Guidance on council seagrass monitoring

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June 2023

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Suggested citation for this guidance document:

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

Executive summary

Seagrass (*Zostera muelleri*) is a critical component of coastal ecosystems, providing several ecosystem services. *Z. muelleri* is an at risk-declining species in New Zealand, and loss of seagrass in New Zealand and internationally has been attributed to stressors such as sedimentation, nutrient enrichment, and physical disturbances. The extent of seagrass has been monitored by authorities around New Zealand over the past few decades. In many regions, significant changes in extent have been identified since the early 1940s. Due to a lack of national guidance on how to monitor seagrass habitats, there is a wide variation in monitoring methodologies and effort across different regions of New Zealand.

Since there is not a "once size fits all" approach to monitoring seagrass, background information, guidance, and considerations are suggested for possible monitoring methods, along with several recommendations. Monitoring seagrass covers both mapping its overall extent and tracking its health, utilising seagrass-specific and environmental indicators. To allow for differences in council priorities and resources, we've suggested a "bronze", "silver", and "gold" approach to monitoring (Figure 1).

For councils that are just starting to explore seagrass monitoring, this report should guide them in selecting methods that work best for their circumstance, while being consistent across councils.

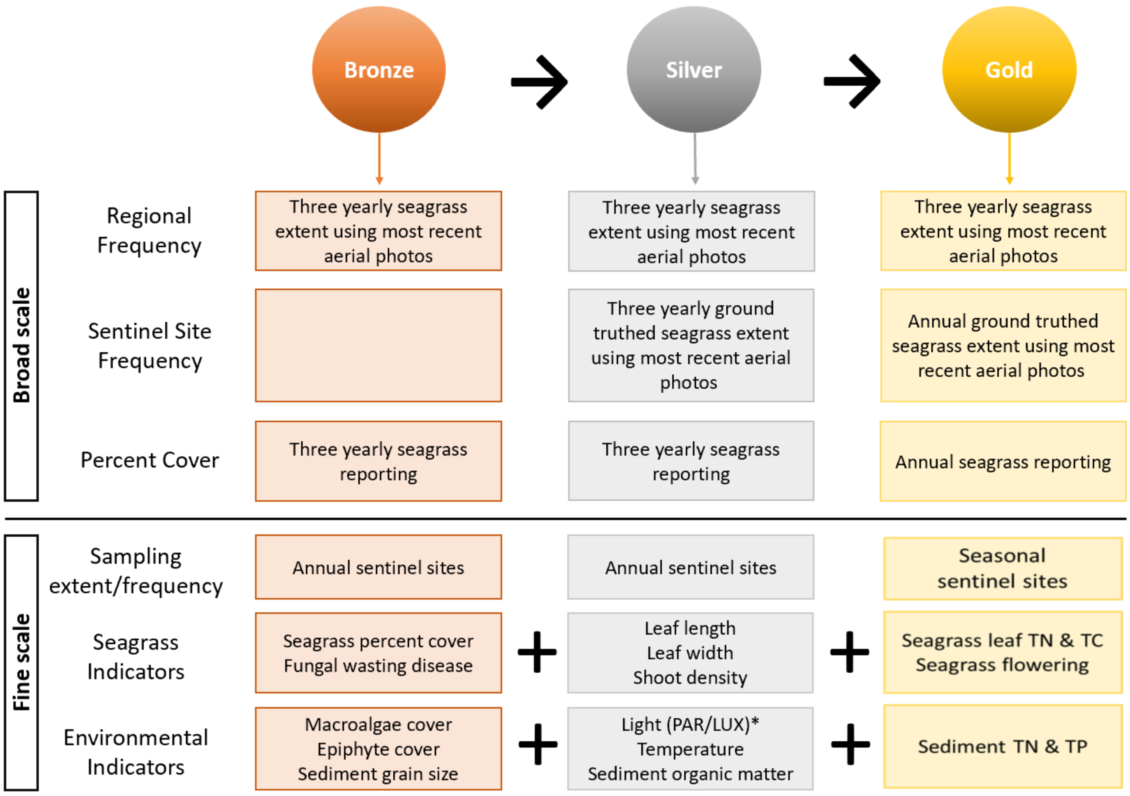

Figure 1. A three-tiered approach to mapping seagrass extent, percent cover, health indicators and stressors. + symbols indicate that lower levels are in addition to variables in higher levels (e.g., gold seagrass indicators include both silver and bronze seagrass indicators). PAR is photosynthetically active radiation and LUX is illuminance. TN is total nitrogen, TC is total carbon, and TP is total phosphorus. Complexity, information gathered, and cost decreases from gold to bronze. *It is preferable to measure light in PAR, however if relationships can be established between PAR and LUX, Hobo LUX loggers can be utilised to decrease costs.

1 Introduction – monitoring seagrass habitats to inform management

1.1 Background – seagrass systems in New Zealand

Seagrass habitats are a critical component of the estuarine ecosystem, providing several ecosystem services including habitat, food, and nursery areas for a range of fish and macroinvertebrates, which supports biodiversity (Morrison et al. 2014). Seagrasses can trap sediments and process nutrients to improve water quality, whilst providing a carbon sink removing CO_2 and sequestering carbon within their sediments (Unsworth et al. 2018). Seagrass ecosystems are under threat globally from a range of human induced stressors including eutrophication, sedimentation, turbidity (reducing light availability), changing water temperatures, grazing by waterfowl, and physical disturbances (dredging, moorings, marine structures; Orth et al. 2006, Roca et al. 2016, Unsworth et al. 2018).

In New Zealand, there is one species of seagrass, *Zostera muelleri*, sometimes referred to as eelgrass (and further referred to in this report as seagrass), and three Māori names (karepō, nana and rimurehia). *Z. muelleri* is a native species with a national threat status of 'at risk-declining' according to the New Zealand's Threat Level Classification System managed by the Department of Conservation (DOC; de Lange et al. 2018). Broad-scale mapping by regional authorities has identified significant losses of seagrass beds throughout New Zealand. The direct causes of such changes have not been determined and may vary in different locations but are likely to involve compounding impacts of sedimentation following the conversion of land from native forest to agricultural and urban land-use (Morrison et al. 2014, MfE & Stats NZ 2022), sediment nutrient enrichment, reduced light availability, marine heat waves, physical disturbance (e.g., loss from land reclamation) and disease.

Some regions of New Zealand have had increases in seagrass extent in the last two decades (Schwarz et al. 2004). These increases have been mainly observed in Auckland (around Waitemata and Manukau Harbours) and Northland (Whangārei Harbour), areas that historically suffered extensive seagrass loss as nearby lands were developed. These recent increases could be a partial recovery of former seagrass cover in response to a reduction of one or multiple stressors. For example, improvements in wastewater treatment from minimally treated wastewater in the 1960s and 1970s may have led to improved coastal water quality, as has been suggested for Whangārei Harbour (Matheson et al. 2017). Increasing sea surface temperature and more settled weather (e.g., less rainfall and increasing droughts) could also positively affect seagrass expansion. However, as these temperatures are sustained and continue to increase with climate change, they may have detrimental impacts, especially if combined with light stress (Matheson 2022). Unfortunately, historical monitoring data is lacking to confirm the main drivers and degree of seagrass expansion or loss in New Zealand. Drivers of these patterns can be improved with current and future monitoring programmes.

Across New Zealand there are three key habitats where seagrass is generally distributed: soft intertidal sediments (predominant habitat), subtidal sediments (historically larger cover), and within soft intertidal sediments on rocky intertidal flats (in isolated locations throughout New Zealand, e.g., Taranaki, Hawkes Bay, Gisborne, Kaikoura). Historically there may also have been seagrass in soft sediment patches associated with subtidal rocky reefs.

1.2 Regulatory framework

There are several regulatory frameworks that direct councils to protect and restore habitats of indigenous biodiversity such as seagrass. The New Zealand Coastal Policy Statement (2010) requires councils: "*To protect indigenous biological diversity in the coastal environment*" and specifically to *"avoid adverse effects of activities on: indigenous ecosystems and vegetation types that are threatened in the coastal environment" and to "avoid significant adverse effects and avoid, remedy or mitigate other adverse effects of activities on: (iii) indigenous ecosystems and habitats that are only found in the coastal environment and are particularly vulnerable to modification including.... eelgrass....*" (Policy 11; page 16). Each Council's regional coastal plan is required to give effect to the Coastal Policy Statement, through identification of issues, objectives, and policies to support the health of the coastal environment.

Te Mana o te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020 is a strategic document from DOC that provides guidance management of biodiversity, especially indigenous biodiversity, in New Zealand. Currently the Coastal Special Interest Group (CSIG) is working with agencies/groups highlighted in the document to achieve better outcomes for coastal biodiversity. These integrated management approaches will also help with outcomes for seagrass health and restoration.

Some Regional Councils have designated areas of significant indigenous vegetation in their regional coastal plans for stronger protection of specific species or habitats (e.g., Significant Natural Areas, Areas of Significant Conservation Value, Significant Ecological Areas, Significant Conservation Areas) potentially giving seagrass additional protection.

The National Policy Statement for Freshwater Management 2020 (NPS-FM) directs Regional Councils to recognise the interactions between freshwater, land, and sensitive receiving environments, including estuaries. For some councils, this is interpreted as setting freshwater limits to protect ecological and cultural values within estuaries, including seagrass habitats.

The resource management system reform is repealing the Resource Management Act to enact three new pieces of legislation: the Spatial Planning Act, Natural and Built Environments Act, and the Climate Adaptation Act. These will involve the development of regional spatial strategies and targets/environmental limits, whilst adapting and preparing for a changing climate. These will involve identifying areas that may require protection, improvement, or active restoration, as well as identifying suitable environmental targets to drive improvements in the natural environment. A National Planning Framework will set natural environmental limits and targets, including for estuaries, for development within those environmental limits. These may include provisions to achieve restoration of marine habitats, including seagrass beds.

The Parliamentary Commissioner for the Environment in 2019 highlighted issues in environmental monitoring and reporting (PCE 2019), and work is underway to amend the Environmental Reporting Act to improve state of the environment reporting. Unlike many other environmental realms, the coast and estuaries have often been left behind in terms of national frameworks that standardise monitoring and reporting requirements. This has led to a variety of monitoring methods, standards, and investment for monitoring across councils, which can be difficult to assimilate to report on the state of coastal ecosystems, including estuaries, across New Zealand.

1.3 Purpose and goals

This document aims to provide regional councils with guidance on developing and implementing seagrass monitoring programmes, incorporating broad-scale mapping approaches for characterising seagrass extent, and fine-scale monitoring of indicators of seagrass health and condition, as well as indicators of stress. Fine-scale seagrass monitoring can help identify the causes of loss or expansion in seagrass extent and improve our understanding of limits and thresholds that support seagrass health. Early determination of fine-scale stress to seagrass may allow for adaptive measures to help stop, and reverse, seagrass decline.

A key goal is to facilitate the standardisation of monitoring methods, and to support increased consistency for environmental reporting. In doing so it is hoped this will provide an opportunity to develop and include seagrass indicators in future national environmental reporting, such as the Ministry for the Environment – Our Marine Environment 3 yearly reporting (MfE & Stats NZ 2022).

For this report, we define seagrass extent (assessed using broad-scale monitoring methods) as the mapped extent of seagrass cover across a defined area. Monitoring the change in seagrass extent over time is one way to assess the impacts of environmental stressors. Broad-scale mapping approaches (e.g., ground-truthed field surveys mapped onto aerial photos or remote sensing using spectral signatures to detect vegetation) have been used to assess changes in seagrass extent, spatial location of seagrass and, in some cases, percent cover. We use the term fine scale monitoring to represent monitoring of seagrass and environmental health indicators.

An important part of any monitoring programme includes planning for data analysis post collection. While we address sampling frequency and methodologies to capture the cause of potential changes outside of natural variability, specific data analysis approaches are out of the scope of this document. The way monitoring programmes are set up can vary and the recommendation is to refer to the references within for guidance on appropriate data analysis approaches.

Since seagrass losses in some regions have been significant, there is a lot of interest in seagrass restoration. Different approaches to seagrass restoration in New Zealand are being trialled now (see Appendix A), but it is beyond the scope of this document to provide guidance on restoration or review the projects currently under way.

As with all environmental monitoring in New Zealand, Mātauranga Māori is an important consideration for understanding the local significance of seagrass habitat and its linkages with mahinga kai and taonga species within each region. We recommend monitoring programmes within each council should be co-developed with mana whenua to acknowledge any tohu (environmental indicators) related to seagrass as well as include all aspirations for seagrass health and extent. However, specific Mātauranga Māori approaches to monitoring seagrass are outside of the scope of this document.

With legislative reforms and reviews currently in progress along with constant improvement and availability of technology, the expectation is to review the current guidance after 3 years to ensure its contents are still relevant and the recommendations are fit for purpose.

2 Mapping seagrass extent and percent cover

Monitoring change in habitat extent over time is one way to assess the impacts of environmental stressors. Various tools, including remote sensing (i.e., using the spectral signature from imagery to detect vegetation), are used to map key habitats such as seagrass. Advantages of remote sensing include assessing large areas quickly, efficiently, and consistently, as well as providing images for remote parts of the coast that are difficult to access. Methods used to monitor the extent of seagrass over time have varied across councils and other agencies (e.g., Department of Conservation (DOC), Ministry for Primary Industries (MPI), National Institute of Water and Atmosphere Research (NIWA), Cawthron Institute, Universities, and consultancies). To date, there has not been a nationally consistent approach to monitoring seagrass extent. Figure 2 provides an overview of the different methods of data capture, sensor options and classification methods available for mapping seagrass extent and percent cover.

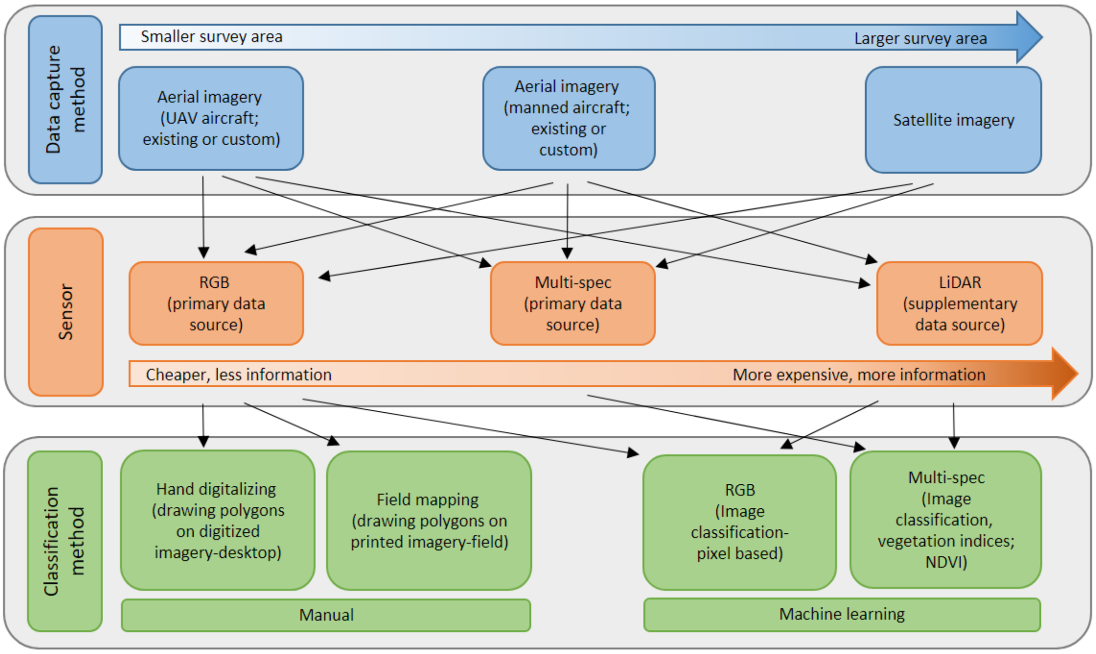

Figure 2. Flow chart of monitoring options for seagrass extent. UAV = unmanned aerial aircraft, RGB = refers images captured with only the red, green, and blue bands of the electromagnetic spectrum, Multi-spectral = imagery with several wavelengths across the electromagnetic spectrum including red, green, and blue, LiDAR = light detection and ranging, NDVI = Normalised Difference Vegetation Index.

Since 2014, DOC has hosted an online portal[1] collating seagrass spatial mapping data in New Zealand, including some regional council data. The most recent nationwide update was in 2018. The DOC portal includes data collected using a wide range of methods with variable spatial accuracy, and a lack of consistency in mapping classifications, terminology, and associated metadata (Anderson et. al 2019). Aligning data collection methods will allow for better collation of data on a national scale and could support improved reporting of seagrass extent in national environmental reporting.

To date, regional councils have used three main methods of image capture (Appendix B): unmanned aerial vehicles (drones), manned aerial imagery and satellite imagery. These image capture methods are suitable for mapping intertidal seagrass, when exposed at low tide. Under

[1] https://www.seasketch.org/#projecthomepage/5357cfa467a68a303e1bb87a

ideal conditions, e.g., in areas with high water clarity with no surface glare, they can also capture detail in the shallow subtidal zone. Council approaches for mapping have included field-based assessments of seagrass extent (some repeated over time), desktop-based approaches using historical images to compare with current extent, or targeted studies using transect or quadrat-based sampling approaches (Appendix B).

There are currently two general methods used for mapping seagrass, manual or automated digitisation:

1) **Manual digitisation** of seagrass beds uses orthorectified imagery captured by either drone, plane, or satellite, and manual human interpretation and digitising of polygons using Geographic Information System (GIS) programmes. This can be aided with oblique photos and is commonly (but not always) supported by ground-truthing of features visible on the imagery via field surveys.

2) **Automated digitisation** uses machine learning based on the spectral analysis of imagery captured by either drone, plane, or satellite. This method works best with ground-truthing of features visible on imagery to train the machine learning and to determine the accuracy of automated classification (Tait et al. 2019). Although this approach has been used extensively internationally for some time (Traganos and Reinartz 2018, Coffer et al. 2020), seagrass mapping with automated digitisation remains largely in development in New Zealand, with few councils currently using it as a primary method (Taranaki Regional Council 2020, Ha et al. 2020).

The remainder of this section includes recommendations for mapping seagrass extent and capturing data to align across councils (Sections 2.1, 2.2, and 2.3) followed by details on mapping methods (Section 2.5) and types of aerial images (Section 2.6).

2.1 Definitions and thresholds for classification

The use of different classification definitions and thresholds make it difficult to maintain consistency in seagrass monitoring and management. Below is a standardised classification procedure to ensure consistency.

Scale of Mapping

To align council data, it is recommended that the smallest unit to be digitised for larger scale mapping projects (e.g., regionwide or whole estuaries/reefs) should have a short-axis dimension of at least 2 m to align with the National Estuary Monitoring Protocol (NEMP – Robertson et al. 2002). Note, however, that handheld GPS units often have an error of +/-3 m and ground-truthing is likely to be done using handheld GPS units and mapping patches smaller than 3 m may require support from high resolution aerial images (e.g., drone or aerial images).

For detailed mapping at a local scale, if ground-truthing is done with a real time kinematics (RTK) unit or very high-quality imagery is available (with precisions as fine as 1-2 cm), it's possible to map smaller patches (in the scale of metres^2) to a resolution of 0.5 m.

Percent cover classification

Multiple categories of percent cover have been applied throughout New Zealand monitoring programmes which have led to challenges collating data nationally. Classification using 'fine percent cover values' (percent cover bands in 10% increments - see Table 1) is preferred, but if coarse classes only are possible, we recommend aligning percent cover classification with those of Coastal and Marine Ecological Classification Standard (CMECS; FGDC 2012) to help align data nationally (Table 1). Visual examples of different percent cover classes are presented in Figure 3.

Areas are to be mapped if seagrass extent of the ‘coarse percent cover value’ is ‘sparse’ (1-30% cover) or greater (i.e., exclude areas with trace, or <1%, seagrass).

There are numerous approaches to recording percent cover, which include a visual estimate against a reference guide (Figure 3), counting the number of intersections in a gridded quadrat, using a dots-on-rocks approach (Meese & Tomich, 1992), or using automated classification approaches. In New Zealand, the most common approach is comparison to a visual estimate guide (e.g., Scott-Simmonds et al. 2022, Stevens et al. 2022, Roberts et al. 2022).

Table 1. Percent cover classes in the Coastal and Marine Ecological Classification Standard (CMECS)

Coarse percent cover values	Fine percent cover values
Trace or absent	< 1%
Sparse (1 to < 30%)	1 to < 10%
	10 to < 20%
	20 to < 30%
Moderate (30 to < 70%)	30 to < 40%
	40 to < 50%
	50 to < 60%
	60 to < 70%
Dense (70 to < 90%)	70 to < 80%
	80 to < 90%
Complete	90 to 100%

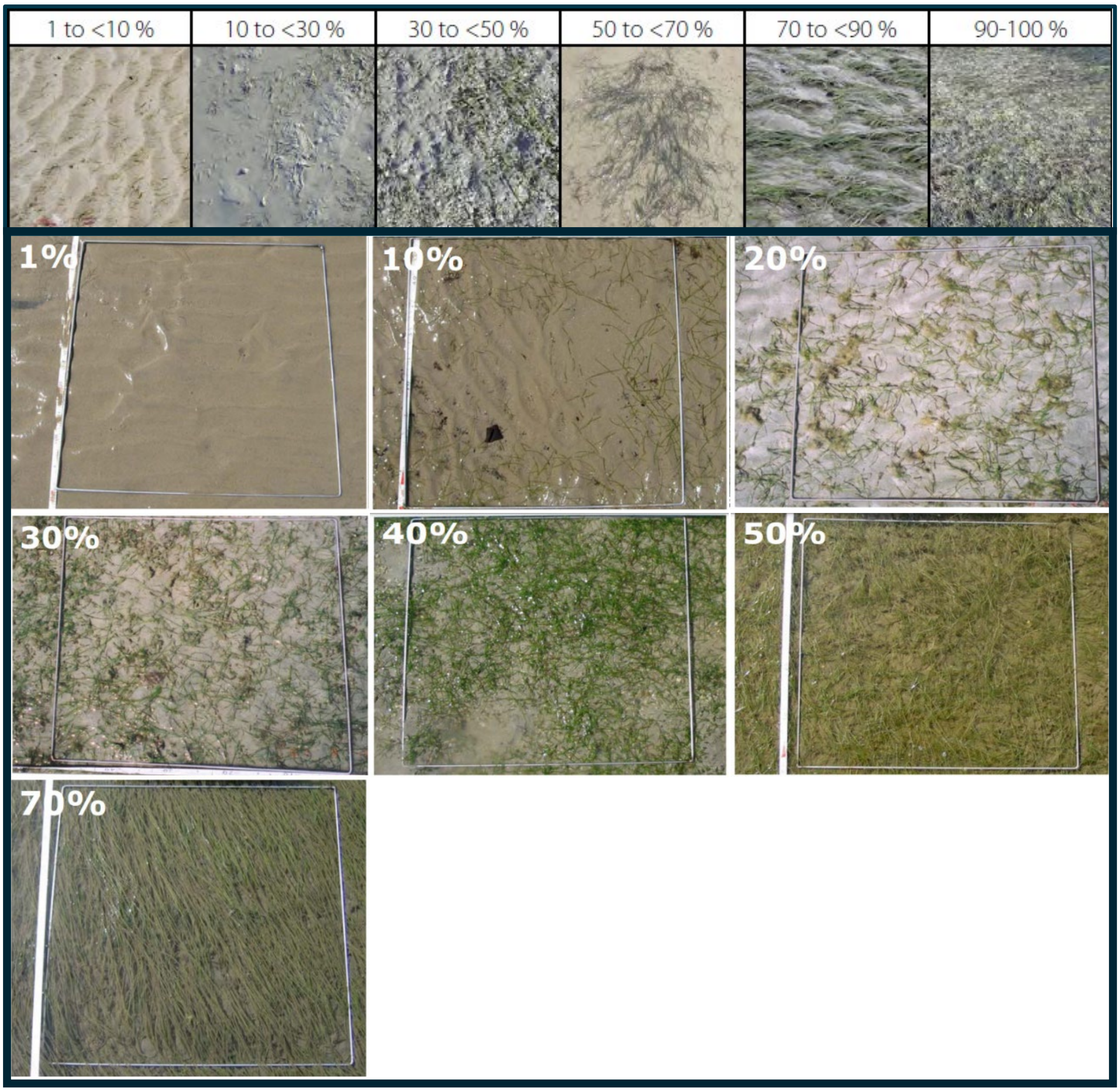

Figure 3. Visual examples of seagrass percent cover taken from Stevens et al, 2020b (top panel) and Seagrass-Watch ID field guide and summary (bottom panel).

Discrete measures vs spatial averaging
Wherever it is possible to map seagrass areas discretely, percent cover classifications should be applied to specific patches or an area of a known size. However, in cases where it is either not possible to map individual patches (e.g., due to poor photo resolution or difficulty detecting sparse cover from aerial photos), or the scale of area is too large to map sparse patches individually, seagrass can be recorded as an average cover over a larger area. In situations where discrete patches of seagrass are less than 1 m apart, and which if grouped together would be more than 10 m across their long dimension, these can be mapped as one feature.

Patch vs meadow
Seagrass can cover large areas up to 92,000 km^2 (Gallagher et al. 2022). However, that habitat isn't always continuous, and a wide range of terms have been used to describe smaller units of seagrass including patches or meadows. Patches are defined as anything >1m diameter to less than the minimum meadow size. Meadows have been defined as being from 100 m minimum diameter to 1km across at their widest (McKenzie et al. 2022) to anything over 1 ha or 10,000 m^2 (Anderson et. al 2019). The size of a seagrass patch or meadow has implications for management because impacts on seagrass can be size-dependent. For example, the same activity may disproportionally affect a small area of seagrass more than a large area because the small area may be prone to complete loss while the large area has more capacity to support recovery. Similarly, a single meadow may have greater resilience than the equivalent area made up of discrete patches due to decreased edge effects.

To address this, it is recommended councils use a consistent size definition for meadows and patches, with coarse percent cover classes (e.g., sparse/moderate/dense/complete) used as modifiers as follows:
Patch: any single area of seagrass >1 m^2 – 1000 m^2 in area and >1 m apart from another area;
Meadow: any single area of seagrass >1000 m^2.
For example, a 100 m^2 area of seagrass with 20% cover would be described as a sparse patch, while a 1ha (10,000 m^2) area of seagrass with 70% cover would be classed as a dense meadow.

Note that seagrass "bed" is a term often used to describe a location where seagrass is located. However, it does not provide an indication of area covered by seagrass so it is not included as a term with a size definition in this document.

Definitions and thresholds for classification summary
- Include all units with short axis > 2m
- Percent cover classification should align with the Coastal and Marine Ecological Classification Standard (CMECS)
- Minimum percent cover to include is 1% or greater
- Where possible, map seagrass areas discretely unless imagery too poor or area too large
- Seagrass patch is any single area of seagrass >1 m^2 – 1000 m^2 in area and >1 m apart from another area
- Seagrass meadow is any single area of seagrass >1000 m^2

2.2 Seagrass mapping monitoring effort and frequency

To enable all councils to participate in aligned seagrass extent mapping, a three-tier proposal is shown below (Figure 4), that identifies a bronze, silver, and gold standard. The bronze is considered the bare minimum to map seagrass cover. It includes mapping regional extent and percent cover of seagrass using, at a minimum, the coarse percent cover values from CMECS (Section 2.1) with the most recently available aerial imagery without any ground truthing every three years. The silver approach is the same as the bronze programme but includes ground truthing every 3 years at sentinel sites. The gold approach requires mapping aerial imagery and recording seagrass percent cover every three years across the region and ground truthing sentinel sites annually. To understand when annual extent changes are significant versus natural variability, it's recommended to map seasonal changes in extent at sentinel sites for the first few years.

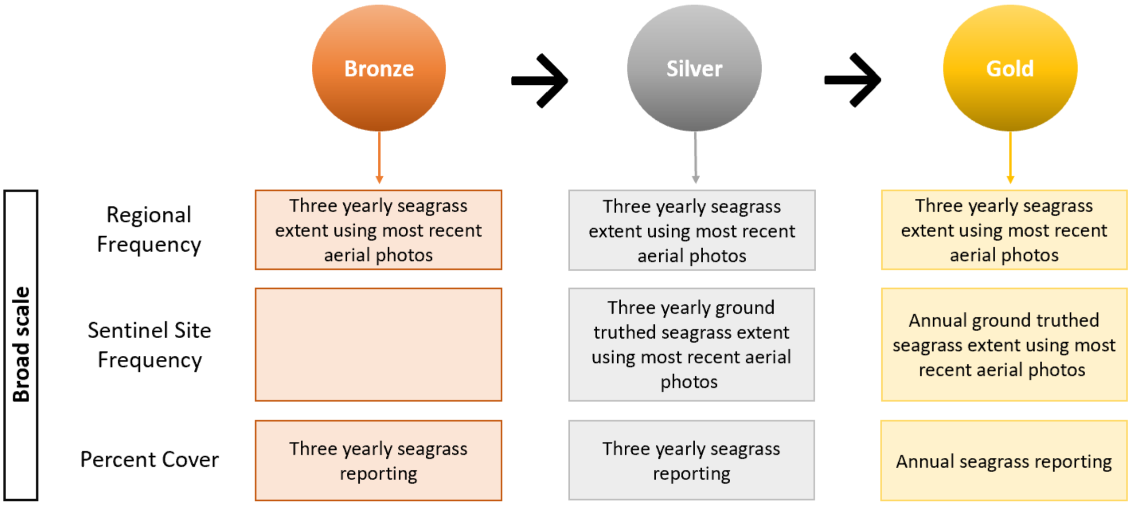

Figure 4. A three-tiered approach to mapping seagrass extent and percent cover.

2.3 Data Capture Guidance

This section provides information about things to consider when capturing the imagery. Details about different options to collect aerial images are in Section 2.6.

2.3.1 Choosing sentinel sites

Sentinel sites are typically selected for inclusion in State of the Environment monitoring programmes on the basis that they are representative of a particular region or environment type, for the attribute or parameters that will be monitored. They also are chosen for long-term monitoring to detect and understand changes in the ecosystem or habitat of interest. Often referred to as canaries in the coal mine, sentinel sites serve as an indicator of what's occurring in that region, based on the assumption that any changes observed at these sites are likely to be representative of changes that are occurring at a wider scale. Long-term monitoring of sentinel sites is one of the only ways that we can: define the state of the environment, understand the causes and magnitude of natural variability, provide baseline information so environmental changes relating to management decisions can be detected, identify changes driven by manageable, human driven stressors, and track key trends to inform future management strategies (Sustainable Seas, 2021).

The NEMP (Robertson et al. 2002) includes a decision matrix that helps users weigh factors (both issues and characteristics) to rank estuaries within a region which may help in choosing seagrass monitoring sites. When mapping extent, sites can mean entire estuaries or a series of patches along the coastline (when not in an estuary). When referring to sites for seagrass health, often those are sites within an estuary or series of patches. When reporting, it's important to include the site definition and area.

Selecting representative sites

Sentinel seagrass sites should be selected to be representative of stressor gradients existing in the catchment or in the estuary. For example, consideration could be given to proximity to river inflows (thus catchment pressures, nutrient and sediment loading variability), discharges from land (e.g., urban rural areas and stormwater networks), disturbances/activities in the estuary or along the coast (e.g., mooring sites or aquaculture) and distribution across spatial gradients (e.g. mud content, bathymetry, sub-estuary environments). As a minimum, at least one low impact site should be included as a benchmark or reference site against which to assess effects of natural/climatic variation, opposed to effects of land use or other stressors.

2.3.2 Time of year

Z. muelleri coverage and condition often exhibits degrees of spatial and temporal i.e., seasonal, variations (Turner & Schwarz, 2006 and references therein). As such, monitoring efforts need to be standardised in space and time to prevent these factors from confounding data and its subsequent analysis. Despite this standardisation, there will still likely be natural variability in seagrass indicators.

For councils to be able to collate data on a national level, monitoring seagrass is best from September through to May when seagrass is likely to be nearing, or at peak of its annual growth cycle and when it tends to flower in New Zealand (Kerr and Strother 1989). Because of the length of this window, councils should work within a 2-month window between September and May to limit variation as much as possible.

2.3.3 Image resolution

The recommended minimum resolution is 0.3 m (30 cm/pixel) to align with most regional aerial imagery taken by Land Information New Zealand (LINZ) flown with that resolution.

2.3.4 Environmental conditions

Environmental conditions can affect your flight time and image capture quality. If image capture is going to be part of a repeated monitoring survey, it is important to keep environmental conditions consistent across surveys. If working with a contractor, it is recommended ensuring environmental conditions are covered as part of your planning process, particularly appropriate tide height.

Below is a list of considerations. Note that to accommodate all these considerations could leave a small window of time to collect imagery. It might require a bit of trial and error to find the best conditions for the planned classification method:

- Height of tide will affect imagery in intertidal areas. Preferably take images at low tide. Even slightly submerged zones within the survey area will have a different appearance to the exposed areas, which will affect the image classification.
- Calm wave conditions are preferable with clear water (as best as possible).
- Light conditions can have a significant effect on image quality in a couple of different ways.
    - Image colour may be affected by how sunny or cloudy the conditions are. Heavily overcast conditions may result in darker images which can affect image classification.
    - The angle of the sun can also affect the images in conflicting ways.
        - The higher the sun is in the sky, the less shadow cast will affect the imagery for areas with varied topography.

    - However, if taking photos near water, high reflectivity from mid-day sun can create white spots in the imagery that affect mapping. Avoid taking images from 11 am-1 pm to prevent this issue.
- Less time out of water. Dry seagrass can be difficult to distinguish in aerial images regardless of resolution.
- Images in deeper than 1 m of water are difficult to later classify and some automated classification methods may be less successful with under water images.

2.3.5 Camera type

Cameras can take images using different wavelengths. A traditional digital camera uses a filter to block the invisible light, and only captures the visible light that falls onto the sensor with 3 wavelengths (red, green, and blue – RGB). A multi-spectral camera captures light from a narrow range of wavelengths across the electromagnetic spectrum allowing for more advanced image collection and analysis. These wavelengths include frequencies that are invisible to the human eye, such as infrared light.

Since council resourcing may determine the type of camera available for surveying, there is no specific recommendation for the type of camera needed for imagery. Tait et al. (2019) found that the classification of algal species was less than 80% when using RGB cameras alone compared to 82% with a multi-spectral camera. While those numbers are similar, multi-spectral cameras are preferred. The additional wavelengths recorded in multi-spectral cameras can enhance classification by, for example, deciphering between similarly coloured species (e.g., *Ulva* spp. vs seagrass). Of note is that accuracy of classification improved to over 90% when the two camera types were combined. As a minimum to achieve an optimal image quality, it is recommended that the camera resolution is no less than 20 mega pixels (what most drones come with as their standard camera).

When selecting a camera, it's important to consider Ground Sampling Distance (GSD), the distance between two consecutive pixel centres measured on the ground. When attempting to perform image classification with GIS, you need pixels no greater than 2-5 cm. The smaller the GSD, the higher the image resolution. A GSD calculator[2] can be used to understand the relationship between GSD and camera specifications.

2.3.6 Image and data storage

Since councils have their own storage systems, there is no specific recommendation on how to store aerial images, but it is an important consideration when planning. Remote sensing images can take up significant storage space. For example, high resolution drone imagery can involve 100s to 100,000s of images for a single estuary, each with a relatively large file size. There can be losses of resolution when stitching images together, and total file sizes can become unworkable due to their large size. Councils may have in house rules regarding image storage. Consulting IT is a good idea because they may have alternate or offsite servers that can handle the large space requirements. However, offsite servers can result in slow image processing on a local machine. If images are stored on an offsite server, putting a copy of the images on an external hard drive to use while working with GIS software is highly recommended, particularly for initial processing. Also of note is that some image processing software will store the image outputs in the cloud, which can result in slow image loading and rendering times.

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[2] A GSD calculator example: https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-calculator

When storing images, it is important to capture the metadata associated with them. Be clear with what the time the data layers represent (e.g., month and year of image, ground truthing, or report year).

Data capture guidance summary

- Choose sentinel sites across stressor gradients and based on other key regional criteria
- Monitor in a 2-month window between September and May
- Minimum resolution of imagery should be 0.3 m (30 cm/pixel)
- Consider environmental conditions before capturing images (e.g., tide height, wave conditions, light conditions)
- Use an RGB + multi-spectral camera where possible, with a minimum of 20 megapixels
- Plan for storage of large data, and image files, and appropriate metadata

2.4 Subtidal seagrass

Subtidal seagrass is regarded as an especially valuable fish habitat (M. Morrison, NIWA), and represent areas of seagrass most vulnerable to deteriorating coastal water quality (i.e., indicated by the 90% loss of subtidal seagrass in Tauranga Harbour; Park 1999), and to impacts of increasing sea level rise (e.g., decreasing water clarity, and submersion of intertidal seagrass; Rullens et al. 2022).

For water bodies with high water clarity and shallow depths, aerial imagery may be suitable for mapping subtidal seagrass (Park 1999). In many locations the depth may be too great, or water clarity too poor to enable aerial techniques for mapping subtidal seagrass. As noted above, some automated classification methods are less successful at detecting seagrass properly when overlaying water changes the colour palette of the image.

Several methods are available for assessing subtidal seagrass, such as mapping from a boat (with the aid of scuba divers/snorkelers; Clark and Crossett 2019), utilising remote video options such as remote operated vehicles (ROV) or drop cameras (WRC, 2022 unpublished). For example, Waikato Regional Council have developed an inexpensive drop camera rig that captures a 0.25 m^2 quadrat in-frame and provides a live video surface feed. When deployed from a boat, video can be captured via drift transects or trolling slowly. Paired with GPS tracks, a spatial map of seagrass percent cover and extent can be created.

Multibeam mapping uses a type of sonar (**SO**und **NA**vigation and **R**anging) system that sends and receives pulses of sound to the seafloor to create a picture of the geological composition of the seafloor. This mapping technique was used to detect subtidal seagrass in the Marlborough Sounds (Anderson et al. 2020).

Internationally, other methods are being trialled for monitoring seagrass subtidally, including the use of uncrewed surface vessels outfitted with an altimeter[3].

[3] https://www.hydro-international.com/content/article/enhanced-solutions-for-seagrass-monitoring

2.5 Mapping methods

Accuracy of mapping depends on several factors (classification technique, data points vs polygons, validation data, etc.) so specific recommendations are not possible. However, going over data capture and analysis plans with the person analysing the data (e.g., GIS team if internal, consultant if external) is recommended to capture what is needed for the best accuracy. Note that some methods may require multiple trials to determine the best mapping methods. See Table 2 for a list of pros and cons of different mapping methods with details in the sections below.

To date, the only national dataset of seagrass mapping is managed by DOC. To add any new surveys to this dataset, images, metadata and a link to the associated report (including mapping methodology) should be sent to ourestuaries@doc.govt.nz. This will enable publicly funded data to be used for wider scale comparisons and national reporting.

Table 2. Pros and cons for image classification methods.

Method		Pros	Cons	Cost of each survey at one site (inc. time; $-$$$)
Manual	Hand digitising of aerial imagery	• No field time necessary (but recommended – see Cons) • Quick and easy • Large areas up to region scale can be mapped with reasonably high accuracy by staff with minimal GIS training in a short period of time. • Relatively low cost	• Potential for misclassification • Difficult to map sparse, low-percent cover patches • Not necessarily without field time/costs because field validation recommended (for new images) or the use of alternative images (e.g., obliques) to verify feature classification • Need software and GIS competency • Availability and quality of aerial images	$$ (moderate time investment to distinguish features on imagery)
	Field mapping	• Simple – can determine % cover from image guide • Certainty	• Difficult to accurately map sparse, low-percent cover patches • Site access • May not be practical for larger water bodies	$$$ (high time investment to travel to and walk around seagrass sites)

Method		Pros	Cons	Cost of each survey at one site (inc. time; $-$$$)
Machine learning	Image classification[4]	• Potential for highly accurate outputs (depending on classification effort) • Pixel-based classification can be more effective for patchy/ sparse areas than human eye • Efficient after setup	• Need high level GIS competency • High time requirement to set up classification • If several misclassified areas, high time requirement to manually reclassify • Processing time • Still requires field validation	$$ (high time investment initially to set up classification; efficiencies realised in repeat surveys after initial training process is complete)
	Normalized Difference Vegetation Index (NDVI)	• Possible in Drone Deploy and ArcGIS pro • Robust for patchy sparse seagrass at high ground-pixel resolution	• Still requires field validation • High level of GIS competency • Additional processing steps and larger datasets	$$ (can be done relatively easily, validation can require time; end product would be better than RGB)

2.5.1 Mapping Repeatability

To ensure repeatability over time and minimise methodological artefacts, it is recommended that details of surveys across years are well documented. For example, people may walk different lines along the edge of a seagrass bed without an understanding of how it was done previously. Likewise, training samples for machine learning are not always usable across images taken with different conditions (time of day, season, different tide heights etc.). Different samples can also result in dissimilar classification results. Much like the associated metadata recorded with your images (Section 2.3.6), recording detailed methodology and reviewing these details prior to resampling will improve similarity across surveys.

2.5.2 Manual digitisation

Manual methods refer to mapping approaches that do not involve any machine learning assistance in the classification process. To date, manual methods have been the most commonly and reliably used methods for mapping seagrass in New Zealand.

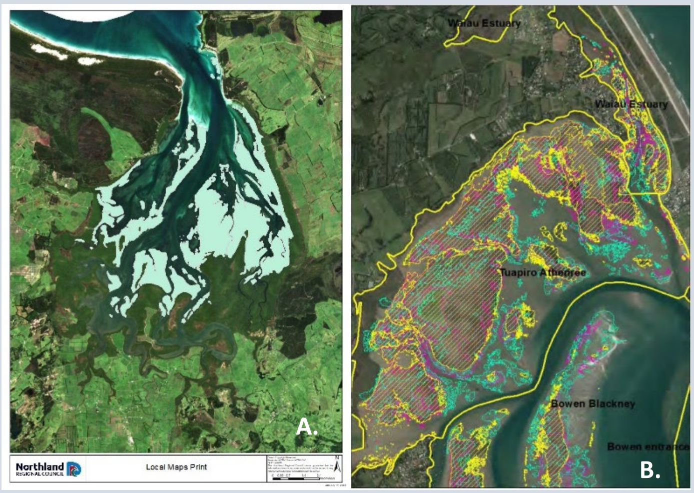
2.5.2.1 Hand digitising

Depending on the resolution of the imagery that is being used, it may be possible for the mapping exercise to be an entirely desktop-based process (i.e., manually drawing polygons around seagrass features using council GIS software). Although this is useful for mapping large areas or historic photos (Gillespie et al. 2011, Park 2016), there will always be a degree of uncertainty around the classification accuracy, particularly for determining percent cover, unless ground truth field surveys are incorporated to validate the mapping efforts. Two examples of hand digitising are included below as case studies to highlight this method to map seagrass. Please note that these examples do not use the CMECS classification recommended above (Section 2.1).

Note on historic imagery: Historical imagery can be accessed at retrolens.co.nz, a compilation of crown archived imagery between 1936 to 2005. These are available for download and can be

[4] for a list of potential references, see Appendix C

geo-referenced and orthorectified following LINZ standards[5]. Check internally with GIS teams if this process has already been undertaken for your region.

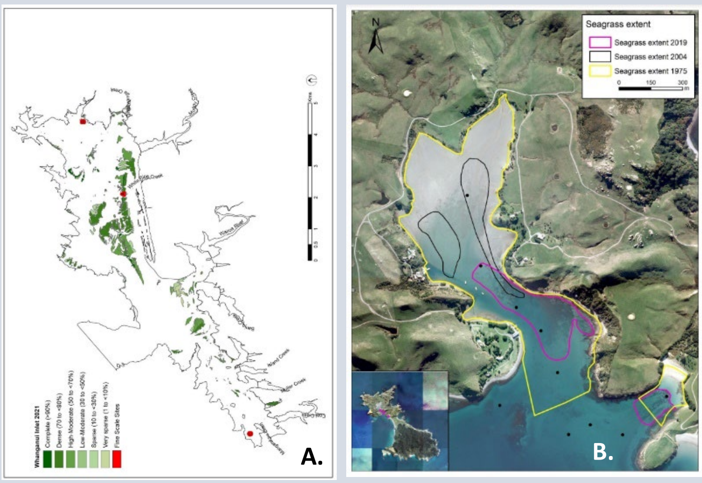


A. In 2015, Northland Regional Council (NRC), hand digitised seagrass from aerial images to assist with the identification of ecologically significant areas in the coastal area of Northland as part of the development of the new Regional Plan. The protocols used by NRC were adapted from protocols developed by Wilton & Saintilan (2000) for mapping mangrove and saltmarsh habitat. For details of the protocol see Appendix C. Photo is of Rangaunu Harbour – light blue areas are seagrass habitat (Northland Regional Council).

B. In 2011, Bay of Plenty Regional Council mapped seagrass across the region using aerial photography. Polygons of seagrass were grouped into percent cover classes and mapping was mainly a desktop exercise with minimal input from ground truth surveys. Current extent was also compared to historical images to determine change over time. For details of the protocol see Park (2016). Colours in photo are seagrass extents in Tauranga Harbour over time 1959 (aqua), 1996 (purple), and 2011 (yellow).

2.5.2.2 Field mapping

The ability to map all features >2 m in diameter (as recommended in the NEMP; Robertson et al. 2022) is largely dependent on the quality of the aerial imagery available. If image resolution is too low or if there is uncertainty about features in the imagery (e.g., areas of low cover, e.g., <20% seagrass cover, are not always clearly visible on satellite or aerial imagery), councils may choose to validate images by ground truthing. Ground truthing involves visiting sites to verify features in images or walk the permitter of seagrass patches/beds. It is often constrained by the available budget, particularly in larger estuary/coastal systems. Two examples of field-based ground truthing are included below to highlight methods used in New Zealand. Please note that the second example does not use the CMECS classification recommended above (Section 2.1).



A. The method outlined in the NEMP (Roberston et a al. 2022) and subsequent extensions (e.g., Scott-Simmonds et al. 2022, Stevens et al. 2022, Roberts et al. 2022) includes verifying features evident on aerial photos in the field and subsequently digitizing them into GIS layers (e.g. ArcGIS). Seagrass cover is classified using the 6-category rating scale in Figure 3 (top panel) and maps of the dominant surface features are produced with a horizontal accuracy typically of 2-5 m.

B. Seagrass meadow extent was first digitised from recent aerial photographs using GIS. The boundary of each seagrass meadow was then ground-truthed by tracking the perimeter of the bed using a GPS with single position fixes recorded every 5 seconds using observers from a vessel and snorkelling. Following previous survey methodology (Schwarz et al. 2006), seagrass meadow boundaries were determined as the point where seagrass cover exceeds 5%.

5 https://www.linz.govt.nz/sites/default/files/Georeferencing%2520and%2520orthorectification%2520guidelines%25202014%2520.pdf

2.5.3 Machine learning methods

Machine learning is a technique that uses algorithms to help GIS software decide the most likely class of a feature in an image. These techniques, including deep-learning, are becoming a key tool in a variety of fields and are improving dramatically. Machine learning methods that have been used to map seagrass vary. For a list of some of the more common approaches and references, see Appendix D.

The procedures around image preparation and correction for machine learning are complex and are not covered in this document. Utilising machine learning has the potential to increase up-front costs, but dramatically reduce ongoing costs for future monitoring. Below some key considerations are outlined but it is not an exhaustive list because this section could form its own document. These procedures are important when considering pulling together national datasets.

Note that to classify vegetation from images, images may require corrections prior to starting (particularly for satellite imagery). These can vary depending on if seagrass is above or below water, but include the following (see Traganos and Reinartz (2017) for more information):

1. Land and cloud
2. Sun glint
3. Atmospheric correction
4. Water column

Machine learning approaches require good knowledge of the biotic and abiotic features being mapped to validate the accuracy of the mapping. For satellite imagery, advice from Apollo Mapping is that it is almost always quicker to manually digitise features from scratch than to make corrections to automatically generated polygons. Where there is still ambiguity between visual features, ground truth samples will help to improve the accuracy of this process (see Section 2.6.1.3 for more on ground truth sampling). However, as technology and classification techniques improve, machine learning could provide the opportunity for less labour and decrease overall costs.

2.5.3.1 RGB image classification

Image classification is done using GIS software like the ArcGIS products or R. There are a few possible approaches to classifying images based on access to software, skills, and funding. Image classification with GIS software is an approach that classifies images based on different features of the images captured. Classes are the groups that features in the image are put into. For example, if mapping habitat, there could be several classes split by species present.

The first step for image classification is to designate the training samples which include a subset of points or areas in the imagery that are known features. These samples train, calibrate and then test the classification model before it is applied to the full image. Image classification for monitoring on ArcGIS is either supervised or unsupervised and based on objects pr pixels in the image (Table 3). Both supervised and object-based classification require training samples. The number of training samples used for classification can depend on the image, but the more training samples per class the better. Without trial and error, it is challenging to know exactly what you need to capture in the field before attempting image classification. Talk to a GIS team or consultant to help guide the number and type of samples needed.

Table 3. Image classification types in ArcGIS.

Classification types			
Supervised	**Unsupervised**	**Object-based**	**Pixel-based**
A human operator manually identifies each class and provides training samples (polygons) for each class.	The algorithm automatically identifies distinct spectral classes	A pre-processing step called "segmentation" is used to identify shape/colour "segments" which are then used as units for classification. Ideal when limited spectral information is available (i.e., RGB)	Each pixel is a unit that can be classified based on its colour. Not very good with limited spectral information (i.e., RGB)

If the software has multiple classification models or parameters to choose between, the known set is split into three subsets – training, validation, and testing. If there is only one model and no parameters to choose between, then the known set is split into two subsets – training and testing. The training data is supplied to the model or software to help it learn to classify the different visual features within the image, so that the software can classify the image in an automated manner. If there are multiple models or parameter values, each of these is trained using the training subset. Once the model is trained, the validation subset is classified, and the accuracy of that classification is used to choose the best model or parameter values to decide the final model. Once the final model is chosen, the testing subset is then classified, which tell us what the classification accuracy will be when we classify the full image. The full image is then classified, which will result in a map of seagrass, with a quantified accuracy. Creating confusion matrices from the classified image and training dataset provide the level of accuracy of the classification process. A Cohens Kappa value of >0.85 is accepted as a suitable level of accuracy for habitat classification (Tait 2020).

This method can be time consuming, depending on the biological knowledge and GIS skillset of the person classifying the images as well as the quality of the image and training samples. Many classification approaches must go through multiple iterations to ensure features are being classified correctly. These iterations are to ensure that all the classes have been identified and the spectral variation within classes has been included in the training samples. However, if environmental conditions are similar across multiple data capture sessions (see Section 2.3.4), then subsequent image classifications should be faster.

2.5.3.2 NDVI

The Normalized Difference Vegetation Index (NDVI) can be used to identify seagrass meadows if both the red band and near infrared band have been captured. NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) and is calculated with the below formula using the NIR and red channels.

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

NDVI always ranges from -1 to +1. Bare ground, rock, sand, and snow will typically have low NDVI values close to zero (e.g., -0.1 to 0.1), surface water (oceans, lakes and rivers) will also have a low or negative score, while sparse vegetation such as shrubs and grassland will have moderate

NDVI values (0.2-0.5) while very dense vegetation such as forest will have high NDVI scores (0.6 -0.9).

This method is often used to highlight vegetation features that are then manually digitised which is relatively simple, cheap, and effective. Several studies have used the NDVI value to map intertidal seagrass beds and assess temporal and seasonal changes in extent. NDVI has also been used as a first pass for further machine learning classification methods discussed in Appendix D.

Specialist software for post processing of drone imagery, such as DroneDeploy can perform the NDVI calculation and produce raster layers for 'Plant health'. Unfortunately, although the NDVI values are shown within the drone deploy software, the exported raster layers do not show the NDVI score. A simplified shapefile with the NDVI scores can be exported but this will not have the resolution to map seagrass beds accurately. A five-band multispectral Geotiff can be exported and the NDVI can then be calculated in ArcGIS Pro using the raster function, NDVI. The ArcGIS Pro NDVI function can also be used on other raster layers, such as satellite images, that have both the red and infrared bands. If the red and infrared bands are in different raster layers, the composite bands function in ArcGIS Pro can be used to create a raster layer with both the red and infrared bands.

Once the NDVI has been calculated, the reclassify and raster to vector functions in ArcGIS Pro can be used to create shapefiles which can be used to delineate seagrass habitat. However, this can have a high level of error and requires manual correction.

Other algorithms have been developed to assess plant health including enhanced normalized difference vegetation index (ENDVI; Zhang 2014), green normalized difference vegetation index (GNDVI; Chand and Bollard 2021), renormalized difference vegetation index (RDVI; Pu et al. 2015), soil-adjusted vegetation index (SAVI; Bargain et al. 2012), and optimised soil-adjusted vegetation indices (OSAVI; Bargain et al. 2012) which may also be useful for mapping seagrass.

2.6 Imagery types

Below is the description of different imagery types used for seagrass mapping in New Zealand. See Table 4 for a list of pros and cons of each listed method with details in the sections below. Since collecting a good orthorectified image is key to successful mapping, we recommend prioritising capturing high quality imagery. Some councils employ properly skilled drone operators and surveyors that can ensure image capture is high quality. However, if that expertise isn't available in house, it is worth considering contracting to a qualified surveyor to ensure accurate data collection.

Table 4. Pros and cons for imagery types. Because resolution and cost depend on several factors, these values are general. For example, cost can change depending on the image resolution you want, or drone set up and camera. Some ratings taken from Tait (2020).

Method	Pros	Cons	Resolution (scale low [>1 m/pixel] to high (≤3 cm/pixel)	Area (*-***)	Cost (includes per time & area – scale $ to $$$)
Unmanned aerial vehicle (UAV) /drone	• Custom (area, timing, frequency, tide, camera specifications) • High resolution • Can get elevation data (if tied to RTK or well-defined physical features) • RGB/Multispectral capable • Good for survey areas smaller than 10 ha • Can be used to match scales between in situ sampling (meters) to coarser resolution imagery (tens of meters plus) • Can be used to get both downward facing and obliques to help with understanding which biota is present.	• High setup cost and training • Need to be able to access site and might require some landowner permission • Limited spatial coverage (<8 km^2) • Civil Aviation Authority (CAA) flight constraints may limit flight • Limited by weather (e.g., wind) • Expensive to buy/ maintain/replace • Require licensed operators • Photogrammetry won't always do well over water and featureless surfaces	High (1.9-2 cm)	*	$ - $$$
Manned aerial	• Custom (area, timing, frequency, tide, camera specifications) • Already collected in many regions • RGB/Multispectral capable • Good for survey areas larger than 10 km^2	• Contracting costs • Routinely scheduled imagery (e.g., LINZ coverages) often several years apart. • Requires ideal flight conditions – regional imagery often not aligned with low tide (i.e., often collected for multiple purposes)	Moderate	**	$ (imagery supplied by government) - $$$ (contracted imagery)
Satellite	• Higher frequency of sampling • Large spatial area • Several free image platforms • RGB/Multispectral capable • Good for survey areas greater than 10-100 km^2	• Clouds can preclude use of images • Resolution of free images may not be high enough depending on seagrass patch size • Price increases for newer and/or higher resolution data • Restricted timeframe of images	Low (higher from commercial provider)	***	$

2.6.1 UAV/Drone imagery

A drone is an unmanned aircraft, often referred to as an unmanned aerial vehicle (UAV) or a remotely piloted aircraft (RPA). Drones provide the opportunity to photograph large areas (<10 ha) quickly. In many scenarios there are limits to flight heights and distances away from the pilot and/or aerodromes that can restrict the mapping area. However, many dedicated providers have additional capability and can operate under expanded parameters. Also, it is necessary to fly the drone from a location close to the site, which means remote sites with no access will still be hard to map. Overall, drones are a useful monitoring tool for smaller estuaries/reefs and can be a relatively low-cost method. Existing capacity within councils (e.g., experienced and trained pilots with suitable equipment, post-flight data processing systems in place, and limited ground-truthing or ground control points are needed) will help keep costs down. Costs can become very high where data capture and processing capacity is being built/must be contracted out or where larger areas require mapping.

Recommendations for survey methodology (not already mentioned in Section 2.3):

- Drone specifications: RTK capable (encouraged but not mandatory[6])
- Ground control points**:** ten as bare minimum[7] (distributed across survey area)
- Drone pilot training: As a drone pilot in New Zealand, you are required to know the Civil Aviation Authority (CAA) Part 101 rules. Check with your council for any specific requirements to comply with public liability insurance. It is recommended that each pilot undertakes training to understand the 101 rules and has spent time practicing drone flying in safe zones to ensure public safety. See www.dronetraining.co.nz for further information about Part 101 limitations and requirements.

2.6.1.1 Equipment

There are a range of drone models and camera specifications available. The size of the potential survey area is an important factor to consider when choosing a drone.

Nationally and internationally, researchers have used a DJI Phantom. These can be purchased for approximately $1000 NZD. A DJI Phantom 4 with RTK + D-RTK 2 (without the base station) can be purchased for approximately $10,000 NZD. The advantage of the added RTK feature to the drone is that it carries an onboard GNSS RTK receiver that gathers data from satellites and a stationary base (ground) station to more accurately correct image location, in real time, as it flies. Satellite data—by itself, and in any case—is error-prone due to tropospheric delays, etc., providing a maximum accuracy of about 1m. The data from a ground station is factored in to correct satellite signal error, bringing accuracy down to cm-level range.

Familiarity with onboard camera settings is important. Many drones have RGB cameras on them but can be outfitted with multi-spectral cameras as well. See Section 2.3.5 for a more detailed explanation of different camera capabilities.

2.6.1.2 Flight planning

Flight time is dependent on survey area size and flight elevation (which in turn is dependent on the desired image quality or GSD). As mentioned in Section 2.3.5, the smaller the GSD, the higher the image resolution. However, this will be a trade off with flight elevation, and

[6] Higher initial cost, but will save time in surveying ground control points with more surveys

[7] There are scenarios where they aren't essential. For example, where plenty of consistent (i.e., haven't moved) natural or man-made features are present.

therefore the survey area that can be flown per battery. Adjust flight height based on camera specification. A GSD calculator[8] can be used to understand the relationship between GSD, flight height and camera specifications.

Aerial images for an area <10 ha can be easily and quickly collected using drones. For example, an elevation of between 60-70 m provides a resolution of 2 cm (CAA rules limit the altitude of drones to 120 m). Ten hectares can be flown in approximately 12 minutes at 70 m. Image overlap should be 80% and is the default setting in most software when set to collect imagery capable of being stitched into 3D models.

Flight time can also be affected by windy conditions. If possible, windy days should be avoided as there is added risk of something going wrong when piloting a drone. Wind will cause the drone to use more battery, it may also result in worse image quality due to added movement when taking the photos.

Flight paths can be planned using specialist drone apps to capture a series of photos at known positions which can then be stitched together to create one large ortho-mosaic image. Some examples are:

- DroneDeploy
- Map Pilot Pro
- DJI Pilot

These drone apps have different subscription levels for different features. Some also work better on a desktop or either iphone or android (but not necessarily both), so it is worth checking them out before starting. Also test the apps with the drone being used before going into the field.

Be aware that for large areas where battery power will not last the entire flight, the drone will pause the flight path and come back for a battery change before resuming the planned flight path.

Ground control points (GCPs) are positions within the survey area that have been verified using accurate survey equipment (i.e., Trimble RTK GPS) and have been clearly marked so that they can be identified in the drone imagery (e.g. Figure 5). GCPs are necessary to create an accurate, geo-rectified ortho-mosaic image. Generally, GCPs should be evenly and systematically spaced across the survey area. They should also be positioned towards the outer extent of the survey area (but not too close to the survey boundary to capture the GCPs with overlapping images). DroneDeploy recommends that GCPs are placed 15 m away from the edge of the planned flight path and any surface water features. GCPs located too close to the perimeter of the flight path are likely to be captured in less images by the aircraft (each GCP needs to be visible in at least three images to be used for processing). Ten GCPs should be recorded as a minimum, more may be preferable. Extra ground control points can be used as check points to assess the accuracy of any outputs.

[8] A GSD calculator example: https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-calculator

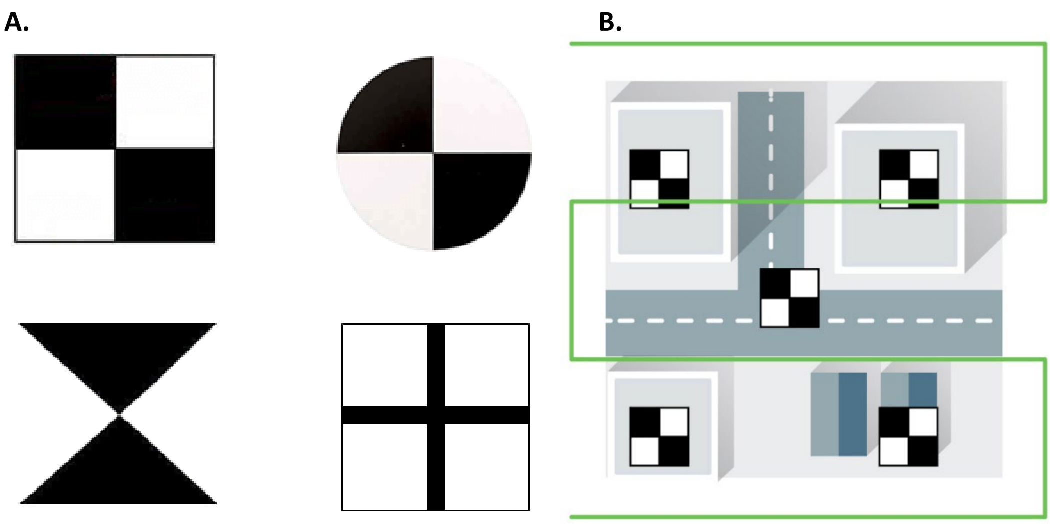


Figure 5. A) Examples of different ground control points (GCPs) that can be used for drone surveys (Alevizos 2019). B) Example of suggested GCP placement for a survey (PIX4D).

2.6.1.3 Ground truth surveying

Ground truth surveying should also be carried out as part of the drone image capture process. The purpose of carrying out a ground truth survey is to use field observations to verify the classification of visual features captured in the drone imagery. Having accurate field observations helps to verify that the feature of interest (i.e., seagrass), is being correctly identified during the image classification process. Even if the drone imagery is of high resolution, the ground truth survey can help to identify other similar features that could confuse the classification process (e.g., sea lettuce being mistaken for seagrass). Ground truth surveys can be carried out using a transect/quadrat-based approach. Samples should be representative of the entire survey area (e.g., different tidal zones, different habitats, etc.). Samples should be photographed and georeferenced so that they can be visually paired up with the drone imagery during the image training process. The main biotic and abiotic features should be recorded, with an estimate of percent cover (e.g., seagrass 60%, *Ulva* 5%, sand 35%). Survey 123, Collector and FieldMaps (ArcGIS applications) using a mobile device, would be an effective and efficient means of recording ground truth survey, provided the mobile device is paired with a high accuracy (2.5 m if stationary) GPS logger[9].

2.6.1.4 Photogrammetry

Specialist software is required for the post processing of the drone imagery. The following programmes can be used for photogrammetry (the process of stitching the photos together in the correct geographic position to produce the geo-rectified ortho-mosaic image):

- Drone2Map (ArcGIS)
- ReCap Pro (Autodesk)
- Metashape (Agisoft)
- Meshroom – free, open source
- Pix4D – can use on mobile device and desktop
- DroneDeploy

[9] E.g., https://bad-elf.com/pages/be-gps-2200-detail

2.6.2 Manned Aerial imagery

Aerial orthophotos are the primary imagery used in broad-scale mapping in New Zealand and are useful as they can provide high resolution imagery of targeted areas. LINZ makes New Zealand's most current publicly-owned aerial imagery – covering 95% of the country – freely available to use under an open licence through the LINZ Data Service, and now through the LINZ Basemaps service. Resolution ranges from 0.075-0.4 m per pixel and flight frequency is variable (every few years). Historical coverage is also available in many areas commencing from ca. 1940. Many councils also commission localised high resolution aerial photography, particularly of urban areas.

It is possible to commission area-specific aerial imagery for mapping purposes. The cost is directly related to the spatial coverage and resolution of photography that is required, and the constraints on conditions when the area is to be photographed (e.g., only at low tide).

As for UAV/drone imagery (Section 2.6.1.3), ground truth surveying is required to verify the classification of visual features.

2.6.2.1 Oblique images

Oblique Images can be collected by manned aerial survey or by drone (Figure 6). Many suppliers provide access to oblique images for several regions on a licence basis. For example, the oblique imagery provider 'Photoblique' uses a camera angle of 25 degrees with a resolution of 5cm per pixel. The distance between image capture is 1000m x 250m. Oblique images can be used to map seagrass habitat, but the authors are unaware of anyone using them for mapping exclusively. They are more commonly used for verifying other imagery.

Figure 6. Example of oblique image, showing seagrass habitat in Houhora Harbour, Northland. Credit: Photoblique.

2.6.3 Satellite imagery

Satellite imagery provides imagery over large spatial areas that is frequently collected and relatively quickly available. It is often possible to get recent imagery at a relatively low cost, while historical imagery is generally available at very low cost. There are a few drawbacks to the freely available imagery – often it has coarse image resolution (best possible – 10 m per pixel), tidal coverages are variable, and spatial accuracy can be relatively poor. Additionally, images need to be filtered for the appropriate conditions, which limits the number of passes that are acceptable. For example, a satellite that passes a seagrass bed every seven days may only get an appropriate image every 2nd or 3rd month. While these images are freely available on several different online platforms, they can be difficult to download and analyse without technical support. Many of these satellites record RGB bands, but also carry multispectral sensors that capture other wavelengths useful for mapping vegetation (e.g., near infrared). An example of mapping seagrass using freely available satellite imagery (Landsat) has been completed in Tauranga Harbour, with similar results to hand digitisation of aerial imagery (Ha et al. 2021).

Commercial satellite providers have also been providing images for decades. Historically, these images were higher spatial resolution (as high as 0.31 m per pixel), but with fewer spectral options. That has been changing over time with the availability of increased spectral richness with some commercial providers generating hyperspectral images. Generally, the cost of high-resolution satellite imagery is going down, but it can be challenging to determine the cost of images because different providers offer different plans (e.g., one fee covers a certain number of image downloads before a top up versus a yearly subscription, etc.). The American Association for the Advancement of Science published a summary of the cost from some of the top providers in July 2022. They range in price from $10 USD to $25 USD per km^2 with many of them requiring a minimum order of 25-49 km^2. It is also possible to commission commercial providers to photograph a specific area.

For a description of satellite sensors, their providers, and resolution, please see Appendix E. Because technology is constantly improving, satellites with fine resolution are becoming a more viable monitoring tool than ever before. Like aerial images, satellite images can be ground truthed in the field. Some locations also have time series of images that can provide more information on changes in seagrass extent.

2.6.4 LiDAR

Light Detection and Ranging (LiDAR) uses pulsed laser light to measure distances to earth. These distances combined with other data recorded by the airborne system (e.g., altitude) provide three-dimensional information about the Earth's surface. While expensive, LiDAR has high resolution and can penetrate the water column better than some other types of imagery (Veetil et al. 2020). Internationally, a high degree of correlation has been found between LiDAR intensity and the presence of seagrass (Pan et al. 2015) and LiDAR intensity data has been used to identify saltmarsh habitat in New Zealand (McDonald et al. 2020).

Many councils have collected LiDAR data for other purposes, and it may be available for use at little to no additional cost. However, if the LiDAR was flown for another purpose at high tide, it may not get through water due to turbidity. Specifying tide times and weather windows for imagery could improve LiDAR's use but could also increase the cost.
Internationally, LiDAR has been used to map seagrass (Letard et al. 2021) and some studies have found higher accuracy in LiDAR mapping compared to multi-spectral mapping (Veetil et al. 2020). To our knowledge, no one has used it in New Zealand for that purpose.

3 Monitoring seagrass and environmental health indicators

Bioindicators can be used to complement snapshot environmental data collected in monitoring programmes, providing a time-integrated component, which reflects both past and current environmental conditions (McMahon et al., 2013). A range of seagrass health indicators have been developed for use in environmental management (McMahon et al., 2013, Roca et al., 2016), which provide early warning indicators into seagrass stress from a range of environmental and anthropogenic stressors (Table 5).

The purpose of monitoring seagrass and environmental health indicators is to:

1. Gain possible insight on the factors leading to changes in seagrass extent over time (identified through broadscale extent monitoring);
2. Develop our understanding of stressor limits and thresholds that support seagrass health;
3. And develop early warning indicators of decline.

It may also provide an opportunity to include seagrass indicators in future national environmental reporting, such as the Our Marine Environment (Ministry for the Environment) three yearly reporting. The collection of regional seagrass and environmental health indicators is critical to building seagrass models. Future modelled data may allow us to better understand what drives seagrass habitat recovery and loss, and to forecast what is likely to happen under different management scenarios. Once a baseline of seagrass health data is developed for each monitoring site (to establish natural patterns and trends) this data can be used to help assess when management intervention is required (e.g., a sustained loss in percentage cover with increasing sediment mud content).

Seagrass health monitoring should be standardised in space and time to limit natural variability in seagrass indicators. Annual sampling is required as a minimum and should fall within the same 2-month window between September and May each year. It will take multiple years of regular repeated sampling before data will be suitable for trend analysis.

Currently, councils do not have specific long-term seagrass health indicator monitoring programmes; however, many have state of the environment (SOE) estuarine monitoring sites located in seagrass beds (Appendix F). Some councils have completed individual studies looking at feasibility of assessing seagrass health or have added additional seagrass monitoring as part of broad-scale mapping programmes or investigative programmes (Appendix F). Councils may be able to identify existing monitoring sites that also have seagrass beds or utilise consent condition monitoring of seagrass beds. These may be suitable for additional seagrass indicators, to complement the existing monitoring. Another option is to extend existing monitoring programmes to include a new subset of seagrass sites.

To enable all councils to participate in seagrass health monitoring, a three-tier approach is proposed below (Figure 7). It identifies ‘bronze’, ‘silver’, and ‘gold’ options to help assess and monitor seagrass health. The bronze is considered the minimum to assess end point change in seagrass cover, complemented with a limited number of environmental variables to support assessment. The bronze standard aligns with the NEMP (Robertson et al. 2002), which provides simple to collect, and robust indicators of seagrass and environmental health. Silver and gold options enable early detection of environmental deterioration and increases the power and likelihood of predicting causative changes in seagrass health and condition. However, this must be weighed against the increase in cost and time required. Destructive methods (such as seagrass biomass) are not included here, due to limited seagrass habitats in some regions, and limiting post-processing times.

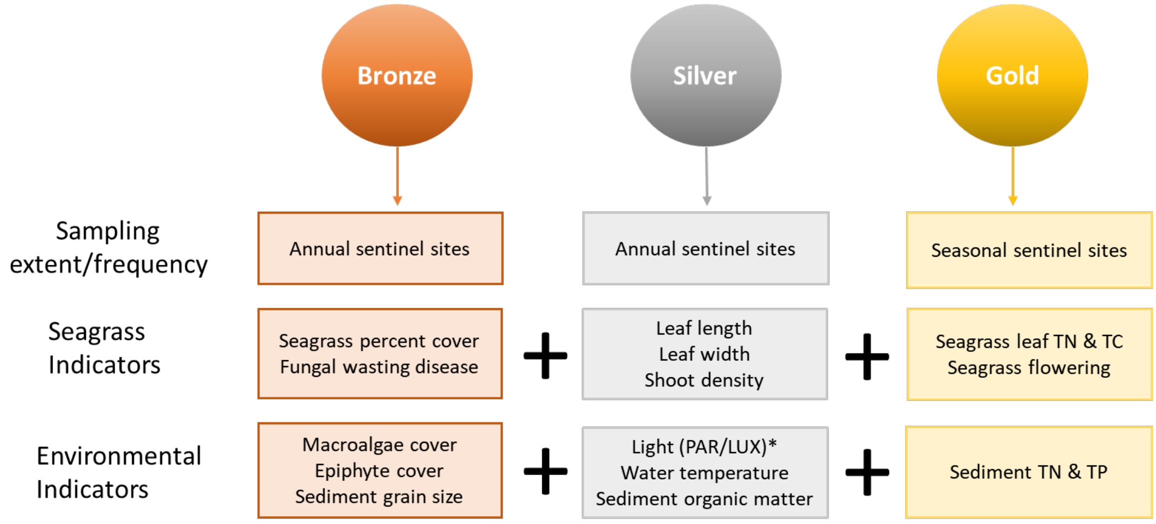


Figure 7. A potential three-tiered approach to seagrass indicator and stressor monitoring, where the silver and gold options include the indicators from the lower option (e.g., silver also includes all the bronze indicators). + symbols indicate that lower levels are in addition to variables in higher levels (e.g., gold seagrass indicators include both silver and bronze seagrass indicators). PAR = photosynthetically active radiation, LUX = a unit of illuminance, TN = total nitrogen, TP = total phosphorus, TC = total carbon. *It is preferred to measure light in LUX, however if relationships can be established between PAR and LUX, Hobo LUX loggers can be utilised to decrease costs.

A methodology is provided below, which provides a guidance framework to be developed to suit the needs in different regions. There may be additional environmental parameters that can be considered depending on resourcing and questions of interest. There are numerous additional in-situ measurements of environmental conditions that may be useful (e.g., current velocity, water depth/duration, sedimentation rate, heavy metals), and other external correlative factors such as rainfall, storm events, flood plumes and climatic oscillations (e.g., El Nino-Southern Oscillation).

3.1 What information does each method provide and why is it useful?

Seagrass indicators provide evidence of stress from a variety of sources and are described below in Table 5. Most of these studies were conducted outside of New Zealand, and not necessarily on *Zostera* species. Interpretation of results should consider the differences in biological, environmental, and climatic conditions between *Z. muelleri* in New Zealand and the referenced studies.

Table 5. Seagrass indicators and description. Extracted from Crawshaw 2020 and Clark et al. 2019.

	Descriptor of indicator	Indicator response to stress
Seagrass health indicators		
Seagrass percentage cover (%)	Percentage seagrass cover is a population level indicator of seagrass health (Martínez-Crego et al., 2008), and can respond to light stress over the timescale of months (McMahon et al., 2013). Seagrass cover is expected to decrease with increasing anthropogenic stressors (Martínez-Crego et al., 2008, Guimarães et al., 2012).	Decrease
Leaf length	Seagrass leaf length is an individual level descriptor of plant health, and generally seagrass will decrease in length in response to a range of stressors (Cabaço et al., 2008, Martínez-Crego et al., 2008). Seagrass may lengthen their leaves to aid with light harvesting in low light situations (Matheson, pers comms).	Decrease
Leaf width	Seagrass leaf width will generally decrease in response to light stress, and also alters the photosynthetic performance of seagrass (Collier et al., 2012, Bertelli & Unsworth, 2018). However, due to the cost of loss of photosynthetic efficiency, some seagrasses show an increase in width to boost light adsorption (Ralph et al., 2007, Collier et al., 2012). Based on this information, wider seagrass leaves are assumed to indicate light stress, however this has not been tested on *Z. muelleri*. Further monitoring of leaf width and light availability may further refine the response of this indicator to environmental stressors.	Decrease
Shoot density	Shoot density is the number of seagrass shoots per unit area and will generally decrease in response to increased stressors (Mayot et al., 2006, Pergent-Martini et al., 2005, Neckles et al., 2011).	Decrease
Seagrass flowering	Sexual reproduction by seagrasses (e.g., flowering) is not well examined across New Zealand, and its presence has recently been identified in studies across the country (Clarke & Berthelsen 2021). Research suggests that flowering is plant cover and biomass dependant, with flowering only occurring in higher seagrass density (Dos Santos & Matheson 2016; Zabarte-Maeztu et al., 2021). For intertidal *Zostera muelleri*, higher plant cover, biomass and leaf size has been associated with greater reproductive capacity (ability to produce flowering shoots) (Dos Santos & Matheson 2016; Zabarte-Maeztu et al., 2021).	Decrease
Fungal wasting disease	Caused by the slime mould *Labyrinthula zosterae (*Burdick et al., 1993), likely linked to widespread losses of seagrass internationally. This disease is likely to naturally occur in seagrass meadows, but outbreaks can occur with low light, warm temperatures and lower salinity, and seagrass can be more susceptible when stressed (Matheson 2009, Hughes et al. 2018, Groner et al. 2021). It has been recorded thus far in Nelson, Marlborough, and the Coromandel (Berthelsen et al. 2016, Sunde et al. 2017; Clark & Crossett 2019).	Increase
Stressor indicators		
Macroalgae cover	Excessive growth of macroalgae can indicate increased nutrient inputs and can have detrimental effects on seagrass due to smothering and low light availability (Neckles et al. 1993; McGlathery 1995; Short et al. 1995).	Increase
Epiphyte cover	Like macroalgae, excessive growth of epiphytes can be a useful indicator of increased nutrient inputs (Neckles et al. 1993; Nelson 2017). In New Zealand there has been limited studies of epiphytes on seagrass, two previously reported include the filamentous green algae species *Chaetomorpha ligustica* (Zabarte-Maeztu et al. 2022), and *Cladophora* spp (Crawshaw 2020).	Increase
Sediment characteristics	Sediment characteristics (particle grain distribution, total organic carbon, and nutrients) can influence the health of seagrass beds. Fine muddy sediments can smother seagrass and reduce the suitability of the sediment for seagrass presence, as well as reducing the available light environment through resuspension (Zabarte-Maeztu et al. 2020; Zabarte-Maeztu et al. 2021). Sediment nutrients are used as an indicator of sediment nutrient enrichment and are useful for comparisons of sediment environmental conditions between sites.	
Light environment	Seagrass requires high light availability for photosynthesis, and this indicator relates back to sedimentation and nutrient enrichment. Seagrasses have been shown to respond to decreasing light by reducing biomass, shoot density and growth (Bulmer et al., 2016 and refs within). Potential minimum light availability requirements and photosynthesis saturation light requirements have been identified in a number of New Zealand papers (Bulmer et al. 2016; Schwarz 2004; Matheson 2022).	Decrease
Water temperature	High temperatures can result in thermal stress resulting in a reduction of leaf and shoot density, above-ground biomass, and leaf senescence (York et al. 2013). Recent marine heatwaves could contribute to seagrass losses, as bleached seagrass reported washing up on shore (Matheson, per comms).	Increase
Leaf nitrogen content	The leaf nitrogen content indicates the availability of nitrogen in the water column and is expected to increase when there is an abundance of nitrogen availability (Martínez-Crego et al., 2008). Leaf nitrogen can also increase in response to shading (Fernandez et al., 2001, Cabaço et al., 2008, Roca et al., 2016).	Increase
Leaf carbon/nitrogen ratio	Seagrass leaf C:N ratio is expected to be lower when seagrass increases nitrogen uptake and storage in the tissues (Burkholder et al., 1994). The C:N ratio also decreases when light conditions decrease (McMahon et al., 2013).	Decrease

An indication of relative cost and time required for each monitoring method is provided in Table 6. The bronze framework for seagrass indicator and stressor monitoring is the least labour intensive with minimal post-sampling processing time. Most indicators can be assessed in the field, or photographs taken for processing back in the office, apart from sending sediment samples for analysis. The initial cost of sending a team into the field should also be factored in.

Table 6. Estimations of cost and time for each monitoring method. TN = total nitrogen, TC = total carbon.

Method	Cost (scale $ to $$$)	Time (scale + to +++)
Seagrass percentage cover	$	+
Leaf length	$	++
Leaf width	$	++
Shoot density	$	++
Seagrass flowering	$	+++
Fungal wasting disease	$	+
Macroalgae cover	$	+
Epiphyte cover	$	+
Sediment characteristics	$$	+
Light environment	$$	++
Water temperature	$$	++
Leaf TN & TC	$$$	++

3.2 Methodology for seagrass health indicator monitoring

3.2.1 Site selection

See Section 2.3.1 for guidance on choosing sentinel sites. The number of sites monitored will depend on the size of the area of focus, the number and location of patches/beds throughout the area, and the varying catchment, or sub-catchment stressors of interest. Broadscale maps of seagrass beds (or aerial imagery) can be used to locate seagrass beds to select representative sites. Where possible, it is recommended to include several sites within each area of focus. The monitoring of a site should ideally encompass the entire seagrass patch/meadow if size of the area is not a limiting factor.

3.2.2 Field work timing

As mentioned in Section 2.3.2, there can be high seasonal and spatial variability in seagrass bed coverage, therefore it is important to standardise the timing of fine-scale monitoring. This variability also means it may take some time to build up a representative picture of seagrass bed dynamics.

Field work should be completed between September to May when seagrass beds are at their maximum growth and coverage. A 2-month window should be selected within this period to complete all monitoring. For intertidal and rocky shore sites, fieldwork should be conducted during low tide.

3.2.3 Sampling design

Most regions within New Zealand have a large range of physical, chemical, and biological conditions both within and between estuaries/reefs due to differences in spatial extent, stressors, topography, and environmental gradients. While selection of monitored sites should encompass a range of locations, variation within those locations themselves should also be considered. Samples within an estuary/reef site should be collected across identified gradients. When combined with measurements of variables that represent either correlative or explanatory factors, these sample can help explain the variability observed (Thrush et al. 2021). Some key gradients to consider include tidal height (exposure time), sediment grain size, turbidity, and other catchment pressures (urban vs. rural).

Survey design will vary among locations depending on the topography, proximity to channels, and other environmental gradients. For larger seagrass habitats, this includes sampling from both the high intertidal limit of the seagrass bed to the edge of the seagrass towards the channel/low tide mark/subtidal. Where available, LiDAR data should be used to help identify the tidal height and tidal inundation range to design the survey accordingly. For rocky shorelines, the exposure gradients may also be used to designate sampling locations. This data can then be used as an explanatory variable and would best be analysed using regression-type approaches.

A gradient sampling design should be used to capture the range of tidal heights/depth across the seagrass bed and could include multiple locations if sampling a large meadow, ideally covering the full spatial extent (Figure 8). Multiple transects are required and can either be set up as permanent transects or randomly selected. Transect lines should be set up parallel to the shoreline, with a minimum of three transect lines (one at the shallow edge of the seagrass bed, one in the middle, and one at the deeper edge of the seagrass bed; Short et. al 2015). Depending on the gradients, the sampling method can either be in a block design, or fixed-point sampling down a transect line (with the transect possibly split into multiple blocks based on depth). The start and end of each transect line should be marked with a GPS to allow revisiting in the future, and compass direction recorded.

<u>Block design</u>
Several sampling locations should be pre-determined to encompass representative tidal elevations (Figure 9). At each sampling location along the transect, a 15 x 10 m plot subdivided into 12 equal sized plots is used for subsampling the seagrass and environmental indicators (or scaled smaller if required depending on seagrass bed size; Robertson et al. 2002). The GPS location should be recorded in each location.

<u>Fixed-point design</u>
Pre-determined quadrats should be sampled at equal distances along the length of the transect line, or at predetermined random points. The GPS location should be recorded in each location.

It is recommended to conduct a pilot study to optimise effort and cost efficiency for the long-term monitoring programme, collecting a higher replicate number than proposed to analyse before the next survey and determine the optimum sample size. A power analysis can be used to refine the sampling design and suitable replication for the monitored sites.

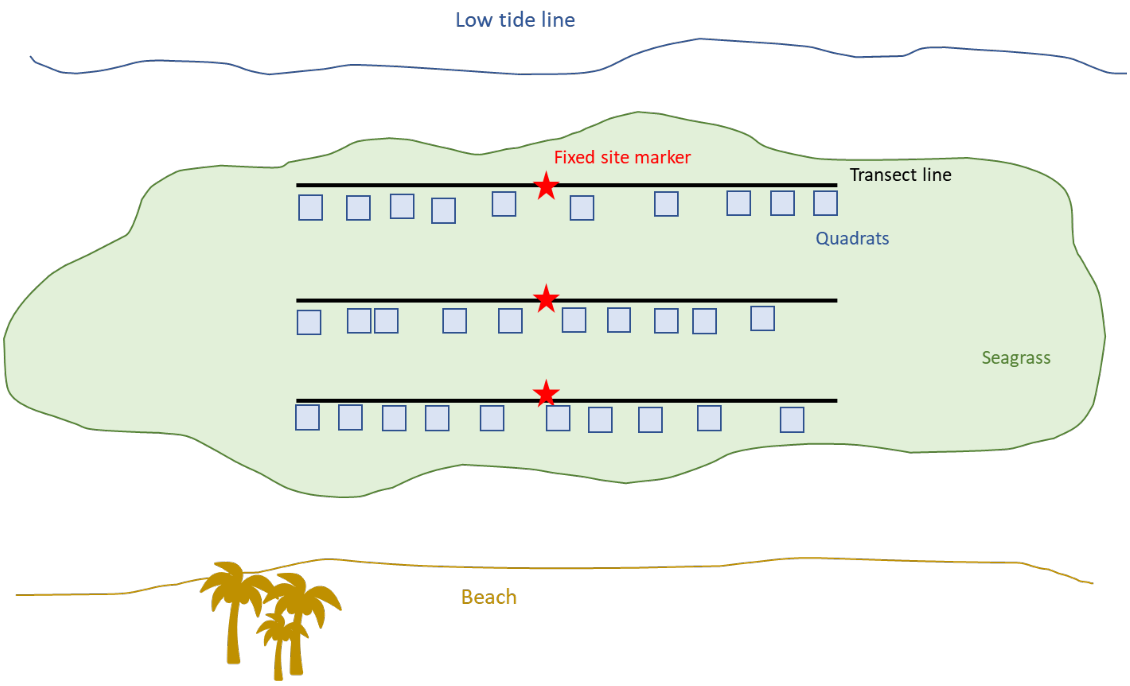


Figure 8. Gradient sampling design for seagrass health indicators, ensuring coverage of the seagrass across the identified depth gradient.

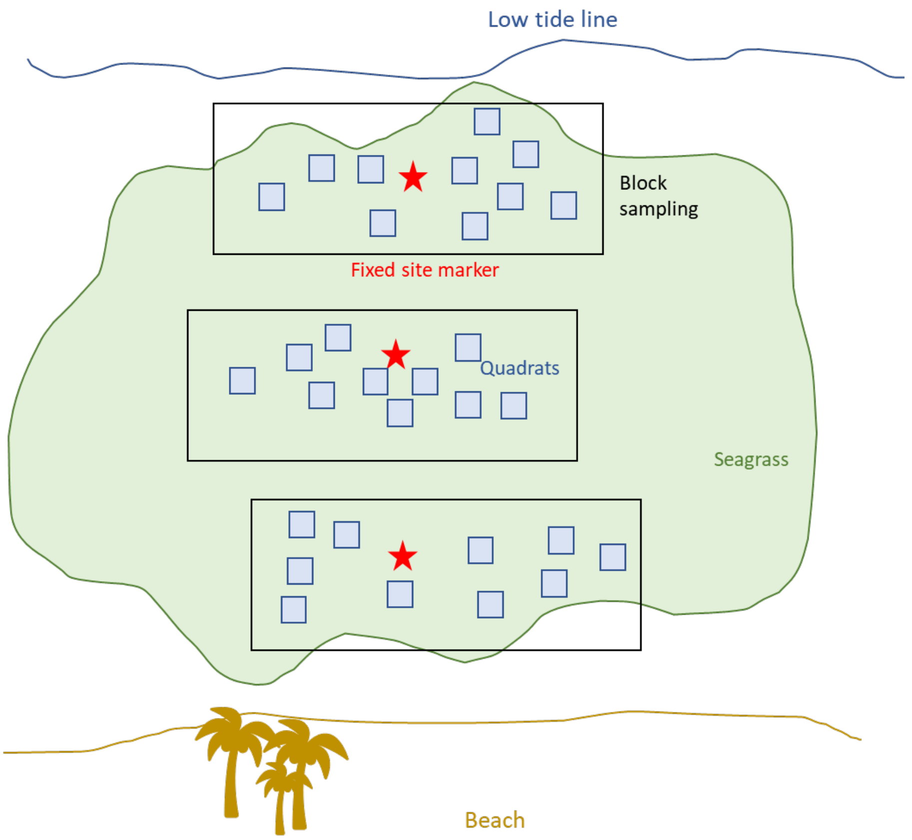


Figure 9. Block sampling design for seagrass health indicators, ensuring coverage of the seagrass across the identified depth gradient.

3.2.4 Site description

Take notes of the broader site area, including notes on any indications of physical damage (e.g., scours from anchoring, waterfowl grazing etc), wider macroalgae present, and other things of interest (discharges, catchment activities). A site photo may also be taken for future reference.

3.2.5 Seagrass percentage cover

A 0.25 m^2 quadrat should be used for assessing seagrass percent cover, sampled haphazardly. This may be an open quadrat or gridded, depending on post processing method (open quadrat for photographic processing, gridded may be helpful for field assessment). Percent cover can be either assessed in the field on the day, or using a photograph taken for analysis later on a computer. Photographs of all quadrats are recommended with respect to record keeping, changes in staff and data continuity. If using photography, ensure the whole quadrat outline is within the frame, and no shadows are present, or reflections off surface water. A visual assessment or dots-on-rocks approach may be utilised for calculating percent cover. Percent cover should be assessed using the CMECS standard (Table 1, Figure 3). If there is high macroalgae cover present, assess macroalgae percent cover before removing the algae to assess seagrass cover. A minimum of 15 quadrats is proposed as a starting point for a pilot survey.

Note on patchiness: if your seagrass is highly patchy, consideration should be made to re-sampling when a quadrat lands on bare ground, as this may affect site averaging and not be representative of the site as a whole. For example, if you have high herbivory pressure or a naturally patchy environment, like exposed rocky reef, some selective sampling might be needed to ensure that sampling covers areas with seagrass present to enable monitoring health over time.

Note on percent cover methodology: Clark and Crossett (2019) trialled three visual biomass assessment techniques as a non-destructive and rapid method for biomass sampling. Visual biomass ranks and seagrass cover estimated using a dots-on-rocks approach were found to be the best proxies for harvested above ground biomass. See Clark and Crossett (2019) for further information on potential biomass proxies from percent cover.

3.2.6 Leaf length and width

Seagrass leaf length and width should be determined within each quadrat, randomly selecting 10 seagrass blades, and measuring the maximum length and width along the blade. Leaf length should be measured from the base of the sheath to the tip of the leaf (Figure 10). Data should be averaged and reported on as an average (median) of the leaf length or width and reporting variation (standard deviation and/or error).

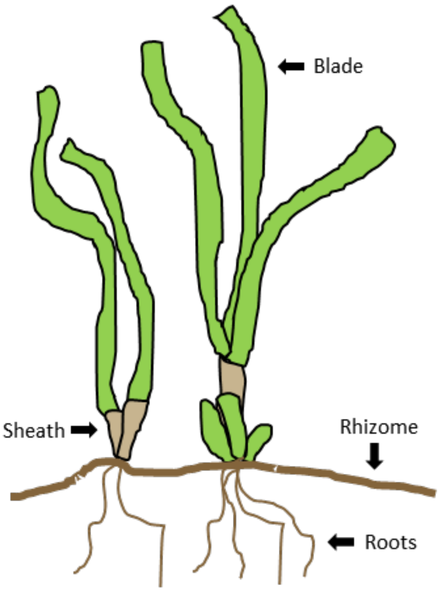


Figure 10. Diagram of seagrass anatomy.

3.2.7 Shoot density

Shoot density should be determined within each quadrat, either by directly counting all shoots rooted within the quadrat if seagrass percent cover is <25% or subsampled within a smaller sub-quadrat if seagrass percent cover is >25% (Neckles et al. 2012). If using a gridded quadrat could use 5 random squares from a 25 square quadrat. Shoot density should then be scaled-up to the quadrat size before analysis.

3.2.8 Seagrass flowering

Seagrass flowering was previously considered to occur infrequently in New Zealand seagrass (Turner & Schwarz 2006), although recent studies have found it is more prevalent than first thought and has been documented in the North and South Island (Zabarte-Maeztu et al. 2021; for a review see Clark & Berthelsen 2021).

Seagrass flowering should be visually assessed within the entire 0.25 m^2 quadrat (depending on time allowance, this can be in a reduced number of the quadrats along each transect). The number of individual flowering shoots should be counted. See Figure 11 for examples of seagrass flowering.

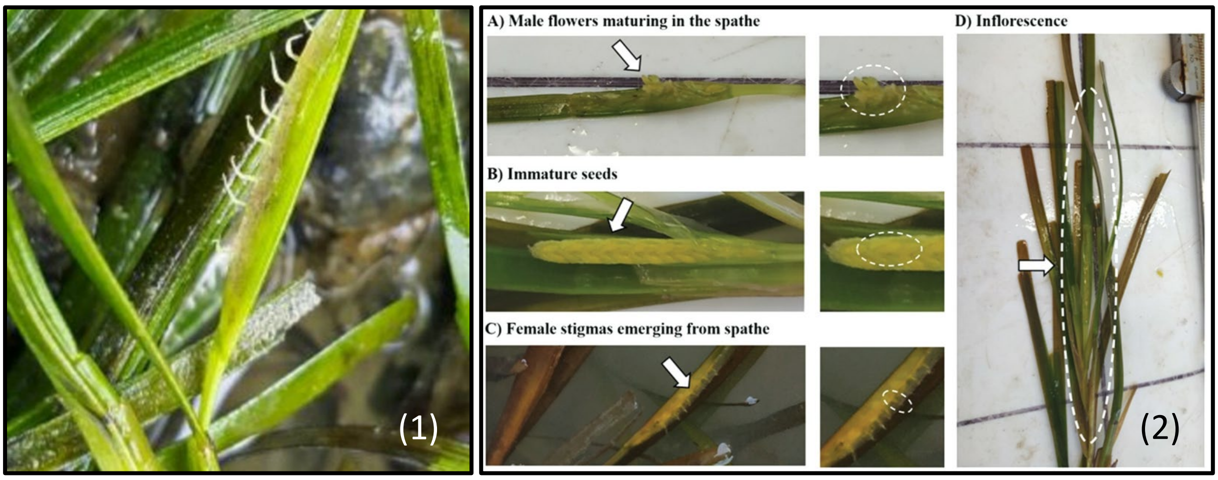


Figure 11. (1) Seagrass flowering in *Z. muelleri* showing protruding stigma to catch pollen for fertilisation (from de Kock et al. 2016). (2) Identification of flowering in *Z. muelleri* (Zabarte-Maeztu et al. 2021).

3.2.9 Fungal wasting disease

Fungal wasting disease manifests as patches of darkened seagrass leaves (Figure 12) and has been confirmed to be linked with the protozoan *Labyrinthula zosterae* (Berthelsen et al. 2016; Burdick et al. 1993). This disease has spread globally and is linked to seagrass losses internationally (Lorus & Milne, 1951; Ziegler et al. 1961; Ralph & Short 2002).

Visually assess the prevalence and severity of fungal wasting disease on 10 randomly selected individual leaves within each quadrat, using the Wasting Index Key in Figure 12, developed by Birdick et al. (1993).While leaf colours can vary naturally or can be impacted by other things (e.g., repairs from bites or tears), fungal disease is usually characterised by quite dark colouration.

If unsure about the colouration, and funding allows, a representative subsample may be taken and sent for histological processing and identification at Cawthron (it is not a routine offered service, but may be available on request). Further work could be done to formally test the reliability of visual methods in the field and under a microscope compared with histological testing.

Note on histological testing: Select a representative sub-sample of leaves and roots and place them into formalin seawater for 48 hours, followed by a change to 70% ethanol. If access to formalin is not possible, wet seagrass can be placed in a plastic bag and kept chilled (but not in direct contact with ice) and shipped to a location with formalin (this is less ideal). The preserved samples are then sent to a medical laboratory for standard histological processing, which produces haematoxylin and eosin (H&E)-stained slides.

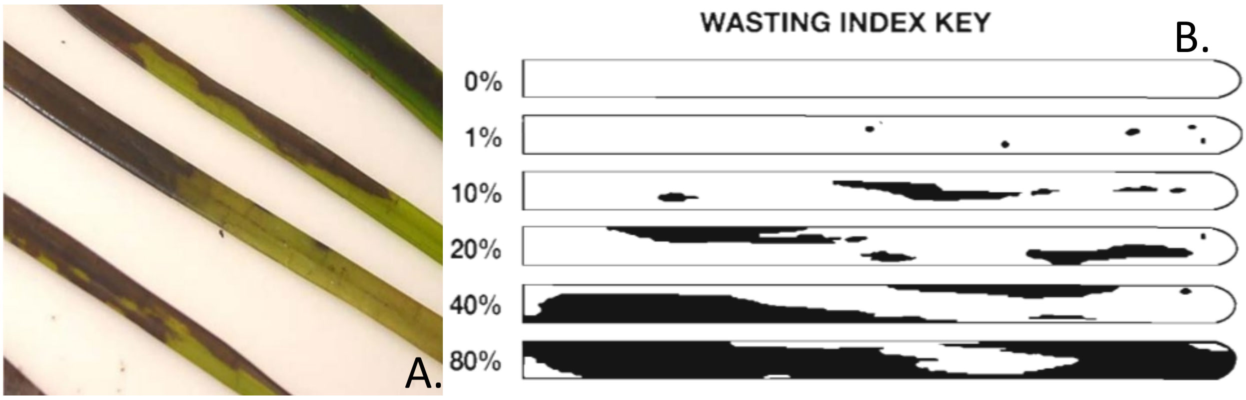


Figure 12. (A) Blackened seagrass blades indicating *L. zosterae*. Source: Berthelsen et al. (2016) and (B) The fungal wasting disease index key developed by Birdick et al. 1993.

3.2.10 Macroalgae percentage cover

The same method is utilised for assessing macroalgae percentage cover as is used for seagrass percentage cover (Section 3.2.5; a quadrat and determining percentage cover using CMECS), with the addition of noting what species of macroalgae is present on the seagrass (see Figure 13 for examples). This should be assessed separately for each species of algae, and then combined as a total macroalgae cover.

Figure 13. Examples of algae cover on seagrass beds. Left = sea lettuce (*Ulva* sp.). Right = neptunes necklace (*Hormosira banksii*).

3.2.11 Epiphyte percentage cover

Depending on the prevalence of epiphytes on the seagrass bed, the percentage cover can either be estimated using the same method as for seagrass percentage cover (Section 3.2.5; a quadrat and determining percentage cover using CMECS), or on a selection of 10 haphazardly selected seagrass leaves within each quadrat (and assessed using the Wasting Index Key described above). Photo examples of epiphyte growth on seagrass is shown in Figure 14.

Depending on the scale of influence of the bloom it may be worthwhile sending an example for identification, to build up a knowledge base of what species are present on seagrass throughout New Zealand.

Figure 14. Examples of epiphyte growth on seagrass beds in Tauranga Harbour.

3.2.12 Sediment characteristics

Four sediment characteristics were selected for monitoring that are standard measurements conducted by most regional councils and recommended in the NEMP (Robertson et al. 2002). These were selected to provide an indication of environmental conditions relating to sedimentation and nutrient enrichment.

Sediment sampling should be undertaken in accordance with your specific council's standard sediment SOE monitoring protocols. In general, the standard protocol is to take 10 replicate sub-samples using a cut-off syringe, of the top 2 cm of sediment, pooled together in a clean plastic jar or bag. This is stored on ice and sent for processing. The sample should be sent for analysis of:

- Particle size distribution (% mud, sand, gravel)
- Total organic carbon
- Total nitrogen
- Total phosphorus

Depending on the objective of the survey, sediment characteristic samples may be taken as representative samples at a select few sites within the seagrass bed (such as an average along each transect) to reduce processing costs.

3.2.13 Light environment and temperature

Hobo light/temperature loggers (HOBO MX Light/Temperature) can be a cost-effective way to measure relative light and temperature exposure at seagrass sites. The loggers measure light in LUX, which can be converted to PAR (photosynthetically active radiation) using existing conversions (Thimijan & Heins 1983) or ideally, a correction factor created specifically to each site.

Loggers should be deployed over a minimum of a 2-week period during the site sampling period sampling at 10-minute intervals (to capture a full spring/neap cycle). Loggers can be attached to short waratahs and pushed into the sediment, so the logger is sitting at the top height of the seagrass leaves (Bulmer et al. 2016). This can minimise the chance of the logger being moved by tides or waves. Alternatively, if you are not measuring light your council may measure water or air temperature in a regional location that can be used as a proxy for temperature change.

The data should be cleaned to remove periods of night and tidal exposure.

3.2.14 Leaf nitrogen and carbon content

Processing of leaf nitrogen and carbon content can be costly, thus the sampling should be scaled depending on budget availability, such as only collecting a few quadrats within each transect line. Ten randomly selected leaves should be cut at the base of the seagrass sheath from each quadrat, washed in freshwater to remove epiphytes or algae, and dried in an oven at 60°C. The dried sample should be homogenized and sent for laboratory analysis (standard testing at laboratories such as Hills Laboratories).

Seagrass health monitoring summary

- Three tiered approach to monitoring (bronze, silver, gold)
  - Bronze: Seagrass percentage cover, fungal wasting disease, macrophyte cover, epiphyte cover, sediment grain size
  - Silver: Bronze + leaf length, leaf width, shoot density, light, water temperature, sediment organic matter
  - Gold: Bronze + Silver + seagrass leaf TN and TC, seagrass flowering, sediment TN and TP
- Sentinel sites incorporating local stressor gradients
- Two-month timeframe for monitoring between September and May
- Sampling design - transects or block design based on environmental gradients

4 Citizen science and community engagement

Citizen science may be one pathway to increase coverage of seagrass monitoring across New Zealand by engaging the public, community groups, or tangata whenua. There are several international initiatives that could be leveraged to support this, the key ones being Seagrass Spotter[10] and Project Seagrass[11] (which are partner organisations), Seagrass Watch[12], iNaturalist[13] and Marine Metre Squared[14]. A number of these programmes provide a space to collect and upload pictures of seagrass observed around the world, which could be used to capture information on remote sites, or information on percentage cover of seagrass or instances of seagrass flowering.

Seagrass Spotter is a citizen science project that enables users to take photos of seagrass and upload it to a global map, providing an understanding of where seagrass occurs across the globe. There are several groups engaged with this project in New Zealand, with the highest observations occurring around Nelson-Tasman, Auckland, and Bay of Plenty regions. It can be useful for recording one-off pictures from remote or isolated environments.

Two wider biodiversity monitoring platforms are Marine Metre Squared and iNaturalist, which allow the users to upload observations about a range of marine (and terrestrial) species. Marine Metre Squared has a rocky shore and soft sediment shore monitoring guide and resources, to help community scientists set up and record long-term monitoring programmes, with the highest engagement occurring in Otago and Auckland regions.

Project Seagrass and Seagrass Watch are environmental monitoring groups supported by a team of research scientists to engage the community in detailed seagrass monitoring. They have standardised methodologies for fine-scale seagrass sampling and produce reports and scientific publications on outcomes of the research. Although these programmes aim to include citizen scientists in seagrass monitoring, this has not been a very effective way of engaging with the community, with a recent review highlighting that the majority of participants were educated community members often with a working role in marine science or management (Dalby et al. 2021).

[10] https://seagrassspotter.org
[11] https://www.projectseagrass.org
[12] https://www.seagrasswatch.org
[13] https://www.inaturalist.org
[14] https://www.mm2.net.nz

In New Zealand, one way community groups have engaged in monitoring programmes is through restoration efforts. Just north of Wellington, the Guardians of Pauātahanui Inlet successfully monitored seagrass restoration trials from 2014-15 (Matheson et al. 2016). Further north, in the Whangārei Harbour, the Whangārei Harbour Kaitiaki Roopu and other members of the local community supported the Regional Council and NIWA scientists to monitor seagrass restoration planting trials from 2008-2010 (Matheson et al. 2017).

Citizen science programmes can be a useful monitoring tool. Often programmes require an initial large investment in time and sometimes cost for materials for them to be successful. Council involvement should be high at the start to ensure the data collected can be incorporated into a monitoring programme. Once up and running, time and costs to council may decrease with staff only involved in an advisory capacity.

5 Conclusions, recommendations, and looking forward

There has been a range of methods previously used by, and for, regional councils to monitor seagrass. Early indications are that with a changing regulatory environment, councils will need to increase their understanding of key attributes, which includes seagrass habitats, and have the ability to consistently report on state and trends. This report has provided three tier scales (bronze, silver, gold) for both broad-scale (extent) and fine-scale (health) of seagrass to increase consistency in reporting while also allowing for flexibility to account for differences in seagrass prevalence, finances and capability across regional councils.

For mapping seagrass extent, we recommend that all councils conduct extent surveys using aerial imagery (be that satellite or aerial flight photography) every three years at a minimum, with variation in the area covered depending on costs and regional scale. For this, we have provided several possible methods to process the imagery, from hand digitising to fully automated GIS processing methods. As resolution of satellite imagery continues to improve and cost of commercial providers goes down, this method may become preferred in the future.

For seagrass indicator/stressor monitoring, we recommend setting up several sentinel sites to collect detailed data on important seagrass or environmental attributes. This will help link the causes of change identified in seagrass extent monitoring using a suite of indicators, with the breadth of these building upward from the bronze level.

Citizen science can be a way to increase observations and increase community interest and involvement in estuary and intertidal reef health – with simple indicators and international forums that act as data repositories (e.g., Seagrass Spotter). Interested parties can also continue to be active in restoration trials, which are likely to increase as methodology for restoration in New Zealand becomes more standardised.

Restoration of seagrass is a growing field of research (see Appendix A), and there are still limited examples of successful restoration programmes in New Zealand. Enhancing environmental conditions to support seagrass beds is a key priority and will be underpinned by data collected through fine-scale monitoring programmes nationally. Seagrass restoration could also be included in future guidance. While this guidance is still in its early stages, results from some of the restoration development could feed into that work.

We support broad-scale monitoring becoming a regular national reporting topic, such as in MfE/Stats NZ Our Marine Environment reports. For this to occur, further investigation is needed to enable regular updates to the national seagrass inventory database (currently managed by DOC) and to connect the information to LAWA Estuaries. Further discussions with partners at MfE and Stats NZ would allow them to share the new seagrass monitoring parameters once they are recorded across the country. Even though DOC has started creating national maps of seagrass cover across New Zealand with their online repository, data collation will be easier with consistent methodology nationwide. Over time, these maps would be able to highlight changing areas of seagrass cover and improved by incorporating more frequent remote sensing tools, like satellite. Maps of changing seagrass extent will also be informed by the health and environmental indicators to understand why there are losses or gains in cover. Health and environmental indicators collected similarly on a national scale can allow for comparison of stressors across regions for potential management solutions.

The expectation is to review the current guidance after 3 years to ensure its contents are still relevant and the recommendations are fit for purpose. That will give councils time to implement or update existing programmes and feedback to the next iteration of the document. It should also be enough time to fully incorporate current legislative reforms, any updates of monitoring protocols/best practice methodologies, and improvements and availability of technology. The data collected through seagrass indicator monitoring programmes may support a future meta-analysis to understand the relationship between environmental stressors and seagrass health in New Zealand, to allow better protection and enhancement of environmental conditions to support healthy seagrass beds.

6 Acknowledgements

We appreciate the national perspectives regarding seagrass monitoring that were provided to the working group from Helen Kettles early on in development of the guidance. We also thank the following people for their time reviewing the document and providing input on different drafts of this document: Melanie Burns, Nuwan DeSilva, Eleanor Gee, Stephen Hunt, Helen Kettles, Kathleen Kozyniak, Megan Oliver, Stephen Park, Keryn Roberts, Kate Schimanski, and Sam Thomas. Both Leigh Stevens and Michael Townsend provided thorough and substantial feedback that contributed to the final version of this document. Finally, we’d also like to thank our reviewers for their valuable contributions to this guidance: Anna Berthelsen, Dana Clark, Fleur Matheson, and Leigh Tait. Their reviews were supported by MBIE Envirolink Grant 2322-HBRC268.

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8 Appendix A

Restoration of seagrass beds

Seagrass has been lost from many harbours, estuaries, and reefs around New Zealand. While the ecological values of seagrass beds are well understood (Matheson et al, 2009), how to restore and enhance beds that are degraded or lost is not so well understood. However, there are several emerging tools and techniques trialled internationally with relatively high levels of success (Tan et al. 2020). There have been several restoration efforts around New Zealand however these have relied on transplanting seagrass from existing beds (Handley, 2022), and often the initial cause of seagrass decline has not been addressed.

Transplanting seagrass from one location to another can be damaging to the donor bed where it is removed from, however trials in New Zealand have shown relatively rapid recovery of donor beds (Matheson et al. 2016, 2017, 2022). Clark and Berthelsen (2021) identify the need for low impact restoration methods. Overseas, seagrass plants propagated from seed are used to restore seagrass beds. However, in New Zealand reports of seagrass producing seed are rare. This could be due to the inconspicuous nature of the flowering shoots of the plant (Matheson et al, 2009).

Flowering and seed production of seagrass in New Zealand is now thought to be more common than was previously thought (Dos Santos and Matheson 2016, Zabarte-Maeztu et al. 2021, Hindmarsh and Hooks 2022). Cawthron Institute, Westpac NZ Government Innovation Fund, Port Nelson and OneFortyOne are currently developing a blueprint for seed-based seagrass restoration in New Zealand[15]. The first version of the blueprint is expected to be delivered in 2024 and it will be a living document and that continues to be updated as they find out more about seed-based restoration.

The blueprint (in the form of a living document) will explain step-by-step how to carry out seed-based seagrass restoration including:

- Guidance on when and where to find seagrass seeds.
- How to collect seeds and methods for processing, storing, and germinating them.
- How to sow seeds in the wild (including information on the best places and times to sow them and any equipment or resources required).
- Information to help end-users choose a suitable site for restoration (including information on what environmental conditions are required to support seagrass growth and highlighting the importance of iwi engagement).
- Previously established decision-making framework(s) for seagrass restoration from the literature, customised for our local situation in NZ.

The major requirement for any consideration of seagrass restoration is understanding the current limitations for its absence. If the causes of seagrass decline are not addressed prior to commencing restoration, then the success of the restoration is likely to be compromised.

[15] https://www.cawthron.org.nz/research/our-projects/seagrass-restoration/

9 Appendix B

Previous aerial extent mapping of seagrass for and/or by regional and district councils

Summary of previous seagrass extent and percent cover monitoring conducted by local councils[16]. Please note that the references in this table are not meant to be a comprehensive list of all work in each location, but a representation of frequency and type of mapping work in different parts of New Zealand. There are likely to be many other studies that could be referenced as any broad-scale monitoring carried out under the NEMP will have mapped seagrass extent and percent cover where seagrass was present. Also, not all studies will have used the CMECs classification for percent cover as mentioned in Section 2.1 and used be used as a reference only.

Regional Council	Image Capture Method	Seagrass Classification Method	Purpose	Example reference(s)
Northland Regional Council	Aerial photography	Hand digitising	Mapping habitat for ecologically significant areas.	Northland Regional Plan
	Aerial photography	Hand digitising	Whangārei Harbour: Mapping seagrass cover change since 1940s Included maps of iwi historical accounts of seagrass change	Dickie 1984 Morrison 2003 Reed et al. 2004
	Aerial photography	Hand digitising	Bay of Islands; Mapping seagrass cover change from 1960 to 2010 Mapping seagrass cover change from 1930s to 2010	 Matheson et al. 2010 Booth 2019
Waikato Regional Council	Aerial photography	Hand digitising	Monitor subtidal seagrass cover change from 2012.	Clark & Crossett 2019
	Aerial photography	Hand digitising	Mapping intertidal estuarine habitats.	Needham et al. 2013 a, 2013b Graeme 2005a, 2005b, 2005c, 2006, 2007, 2008a, 2008b, 2010, 2012, 2013a, 2013b, 2013c
Bay of Plenty Regional Council	Satellite imagery	Desktop classification (machine learning)	Monitor seagrass cover change from 1990.	Thang et al 2021
	Aerial photography	Hand digitising	Monitor seagrass, mangrove and saltmarsh cover change from ~1940s.	Park 1999, 2000, 2016
Hawkes Bay Regional Council	Drone photography	Hand digitising	Seagrass patch monitoring.	Data to be in next three yearly State of Environment report
Taranaki Regional Council	Drone photography	Desktop classification (machine learning)	Monitor seagrass cover.	TRC 2020
	Aerial photography	Hand digitising	Broad-scale monitoring to map estuarine intertidal habitats.	Robertson 2019
Horizons Regional Council	Aerial photography	Hand digitising	Broad-scale monitoring to map estuarine intertidal habitats.	Robertson & Stevens 2016
	Drone photography		Test flights to trial timing, flight profiles, and post processing.	

[16] Some monitoring is also carried out by Department of Conservation and surveys are conducted by research and consultancy agencies.

Regional Council	Image Capture Method	Seagrass Classification Method	Purpose	Example reference(s)
Greater Wellington Regional Council	Aerial photography	Hand digitising	Broad-scale monitoring to map estuarine intertidal habitats.	Stevens & Robertson 2008, 2013 Stevens & Forrest 2020d
	Aerial photography	Hand digitising	Porirua Harbour: Seagrass extent in Pauātahanui Inlet Change in seagrass cover from 1940s	Healy 1980 Matheson and Wadhwa 2012
	None	Ground-truthing only	Eastern Bays – Seagrass extent in Lowry Bay	Overnaars 2019
Tasman District Council	Aerial photography	Hand digitising	Broad-scale monitoring to map estuarine intertidal habitats.	Tuckey & Robertson 2003 Clark et al. 2006, 2008 Clark & Gillespie 2007 Stevens & Robertson 2015b, 2015c Stevens 2018b Stevens et al. 2020a, 2020c, 2020e, 2022
Nelson City Council	Aerial photography Drone photography	Hand digitising	Monitor seagrass cover.	Šunde et al. 2017 Gillespie et al. 2011 Clark et al. 2008 Stevens & Robertson 2015a Stevens & Forrest 2019a, 2019b Stevens et al. 2020e Scott-Simmonds et. al 2022
Marlborough Regional Council	Aerial photography	Hand digitising	Baseline seagrass patch monitoring and broad-scale monitoring to map estuarine intertidal habitats.	Stevens et al 2016, 2018a Gillespie et al. 2012 Berthelsen et al. 2016, 2018
Environment Canterbury	Aerial photography	Hand digitising	Broad-scale monitoring to map estuarine intertidal habitats.	Bolton-Richie et al. 2018
	Satellite imagery	Spectral un-mixing	Broad-scale monitoring to map estuarine intertidal habitats	Tait et al. 2022
Otago Regional Council	Aerial photography	Hand digitising	Broad-scale monitoring to map estuarine intertidal habitats.	Stevens & Robertson 2017a, 2017b Roberts et al. 2021, 2021b Roberts et al. 2022
Environment Southland	Satellite imagery Aerial photography	Hand digitising	Mapping intertidal estuarine habitats.	Stevens et al 2017, 2020, 2021 Roberts et al 2021b

10 Appendix C

Details of the desktop digitising methods used by Northland Regional Council as part of the development of the new Regional Plan.

Seagrass habitat was mapped at a maximum scale of 1:5000, with the majority mapped at a scale of 1:1000 or less using the following protocols:

- The minimum polygon size has a maximum axis length of at least 10 m.
- Where habitat boundaries were obscured by shadow, either between habitat types or at the landward boundary, then the start of the shadow was taken as the habitat boundary. i.e., any shadow was not included as 'seagrass habitat'.
- Seagrass habitat separated by distinct geomorphological features (e.g., channels) was digitised as separate polygons, even if the distance between the stands was less than 10 m.
- Patches of seagrass within 50 m of a main bed were included within the same polygon. Patches >50 m from a main bed were excluded.
- When the seagrass habitat was patchy, the edge of the polygon was made by drawing to the next nearest patch.
- When individual or two small patches of seagrass were encountered these were drawn as individual polygons. If three or more patches were present these were drawn as one polygon, subject to the other rules above.

11 Appendix D

Machine learning approaches

The below table highlights methods of different seagrass mapping approaches (Mederos-Barrera et al. 2022). However, a review in 2019 by Pham et al. highlighted that no single technique has been determined for diverse marine environments.

Authors	**Year**	**Platform**	**Pre-processing**	**WCC**	**Classifier**	**Max. Depth**
Le Quilleuc et al.	2021	Pleiades-1	RC, AC	Sagawa	NN, MLC, SVM	15 m
Marcello et al.	2021	Sentinel-2, WV-2, CASI, Pika-L	RC, AC, SGC	No	MLC, SVM	20 m
Nguyen et al.	2021	Landsat-8, Sentinel-2	AC, SGC	Lyzenga	MLC	5 m
Vahtmäe et al.	2021	CASI-2, Sentinel-2	GC, RC, AC, SGC, MNF	Lee	MD	3 m
Bakirman and Gumusay	2020	WV-2	RC, AC	Lyzenga	RF, SVM	20 m
Ha et al.	2020	Sentinel-2	RC, AC	Sagawa	MLC	1.5 m
Rende et al.	2020	Pleiades-1	RC, AC	Lyzenga	KNN, RT, DT	10 m
Vahtmäe et al.	2020	CASI-2	RC, AC, SGC, MNF	Maritorena	MD	4 m
Poursanidis et al.	2019	Sentinel-2	PS, SGC	No	SVM,RF	30 m
Su and Huang	2019	WV-2	RC, AC	Lee	ISODATA	2 m
Wicaksono et al.	2019	WV-2	RC, AC, SGC, PCA	Lyzenga	RF, DT, and SVM	7 m

Poursanidis et al.	2018	WV-2	RC, AC, PS	Lyzenga	SVM, NN, KNN, FR	30 and 45 m
Topouzelis et al.	2018	Landsat-8	RC, AC	No	OBIA	40 m
Traganos et al.	2018	Sentinel-2	RC, AC, SGC	Lyzenga	SVM	Shallow and deeper
Hafizt et al.	2017	Sentinel-2	SGC	Lyzenga	ISODATA	Shallow
Manuputty et al.	2017	WV-2	GC, RC, AC, PCA	Lyzenga	SVM	Shallow
Manuputty et al.	2016	WV-2	GC, RC, AC	Lyzenga	SVM	Shallow
Topouzelis et al.	2016	Sentinel-2	GC, RC, AC, PS	No	MLC	Shallow and deeper
Wahidin et al.	2015	Landsat 8	GC, RC, AC	Lyzenga	SVM, RF, DT, KNN, Bayesian	Shallow
Manessa et al.	2014	WV-2	RC, AC, SGC	Lyzenga	MLC	Shallow
Zhang et al.	2013	AVIRIS	GC, MNF, RC, AC, SGC	Lyzenga	RF	3.5 m
Knudby and Nordlund	2011	IKONOS	RC, AC, SGC	Lyzenga	MLC, regression	7 m
Sagawa et al.	2010	IKONOS	RC	LyzengaSagawa	MLC	16 m
Phinn et al.	2008	QuickBird-2, Landsat-5, CASI-2	RC, AC, SGC	No	Regression	3 m

AC: atmospheric correction, DT: Decision Tree, FR: fuzzy rules, GC: geometric correction, KNN: K-nearest neighbours, MD: minimum distance, MLC: maximum likelihood classifier, MNF: minimum noise fraction, PCA: principal component analysis transform, PS: pansharpening, RC: radiometric correction, RF: random forest, RT: random tree, SGC: sun glint correction, SVM: support vector machine, WCC: water column correction.

12 Appendix E

Satellite image sensor information as at 2020

Table taken from NIWA Envirolink review of satellite image possibilities for monitoring seagrass in Hawke's Bay (Schimel 2020):

Sensor	Type	Carrier satellite	Operator	Scientific / Commercial	Spatial resolution at nadir (m)	Bands	Dates
Hyperion	HS	Earth Observing-1	NASA	Scientific	HS: 30	HS: 220	2001-2015
CHRIS	HS	PROBA-1			HS: 18		2001-
HICO	HS	International Space Station		Scientific	HS: 90		2009-2014
PRISMA	HS	PRISMA			HS: 30		2019-
Advanced Land Imager (ALI)	MS	Earth Observing-1	NASA	Scientific	Pan: 10 MS: 30	MS: 10	2000-2017
Operational Land Imager (OLI)	MS	Landsat 8	NASA/USGS	Scientific	Pan: 15 MS/SWIR: 30	MS: 6 (Coastal, B, G, R, NIR, Cirrus) SWIR: 2	2013-
Landsat Enhanced Thematic Mapper Plus (ETM+)	MS	Landsat 7	NASA/USGS	Scientific	Pan: 15 MS/SWIR: 30	MS: 4 (B, G, R, NIR) SWIR: 2	1999-
Landsat Thematic Mapper (TM)	MS	Landsat 4, 5	NASA/USGS		MS: 30		
Landsat Multispectral Scanner (MSS)	MS	Landsat 1, 2, 3, 4, 5	NASA/USGS		60		1972-1992

Sensor	Type	Carrier satellite	Operator	Scientific / Commercial	Spatial resolution at nadir (m)	Bands	Dates
MSI	MS	Sentinel-2	ESA	Scientific	Multiple: 10, 20, 60	MS: 10 (Coastal, B, G, R, Red edge 1/2/3, NIR, Water vapour SWIR: 3	2015-
SpaceView 110	MS	WorldView-4 (formerly GeoEye-2)	MAXAR (formerly DigitalGlobe)	Commercial	Pan: 0.31 MS: 1.24	MS: 4 (B, G, R, NIR)	2016-2019
WV110	MS	WorldView-3	MAXAR (formerly DigitalGlobe)	Commercial	Pan: 0.31 MS: 1.24 SWIR: 3.7 CAVIS: 30	MS: 8 (R, R edge, Coastal, B, G, Y, NIR, NIR-2) SWIR: 8 CAVIS: 12	2014-
WV110	MS	WorldView-2	MAXAR (formerly DigitalGlobe)	Commercial	Pan: 0.46 MS: 1.85	MS: 8 (R, R edge, Coastal, B, G, Y, NIR, NIR-2)	2009-
	Pan	WorldView-1	MAXAR (formerly DigitalGlobe)	Commercial	Pan: 0.5	N/A	2007-
	MS	GeoEye-1	MAXAR (formerly DigitalGlobe)	Commercial	Pan: 0.41 MS: 1.64	MS: 4 (B, G, R, NIR)	2008-
BGIS 2000	MS	QuickBird-2	MAXAR (formerly DigitalGlobe)	Commercial	Pan: 0.60 MS: 2.40	MS: 4 (B, G, R, NIR)	2001-2014
OSA	MS	IKONOS	MAXAR (formerly DigitalGlobe)	Commercial	Pan: 0.82 MS: 3.28	MS: 4 (B, G, R, NIR)	2000-2015
	MS	Pleiades (1A and 1B)	Airbus	Commercial	Pan: 0.5 MS: 2.0	MS: 4 (B, G, R, NIR)	2011-

Sensor	Type	Carrier satellite	Operator	Scientific / Commercial	Spatial resolution at nadir (m)	Bands	Dates
	MS	SPOT 6/7	Airbus	Commercial	Pan: 1.5 MS: 6.0	MS: 4 (B, G, R, NIR)	2012-
SPOT High Resolution Visible (HRV) multi-spectral mode (XS)	MS	SPOT 1, 2, 3			Pan: 10 MS: 20	MS: 3 (G, R, NIR)	1986-2009
HRVIR	MS	SPOT 4			Pan: 10		1998-2013
high resolution geometrical (HRG)	MS	SPOT 5			Pan: 2.5 MS: 10		2002-
	MS	SkySat (constellation)	Planet Labs	Commercial	Pan: 0.5 (formerly 0.8) MS: 1.0	MS: 4 (B, G, R, NIR)	2014-
		PlanetScope (constellation)	Planet Labs (US)	Commercial	Pan: 1.5 MS: 3-5	MS: 4 (B, G, R, NIR)	
	MS	Ziyuan-3A	MLR (China)		2.5 Infrared: 6		2012-
	MS	SuperView-1			Pa: 0.5 MS: 2.0	MS: 4 (B, G, R, NIR)	2018-

*images used in various papers

13 Appendix F

Examples of previous fine-scale seagrass health monitoring conducted for and/or by regional or district councils.

A range of studies have been conducted across local city, district and regional councils relating to seagrass health. These are summarised in the table below. Several of these studies were specifically designed to investigate the health of seagrass beds with a wide number of indicators investigated (Waikato Regional Council and Bay of Plenty Regional Council). Please note that the references in this table are not meant to be a comprehensive list of all work in each location, but a representation of frequency and type of mapping work in different parts of New Zealand.

Most studies involved a smaller number of indicators (e.g. just percent cover, or 1-2 others) linked in with other estuarine monitoring programmes. The most commonly used seagrass health indicators were percent cover (6 councils), above ground biomass (5 councils), leaf length, fungal wasting disease and macroalgae cover (3 councils each; Table 7).

Regional Council	Purpose of study	Seagrass indicators used	Stressor information	Key outcomes/findings	Reference(s)
Northland Regional Council	Seagrass restoration trial monitoring – Whangarei Harbour	Percent cover, biomass, shoot density, leaf dimensions, chlorophyll fluorescence	Sediment organic matter, grain size, light availability/water clarity, water depth and temperature, sediment level, turbidity, salinity, conductivity, nutrients, phytoplankton biomass	Demonstrated successful seagrass restoration planting with sods and sprigs and recovery of donor site	Matheson et al. (2017), Matheson et al. (2009)
	Seagrass assessment Eastern Bay of Islands	Percent cover, biomass	Sediment organic matter, grain size, light availability/water clarity, turbidity, salinity, phytoplankton biomass	Assessment of past and present state, threats, and management options	Matheson et al. (2010)
Waikato Regional Council	Fine-scale subtidal seagrass health	Percent cover, leaf length, above ground biomass, macroalgae cover, epiphyte/sediment cover, fungal wasting disease		Trialled new method for visual biomass assessment	Clark & Crossett (2019)
	Seagrass and contaminant stressor investigation – Aotea Harbour	Percent cover, biomass, leaf dimensions, nutrient content, chlorophyll fluorescence	Sediment organic matter, grain size, porewater nutrients, terrestrial herbicides, light, water depth	Relationships with porewater ammonium and herbicides	Dos Santos (2011)

Regional Council	Purpose of study	Seagrass indicators used	Stressor information	Key outcomes/findings	Reference(s)
	Seagrass and sediment investigation – Whangapoua and Raglan Harbours	Seagrass cover, biomass, chlorophyll fluorescence	Sediment organic matter, grain size, nutrients, redox	Relationships with redox, sediment phosphorus and organic matter	Matheson and Schwarz (2007)
Bay of Plenty Regional Council	Trial fine-scale seagrass indicators to develop annual monitoring network	Percent cover, leaf length, leaf width, above ground biomass (leaves), below ground biomass (rhizomes), above:below ground ratio, leaf N content, leaf 15N content, leaf 13C content, leaf C/N ratio, non-structural carbohydrates rhizomes	Sediment grain size, organic matter, light (PAR, LUX), porosity, chlorophyl a, phaeopigment	Wide combination of stressor and seagrass health indicators allowed environmental relationships to be established for a number of indicators (physical and chemical)	Crawshaw (2020)
	Seagrass and contaminant stressor investigation – Tauranga Harbour	Percent cover, biomass, leaf dimensions, nutrient content, chlorophyll fluorescence	Sediment organic matter, grain size, porewater nutrients, terrestrial herbicides, light, water depth	Relationships with porewater ammonium and herbicides	Dos Santos (2011)
	Seagrass and sediment investigation – Tauranga Harbour	Seagrass cover, biomass, chlorophyll fluorescence	Sediment organic matter, nutrients, redox, porewater sulphide	Relationships with redox, sediment phosphorus and organic matter	Matheson and Schwarz (2007)
Hawkes Bay Regional Council	Drone flights and fine-scale indicators trial	Percent cover, blade length, shoot density, leaf density		Data to be in next three yearly SoE report	
	Field assessment – Pōrangahau estuary	Biomass	Sediment grain size, salinity, turbidity, nutrient, phytoplankton biomass	Regional Council scientists identified new seagrass patches in the estuary. These were assessed, evidence for past occurrence examined, potential threats and remedial actions identified.	Matheson (2018)
Greater Wellington Regional Council	Assessment of seagrass loss from baseline monitoring (e.g. Porirua Harbour)	Temporal changes in spatial extent, percent cover, macroalgae cover		Porirua seagrass loss of 48.1ha (26%) since baseline. Over monitored period seagrass extent has been variable.	Stevens & Forrest (2020)
	Seagrass restoration trial monitoring – Pauātahanui Inlet	Percent cover	Light availability, sediment porewater nutrients, salinity, turbidity, water nutrients	Seagrass restoration planting with sods was not successful after two very small-scale attempts. Restoration site likely too heavily impacted with siltation effects. However, donor site recovered well from plant extractions.	Matheson et al. (2016) Zabarte-Maeztu et al. (2020)

Regional Council	Purpose of study	Seagrass indicators used	Stressor information	Key outcomes/findings	Reference(s)
	Comparison of existing, potential, and historical seagrass sites in Pauātahanui Inlet	Percent cover, biomass, shoot density	Grain size, porewater nutrients, sulphide, redox, light availability, (modelled) sedimentation rate, wave period, suspended sediment, salinity and current velocity	Historical sites had higher mud, bulk density, porewater ammonium, lower light (when submerged) and redox	
Tasman District Council	Whanganui/Westhaven Inlet, assessment of seagrass loss from a reference estuary.	Temporal changes in spatial extent, percent cover, macroalgae cover	Grain size, sediment nutrients, trace metals, sediment oxygenation	Loss of 531ha (74%) of >50% cover seagrass between 2013 and 2021. No obvious catchment nutrient or sediment drivers.	Stevens et al. (2022)
	Broad scale assessments in Waimea, Moutere, Motueka, Motupipi, Ruataniwha. Synoptic assessments of all estuaries in the region.	Spatial extent, percent cover, macroalgae cover	Grain size, sediment nutrients, trace metals, sediment oxygenation		Stevens et al. (2020) Robertson & Stevens (2012)
Nelson City Council	Compare differences in sediment composition and seagrass between high and low vehicle usage. Monitor health of seagrass beds.	Percent cover, fungal wasting disease, macroalgae cover, above ground biomass. Temporal changes in spatial extent, percent cover, macroalgae cover	RDL depth, grain size, sediment PAH, epifauna, infauna, no and size of cockles, heavy metals, sediment AFDW	Physical disturbance to seagrass by vehicle traffic identified. Fungal wasting disease identified, suggest further fine-scale seagrass studies.	Šunde et al. (2017) Gillespie et al. (2012) Gillespie et al. (2011) Clark et al. (2008) Stevens & Forrest (2019 a, b) Stevens et al. (2019, 2020)
Marlborough District Council	Health of seagrass beds	Percent cover, above ground biomass, fungal wasting disease, macroalgae cover	Grain size, sediment nutrients, trace metals, sediment oxygenation, salinity, SVOCs, tributyl tin, epibiota, infauna		Berthelsen et al. (2016)
Canterbury Regional Council	Sentinel sites as part of State of Environment fine scale intertidal monitoring.	Percent cover and macroalgae cover	Grain size, sediment nutrients, trace metals, redox, epifauna, and infauna.		
Otago	Establish baseline and assess seagrass loss from baseline (e.g. Blueskin)	Temporal changes in spatial extent, percent cover, macroalgae cover	Grain size, sediment nutrients, trace metals, sediment oxygenation, macroalgal extent	Blueskin Bay baseline 33ha in 2021. Some macroalgal smothering and vehicle tracks.	Roberts et al. (2021)

Regional Council	Purpose of study	Seagrass indicators used	Stressor information	Key outcomes/findings	Reference(s)
Environment Southland	Assessment of seagrass loss from baseline monitoring (e.g. New River Estuary). Assessment of seagrass in a reference estuary (i.e. Freshwater Inlet)	Temporal changes in spatial extent, percent cover, macroalgae cover	Grain size, sediment nutrients, trace metals, sediment oxygenation, mud and macroalgal extent	New River Estuary loss of 77ha (82%) between 2001 – 2021. Significant incraeases in mud extent and macroalgae cover. Freshwater Inlet 340ha seagrass of which >75% is above 50% cover. No obvious stressors	Roberts et al. (2021) Stevens et al. (2020)

Table 7. Summary of previously monitored seagrass health indicators conducted for and/or by local councils.

	Northland RC	*Waikato RC*	*Bay of Plenty RC*	*Hawkes Bay RC*	*Greater Wellington RC*	*Tasman DC*	*Nelson City*	*Marlborough RC*	*Environment Canterbury*	*Otago RC*	*Environment Southland*
Percent cover	x	x	x	X	x	x	x	x	x	x	x
Above ground biomass	x	x	x	X	x		x	x			
Leaf length	x	x	x	X	x						
Shoot density				X	x						
Leaf density	x			X							
Leaf width	x	x	x		x						
Below ground biomass	x	x	x	X	x						
Biochemical indicators			x			x					
Fungal	x	x					x				
Macroalgae	x	x			x	x	x		x	x	x
Epiphyte/sediment cover		x				x					
Nutrient content		x	x								
Flowering shoot/inflorescence density		x	x		x	x					
Chlorophyll fluorescence (photosynthetic potential)	x	x	x								
Depth limit	x										