Steering our waka through turbid waters

Research priorities over the next 5 years for sediments in the coastal marine area of Aotearoa New Zealand

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Good science, good decisions

Cover: Sediment plumes north of Oamaru. *Photo: © Kim Westerskov*.

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Contents

Executive summary

This report has been prepared for the Department of Conservation (DOC) to identify research priorities in the coastal marine area (CMA) of Aotearoa New Zealand over the next 5 years.

The research priorities were informed by consideration of supporting information (including values relating to the CMA; the adverse ecological effects of sediments; the degree to which Aotearoa New Zealand's CMA is currently stressed by sediments; legislation; management approaches; mātauranga Māori; management needs and opportunities; and current research of relevance to the CMA of Aotearoa New Zealand) combined with consultation with a range of stakeholder groups (Crown Research Institutes, universities, central government management agencies, regional councils and unitary authorities, non-governmental organisations, and private businesses and individuals).

The research priorities are intended to support management under the Resource Management Act 1991 of the effects of sediments on ecosystems in the CMA and on the associated human uses and values derived from those ecosystems.

The outcome sought is healthy, diverse, productive and resilient coastal ecosystems that support life and sustainably provide for the diverse needs of people and communities, both today and in the future.

The recommendations are for actions that are likely to have the greatest impact over the next 5 years. It should be noted that important research that is already underway is not repeated here, but rather the recommendations reflect opportunities identified and gaps remaining to be filled. In no particular order, the highest priority research areas are:

- **Motivating people:** This includes gaining a better understanding of why no apparent progress is being made despite the range of information and tools that are already available, and developing ways to understand and change people's behaviours, including through the use of incentives.
- **Understanding the minimum environmental conditions for success:** The minimum necessary environmental conditions for successful restoration should be determined, and mātauranga Māori (traditional knowledge) should be applied to restore and enhance sediment-impacted habitats.
- **Developing iwi-based indicators:** Quantitative and qualitative iwi-based indicators should be developed that measure the abundance of taonga (treasured) species and the mauri (life force) of coastal ecosystems.
- **Identifying the sources of sediment:** Tools for sediment source attribution at the scale of individual activities and land parcels should be developed.
- **Supporting limits-based management:** Stressor–response relationships, thresholds, cumulative effects and stressor interactions that are specific to National Policy Statement for Freshwater Management (NPSFM) limit-setting processes should be investigated to ensure they will also deliver objectives in the CMA. Simple methods for calculating sediment load limits while accounting for legacy effects and methods for translating sediment load limits into plan rules need to be developed. This work will need to be supported by improved sediment-load models and simple quantitative methods, including sediment budgets, for estimating sediment dispersal, deposition and retention in the CMA.

- **Developing physical–ecological–economic models:** Integrated physical–ecological–economic catchment-scale models should be developed based on new ecological knowledge and new methods for cost–benefit analyses that also incorporate non-market valuations of ecosystem goods and services.

Mātauranga Māori and kaupapa Māori principles can be applied to all of these research themes and tasks.

Climate change is viewed as a cross-cutting theme in the sense that much of our current understanding of sediment impacts is likely to be contingent on the climate.

Ki uta ki tai (source-to-sea) thinking represents an ideal – even essential – paradigm for developing the kind of long-term research that is needed to support the management of sediments in the CMA.

It is important that the respective research communities working on ecosystem-based management and limits work together and understand policy and management needs.

Research goals should be reviewed and redirected as appropriate every 3–5 years as more knowledge is gained.

He Whakarāpopoto

Kua whakaritea tēnei pūrongo mō Te Papa Atawhai (DOC) hei tautuhi i ngā rangahau matua i te wāhi o te takutai moana (CMA) o Aotearoa mō ngā tau e 5 kei mua nei.

He mea whakamōhio ngā rangahau matua nā te whiriwhiri i ngā pārongo tautoko (ina rā, ngā uara e pā ana ki te CMA; te pānga kino o te parakiwai ki te pūnaha hauropi; te rahi o te pēhitanga o te CMA o Aotearoa e te parakiwai; te whakature; ngā tikanga whakahaere; te Mātauranga Māori; ngā hiahia me ngā whaiwāhitanga o te whakahaere; me te rangahau o te wā e hāngai ana ki te CMA o Aotearoa). Āpiti atu ko te torotoro whakaaro ki ngā tū rōpū whaipānga (ngā Whare Rangahau o te Karauna, ngā whare wānanga, ngā umanga whakahaere kāwanatanga pokapū, ngā kaunihera ā-rohe me ngā kaunihera matua, ngā rōpū kei waho o te kāwanatanga, ngā pakihi tūmataiti me ngā tāngata takitahi).

Ko te take o ngā rangahau matua i raro i te Ture Whakahaere Rawa 1991 he tautoko i te whakahaere o te pānga o te parakiwai ki ngā pūnaha hauropi i roto i te CMA me te whakamahinga a te tangata me ngā uara ka takea mai i aua pūnaha hauropi.

Ko te whakaputanga kia kitea he hauora, he kanorau, he makuru, ā, he takutai pūnaha hauropi pakari e tautoko ana i te koiora me te whāngai noa i te rau hiahia o te tangata me ngā hapori o te nāianei me te āpōpō.

He taunakitanga ēnei mō ngā mahi e whakapaetia ana he nui rawa te pānga i ngā tau e 5 e haere ake nei. Kia kīia i konei ko ngā rangahau hira kua tīmata kē kāore e tāruatia i konei, engari kia kitea he traumatising e āta tautuhi whaiwāhitanga ana me ngā āputa e tāria ana kia whakakīia. Kāore hoki i whakaraupapatia, heoi anō koia ēnei ko ngā rangahau matua taioreore:

- **Te whakamanawa i te tangata:** Kei konei me whakapai ake te māramatanga ki te take kāore noa he koke whakamua ahakoa te nui o ngā momo pārongo me ngā rauemi e wātea ana; me whakawhanake ngā ara kia mārama, kia panoni hoki i te whanonga o te tangata, tae atu ki te whakatairanga kia tahuri mai te tangata.
- **Te whai māramatanga ki te mōkito o ngā āhuatanga taiao mō te angitu:** me whakatau ngā āhuatanga taiao mōkito e hiahiatia ana kia angitu te whakarauora mauri, ā, me whakamahi ko te mātauranga Māori hei whakarauora, hei whakahoki i te mauri ki ngā nōhanga kua pāngia e te kino o te parakiwai.
- **Te whakawhanake paetohu ā-iwi:** me whakawhanake paetohu ā-iwi mō te tatau me te kounga e ine ana i te nui o ngā momo me te mauri o ngā pūnaha hauropi takutai.
- **Te tautuhi i ngā pūtake o te parakiwai:** me whakarite he tikanga e tohu ana i te pūtake o te parakiwai mō ngā mahi takitahi me ngā rohe whenua hoki.
- **Te tautoko i te whakahaere ā-tepenga:** te urupare ki te kaipatu, ngā tauārai, te huihuinga o ngā pānga, te hua o te taupāpā kaipatu e hāngai ana ki te Tauākī Kaupapa Here ā-Motu mō te Whakahaere Wai Māori (NPSFM), kia whakatewhatewhatia ngā whakahaere ā-tepenga kia kitea e tutuki ana ngā whāinga i te CMA. Kia whakaritea he hātepe ngāwari hei tatau i te rahi o te parakiwai tae noa ki te rahi o te pānga o mua me te whakarite hātepe hei whakamārama i te rahi o te parakiwai kia oti ai he mahere ture. Mā roto mai o te CMA kia tautokona tēnei mahi e ngā tauira parakiwai kua whakahoutia me ngā hātepe tatau, me ngā tahua parakiwai hoki, hei tatau i te nekeneke o te parakiwai, e tau ana ki runga i te papa moana me te noho tonu.

- **Te hanga tauira e whakaatu ana i ngā take, ā-ōkiko, ā-hauropi me te ohaoha:** me hanga he tauira pāhekoheko (ōkiko-hauropi-ohaoha mai), arā he tauira kōputunga wai ki ngā mātauranga hauropi hou me ngā hātepe hou mō te tātaringa utu whaihua, ā, tae atu hoki ki ngā wāriu mākete-kore o te tāke hokohoko hauropi.

Ko te Mātauranga Māori me ngā mātāpono kaupapa Māori ka whakamahia ki ēnei tāhū rangahau katoa me ngā mahi.

Kei te mātua tirohia te panonitanga āhuarangi hei take pāhekoheko ina rā ko te nuinga o tā tātou māramatanga ki ngā pānga parakiwai kei te āhua tonu o te āhuarangi.

Ko te whakaaro nei 'Ki uta ki tai (source-to-sea)' he whakaaro tiketike tonu – he tauira hei whakawhanake i te rangahau pae tawhiti e hiahiatia ana ki te tautoko i te whakahaerenga o ngā parakiwai i roto i te CMA.

He mea nui kia mahi tahi ngā hapori rangahau e mahi ana i te whakahaere hauropi me te whai māramatanga hoki ki ngā hiahia kaupapa here me te whakahaere.

Me arotake, me whakahāngai anō i ngā whāinga rangahau ia 3-5 ngā tau ka piki haere te mōhiotanga.

1. Introduction

There is a golden opportunity here to get on top of sediments in the CMA.[1]

It has been known for decades that sediment runoff from the land is a major cause of damage to coastal ecosystems, which has flow-on effects for the human uses and values that are derived from these ecosystems. In Aotearoa New Zealand, this problem is exacerbated by intense rainfall, fragile soils, steep terrains, short rivers and streams, and, most importantly, the fact that the landscape is spectacularly bare of native forest, which otherwise would be the single best protection against soil erosion and mass wasting.

The root cause of the degradation is too much sediment of the wrong type entering the coastal marine area (CMA). The simple solution is to reduce sediment runoff. However, in reality there are numerous obstacles to this, many of which come down to limited resources. Therefore, it is important to determine how efforts to reduce sediment runoff can be targeted to make the most effective use of the available resources, and to identify those places that have such a legacy of degradation that no amount of money spent would give a result.

Humans use natural and physical resources to survive and flourish, so the landscape can never be returned to a pristine state where all the land is blanketed by native vegetation. Land managers need to assess how far they can turn the clock back to ensure that Aotearoa New Zealand's natural ecosystems are protected and rehabilitated while still allowing nature's resources to be used to make a decent living. Other important questions include who gets to decide the balance, who should speak for future generations, and who will pay?

Any work that is undertaken needs to fit within the resource management framework prescribed by the Resource Management Act 1991 (the RMA) and must consider the principles of Te Tiriti o Waitangi (the Treaty of Waitangi). Land managers need to decide when an adverse effect is significant, when an assessment of environmental effects (AEE) is fit for purpose, and how compliance should be monitored.

The amendments to the National Policy Statement for Freshwater Management (NPSFM) in 2014 caused a shift in planning and decision-making in Aotearoa New Zealand. The NPSFM mandates a limits-based approach to freshwater management, which requires true multi-disciplinary, integrated, ki uta ki tai (source-to-sea) thinking.[2] The CMA is mentioned in the NPSFM, and regional councils are running collaborative NPSFM planning processes that attempt to explicitly integrate catchments with their respective adjacent CMAs. However, this transformation in management has also raised a host of new questions. For instance, how are aspirations for the CMA constrained by what is possible to achieve in freshwater environments, how can sediment load limits be set, how can objectives account for spatial and temporal variability in the CMA, and what are the thresholds or tipping points that must be avoided?

[1] Quotes that were gathered during consultation are presented throughout this report to give an idea of the varied opinions across the range of stakeholders surveyed.

[2] https://environment.govt.nz/acts-and-regulations/national-policy-statements/national-policy-statement-freshwater-management/history-of-the-national-policy-statement-for-freshwater-management/

This report is intended to start a conversation about the types of research needed to bring about change in the CMA. The research will enable better decisions to be made, better policies and rules to be written, more informed personal choices to be made, people's behaviours to be changed, better technology to be available for use, and more strategic and collaborative work to happen.

Research needs to be co-developed and co-implemented, which starts with formulating research questions jointly with iwi and hapū.

The outputs from the proposed research areas will be of value to a broad range of people in many different roles. For example, methods for sediment source tracking to target mitigation may be used by resource managers; standardised, cheap tools for measuring turbidity to contribute to State of the Environment (SOE) monitoring may be used by communities; and tools that change the way people behave or view the world may be used *on* people. Obtaining new knowledge will also be important – for instance, what are the pre-conditions to successful restoration, what level of sedimentation can a shellfish bed sustain, and what does 'natural' look like and how far are we from it?

1.1 Objective

The Department of Conservation (DOC) received funding from Budget 2018 to research a key threat to marine habitats that can be managed under the RMA. In a recent report on anthropogenic threats to Aotearoa New Zealand's marine habitats, MacDiarmid *et al*. (2012) ranked increased sediment loading through river inputs as third equal with bottom trawling in terms of its effects, and marine sedimentation as the most important marine pressure that could be mitigated under the RMA (e.g. through the management of land-derived sediments and marine-based activities under regional policies, plans and consents). Therefore, this topic was chosen for this project.

We know what we need to do – why haven't we done it?

When considering the adverse effects of sediments in the CMA, local authorities must give effect to Policy 22 of the New Zealand Coastal Policy Statement 2010 (NZCPS) (DOC 2010) by:

- Assessing and monitoring sedimentation levels and impacts on the coastal environment.
- Requiring that subdivision, use or development will not result in a significant increase in sedimentation in the CMA or other coastal water.
- Controlling the impacts of vegetation removal on sedimentation, including the impacts of harvesting plantation forestry.
- Reducing sediment loadings in runoff and in stormwater systems through controls on land-use activities.

Under the Conservation Act 1987, DOC advocates for conservation values and supports the Minister of Conservation with coastal management functions. In 2018, DOC produced NZCPS guidance for sediments[3] and also wrote a report to the Minister of Conservation summarising its review of the

[3] www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/policy-statement-and-guidance/

effects of the NZCPS on RMA decision-making, in which sediment was highlighted as a particular issue of ongoing concern (DOC 2017).

Before DOC can improve the effectiveness of its advocacy for the reduction of adverse effects of sediments in the CMA and its support of regional councils in addressing these effects, it is important that the key management information needs and gaps and any further research that is needed to address these are identified.

I've really struggled with the disconnect (perceived or actual) between science and what we are or aren't doing on the ground. The ultimate would be to have science that informs operations … it's delivered and then change monitored. Simple eh LOL.

In response, the objective of this report is to identify and prioritise the research required to fill gaps in knowledge and to develop the tools needed to inform and support actions that can be taken by a wide range of stakeholders to variously reduce, mitigate and control the effects of sediments on marine, coastal and estuarine ecosystems.

1.2 Desired outcome

The outcome being sought is healthy, diverse, productive and resilient coastal ecosystems that sustain life and sustainably provide for the diverse needs of people and communities, both today and in the future.

1.3 Scope of this report

This report identifies research priorities over the next 5 years but also signals research directions beyond that. The recommendations incorporate mātauranga Māori (traditional knowledge), Western science and citizen science.

The report focuses on sediment effects in the CMA from 12 nautical miles offshore (the limit of applicability of the RMA[4]) to the landward influence of salt water. For the purposes of this report, the term 'effects' includes effects due to catchment sediments and effects due to disturbance of native marine sediments (e.g. by seabed mining or dredging). These effects are not confined to effects on ecology but also include effects on human uses and values.

1.4 Report structure

The recommendations for priority research over the next 5 years made in this report were developed through a combination of desktop research, which provided supporting information, and targeted consultation.

- Section 2 of this report provides the supporting information.
- Section 3 describes the targeted consultation.
- Section 4 presents the recommendations for research.

[4] Note that the RMA is currently being reformed (see https://environment.govt.nz/what-government-is-doing/areas-of-work/rma/resource-management-system-reform/). However, the content of this report remains relevant.

2. Supporting information

The recommendations presented in this report were informed by consideration of values relating to the coastal marine area (CMA); the adverse ecological effects of sediments in the CMA; the degree to which Aotearoa New Zealand's CMA is currently stressed by sediments; legislation relevant to the CMA; different management approaches (limits-based vs. ecosystem-based); mātauranga Māori; management needs and opportunities; and current research of relevance to the CMA of Aotearoa New Zealand.

This body of supporting information, which provides a foundation for the recommendations, is presented in this section.

2.1 Values relating to the CMA

The CMA, which extends from the landward limit of salt water into deeper water beyond the surf zone, provides numerous values.[5] Sinner *et al*. (2014) defined values as 'things that matter', while Denne *et al*. (2013) defined non-market values as 'those that are not usually expressed in monetary terms or associated with commercial activities … They include recreational uses, scenic qualities, food gathering and the values that people place on natural environments just because they exist'. Non-market values exclude extractive use values but include *in situ* values (fishing, recreational use), option values and passive use values. Among these, passive use values are independent of the present use of the resource, pertaining more to the mere existence of the resource, and include existence values (knowing that particular environmental assets exist – e.g. endangered species) and bequest values (the desire to bequeath resources – e.g. habitat preservation).

To gain an idea of the kinds of values humans derive from the CMA, Rebecca Jarvis, at the Auckland University of Technology (AUT), asked members of the public to mark the places that are important to them on an interactive map of the Hauraki Gulf to inform development of the Sea Change – Tai Timu Tai Pari Hauraki Gulf Marine Spatial Plan.[6] This resulted in 14 values being reported: recreation or leisure (21% of 'value points'), scenery (20%), conservation (9%), native species (9%), wilderness (6%), tourism (6%), community (6%), historical (6%), identity (5%), home (3%), cultural (3%), research (2%), employment (2%) and spiritual (1%).

2.1.1 Māori cultural values

Denne *et al*. (2013) noted that 'Māori have some additional and distinct values as recognised under the Treaty of Waitangi' and that there 'is a legal requirement to address these values in decision-making under the Resource Management Act, the Local Government Act and the Conservation Act'. Dean Whaanga (Ngāi Tahu) further noted that 'the RMA recognises and provides for, as a matter of national importance, the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, wāhi tapu, and other taonga' and 'some of the statutory recognised values include (but are not limited to): wāhi taonga, mahinga kai, nohoanga, customary fisheries, taonga

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[5] Ecosystem goods and services is an alternative, or complementary, paradigm. Ecosystems are generally considered to provide services in four different categories: supporting, provisioning, regulating and cultural (Roberts *et al*. 2015). Examples for the CMA include nutrient cycling and waste purification (supporting); food, pharmaceutical precursors and navigation (provisioning); climate regulation and carbon sequestration (regulating); and manaakitanga (caring for each other) and recreational activities (cultural). Closely aligned with this is the concept of natural capital, which can be defined as the stock of renewable and non-renewable resources from which ecosystem goods and services flow (Costanza *et al*. 1997).

[6] www.seachange.org.nz/the-voices-of-the-gulf/surveys/#Haurakisurvey

species management, dual place names, mana whenua, tangata whenua, kaitiakitanga and the role of tangata whenua as kaitiaki, customary fisheries management tools, Treaty of Waitangi principles, customary management' (Wedderburn 2015).

Māori cultural values derive from both physical and spiritual aspects of the marine environment. They are viewed as 'taonga tuku iho' (treasures that are passed down from generation to generation) and require protection and enhancement, the responsibility for which resides with kaitiaki (guardians).

Understanding, protecting, enhancing and regenerating cultural values and taonga are of the utmost importance to iwi/hapū (tribes/sub-tribes), and the success of any management interventions will be measured by how well cultural values are enhanced. Iwi/hapū cultural values, whakapapa (genealogy) and kōrero (stories) associated with whakapapa connections need to be acknowledged.

Cultural values will vary from hapū to hapū and rohe to rohe (place to place). Iwi/hapū have the right, and should be given the opportunity, to identify and share the cultural values associated with their respective rohe. Hence, an important first step in any research or management initiative is the gathering and sharing of cultural values. Based on previous experience in working with mana whenua (Māori who have power over the land and/or an ancestral connection to the land), cultural values associated with the coastal environment may include (but should not be limited to) healthy and abundant kaimoana (seafood) species; swimmable, clear and unpolluted coastal waters; te reo Māori place names and celebrating the stories behind those names; empowering kaitiaki; and enhancing mauri (life force).

2.2 Adverse ecological effects of sediments in the CMA

Catchment deforestation and land-use intensification have increased sediment runoff from the land and associated sedimentation in the CMA by one to two orders of magnitude in many parts of the world (Thrush *et al*. 2004). It is known that sediments (particularly fine sediments) exert widespread, critical and diverse adverse effects on marine, coastal and estuarine ecosystems, which represent a major threat to marine biodiversity and ecosystem functioning worldwide (Thrush *et al*. 2004; Syvitski *et al*. 2005; Crain *et al*. 2008; Doney 2010). For instance, sediments smother shellfish beds, seagrass meadows and reefs; reduce light penetration, which degrades seagrass and reduces phytoplankton primary productivity, with knock-on effects up the food chain; cloud the water, making it harder for native bird and fish visual predators to hunt; directly damage shellfish and fish by clogging and abrading their gills; hinder the settling and establishment of juvenile shellfish; and muddy the seabed, reducing oxygenation and accelerating nutrient release into the water column, which can cause chronic and dangerous algal blooms and make the environment less habitable for many animals.

Sediments are now having major impacts on rocky reef systems, and there is a huge load to come from increased dropping of coastal radiata pine forests, such as in the Bay of Plenty, which will annihilate some nearshore reef systems.

Sediments progressively accumulate in the CMA, which has resulted in most of Aotearoa New Zealand's estuaries currently being at an advanced stage of infilling. As infilling has progressed, some habitat has been lost but other habitat has also been formed. For example, spread of the mangrove *Avicennia marina* in the upper North Island has been linked to increased estuarine sedimentation causing the expansion of intertidal flats. This, in turn, creates habitat that is suitable for mangrove colonisation, resulting in the loss of unvegetated sandy intertidal habitats and, ultimately, open water.

Adverse ecological effects also adversely affect the associated human uses and values[7] derived from those ecosystems. Historic observations can provide a description of baseline conditions that restoration and regeneration programmes can work towards to enhance and protect Māori values. For example, while collecting mātauranga ki te moana to describe the historic state of the environment in Tauranga Moana (Tauranga Harbour), researchers observed changes from sandy substrates to more mud-dominated substrates within the lifetime of many kaumatua, illustrating the rapid rate at which sediment accumulation has occurred (Taiapa *et al*. 2014a and references therein).

Tangata whenua (the iwi/hapū that hold mana whenua over an area) have identified sediment smothering as having devastating effects on mahinga kai (food-gathering places), biodiversity and ecological habitats within Te Awanui (Tauranga Harbour) (Ellis *et al*. 2008), and are particularly concerned about the effect of sedimentation on kaimoana and seagrass beds (Waitangi Tribunal 2010). Increased turbidity as a result of suspended sediments can limit light penetration and therefore impede the growth of plants such as seagrass (Dos Santos 2011). An increase in suspended sediments can also clog the gills of filter feeders such as tuangi (New Zealand cockles), mussels and pipi, which can retard growth and lead to shellfish loss (Teaioro 1999). Tangata whenua also relate sedimentation to the decline in mud crab populations, as the people of Te Tāhuna o Rangataua have noted the pāpaka (paddle crabs) that were once present in large concentrations on the mudflats of the bay have almost completely disappeared (Waitangi Tribunal 2010).

Over the long term, sediments present a real difficulty as, unlike nitrogen, which can be buried in the bed sediments or denitrified and returned to the atmosphere, or microbes, which die, sediments do not change form or become inactivated. Consequently, sedimentation effects can be very long-lived with a legacy that can span generations.

2.2.1 Acute versus chronic effects

Ecological effects can be divided into acute and chronic categories:

- **Acute effects** occur rapidly and are often severe – for example, the smothering of shellfish beds by sediment washed down from the catchment by heavy rain, which can result in widespread death of shellfish within days of sediment deposition.
- **Chronic effects** occur slowly over longer timescales but can still be severe in the long term – for example, the slow muddying of a seabed, which fundamentally reduces its capacity to support life. From a utility perspective, the shoaling of channels can hinder navigation, necessitating dredging, and sediments can block drainage, causing flooding.

This dichotomy is useful, as management responses to the two different types of effects may differ significantly.

2.2.2 Importance of sediment size

Fine sediments (approximately fine silt and smaller) cause more damage than coarse sediments for a number of reasons. Firstly, fine sediments are more effective per unit mass of sediment than coarse sediments in attenuating light in the water column, which adversely affects primary producers. Fine sediments also cause a greater reduction in seabed permeability than coarse sediments, which affects gas and solute transport across the sediment–water interface and within the seabed, in turn

[7] Or, in the complementary paradigm, ecosystem goods and services.

affecting a range of biogeochemical seabed processes and the suitability of the seabed as habitat for a variety of animals. Finally, fine sediments are more readily ingested than coarse sediments, which can harm animals.

2.2.3 Suspension feeders and deposit feeders

Suspension feeders (e.g. mussels, pipi) are most likely to be directly affected by an increased suspended-sediment concentration – excessive sediment particles in the water can clog their filter-feeding structures, interfering with their food collection and potentially affecting their growth and condition. In addition, many deposit feeders and grazers (e.g. kina) may be indirectly affected by increased turbidity as a result of increased suspended-sediment concentration reducing the ability of the microphytobenthos on which they feed to photosynthesise and grow, potentially causing food limitation.

2.2.4 Effects on ecosystem functioning

A growing body of work has shown that sediments have multiple effects on ecosystem functioning, such as nitrogen cycling and fluxes between the seabed and the water column (e.g. Tay *et al*. 2013; Pratt *et al*. 2014). Much of the research to date has focused on the effects of fine sediments on soft-sediment habitats in estuaries, with fewer studies on rocky reefs and algae-dominated communities and very little research on threatened species in these environments (e.g. seabirds). However, it is clear that hard substrates are at least equally adversely affected by sediments. For instance, fine sediments influence the composition, structure and dynamics of rocky coast assemblages, and can affect the attachment and survival of algal species on intertidal reefs. The effects of fine sediments on rocky reefs can be spatially dependent and related to gradients in suspended sediments and light availability (Blain *et al*. 2019; Tait 2019).

2.2.5 Tipping points

Thrush *et al*. (2004) raised the spectre of tipping points in marine ecosystem responses to sediments and commented on the difficulties associated with trying to predict the long-term trajectory of stressed ecosystems, noting that 'the potential for ecosystems undergoing radical shifts in structure and function is not fully understood, and there could be critical thresholds beyond which recovery to some previous valued state is unlikely'. Recent studies have reported changes in the structure and function of communities and ecosystems as a result of anthropogenic impacts, including sediment (Hewitt and Thrush 2019). Work on ecosystem interaction networks (Thrush *et al*. 2014) has advanced our understand beyond simple cause-and-effect frameworks and shed more light on the concept of tipping points.

2.2.6 Catchment sediments versus disturbance of native marine sediments

Resuspension of previously deposited sediment is the gift that keeps on giving.

The disturbance of native marine sediments by activities such as seabed dredging, spoil dumping and bottom trawling can result in fine sediments being released into the water column, which can have adverse effects on the ecosystem. However, the discharge of catchment sediments at the coast in runoff is currently considered a greater cause for concern, particularly at large spatial scales. There are three main reasons for this: (1) catchment sediments that make their way into the CMA tend to be finer than native marine sediments; (2) catchment sediments are typically geochemically distinct from native marine sediments, and (3) catchment sediment runoff today is typically greatly elevated relative to pre-human occupation.

The last reason is probably the most significant. For example, Green and Daigneault (2018) reported that, when the Kaipara Harbour catchment was fully forested, prior to human occupation, the annual-average catchment sediment load to the harbour was around 100,000 tonnes per year. Today, under a largely deforested catchment and with massive loss of natural wetlands which otherwise would act as sediment traps, it is around seven times higher than that. Much of that sediment deposits inside the harbour, giving annual sedimentation rates up to 10 times greater than what is believed to be the 'natural' sedimentation rate. Similarly, a study undertaken in Marlborough's Pelorus Sound / Te Hoiere illustrated the profound changes in sedimentation rates that have occurred since European settlement (Handley *et al*. 2017). Sediment accumulation rates increased from 0.2–1.2 mm/year prior to European settlement to 1.8–4.6 mm/year after colonisation. This increase was predominately due to forest clearance in the 19th and early 20th centuries, followed by sheep farming with the regular burning of scrub through the middle years of the 20th century, the regeneration of native forest over the last 30–40 years, and an increase in pine planting from the turn of the 20th century to today. Associated with these changes in sedimentation rate are significant ecosystem effects, which have contributed to a decline in benthic biodiversity (Handley *et al*. 2017).

2.2.7 Relevance of climate change

Coastal marine ecosystems face further threats associated with climate change, particularly as a result of increasing air and water temperatures, decreasing ocean pH and nutrient concentrations, alterations to current, rain and wind patterns, and sea-level rise. These changes will affect habitats and the flora and fauna within them, with intertidal habitats (both soft- and hard-bottom), kelp forests and subtidal rocky reefs being most sensitive to changing conditions. Marine shellfish are highly sensitive to a decreasing pH, an increasing frequency of extreme rainfall events and increasing water temperatures. Effects at lower trophic levels will have knock-on effects at higher levels, including top predators.

We should be tapping into personally held knowledge and observations to better understand climate change.

Local actions, such as reducing anthropogenic stressors and disturbance, can increase the health of ecosystems, increasing their resilience and adaptive capacity in the face of climate change.

2.2.8 Remediation and mitigation

Once sediment has accumulated in the CMA, there are very few realistic options for remediation. It is typically not practical to remove problematic sediment by dredging, and every attempt to reseed shellfish populations on seabeds that have become muddy has failed to date. Therefore, mitigation is usually the most effective action.

When action is applied, it is often done in the 'easy' areas and avoids hard topics like private land (farmers) and forestry.

Broadly speaking, mitigation aims to reduce sediments at the source by minimising sediment erosion on the land and/or intercepting sediment runoff from the land before it reaches the CMA. This will lessen acute effects, slow the rate of chronic degradation, and give the system room to breathe and cleanse itself of the sediments to the maximum extent possible. However, actions to reduce sediment loss from the land will typically take several decades to become fully effective, and the response of the CMA is likely to lag behind the implementation of those actions by some considerable time. Hence, significant change will likely occur over generations.

Reducing catchment sediment runoff is necessary to protect and rehabilitate marine, coastal and estuarine ecosystems and will also bring co-benefits. For example, lowland vegetated wetlands will sequester nutrients as well as sediments, and retiring pastoral land and returning it to forest will help reduce agricultural sources of contaminants. Reducing sediment runoff will lessen the compounding effects of multiple contaminant stressors and improve resilience to other stressors, including invasive species, overfishing and future climate change.

2.2.9 Sediment metrics

Many possible sediment metrics exist, including the suspended-sediment concentration, visual clarity and turbidity. However, the sedimentation rate is particularly useful as it is indicative of the broad spectrum of adverse sediment effects – i.e. where the sedimentation rate is high (relative to the 'natural' rate under native forested catchment), adverse sediment effects are expected, and *vice versa*. Many studies in Aotearoa New Zealand have linked increased catchment sediment loads (e.g. under deforestation) with increased sedimentation rates (e.g. Sheffield *et al*. 1995; Goff 1997; Swales *et al*. 2002).

Another key metric is seabed muddiness,[8] which has a profound effect on the types of animals and plants that are able to live and thrive within and on the bed sediment. This is at least partly due to the fact that the mud content of the seabed affects its permeability: the muddier the seabed, the lower the concentration of dissolved oxygen in the porewater and the less suitable it is for a range of shellfish and other invertebrates, as well as seagrass growing on intertidal flats. A less muddy seabed also tends to be associated with clearer water. Consequently, Robertson *et al*. (2016) noted that 'it is obvious that extensive areas of soft mud will cause ecological damage' and proposed that 'if >15% of an estuary's area is soft mud, then a high impact threshold has been breached'.

Cawthron Institute, the National Institute of Water and Atmospheric Research (NIWA) and the University of Waikato have recently developed a National Mud Benthic Health Model (BHM) to detect sediment effects on estuarine benthic communities (Clark *et al*. 2020). This model builds on the Mud BHM (Hewitt & Carter 2020) that has been used by Auckland Council to monitor sediment effects in their estuaries since 2002 but could only be applied within the Auckland region. The new National Mud BHM was developed using data collected by councils across Aotearoa New Zealand, allowing it to be applied anywhere in the country, and will enable managers to track the relative health of sites through time and to identify thresholds for undesirable conditions, which may trigger management action.

[8] 'Mud' refers to sediment with a particle size of less than 63 µm. Particles in this size range feel smooth or 'slimy' when worked between the fingers. Technically, 'mud' includes silt (4–63 µm), clay (1–4 µm) and colloidal material (< 1 µm). Seabed muddiness is typically expressed in terms of the percentage of the seabed sediment by weight that is composed of mud. The remainder is composed of sediment grains that are coarser than mud, which is typically 'sand' (63 µm to 2 mm, including very fine sand, fine sand, medium sand, coarse sand and very coarse sand).

2.2.10 Monitoring sediment stress

Long-term monitoring is critical for detecting and understanding both natural and human-induced changes in ecosystems. However, ensuring a consistency in methodology and comparability of data remains a challenge (Ellingsen *et al*. 2017). Standardisation of methods and quality assurance protocols have recently received attention due to the requirement for robust and nationally comparable environmental datasets. The National Environmental Monitoring Standards (NEMS) is a series of standards prepared by the NEMS steering group and the Ministry for the Environment (MfE) that is intended to ensure consistency in the application of work practices specific to environmental monitoring and data acquisition throughout Aotearoa New Zealand.

A robust methodology for quantifying deposited sediment is not currently available. However, sediment plates, sediment traps and sediment cores are employed to estimate sedimentation rates (Townsend & Lohrer 2015) and can also be used to assess changes in the grain size of settled sediment. Each method has its advantages and disadvantages and is typically suited to a specific habitat or environment, making comparisons between datasets problematic.

We lack clear, usable frameworks to determine the amount of sediment a particular coastal system can withstand before adverse effects become serious and difficult to restore …. and tools or frameworks to 'allocate' sediment thresholds or loads back up into freshwater catchments to drive management controls.

Measuring suspended sediment typically involves discrete and/or continuous sampling of the water column. Discrete water sampling of suspended sediment (as either total suspended solids (TSS) or suspended-sediment concentration (SSC)) is undertaken by many unitary, regional and district authorities (Dudley *et al*. 2017), whereby small water samples (1–2 L) are typically collected at monthly intervals to provide valuable insight into long-term changes in water quality. However, this sampling method does not provide the required resolution to describe the rapid accumulation of sediment associated with episodic storm events.

Electronic sensors that measure light attenuation, backscattering and forward scattering, from which SSC can be inferred, provide higher temporal and spatial resolutions than water samples and can also be activated automatically or remotely to capture data during storms. The use of remote sensing (e.g. satellite imagery) is still developing.

Hewitt & Thrush (2019) considered the problem of designing monitoring programmes to detect tipping points and concluded that within-year sampling increases the likelihood of detecting when systems are approaching these. They recommended that ecological knowledge should be utilised when designing long-term monitoring programmes and to increase the likelihood that short-term or infrequent datasets can reveal whether a tipping point has been crossed.

2.3 Sediment stress in Aotearoa New Zealand's CMA

Every regional council in Aotearoa New Zealand collects environmental data to monitor their respective air, land and water resources. These data indicate that CMAs that are backed by catchments with less-than-complete native forest cover are exhibiting various degrees of sediment stress. Thrush *et al*. (2013) noted that 'in New Zealand estuaries, sediment entering from the land is a major stressor. Increased sedimentation rates have been documented, with concomitant changes to tidal flows, the ratio of sand to mud flats and the disappearance of widespread cockle beds (along with other native suspension-feeding shellfish), loss of seagrass and expansion of mangroves'; and Morrison *et al*. (2009) concluded that 'arguably the most important land-based stressor [in Aotearoa New Zealand] is sedimentation, including both suspended sediment and deposition effects'. More specifically, Haggitt *et al*. (2008) argued that sediments and fishing were likely to be having the greatest impacts on the ecology of Kaipara Harbour, noting that catchment sediments degrade habitat and water quality, with concomitant wide-ranging adverse effects on ecosystem values, services and functions (including fish and shellfish), whereas fishing (notwithstanding bottom trawling) directly affects fish and shellfish populations.

2.4 Legislation of relevance to the CMA

2.4.1 Resource Management Act

Section 5 of the Resource Management Act (the RMA) states that the purpose of the Act is to promote the sustainable management of natural and physical resources, where ‘sustainable management’ means managing resources to provide for the wellbeing of people and communities while sustaining the potential of resources to provide for future generations; safe-guarding the life-supporting capacity of ecosystems; and avoiding, remedying or mitigating any adverse effects of activities on the environment.

‘Environment’ is broad in scope and includes ecosystems, natural and physical resources, and amenity values (section 2 of the RMA), while ‘effect’ also has a broad meaning, including positive and adverse effects, temporary and permanent effects, and cumulative effects (section 3 of the RMA).

Natural and physical resources are managed through policies and plans, as well as consents, heritage orders and designations, and compliance processes, which include monitoring and enforcement. There is a logical hierarchy here: policy provides the foundation for plans; plans provide a framework for consenting processes; and consents are the basis for monitoring and compliance.

The RMA requires each regional council and unitary authority to create a regional coastal plan to support sustainable management of their coastal environment. These plans may include objectives, policies and rules that govern activities associated with use and development of the CMA. The Minister of Conservation approves regional coastal plans, changes to plans and any provisions of a combined plan that applies in the CMA. Both regional plans and regional coastal plans must give effect to the New Zealand Coastal Policy Statement (NZCPS; DOC 2010).

Sections 12 and 15 of the RMA set out duties and restrictions on the use of CMAs. For example:

- Section 12(1)(d) of the RMA states that no person ‘may deposit in, on, or under any foreshore or seabed any substance in a manner that has or is likely to have an adverse effect on the foreshore or seabed’ unless expressly allowed by a rule on an operative or proposed regional coastal plan or a resource consent. This captures the deposition of sediment (as a ‘substance’).
- Section 15(1) of the RMA prohibits the discharge of any ‘contaminant into water’ or ‘contaminant onto or into land in circumstances which may result in that contaminant … entering water’. Sediment suspended in the water column is captured in this section (as a ‘contaminant’).

Regional councils and unitary authorities are primarily responsible for managing the discharge of contaminants (including sediment) into water, maintaining and enhancing the quality of water (including coastal water), and managing the effects of activities in the CMA. There is also provision for an Environmental Protection Authority to handle ‘nationally significant’ matters. The RMA applies seawards to the limit of the territorial sea (12 nautical miles offshore).

Where a resource consent is required under section 12 or 15 of the RMA, consent conditions can compel the use of methods to prevent any sediment that is generated by land use activities from entering the CMA and can require monitoring to be carried out to assess any sediment effects, including effects on biological and ecological health. For controlled and restricted discretionary activities, the regional plan will determine the scope and nature of any conditions of consent. For discretionary and non-complying activities, any type and number of conditions may be imposed.

Section 35 of the RMA sets out the duties of local authorities to gather information, monitor and keep records. This includes State of the Environment (SOE) monitoring and consent compliance monitoring.

2.4.2 NZCPS

The NZCPS (DOC 2010) states the policies that are required to achieve the purpose of section 5 of the RMA in relation to the coastal environment.

A key consideration is Objective 1, which 'seeks to safeguard the integrity, form, functioning and resilience of the coastal environment, and sustain its ecosystems by, inter alia, maintaining coastal water quality'. NZCPS policies and rules that aim to manage sediment runoff to the coast need to refer to measurable limits or standards wherever possible, and local authorities are directed in Policy 7 (*Strategic planning*) to set thresholds in their plans where practicable, including zones, standards or targets, or to specify acceptable limits to change to assist in determining when activities that cause adverse cumulative effects are to be avoided. Consideration needs to be given to the sensitivity of the receiving environment, the preservation of natural character and uses of the CMA (e.g. aquaculture). Any limits that are set should underpin strategies for whole-catchment management. Policy 28 requires the collection of monitoring data to gauge the effectiveness of the NZCPS in achieving its objectives.

Policy 22 is of particular relevance to this report, as it originated from the acknowledgement that sedimentation in the coastal environment is a far-reaching and significant threat. This Policy provides 'explicit direction on assessing and monitoring sedimentation levels and controlling the impact of land use activities and development on sedimentation' and includes four policy areas:

1. Assess and monitor sedimentation levels and impacts on the coastal environment.
2. Require that subdivision, use or development will not result in a significant increase in sedimentation in the CMA or other coastal water.
3. Control the impacts of vegetation removal on sedimentation, including the impacts of harvesting plantation forestry.
4. Reduce sediment loadings in runoff and in stormwater systems through controls on land use activities.

By directly addressing sedimentation, Policy 22 seeks to effectively protect and improve the ecological health of marine areas.

The Policy 22 Guidance Note (DOC 2018) points out that implementation 'requires careful consideration of all of the NZCPS 2010 objectives and policies'. It states that Policy 22:

> *… relates directly to [Objective 1] because reducing the amount of sediment entering the coastal environment will help to maintain or enhance coastal water quality. Furthermore, ensuring that land use activities do not significantly increase sedimentation rates and putting controls in place that reduce sediment loadings in runoff and stormwater systems will help to*

maintain and enhance natural biological and physical processes in the coastal environment and to protect natural ecosystems such as shellfish beds. (DOC 2018: 7)

Implementation of Policy 22 also requires 'careful consideration' of Policies 1 (*Extent and characteristics of the coastal environment*), 4 (*Integration*), 8 (*Aquaculture*), 11 (*Indigenous biological diversity*), 13 (*Preservation of natural character*), 14 (*Restoration of natural character*), 21 (*Enhancement of water quality*) and 23 (*Discharge of contaminants*) of the NZCPS.

The Policy 22 Guidance Note also elaborates on the four policy areas that constitute Policy 22:

- Implementation of the first policy area (*Assessing and monitoring sedimentation levels and impacts*) will require a range of information on trends, critical source areas and sensitivity of the receiving environment.
- The second policy area (*Managing subdivision, use and development*) will be implemented through the RMA planning hierarchy of regional policy statements, regional plans and district plans that are required to give effect to the NZCPS. Regulatory methods include plan rules (e.g. rules governing subdivision, which may include references to codes of practice and standards) and non-regulatory methods, including education, incentives and support for community initiatives.
- The third policy area (*Controlling vegetation removal*) directs that the impacts of vegetation removal on sedimentation be controlled.
- The fourth policy area (*Reducing sediment loadings in runoff and stormwater systems*) directs that sediment loadings in runoff and stormwater systems be reduced by placing controls on land use activities.

2.4.3 National Policy Statement for Freshwater Management

The National Policy Statement for Freshwater Management (NPSFM) establishes a legal and policy framework for building a national limits-based scheme for freshwater management. It represents, among other things, a response to the contention that cumulative effects of diffuse-source contaminants – which includes sediments – can only be managed effectively by setting limits.

The management process prescribed by the NPSFM centres on limiting resource use in 'freshwater management units' to achieve specific, agreed values. The steps involved include:

- Stakeholders agreeing on desired values
- Identifying the 'aspects to be managed' for each value
- Identifying 'attributes'
- Deciding on the 'state' of each attribute needed to provide for the value at the desired level
- Converting attribute states into objectives
- Formulating limits that will result in the achievement of objectives
- Developing a suite of management actions that, when implemented, will limit resource use accordingly
- Considering the social, cultural and economic implications of the limits and associated management actions for resource users, people and the community.

The NPSFM requires that the overall water quality in a region is maintained or improved and the life-supporting capacity, ecosystem processes and indigenous species (including their associated ecosystems) of fresh-water are safeguarded. There are two compulsory national values that must be provided for: ecosystem health and human health for recreation.

The framework of the NPSFM considers and recognises Te Mana o te Wai (the integrated and holistic wellbeing of a freshwater body) as being an integral part of freshwater management. Te Mana o te Wai 'incorporates the values of tangata whenua and the wider community in relation to each water body', and upholding this 'acknowledges and protects the mauri of the water'.

A National Objectives Framework (NOF) was added to the NPSFM as part of the 2014 amendments, with the intention of providing nationally consistent guidance (while allowing for regional and local variation) to establishing freshwater objectives. To achieve this, it lays out relationships between values, attributes and attribute states. The national bottom line is the dividing line between attribute states D and C, and attributes that provide for the compulsory national values must not be allowed to fall below the national bottom line, with some exceptions (e.g. cases where the existing water quality is due to natural processes and where existing infrastructure contributes to the existing water quality (Policy CA3)). The NOF is not exhaustive, only covering a subset of freshwater environments, some of the attributes that are likely to need to be managed to provide for the two compulsory national values, and no values other than the two compulsory national values.

The CMA (including estuaries) is excluded from the definition of 'freshwater' in the NPSFM. Nevertheless, when referring to the NZCPS, the NPSFM acknowledges that the 'management of coastal water and freshwater requires an integrated and consistent approach'. Policy A1 of the NPSFM requires that regional councils have regard to 'the connections between freshwater bodies and coastal water' (and also to the 'reasonably foreseeable impacts of climate change') when setting freshwater objectives and associated limits for water quality, and Policy B1 requires the same regard when setting environmental flows and/or levels for water quantity. Consequently, collaborative processes that are run under the NPSFM need to consider freshwater and downstream CMA receiving environments simultaneously. This is confirmed by Objective C1 of the NPSFM, which is to 'improve integrated management of freshwater and the use and development of land in whole catchments, including the interactions between freshwater, land, associated ecosystems and the coastal environment'. Further goals of integrated management are to 'avoid, remedy or mitigate adverse effects, including cumulative effects', and to 'provide for the integrated management of the effects of the use and development of…. land and freshwater on coastal water'.

Regional councils are aware of the need to consider the CMA when setting objectives and limits for freshwater and see the implementation of the NPSFM as an opportunity to integrate coastal and freshwater management. For example, Greater Wellington Regional Council established a Whaitua committee to implement the NPSFM in the Te Awarua o Porirua Whaitua. This whaitua (designated area) is centred on Porirua Harbour, and ki uta ki tai models that link the harbour to the catchment were used to set objectives and limits that are integrated across freshwater and the harbour.

2.5 Ecosystem-based management

For the purposes of this report, it is useful to distinguish between limits-based management (as prescribed in the NSPFM; see section 2.4.3) and ecosystem-based management (EBM).

EBM is a location-based approach to management that emphasises the health of the whole ecosystem and accounts for ways in which things or actions in that place affect each other. It aims to consider a broad range of human interactions with the ecosystem, including social, cultural, economic and environmental drivers. Inherent to EBM is a spatial approach to management, which typically means spatial zoning to minimise environmental impacts, maximise ecosystem services and reduce user conflict.

EBM is usually described in terms of what it seeks to achieve and the methods it employs rather than what it actually is. For instance, Levin & Lubchenko (2008) stated that EBM is 'an integrated approach which considers all key activities, particularly anthropogenic, that affect marine environments'; Witherell *et al*. (2000) noted that EBM is a 'strategy to regulate human activity towards maintaining long-term system sustainability'; and Christensen *et al*. (1996) described EBM as 'management driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem structure and function'. ESA (1995) listed eight 'principles' of EBM: long-term sustainability as a fundamental value; clear, operational goals; sound ecological models and understanding; understanding of complexity and interconnectedness; recognition of the dynamic character of ecosystems; attention to context and scale; acknowledgment of humans as ecosystem components; and commitment to adaptability and accountability.

The shift to EBM is generally recognised as a response to the need for a more integrated approach to management, and the goals of EBM typically centre on sustainability. EBM is recognised as including certain core features, including trade-offs and collaborations, a scientific basis, and the involvement of humans and human institutions. Steps required to implement an EBM approach include defining clear and concise goals, defining indicators, setting thresholds, conducting risk analysis, and performing monitoring and evaluation. Marine systems bring special challenges to the EBM approach because they are complex and it is difficult to obtain high-quality data at appropriate spatial and temporal scales.

There are many examples of enterprises in Aotearoa New Zealand that have the hallmarks of EBM, including the Sea Change – Tai Timu Tai Pari Hauraki Gulf Marine Spatial Plan (Sea Change Stakeholder Working Group 2017). Setting limits to achieve specific targets that derive from agreed values, as laid out in the NPSFM, also has some characteristics of EBM (e.g. defining clear operational goals; having long-term sustainability as a fundamental value; scientific basis; defining indicators; setting thresholds) and readily serves as at least one element of a complete EBM approach, especially when married with monitoring and a commitment to adaptive management as the limits come on line. However, it could be argued that limits are too reductionist and do not properly recognise the complexity and connectedness of marine ecosystems.

2.6 Mātauranga Māori

The Māori world view is exactly that: a holistic approach to the environment. Ki uta ki tai, the verbal manifestation of this approach which recognises that everything is connected from the mountains to the sea, provides a powerful foundation for managing sediments.

Mātauranga Māori is an aspect of knowledge that is intricately linked with Māori culture, customs and traditions; it is a taonga (treasure) and contains deep knowledge that needs to be treated and used in an appropriate manner.

Mātauranga Māori encompasses all states of knowledge that have been developed and handed down through the generations and, as such, has been described as 'a transfer of knowledge and transgenerational beliefs that are disseminated through oral tradition and first hand observation' (Harmsworth & Awatere 2004). Mead (2012) recognised mātauranga Māori as a pool of knowledge, embracing and inclusive; a collection of past, present and future interactions and experiences, built and developed over time through interactions with the physical and spiritual worlds. Taiapa *et al*. (2014b) further recognised that mātauranga Māori does not exist in isolation but rather is part of a matrix of connections through time and space. When mātauranga is transferred, it represents a combination of mātauranga from generations past and consequently carries the mana (prestige), mauri (life force) and wairua (spirit) of its descent. It is important to recognise that mātauranga Māori also has a whakapapa (genealogy), which links it back to the land and sky and all that they encompass.

This view is based on a complete awareness of the environment and acknowledges the deep relationship tangata whenua (the iwi/hapū (tribes/sub-tribes) that hold power over an area) have with their spiritual and physical surroundings. The protection and enhancement of environmental values have strengthened pathways for future generations by further reinforcing the whakapapa of tangata whenua to the environment. Mātauranga Māori continues to shape Māori beliefs, customs and practices and is upheld through tikanga (cultural practices) such as karakia (prayers), korero (stories), waiata (songs) and whakataukī (proverbs).

2.6.1 Kaupapa Māori principles

The following fundamental principles are consistently applied by Māori to any kaupapa of significance and so were also applied in this study:

- **Tino rangatiratanga** – self-determination, independence, and acknowledging that iwi/hapū are individual and distinctive. Employing this principle in a research setting will allow iwi/hapū to manage their aspirations and destiny. It asserts that mātauranga Māori belongs to iwi/hapū, its use is determined by iwi/hapū and its integrity must be protected. This principle allows engagement with iwi/hapū to be at the appropriate level, which may include iwi governance to provide specific strategic directives.
- **Mana whakahaere** – authority for decision-making. This principle focuses on effective and authentic participation of iwi/hapū in resource management and monitoring, recognising that the right to make decisions originates from whakapapa to an area.
- **Tikanga/kawa** – guided by cultural procedures and customs. This principle aims to ensure that research is conducted in ways that are consistent with cultural guidelines of conduct and that research programmes allow for and respect the significance of traditional customs and are in accordance with traditional and cultural practices that intimately link te ao Māori (the Māori world view) to past and future generations.
- **Taonga tuku iho** – recognises the significance of all taonga, including the marine environment and mātauranga, and the intergenerational transfer of knowledge and ways of thinking and sustaining taonga through time. It is important to acknowledge the origins and creation of this principle both physically and spiritually, and to ensure that stories are shared and celebrated.
- **Kotahitanga** – collaboration, achieving a common purpose. This principle is linked to the principle tino rangatiratanga and recognises the individuality and uniqueness of the individual person, whānau (family), hapū and iwi, acknowledging that each has a valuable skill, resource base and knowledge.
- **Whanaungatanga** – establishing relationships. This principle is intimately linked with the principle kotahitanga, both of which are at the core of collaboration. Whanaungatanga also refers to how well whānau, hapū and iwi wellbeing and prosperity are enhanced through interactions with the environment.
- **Manaakitanga/kaitiakitanga** – care and guardianship. These principles recognise the importance of iwi/hapū roles in caring for and safeguarding whānau, taonga tuku iho, mātauranga and the range of values of cultural importance. Kaitiakitanga is a fundamental

and important role that iwi/hapū should be supported to fulfil. Manaakitanga and kaitiakitanga are the 'on the ground' actions that will empower iwi/hapū to protect, regenerate and enhance the mauri of the marine environment.

Māori customarily viewed rivers and streams as holistic systems, and rangatiratanga was held by the hapū who exercised collective authority over the river and acted as kaitiaki (guardians). This is highlighted in the Waitangi Tribunal (2010) report, which states that 'waterways were not something to be analysed by the constituent parts of water, bed and banks, or of tidal and non-tidal, navigable and non-navigable portions'.

2.6.2 Frameworks

Mātauranga- and tikanga-based frameworks have been developed for managing natural freshwater environments (see Awatere & Harmsworth 2014; Clapcott *et al*. 2018, and references therein). Much of the published literature has focused on the need for better engagement frameworks that allow iwi to be partners at both the governance (rangatiratanga) and operational (kaitiaki) levels (Awatere & Harmsworth 2014).

2.7 Management needs and opportunities

We don't expect certainty, but we need and require clarity.

Taken together, the demands, obligations and opportunities associated with the RMA, the NZCPS, limits-based management under the NPSFM, ecosystem-based management and mātauranga Māori cast a very wide net in terms of the scientific knowledge, information and tools that might variously be required to manage sediment effects in the CMA and achieve the overarching purpose of the RMA.

There is considerable scope for extending and refining the learnings from Te Mana o te Wai (see section 2.4.3) and applying the results through a process that could be called 'Te Mana o te Tai' to manage the impacts of sediments on coastal and marine ecosystems. Te Mana o te Tai could include Whakamana o te Tai, in which the mana and prestige of coastal ecosystems are raised to protect and enhance iwi/hapū cultural values.

Monitoring is a central requirement but presents special challenges for sediments in the CMA. Sediment runoff is dominated by rare but large events, which can be difficult to capture, and metrics such as suspended-sediment concentration, visual clarity and light penetration are typically highly variable spatially and temporally over a wide range of scales. Key metrics (see section 2.2.9) are better suited for monitoring but bring their own difficulties – for instance, sedimentation rate is highly variable spatially and fundamentally difficult to measure, and seabed muddiness evolves slowly.

Models need to be clearer about assumptions, limitations and uncertainties; we also need to be clear about what data are required to parameterise, calibrate, validate and drive models.

The NPSFM, with its directives to have regard for the CMA when setting freshwater objectives and associated limits, equates to ensuring that limits on water extraction and diffuse-source contaminant loads that are designed to achieve freshwater objectives will also achieve some objectives for the CMA. Achievement of this will require ki uta ki tai (source-to-sea) sediment models that can be used in integrated catchment planning processes. However, while such models do exist, they are virtually impossible to validate, have fundamental difficulties (e.g. accounting for feedback between morphology and flows as the morphology evolves over long timescales) and are associated with numerous 'smaller' technical issues that need to be resolved (e.g. accounting for sequences of events and associated antecedent sediment runoff to the CMA).

Resources for planning processes are also limited, so simple-to-apply tools or guidelines for determining sediment load limits will need to be developed. It will also be important for lessons to be learned and guidance to be taken from those instances where resources are available to apply one or more of the more detailed methods for determining limits.

With the exception of the southwest coast of the South Island, there are no truly pristine CMAs (including estuaries) in Aotearoa New Zealand that can be used as controls in experimental research, making it difficult to determine, among many other things, baseline or 'natural' conditions. For example, while the proposed Australian and New Zealand Environment and Conservation Council (ANZECC) guideline for sedimentation rate (Townsend & Lohrer 2015), which is based on deviation from a natural rate, is potentially very useful, its implementation will be hampered by a lack of data on the natural sedimentation rate in different coastal environments. Furthermore, limited historical monitoring also makes it difficult to determine trends with any degree of confidence.

Development of an estuaries NOF would provide a vehicle for objective setting in collaborative planning processes for at least part of the CMA, in the same way that the freshwater NOF does for freshwater and would also provide a focus for organising research. However, careful thought will need to be given to handling temporal and spatial variability when designing attributes.

There are still large information gaps regarding Aotearoa New Zealand-specific stressor–response relationships, including data and objective methods for identifying thresholds and eliciting interactions with other stressors.

Contrary to the views espoused by many, we are not swimming in data, and many of the phenomena we study just don't have enough data to describe them fully or account for local variations or uncertainty.

The ecological condition of estuaries needs to be evaluated to set objectives and assess progress towards achieving those objectives. Although a range of robust methods is available for assessing and quantifying this, and high-level indices that combine information on underlying attributes will be useful tools, the results need to be unambiguously related to values for objective setting.

2.8 Current research of relevance to the CMA

2.8.1 Institutional research programmes

Large, institutional programmes have been researching sediments and associated adverse effects in the CMA since at least the early 1990s, an early example of which is the National Institute of Water and Atmospheric Research's (NIWA's) *Mitigating sediment pollution* (1994–1996) programme. Research has also underpinned innovative multidisciplinary commercial projects, which have themselves conducted a considerable amount of research (e.g. work at Okura River estuary, Auckland).

NIWA's *Catchments to estuaries* programme is investigating the physical and geochemical processes that control the transport, transformation, fate and effects of land-derived contaminants, including sediments, in estuaries, with current projects including examination of the effects of sediments on light transmission and particle settling, the effects of temporarily settled 'muddy marine snow' on seagrass meadows, and the light requirements of seagrass. Alongside this, NIWA's *Biological traits* programme is developing ways to measure ecosystem health and vulnerability to human activities based on species functionality, using trait–stressor relationships to predict sudden responses of ecosystems to cumulative stress and to determine which species and levels of diversity are needed to maintain function in different marine ecosystems. NIWA's *Changes in juvenile fish habitats* programme has looked at how juvenile fish populations and their associated environments have changed over time, which includes the impacts of sediments on habitat.

NIWA has also been researching and trialling methods for seagrass restoration for at least the past decade, including in Whangarei and Porirua harbours. They have found that sediment biogeochemistry and sedimentation rates probably control seagrass persistence more strongly than the light climate, so all of these aspects need to be managed to maximise the chances of restoration success. In addition, NIWA and the University of Waikato are developing photosynthesis–irradiance curves to understand how the suspended-sediment concentration (SSC) affects intertidal sandflat productivity and the way in which this is likely to vary in the future as water depths over intertidal flats increase under sea-level rise.

Cawthron Institute is leading a variety of monitoring programmes that have been designed to detect the impacts of sedimentation and/or changes in SSC/turbidity as a result of certain human activities (e.g. dredging) in marine soft-sediment and rocky shore habitats. Some of the monitoring effort makes use of the Institute's coastal monitoring buoys, which collect water-quality (including turbidity) data remotely. The long-term datasets that have resulted from these efforts to date could be used for additional research in this space.

The University of Canterbury's Centre of Excellence in Aquaculture and Marine Ecology continues to work on intertidal rocky shore ecology, with an emphasis on human-induced impacts, including sediments. The University of Canterbury has also established seagrass and rocky-reef monitoring programmes in the South Island to investigate the impacts of human stressors, and recent work has shown how sediment stress affects seagrass recovery and seagrass-associated biodiversity.

The University of Auckland's Institute of Marine Science has undertaken extensive research effort in the CMA, including studies on how sediments reduce the recovery potential and seafloor resilience to other stressors and disturbances; monitoring and predicting climate change impacts on marine systems; shellfish and seagrass restoration; mangrove management; tipping points in marine ecosystems; ecological impact assessment, particularly of diffuse-source and cumulative effects; and interactions between ecosystems and society, including processes for change and helping society make informed choices around the restoration, conservation and use of marine ecosystems.

2.8.2 Government-funded research programmes

Government-funded research programmes bring together the best teams from multiple institutions and disciplines. For instance, the Ministry of Business, Innovation & Employment (MBIE)-funded programme *Community concerns, key species and wahi taonga – recovery trajectories of the marine ecosystem from the Kaikōura earthquakes* (MBIE, 2017–2021), which is being jointly run by Cawthron Institute and the University of Canterbury, is investigating the effects of turbidity, light and temperature on the growth and survival of juvenile large brown algae, with a focus on the post-earthquake responses of species under climate change, with higher temperatures and potentially increased numbers of storm events leading to increased sedimentation and associated lower light levels. In addition, the *Resilience of benthic communities to the effects of sedimentation* programme (MBIE, 2016–2021; NIWA, Victoria University of Wellington and University of Waikato) is using field surveys and laboratory experiments to look at the effects of seabed disturbance, including by mining, on the deep-ocean benthos by investigating acute and lethal thresholds, as well as the chronic effects of settled and suspended sediments (although this work is beyond the CMA, some aspects of its findings may be relevant).

The *Sustainable Seas* National Science Challenge[9] has a specific focus on EBM,[10] which is described as 'a holistic and inclusive approach to managing marine environments' that will 'lead to fundamental changes in the way we manage our marine environment'. In particular, *Sustainable Seas* 'envisages EBM as a platform for realising its twin objectives of healthy functioning ecosystems and a thriving blue economy' and aims to 'provide underpinning research and tools to support the design and implementation of an EBM approach tailored to Aotearoa New Zealand'.

Phase I of *Sustainable Seas* (2014–2019) included a number of themes that worked in partnership with the *Tangaroa* theme,[11] which provided specifically for Māori priorities and a Māori research approach. The large, 3-year Phase I project *Tipping points in ecosystem structure, function and services* investigated the effects of multiple stressors, including sediments, and cumulative impacts on marine ecosystems, with an emphasis on tipping points. Amongst a wealth of scholarly articles, the project also produced a dataset from a national tipping-point experiment, which was complemented by a metadata catalogue, and developed guidance for monitoring for tipping points in the marine environment. Other particularly relevant Phase I projects include *Defining rocky reef tipping points associated with the Kaikōura earthquake*; *Estimating historic effects from sedimentation and fishing*; *Sediment tolerance and mortality thresholds of benthic habitats*; *Stressor footprints and dynamics*; and *He Pou Tokomanawa: kaitiakitanga in practice in our marine environment*.

Phase II of *Sustainable Seas* (2019–2024) is extending the Phase I research under four themes and retaining the partnership with *Tangaroa*. Of particular relevance to this report is the *Degradation and recovery* theme, which is developing methods for mapping stressor footprints and associated effects on ecosystem services; methods for assessing the recovery potential of degraded habitats; ways of assessing how ecological degradation and recovery alter people's values from a mātauranga and tikanga Māori context; and tools for improving management of cumulative effects. In addition, the *Ecological responses to cumulative effects* project is addressing the cumulative effects of multiple stressors on soft-sediment and rocky-reef biodiversity and ecosystem function, with a view to developing models and decision-making processes as part of an EBM approach. A project is also being undertaken in Ōhiwa Harbour on the potential for shellfish populations to rehabilitate the negative effects of sediments and nutrients, while the *Spatially-explicit cumulative effects tools* project is also working to incorporate the cumulative effects of multiple stressors into decision-making via existing marine spatial management tools.

There are also several Phase II projects under the *Addressing risk and uncertainty* theme. For instance, the *Communicating risk and uncertainty* project is developing guidelines, models and tools that explicitly identify risk and uncertainty and that address multiple stressors and can be incorporated into EBM. In addition, the *Perceptions of risk and uncertainty* project is looking at ways to develop marine decision-making practices that are more inclusive and understanding of different perceptions of risk and uncertainty and that promote Māori rights, interests and values, acknowledging that different perceptions of risk and uncertainty can be a source of conflict in decision-making.

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9 www.sustainableseaschallenge.co.nz/

10 www.sustainableseaschallenge.co.nz/about-us/why-do-we-need-ebm/

11 www.sustainableseaschallenge.co.nz/our-research/phase-i-20142019-research/tangaroa/

Projects under the *Enhancing EBM practices* theme are considering issues around the implementation of EBM in terms of practice, policy, regulation and legislation, as well as issues around the implementation and practice of EBM relating to Treaty rights, responsibilities and obligations. The *Enabling kaitiakitanga and EBM* project is investigating how EBM can be incorporated with kaitiakitanga practices. The *Tangaroa* project, which is being led by Māori researchers, is exploring and applying mātauranga Māori and considering how it can be 'harmonised' with Western science. Key central goals of this project are supporting and equipping kaitiaki and enabling tangata whenua- and rohe (place)-specific approaches and outcomes, and it is also working collaboratively across projects to ensure a te ao Māori (Māori world view) approach to research outputs and outcomes.

Research being undertaken in the *Our Land and Water* National Science Challenge[12] is also relevant to this report. For example, *Cascades of soil erosion* (2017–2018) has developed a model that can be used by regional councils to evaluate the impact of changes to land use and management on catchment sediment yield, which is intended to assist in the effective targeting of mitigation expenditure.

2.8.3 Industry and community involvement

The aquaculture industry is actively involved in mussel reef restoration projects aiming to improve water quality and address sedimentation problems in the Hauraki Gulf / Tīkapa Moana and the Marlborough Sounds. These projects are building on the positive ecosystem services that shellfish provide by stabilising seabed sediments and research that has shown that large-scale historic shellfish beds have been lost from our coastal systems.

The Nature Conservancy, University of Auckland, NIWA, Revive our Gulf, the Department of Conservation (DOC) and Fisheries New Zealand are also contributing significant effort, including research, around the restoration of green-lipped mussel beds in the Hauraki Gulf, building on the Sea Change – Tai Timu Tai Pari Hauraki Gulf Plan (Sea Change Stakeholder Working Group 2017).

DOC is also running several initiatives. For instance, in its flagship wetland conservation and science programme *Arawai Kakariki*, DOC is working with scientists, iwi, other partners and the community to apply science to the restoration and improved management of three core wetlands (Whangamarino, Ō Tū Wharekai and Awarua-Waituna). In addition, through the *Ngā Awa river restoration* programme, DOC is working alongside local iwi, hapū and whānau, as well as regional councils, landowners, businesses, community groups, Fish & Game, the Ministry for the Environment (MfE) and other agencies to apply research to the restoration of 14 priority rivers. Also, DOC's Living waters programme, which is being run in partnership with Fonterra, is 'bringing nature back to farms' by applying science and working with farmers to improve freshwater quality/habitat on farms.

2.8.4 Development of innovative local, regional and national tools and models

There are instances of mātauranga Māori being implemented to manage mahinga kai (food-gathering places) (Schweikert *et al*. 2012; Kainamu-Murchi *et al*. 2018), including the development of online marine-based tools for kaitiaki (see Manaaki Te Awanui 2019), some of which include specific references to the effects of fine sediments in the marine environment. In addition, fledgling estuarine management frameworks are under development with iwi. For example, NIWA is working with Ngāi Tai ki Tāmaki to develop an estuarine cultural assessment framework for methods and

[12] https://ourlandandwater.nz/

monitoring tools to support cultural values and the management of estuaries. This is an outgrowth of several years of work developing cultural values-based assessment frameworks in the freshwater space. The recently completed *Oranga Taiao Oranga Tāngata* programme (MBIE, 2015–2019; led by Massey University) involved the development of an Estuarine Cultural Health Index and an Integrative Spatial Planning Tool for Tauranga Harbour.

Cawthron Institute, NIWA and the University of Waikato have recently developed the National Mud BHM for detecting sedimentation effects on estuarine benthic communities. This model was developed using data collected by councils across Aotearoa New Zealand, allowing it to be applied anywhere in the country, and its five-category health score system allows managers to easily track the relative health of sites through time or identify thresholds for undesirable conditions, which may trigger management action.

NIWA is currently collaborating with the International Atomic Energy Agency to incorporate hydrogen isotopes associated with fatty acid biomarkers into the *CSSI sediment source tracing method* to enable the identification of sediment sources by elevation in the landscape, as well as by landuse (Andrew Swales, NIWA, pers. comm.).

NIWA is also developing a three-dimensional estuarine–coastal numerical model, which will be coupled with a catchment model for diffuse-source contaminant accounting, and is starting work on producing model products to inform ecological effects thresholds (Andrew Swales, NIWA, pers. comm.).

MfE's *Environmental monitoring and reporting* project is exploring data standardisation and data sharing to facilitate the national-scale interpretation of regional data, one goal of which is to have environmental data collected by regional councils more widely available through Land, Air, Water Aotearoa (LAWA).[13]

2.8.5 Supporting research in freshwater and terrestrial systems

Several freshwater and terrestrial projects will also support work in the CMA. For example, the Waterways Centre for Freshwater Management's *End-of-river environments* theme[14] aims to 'develop best practice for the protection of ecological, iwi, community and recreational values in lower catchment environments, such as river mouths, coastal lakes and estuaries'. In addition, Landcare Research's *Smarter targeting of erosion control* programme[15] (2018–2023) is producing an event-based (as opposed to annual-average) catchment erosion model that deals with both sediment load and sediment quality, which is being informed by a new understanding of fine-sediment dynamics in rivers, the effect of fine sediments on water quality and the contribution of river-bank erosion. This programme is also investigating erosion mitigation performance and mitigation economics, including cost–benefit analyses. Finally, NIWA's *Suspended sediment dynamics in New Zealand rivers* project[16] is using large sets of high-frequency flow and SSC measurements to look at the impacts of catchment characteristics on the timing of sediment delivery during runoff events.

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[13] https://environment.govt.nz/facts-and-science/science-and-data/environmental-reporting/improving-environmental-reporting-data/
[14] www.waterways.ac.nz/Research/Research_priorities.shtml
[15] www.landcareresearch.co.nz/discover-our-research/land/erosion-and-sediment/smarter-targeting-of-erosion-control/
[16] https://niwa.co.nz/freshwater-and-estuaries/research-projects/suspended-sediment-dynamics-in-new-zealand-rivers-impacts-of-catchment

3. Consultation process

Targeted consultation – with CRIs, universities, central government management agencies, regional councils and unitary authorities, NGOs, and private businesses and individuals – was combined with the supporting information to develop the recommendations in this report.

3.1 Overview

The consultation process consisted of:

1. Initial consultation
   a) People were asked what, in their opinion, are the most useful research, guidance and tools currently available and where the research gaps are. Although individuals with experience in mātauranga Māori were consulted during the initial consultation, iwi and iwi environment management units were not consulted, as this was beyond the scope of the project.
   b) All of the responses were assembled into a large 'wish-list', organised by themes and objectives.
   c) The 'wish-list' was summarised.
2. Survey of research priorities
   a) People were asked to choose their top 5 objectives from the summarised 'wish-list' in terms of contributing to the desired outcome and to also provide comments where applicable.
   b) All of this information was considered in the context of the desired outcome, the scope, background information, legislation, different management approaches (limits-based vs. ecosystem-based), mātauranga Māori, management needs and opportunities, and current research to produce a draft set of recommendations.
3. Focus group meeting
   a) A focus group was convened to discuss and critique the draft set of recommendations.
   b) The recommendations were revised.

3.2 Initial consultation

In July 2020, emails were sent to individuals asking for comment on:

- Science gaps
- The most useful scientific advances over the past decade or so
- Information/tool gaps
- The most useful/used information/tools produced over the past decade or so
- Information on current research or information/tool development

In total, 230 requests for comment were made to individuals from:

- Non-university research institutes (*n* = 66), including:
  - NIWA – 43
  - Landcare Research – 7
  - Cawthron Institute – 14
  - Institute of Environmental Science and Research (ESR) – 1
  - Scion – 1
- Universities (*n* = 29), including:
  - University of Auckland – 7

- University of Otago – 3
  - University of Canterbury – 3
  - Auckland University of Technology (AUT) – 3
  - Victoria University of Wellington – 1
  - University of Waikato – 10
  - Lincoln University – 1
  - Massey University – 1
- Private sector consultants (*n* = 23)
- NGOs/industry (*n* = 14)
- Central government agencies (*n* = 27), including:
  - MfE – 3
  - DOC – 11
  - Ministry for Primary Industries – 6
  - Other – 7 (this category included one facilitator, four private consultants and two non-regional council managers)
- National Science Challenges (*n* = 2)
- Regional councils / unitary authorities / district councils, individually and via the Coastal Special Interests Group (CSIG) (*n* = 69)

Comments were received back by email and via telephone calls, video calls and personal meetings, during which notes were taken. Most people responded individually, but some prepared responses on behalf of institutions or working groups following internal consultation.

In terms of regional councils / unitary authorities / district councils, self-selected members of the CSIG provided feedback in a 120-minute facilitated videoconference; written responses were received on behalf of two regional councils, one city council and one unitary authority; and personal interviews were conducted with four individuals from regional councils.

The overall response rate for all sectors except regional councils / unitary authorities / district councils was 34% (54 responses from 161 requests) and can be broken down as:

- Non-university research institutes – 23 (35%)
- Universities – 8 (28%)
- Private sector consultants – 3 (13%)
- NGOs / Industry – 4 (29%)
- Central government – 14 (52%)
- National Science Challenges – 2 (100%)

The responses to the questions around the most useful scientific advances and most useful/used information/tools are presented in Appendix 1.

All of the responses were assembled into a large 'wish-list', organised by themes and objectives (see Appendix 2), which was then summarised for further consultation (see Appendix 3).

3.3 Survey of research priorities

Invitations were sent to 141 individuals to complete an online survey and nominate their top 5 objectives (in order) *vis-à-vis* contributing to the stated outcome. Appendix 3 shows the descriptions of the objectives that accompanied this survey.

It is difficult to choose only five objectives when many more than five are very important.

Invitations were sent to all individuals who contributed to the ‘wish-list’, as well as some additional people who were specifically selected. All invitees were also encouraged to forward their invitations to other individuals within their respective organisations.

A total of 69 individuals responded to the survey. In addition to their top 5 objectives, the respondents were asked who they worked for and their primary job role. The number of respondents by primary job role is shown in Fig. 1.

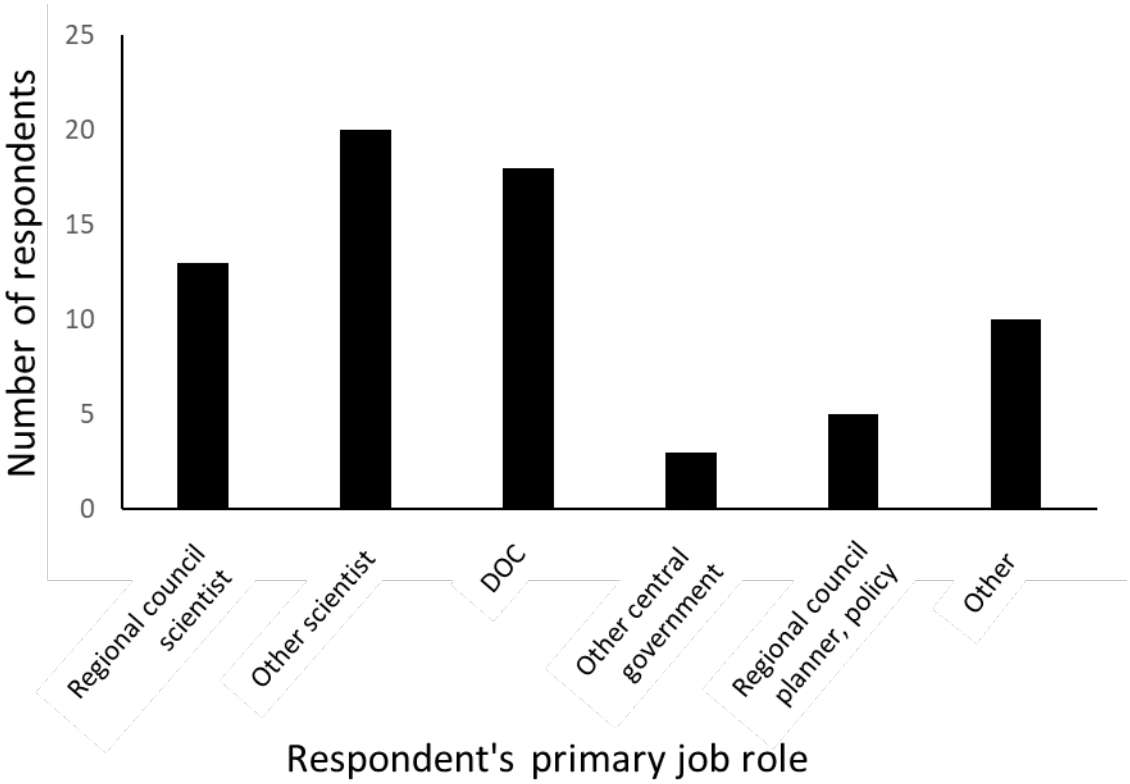


Figure 1. Number of survey respondents by primary job role.

It should be noted that:

- The ‘Other’ category includes one facilitator, four private consultants, two non-regional council managers, one Chief Executive Officer of a non-governmental organisation (NGO) and one policymaker from an NGO.
- The ‘Other central government’ category includes one senior manager and two senior policymakers.
- The ‘DOC’ category includes a wide variety of job roles within the Department of Conservation.

A ‘prioritisation score’ was calculated for each objective *O* from the responses by incrementing by 5 for every respondent that nominated objective *O* as their top priority, by 4 for every respondent that nominated objective *O* as their second priority, and so on down to their fifth priority. The prioritisation score for all respondents is shown in Fig. 2.

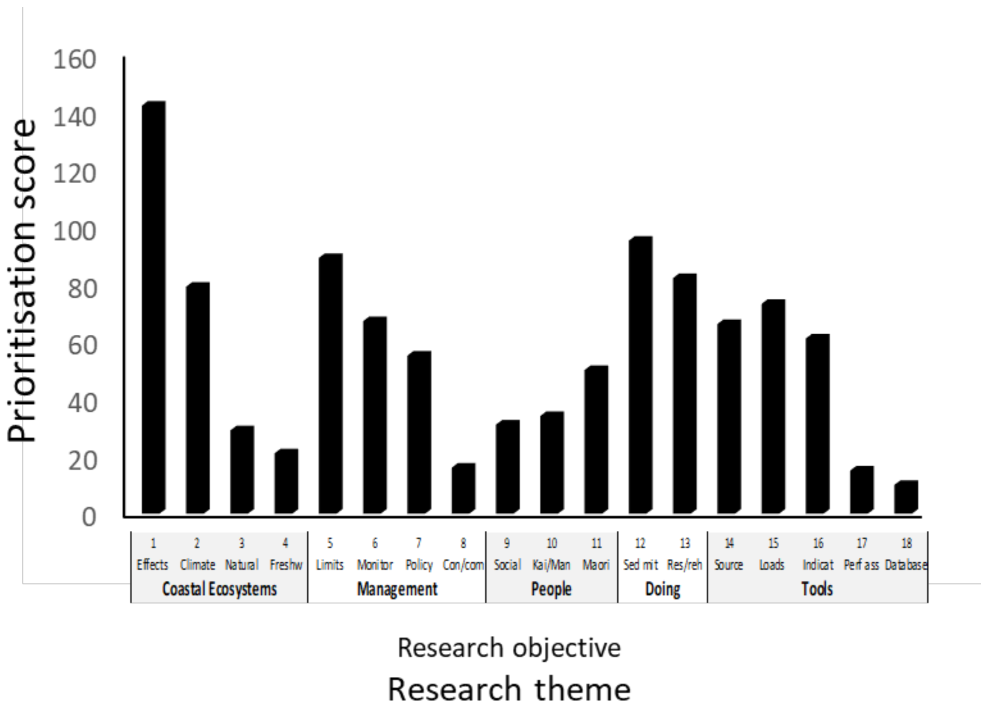
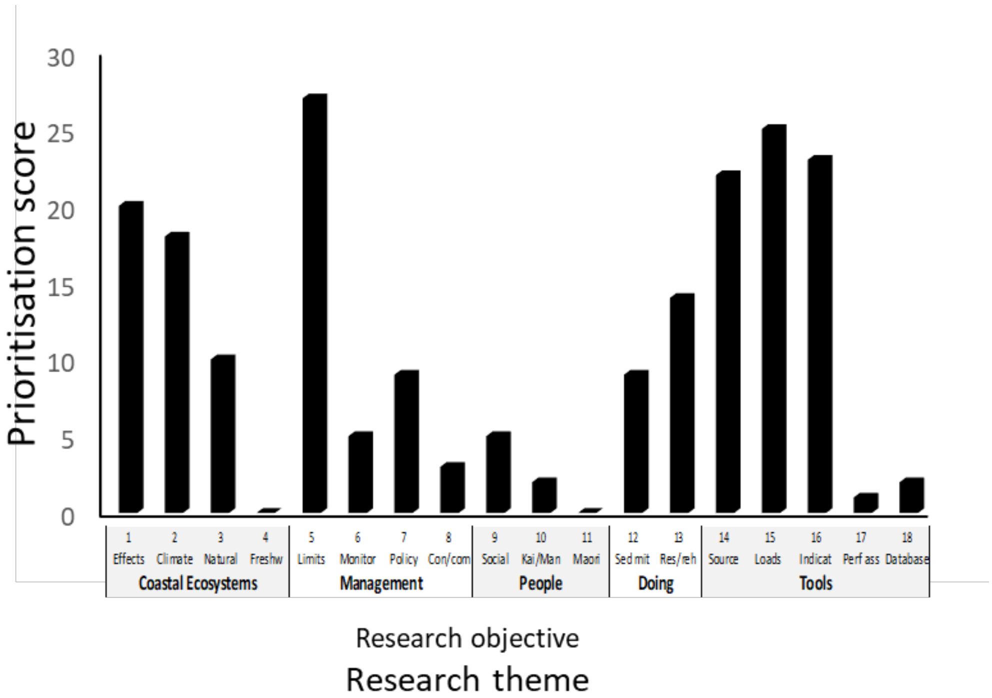


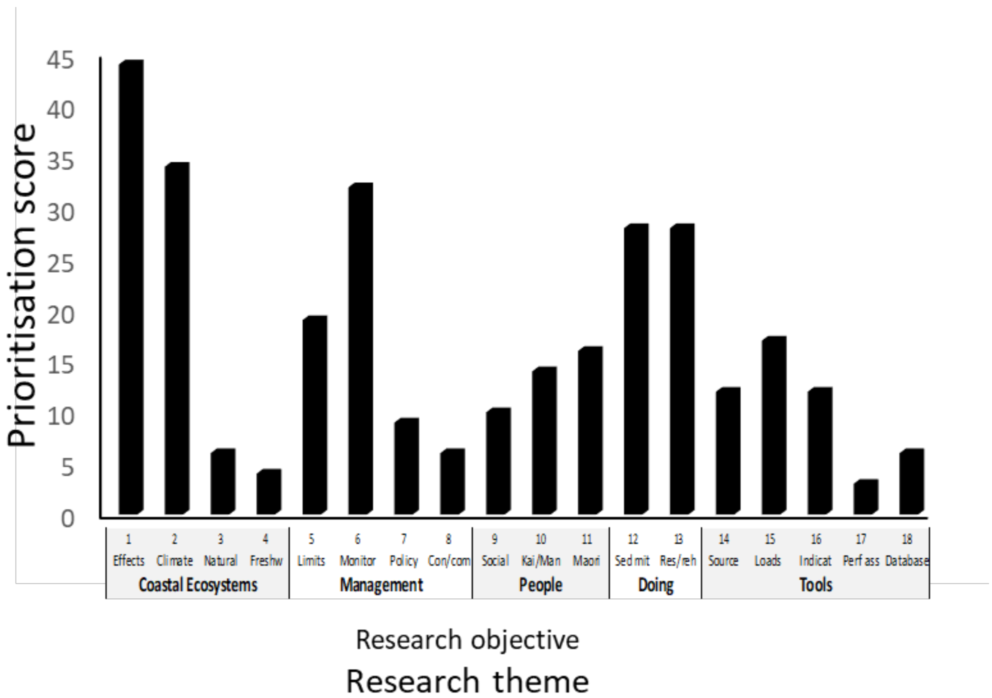
Figure 2. Prioritisation scores for each objective, grouped by themes, across all respondents.

Prioritisation scores were also calculated by primary job role or who the respondent worked for, as shown in Fig. 3(a to f).

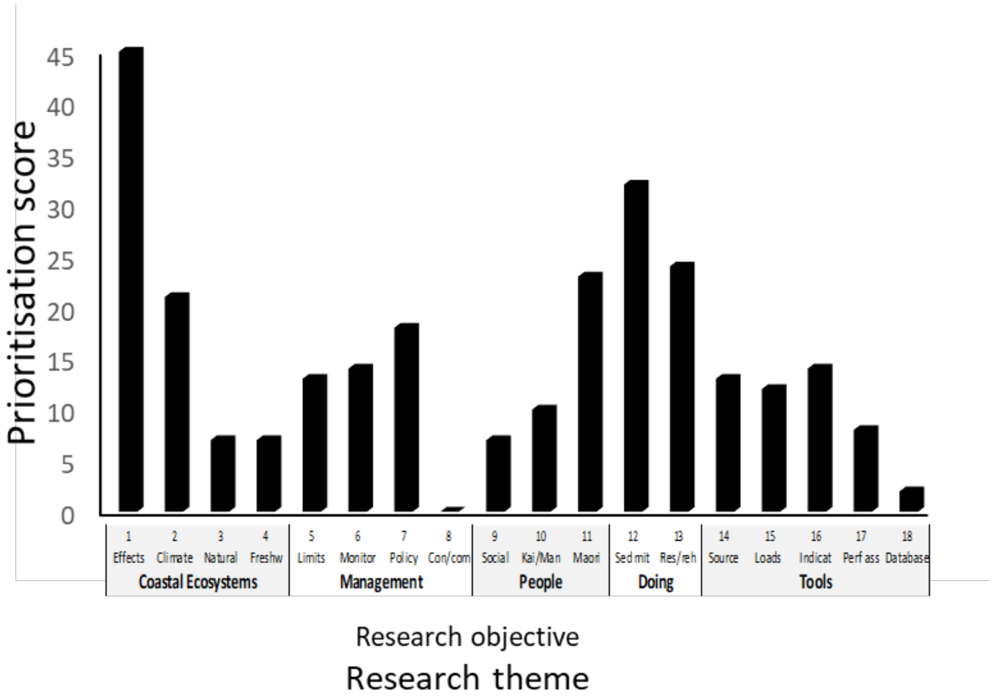
(a) Respondent's primary job role: regional council scientist.



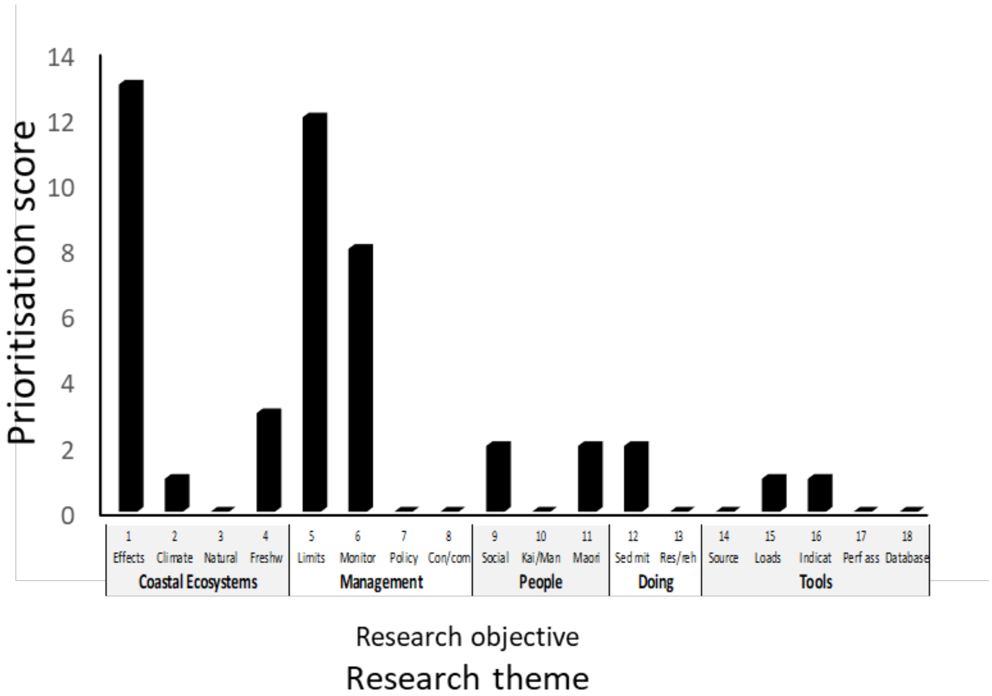
(b) Respondent's primary job role: other scientist.



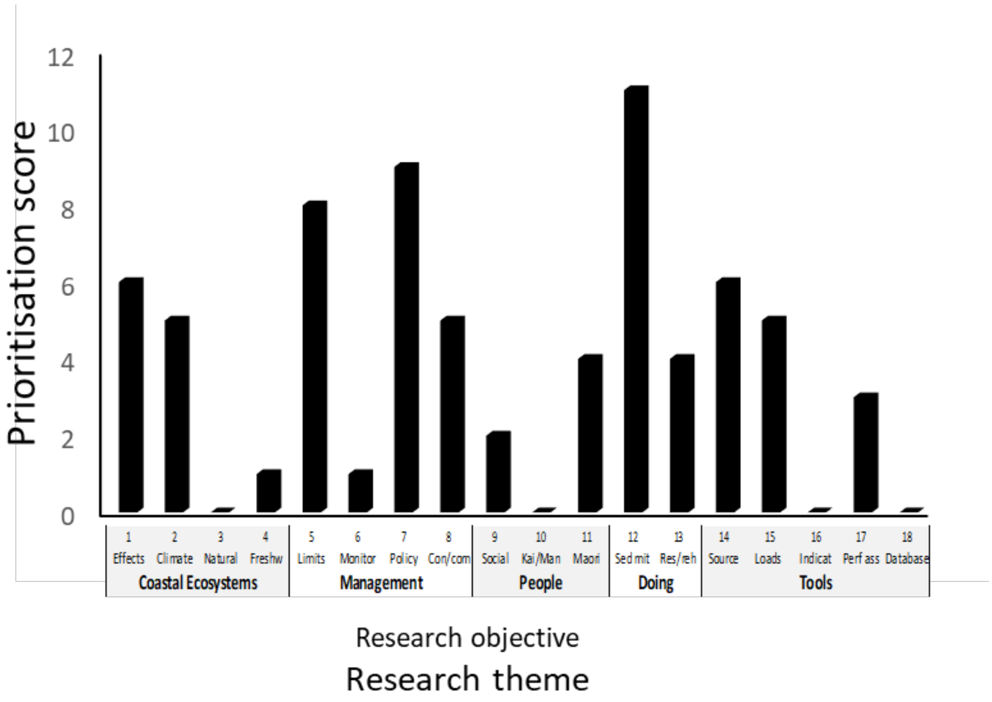
(c) Respondent's primary job role: DOC.



(d) Respondent's primary job role: other central government.



(e) Respondent's primary job role: regional council planner, policy.



(f) Respondent's primary job role: other.

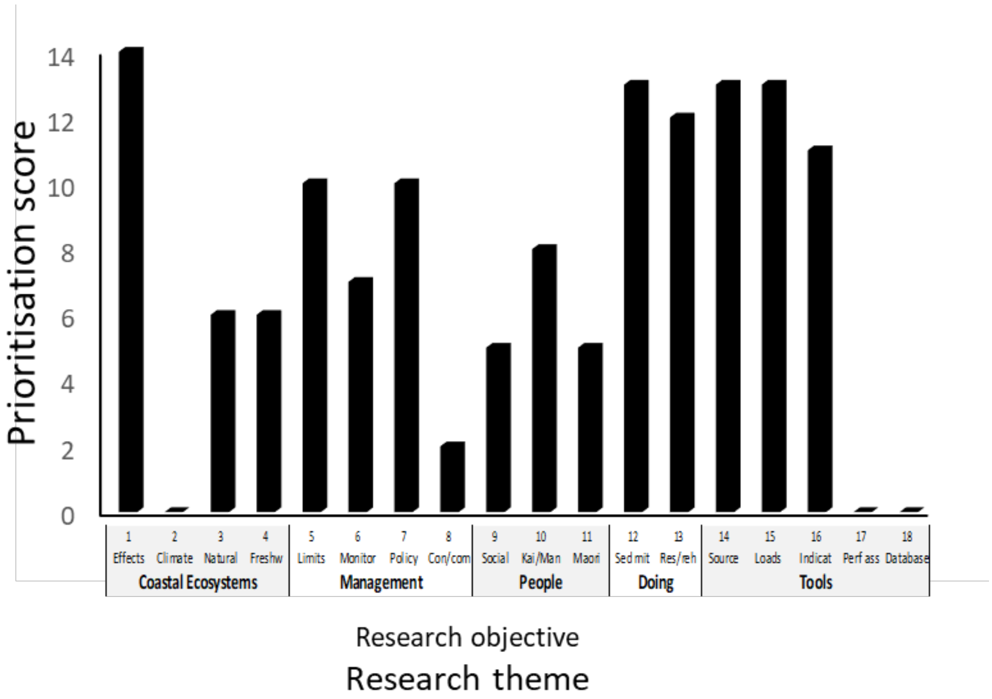


Figure 3. Prioritisation score of each objective, grouped by themes, according to the respondents' primary job roles or who they worked for. (a) Regional council scientist. (b) Other scientist. (c) DOC. (d) Other central government. (e) Regional council planner, policy. (f) Other.

3.4 Focus group

A focus group meeting was conducted in December 2020. The members of the group were chosen to provide a wide range of perspectives and included two policymakers, a Māori researcher, a marine scientist, a private consultant, a manager, a regional council scientist and an economist.

Each member of the group was provided with the draft (at that date) research priorities report, which comprised the objective, rationale and desired outcome; the process conducted to date; the summarised 'wish-list' (see Appendix 3); the survey of research priorities; a review of current research (see section 2.8); an analysis of information; and draft research recommendations.

The meeting was conducted by Zoom, was facilitated, and ran for 2 hours. It was explained to the participants that feedback was being sought on the 'big picture' represented by the draft research prioritisation report – i.e. do the large themes seem appropriate, what has been missed and are there better ways to organise the information?

To prime discussion, two big-picture themes were introduced that were considered to have emerged to date: mātauranga Māori and limits-based management. These two subjects elicited much discussion, with general agreement that they were key themes. In addition, the group discussed the difference between ecosystem-based management and limit-setting; the adaptation of mātauranga place-based knowledge (such as tools, frameworks based on tikanga (cultural practices), case studies); the need for more partnerships (e.g. iwi, businesses and cross-research programmes); the opportunities for integrating science and economics in catchment-scale models; and the need to elicit and focus on values.

Post-meeting, our view was that the group had largely endorsed the draft report, with no objections to the research themes it included and the way in which they had been presented and justified, and no major gaps.

A key challenge issued by the group was for us to clearly identify what needs to be done now for best effect, as opposed to presenting a 'wish-list' of research tasks.

4. Recommendations for priority research over the next 5 years

Long-term targets are required, as part of a long-term vision. We need to plan for 5 generations down the road.

The recommendations made in this section are intended to fill research gaps. Consequently, if research is already being undertaken in a particular area, it is not recommended here. They have been chosen to have the greatest impact and are responses to opportunities identified.

In no particular order, the highest priority research areas are:

- **Motivating people:** People are key to everything; with all the science in the world, if people do not act, then nothing will be achieved. Therefore, there is a need to understand how people can be motivated to act, including the best uses (and pitfalls) of different kinds of incentives. In particular, it is important to investigate why progress is not being made despite all the information and tools that are already available.
- **Understanding the minimum environmental conditions for success:** Although there has been, and continues to be, significant research on ecosystem restoration, regeneration and enhancement in the CMA, including the development of methods for restoring seagrass, shellfish beds and other habitats/species of cultural significance to Māori, there is still little information available on the minimum necessary environmental conditions for success, which could be significantly hindering restoration efforts. It is important to understand this to avoid wasting time, money and expectations on lost restoration causes. Mātauranga Māori could be applied to the restoration and enhancement of sediment-impacted habitats.
- **Developing iwi-based indicators:** There is considerable scope to develop both quantitative and qualitative iwi-based indicators that measure the abundance of taonga species and the mauri of coastal ecosystems. Cultural-based tools will support iwi decision-making processes and cultural values, uses and practices, facilitating the protection and restoration of the environment and taonga.
- **Identifying the sources of sediments:** Source attribution, particularly at the scale of individual activities and land parcels, is crucial to ensure that mitigation is effectively targeted to make the best use of limited budgets and manpower. Although tools are available for source attribution at the subcatchment scale, there is a clear need for tools to be developed for source attribution at the scale of individual activities and land parcels.
- **Supporting limits-based management:** Research supporting limits-based management is required to ensure that the CMA is fully accounted for as the NPSFM is implemented for freshwater. There is currently no large, integrated body of research that is working to develop the knowledge and tools that are needed for this. Although the *Sustainable Seas* National Science Challenge is continuing to develop management models, tools and guidelines that incorporate knowledge of sediment effects, these appear to be more specifically aimed at supporting ecosystem-based management (EBM). Therefore, there is a need for knowledge of stressor–response relationships, thresholds, cumulative effects and stressor interactions that is specific to NPSFM limit-setting processes – for instance, in defining attribute bands and bottom lines and in setting objectives. Simple methods are also needed for calculating sediment load limits while accounting for legacy effects and for translating sediment load limits into plan rules. This work will need to be supported by

improved sediment-load models and simple quantitative methods, including sediment budgets, for estimating sediment dispersal, deposition and retention in the CMA.

- **Developing physical–ecological–economic models:** Decisions regarding resource use and the environment are based on numerous factors, not just 'the science'. Therefore, the development of integrated catchment-scale physical–ecological–economic models to support scenario testing and decision-making is important. While there are existing models, these need to be improved with new ecological knowledge and methods for cost–benefit analyses and also need to incorporate non-market valuations of ecosystem goods and services.

Climate change is viewed as a cross-cutting theme in the sense that much of what is currently known is likely to be contingent on the climate. For instance, ecological thresholds may vary with water temperature and acidity, both of which will change under continued global warming. Researchers need to be alert to possible contingencies and employ ways to elucidate them. Modellers also need to be alert to climate change to make credible predictions – for instance, by accounting for how the runoff and fate of sediments in the CMA are likely to change under different rainfall and wind patterns in the future. To reduce the potential for unpleasant surprises, blue-sky climate-change research needs to be supported.

4.1 Rationale for making these recommendations

4.1.1 People

Social research[17] did not score particularly highly. However, the following comment from a respondent was particularly noteworthy:

> *We have good information about the effects of sediments on harbours and estuaries (physical and ecosystems) … a reasonable idea of where the sediment is coming from … and some reasonable intervention methods to capture sediments at all stages (catchment land use, freshwater, development). We can always improve this knowledge and add more detail – there are benefits in doing that. But we know what the issues are and already have tools to prevent/manage it. And yet the problem continues. So at this stage it seems most barriers to progress … are social and/or political (including economic). In the end, many of the issues are ultimately political … perhaps what we really need is better social science?*

We need to realise that information alone will not change people's minds or behaviour. People are not always rational. People often (subconsciously) make decisions based on emotion.

This comment raises the question, if we have known what is needed and why for a long time, then why do we not already have it? Is it a problem with the research – capacity, capability, funding, commitment, timeframes, incentives? Or is it a problem with uptake? Maybe everything we need is in fact out there, but we do not know it; or maybe our institutional structures, statutes or planning mechanisms are not up to task. It is important that the answers to these questions are obtained and acted on to make as much progress as possible in the next 5 years.

[17]Italicised phrases in this section are names of objectives formulated and discussed during the consultation – see Appendix 2 and Appendix 3.

Although there is a wealth of work on the way people make decisions, perceive risk and uncertainty, and hold values, there seems to be less understanding of how people's behaviour can be changed and how people can be motivated to take action, including through the use of different kinds of incentives. Therefore, these issues are considered a top priority for research.

4.1.2 Mātauranga Māori

We need more mātauranga Māori, not just in the field and in science, but also in management and policy.

The prospects for reversing environmental degradation and protecting and revitalising the mauri of marine systems will be greatly increased if Māori are included as full participants in research, making use of mātauranga Māori in accordance with tikanga alongside other epistemologies and management approaches.

4.1.3 Mitigation and restoration

Mitigation costs are private while benefits are wider – farmers incur expenses on in-field [mitigation] methods while benefits spill over broadly to the society. With low private gains, farmers may underinvest on mitigation technologies.

The two objectives under the 'Doing' theme (*Sediment mitigation*, and *Restoration and rehabilitation*) were rated particularly highly by DOC, which may reflect this organisation's conservation focus. Much work has been, and continues to be, undertaken on restoration methods for different types of marine habitat. However, while it is recognised that there are minimum necessary environmental conditions for success, little seems to be known about these, which could be significantly hindering restoration efforts. Therefore, research is required to redress this.

The possibilities for land-based sediment mitigation are already largely known, and research is occurring elsewhere on mitigation performance and cost. However, targeting effort to maximise effectiveness, which is addressed in *Sediment mitigation*, is a key gap. Improved targeting of mitigation will be underpinned by the initiatives being undertaken as part of *Source attribution*. Feedback from the community indicated that there is a particular need for source attribution at the scale of individual activities and land parcels, so this is considered a top priority.

4.1.4 Limits

Understanding effects in relation to expected outcomes is critical - but I don't think limit-setting will necessarily be a primary or sole tool for management of such complex ecosystems, because of the really strong links between different attributes.

Limits was scored highly by respondents in the 'Regional council scientists', 'Regional council planner, policy' and 'Other central government' groups.

The *Sustainable Seas* National Science Challenge is continuing to develop management models, tools and guidelines that incorporate knowledge of sediment effects, but these appear to be more specifically aimed at supporting EBM. While limits can be included as part of an EBM approach, the way in which they have been mandated in Aotearoa New Zealand via the NPSFM requires particular knowledge and tools, and these are not currently being produced. Therefore, there is a need for an improved knowledge of stressor–response relationships, thresholds, cumulative effects and stressor interactions that is specific to NPSFM limit-setting processes – for instance, in defining attribute bands and bottom lines and in setting objectives.

I think the question that needs answering first is – do we set limits in estuaries at all? Do we do them in the same way as is being done for freshwater and, if so, how do we account for the greater variation in both sediment distribution, settlement and response at an estuary level?

Simple methods are also needed for calculating sediment load limits while accounting for legacy effects and for translating sediment load limits into plan rules. Accounting for legacy effects is considered particularly important and will be especially difficult. This work will need to be supported by improved sediment-load models and simple quantitative methods, including sediment budgets, for estimating sediment dispersal, deposition and retention in the CMA.

A cornerstone of the limit-setting process is the ability to predict how much sediment is lost from the land under different circumstances and where it is transported to in the CMA. Gaps in this regard would be addressed through the *Sediment loads, delivery and fate* objective (which was scored highly by all respondents) – particularly the need for simple quantitative methods, including sediment budgets, for estimating sediment dispersal, deposition and retention in the CMA.

Limit setting is considered a key priority because limit-setting processes are now underway in freshwater environments and the NPSFM National Objectives Framework (NOF) is currently being expanded to include sediment attributes. Therefore, it is important to ensure that freshwater objectives and associated limits will also deliver objectives in the CMA. For example, in Southland, it is recognised that achieving objectives in the CMA will require more stringent limits than achieving objectives in freshwater, so the limit-setting process is falling squarely on the CMA.

4.1.5 Policy, planning and decision-making

Policy, planning and decision-making was scored only moderately by respondents. However, the authors consider that spatially explicit, integrated physical–ecological–economic catchment-scale models are essential in these arenas and need to be improved with new ecological knowledge and new methods for cost–benefit analyses that also incorporate non-market valuations of ecosystem goods and services. There is also a strong case for exploring potentially transformative ideas, such as charging to discharge sediment, and working with business to develop environmental certification processes for activities in the CMA.

[Current models] ignore the heterogeneity of land users and mitigation options; there is a mismatch between costs, which are easily identifiable, measurable (in monetary terms) and often borne by individuals, and benefits, which accrue to the community (often not the local community) and which can be hard to monetise.

4.1.6 Climate change

Climate change was scored highly across all respondents. Coastal marine ecosystems face numerous and significant threats associated with climate change, particularly from increasing air and water temperatures; decreasing ocean pH and nutrient concentrations; alterations to current, rain and wind patterns; and sea-level rise. Intertidal habitats (both soft- and hard-bottom), kelp forests and subtidal rocky reefs are most sensitive to changing conditions, and marine shellfish are also highly sensitive, particularly to a decreasing pH, an increasing frequency of extreme rainfall events and increasing

Climate change – especially sea level rise and storms – will likely overwhelm all our finer scale efforts so should also be a priority, starting now to look at longer term adaptation.

water temperatures. Local actions, such as reducing anthropogenic stressors and disturbance, can increase the health of ecosystems, which will likely increase their resilience and adaptive capacity in the face of climate change.

4.2 What is not included

4.2.1 Effects of sediments

Biological, ecological and physical effects of sediments was scored highly across all respondents, particularly 'Other scientists', as a fundamental knowledge of sediment effects is seen as a bottom-line requirement. There has been, and continues to be, significant research effort on sediment effects in intertidal soft-sediment and rocky-reef habitats, including cumulative effects and the effects of stressors in combination with other stressors, especially in *Sustainable Seas*, although less work has focused on subtidal habitats. The issue of thresholds in the various responses to stressors has also been the subject of much research, which has traversed species-level through to high-level ecosystem functionality. All of this is considered high-priority research, but its duplication is not recommended here.

4.2.2 Ecosystem-based management

It is notable that none of the respondents mentioned EBM *per se* as an area needing further research (although various elements of EBM were mentioned). *Sustainable Seas*, which runs until 2024, has EBM as a central focus and is taking multidisciplinary and interdisciplinary approaches and has integrated stakeholders and end users into research teams to help direct research and maximise uptake of the research products. Therefore, it was considered that there was no need to recommend duplication of this effort.

4.2.3 Monitoring

We just need to reduce the amount of sediment entering the CMA. The monitoring people can tell us when to stop. It's not rocket science.

Monitoring was scored highly by 'Other scientists' but not by other types of respondents, including 'Regional council scientists'. Therefore, since regional councils are primarily responsible for monitoring, this objective cannot be recommended as a high priority. Nevertheless, there are important gaps in monitoring, particularly in terms of the need for improved methods for measuring sedimentation rate and extending its use to subtidal habitats. There is also good potential for monitoring the health of estuarine fishes and the use of fishes (particularly marine juvenile migrants) as biological indicators of environmental change.

5. Implementation of the recommendations

5.1 Māori engagement

Mātauranga Māori and the kaupapa Māori principles, as described in section 2.6, can be applied to all research themes and tasks. For instance, ki uta ki tai, the whakatauki (proverb) that recognises that everything is connected from the mountains to the sea, provides a powerful foundation for managing sediments. Engaging tangata whenua will strengthen the use of cultural practices associated with caring for marine ecosystems, and embracing a Māori approach to sustainability research will play an important role in expanding the epistemological background from which future strategies can be developed. In particular, it will be important to:

- Acknowledge the importance of mātauranga Māori, but also recognise that work is still required to elevate this so that it is afforded the same status as evidence derived from other sciences. It is hoped that the acknowledgment and endorsement of mātauranga Māori within this report will help further the research movement in this area, with an emphasis on the effects of sediments in the marine environment.
- Incorporate tikanga-based approaches in research that align with the kaupapa Māori principles. Including iwi in management of the CMA will unlock the full potential of mātauranga and ensure that Māori values and interests are accurately represented and protected while enabling mana motuhake (independence) and kaitiakitanga (guardianship). This mahi (work) will also support tino rangatiratanga (acknowledging that iwi/hapū are individual and distinctive), which is at the core of empowering self-determination and capacity-building at all levels and is consistent with obligations under Te Tiriti o Waitangi.
- Recognise that tikanga-based frameworks for engagement may need to be adapted to allow mana whenua to work within tikanga that are specific to their cultural identity and rohe moana (customary fishing area).
- Acknowledge that sharing of the cultural and spiritual values that iwi/hapū associate with those coastal environments, habitats and species that are being impacted by sediments will be central to working with iwi/hapū.
- Understand that engaging with iwi/hapū will require the development of partnerships at Treaty/governance levels. Establishing high-level organisational agreements early in the process will set the stage for enduring working relationships and allow for engagement and collaboration with local kaitiaki.
- Recognise that research directions will need to be co-developed with iwi/hapū as part of enduring partnerships, and tangata whenua need to be acknowledged and supported as partners in research. Iwi should be included in the early phases of conceiving and planning research initiatives, as well as in the implementation of research programmes at both governance and operational levels, as this will underpin the enduring relationships and partnerships required to sustain and maintain collaboration with Māori and allow their full participation and exercising of tino rangatiratanga, tikanga, taonga tuku iho, mahitahi, manaakitanga and kaitiakitanga.
- Understand that place-based mātauranga Māori is important, but also recognise the need for frameworks and processes to be developed that can be transferred and utilised in other rohe.

5.2 Collaboration

Collaboration cannot be forced – true, effective collaboration must be personal at the most basic level. It is clear from the review of current research presented in section 2 that much collaboration is already occurring, at least within research disciplines. This is exemplified by the *Sustainable Seas* National Science Challenge, which seeks the best teams, fosters collaboration as a specific goal and demonstrates that collaboration across research institutions/organisations is quite workable.

However, there are fewer examples of collaboration across disciplines. Managing sediment requires a ki uta ki tai approach, which brings into play numerous disciplines, including sediment erosion; sediment transport in rivers, streams and the CMA; sediment biogeochemistry; and marine ecology and biology. It is also important to remember that decision-making, policy, and community and individual action are not only about the physical sciences – they also involve considerations of cost, behaviours, aspirations, and statutory constraints and obligations, including those under Te Tiriti o Waitangi. Therefore, there is a need for collaboration across this whole spectrum.

The authors acknowledge that the way in which limits-based management and EBM are presented as a dichotomy in the present report is somewhat false. This approach was chosen as a convenient way of organising and presenting the various themes and to promote further thinking. Setting objectives and associated limits is a recognised and accepted part of EBM yet, in the authors' view, the respective research communities that are working on EBM and limits are not well integrated or connected – or even communicating with each other. Furthermore, and exacerbating this schism, the NPSFM and the NZCPS have very different characters, with the former being very prescriptive and reductive and the latter being more about high-level principles and aspirations. To effectively manage the CMA, the authors firmly consider that these two worlds need to be working together. It is quite unlikely that simply turning off the sediment tap will solve every sediment issue in the CMA, which is impacted by numerous stressors and driven by complicated land- and ocean-side forces. However, there is also a need to be able to draw firm lines in the sand, including being willing and able to say how much sediment is too much and why – and scientists grappling with both sides of this issue need to be working together.

5.3 Study sites

Let's all work in the same catchment for once, and stay there for long enough to see the environmental response.

The effective management of sediments requires ki uta ki tai thinking, as sources of sediments on the land may be very distant from sinks in the CMA and mitigation methods are not usually located in the CMA. Ki uta ki tai is an ideal – even essential – paradigm for developing the kind of long-term research that is needed in focus areas spanning the land and sea to support the management of sediments in the CMA.

Several such enterprises are already underway. For example, Landcare Research's *Integrated catchment management for the Motueka River* programme[18] ('From ridge tops to the sea') (2000–2011) aims to provide 'information and knowledge that will improve the management of land, freshwater, and near-coastal environments in catchments with multiple, interacting, and potentially conflicting land uses'. Other outstanding examples of this kind of 'joined-together research', which can go a long way towards ensuring that relevant and excellent research is being carried out by fostering collaboration and expanding capability, have supported and been embedded in real-world

[18] https://icm.landcareresearch.co.nz/

planning processes, including the *Kaipara Harbour sediment mitigation study* (Green & Daigneault 2018) and the *Te Awarua-o-Porirua Whaitua* planning process (Te Awarua-o-Porirua Whaitua Committee 2019). The former was notable for its development of a spatially explicit integrated physical–ecological–economic model of Kaipara Harbour and its surrounding catchment, while the latter included an integrated consideration of physical, ecological, economic, cultural and social issues. In some ways these are ideal springboards for science because they need to solve real-world problems.

Sustainable Seas employs a strategy of targeting research to a designated 'Focal Area' while also providing for opportunities to work with local communities as they arise and in case studies beyond the Focal Area. This is a sensible approach, as it acknowledges the importance of 'place-based research' while recognising that opportunities to conduct good research with partners and stakeholders can arise anywhere.

5.4 Capability

A common observation during this process was that scientists do not really understand the needs of policy and management, which is an obstacle to the production and uptake of useful science products. It is unlikely to be surprising that, in the authors' experience, the scientists who are producing some of the 'most useful' science are also those who are working most closely with the users of that science. This needs to be encouraged and facilitated and can take many forms.

A lot of the research community don't understand how policy development works and happens in practice. So part of the communication/people needs (as I see it) include the requirement to upskill researchers on these processes and interactions, and how best to influence and interact with them.

The authors have often been surprised by the lack of basic understanding amongst scientists of the statutes and policies, and the processes that arise from them, that direct resource use and management in Aotearoa New Zealand. (It should be noted that none of the users of science explicitly stated this, but it is possible that they do not see the depth of this problem, as they might communicate mainly with enlightened scientists or it is possible that scientists become enlightened when they talk to users.) Some organisations also appear to lack initiatives to educate staff on the basic principles of resource management in this country and keep them up to date on developments in this area. This particular problem could be readily solved, but the fundamental issue around incentives and the way in which scientists are recognised and rewarded is not so easily resolved. As one respondent stated:

> *We cannot get researchers to do boring, management-focussed research because there is no paper in it.*

5.5 Implementation approach

To be truly effective, any research will need to be actively coordinated, managed and promoted at the national level. This will include:

- Strategic coordination
  - Ensuring the national research effort is balanced and sustained
  - Coordinating with terrestrial and freshwater research strategies
  - Coordinating with government, institutional and sector research strategies
- Funding
  - Lobbying of central government for adequate research funding
  - Developing opportunities with industry research organisations to co-fund projects
  - Appealing to philanthropical organisations for research support
- Leadership
  - Seeking opportunities to add value to research projects (e.g. by involving local industry and community groups), and developing opportunities for key stakeholder groups to manage research programmes collaboratively
  - Providing support and guidance to organisations that are planning research proposals (e.g. by serving on technical steering groups)
  - Fostering communication and collaboration amongst researchers, particularly between marine researchers and their freshwater and terrestrial counterparts
- Uptake
  - Facilitating the uptake of research products
- Operations
  - Providing a hub for information transfer
  - Ensuring that the best teams are assembled for research projects
  - Working with tertiary education institutes to attach students to research projects
  - Finding opportunities for citizens to contribute to the research effort

These are significant demands. To prevent the recommendations made in this report from languishing, an individual needs to be given responsibility for its implementation, with associated funding and resourcing. To be effective, this individual will need to be proactive and immersed in the research and management arenas. A committee of volunteers could also be formed to assist the individual.

Research priorities should be reviewed and redirected as appropriate every 3–5 years because they will change over time as both the management scene and the science evolve.

A concluding remark

The authors were asked by a focus-group participant to stand up and state the one most important thing to be done in the coming 12 months. Our response: 'Do not let the freshwater waka sail on without its salty counterpart! But we must act quickly – the currents are running swiftly …'.

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Appendix 1

Most useful resources to date

During the initial consultation, respondents were asked what they viewed as being the most useful or used scientific advances, tools and information produced over the past decade or so. The following list outlines what they said.

Ministry for the Environment's (MfE's) *Managing upstream* project.[19]

Suspended sediment yield estimator and estuarine trap efficiency.[20]

National Institute of Water and Atmospheric Research's (NIWA's) literature review *Landuse impacts on freshwater and marine environments in New Zealand*.[21]

We can now make massive dynamical computations that would have been unheard of a decade ago.

We now have greater insights into thresholds of suspended-sediment concentration (or light) that affect ecological interaction networks.

Greater knowledge on the sensitivities of individual estuarine species and assemblages to mud, with a greater number of health metrics now available to track the ecological impacts of mud.

A real recognition that land, freshwater and near-coastal marine environments are closely linked and that you cannot manage one part without reference to the others.

The application (including in models) of new and higher resolution data obtained from technological advances (e.g. remote sensing, real time sensor tech).

Identifying the connection and intersection between scientific knowledge and mātauranga Māori (indigenous knowledge).

Work showing population genetics can be used to identify dispersal patterns, colonisation events, and past large-scale disturbances, which demonstrates that you can only understand the present small-scale processes if you also consider past large-scale processes.

Studies showing how future acidification may have significant impacts on primary productivity and survival, in particular of calcareous seaweed.

Progress on seagrass restoration methods.

Taxonomic work is fundamentally important; we need to know what is here before we can document changes and/or loss.

Recent research showing how marine heatwaves, invasive species and positive species interactions are important in controlling biodiversity.

Defining the issue in terms of ecological effects; identification of high-risk/degraded areas; classification of estuaries and their susceptibility to sedimentation; advances in understanding legacy impacts of historic activities and how they still have an active and dynamic role in current coastal sedimentation; improvements in understanding of sediment erosion, runoff, dispersal and accumulation processes and modelling.

Recognition that ecological thresholds exist.

Relevance of different land uses and soil types.

Erodible land modelling.

Nationally consistent and relatively easy-to-use approach provided by the Catchment Land Use for Environmental Sustainability (CLUES) model.[22]

Methodology for measuring sedimentation rate with corresponding guidelines for interpretation.

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[19] https://environment.govt.nz/publications/managing-upstream-estuaries-state-and-values-project-stage-1a-report/
https://environment.govt.nz/publications/managing-upstream-estuaries-state-and-values-methods-and-data-review-stage-1b-report/
[20] https://data.mfe.govt.nz/layer/103686-updated-suspended-sediment-yield-estimator-and-estuarine-trap-efficiency-model-results-2019/
[21] https://environment.govt.nz/publications/land-use-impacts-on-freshwater-and-marine-environments-in-new-zealand/
[22] https://niwa.co.nz/freshwater-and-estuaries/our-services/catchment-modelling/clues-catchment-land-use-for-environmental-sustainability-model

Better understanding of the effects (both catastrophic and chronic) of sediments on estuarine ecosystems.

Sedimentation interactions with nutrient loading and heavy-metal contamination.

The *Sustainable Seas Tipping Points* project provided empirical evidence of the combined effects of suspended sediment and nutrient loading on benthic community structure and ecological functioning across New Zealand estuaries.[23]

Response of taxa and functional traits to sediment mud content.

Historical sediment accumulation rates and sediment source tracking.

The Tauranga Harbour Sediment Study provided useful information on how climate change is expected to alter sedimentation rates.[24]

Method for setting catchment sediment load limits to achieve estuary sedimentation targets.

Compound specific stable isotope (CSSI) sediment source tracing.[25]

Semi-empirical models for predicting water clarity and light penetration in estuaries.

Understanding of multiple-stressor interactions.

Methods for *in situ* measurement of particle size and settling velocity.

Research that has informed management of mangrove habitat expansion in northern estuaries.

Growing understanding of the effects of sea-level rise on estuarine habitats.

Collective work that suggests there are multiple effects of sediments on coastal ecology.

Work on ecosystem interaction networks have enhanced our mechanistic understanding of the biophysical effects of sediments on coastal ecosystem interactions and has moved us forward from the simple cause-and-effect frameworks.

Understanding the functional (but not lethal) effects of relatively small sediment deposits on functionally important species.

Interactions between nitrogen and sediments (e.g. increased sediment mud content alters seafloor nitrogen cycling; increased water column turbidity alters seafloor nitrogen cycling).

Understanding the effect of sediment on feeding of shellfish (e.g. scallops).

The effect of mud on subtidal communities.

Ecological integrity indicators.[26]

Effects of catastrophic coastal landslides on the Te Angiangi Marine Reserve, Hawke's Bay.[27]

Catchment–harbour sediment modelling for regional councils showing potential sediment dispersal under varying urban development and climate change scenarios.

Cost–benefit analysis models being used to evaluate methods for managing land-based sedimentation threats.[28]

Parliamentary Commissioner for the Environment (PCE) 2020 *Managing our estuaries* report.[29]

Use of both water-column and benthic metrics to delineate how far a catchment extends offshore to visualise connectivity between land and coast.

Developments in remote monitoring, both using buoys and satellite imagery, have really advanced the data available for system modelling and, in the future, potentially for compliance.

Methods developed for estuarine synoptic surveys initially by Cawthron Institute and more recently by Wriggle and Salt Ecology have provided useful protocols for repeat surveys. Similarly the work on a cultural approach to estuary monitoring (the

[23] https://www.sustainableseaschallenge.co.nz/our-research/tipping-points-in-ecosystem-structure-function-and-services/
[24] https://niwa.co.nz/coasts/update/coasts-update-02-september-2010/tauranga-harbour-sediments-in-2051
[25] https://niwa.co.nz/our-services/stable-isotope-analytical-facility/compound-specific-isotope-analysis
[26] www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/marine-protected-areas/ecological-integrity-of-new-zealands-marine-ecosystems/
[27] https://researchcommons.waikato.ac.nz/handle/10289/7916
[28] https://streamlined.co.nz/wp-content/uploads/2018/02/KHSMS-Summary-Report-V43_FINAL_20_Dec_Revision_1_30_Jan_2018.pdf
[29] www.pce.parliament.nz/publications/managing-our-estuaries

estuary equivalent to the Cultural Health Index for rivers).

The marine governance space, bringing in a cultural lens.

Pilot National Objectives Framework (NOF) for Estuaries narratives for sediment.

Traits Based Index (TBI) for tracking multiple stressors better than a number of other more complex metrics.

Early modelling tools (CLUES, SedNetNZ, *etc*.) have been useful to link management actions on land to freshwater and beyond, and this has reinforced the system approach to both understanding and management.

Mauri assessment tools, other kaupapa Māori based tools, such as work by Manaaki Te Awanui in Tauranga.[30]

Advances in the application of methods for treating/reducing stormwater and sediment runoff.

Development of the National Environmental Monitoring Plan (NEMP).

Development of the Estuary Trophic Index (ETI).[31]

Aerial photography depicting land-use change over time.

Free and cheap satellite imagery.

Light detection and ranging (LiDAR).

New tools that are emerging that may enable us to more efficiently sample marine estuarine systems over large scales (e.g. eDNA).

The Australian and New Zealand Environment and Conservation Council (ANZECC) guidance for estuary sedimentation is a good starting point for the development of sedimentation monitoring guidelines.

The *Sustainable Seas Tipping Points* programme provided a framework for monitoring to detect tipping points, which can be applied in the context of sedimentation.[32]

NIWA River Maps is a useful tool.[33]

PUFTS (Portable Underway Flow-Through Sampler) – system for rapid and geo-referenced/spatial surveys of estuarine and coastal water quality.[34] Applications: State of the Environment (SOE) monitoring, data for model validation, remote sensing ('sea-truthing'), survey of muddy plumes.

Published comparison of methods (7-year study) and recommendations for use of sediment-accretion plates.

Sediment core dating and determination of sedimentation rate and grain size to assess reference conditions

Update of National Estuary Monitoring Protocol and attempts to standardise monitoring across councils (this has been attempted in the coastal Special Interest Group (SIG) with sediment plates).

Fact sheets or instructional guides for councils and community groups (where can they have the most impact, e.g. salt marsh restoration).

Guidance on policy approaches to managing sediment and consent conditions.

Guidance on monitoring the impacts of sediment in the coastal environment (beyond estuaries).

Tapuwae o Rongokako Marine Reserve data of various kinds – this is as near to natural as anywhere, but a different natural modified by sedimentation.

New Zealand Coastal Policy Statement 2010 (NZCPS) guidance note for Policy 22: Sedimentation.[35]

Our Estuaries Hub, including page summarising all of New Zealand's estuary and catchment restoration initiatives.[36]

From an economic perspective, the 2018 joint study by MfE and the Bay of Plenty Regional

[30] www.mtm.ac.nz/tauranga/
[31] https://niwa.co.nz/freshwater-and-estuaries/research-projects/the-new-zealand-estuary-trophic-index
[32] www.sustainableseaschallenge.co.nz/our-research/tipping-points-in-ecosystem-structure-function-and-services/
[33] https://shiny.niwa.co.nz/nzrivermaps/
[34] https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.1002/lom3.10405
[35] www.doc.govt.nz/globalassets/documents/conservation/marine-and-coastal/coastal-management/guidance/policy-22.pdf
[36] www.doc.govt.nz/nature/habitats/estuaries/restoring-estuaries-map/

Council that surveyed the advances made in the current cost–benefit analysis models in managing sedimentation threat.

NZ Marine Impacts Gateway – searchable database for threats to New Zealand's marine environments (needs updating).

The DOC Marine Reserves Monitoring Framework has sediment as one of the variables to measure (see water quality chapter and habitat chapter, which includes sedimentation).

The Department of Conservation (DOC) / Air New Zealand Sentinel Sites partnership has a focus collaborative research at place. It is a great opportunity for integrated research that connects with iwi, agencies, business and community aspirations. Sediment has been identified as a site-based issue. The website is to be updated shortly with more details.[37]

DOC is adding a new spatial Data Hub to the Our Estuaries pages. This will allow visualisation of a broad range of sediment data in catchments and coastal waters. It will be finished in the next couple of months.

Visualisation tools.[38]

Catchment-based indicators and dashboards extending into the coastal marine area (CMA) (these need more work but the concepts are great).

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[37] www.doc.govt.nz/nature/habitats/marine/type-1-marine-protected-areas-marine-reserves/marine-sentinel-site-programme/

[38] www.doc.govt.nz/estuaries

Appendix 2

'Wish-list' of research tasks, organised into themes and objectives

The following list of priority research areas, grouped by themes and objectives, was obtained from the initial consultation.

THEME Coastal ecosystems

OBJECTIVE Biological, ecological and physical effects of sediment

Coastal fisheries

Task Influence of river plumes on coastal fisheries, both positive and negative, addressing the different types of marine settings rivers empty into (estuarine, sheltered coast, exposed coast).

Task Effects of sedimentation on selected fished species, fisheries habitats, and habitat landscapes, including both direct impacts, such as adverse physiological and behavioural effects on fished species, and indirect impacts, such as loss of critical habitats and reductions in prey assemblages.

Task Influence of changes in river flows (e.g. by water extraction) and associated sediment, debris and nutrient loads on coastal fisheries.

Task Effect of geochemistry of sediments on fishery values.

Stress response, resilience and stressor interactions

Task Interactions between sediments and nutrients.

Task Effects under combination of deposited and suspended sediment.

Task Consideration of human uses as an interactive stressor with sediment, e.g. fishing, mining, and dredging.

Task Effect of genotypic plasticity on species resilience and response to sediment stress.

Taonga species

Task Rohe-based sediment effects on taonga species, with consequences for human use, e.g. manaakitanga.

Mātauranga Māori is not confined to the qualitative domain; it is also quantitative and action. We need to embrace these aspects as well.

Thresholds

Task Ecological and species thresholds for suspended sediments.

Task Ecological and species thresholds for seabed mud content that take account of other stressors (e.g., nitrogen).

Task Extend seabed mud content ecological and species thresholds to subtidal habitats, different estuary types and bioregions.

Task Ecological and species thresholds for sedimentation rate.

Task Thresholds for human amenity, e.g. swimming, wading, aesthetics.

Birds

Task Sediment effects (direct effects, and effects on habitat) on seabirds, waders and shorebirds.

Ecosystem functionality

- Task Effects of light reduction on subtidal and intertidal productivity.
- Task Negative effects of sediments on trophic pyramids.
- Task Trade-offs associated with the loss of coarse-grain and shell-bank habitats associated with mangrove spread.
- Task Effect of fine sediments on the nutrient "carrying capacity" of estuarine and coastal systems.

Hard bottoms

- Task Sediment impacts on rocky-reef and kelp-dominated communities, coralline algae and paua.

Hard-bottom habitats have not received as much attention as soft-bottom habitats, yet they are at least equally valuable and vulnerable to sediment stress.

Suspended sediments

- Task Tolerances of mid-water-column filter-feeders and visual predators to suspended fine sediments.

Deposited sediments

- Task Extend work on sediment dumps to macroalgae, hard bottoms and inner-shelf subtidal habitats.
- Task Chronic effects of repeated cycles of fine-sediment deposition on benthic communities in exposed / high-energy / subtidal environments.

Organically-rich sediments

- Task Effects of organically rich sediments on coastal habitats, e.g. deposition of waste from open-ocean marine farms.

Microphytobenthos and macroalgae

- Task Direct effects of suspended sediments on macroalgae and indirect effects on productivity and habitat, with consideration of different NZ species, different habitats, duration of sediment impact, remobilisation of sediment, light reduction and smothering.
- Task Effect of suspended sediments on light climate and benthic primary production.
- Task Productivity–irradiance curves for MPB.
- Task Productivity–irradiance curves for macroalgae such as seagrass.

Native marine sediments and spoil disposal

- Task Effects of resuspended native marine sediments.
- Task Effects of dumping of dredge spoil.

The physical and chemical properties of [resuspended marine] sediments, and their resulting ecological effects, may be very different from terrestrial ones.

OBJECTIVE Climate change

- Task Ecological, physical and amenity consequences of loss of marginal, depositional habitats under sea-level rise.
- Task Methods for forecasting the effect of sea level rise on shoreline erosion and estuary hydrodynamics.
- Task Modulation of sediment impacts by marine heatwaves under climate change.
- Task Effects of climate change on functionality and resilience of sediment-stressed systems.

OBJECTIVE Natural state

Task Guidelines on what level of sedimentation is natural in estuaries, in different parts of estuaries (e.g. upper reaches verses open tidal flats), and in subtidal coastal environments.

People forget that sediment is natural, too.

Task Knowledge of the baseline / natural state to assess trends, interpret indicators of health and stress, set rehabilitation and restoration goals, and specify objectives.

OBJECTIVE Requirements for freshwater

Task Experimental and monitoring studies of the requirements of intertidal and subtidal ecosystems for freshwater.

THEME Management

OBJECTIVE Limits

Task Critical review and assessment of the cases for and against using limits to manage sediments in the CMA.

Keep in mind policy difference between thresholds and limits. I think we actually have pretty good thresholds for most things but translating that to a general estuary level is hard and translating that to a limit even harder.

Objectives

Task Framing objectives to maximise environmental, social and economic outcomes.

Task Accounting for spatial and temporal variability when setting objectives.

Task Incorporating thresholds in the setting of objectives and consequent limits.

Task Taking current state into account when setting objectives.

Task A National Objectives Framework for estuaries.

Sediment load limits

Task Methods for setting sediment load limits, including simple mass–balance source-to-sink models.

If a load-based approach is being considered, then knowing the likely accuracy of load estimates is critical.

Task Methods for accounting for resuspension of previously deposited sediment when setting catchment sediment load limits.

Task Accounting for spatial and temporal variability when setting sediment load limits.

Task Accounting for legacy sediments when setting sediment load limits.

Task Methods for translating sediment load limits into plan rules.

Task Adaptive management frameworks around sediment load limits.

OBJECTIVE Monitoring

Methods

Task Following recent ANZECC guidance, sedimentation rate is becoming an increasingly important metric. Plates installed on the seabed are commonly used to measure sedimentation rate. Tasks include:

A lot of decisions are based on monitoring … programmes need to be robust and affordable.

- Guidelines for use of sedimentation plates in order to maximise data quality and to ensure that data collected by different agencies can be compared.
- New methods for measuring sedimentation rate that are suitable for energetic and subtidal habitats and less prone to operator error than plates.
- Methods for effectively scaling up point measurements of sedimentation rates to larger areas, for example, using LiDAR data.

Task Cost-effective methods for monitoring sediments in open-coast kelp forests.

Task Cost-effective methods for mapping soft-sediment seabeds and quantifying seabed mud content.

Task Methods for mapping and characterising turbidity and light in coastal waters, including methods for near-bed (as opposed to sea-surface) measurements.

Task Inclusion of biological indicator fish species (e.g. snapper; flounder) and histological indicators in routine long-term environmental monitoring with a view to understanding the extent to which physico-chemical conditions are affecting the health of estuarine fishes.

Task Use of fish (particularly marine juvenile migrants) as biological indicators of environmental change.

Task Opportunities for citizen scientists to contribute to SoE and other types of monitoring.

Data analysis, presentation and dissemination

Task Guidelines for interpreting the ecological significance of trends in monitoring data.

Task Guidelines for SoE and issues-based monitoring.

Task Methods for presenting ecological/physical monitoring data in the context of ecosystem services to aid understanding.

Task Interactive, online tools for displaying regional council sediment monitoring information.

OBJECTIVE Policy, planning and decision-making

Institutional issues

Task Obstacles to DOC, MFE, regional councils and Treaty Partners working together in a coordinated way.

Task Analysis of science capacity and capability as a limiting factor in our ability to manage sediments.

Scenario testing and decision-making

Task Spatially explicit, integrated physical–ecological–economic catchment-scale models.

Task Improved methods for cost-benefit analyses, e.g. system dynamics models.

Task Valuation of non-market ecosystem goods and services (ecological, cultural, intergenerational social benefits) to support decision-making and cost–benefit analyses.

The consideration of benefits matters to ensure that a stringent policy does not get voted out merely because it is found too expensive, but rather the costs are weighed against the benefits to identify the optimal combination.

Policy analysis and development

Task Effectiveness of the NZCPS sedimentation policies and other national instruments on management of sediments.

Task Role of MPAs in terms of ecosystem and species resilience to sediment impacts.

Treatment of sediment impacts on shorebirds in plans and consenting.

Task Spatial zoning and mapping of marine ecosystems, based on functions and stressors, to aid spatial planning and regulation of human activities and impacts.

Innovative ideas

Task Explore the concept of charging to discharge sediment.

Task Development of policy and informing decision-making by exploration of the counterfactual.

I do wonder whether sediment charging like water charging would also be beneficial.

Task Environmental certification processes, e.g. for international marketing.

OBJECTIVE Consenting and compliance

Task Uniform exception-based procedures for council officers evaluating consent applications.

Task Guidelines for producing robust, consistent and comprehensive AEEs for evaluating direct and cumulative sediment effects.

People didn't need a consent to cause damage, but now they need one to fix it. Often the work will cost less than the consent to do the work.

Task Tools for putting sediment load limits into discharge and land-use consents.

Task Methods for converting suspended-sediment concentration, which is what is commonly specified in consent conditions, into equivalent sediment loads to link back to mitigation and to help place consents in wider context.

Task Methods for estimating relative importance of sediment loads at the very local scale in order to, for example, assess relative importance of an unauthorised discharge of sediment into a harbour.

Task Relative importance of average versus extreme events in the context of compliance.

THEME People

OBJECTIVE Social research

Public engagement

Task New ways to share what we already know with the general public in order to improve engagement and increase sense of connection to the marine environment.

We need storytelling, and the stories need to be local and engaging.

Task Accessible and holistic understanding of how estuaries work from a sediments point of view.

Task Understanding community perceptions of sediment issues and the implications for management and consenting.

Behaviour change

Task Changing behaviour by "nudging" people.

Task Understanding how to use incentives to best effect..

Task Methods for promoting and facilitating public engagement.

Task Use of Community-Based Social Marketing (CBSM) approaches to understand how to motivate behaviour changes.

Task Explore and discuss the issue at the "intimate" scale.

OBJECTIVE Kaitiakitanga/Maanakitanga

Task Develop, with kaitiaki, monitoring tools to assess sedimentation and related ecosystem effects.

Task Share the rich knowledge mātauranga can provide to educate society in order to promote the protection and enhancement of our marine environment.

Task Develop regenerative mindset to foster approaches to revitalize species and ecosystems degraded by sediment deposition.

OBJECTIVE Māori as partners

Task Develop place-based engagement frameworks to empower iwi.

Task Processes for ensuring Māori values and the retention of mātauranga are protected and applied appropriately.

Task Leverage mātauranga to develop innovative approaches and solutions to the issue of sediment.

THEME Doing

OBJECTIVE Sediment mitigation

Task Effective, practical and cheap methods for reducing catchment sediment loss across different land uses and geology.

Task A decision support tool that helps landowners to determine (prioritise) which GMPs or mitigation options would be most suited to their farm or catchment.

Task Methods for restoring wetlands.

Task Optimal management strategies for reducing sediments at source.

Task Experimental and monitoring studies of effectiveness of mitigation with respect to outcomes in the CMA.

Task Catchment management tools that can be readily used by catchment groups to prioritise its protection/restoration efforts at different scales.

Task Demonstrating that good management practices lead to water quality improvements at the farm to catchment scale, in order to encourage landowners and catchment groups to adopt GMPs and mitigation options.

It's hard for people who want to make changes to get support. It is difficult to trial things, to be innovative. The RMA process has become an industry – for a cocky it is just too hard.

OBJECTIVE Restoration and rehabilitation

Recovery dynamics

Task Recovery trajectories, timeframes, hysteresis and lags following reduction of sediment runoff.

… what is needed most is good monitoring of outcomes that can then be used to determine how to actually turn off the tap.

Planning and evaluation

Task Minimum conditions for success for rehabilitating degraded habitats.

Task Guidance on determining when habitats are beyond rehabilitation.

Task Prospects for placement of dredge spoil to improve habitats.

Task Estimate percentage loss of coastal habitats (e.g. over the last 100 years) and set goals for coastal habitat restoration and expansion of coastal habitat remnants .

Task Efficacy and risks of direct intervention, e.g. dredging, hydro flushing.

Task Methods for monitoring success of restoration.

Methods

Task Restoration methods for seagrass.

Task Restoration methods for shellfish beds.

Task Acknowledge and understand the restorative effects of shellfish aquaculture.

Task Methods for restoration under large catchment sediment loads.

Task Explore the use of restorative aquaculture to aid in coastal habitat restoration, including the beneficial role that aquaculture can play in providing ecosystem services.

Task Restoration methods for rocky reefs.

Task Mātauranga Māori applied to restoration.

THEME Tools

OBJECTIVE Source attribution

Task Validation of compound-specific stable isotope (CSSI) sediment tracking.

Task Methods for source attribution at the scale of individual activities and land parcels.

Task New source-attribution tools (analytical, geochemical, biological).

It is critical that we can prove the relative sources/catchments/activities that are contributing to the issue.

OBJECTIVE Sediment loads, delivery and fate

Loads

Task Event-scale catchment sediment load model (as opposed to annual-load model).

Task Methods for decomposing predictions of total load into grainsize components.

Fate and remobilisation in the CMA

Task Lag times of sediment delivery to the coast.

Task Simple methods for estimating sediment dispersal, deposition and retention in estuaries.

Task Simple methods for estimating sediment dispersal in open-coast settings.

Most models don't have enough data to parameterise them fully.

Task Salt-induced flocculation of sediment in river plumes and effects on water optics.

Task Impact of stream gravel removal on substrate diversity in estuaries.

Task Cohesive sediment erosion, transport, deposition and effects on water quality and sedimentation.

Climate change

Task Effects of climate change on sediment runoff, delivery and accumulation in the CMA.

Estuary infilling

Task Ecological consequences and forecasting of estuary infilling.

OBJECTIVE Indicators, risk, drivers, calculators, guidance

ANZECC guidelines for sedimentation

Task Improved and extended guidance on how to apply ANZECC guidelines for sedimentation.

Ecological and cultural health

Task Tools for assessing mauri at a local level based on mātauranga Māori.

Tools need to be informed by mātauranga Māori and designed to support Māori values and aspirations, particularly at the local level.

Risk, threat and vulnerability

Task Methods to identify habitats vulnerable to sediment stress.

Task Methods for distinguishing between natural and anthropogenic components of sediment stress.

Task Methods for determining key drivers of change, e.g. nitrogen versus sediment versus overfishing, *etc*.

Task Guidelines and formalised frameworks for risk assessment of sediment impacts.

Task Better understanding of natural variability in morphology, sediment dynamics and species and communities to better distinguish between stressed and non-stressed systems.

Task National map of catchment extension into the CMA based on water-column and benthic.

Councils need practical outputs that they can utilise immediately, such as protocols, guidelines, attribute tables and so on.

Freshwater requirements

Task Methods for assessing and managing freshwater requirements.

Dealing with numbers.

Task Simplified methods for translating sediment loads and concentrations in freshwater runoff into sediment metrics such as sedimentation rate, SSC, visual clarity and light penetration.

Task Back-of-the-envelope calculators for reality-checking of models and measurements (e.g. sedimentation rates, sediment loads, SSC).

OBJECTIVE Performance assessment

Task Learning from consent monitoring of large developments (e.g. Transmission Gully Motorway, Okura Estuary subdivisions).

Task Experimental and monitoring studies of effectiveness of sediment mitigation with respect to outcomes in the CMA.

Task Learning from experience and success stories - what worked, what didn't?

OBJECTIVE National databases and datasets

Task Open-access, national database of sedimentation-plate data.

As a nation, we still don't encourage or facilitate the sharing of data very well.

Task Mendeley library of New Zealand references (peer-reviewed and grey literature) that agencies and researchers can access and contribute to.

Task Minimum requirements for national datasets.

Task National LIDAR mapping programme.

Appendix 3

Summarised ‘wish-list’

The following summarised ‘wish-list’ was produced by collating the research priorities obtained during initial consultation (see Appendix 2). A range of stakeholders were then asked to choose their top 5 objectives from this list.

THEME Coastal ecosystems

OBJECTIVE Biological, ecological and physical effects of sediment

Understanding of the biological, ecological and physical effects of sediment is the foundation of our response to the sediment threat. Although we have made good progress, there are still significant unknowns regarding sediment impacts on **coastal fisheries, birds, rocky reefs, kelp beds, microphytobenthos and macroalgae**. We also lack understanding of effects on **taonga** at the rohe scale, including in the context of human use, for example, **manaakitanga**. At a higher level, we need better understanding of effects on **ecosystem functionality**, including effects of fine sediments on light reduction on **subtidal and intertidal productivity** and the effects on **nutrient “carrying capacity**”. We need to identify **thresholds** in ecological and biological responses to sediment stress, including ecological and species thresholds for suspended sediments, and thresholds for **human amenity**. We need to understand tolerances of mid-water-column filter-feeders and visual predators to **suspended fine sediments**, and we need to extend work on **sediment dumps** to macroalgae, hard bottoms and inner-shelf subtidal habitats. Research should account for **multiple-stressor interactions**, including interactions of sediments with nutrients and with human use. Research should not focus exclusively on effects of catchment sediment: we also need to understand effects of **resuspended native marine sediment** and effects of dumping of **dredge spoil**.

OBJECTIVE Climate change

Climate change will exacerbate the adverse effects of sediments in the coastal marine area; reducing sediment impacts will improve ecosystem resilience and their capacity to adapt. To prepare, we need improved understanding of the effects of climate change on **functionality and resilience** of sediment-stressed systems. A potentially significant threat that we have limited understanding of is the ecological, physical and amenity consequences of loss of **marginal, depositional habitats** under sea-level rise; models that forecast the effect of sea-level rise on **shoreline erosion and estuary hydrodynamics** will help us plan for the threat. Improved understanding of the way **marine heatwaves** modulate sediment impacts may inform management “safety margins”.

OBJECTIVE Natural state

We need knowledge of the **natural (pre-catchment deforestation) state** to assess trends, interpret indicators of health and stress, set rehabilitation and restoration goals, and specify objectives. To apply the ANZECC sedimentation guidelines, we need to know **pre-deforestation sedimentation rates** in different parts of estuaries (e.g. upper reaches verses open tidal flats), and in subtidal coastal environments.

OBJECTIVE Requirements for freshwater

We need to understand the **requirements of coastal ecosystems for freshwater**.

THEME Management

OBJECTIVE Limits

The **case for taking a limits-based approach to managing sediments** in the CMA is not settled and needs to be critically evaluated. We also need to reappraise the case for **National Objectives Framework for the CMA**. Limits-based management centres on deciding objectives and then determining limits needed to achieve those objectives. There are fundamental issues associated with **objective** setting that need to be resolved, including accounting for spatial and temporal variability, incorporating thresholds and taking account of current state. We need simple methods for setting **sediment load limits**, which will include using mass–balance source-to-sink models, and those methods need to account for **legacy sediments**. We need to derive principles for **adaptive management frameworks** around sediment load limits, and be able to **translate sediment load limits into plan rules**.

OBJECTIVE Monitoring

Monitoring underpins effective management. Following recent ANZECC guidance, sedimentation rate is becoming an increasingly important metric, however we need **new methods for measuring sedimentation rate** that are suitable for energetic and subtidal habitats and less prone to operator error than sedimentation plates. We also need **cost-effective and practical methods** for monitoring sediments in open-coast kelp forests, mapping soft-sediment seabeds, quantifying seabed mud content, and mapping and characterising turbidity. To engage the public and make use of a potential significant resource, we need to develop opportunities for **citizen scientists** to contribute to SoE and other types of monitoring. **Interactive, online tools** for displaying regional council sediment monitoring information are needed; this may include presenting ecological/physical monitoring data in the context of **ecosystem services** to aid understanding.

OBJECTIVE Policy, planning and decision-making

Policy, planning and decision-making are at the critical interface between science and action. There are **institutional issues** that need to be addressed, including identifying and overcoming obstacles to DOC, MFE, regional councils and Treaty Partners working together in a coordinated way, and looking at whether science capacity and capability are limiting our ability to manage sediments. We already have some good **spatially explicit, integrated physical–ecological–economic catchment-scale models** for scenario testing and decision-making, but these need to incorporate new knowledge on **links between sediment metrics and ecological response**, and they can be improved and complemented by new methods for **cost-benefit analyses** that also incorporate **non-market valuation** of ecosystem goods and services. There is scope for **innovative thinking**, for example, developing policy and informing decision-making by exploration of the counterfactual; charging money to discharge sediment; and developing environmental certification processes, e.g. for international marketing . We also need to be continually evaluating the **effectiveness of implemented policy** and looking for **policy gaps**.

OBJECTIVE Consenting and compliance

Regional councils require guidance and standardised procedures for consenting and compliance, including uniform exception-based procedures for council officers evaluating **consent applications**, and guidelines for producing robust, consistent and comprehensive **AEEs** for evaluating direct and cumulative sediment effects . **G**uidance for putting sediment load limits into **discharge and land-use consents is needed**.

THEME People

OBJECTIVE Social research

For all the science and technology, people are still at the heart of this mahi. We need better ways of **story-telling** to engage and motivate the public. To change people's behaviour, we need to understand their **values and perceptions of sediment issues** and how they are **personally** and intimately affected, and we need to understand and use ways to **motivate behaviour change**.

OBJECTIVE Kaitiakitanga/Maanakitanga

Strengthen the active use of **cultural practices associated with the caring for marine ecosystems** that are intimately linked with the ability to sustain and care for their whanau while maintaining their connections the sea.

OBJECTIVE Māori as partners

Provide for and encourage the use of a **foundation in Māori values and the retention of Māori ways of knowing** through the development of novel, innovative and unique knowledges and research. A Māori approach to sustainability research plays an important role in expanding the epistemological background from which future strategies can be developed.

THEME Doing

OBJECTIVE Sediment mitigation

The hard work starts on the land with mitigating sediment runoff. This requires **effective, practical and cheap methods** for reducing catchment sediment loss across different land uses and geology, and ways to identify and cost **best options** and **prioritise implementation**. We should be equipping **catchment management groups** as well as individual landowners. To develop **optimal management strategies** for reducing sediments at source, we need experimental and monitoring studies of **effectiveness of mitigation with respect to outcomes in the CMA**. Being able to demonstrate outcomes will encourage landowners and catchment groups to invest in mitigation and adopt GMPs.

OBJECTIVE Restoration and rehabilitation

Habitat restoration / rehabilitation needs to be planned, prepared for, and monitored. Guidance is required on how to **prioritise** restoration. To plan properly and manage expectations, we need to understand **recovery trajectories and timeframes**. We need guidance on **minimum conditions for successful intervention**, and when habitats are beyond repair. **Innovative and practical methods** for restoring and rehabilitating seagrass meadows, shellfish beds and rocky reefs are required, which may be informed by mātauranga Māori. Restoration methods need to recognise and accommodate for the fact that it may take significant time to reduce catchment sediment runoff, or even that it may not be possible in some places. We should take opportunities to explore the use of **aquaculture** to aid in habitat restoration.

THEME Tools

OBJECTIVE Source attribution

Source attribution facilitates the effective targeting of mitigation measures. It also provides basic information needed to set up source-to-sea sediment models, which can be used to plan catchment sediment load limits. Compound-specific stable isotope sediment tracing is a powerful tool that has been used to widely to good effect, but it needs more **validation** against data. New tools for source attribution at the scale of **individual activities and land parcels** are needed to really fine-tune targeting of mitigation. New tools (analytical, geochemical, biological) will also provide **converging lines of evidence**.

OBJECTIVE Sediment loads, delivery and fate

The cornerstone of management and analysis – assessment of effects, consent decision-making, planning, cost–benefit analysis – is being able to predict how much sediment is lost from the land under different circumstances and where it ends up in the CMA. Although we have good annual-load models, we lack **event-scale load models**, which are needed to predict event-scale adverse effects, such as smothering, and longer-timescale models to predict **estuary infilling**. We need to able to partition total loads into **constituent-grainsize components**, especially the finer grainsizes, which are the most ecologically and biologically damaging. Although there are numerous sophisticated numerical hydrodynamic and non-cohesive-sediment transport models, **cohesive-sediment transport and flocculation** are not well understood, which significantly affects our ability to predict sediment fate in the CMA. To complement the sophisticated models we need **simple quantitative methods**, including sediment budgets, for estimating sediment dispersal, deposition and retention in the CMA. **Climate change** will bring rising sea level and changes to wind and rainfall patterns; sediment runoff, delivery and accumulation in the CMA will be affected. To plan for the future, we need models that can account for this.

OBJECTIVE Indicators, risk, drivers, calculators, guidance

Tools assimilate and organise the science to make it usable. We need improved and extended guidance on how to apply ANZECC guidelines for sedimentation. We need **indicators of mauri** at a local level based on mātauranga Māori for ecological and cultural health assessments. We need tools for assessing and mapping **risk, threat and vulnerability**, which includes ways to distinguish between **natural and anthropogenic components of sediment stress**. We also need a better understanding of **natural variability** to better distinguish between stressed and non-stressed systems. We need ways to cope with numbers, for example, **methods for translating sediment loads and concentrations in freshwater runoff into sediment metrics** such as sedimentation rate and visual clarity, and **back-of-the-envelope calculators** for reality-checking of models and measurements. We need methods for assessing and managing **freshwater flow requirements**.

OBJECTIVE Performance assessment

We need to learn from experience and success stories – **what worked and what didn't?** This includes learning from **consent monitoring of large developments** such as the Transmission Gully Motorway and the Okura Estuary subdivisions. Experimental and monitoring studies of the **effectiveness of sediment mitigation with respect to outcomes in the CMA** are required.

OBJECTIVE National databases and datasets

We need guidelines for the **minimum requirements for national datasets**; an open-access, **national database of sedimentation-plate data**; and a **Mendeley** library of New Zealand references (peer-reviewed and grey literature) that agencies and researchers can access and contribute to.