BEFORE THE OTAGO REGIONAL COUNCIL AND DUNEDIN CITY COUNCIL

IN THE MATTER	of the Resource Management Act 1991 (**Act**)
AND	
IN THE MATTER	Resource Consent Applications ORC RM19.441 and DCC LUC-2019-658 – Port Otago Ltd – Te Rauone Beach Rock Groynes and Sand Re-nourishment

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STATEMENT OF EVIDENCE OF LEIGH TAIT

ON BEHALF OF PORT OTAGO LIMITED

Date 1 December 2020

STATEMENT OF EVIDENCE OF CONSTRUCTION AND BEACH RE-NOURISHMENT IMPACTS TO SEAGRASS BEDS FOR PORT OTAGO LIMITED

INTRODUCTION

1 My full name is Leigh Wayne Tait.

2 I am currently employed by the National Institue of Water and Atmospheric research (NIWA) as a Scientist (Marine Ecology). I have a PhD from the University of Canterbury (Marine Ecology) and over 10 years experience, including three years as a Postdoctoral fellow at University of Canterbury and Oregon State University (USA), and 7 years in my current position at NIWA. I am a member of the New Zealand Marine Sciences Society.

3 I have experience providing ecological impact assessments for the construction of seawalls in the Avon-Heathcote Estuary related to the post-earthquake rebuild in Christchurch (contracted by the *Stronger Christchurch Infrastructure Rebuild Team*), and for the construction of sewage pipelines and associated rock armouring for wastewater redirection (*Christchurch City Council*). I led and completed the offshore kelp monitoring programme for *Port Otago Ltd* in relation to the capital dredging of Otago Harbour, and I designed and implemented the inshore rocky reef monitoring programme for the long-term maintenance dredging programme. I am also involved as a key member of a monitoring programme to detect ecological impacts of the Scott Base rebuild (*Antarctica New Zealand*) on marine benthic communities.

4 My evidence is given in support of the resource consent application lodged with the the Otago Regional Council and Dunedin City Council in December 2019 by Port Otago Ltd. I understand that the application relates to the proposed construction of rock groynes and the deposition of sand to rehabilitate Te Rauone Beach in Otago Harbour which has been subject to significant erosion. The works include the following:

4.1 Construction of three rock groynes which will extend 70-80m from the existing shoreline. The groynes will be constructed of 0.5 m diameter rocks which will form the armour layer of the structure with smaller rocks (around 0.2 m diameter) forming the core of the structure.

4.2 Post construction of the groynes, sand will be deposited along the north end of Te Rauone Beach. The deposition area relates to approximately 300 metres of coastline located in front of the Te Rauone Beach Reserve. The total initial deposition is predicted to be 26,500m^3 - 34,000m^3, more or less, to be determined by an updated survey.

4.3 Maintenance requirements will be dependent on monitoring and inspections, but may include renourishment top ups as determined under a Maintenance and Operation Plan.

5 I am familiar with Section 8 of the AEE and Ryder Environmental Ltd's Ecological Impact Assessment attached to the AEE as Appendix E.

6 I record that I have read and agree to abide by the Environment Court's Code of Conduct for Expert Witnesses as specified in the Environment Court's Practice Note 2014. This evidence is within my area of expertise, except where I state that I rely upon the evidence of other expert witness as presented to this hearing. I have not

omitted to consider any material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

7 My evidence will deal with the following:

7.1 Background and role;

7.2 Summary of methodology;

7.3 Summary of the effects of groyne construction and beach renourishment on seagrass;

7.4 Comments on submissions;

7.5 Comments on Section 42A report;

7.6 Proposed conditions; and

7.7 Conclusions.

BACKGROUND AND ROLE

8 I was engaged by Port Otago, after the Department of Conservation (DoC) and ORC's consultant ecologist, Ms Hilke Giles, raised concerns that the effects on benthic communities (infauna) and the seagrass beds to the south of the project footprint had not been adequately dealt with within the Ryder Ecological Assessment submitted with the AEE (Appendix E).

9 My scope of works included to; analyse existing data on seagrass beds in the region of Te Rauone Beach; identify the potential risk of the proposed groyne construction on seagrass beds; identify suitable thresholds for implementing management interventions; propose management and intervention; and propose a monitoring regime to detect changes in seagrass beds.

10 I prepared a report entitled "*Managing and mitigating impacts to seagrass beds: Te Rauone erosion remediation*" (Appendix A) which identified the range and variation of seagrass cover between 2015 and 2020. From this analysis, thresholds for management and intervention were developed, and an associated monitoring programme to detect construction related changes to seagrass beds and provide timely intervention was proposed.

11 I note that monitoring of benthic communities (burrowing and epifaunal species - infauna) was omitted as part of the adaptive management actions proposed because the benthic surveys undertaken by Ryder Environmental noted a range of burrowing and epifaunal species present within and adjacent to the construction footprint, however, also noted, there were few valued or habitat forming species besides seagrass. I therefore advised that seagrass should be used as the defining metric of ecological health for several reasons:

11.1 Seagrass provides a range of important ecosystem functions, including providing habitat for many species such as cockles (Lohrer et al. 2012, 2016).

11.2 Seagrass is conspicuous and can be monitored at large scales.

11.3 Benthic infauna assemblages are made up of many species, which vary considerably in both space and time.

11.4 Benthic infauna can only be monitored through small scale destructive coring, making it difficult to efficiently sample large areas.

12 Seagrass is a highly valued ecosystem engineer that provides important ecological services (e.g., sediment stabilisation (Fonesca 1989), nutrient processing (Morris et al. 2008; Bulmer et al. 2018), and carbon sequestration (Bulmer et al. 2020)), as well as providing food and habitat for a range of organisms, including juvenile fish (Lohrer et al. 2016). This key habitat-forming species represents a useful ecological indicator for understanding broader changes including water quality (Montefalcone 2009).

SUMMARY OF METHODOLOGY

13 In the first instance, literature and seagrass specialists (pers. Comm. Drew Lohrer, Richard Bulmer) were consulted. While there were few studies explicitly looking at the impacts of groyne construction on benthic communities, there were several studies examining the hydrodynamic changes associated with coastal hardening. The consensus is that these structures reduce currents, locally enhance accretion, but can lead to downstream erosion (Schoonees et al. 2019).

14 Following literature review, and seagrass expert consultation, I deemed it critical to identify the natural range and variability of seagrass within the region of Te Rauone Beach. To do this, I analysed aerial imagery collected by Ryder Consulting Ltd, on behalf of Port Otago Ltd. Furthermore, satellite images were also used to better examine annual, and inter-annual variability of seagrass beds. Combined, these two methods provide an in-depth time-series of seagrass cover over the region encompassing the outer Otago Harbour.

15 Images from the Sentinel-2 satellite (*Sentinel-2 imagery courtesy of European Space Agency*) were used for identifying seagrass beds during periods of low tide within Otago Harbour. Within five regions spanning Te Rauone Beach (two regions), Omate Beach (two regions), and a single region near Harwood (as a secondary control site), four 50 x 50 m polygons were established over intertidal flats, with the cover of seagrass within each polygon estimated for each cloud-free, low-tide satellite images between December 2015 and August 2020. The average cover across the four 50 x 50 m polygons was used to set minimum thresholds of seagrass cover.

16 Aerial images were collected via manned fixed-wing aircraft and targeted seagrass beds in the outer reaches of Otago Harbour. Imagery was collected on five separate occasions (December 2015, April 2016, October 2016, August 2017, and April 2018). The minimum total cover of seagrass over this period was used to set the management thresholds across four regions (two regions on Te Rauone Beach, and two regions on Omate Beach).

17 Using the within site variability and minimum identified coverage of seagrass beds, three management thresholds were identified representing loss of seagrass beyond the minimum coverage for four regions. These three thresholds are the minimum cover minus 10, 30, and 50 % of the range of that site. Thresholds for both satellite and aerial imagery were proposed.

SUMMARY OF THE EFFECTS OF GROYNE CONSTRUCTION AND BEACH RENOURISHMENT ON SEAGRASS

18 Seagrass species have regularly shown declines in national and international regions, often as a result of reductions in water clarity, increases in nutrient loading and sediment deposition (Duarte 2002). Deep subtidal seagrass beds respond negatively to declining water clarity (Longstaff and Dennison 1999), but studies on intertidal beds in New Zealand reveal resistance to high turbidity on account of their proximity to the surface, and daily emersion which greatly enhances access to sunlight (Bulmer et al. 2018; Drylie et al. 2018). The risk of insufficient light for photosynthesis contributing to decline in intertidal seagrass beds is low.

19 The introduction of groyne structures and beach renourishment, however, has the potential to alter hydrodynamic regimes and redirect patterns of sediment erosion/accretion (Schoonees et al. 2019), with the potential to impact seagrass beds. The intended (i.e., halting Te Rauone Beach erosion) and un-intended (e.g., shifted erosion or accretion patterns) consequences of groynes have the potential to affect the net balance of seagrass cover.

20 Despite the potential negative consequences of construction activities on seagrass beds, groyne construction and renourishment along Te Rauone Beach has the potential to stabilise sediments and reduce water flow (Schoonees et al. 2019). Current velocities are a key limiting factor to the establishment and persistence of seagrass beds (De Boers 2007). Reducing current speed along Te Rauone Beach has the potential to increase the habitable range of seagrass along this fast eroding shoreline (Hart 2020).

21 However, there are uncertainties around the spatial alteration of current velocities and the consequences to seagrass beds, as well as the immediate effects of construction activities. To account for this uncertainty, a monitoring programme, monitoring targets, and intervention measures are proposed (Appendix A).

21.1 A baseline monitoring campaign will be undertaken prior to construction activities, as outlined in the report in Appendix A.

21.2 Scaled back aerial imaging will be completed monthly during the construction process, as outlined in Appendix A.

21.3 If management thresholds are reached, a “triggered monitoring regime” will be implemented with greater monitoring frequency, as outlined in Appendix A.

21.4 Three management thresholds are designed to apply increasingly stringent intervention measures with increasing trigger severity, as outlined in Appendix A.

22 Implementation of regular monitoring and adherence to pre-defined metrics which trigger actions designed to halt and improve seagrass cover will ensure that ecological

effects of the construction are short term, or that the groyne construction provides positive benefits to the habitable range for seagrass.

COMMENTS ON SUBMISSIONS

Department of Conservation (DoC)

23 I note that DoC have written to confirm that their concerns raised in their submission have been addressed through the proposed conditions, draft Environmental Management Plan and proposed adaptive management actions. I have however addressed their relevant submission points and subsequent correspondance with Port Otago where they have raised further concerns within Table 1 below. These are also referred to in the Otago Regional Council's reporting officer, Ms Hilary Lennox's s42A report.

Table 1 - Issues raised by DoC

Issue raised by DoC	Response
<u>Original submission</u>	
The dumping of sand, and potential spread of sediment from the works, have the potential to adversely affect cockles and seagrass beds, particularly if construction and ongoing replenishment are not well managed. Although the application considers that significant adverse effects are unlikely, the proposed adaptive management approach would only respond once those adverse effects have already occurred, rather than avoiding or minimising effects in the first place.	As discussed within my summary of effects above, implementation of frequent monitoring and the use of very low-thresholds of change will lead to halt of activites. Depending on the severity of the trigger, a range of intervention measures will be implemented that will ensure that no construction or replenishment activities re-start until problems have been addressed and seagrass have shown recovery. Adherence to pre-defined metrics which trigger actions designed to halt and improve seagrass cover will ensure that ecological effects of the construction and renourishment are short term, or that the groyne construction provide positive benefits to the habitable range for seagrass.
<u>Further concerns raised post submission</u>	
The application includes monitoring of benthic communities, but these are not included in the draft consent conditions.	This matter is addressed in paragraph 11 above.
The degree to which the structures may retain drift seaweeds and the resulting nutrient enrichment has not been addressed. This would cause amenity (visual and smell) impacts, so could	I do not consider that drift seaweed is an issue which warrants consideration as part of this application as there is no available evidence suggesting that similar structures enhance the

require a response regardless of the ecological impacts.	accumulation of macroalgae through hydrodynamic processes. Existing evidence points strongly to wind driven movement and accumulation of macroalgal blooms (Lanari & Copertino 2019). Further, there is little evidence of Otago Harbour having an issue with excessive macroalgal blooms. Large scale removal of macroalgal biomass has its own set of impacts associated with removal methodologies.
We would prefer that seagrass monitoring continue at reduced frequency for two years post-construction, rather than one. We realise that the current draft conditions allow for monitoring to be extended based on results, but we'd prefer that the default allows two years to pick up any longer-term effects of the works.	The proposed conditions stipulate that monitoring will continue beyond 1 year if negative impacts of the contruction are detected. This decision will be made by an independent expert and will consider both the frequency that thresholds were reached during the monitoring campaign and any negative trajectories. Overall, negative impacts of the construction and renourishment are unlikely, but the proposed adaptive management actions provide significant contigency to detect and act on negative trends. Further extension of the monitoring programme without sufficient evidence adds little to the proposed conditions.

Simon James

24 The submission in opposition by Mr James considers that the immediate proximity of the cockle beds is a concern and that the effect the work may have on this seems not to be considered. As discussed in paragraph 11 above, monitoring of these infauna species is destructive. Furthermore, studies find highly positive correlations between seagrass beds and cockle beds (Lohrer et al. 2012, 2016), making the use of seagrass metrics highly relevant to the health of cockle beds in the region.

25 No other submissions deal directly with the impacts of groyne construction and beach renourishment to seagrass and benthic communities.

RESPONSE TO SECTION 42A REPORT(S)

26 I note that a summary of the issues raised by Dr Giles throughout the process is attached to Ms Lennox's s42A report. Of those issues, Ms Giles states that *"the NIWA report does not provide a monitoring programme but, instead, a proposed monitoring programme containing suggestions and options for monitoring. This is highlighted by the frequent use of "should", "it is suggested" and "ideally". As a result, it is not clear what exact (or minimum) monitoring is proposed as part of the application*." Whilst I note that the proposed conditions of consent adequately address the need for

monitoring by referring to my report, I have revised my report which is attached to my evidence addressing this issue.

PROPOSED CONDITIONS

27 A suite of proposed conditions are attached to Ms Lennox’s s42A report. I have read the conditions and support them as they relate to the effects of groyne construction and beach renousrishment on seagrass.

CONCLUSIONS

28 The proposed activities have the potential to have positive outcomes for the spatial extent and persistence of seagrass beds in the region.

29 However, the recommended monitoring and mitigation strategy (Appendix A) will enable timely detection of negative trends and provide multiple mitigation and intervention measures designed to act quickly and, in the most severe cases, use active remediation methods.

30 I am happy to answer any questions that the Hearing Panel may have for me in relation to my evidence.

Appendices:

Appendix A – Managing and mitigating impacts to seagrass beds

Managing and mitigating impacts to seagrass beds

Te Rauone erosion remediation

Prepared for Port Otago Ltd

October 2020

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Executive summary

Te Rauone Beach near the heads of Otago Harbour has been subject to significant erosion, reducing amenity features of the beach and threatening infrastructure and property. Port Otago Ltd plan to undertake a beach management scheme involving the construction of three rocky groynes and replenishment of sand to stabilise Te Rauone Beach.

Following ecological assessments of the marine intertidal zone within and adjacent to the footprint of construction, concerns about the consequences of construction activities to nearby seagrass beds have been raised. Seagrass is a highly valued ecosystem engineer that provides a range of important ecological services. The introduction of groyne structures has the potential to alter hydrodynamic regimes and redirect patterns of sediment erosion/accretion. High current velocities are a key limiting factor to the establishment and persistence of seagrass beds, and the introduction of groynes to Te Rauone Beach has the potential to increase the habitable range of seagrass along this fast eroding shoreline. There are, however, uncertainties around the spatial alteration of current velocities and transport of introduced sediments, and the consequences to seagrass beds within the construction footprint and nearby.

Port Otago Ltd have contracted NIWA to outline the current status of seagrass in the region of Te Rauone Beach, identify thresholds for management intervention, recommend intervention measures, and a monitoring programme for timely identification of impacts of the planned groyne construction on the sea grass beds. This report summarises the time-series of seagrass bed cover in the region of Te Rauone beach and identifies threshold metrics and parameters for monitoring that will enable the detection and intervention of impacts to seagrass beds.

Analysis of seagrass beds from both aerial and satellite imagery reveal seasonally dynamic changes in bed coverage, but long-term consistency in cover. Locations nearest areas of high coastal erosion at the eastern range of Te Rauone Beach had the lowest coverage of seagrass, with discrete intertidal regions frequently revealing no detectable beds. From these region-specific trends, thresholds of minimum seagrass coverage are proposed to detect 10%, 30%, and 50% loss of seagrass beds.

We propose a hierarchy of intervention measures suitable for each threshold (i.e., 10%, 30%, and 50% loss) and a monitoring programme to enable timely identification of change to seagrass cover and determine whether this change is natural or caused by the proposed activities, including recommendations of the frequency of monitoring under routine and threshold exceedance scenarios.

1 Introduction

1.1 Background

Te Rauone Beach near the heads of Otago Harbour has been subject to significant erosion, reducing amenity features of the beach and threatening infrastructure and property. Port Otago Ltd plan to undertake a beach management scheme involving the construction of three rocky groynes and replenishment of sand to stabilise Te Rauone Beach.

Following ecological assessments of the marine intertidal zone within and adjacent to the footprint of construction by Ryder Consulting Ltd (Goodwin and Tocher 2020), concerns about the consequences of construction activities to nearby seagrass beds have been raised by regulatory authorities. Benthic surveys revealed a range of burrowing and epifaunal species present within and adjacent to the construction footprint (Goodwin and Tocher 2020), however, there were few valued or habitat forming species besides seagrass. This key habitat-forming species represents a useful ecological indicator for understanding broader changes including water quality (Montefalcone 2009).

Seagrass is a highly valued ecosystem engineer that provides important ecological services (e.g., sediment stabilisation (Fonesca 1989), nutrient processing (Morris et al. 2008; Bulmer et al. 2018), and carbon sequestration (Bulmer et al. 2020)), as well as providing food and habitat for a range of organisms, including juvenile fish (Lohrer et al. 2016). Worldwide these species have shown notable declines, often as a result of reductions in water clarity and sediment deposition. Given the ecological importance and responsiveness to disturbance, seagrass represent an ideal candidate for broad scale identification of construction related impacts to benthic communities.

Deep subtidal seagrass beds respond negatively to declining water clarity (Longstaff and Dennison 1999), but intertidal beds are more resistant to high turbidity on account of their proximity to the surface, and daily emersion which greatly enhances access to sunlight (Bulmer et al. 2018; Drylie et al. 2018). The risk of insufficient light for photosynthesis contributing to decline in intertidal seagrass beds is low. The introduction of groyne structures, however, has the potential to alter hydrodynamic regimes and redirect patterns of sediment erosion/accretion (Schoonees et al. 2019), with the potential to impact seagrass beds. The intended (i.e., halting Te Rauone Beach erosion) and un-intended (e.g., shifted erosion or accretion patterns) consequences of groynes have the potential to affect the net balance of seagrass cover. The footprint and speed of these processes will likely dictate the impacts to nearby seagrass beds.

Despite the potential negative consequences of construction activities on seagrass beds, groyne construction along Te Rauone Beach has the potential to stabilise sediments and reduce water flow (Schoonees et al. 2019). Current velocities are a key limiting factor to the establishment and persistence of seagrass beds (De Boers 2007). Reducing current speed along Te Rauone Beach has the potential to increase the habitable range of seagrass along this fast eroding shoreline (Hart 2020). However, there are uncertainties around the spatial alteration of current velocities and the consequences to seagrass beds.

1.2 Scope of the report

This report summarises time-series of seagrass bed cover in the region of Te Rauone Beach and identifies threshold metrics for setting management interventions. Specifically, this report outlines:

1. ***Time-series of seagrass cover***: establish a time-series of seagrass cover from aerial imagery from 2015-2020;
2. ***Proposed management thresholds***: identify metrics to trigger management and intervention measures;
3. ***Possible management interventions***: identify those measures and when they should be implemented;
4. ***Proposed monitoring programme***: propose a monitoring scheme for timely management intervention.

2 Methods

The seagrass beds within regions of Otago Harbour cover large areas of intertidal and subtidal sand-flats (Fyfe et al. 1999; Goodwin and Tocher 2020). Also abundant in Otago Harbour are several species of macroalgae (from giant kelp *Macrocystis pyrifera*, to nuisance species such as *Ulva* spp). Aerial imagery is one of the few techniques that can appropriately capture the full coverage of these habitats, however, robustly and objectively analysing this imagery presents some challenges.

- “Hand-captured” images taken from fixed-wing manned aircraft, while providing excellent spatial coverage, provide relatively poor pixel resolution for species level identification.
- Accurate orthomosaic production and georeferencing is problematic for single ‘strips’ of images.
- Typical ‘RGB’ (Red-Blue-Green) images do not have enough bands to identify unique spectra which aid in automated detection procedures.

Small scale drone imagery can capture high pixel resolution and high spectral resolutions to identify differences between species of seaweed and other flora through both object-based, and pixel/spectral based procedures (e.g., Tait et al. 2019). Satellites on the other hand provide a consistent, standardised, high coverage dataset across a wide range of electro-magnetic radiation wavelengths. Some repeat orbiting satellite imaging products are also freely available. The main caveat is that pixels are very large (10+m) which means that the spectral signatures of multiple species can contribute to the spectra of a single pixel.

2.1 Satellite estimates of seagrass coverage

Images from the Sentinel-2 satellite (*Sentinel-2 imagery courtesy of European Space Agency*) were used for identifying seagrass beds during periods of low tide within Otago Harbour. Within five regions, four 50 x 50 m polygons were established over intertidal flats, with the cover of seagrass within each polygon estimated for each satellite image between December 2015 and August 2020 (Figure 2-1).

Sentinel-2 has pixels of 10 m in the blue, green, red and near infrared bands (12 band total) of the electromagnetic spectrum and has particularly high spectral resolution in the “red-edge” region (between 700-800 nm). This region of the electro-magnetic spectrum is highly relevant for vegetation which reflect high proportions of these wavelengths as a by-product of photosynthesis.

Spectral signatures of several habitat types were determined with the use of Senntinel-2 satellites. These habitats included ‘water’, ‘bare sand’, ‘terrestrial vegetation’, and ‘seagrass’ (Figure 2-2). The spectral signatures as determined from the Sentinel-2 satellite show signal overlap between terrestrial vegetation and seagrass (Figure 2-2). To separate seagrass from terrestrial vegetation and other habitat types, a series of masking, filtering and band manipulations were also performed. Firstly, cloud-free images were selected by using quality control bands available as metadata within satellite imagery. The acceptable percentage of cloud was set to 30%. The edges of the estuary were masked by an elevation layer to consider only pixels within the intertidal zone.

The NDVI[1] and NDWI[2] indices were used to separate vegetation from bare sediments and water. The resulting output was a separate layer which identifies aquatic vegetation within the estuary. While these indices are frequently used to assess vegetation health from the strength of the NDVI signal, in this case it is not possible to separate "health" and "biomass". Therefore, the NDVI is used exclusively to detect vegetation.

Figure 2-1: Study regions investigated by satellite imagery (A) and intertidal aquatic vegetation coverage (B) in Otago Harbour (blue, green, red coloured areas). Blue-green-red scale shows the strength of the NDVI index, a measure of vegetation health or biomass (blue= low density, red = high density). Imagery courtesy of European Space Agency (Sentinel-2).

[1] Normalised difference vegetation indices

[2] Normalised difference water indices

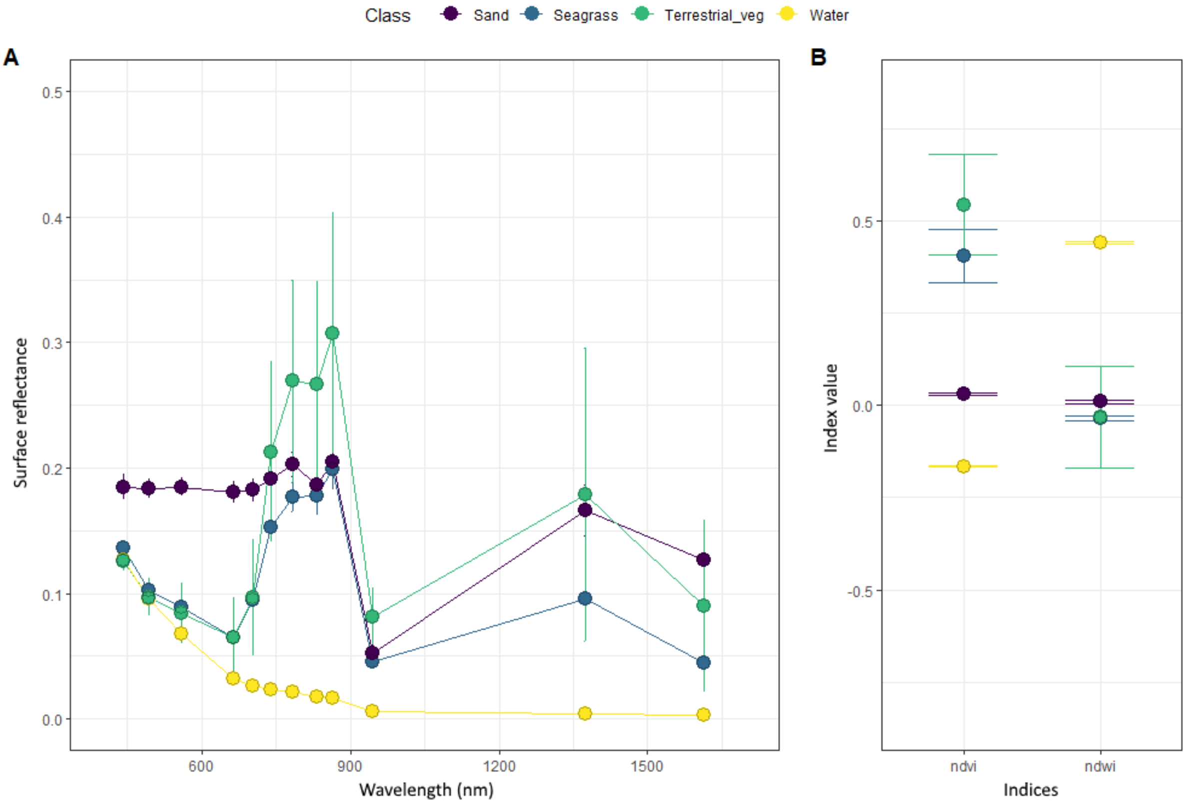


Figure 2-2: Spectral reflectance (A) and indices (B) of multiple classes as identified from Sentinel-2 satellite. Error bars show the standard deviation (SD) in signal strength from three replicate plots.

2.2 Aerial imagery estimates of seagrass coverage

Aerial images were collected via manned fixed-wing aircraft and targeted imaging of seagrass beds in the outer reaches of Otago Harbour. Images were taken at an altitude of approx. 1500 m, with a Nikon D810, and a 70 mm focal length lens. Imagery was collected on five separate occasions (December 2015, April 2016, October 2016, August 2017, and April 2018).

Individual images were stitched together using photogrammetry software (Agisoft, Metashape) and were imported into GIS software (ArcGIS Pro) where they were georeferenced against features (e.g., man-made features such as wharfs, channel markers, road markings, and houses). Once georectification procedures were completed, and stitches were relatively error free within the study zone, manual identification of seagrass beds was completed. This was done by manually selecting the regions of seagrass identifiable in the imagery. These beds are identified by a mixture of shape and colour, but low densities of seagrass can easily be mistaken for bare sand, while patches of macroalgae can also be mistaken for seagrass beds.

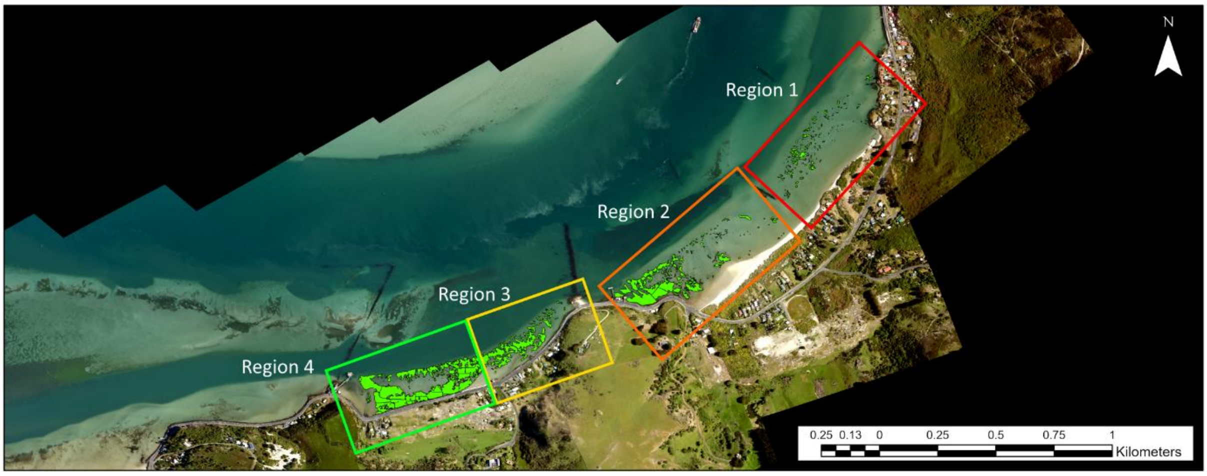


Figure 2-3: Aerial imagery indicating the 4 regions across two beaches (Te Rauone Beach [Region 1 and 2] and Omate Beach [Region 3 and 4]) used to identify seagrass coverage.

2.3 Determining management thresholds

Management thresholds were developed for both the satellite imagery and aerial images to allow cross referencing and validation across two independent datasets. Satellite imagery provides a more standardised and objective metric for change, however, the availability of imagery for monitoring purposes is not guaranteed. Alignment of low tides, and little to no cloud coverage at the time of satellite imagery capture is required. Evidence to date suggests that these conditions align frequently (27 of 56 months), but unfavourable conditions can cause gaps in the dataset lasting up to 5-6 months. Another downside of the satellite dataset is the inability to retrieve meaningful metrics of seagrass when submerged by the water column.

Aerial imagery on the other hand can allow visual observations of seagrass below the water surface under good conditions. These datasets can be collected when required and can generally be scheduled to align with optimum conditions. However, the available timeseries for these images is sparse (five sets of imagery between 2015 and 2019). Quantifying seagrass bed extent requires manual selection of bed extent which requires knowledge of the beds themselves and introduces subjectivity when it comes to gradients of seagrass sparsity.

Because of the relative strengths and weaknesses of each dataset, threshold metrics for both datasets are provided. Threshold metrics are calculated by determining the maximum and minimum seagrass bed cover for each region (regions 1-4 for aerial imagery, and regions 1-5 for satellite imagery). Thresholds of 10, 30 and 50 % of this range are then subtracted from the minimum seagrass cover for each site to determine the m^2 coverage that will trigger warnings of increasing severity. Applying a threshold approach which considers the past five years of seagrass coverage (5 years of satellite images, 2.5 years of aerial images) enables seasonal and annual variability in the seagrass beds to be considered. Considering historic changes in seagrass distributions improves the ability of monitoring to determine whether the proposed development has caused a change in seagrass coverage which may be greater than what seagrass beds have previously recovered from.

3 Results

3.1 Satellite time-series of seagrass cover

Satellite based estimates of seagrass coverage show large seasonal variation, but consistent long-term coverage within each region (Figure 3-1). Region 5 is less directly influenced by the main channel of Otago Harbour and shows the greatest variation over the 5-year period, but also the lowest seasonal variation. Despite significant seasonal or monthly variation at regions 1-4, there are few consistent trends in the range of seagrass cover for each season (Figure 3-2). The large overlap in the notches (indents of the box and whisker plots) shows that for many sites the difference in mean seasonal coverage is not significantly different. Combined coverage across all seasons was therefore used to estimate the range of values expected at each region (Figure 3-3).

Region 1 nearest the proposed groynes and areas of current erosion showed the lowest cover of seagrass beds (Figure 3-3). During the c. 5-year period of image acquisition, the two polygons nearest the area of active erosion (i.e., the eastern region of Te Rauone) have frequently had no detectable seagrass (i.e., 0 m^2). No other polygons within regions 2-5 had less than 59 m^2 cover of seagrass over the same period (Figure 3-2).

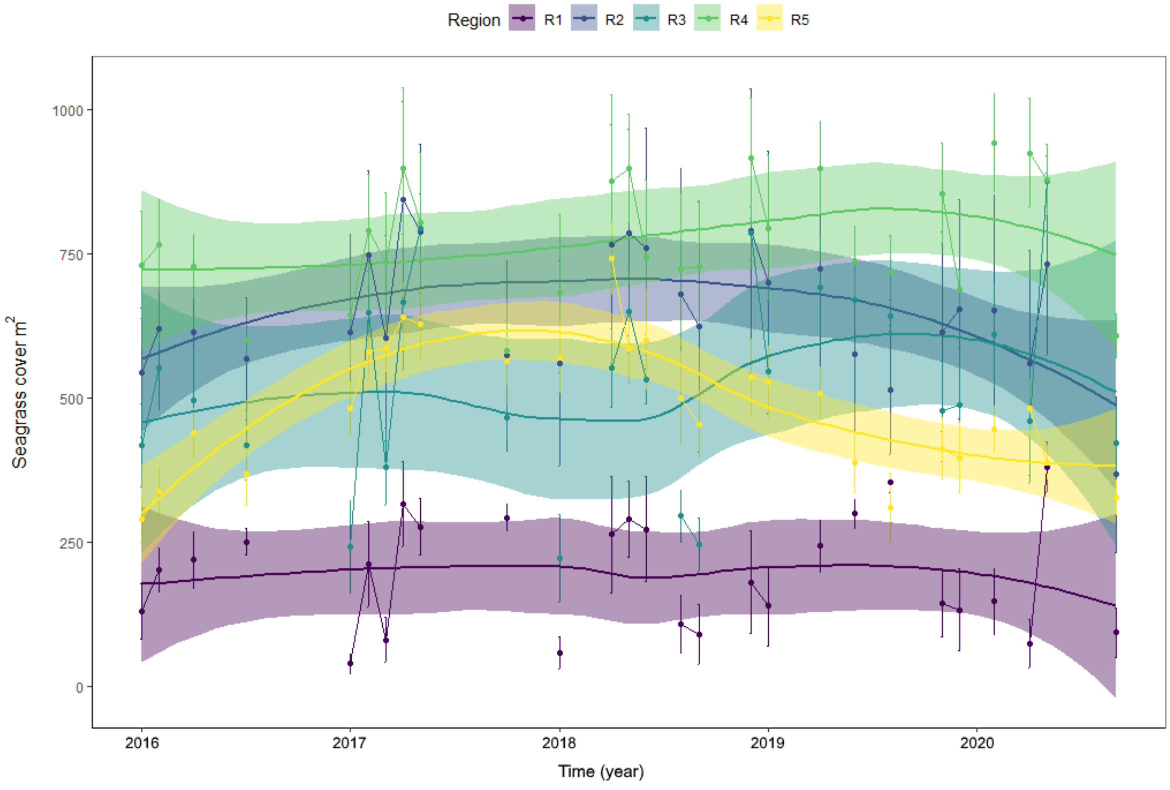
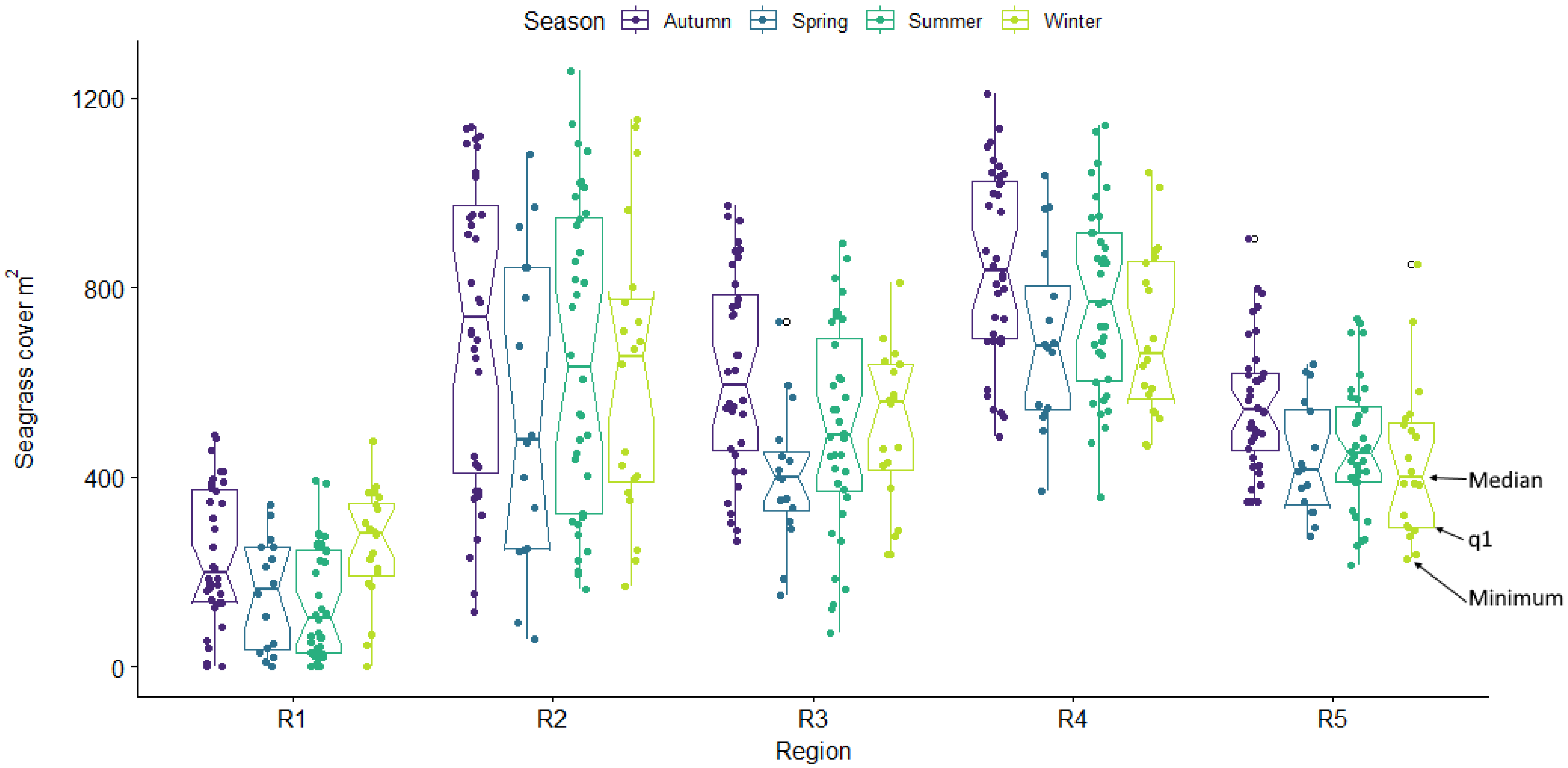
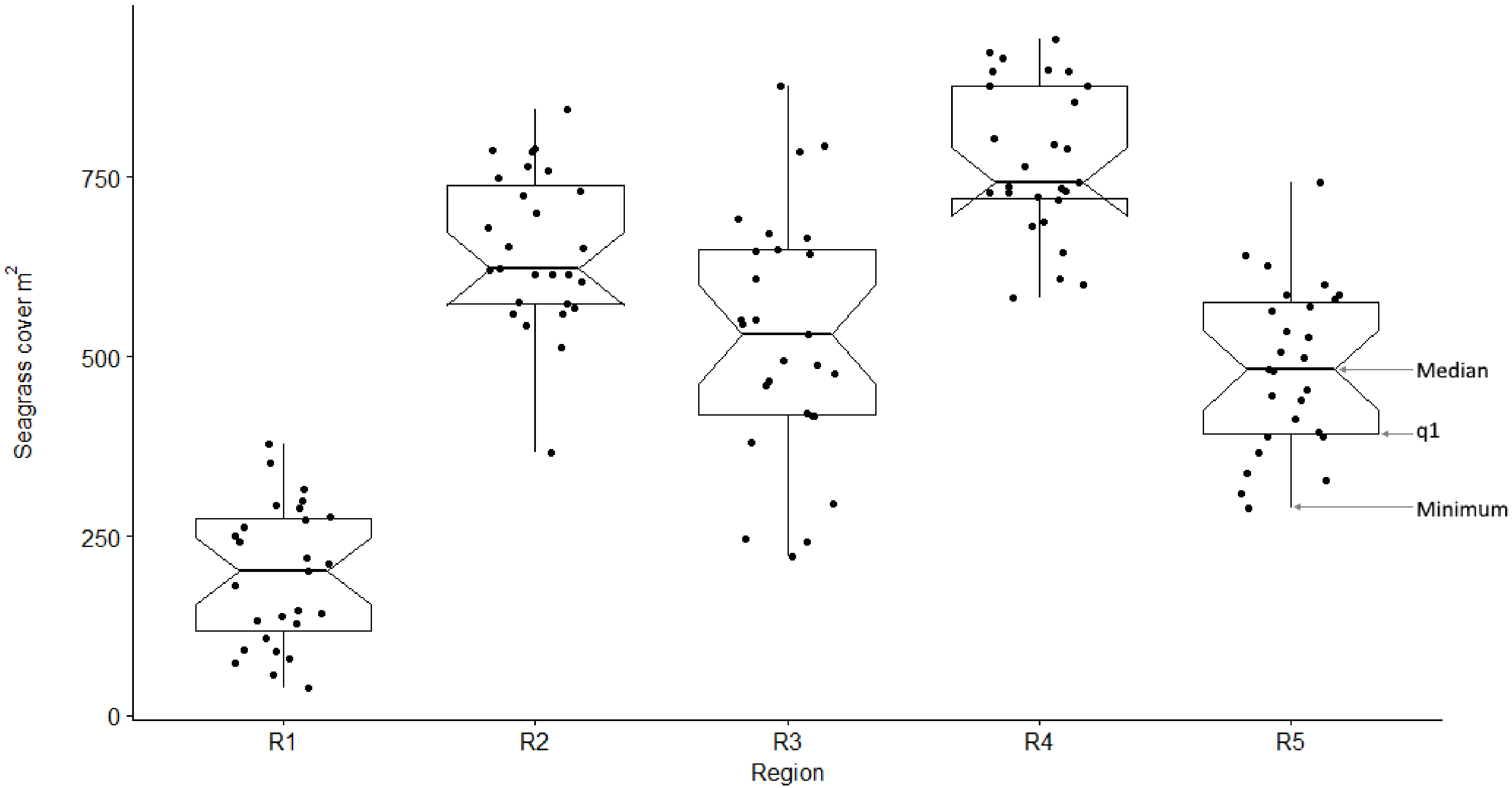


Figure 3-1: Timeseries of seagrass cover at five regions of increasing distance from Te Rauone Beach. 'Region 1' closest to proposed activities, 'Region 5' furthest). Plots show the mean and standard deviation (n = 4 for each region). Filled trend lines are "loess" fits with 95% confidence intervals.



median	198	165	104	281	737	480	632	653	592	398	488	559	836	677	768	659	541	414	449	399
min	0	0	0	0	114	59	165	170	264	150	72	237	486	372	357	466	349	275	216	226
q1	140	37	31	192	408	248	322	388	456	329	369	414	691	542	604	565	455	342	391	295

Figure 3-2: Box and whisker plots of seagrass cover for each region split by season. Each 'box and whisker' shows the minimum, lower quintile, median, upper quintile, and maximum value. The lower ranges of coverage for each region/season combination are plotted below. Note that each replicate is plotted and not combined for a regional average.



	R1	R2	R3	R4	R5
median	201	622	531	743	481
min	39	366	221	581	289
q1	118	574	419	720	391

Figure 3-3: Box and whisker plots of seagrass cover for each region. Each 'box and whisker' shows the minimum, lower quintile, median, upper quintile, and maximum value. The lower ranges of coverage for each region/season combination are plotted below. Note that the four replicates for each region are combined for an average cover.

3.2 Aerial seagrass estimates

Aerial analysis of seagrass coverage shows similar trends as satellite imagery, with low cover of seagrass nearest the proposed construction area (Region 1), but high coverage at regions 2 and 4 (Table 3-1; Figure 3-4). Seagrass cover as estimated shows region specific variation, with region 2 and 4 showing gradual increases from December 2015 to April 2018, whereas regions 1 and 3 show declining cover initially, but increases in April 2018 (Table 3-1). Significant variability in the timing of imagery capture makes comparisons between sampling periods difficult but does suggest that the western and eastern regions of each beach (Te Rauone and Omate Beaches) have some similarities.

Table 3-1: Cover (m^2) of seagrass beds across four regions during five sampling periods between December 2015 and April 2018.

	December 2015	April 2016	October 2016	August 2017	April 2018	Range (min-max)
Region 1	2984	2737	1698	1905	5080	3382
Region 2	14486	21365	23206	25571	30528	16042
Region 3	13901	8957	14582	15859	20812	11855
Region 4	19029	24230	20543	28930	35349	16320
Sum	49931	57289	60175	72306	91793	

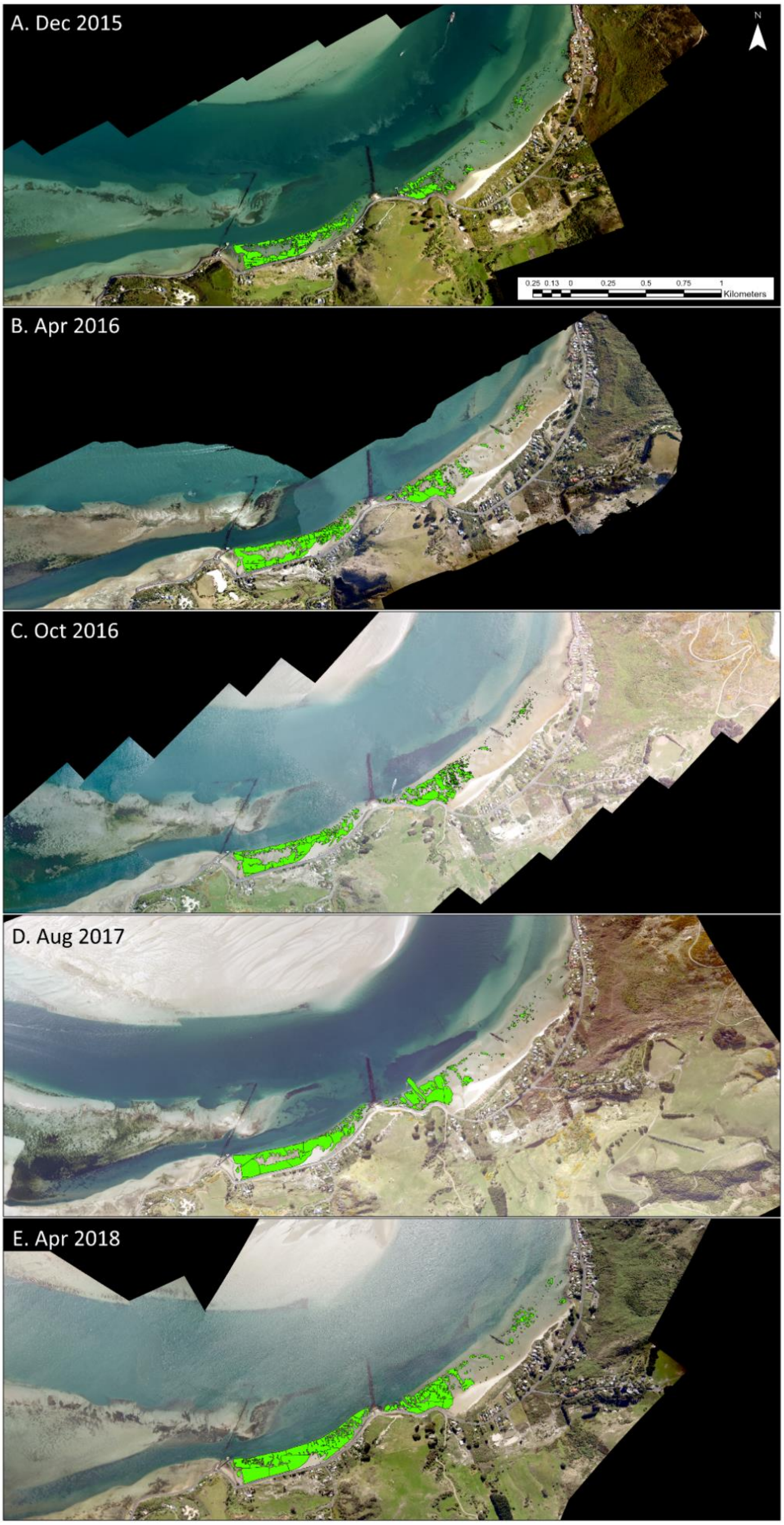


Figure 3-4: Visual determination of seagrass coverage across the study region. Plots show seagrass beds at Te Rauone and Omate Beaches delineated in green from surveys in December 2015 (A), April 2016 (B), October 2016 (C), August 2017 (D), and April 2018 (E).

3.3 Limitations and uncertainties

As mentioned in the methodology (section 2 Methods) there are some assumptions and uncertainties in the estimation of seagrass beds. While all evidence suggests that seagrass beds dominate throughout large regions of Otago Harbour (Fyfe et al. 1999; Goodwin and Tocher 2020), there are also regions of hard substrate dominated by macroalgae. Drift macroalgae can also accumulate along beaches and could contribute erroneously to estimates of seagrass cover. While it is possible to manually sample seagrass beds imaged beneath the water from aerial imagery, the uncertainty increases with the depth of overlaying water. Furthermore, any submerged vegetation will not be detected using automated satellite methods. The limitations of each imagery type are detailed below.

Major limitations to estimates of seagrass cover by satellites:

- Seagrass below the water surface will not be detected;
- Unknown contribution of seagrass and macroalgae in estimates of cover;
- Seagrass patches smaller than 1-2 m^2 are unlikely to be well represented by satellite data.

Major limitations to estimates of seagrass cover by aerial imagery:

- Difficult to visually separate seagrass and macroalgae;
- Difficult to objectively establish the bounds of seagrass patches due to gradients of seagrass blade density (i.e., low density beds can look very similar to bare sediments);
- Limited time series data available and relatively expensive to collect.

Reducing the uncertainty will require assessments of macroalgal contribution to the regions in question through combined in situ and aerial sampling. The addition of more advanced spectral imaging (hyperspectral or multispectral imaging) at high resolution could help establish spectral signatures across gradients of seagrass densities and increase the species resolution of satellite products for monitoring.

4 Proposed management thresholds

By identifying the range and minimum cover of seagrass beds on Te Rauone and Omate Beaches we have calculated several thresholds for satellite (Table 4-1) and aerial imagery (Table 4-2) that represent change beyond the minimum observed cover between 2015 and 2020. A conservative buffer was added to the aerial imagery thresholds (5% lower thresholds than satellite imagery) to account for the fact that this imagery considers the entire coverage of seagrass across Te Rauone and Omate Beaches. For simplicity the thresholds for both satellite and aerial imagery are referred to as “10%”, “30%”, and “50%” thresholds.

The percentage loss thresholds are calculated from the full range (minimum to maximum) for each site and therefore consider the range observed at each site. For example, a site with very consistent coverage (i.e., small range) will have much lower thresholds of seagrass coverage than a site with high variability. However, prior to construction activities, these thresholds will be recalculated as a 6-month rolling average (i.e., the 6 months prior to construction). This will ensure that recent trends in each region are captured appropriately.

The proposed 10%, 30%, and 50% thresholds represent a conservative approach to similar ecological management thresholds and allow increasingly strong intervention measures to be put in place when greater thresholds are crossed. For comparison, thresholds set for the intertidal algae *Hormosira banksii* in relation to human trampling disturbance set thresholds equivalent to 15%, 40%, and 70% decline in the minimum observed cover of this species (Addison et al. 2015). Our proposed thresholds allow management and intervention measures to be implemented in response to smaller changes reducing the risk of deleterious effects of construction to seagrass beds.

Table 4-1: Example calculated thresholds of seagrass cover for three levels of seagrass loss based on a five year average. Minimum, 10%, 30%, and 50% thresholds all calculated from ***mean*** coverage of four 2500 m^2 samples within each region.

	Te Rauone Beach		Omate Beach		
Threshold (m^2)	**Region 1**	**Region 2**	**Region 3**	**Region 4**	**Region 5**
Mean	195	650	527	773	484
Range	340	477	655	361	452
50 % of range	170	238.5	327.5	180.5	226
30 % of range	102	143.1	196.5	108.3	135.6
10 % of range	34	47.7	65.5	36.1	45.2
Minimum observed cover	39	366	221	581	289
10 %	5	318	156	545	244
30 %	0	230	25	473	153
50 %	0	128	0	401	63

Table 4-2: Example calculated thresholds of seagrass cover for three levels of seagrass loss based on a three year average (aerial imagery). Minimum, 10%, 30%, and 50% thresholds all calculated from ***total***

coverage in m^2 of two regions of each beach (Te Rauone and Omate Beaches). Note that the “50%”, “30%”, and “10%” thresholds for aerial imagery are actually 45, 25, and 5% thresholds with the added conservancy.

	Te Rauone Beach		Omate Beach	
Threshold (m^2)	**Region 1**	**Region 2**	**Region 3**	**Region 4**
Mean	2880.8	23031.2	14822.2	25616.2
Range	3382	16042	11855	16320
50 % of range	1521.9	7218.9	5334.75	7344
30 % of range	845.5	4010.5	2963.75	4080
10 % of range	169.1	802.1	592.75	816
Minimum observed cover	1698	14486	8957	19029
10%	1529	13684	8364	18213
30 %	853	10476	5993	14949
50 %	176	7267	3622	11685

Exceeding these prescribed thresholds will be used to trigger management actions and interventions. However, climatic or weather events have the potential to disrupt seagrass beds over larger scales. Because of the region wide influence of such stressors, the occurrence of such events should be evident from threshold exceedance at both Te Rauone and Omate Beach. In the event of any exceedance in any region, the first task will be to establish the cross-region trends. We have developed a guidance framework which will help establish the likelihood of natural vs construction-based impacts (Table 4-3). This table provides broad guidance and is to be applied by suitably qualified ecologist(s) alongside as many lines of evidence as are available at the time of assessment. Such evidence may include, but is not limited to, aerial and satellite seagrass monitoring, sea surface temperature information, and climatic events.

Table 4-3: Guidelines for determining the likelihood of multiple scenarios change relating to construction and other stressors. Colour scale reflects increasing loss of seagrass beyond natural variation (Green no change, yellow = 10%, orange = 30%, red = 50% change).

	Te Rauone Beach		Omate Beach		
Scenario	**Region 1**	**Region 2**	**Region 3**	**Region 4**	**Region 5**
Scenario 1: *NO IMPACT*	Change within natural range	Change within natural range	Change within natural range	Change within natural range	Change within natural range
Scenario 2: Construction activities	Change >50% of natural range	Change >30% of natural range	Change >10% of natural range	Change within natural range	Change within natural range
Scenario 3: External (climate/weather)	Change >30-50% of natural range	Change >30-50% of natural range	Change >30-50% of natural range	Change >30-50% of natural range	Change >30-50% of natural range
Scenario 4: Combined (climate + construction)	Change >50% of natural range	Change >50% of natural range	Change >30% of natural range	Change >30% of natural range	Change >10% of natural range

Management thresholds will use the triggers developed from aerial imagery in the first instance. However, if appropriate satellite imagery is available (e.g., a no cloud, low tide pass occurred on a monthly basis in the period in question) this dataset should supersede the aerial imagery. The aerial imagery enables us to fill the gaps left by random chance in the capture of quality satellite imagery and maintains the agility of a monitoring programme to detect negative changes in a timely fashion.

5 Possible management interventions

To mitigate and manage negative impacts during the groyne construction and post-construction, we propose several interventions. The proposed interventions increase in scope and intensity as increasingly severe seagrass loss thresholds are reached. Across all thresholds, the first intervention measure will be to halt all construction or sediment replenishment activities while investigations get underway. Construction or replenishment activities will only re-start when:

1. Threshold specific mitigation measures are put in place (10% threshold only)

   or

2. Threshold specific recovery metrics are reached (30 and 50% thresholds).

   or

3. External drivers are identified to be the cause of seagrass bed decline and construction activities are not contributing to decline (e.g., Scenario 3 in Table 4-3).

Management actions - 10% threshold

When a 10% threshold is reached that occurs primarily within Te Rauone Beach, with little or no observed change at Omate Beach, the first proposed step will be to halt activities. The primary intervention measure at this stage is to revise the replenishment strategy, including the following possible steps:

1. Halting of replenishment or construction activities;
2. Assessment of the timing of replenishment in relation to tidal cycles, rainfall events and storm surges. Provide a revised replenishment plan that actively avoids likely or potential events likely to mobilise sediments;
3. Assessment of the rate of replenishment. Replenishment plan should include a staged approach to increases in replenishment volumes;
4. Increase frequency and scope of monitoring once new replenishment plan is in place (see below; 6 Proposed monitoring programme). The elevated monitoring regime will revert to the standard regime once seagrass recover to minimum thresholds.

Management actions - 30% threshold

When a 30% threshold is reached that occurs primarily within Te Rauone Beach, with little or no observed change at Omate Beach, the first proposed step will again be to halt activities. At this threshold, management interventions will look to halt further decline in seagrass by actively protecting beds with barriers that will halt erosion or accretion of sediments to seagrass beds. The key intervention measures to be triggered at this stage are:

1. Halting of replenishment or construction activities;
2. Construction of temporary barrier protection of seagrass beds (e.g., stakes and permeable cloth barriers);
3. Increase frequency and scope of monitoring (see below; 6 Proposed monitoring programme);

4. Construction or replenishment activities to resume only after seagrass beds have exceeded minimum values.

Management actions - 50% threshold

When a 50% threshold is reached at any site, the first proposed step will again be to halt activities. If these seagrass beds do not begin to recover some of the lost territory after sustained halting of activities and intervention measures (e.g., barrier protection) then habitat restoration measures will be implemented to replace seagrass through replanting and ensuring that beds do not continue to decline. Key measures taken at the 50% threshold could include:

1. Halting of replenishment or construction activities;
2. Assessment of the likely cause as related to the pattern of seagrass loss across sites (e.g., referring to Table 4-3);
3. Construction of temporary barrier protection of seagrass beds (e.g., stakes and permeable cloth barriers);
4. Increase frequency and scope of monitoring (see below; 6 Proposed monitoring programme);
5. Habitat restoration activities to be triggered if monitoring reveals continued loss;
6. Groyne construction or replenishment activities to resume only after seagrass beds have exceeded minimum values for three consecutive months.

6 Proposed monitoring programme

The monitoring programme will focus around two beaches, Te Rauone and Omate Beaches. Aerial drones will be used to capture low altitude, high overlap imagery during periods of low tide. Traditional RGB imagery is the minimum requirement for analysis, however, collection of “multispectral imagery”[3] is recommended. A baseline monitoring campaign will be undertaken prior to construction activities. This baseline monitoring will include:

1. Aerial imaging of Te Rauone and Omate Beaches, preferably at high spectral resolution;
2. High accuracy GPS sampling of habitat types (e.g., seagrass, macroalgae), including estimates of seagrass density;
3. High accuracy GPS sampling of beach profiles (e.g., RTK GPS).

The purpose of baseline monitoring is to limit uncertainties associated with the relative abundance of macroalgae and seagrass and identify any major variations in the densities of seagrass beds within and between regions.

Following baseline monitoring and once construction activities begin, aerial imaging should be completed at a minimum of once per month. Ideally this imagery would be collected by drones equipped with multispectral capabilities, but RGB is acceptable. However, if management thresholds are triggered (see section 5 above), aerial imaging is to be completed in tandem with high accuracy GPS sampling of beach profiles and habitat sampling to better understand the types of changes that have occurred (i.e., seagrass density, species composition). Under increased monitoring frequency when 10%, 30%, and 50% thresholds are triggered, the monitoring parameters will include:

1. First monitoring survey initiated by seagrass loss thresholds (i.e., “full monitoring”) including;
   - 1.1 Habitat sampling,
   - 1.2 RTK GPS of beach profiles,
   - 1.3 Ideally be completed with multispectral imaging for better species resolution (particularly if baseline monitoring reveals high proportion of macroalgae).
2. Repeat fortnightly “partial monitoring” using aerial drone (without additional habitat-sampling, beach profiles or multispectral imaging);
3. Every three months full monitoring will be completed unless seagrass beds have exceeded minimum cover for specified timeframe depending on the threshold triggered.

This monthly monitoring regime, and triggered monitoring regime will ensure that negative trends are identified early and monitored more intensively to track seagrass progress. Post completion of groyne construction and initial replenishment activities, monitoring frequency will be reduced to 3 monthly for 1 year (and triggered monitoring will be at an increased frequency of once per month).

[3] Multispectral imagery uses cameras with more than just 3 colours or bands and typically captures light beyond the visible wavelengths and is very useful for surveying vegetation and separating different types of vegetation (e.g., macroalgae and seagrass).

Exceedance of thresholds (excluding thresholds which are deemed as not related to construction activities, see Table 4-3) during the post-construction monitoring phase will extend the monitoring regime until threshold specific targets have been reached (e.g., seagrass greater than minimum cover for three months in the case of the 50% threshold) and confirmed 3 months later. For example, if a 50% threshold is exceeded in December 2022 (e.g., 12 months post construction), and seagrass exceeds minimum cover for January, February and March 2023, a further monitoring in June 2023 is needed to confirm that seagrass cover is greater than the minimum before the monitoring regime can be ended.

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Appendix B etc…

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