	2.8	2.3	1.9			0.0		0.0	0.0
Habitat (Freshwater biodiversity)	Avg. type of study	1.8	1.7	1.6	2.1	1.6	3.2	1.8	0.0	0.0
	Avg. rigor of study	2.7	2.7	2.7	2.0	2.3	4.2	3.6	0.0	0.0
	Avg. impact found in study	3.6	3.9	3.8	3.3	2.3	3.8	0.0	0.0	0.0
	Avg. generalisability	2.7	2.5	2.4	2.1	0.8	3.1	0.9	0.0	0.0
Habitat (Terrestrial biodiversity)	Avg. type of study	1.1	1.6	0.9	2.1	1.9		1.5	1.5	1.4
	Avg. rigor of study	1.8	2.3	0.9	2.7	1.2		2.0	3.1	1.4
	Avg. impact found in study	1.7	2.4	1.3	3.3	2.6		2.2	2.6	1.9

Ecosystem service (aspect)	Indicator	Stream fencing	Actively planted riparian areas	Passively regenerating riparian areas	Restored wetlands	Constructed wetlands	Remediation of fish passage barrier	Pest control	Terrestrial weed control	Ecological corridors
	Avg. generalisability	1.3	1.8	1.0	2.7	1.3		1.6	2.0	1.4
Climate regulation (Carbon sequestration and GHG emissions mitigation)	Avg. type of study		1.7	2.0	1.8	0.0			0.0	0.0
	Avg. rigor of study		1.7	2.7	2.1	0.0			0.0	0.0
	Avg. impact found in study		2.2	2.7	3.9	0.0			0.0	0.0
	Avg. generalisability		1.5	2.0	2.2	0.0			0.0	0.0
Natural hazard regulation (Flood and drought resilience)	Avg. type of study		1.1	0.0	1.6	0.0	0.0		0.0	0.0
	Avg. rigor of study		2.2	0.0	3.0	0.0	0.0		0.0	0.0
	Avg. impact found in study		2.2	0.0	3.9	0.0	0.0		0.0	0.0
	Avg. generalisability		1.7	0.0	2.3	0.0	0.0		0.0	0.0
Ethical and spiritual values/ Social connection (Well-being, Kaitiakitanga)	Avg. type of study		1.3		2.3	2.3	0.8	1.3	0.0	0.0
	Avg. rigor of study		2.0		0.8	0.8	0.0	2.0	0.0	0.0
	Avg. impact found in study		2.7		0.0	0.0	0.0	3.3	0.0	0.0
	Avg. generalisability		2.0		1.6	1.6	0.0	1.3	0.0	0.0

Glossary

Te reo Māori

Ako/ākona: learn, study, teach, advise

Āheinga: competence, ability

Awa: river

Hāpaitia raukaha: strength/resilience

Hapori: society

Kahapupuri o Māori: Māori power

Kaitiaki: guardian, custodian, steward

Kaitiakitanga: guardianship, stewardship, trusteeship, trustee

Kākahi: freshwater mussel (Hyridella menziesi)

Karakia: to recite incantation, chant, prayer

Kaupapa Māori: Māori approach, customary practices, principles

Kawatau tukunga iho: expectations of the outcome

Kia kaha te ao Māori, te mātauranga Māori me tikanga Māori: to strengthen the Māori world, Māori education and Māori culture

Kōrero tuku iho: history, oral traditions, stories of the past

Kotahitanga: unity, collective acytion

Mahi tahi: to work together, teamwork

Ngātahi: together, simultaneously, in unision

Māoridom: the Māori world

Maramataka: almanac, calendar in reference to when to plant and fish

Mātanga: experienced, skilled, expert

Mātauranga Māori: Māori knowledge

Matawhānui Māori: broad vision of Māori

Moemoeā: dream, vision

Momo: type, category

Mōteatea: lament, chant

Ngā wawata Māori: Māori aspirations

Pakiwaitara: legend, story, narrative

Papatūānuku: Earth, Earth mother and wife of Rangi-nui

Pepeha: tribal saying, connection

Pūkenga Māori: Māori skills

Pūkenga: skilled, versed in, expertise

Pūrakau: story, narrative, legend

Pūrakau:, customary practices,

Rangatiratanga: right to exercise authority, ownership

Rongoā: treatment, solution, remedy

Taiao: nature

Taonga tuku iho: heirloom, cultural property, heritage

Tauparapara: incantation, chant

Tau utuutu: demonstrate benefit

Te Anga Pūkenga: the skills framework

te ao Māori: the Māori world view

Te kupenga o mātauranga Māori: the network of Māori knowledge

Te māramatanga: understanding

Te mātauranga: knowledge

Te mohiotanga: comprehension

Te puāwaitanga o te taiao: flourishing of nature

Te Pūnaha Hihiko: the dynamic system

Te whakapiki i te Tūhonongatanga: increasing connectivity

Tino rangatiratanga: self-determination, sovereignty, self-governance

Tūhononga te hapori: connect the community

Tūhononga te tangata: connect people

Tūhononga: connection

Tūhonongatanga i te taiao: connection in nature

Tuna: eel, eg, long-fin eel (Anguilla dieffenbachia)

Turangawaewae: place where one has rights of residence and belonging through kinship and whakapapa

Uara: desire, value

Wahakatauākī: proverb

Wāhi tapu: sacred sites

Waiata: song, chant, psalm

Waihanga te whakamana: empowerment

Whaiora te whānau ora/hapori ora: healthy community

Whakapapa: genealogy, history

Whakataukī: proverb – anonymous

Whakawhanake Māori: Māori development

Whanaungatanga: relationship, kinship, relationship through shared experiences

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