9.1 Seagrass quality and extent

Author, affiliation: Anna Berthelsen (Cawthron Institute)

Citation for this chapter: Berthelsen, A. (2024). Seagrass quality and extent. *In:* Lohrer, D., et al. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. Prepared by NIWA, Manaaki Whenua Landare Research, Cawthron Institute, and Environet Limited for the Ministry for the Environment. NIWA report no. 2024216HN (project MFE24203, June 2024). [https://environment.govt.nz/publications/information-stocktakes-of-fifty-five-environmental-attributes]

Preamble: Aotearoa has only one species of seagrass, *Zostera muelleri*, which is commonly also referred to as karepō, nana, rehia, rimurehia and eelgrass. I have interpreted the seagrass quality attribute to exclude other plant species sometimes referred to as 'seagrass', including *Ruppia* spp.

Note that I have used the terms 'habitat' and 'meadows' interchangeably to reflect areas of seagrass regardless of size. Also note that seagrass 'extent' has been encompassed under the seagrass 'quality' attribute given extent is one indicator of wetland condition as per (41).

State of Knowledge of the "Seagrass quality and extent" attribute: Good / established but incomplete – general agreement, but limited data/studies

Overall, I consider the state of knowledge for the seagrass quality and extent attribute to be 'good / established but incomplete'. Internationally and nationally, there is excellent evidence relating seagrass quality (including extent) to ecological integrity. NZ-specific data that quantify stressor impacts on seagrass quality and tipping points are good. Seagrass monitoring guidance for local councils has recently been outlined. However, monitoring of seagrass quality (beyond extent and percent cover) is only routinely carried out in a limited number of areas around the country, leading to a lack of national-scale data and baselines for comparison. Management interventions to protect and restore seagrasses are well known although emerging restoration techniques (seed-based), to facilitate large-scale restoration, are in development.

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

There is excellent evidence globally and in Aotearoa New Zealand (hereafter Aotearoa) to show that seagrass quality is closely tied to ecological integrity. Seagrass meadows are one of the world's most valuable coastal ecosystems (1), offering an array of ecosystem services that benefit society and the environment (2, 3). These services include (but are not limited to) supporting biodiversity and food security, regulating water quality and mitigating climate change (4). Seagrasses are naturally found along coastlines throughout Aotearoa, usually on soft sediments and in low-energy environments such as estuaries and harbours. Their existence within the land-sea interface makes them important for terrestrial, freshwater, estuarine and nearshore coastal ecosystems.

In Aotearoa, seagrass habitats are important for supporting various fish species, including Australasian snapper (tāmure, *Chrysophrys auratus*), trevally (araara, *Pseudocaranx georgianus*) and mullet (e.g., yellow-eyed mullet, aua, *Aldrichetta forsteri*)(5, 6). Seagrass meadows also harbour diverse benthic macrofauna and small mobile invertebrate communities, and are often used by foraging birds – e.g., see reviews by (6-9), and see also (10) and (11). Furthermore, a study in Aotearoa demonstrated that seagrass (artificial mimics) was important for juvenile fish settlement with increased fish numbers associated with higher seagrass blade density (12, 13). Some animal species are closely associated with seagrass meadows. For example, the black (or wide-bodied) pipefish (*Stigmatopora nigra*) is most often observed in subtidal seagrass meadows compared to other habitats (14).

In Aotearoa and overseas, it has been demonstrated that seagrass habitats help to regulate the climate by sequestering carbon dioxide through photosynthesis and storing organic carbon in the sediments beneath them (15-17). Studies have also demonstrated the role played by seagrass meadows in regulating coastal water quality by acting as a natural filter, trapping fine sediments and taking up nutrients and contaminants (e.g., metals from the water) as they grow, thereby improving or maintaining coastal water quality (18-21). Seagrasses also have wave attenuation properties that help to protect coastal shorelines from erosion (22-25).

A2. What is the evidence of impact on (a) ecological integrity ~~or (b) human health~~? What is the spatial extent and magnitude of degradation?

Globally and nationally, there is excellent and good evidence respectively of the impact of degraded seagrass quality on the ecological integrity of coastal systems. For example, overseas, loss of seagrass has led to release of carbon (26, 27) and disrupted marine ecosystems including loss of habitat and food (28, 29). Historical records from Aotearoa indicate the detrimental impacts of seagrass loss on biodiversity such as fish, invertebrates, and birds (see review by [30]). The results of the many recent studies on benefits of seagrass in Aotearoa (see Section A1 above) also support the concept that numerous animal species will be impacted detrimentally, as well as various other ecosystem services, if seagrass is degraded / lost.

Significant historic reductions in seagrass extent have been documented in various estuaries and harbours in Aotearoa (7). Seagrass loss continues today in many places e.g., (31-34).

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Seagrass quality in respect to extent in Aotearoa has declined over time (see review by (7). As such, seagrass is listed as 'at risk – declining' (35). It appears that subtidal seagrass is more vulnerable than intertidal seagrass, likely due to impacts of poor water quality. At least 39 threats were identified overall for seagrass habitat in Aotearoa by (36). Threats deemed to have major impact on seagrass meadows were sedimentation, reclamation, benthic accumulation of debris from marine farms, causeway construction, and nitrogen and phosphorus loading. The interactions among sustained stressors continue to reduce habitat suitability, and thus seagrass quality. Furthermore, lag times between management actions and stressor reduction remain for some cases (see Section B5). While these multitude of stressors are actively interacting to reduce seagrass quality (to varying magnitudes based on location), most can be considered reversible. Natural recovery of seagrass over large scales (i.e., multiple hectares or more) can take a relatively long time (i.e., between five to fifty years - see review by (37)). Furthermore, it is possible that there may not be full recovery without additional interventions. This means that retaining or improving seagrass quality, will be heavily dependent on effective legislative action that affords seagrasses adequate protection, monitoring, risk mitigation, and restoration where needed.

Climate change also impacts seagrass quality (36) and stressors associated with this are predicted to exacerbate over the next 10-30 years (38). See Section D3 for climate change impacts and management actions.

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

Beyond extent and percent cover, there is no routine monitoring of seagrass quality collected on a nation-wide scale across the country. Seagrass extent is monitored by local government for state of the environment purposes within many estuaries nationally[1]. For intertidal meadows, extent mapping is usually conducted following the standardised broadscale method under the national estuary monitoring protocol (NEMP, (39)). Mapping methods for subtidal meadows differ to those in the intertidal, especially for ground truthing, due to the underwater environment e.g., as per (40, 41). Seagrass loss compared to historical extent is sometimes reported in association with mapping where baseline information is available e.g., indicator called '% decrease from baseline' (42). Additionally, information on seagrass percent cover (which relates to quality) is being routinely collected in many estuaries to complement broadscale mapping e.g., (42). There are also some cases where fine-scale monitoring following the NEMP is carried out within a seagrass habitat and data such as percent cover and environmental parameters are collected e.g., (43, 44). Seagrass health (i.e., quality) beyond extent and percent cover is monitored more specifically by councils in some areas e.g., (41, 45). This monitoring can encompass a range of seagrass health indicators such as epiphyte and macroalgal cover, prevalence of fungal wasting disease and biomass and chemical and environmental parameters.

Besides mapping under the NEMP, various monitoring protocols relevant to seagrass quality exist for Aotearoa. Recent guidance for councils outlines seagrass monitoring approaches and methods for seagrass extent/percent cover and seagrass and environmental health indicators (46). The Estuarine Trophic Index also mentions various seagrass/related supporting indicators for assessing estuary trophic state (47). A recent scoping review of the NEMP includes seagrass condition surveys as 'targeted investigations' (48), so perhaps these surveys will be embedded in the NEMP in future. Work that will propose indicator metrics for seagrass quality (to MfE) is underway (Stevens et al. in prep. 2024). The 'wetland condition index' by (49) is also technically applicable to seagrass, although it doesn't appear to be specifically targeted at this habitat type and some of the indicators at least are not relevant e.g., 'dryland plant invasion' and 'fire damage'.

[1] Some seagrass extent data from across Aotearoa are reported on the Department of Conservation 'Our Estuaries Hub'.

Some seagrass quality data are present for Aotearoa across various scattered sources (besides local council SOE monitoring). These data are gathered for individual studies / research or for resource management act (RMA) related processes e.g., (40, 50-54).

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Most seagrass quality monitoring methods require on-the-ground fieldwork and therefore come with various health and safety considerations for field personnel. Weather and sea state including ocean currents are particularly important safety considerations for monitoring subtidal meadows in relation to boating and / or SCUBA diving activities. Safety considerations for monitoring also relate to how the meadow will be accessed in respect to presence of any water channels and areas of deep substrate and whether a 4-wheel drive vehicle or a boat is required. The safest and / or most cost-effective site access option may also require travel over private (including Māori-owned) land in some cases. Accessing private property without the owner's consent can be considered trespassing, so clear communication, establishing good relationships, and addressing any concerns or impacts on the landowner's property or operations would be necessary. Some seagrasses may be in or nearby culturally significant areas.

Depending on the monitoring method used, technical expertise such as mapping / GIS skills and laboratory testing may be required. Monitoring may also require specialised equipment such as light and temperature loggers. Aerial imagery of the seagrass meadow, of suitable quality, taken at low tide and with no cloud cover and likely within a certain season or month, is also required for mapping extent of intertidal meadows. This imagery can be collected by aeroplane, drone or satellite (46). Furthermore, SCUBA diving and boating expertise/equipment and underwater cameras may also be required for monitoring subtidal seagrass.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

I anticipate that the main cost to undertake seagrass quality monitoring (as per 46) is paying field staff for their time. However, depending on the monitoring approach / methods followed, other costs include laboratory analysis of various parameters associated with the seagrass (e.g., leaf TN and TC – approximately $60 each) and sediment (e.g., grain size, organic matter, nutrients – approximate cost range between ten/s to > one hundred dollars each depending on the analysis[1]). There are also various equipment items although most of these are relatively inexpensive except for field loggers to measure temperature and light (cost is at least a couple of hundred dollars each) and GPS (see following section). In general, costs for monitoring subtidal seagrass meadows will probably be higher than for those in the intertidal given they usually require a boat including skipper and SCUBA divers (may also cost multiple thousands of dollars per day) and/or underwater drop- or towed video- cameras (purchase cost is hundreds to thousands of dollars, depending on type/model).

As an example, further details on costs to monitor intertidal seagrass extent following NEMP, one indicator of quality, are as follows. In 2002, the approximate cost to survey one estuary (for all substrate and vegetation types) following the NEMP was estimated to be between $15,000 to $30,000 (39). However, this cost was dependent on the size of estuary and whether suitable aerial

[1] Based on current prices from Hill Laboratory

photographs were available or needed to be obtained for the survey. The approximate cost now will likely differ e.g., to account for inflation and technological advances. Most costs will relate to personnel time spent collecting and analysing data and reporting results, however, key equipment includes GPS ($300 - $800) and ARC GIS or equivalent software ($100 - $3800). New more cost-effective techniques such remote mapping and machine learning, may be used in the future (46) e.g., as per (55, 56).

Monitoring frequency will also dictate costs over time. For mapping extent, for example, the NEMP recommends broadscale monitoring every 5 years while (46) outlines this to be carried out every one to three years depending on whether a gold or silver standard respectively is being followed.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

In Aotearoa, tohu (i.e, ecological and cultural health indicators) have been developed / used for monitoring and management of local estuaries. One example of iwi-led estuarine monitoring methods are those by (57) for Whakatū / Nelson, which include seagrass under the category ‘estuarine vegetation (wet part)’. This is specific to Whakatū and the whānau who co-developed the monitoring assessment, and further review would be required to understand the many estuarine and coastal monitoring assessment throughout Aotearoa and Te Waipounamu. However, it is unknown by the author at what scale this monitoring has been undertaken.

Māori indicators for wetland monitoring were outlined by (49). To my knowledge monitoring of these indicators has not been carried out for seagrasses in Aotearoa. The “Ngā Waihotanga Iho – The Estuary Monitoring Toolkit”[1] provides tools to measure environmental changes that occur in estuaries over time. Among other things, this involves flora identification (broadly for estuaries), but again I am unsure whether it has been implemented for seagrass.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

Seagrasses that are part of larger, continuous coastal habitats tend to have higher habitat quality and ecological functions than isolated or fragmented meadows, all of which relates to ‘landscape connectivity’. Seagrass quality links to sediment- and nutrient-related attributes as both will likely respond to catchment sediment loads. Other characteristics of mud or tidal flats (e.g., ‘sediment carbon’, ‘sediment microbial processes’, ‘sediment bacteria’) can also be influenced (and vice versa) by the establishment, distribution, and quality of seagrass and associated habitats, e.g., mangroves and saltmarsh (15, 58, 59). Seagrass also relates to other stressor-related attributes such as those associated with heavy metals and temperature changes brought about by climate change. Seagrasses that offer limited ‘access to natural areas’ (specifically in relation to human disturbance) also often have higher habitat quality and support more diverse ecological communities.

Seagrasses are transitional habitat found between multiple ecosystems, meaning there will likely be a crossover in monitoring methods with the quality and extent of habitats such as dunes, saltmarshes and mangroves.

[1] https://niwa.co.nz/te-kuwaha/tools-and-resources/ng%C4%81-waihotanga-iho-the-estuary-monitoring-toolkit

Part B—Current state and allocation options

B1. What is the current state of the attribute?

There is good evidence that seagrass habitats have been lost nationally over time (7), although historical baselines aren't necessarily known. The current state of remaining seagrass quality (beyond extent) is not well understood at the national and local level. There is information available from estuaries around the country on seagrass extent and percent cover based on habitat mapping. However, besides for a small number of locations, current knowledge and reporting of the quality of existing seagrass habitats, beyond extent / cover, in Aotearoa are poor.

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

Seagrass systems that have retained their historical extent and that have limited to no evidence of human-induced impacts (e.g., pollution, vehicle or anchor / mooring damage) could be considered a reference state with respect to quality. Seagrasses associated with remote, protected locations such as national parks may best serve as examples of natural states with limited impact from human-induced stressors. However, sites within remote, protected areas may still contain stressors such as from boat anchoring or mooring activities and be subject to climate change impacts. For subtidal seagrasses, offshore islands, where water clarity is good, may provide the best reference areas containing meadows even if the nearby land is not necessarily protected.

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

Advice on ecological quality status thresholds for seagrass (for extent and percent cover/density at least) in Aotearoa are currently in draft (60). Examples of thresholds previously applied or proposed for seagrass in Aotearoa include those by (47) and (61) based on current extent vs baseline. I know of no existing numeric or narrative bands specifically for fine-scale seagrass health monitoring in Aotearoa. (46) states that this type of monitoring can help inform future development of early warning indicators of decline.

Guidelines for allocating scores, on a scale of 0–5, to the various indicator components of the 'wetland condition index' are outlined in (49). Quantitative limits to maintain the ecological integrity of freshwater wetlands are detailed in (62). These are based on attribute states ranging from A (excellent condition) to D (poor condition). However, I do not know of any examples where the 'wetland condition index' or its indicator scores or states have been applied to seagrass (see Section A4-(i) for comment on relevance of this index to seagrass).

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity ~~or human health~~?

There is good evidence for seagrass quality tipping points or thresholds reported internationally (e.g., (29, 63-65) and nationally. In Aotearoa, for example, macrofaunal species diversity can increase with seagrass colonisation in relation to plant % cover (11) and fish abundance can increase when seagrass is present and has a higher plant shoot density - based on artificial seagrass (12, 13). Due to the importance of seagrass for ecological integrity, loss or degradation of this habitat type can directly impact ecological integrity (see Sections A1 and A2). Tipping points or thresholds for seagrass loss / degradation reported for Aotearoa depend on factors including seagrass coverage, biomass, water clarity, nitrogen loads/levels, storm events and sea level rise (e.g., (51, 52, 54, 66-69). Multiple stressors will likely need to be considered given that individual stressors in estuarine systems can be conditional on the state of other stressors (70).

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

Lag time between stressor and impact on seagrass quality will be site- and stressor-dependent. For example, there may be no lag time in cases of direct and severe physical damage, such as shoreline infilling / land reclamation for coastal development. Alternatively, lag times are expected from the impacts of stressors / factors such as land-based nutrient and sediment runoff (71, 72). In terms of the impact of non-indigenous species (such as exotic *Caulerpa*), there will be a timeframe when these are first present before becoming established and spreading. In respect to naturally occurring processes, seagrass extent / biomass / shoot density is known to vary across seasons and can also be influenced by long-term climatic patterns such as El Niño (8). Plant recovery may take time and be slowed (or impossible) when stressors such as poor light penetration to the seabed due to sediment loading are present (see summary of unsuitable parameter conditions in [37]).

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

Mātauranga Māori is place-based and so the local context and ecology is important. Coastal wetlands are highly valued by Māori as important systems that provide habitat for taonga species and as sources of mahinga kai (73). Seagrass (in some areas at least) is viewed by hapū and iwi as crucial to the mauri (life force) of the taiao (environment) (e.g., (40)). Seagrass rhizomes may have been used by historically for food and the leaves for adorning clothing (30). Indigenous-based tohu/indicators (i.e., specific tohu and/or taonga species, see Section A5) could be used to inform bands / allocation options. However, given it is context based, the bands should be informed by the approach exemplified by various iwi and hapū specific environmental assessments. For instance, the estuarine indicators for Whakatū, Nelson (57).

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

In cases where seagrass is destroyed, such as shoreline infilling / land reclamation, there is obviously a direct detrimental relationship between the stressor and seagrass quality. Furthermore, there is also some evidence for Aotearoa on the impacts of other physical stressors such as vehicle and mooring damage, bird herbivory and human perturbation on seagrass quality (e.g., (41, 50, 74, 75). Various studies quantify relationships between seagrass quality and stressors in the water column and sediments caused by issues such as sedimentation and excessive nutrients in Aotearoa (see review by (76). However, there are still challenges associated with disentangling interactions among multiple stressors, respective lag times, additional legacy affects, and overall seagrass quality. In addition, the impact of stressors on ecosystems is usually highly context-specific (i.e., place and history are very important) and so effective management needs to understand and allow for that context.

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

Key management interventions include seagrass protection and the elimination or reduction of stressors. From a policy perspective, the RMA (1991) is a key piece of legislation that sets out how we should manage our environment. In addition, the New Zealand Coastal Policy Statement (77) guides councils in their day-to-day management of the coastal environment. There are various other relevant government-related directions and management implementations, for example for freshwater, climate change mitigation and adaptation, biosecurity, marine protected areas and fisheries. Despite this, government management is failing to fully protect seagrasses in Aotearoa as evidenced by their continued decline in many places.

Seagrass restoration is another management intervention that can be carried out to improve quality of degraded or lost seagrass by government, iwi / hapū, community groups or others interested in recovering estuarine habitat[1]. Removal / management of existing stressors and catchment-based restoration, such as riparian planting and fencing, can indirectly facilitate natural seagrass recovery (e.g., as potentially indicated by (78). The traditional method for actively carrying out direct seagrass restoration involves transplantation from wild meadows e.g., (79). Seed-based restoration also holds promise over larger scales but has not yet been carried out in the field in Aotearoa. A practical guide for carrying out seed-based seagrass restoration in Aotearoa has recently been created and has remaining knowledge gaps outlined (80).

C2-(i). Local government driven

Local governments can take action to protect (e.g., through policy / plans) and restore seagrass meadows at the regional level. A number of local government-driven initiatives have occurred at certain sites within Aotearoa aimed at restoring seagrass habitat directly using the technique of transplantation e.g., (79). There are also many examples of council-supported / led catchment-based restoration, which has potential to facilitate seagrass protection and recovery.

C2-(ii). Central government driven

Central government can provide key funding for the protection, conservation and restoration of seagrass across the country and for improvement of catchment health in general. For example, for relevant DOC activities, projects under the Freshwater Improvement Fund and MfE's 'At risk' catchments programme such as the Te Hoiere/ Pelorus Catchment Restoration Project.

C2-(iii). Iwi/hapū driven

Hapū and iwi are driving the Hinemoana Halo project alongside Conservation International (88), which includes supporting nature-based solutions including restoration of coastal wetlands and seagrass. There are many examples of the suite of tools that hapū and iwi have towards supporting

[1] Department of Conservation. Restoring estuaries. Restoring Estuaries Map. Retrieved March 25, 2024, from https://www.doc.govt.nz/nature/habitats/estuaries/restoring-estuaries-map/

ecological health (89), although are usually restricted to fisheries decisions rather than habitat improvement in estuaries and coastal environments (90).

In addition, in terms of research to inform management interventions, a project on potential estuarine thresholds and interventions, from land to sea, in collaboration with iwi, has aimed to achieve impact by combining knowledge streams to inform catchment-based solutions that lead to improved mauri of catchments and estuaries (82).

C2-(iv). NGO, community driven

A number of community-driven land-based restoration projects (that help to improve catchment health) exist throughout Aotearoa. Some examples include the Manawatū Estuary Trust, the Cobden Aromahana Ecological Restoration Group, and the Waimea inlet restoration project, to name a select few. Additional projects can be found at the DOC Restoring Estuaries Map[1]. NGO's and community groups may wish to support / carry out seagrass restoration in the future.

C2-(v). Internationally driven

Internationally-driven obligations relevant to the protection of seagrass include the Ramsar Convention of which Aotearoa is a signatory meaning it plays a part in the international effort to conserve wetlands[2]. There are multiple Ramsar sites around the country that contain seagrass habitats. Under the Convention to Biological Diversity (CBD), Aotearoa is required to have a national biodiversity strategy and action plan through which obligations under the CBD are delivered. Aotearoa has international climate change obligations such as those under the Paris Agreement. I understand that Aotearoa has also signed other international agreements (e.g., Free Trade) that require conditions around environmental management and climate change to be upheld. Restoring the vitality of degraded systems (which include seagrass ecosystems) is crucial for fulfilling the UN Sustainable Development Goals and for meeting the targets of the UN Decade (2021-2030) on Ecosystem Restoration (UN-DER).

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

Failing to manage seagrass habitats poses a significant threat to coastal environments, triggering a cascade of ecological problems. For example, the degradation of seagrass quality can lead to a reduction or loss of habitat for biodiversity such as fish, invertebrates and birds (See Section A1 for importance of seagrass for biodiversity). Reductions in seagrass quality can sever vital links in the marine food web, which can have cascading impacts on the overall health and biodiversity of coastal ecosystems. Lost / degraded seagrasses may also lose their ability to filter pollutants and excess nutrients from the water, potentially leading to increasingly polluted coastal areas. Increased pollutants may disrupt the delicate balance of marine life and could trigger harmful algal blooms and

[1] Department of Conservation. Restoring estuaries. Restoring Estuaries Map. Retrieved March 25, 2024, from https://www.doc.govt.nz/nature/habitats/estuaries/restoring-estuaries-map/

[2] Ramsar Wetlands - National Wetland Trust of New Zealand | Learn more. (2021, September 7). National Wetland Trust of New Zealand. https://www.wetlandtrust.org.nz/get-involved/ramsar-wetlands/

oxygen depletion zones. Reduction in seagrass quality may also lead to increased erosion of shoreline habitats (e.g., as shown overseas (24)). Overall, impacts on marine ecological health and biodiversity have a detrimental flow-on effect for mauri and cultural practices such as mahinga kai (83, 84).

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

The economic impacts of seagrass degradation / loss are likely to be felt among fisheries, as fish-habitat associations have been quantified between subtidal seagrass and commercially important species such as snapper and trevally (see review by (5)). Furthermore, historical seagrass loss in certain areas within Aotearoa is indicated to have led to a decline of multiple marine-related fisheries (30) and references within. Reduced seagrass quality causing poorer water quality can lead to various detrimental implications for commercial activities such as aquaculture, fishing, tourism, and recreational industries such as water-sports events. Reductions in seagrass quality could also potentially limit their protective capacity as natural buffers that absorb wave energy and lessen storm surge impacts and erosion (e.g., (24, 25)), which is relevant for maintaining coastal infrastructure and tourism.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Climate change places additional pressure on seagrass meadows, for example, through exposure to more frequent and intense storm events, poorer water quality, increasingly frequent extreme temperature events (air and water) and sea-level rise (4, 85, 86).

Reducing / stopping anthropogenic greenhouse gas emissions is crucial for mitigating climate change impacts. Resilience of seagrass habitats to climate change may be improved by limiting impacts from other stressors, such as catchment sediment and nutrient runoff and protection from physical impacts such as boat anchoring / mooring and vehicle driving. Another management action to reduce climate change impacts on seagrass includes providing sufficient space for this habitat to migrate inwards, which can be accomplished through the removal of hard structures on the estuary seafloor such as seawalls and roads to reduce impacts of 'coastal squeeze' e.g., (87). The quality of seagrass habitats that are currently degraded can also be improved through actions such as increased protection and restoration.

References:

1. Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, et al. The value of the world's ecosystem services and natural capital. Nature. 1997;387(6630):253-60.

2. do Amaral Camara Lima M, Bergamo TF, Ward RD, Joyce CB. A review of seagrass ecosystem services: providing nature-based solutions for a changing world. Hydrobiologia. 2023;850(12):2655-70.

3. Mtwana Nordlund L, Koch EW, Barbier EB, Creed JC. Seagrass ecosystem services and their variability across genera and geographical regions. Plos one. 2016;11(10):e0163091.

4. Unsworth RK, McKenzie LJ, Collier CJ, Cullen-Unsworth LC, Duarte CM, Eklöf JS, et al. Global challenges for seagrass conservation. Ambio. 2019;48:801-15.

5. Morrison M, Jones EG, Consalvey M, Berkenbusch K. Linking marine fisheries species to biogenic habitats in New Zealand: a review and synthesis of knowledge: Ministry for Primary Industries Wellington; 2014.

6. Morrison M, Lowe ML, Grant C, Smith PJ, Carbines GD, Reed J, et al. Seagrass meadows as biodiversity and productivity hotspots. 2014.

7. Anderson T, Morrison M, MacDiarmid A, Clark M, Archino R, Tracey D, Wadhwa S. Review of New Zealand's key biogenic habitats. National Institute of Water and Atmospheric Research, Wellington. 2019.

8. Turner S, Schwarz A-M. Management and conservation of seagrass in New Zealand: an introduction. Science for conservation. 2006;264(1):80-91.

9. Rowden A, Berkenbusch K, Brewin P, Dalen J, Neill K, Nelson W, et al. A review of the marine soft-sediment assemblages of New Zealand. NZ Aquatic Environment and Biodiversity Report. 2012.

10. Pullen M. The use of seagrass (*Zostera muelleri*) habitat types by seagrass communities in New Zealand. 2021.

11. Lundquist CJ, Jones TC, Parkes SM, Bulmer RH. Changes in benthic community structure and sediment characteristics after natural recolonisation of the seagrass Zostera muelleri. Scientific reports. 2018;8(1):13250.

12. Parsons DM, Middleton C, Smith MD, Cole RG. The influence of habitat availability on juvenile fish abundance in a northeastern New Zealand estuary. New Zealand Journal of Marine and Freshwater Research. 2014;48(2):216-28.

13. Parsons DM, Morrison MA, Thrush SF, Middleton C, Smith M, Spong KT, Buckthought D. The influence of habitat structure on juvenile fish in a New Zealand estuary. Marine Ecology. 2013;34(4):492-500.

14. Stewart AL. 148.10 *Stigmatopora nigra* Kaup, 1856. In: Roberts CD, Stewart AL, Struthers CD, editors. The fishes of New Zealand.: Te Papa Press; 2015.

15. Bulmer RH, Stephenson F, Jones HF, Townsend M, Hillman JR, Schwendenmann L, Lundquist CJ. Blue carbon stocks and cross-habitat subsidies. Frontiers in Marine Science. 2020;7:504858.

16. Duarte C, Marba N, Gacia E, Fourqurean J, Beggins J, Barrón C, Apostolaki E. Seagrass community metabolism: Assessing the carbon sink capacity of seagrass meadows. Global Biogeochemical Cycles. 2010;24.

17. Lavery PS, Mateo M-Á, Serrano O, Rozaimi M. Variability in the Carbon Storage of Seagrass Habitats and Its Implications for Global Estimates of Blue Carbon Ecosystem Service. PLOS ONE. 2013;8(9):e73748.

18. Short FT, Short CA. The seagrass filter: purification of estuarine and coastal waters. The estuary as a filter: Elsevier; 1984. p. 395-413.

19. Birch G, Cox B, Besley C. The relationship between metal concentrations in seagrass (*Zostera capricorni*) tissue and ambient fine sediment in modified and near-pristine estuaries (Sydney estuaries, Australia). Marine pollution bulletin. 2018;128:72-81.

20. Reidenbach MA, Thomas EL. Influence of the seagrass, *Zostera marina*, on wave attenuation and bed shear stress within a shallow coastal bay. Frontiers in Marine Science. 2018;5:397.

21. Bulmer RH, Townsend M, Drylie T, Lohrer AM. Elevated Turbidity and the Nutrient Removal Capacity of Seagrass. Frontiers in Marine Science. 2018;5.

22. Twomey AJ, O'Brien KR, Callaghan DP, Saunders MI. Synthesising wave attenuation for seagrass: Drag coefficient as a unifying indicator. Marine Pollution Bulletin. 2020;160:111661.

23. James RK, Lynch A, Herman PM, Van Katwijk M, Van Tussenbroek B, Dijkstra HA, et al. Tropical biogeomorphic seagrass landscapes for coastal protection: Persistence and wave attenuation during major storms events. Ecosystems. 2021;24:301-18.

24. Chen W, Staneva J, Jacob B, Sánchez-Artús X, Wurpts A. What-if nature-based storm buffers on mitigating coastal erosion. Science of The Total Environment. 2024;928:172247.

25. Narayan S, Beck MW, Reguero BG, Losada IJ, Van Wesenbeeck B, Pontee N, et al. The effectiveness, costs and coastal protection benefits of natural and nature-based defences. PloS one. 2016;11(5):e0154735.

26. Arias-Ortiz A, Serrano O, Masqué P, Lavery PS, Mueller U, Kendrick GA, et al. A marine heatwave drives massive losses from the world’s largest seagrass carbon stocks. Nature Climate Change. 2018;8(4):338-44.

27. Moksnes P-O, Röhr ME, Holmer M, Eklöf JS, Eriander L, Infantes E, Boström C. Major impacts and societal costs of seagrass loss on sediment carbon and nitrogen stocks. Ecosphere. 2021;12(7):e03658.

28. Kendrick GA, Nowicki RJ, Olsen YS, Strydom S, Fraser MW, Sinclair EA, et al. A Systematic Review of How Multiple Stressors From an Extreme Event Drove Ecosystem-Wide Loss of Resilience in an Iconic Seagrass Community. Frontiers in Marine Science. 2019;6.

29. Reed BJ, Hovel KA. Seagrass habitat disturbance: how loss and fragmentation of eelgrass *Zostera marina* influences epifaunal abundance and diversity. Marine Ecology Progress Series. 2006;326:133-43.

30. Inglis GJ. The seagrasses of New Zealand. In: Green EP, Short FT, editors. World atlas of seagrasses. University of California Press; 2003.

31. Park S. Extent of seagrass in the Bay of Plenty in 2011. Bay of Plenty Regional Council; 2016. Contract No.: Publication 2016/03.

32. Crawshaw J, Park S, Medina R, Hawes I, M. M. Seagrass dynamics in the Bay of Plenty. Bay of Plenty Regional Council; 2023. Contract No.: Environmental Publication 2023/10.

33. Forrest BM, Stevens LM. Fine scale monitoring of Motupipi Estuary. Tasman District Council; 2020. Contract No.: Salt Ecology Report 033.

34. Stevens LM, Forrest BM. Macroalgal monitoring of New River Estuary. Environment Southland; 2020. Contract No.: Salt Ecology Report 054.

35. de Lange PJ, Rolfe JR, Barkla JW, Courtney SP, Champion PD, Perrie LR, et al. Conservation status of New Zealand indigenous vascular plants, 2017. Department of Conservation; 2018. Contract No.: Threat Classification Series 22.

36. MacDiarmid A, McKenzie A, Sturman J, Beaumont J, Mikaloff-Fletcher S, Dunne J. Assessment of anthropogenic threats to New Zealand marine habitats. New Zealand aquatic environment and biodiversity report. 2012;93:255.

37. Clark D, Berthelsen A. Review of the potential for low impact seagrass restoration in Aotearoa New Zealand. Prepared for Nelson City Council. Cawthron Report; 2021.

38. IPCC. IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. 2021.

39. Robertson BM, Gillespie PA, Asher RA, Frisk S, Keeley NB, Hopkins GA, et al. Estuarine environmental assessment and monitoring: a national protocol. Part A: Development. Part B: Appendices. Part C: Application.: supporting councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096.; 2002.

40. Booth J.D, Griffiths R, Booth WE, D'Archino R, Nelson WA, Kerr VC, Willoughby RS. Characterising the shallow, soft-seafloor biomes of northern New Zealand's Bay of Islands. 2023. Contract No.: New Zealand Aquatic Environment and Biodiversity Report No. 310.

41. Clark D, Crossett D. Subtidal seagrass surveys at Slipper and Great Mercury Islands.: Nelson City Council; 2019. Contract No.: Cawthron Report 3697.

42. Roberts KL, Scott-Simmonds T, Southwick M, Stevens LM. Broad scale intertidal habitat mapping of Papanui Inlet (Makahoe). Otago Regional Council; 2022. Contract No.: Salt Ecology Report 088.

43. Forrest BM, Stevens LM. Fine Scale Intertidal Monitoring of Nelson Haven, Paruparuroa. Nelson City Council; 2021. Contract No.: Salt Ecology Report 071.

44. Berthelsen A, Clement D, Gillespie P. Shakespeare Bay Estuary Monitoring 2016. Marlborough District Council; 2016. Contract No.: Cawthron Report No. 2833.

45. Crawshaw J. Seagrass health monitoring in Tauranga Harbour. 2020. Contract No.: Environmental Publication 2020/08.

46. Shanahan B, Crawshaw J, Squires K, McElroy T, Griffiths R, O. W. Guidance on council seagrass monitoring. Coastal Special Interest Group (CSIG) internal report. 2023.

47. Robertson B, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, et al. NZ Estuary Trophic Index Screening Tool 2: determining monitoring indicators and assessing estuary trophic state. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract. 2016(C01X1420):68.

48. Roberts KL, Stevens LM. Scoping review to update the National Estuary Monitoring Protocol. Ministry for the Environment; 2023. Contract No.: Salt Ecology Report 115.

49. Clarkson BR, Sorrell BK, Reeves PN, Champion PD, Partridge TR, Clarkson BD. Handbook for monitoring wetland condition. Coordinated monitoring of New Zealand wetlands A Ministry for the Environment SMF funded project Ministry for the Environment, Wellington. 2003.

50. Šunde C, Berthelsen A, Sinner J, Gillespie PA, Stringer K, Floerl L. Impacts of vehicle access at Delaware (Wakapuaka) Inlet. Nelson City Council; 2017. Contract No.: Cawthron Report 3015.

51. Bulmer RH, Kelly S, Jeffs AG. Light requirements of the seagrass, *Zostera muelleri*, determined by observations at the maximum depth limit in a temperate estuary, New Zealand. New Zealand Journal of Marine and Freshwater Research. 2016;50(2):183-94.

52. Zabarte-Maeztu I, Matheson FE, Manley-Harris M, Davies-Colley RJ, Hawes I. Interaction of substrate muddiness and low irradiance on seagrass: a mesocosm study of *Zostera muelleri*. Aquatic Botany. 2021;175:103435.

53. Overmars F, van Kampen P. Seagrass (*Zostera muelleri* subsp. *novazelandica*) survey, Point Howard, Lowry Bay, York Bay and Hutt River Estuary, December 2018. Hutt City Council; 2019.

54. Tait L, Bulmer R, Rodgers LP. Managing and mitigating impacts to seagrass beds Te Rauone erosion remediation. Port Otago Ltd 2020. Contract No.: NIWA CLIENT REPORT No: 2020313CH.

55. Ha N-T, Manley-Harris M, Pham T-D, Hawes I. Detecting Multi-Decadal Changes in Seagrass Cover in Tauranga Harbour, New Zealand, Using Landsat Imagery and Boosting Ensemble Classification Techniques. ISPRS International Journal of Geo-Information. 2021;10(6):371.

56. Ha N-T, Nguyen H-Q, Pham T-D, Hoang C-T, Hawes I. Superpixel for seagrass mapping: a novel method using PlanetScope imagery and machine learning in Tauranga harbour, New Zealand. Environmental Earth Sciences. 2023;82(6):154.

57. Walker DP. Iwi estuarine indicators for Nelson. Nelson City Council under a FRST Envirolink grant NLCC27; 2009.

58. Hansen W, James WU, Christine JP, William CD, Bente Aa L. Effect of the seagrass Z*ostera capricorni* on sediment microbial processes. Marine Ecology Progress Series. 2000;199:83-96.

59. García-Martínez M, López-López A, Calleja ML, Marbà N, Duarte CM. Bacterial community dynamics in a seagrass (*Posidonia oceanica*) meadow sediment. Estuaries and Coasts. 2009;32:276-86.

60. Stevens LM et al. Advice on Indicators, Thresholds and Bands for Estuaries in Aotearoa/New Zealand. Salt Ecology Report 141, prepared for Ministry for the Environment, June 2024.

61. Stevens LM, KL R, Forrest BM, Scott-Simmonds T. Synoptic Broad Scale Ecological Assessment of Pūrākaunui Inlet. Otago Regional Council; 2023. Contract No.: Salt Ecology Report 111.

62. Clarkson BD, et al. Towards quantitative limits to maintain the ecological integrity of freshwater wetlands: interim report. Department of Conservation; 2015.

63. Serrao-Neumann S, Davidson JL, Baldwin CL, Dedekorkut-Howes A, Ellison JC, Holbrook NJ, et al. Marine governance to avoid tipping points: Can we adapt the adaptability envelope? Marine Policy. 2016;65:56-67.

64. Chartrand KM, Bryant CV, Carter AB, Ralph PJ, Rasheed MA. Light Thresholds to Prevent Dredging Impacts on the Great Barrier Reef Seagrass, *Zostera muelleri* ssp. *capricorni*. Frontiers in Marine Science. 2016;3.

65. Chefaoui RM, Duarte CM, Serrão EA. Dramatic loss of seagrass habitat under projected climate change in the Mediterranean Sea. Global Change Biology. 2018;24(10):4919-28.

66. Robertson BP, Savage C. Thresholds in catchment nitrogen load for shifts from seagrass to nuisance macroalgae in shallow intertidal estuaries. Limnology and Oceanography. 2021;66(4):1353-66.

67. Gladstone-Gallagher RV, Hughes RW, Douglas EJ, Pilditch CA. Biomass-dependent seagrass resilience to sediment eutrophication. Journal of Experimental Marine Biology and Ecology. 2018;501:54-64.

68. Cussioli MC, Bryan KR, Pilditch CA, de Lange WP, Bischof K. Light penetration in a temperate meso-tidal lagoon: Implications for seagrass growth and dredging in Tauranga Harbour, New Zealand. Ocean & Coastal Management. 2019;174:25-37.

69. Flowers GJL, Needham HR, Bulmer RH, Lohrer AM, Pilditch CA. Going under: The implications of sea-level rise and reduced light availability on intertidal primary production. Limnology and Oceanography. 2023;68(6):1301-15.

70. Bulmer RH, Stephenson F, Lohrer AM, Lundquist CJ, Madarasz-Smith A, Pilditch CA, et al. Informing the management of multiple stressors on estuarine ecosystems using an expert-based Bayesian Network model. Journal of Environmental Management. 2022;301:113576.

71. Van Meter KJ, Basu N. Time lags in watershed-scale nutrient transport: an exploration of dominant controls. Environmental Research Letters. 2017;12(8):084017.

72. Hamilton SK. Biogeochemical time lags may delay responses of streams to ecological restoration. Freshwater Biology. 2012;57:43-57.

73. Hayden M, Lundquist C, A K. Hapū and iwi perceptions of cumulative effects: towards supporting kaitiakitanga. National Science Challenges: Sustainable Seas; 2023.

74. Dos Santos VM, Matheson FE, Pilditch CA, Elger A. Seagrass resilience to waterfowl grazing in a temperate estuary: A multi-site experimental study. Journal of Experimental Marine Biology and Ecology. 2013;446:194-201.

75. Ramage DL, Schiel DR. Patch dynamics and response to disturbance of the seagrass *Zostera novazelandica* on intertidal platforms in southern New Zealand. Marine Ecology Progress Series. 1999;189:275-88.

76. Morrison MA, Elliot S, Hughes A, Kainamu A, Williams E, Lowe M, et al. Land-based effects on coastal fisheries and kaimoana and their habitats – a review. 2023. Contract No.: New Zealand Aquatic Environment and Biodiversity Report No. 309.

77. Department of Conservation. NZCPS 2010 guidance note Policy 11: Indigenous biological diversity (biodiversity). https://www.doc.govt.nz/globalassets/documents/conservation/marine-and- coastal/coastal-management/guidance/policy-11.pdf. 2019.

78. Gray T. Restoration of Whaingaroa (Raglan) Harbour. Northland Regional Council; 2011.

79. Matheson F, Reed J, Dos Santos V, Mackay G, Cummings V. Seagrass rehabilitation: successful transplants and evaluation of methods at different spatial scales. New Zealand journal of marine and freshwater research. 2017;51(1):96-109.

80. Berthelsen A, Crossett D, Ho M, Brettle E, Clark D. A blueprint for seed-based seagrass restoration in Aotearoa New Zealand. Prepared for Westpac NZ Government Innovation Fund; 2024. Report No.: 4011.

81. Urlich SC, White FR, Rennie HG. Characterising the regulatory seascape in Aotearoa New Zealand: Bridging local, regional and national scales for marine ecosystem-based management. Ocean & Coastal Management. 2022;224:106193.

82. Lohrer D, Awatere S, Paul-Burke K, Kitson J, A-M S. Ki uta ki tai: mātāpono me te pūtaiao, ngā korero whakamahuki ma te kaitiaki – From mountains to the sea: values and science for an informed kaitiaki / guardian. Sustainable Seas National Science Challenge project Ki uta ki tai: Estuaries, thresholds and values; 2024.

83. Awatere S, King DN, Reid J, Williams L, Masters-Awatere B, Harris P, et al. He huringa āhuarangi, he huringa ao: A changing climate, a changing world. 2021.

84. Ministry for the Environment & Stats NZ. New Zealand's Environmental Reporting Series: Our marine environment 2022.; 2022.

85. Rullens V, Mangan S, Stephenson F, Clark DE, Bulmer RH, Berthelsen A, et al. Understanding the consequences of sea level rise: the ecological implications of losing intertidal habitat. New Zealand Journal of Marine and Freshwater Research. 2022;56(3):353-70.

86. Tang KHD, Hadibarata T. Seagrass meadows under the changing climate: a review of the impacts of climate stressors. Research in Ecology. 2022;4(1):27-36.

87. Saunders MI, Leon J, Phinn SR, Callaghan DP, O'Brien KR, Roelfsema CM, et al. Coastal retreat and improved water quality mitigate losses of seagrass from sea level rise. Global Change Biology. 2013;19(8):2569-83.

88. Conservation International, 2024. Hinemoana Halo, Ocean Initiative. Hinemoana ki uta, Hinemoana ki tai, restorating our connection to the oceans, from our high seas to our coastal wates. Report, 16p.

89. Jackson, A.-M., Mita, N., Hakopa, H. (2017). Hui-te-ana-nui: Understanding kaitiakitanga in our marine environment. Report prepared by University of Otago for Ko ngā moana whakaika Sustainable Seas National Science Challenge. July 2017. 167 p

90. Kainamu and Rolleston-Gabel 2023. A review of te ao Māori perspectives of marine sclaes and where these are impeded by contemporary management. Reported prepared for the Sustainable Seas National Science Challenge, by NIWA. 26p.