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Characterising the shallow, soft-seafloor biomes of northern New Zealand's Bay of Islands

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EXECUTIVE SUMMARY

Booth, J.D.[1]; Griffiths, R.[2]; Booth, W.E.[3]; D'Archino, R.[4]; Nelson, W.A.[4]; Kerr, V.C. [5]; Willoughby, R.S.[6] (2023). Characterising the shallow, soft-seafloor biomes of northern New Zealand's Bay of Islands.

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A surficial biome revealed by underwater imagery is most obviously characterised by its low-relief, mainly coralline red-algae turf, dominated by *Corallina berteroi* and extending over about 40% of the 724 ha of the shallow (≤ 5 m deep) sandy seafloor of 'Ipipiri Platform' in the eastern Bay of Islands. Based on aerial imagery, the spatial extent of surface manifestation of this biome over at least the past 70 y appears to have been remarkably steady. In contrast, the other main surficial, bottom-stabilising, vegetated biome—the shallower clumps and beds of subtidal seagrass (*Zostera muelleri*; about 5%)—has apparently varied substantially in its areal surface expression. The underpinning, mainly medium-to-coarse sand is frequently strewn with *Tawera spissa* shell hash. Subtidal seagrass is rare in New Zealand today, and the soft-bottom algal-turf biome present in the Bay of Islands has not been described from elsewhere in the country. Both are implicated in fishery sustainability. Further, the islands of Ipipiri and their surrounding waters retain great cultural and seafood-harvesting significance to local Māori, they are the focus of intense recreational fishing effort, and the region's high natural character and associated biodiversity are fundamental to its allure for residents and visitors alike.

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1. INTRODUCTION

This study was prompted by community interest in the reasons behind the patterning that is visible from vessels and from the air on sandy seafloors in shallow waters of what we refer to as 'Ipipiri Platform' and which comprises a group of islands ('Ipipiri' to local Māori) in eastern Bay of Islands (35° 12′ °S, 174° 10′ °E), New Zealand (Figure 1). Designated a 'Significant Ecological Area' by Northland Regional Council, the patterns discernible in 2009 aerial images had been categorised as 'seagrass habitat'[7]. However, locals sought to better-characterise this biogenicity so that its ecological significance, and any threats to its integrity and persistence, might be clarified. Our work shows a red-algae dominated biome, most obviously characterised by geniculate corallines but also with individuals and clumps of low-profile, foliose species, covering a considerable proportion (about 40%) of the 724 ha of mainly sandy seafloors ≤ 5 m deep. Seemingly relatively stable over decades, this algal-turf biome exists in counterpoint to adjacent areas of subtidal seagrass for which spatial extents have varied over time (presently about 5%), and consists of New Zealand's only seagrass, *Zostera muelleri*.

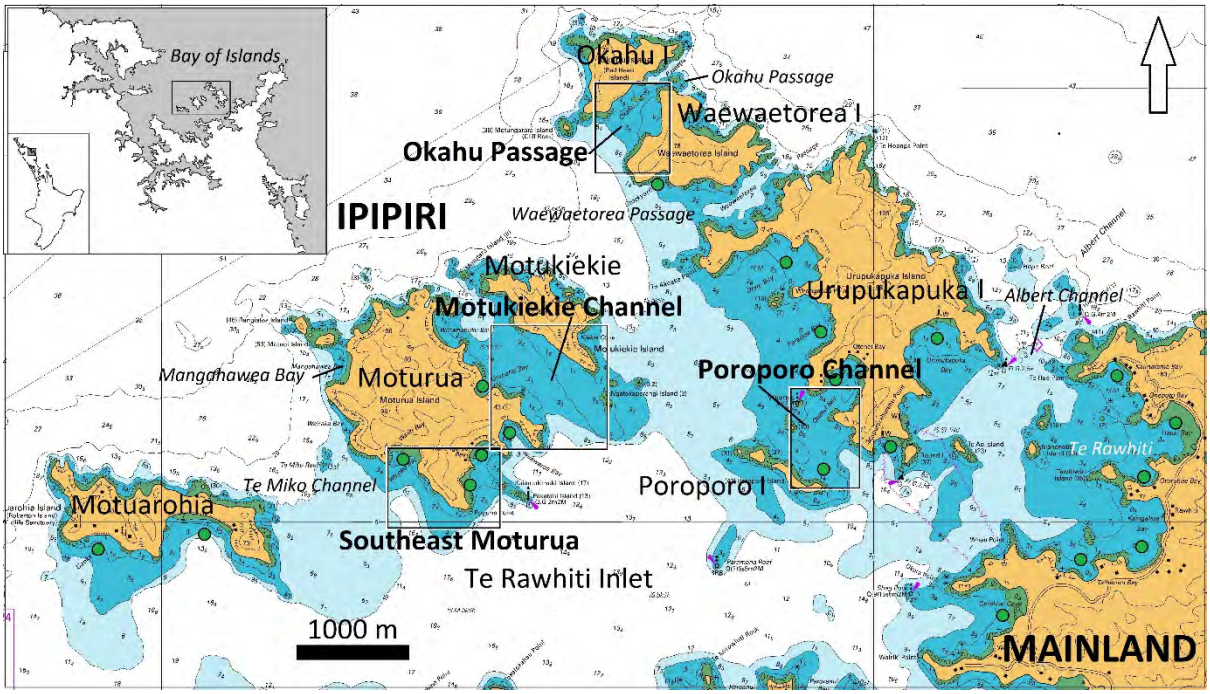


Figure 1: Bay of Islands, in the north of the North Island of New Zealand (inset), comprises in the east the archipelago of Ipipiri atop 'Ipipiri Platform'. The platform is an expanse of mainly sand substrate delineated primarily by the 10-m depth contour (separating light blue and white, the dark-blue areas being up to 5 m deep) (NZ 5125). The four study sites are boxed. Filled green circles indicate location of significant subtidal seagrass (Booth 2019), although surface manifestation has often varied over time.

The shallow, sheltered, generally clear waters of Ipipiri Platform (delineated by the 10-m depth contour, except in the southeast where the 5-m contour separates it from the mainland), comprises an archipelago of seven main islands (Figure 1). Of High Natural Character (Northland Regional Policy Statement[8]) and internationally renowned for its spectacular physical beauty, the region has long been of great cultural and seafood-harvesting significance to Mana Whenua and Mana Moana (the indigenous Māori people having historical and territorial rights over the land and sea respectively), here Ngati Kuta and Patukeha, and, before them, Ngare Raumati. Close to once-populous mainland settlements such as Te

[7] https://localmaps.nrc.govt.nz/localmapsviewer/?map=55bdd943767a493587323fc025b1335c
[8] https://www.nrc.govt.nz/resource-library-summary/plans-and-policies/regional-policy-statement/regional-policy-statement

Rawhiti, it contains large tracts of subtidal seagrass that are still viewed today as crucial to the mauri (life force) of this taiao (environment). Particularly treasured nga taonga tuku iho (handed-down riches) commonly encountered on Ipipiri Platform include highly valued food species such as piper (takeke, *Hyporhamphus ihi*), snapper (tamure, *Chrysophrys auratus*), and scallops (tipa, *Pecten novaezelandiae*) (Ngati Kuta ki Te Rawhiti Hapu Management Plan 2011). Recent scientific research confirms the fishery significance of these biodiverse waters, the extensive vegetated surfaces being important juvenile habitat for snapper and other harvested fish, and for scallops (e.g., Morrison et al. 2014a). Understanding the ecology of, and ecological services provided by, the surficial sea life of the soft seafloors of these waters will assist in managing and—as necessary—safeguarding its ecological functioning. In so doing, the area's cultural significance, its role in fishery production, and the sense of wonderment and well-being brought to the people who live or visit here, are upheld.

The Bay of Islands, a 180-km^2 embayment in the country's North Eastern Coastal Biogeographic Region (DOC 2008), is home to among the most-diverse assemblages of marine flora and fauna in New Zealand (e.g., Hayward et al. 1981, Brook & Carlin 1992, Francis & Evans 1992, Francis et al. 1999, Morley & Hayward 1999, Farr et al. 2009, MacDiarmid et al. 2009, Nelson & D'Archino 2010, Nelson et al. 2012, 2013). This rich biodiversity comes about through 1) its relatively warm water, northern location that is under direct influence of the southeast flowing, subtropical East Auckland Current; 2) its diversity of habitats (soft to hard, estuarine to oceanic, shallow to deep (80 m)); and 3) the many islands that bring physical complexity. This is illustrated no more so than on Ipipiri Platform. Here there are high levels of mixing and turnover of relatively clear (typical Secchi Disc values > 8 m) waters, and comparatively strong tidal currents (ebb flows of 0.05–0.15 m s^{-2}, based on tidal models; MacDiarmid et al. 2009).

Sediments on Ipipiri Platform at depths ≤ 10 m are predominantly coarse sand with shell hash through to fine sand with mud (Hewitt et al. 2010, Matheson et al. 2010, Gibb 2012, Kerr & Grace 2015, Froude 2016, authors' unpubl. obs.). The most detailed examinations of seabed communities here have been those of Hayward et al. (1981) for waters south and southwest of Urupukapuka Island, and Nelson et al. (2012) and Neill et al. (2015) for Te Miko Reef and the associated 'Te Miko Channel'. Other observations of macroalgae on Ipipiri Platform have included those of Hayward et al. (1981), Farr et al. (2009), Hewitt et al. (2010), Bowden et al. (2010), Nelson et al. (2012), Morrison et al. (2014a), Neill et al. (2015), Kerr & Grace (2015), Froude (2016), and Booth (2021). Seagrass—mainly subtidal—has been reported widely on Ipipiri Platform (Hayward et al. 1981, Walls 1987, Hewitt et al. 2010, Matheson et al. 2010, Mountain Harte et al. 2010, Kerr & Grace 2015, Booth 2019, 2020, 2021) (Figure 1).

For the macroinvertebrates on Ipipiri Platform, beds of the often ecologically characterising 1) morning star venerid *Tawera spissa* (from now, 'tawera') were reported by Hayward et al. (1981), Nelson et al. (2012), Hewitt et al. (2010), and Kerr & Grace (2015); 2) glycymeridid robust dog cockle *Tucetona laticostata* ('tucetona') by Hayward et al. (1981), Hewitt et al. (2010), Nelson et al (2012), Neill et al. (2015), Froude (2016), and Booth (2021); and 3) pinnid horse mussel *Atrina zelandica* by Morley & Hayward (1999), Hewitt et al. (2010), Froude (2016), and Booth (2021). Ipipiri Platform also contains Bay of Islands major remnant populations of scallops (Williams et al. 2008, Williams 2009), but recent abundances have been low (https://www.mpi.govt.nz/consultations/review-of-sustainability-measures-2022-april-round/).

Our approach in this study was 1) to use towed-video and drop-camera imagery at four representative sites on Ipipiri Platform (Figure 1) in the austral spring of 2020 to determine the predominant macro-constituents of the surficial life associated with the soft seabeds, 2) to associate the communities revealed with the patterns of colour shade and density of the seabed visible in virtually concurrent aerial imagery, and 3) to apply similar-such signatures to the historical imagery in order to gauge any broad changes in extent over time of the seabed communities. The general biological characteristics of the main biomes revealed are presented, with essential high-resolution, large-format imagery and accompanying commentary in the appendices enabling additional independent characterisations. We acknowledge with gratitude the epithet 'Rimu aria Rakaumangamanga' accorded to the algal-turf biome

of Ipipiri Platform by Mana Moana and Mana Whenua. The name alludes to the obstruse seabed shadow imparted by the algal turf within the horizon of Rakaumangamanga, the revered local maunga (mountain) of the Polynesian triangle.

2. METHODS

Aerial imagery Aerial images used were a subset of the Northland Region Lidar 2018 capture, the Bay of Islands tiles being obtained between December 2018 and August 2019. Image resolution was 25 cm per pixel and horizontal accuracy was ± 500 cm. The tiles were clipped to a 5-m depth contour derived from depth contour polylines (https://www.linz.govt.nz/products-services/data/types-linz-data/hydrographic-data, at scales of 1:22000 to 1:90000). The tiles were also clipped to a coastline polygon from the Northland terrestrial mapping extent (Biospatial Ltd; http://www.biospatial.co.nz/) to create an image tile of Ipipiri Platform extending from the shoreline to the 5-m depth contour. The blue channel was then extracted from the RGB imagery to create a single channel image, this channel being selected because it is the one least absorbed by water. The blue channel was normalised using a bathymetry file to compensate for the effect of depth on absorption of blue light. An edge-affect process was then used to delineate the edge of dark and light pixels associated with the boundaries of seagrass and turf algae habitat. This produced a polyline feature which was converted to a polygon feature. The polygons were then manually classified as seagrass or turf habitat based on the information from the underwater camera images. Some polygons containing both seagrass and turf algae were manually split using the split function in ArcPro 3.0.4. Polygons corresponding to other features such as bare sand, rocks, kelp or man-made structures and vessels were deleted.

Earlier aerial imagery (mid-1900s to 2015; Appendix 2) was used to visually assess the broad, historical distribution of the two putative biomes over time. Its quality seldom allowed detailed mapping.

Bathymetry The most comprehensive, contemporary synoptic data for Ipipiri Platform are those of hydrographic chart NZ 5125 (1994, based on surveys in 1990–92), with depths reduced to Chart Datum (Lowest Astronomical Tide), but we considered these indicative only. Runs of a WASSP S3 Multibeam sounder along the towed-video transects from a 6.7 m vessel on 15 December 2020 provided detailed, localised depth information. Multibeam Chart Datum depths—the only depths associated with the transects given here—may have been about 0.5 m shallower than those of chart NZ 5125.

Seabed imagery Ground-truth imaging of the seabed features visible in the 2018–19 aerial imagery took place during 11–13 November 2020 at four sites (each about 40 ha for depths ≤ 5 m), with 2–4 transects) (Figure 1) using towed-video and drop-camera systems from a 5.5 m vessel. Although not truly concurrent, the November 2020 seabed sampling, overlain on the 2018–19 imagery, is referred to here as the '2020 sampling'.

Being late spring, the greatest variety among life forms was expected. For each transect, NIWA's Seaweed-Cam (D'Archino et al. 2021) was used to acquire a video image of the seafloor every 1 s (the recorded GPS position of each image being ahead by up to 5 m of the actual position, according to depth). The towing speed was such that each 1-s image typically just overlapped the next, so essentially the entire seafloor of each transect was captured. The drop-camera array consisted of two cameras (Go Pro 4 with 2000 lumen Sola video lights), the bottom one at 200-mm height and angled at 45° relative to the seafloor, and the other at 450 mm with a lesser angle. Images were taken every 3 s during the course of two or three 'bounces' of the camera as the vessel slowly maintained way.

An image every 10th second (10 s, 20 s, 30 s, etc.) from the towed video was formally characterised (null, plus five categories) for seagrass cover, algal-turf cover, and sand substrate (Table 1). An 'Other' category encompassed additional seafloor features: cobble/rock, muddy-sand, areas of what appeared to be microphytobenthos film, areas of bottom bioturbation and possible shellfish siphons, and significant presence of detached macroalgae (see Figure 4). Holes and burrows were of three main

categories: 1) what appeared to be simple worm/siphon holes; 2) conical mounds about 30 mm across with an apical hole, and, far-less commonly, 3) dug-outs about 50 mm across that possibly led to burrows. All video imagery is archived at NIWA (Greta Point, Wellington) and accessed through the Marine Biologist (seaweed).

The drop-camera images had highest resolution, the lower camera—being closest to the subject—generally providing the most-detailed imagery. To improve clarity, certain images were digitally enhanced using Adobe Photoshop.

Table 1: Categories to which the seagrass, algal-turf and soft-substrate biomes were assigned (see Figure 2 and Appendices).

	Biome		
Category	Seagrass	Algal turf	Substrate
1	Wispy	Tiny growths	Clean sand
2	Straggle	Clumps	Shell fragments
3	Widespread	Extensive clumps	Scattered whole tawera
4	Near continuous	Near continuous	Extensive tawera hash
5	Continuous & dense	Continuous	Ridges of tawera hash

Benthic sampling Sampling of the seabed to obtain representative living material for laboratory identification was undertaken at selected waypoints using a Ponar grab (sample area 152 x 152 mm) or Box dredge (up to 4.5 l), and by snorkeling. No grain-size determinations were made, but the surficial geology could be broadly categorised from the benthic imagery.

Taxon determinations These were made to the highest resolution possible. Apart from especially elongate items, those at least 20 mm in greatest dimension were considered routinely discernible and were usually identifiable to species. Isolated algae smaller than 20 mm would not, however, have necessarily been distinguished. Further, the density of the algal turf, in particular, sometimes meant few of the associates present were visible, even among taxa > 20 mm.

Seagrass was unambiguous in the imagery. In contrast, the complex taxonomy of the New Zealand coralline seaweeds (e.g., Farr et al. 2009, Nelson et al. 2019, Twist et al. 2019, Nelson 2020) sometimes required genetic profiling in order to identify to species. The photosystem II thylakoid membrane protein D1 (*psb*A) gene was amplified from four *Corallina* spp. specimens using primers *psb*AF1 paired with *psb*AR1 (Yoon et al. 2002), following Twist et al. (2019). Sequences obtained were compared with accessions in GenBank of the National Center for Biotechnology Information using BLAST searches[9] and with unpublished sequences from recent local research. The foliose red-turfing algae were identified from targeted subsampling across the platform.

Worms and echinoderms were generally difficult to identify with confidence, and representative imagery was referred to experts for identification. Gastropods and bivalves, were, in contrast, usually readily identified using published illustrations and keys, with confirmation by experts. Apart from unidentified small pelagic fish near the edge of image frames, the few fish observed were solitary and readily identified.

Biodiversity An overall assessment of the relative diversity of surficial living life of each biome was based on the numbers of taxa routinely visible: ‘low’ (up to 5), ‘medium’ (6–10), and ‘high’ (> 10).

[9] https://blast.ncbi.nlm.nih.gov/Blast.cgi

3. RESULTS

Based on the 2020 sampling, three of the study sites exhibited similar surficial biogenicity over their shallow soft seafloors: two dominant vegetated biomes—seagrass and algal turf (Figure 2), amidst sandy/shelly substrates. At Okahu Passage, however, only algal turf was significant. Often, but not always, seagrass patches adjacent to algal turf contained both taxa. The dominant turfing species was *Corallina berteroi* Mont. ex Kütz. (previously *Corallina ferreyrae* E.Y.Dawson, Acleto & Foldvik). Fragments of crustose coralline algae were mixed with the *Corallina*, with one identified as an undescribed species of *Phymatolithopsis* (*Hapalidiales* ZS Twist 2019, Jeong et al. 2022). *Jania* sp. was also recorded among the turfing algae.

Occurrence of the vegetated biomes in 2020 is summarised below, with further, in-depth imagery and analyses, and the historical aerial imagery, provided in Appendices 1 and 2. Poroporo Channel is dealt with in most detail; the other sites are then characterised in such a way as to minimise repetition.

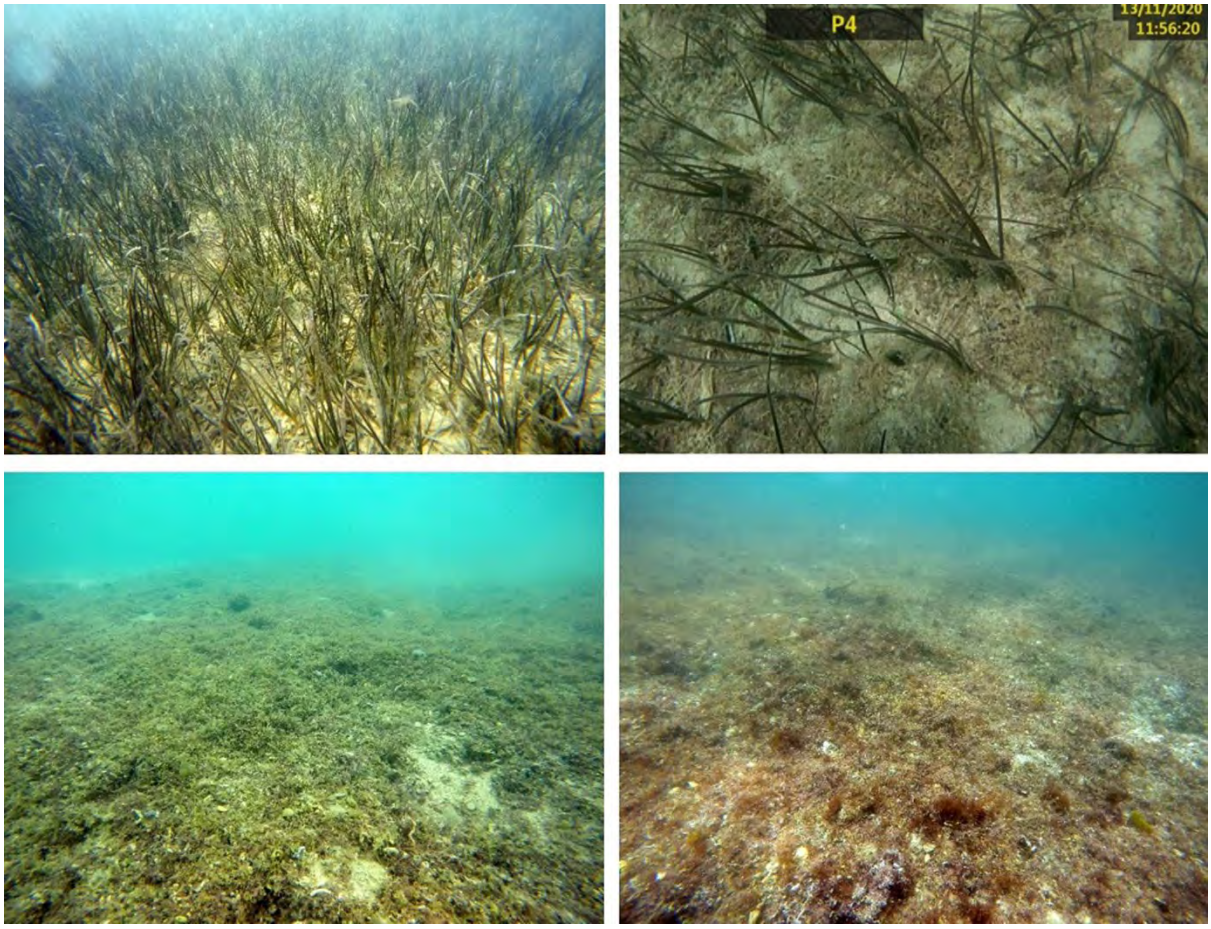


Figure 2: Examples of the seagrass biome (upper left) and the algal-turf (geniculate, lower left; geniculate and foliose, lower right) biome, and a mix of seagrass and geniculate-algae turf (upper right), Ipipiri Platform, 2020.

3.1 Poroporo Channel

Poroporo Channel is very sheltered (no swell and limited fetch), 500–650 m wide and 650 m long (Figures 1 and 3, Section A1.1 of Appendix 1). Sampling took place southeast of an islet near the centre of the channel and from which emanates southeastward an elongate, cobble ridge. Composed mainly of sand, the seafloor slopes gradually to the southeast to 2.5 m depth, before deepening rapidly. The general northwest-southeast orientation of the algal-turf biome presumably reflects tidal currents through the channel, where ebb flows are on the order of 0.05 m s^{-2} (MacDiarmid et al. 2009).

In 2020, seagrass extended to depths of 2.5 m, the putative biome occupying 1.73 ha of the 29.58 ha of waters ≤ 5 m deep. Surface expression varied from occasional emergent stolons to continuous mats (although none were extensive enough to be 'meadows' *sensu* Anderson et al. 2019). Not uncommonly, clumps of algal turf, and scattered shell hash, were present amongst the predominating seagrass. Few associated taxa were observed, leading to a 'low' biodiversity index. Most obviously present was an occasional individual of the carnivorous, scavenging, speckled whelk *Cominella adspersa*—but seldom was it categorically clear they were alive, and certainly in some instances the shells were occupied by hermit crabs. Tawera valves were by far the most abundant component of the shellfish hash. Evidence for worms was confined to what were taken to be their burrows and mounds (Categories 1–2, Figure 4), and there was a scattering of unoccupied tubes of the chaetopterid parchment worm *Chaetopterus.*

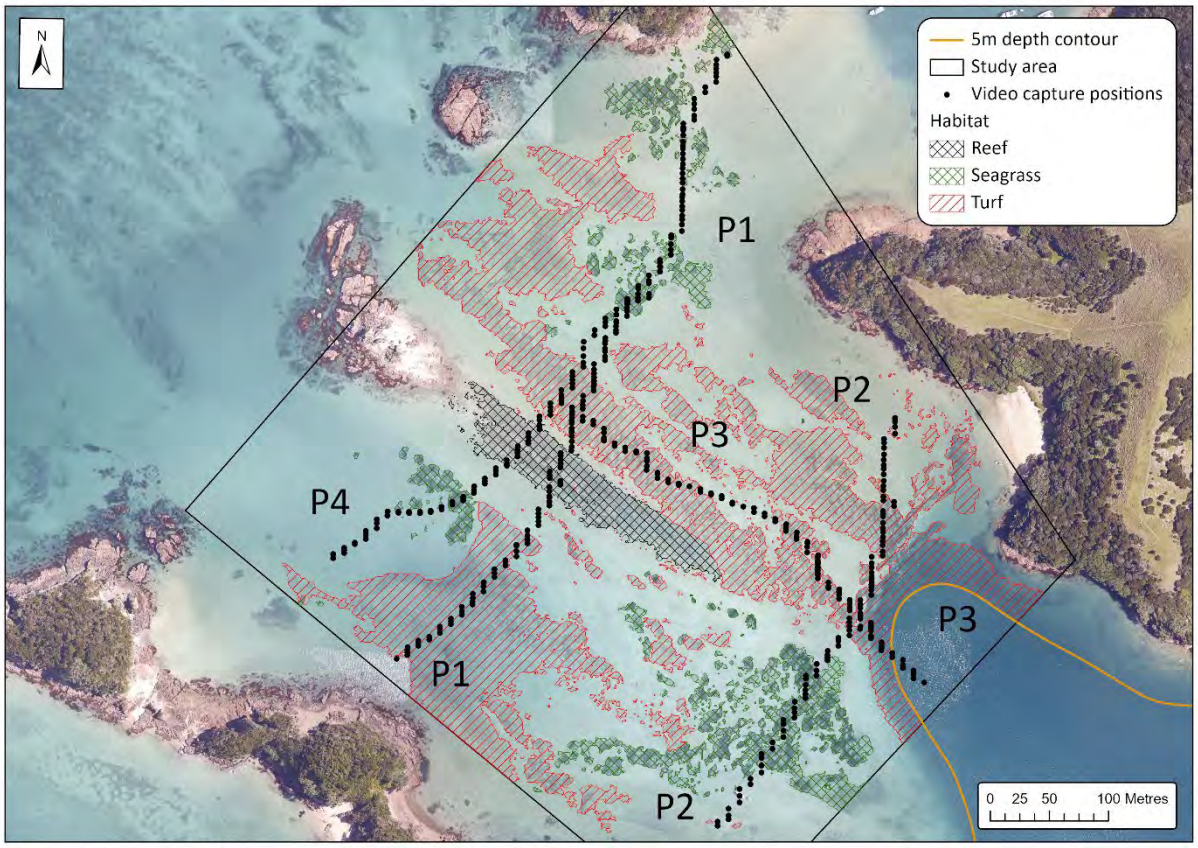


Figure 3: Video-camera transects, and indicative distribution of the putative seagrass (green) and algal-turf (red) biomes, to 5 m depth (Section A1.1 of Appendix 1), Poroporo Channel, 2020.

Algal turf was more widespread than seagrass at depths ≤ 5 m (7.55 ha) and extended from 1.2 m to ≥ 6.7 m. Cover varied from very small clumps (around 0.2 m^2) to almost continuous beds, often forming 'meadows'. At all depths, only coralline species were significant and tawera hash was widespread and sometimes obviously deep (≥ 15 cm). The surficial macro-constituents had 'medium' to 'high' diversity, the speckled whelk being the animal most-often encountered. 'Worm' burrows and mounds were widespread.

The sand biome varied from coarse, 'clean' sand in shallow waters to more muddy sand in deeper waters. Extensive areas of tawera hash were most often observed at 2–5 m (Figure 4), but they did not provide a signature distinguishable in the aerial imagery. The next most abundant hash-shell was tucetona, and then an occasional bubble shell *Bulla quoyii*, oblong venus shell *Ruditapes largillierti*, and sunset shell *Gari* spp. All of these had been reported live here in 1980, with tawera individuals up to 700 m^{-2} (Hayward et al. 1981). Living tawera beds, suggested by densely distributed siphon holes in clean sand, were most often observed at 2–3 m, but the shellfish was almost certainly widespread. The surficial living macro-constituents had 'low' diversity. Speckled whelks were common (about 1 m^{-2}),

usually as individuals, but sometimes as 'egg-laying' groups of 50 or more individuals (Figure 4). 'Turret' shells (*Maoricolpus roseus*, and possibly *Zeacolpus pagoda*) were sparse but widespread. What looked like microphytobenthic film appeared to stabilise many sand surfaces, giving the seafloor a green 'cemented' look (Figure 4). 'Worm' burrows and mounds were widespread and in places abundant. Individual, detached macro-algal fronds or their parts (predominantly *Ecklonia radiata* ('ecklonia')) were sparsely distributed throughout.

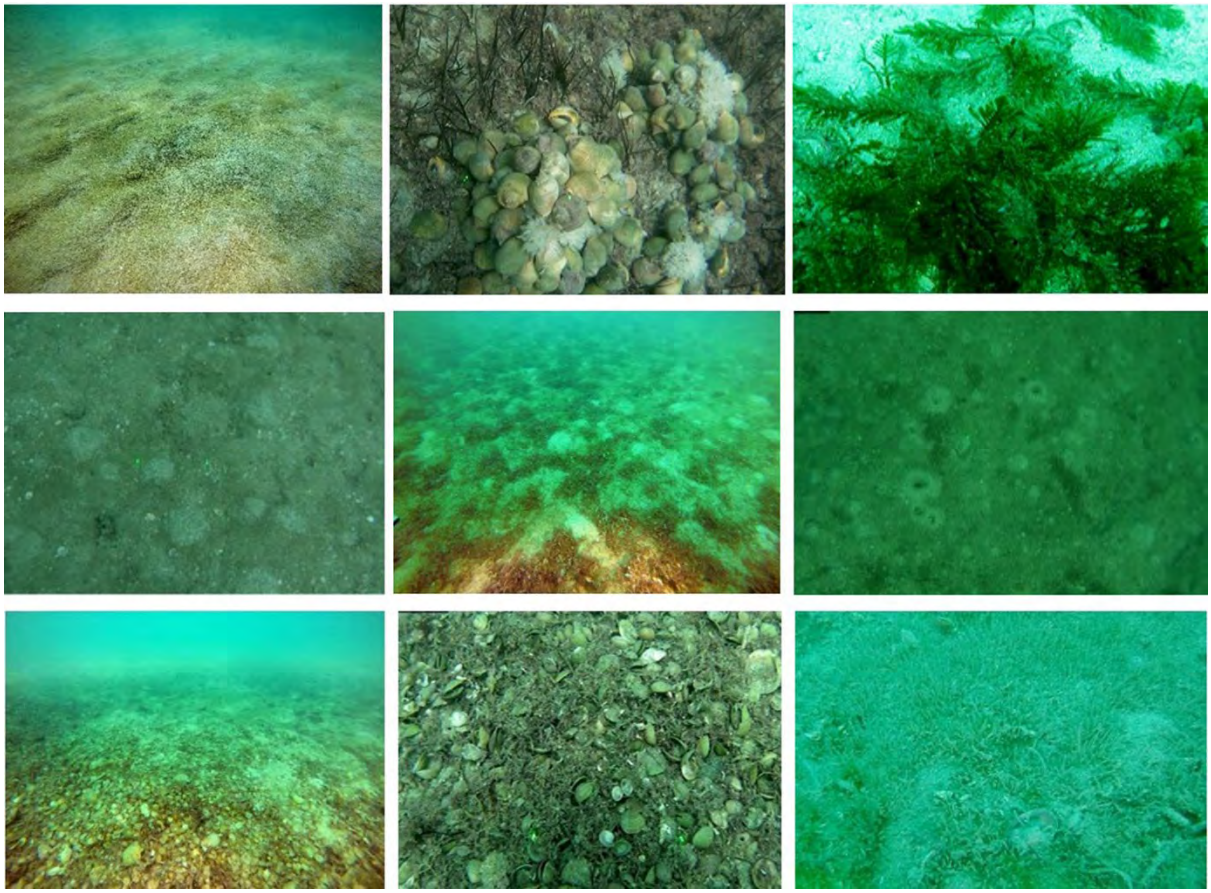


Figure 4: Upper row: microphytobenthic film; egg-laying *Cominella adspersa*; *Caulerpa flexilis* at 10 m on Transect M5 (see Figure 7). Middle row: perturbations presumably resulting from worm and/or crustacean activity. Lower row: shell hash dominated by tawera; worm tubes at 9.5 m on Transect M5.

The historical aerial images suggested stability over time in the distribution of the algal turf, but substantial changes in the extent of surface manifestation of seagrass (Section A2.1 of Appendix 2). Seagrass, although not readily distinguishable in 1951 and 1971, was widespread in 1980, had become greatly diminished in extent in 2009, and then widespread from 2015 onwards. The main localities of seagrass manifestation remained the same irrespective of areal extent.

3.2 Okahu Passage

Okahu Passage (1000 m long and 100–400 m wide) is exposed in its northeast to easterly swells (Figures 1 and 5; Section A1.2 of Appendix 1). A large reef in the centre of the passage isolates the more-sheltered southwest part where sampling took place. Composed mainly of sand and shell hash, the seafloor slopes gradually to the southwest to > 7.6 m. Tidal flows appear stronger here than at the other study sites, possibly reaching 0.1 m s^{-2} during the ebb.

Seagrass was rarely encountered in 2020 and only in trivial amounts. Algal turf was widespread, its 2.91 ha of the 17.39 ha within the 5 m contour often as meadows. At all depths, coralline species

predominated, but in shallow waters of Transect W2 in particular (Figure 5), foliose species were patchily common to depths of about 2 m. The surficial biodiversity was generally 'medium'. The northeast ends of both transects were generally of coarse sand and gravel, probably reflecting stronger tidal currents compared with muddier, deeper, southwestern waters. Extensive living tawera beds were most often observed at 2–3 m, but were almost certainly widespread, in turn contributing to the large areas of shell hash. The biodiversity values here were 'low' among the visible taxa.

In the historical aerial imagery, only algal turf was distinguishable with confidence (Section A2.2 of Appendix 2); seagrass would be expected to appear more darkly. Accordingly, although the images suggest stability in the distribution of the algal turf, it seems unlikely there have been extensive seagrass beds here in recent times.

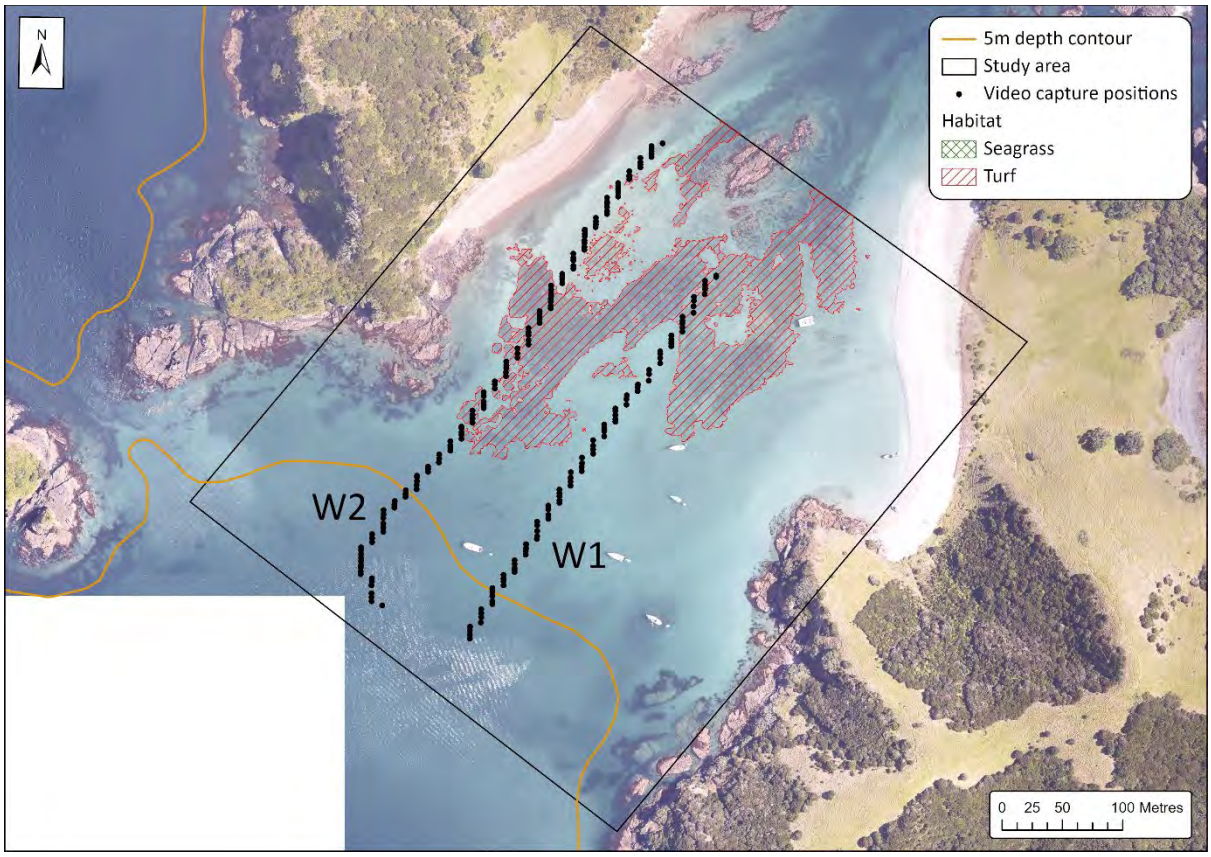


Figure 5: Video-camera transects and indicative distribution of the putative algal-turf (red) biome, to 5 m depth (Section A1.2 of Appendix 1), Okahu Passage, 2020.

3.3 Southeast Moturua

Here the seafloor deepens gradually to 5–6 m, before dropping rapidly (Figures 1 and 6; Section A1.3 of Appendix 1). The site is unaffected by swell but is open to southwest winds of considerable fetch. The seafloor is mainly sand and shell hash, but offshore in the east it appears to be muddy. This presumably reflects otherwise moderate tidal currents and wave action being constrained by the adjacent islets.

Seagrass was particularly widespread and abundant in the shallow embayments, altogether covering (to a depth of 2.5 m) 3.33 ha of the 42.81 ha of seafloor ≤ 5 m deep. Especially on Transect S1 (Figure 6), parchment worms—live and dead—were common among the seagrass. Nevertheless, the biodiversity index was 'low'. Algal turf was extensive (24.01 ha) and often dense, with a 'medium' to 'high' biodiversity index. It extended from depths of 1 m to at least 15 m, with the deepest video footage of it on Transect S1A. At all depths, corallines predominated. *Caulerpa flexilis* was sparsely widespread at

the seaward ends of Transect S1 and S1A, at 8–15 m. The coarse sand substrates in shallow waters became increasingly muddy with depth, with 'low' surficial biodiversity. Dense, widespread beds of shell hash were dominated by tawera.

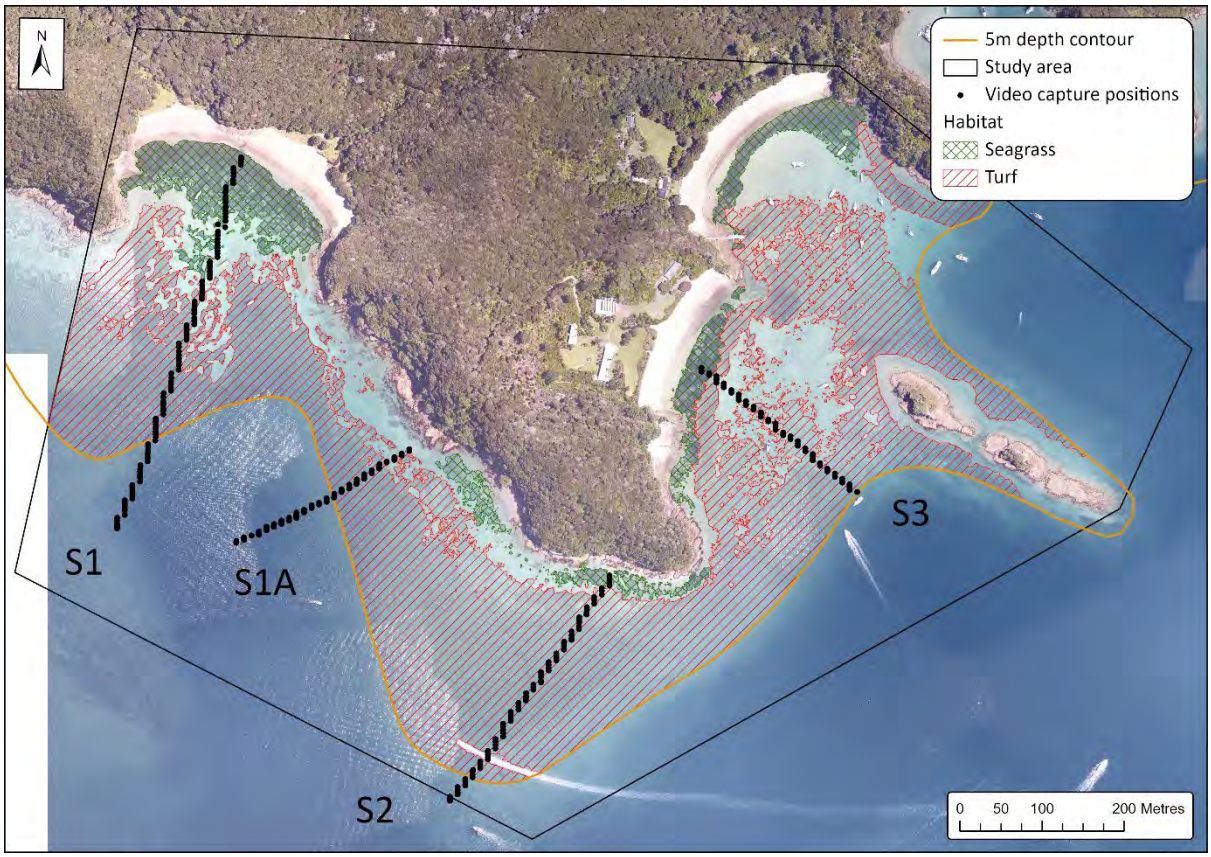


Figure 6: Video-camera transects and indicative distribution of the putative seagrass (green) and algal-turf (red) biomes, to 5 m depth (Section A1.3 of Appendix 1), Southeast Moturua, 2020.

The historical aerial imagery suggested general concurrence in the distribution of the biomes over time (Section A2.3 of Appendix 2). In 1942, however, there was little evidence for seagrass, and the distribution of the algal turf is difficult to distinguish. By 1980, there was extensive seagrass in all bays, but, again, the algal turf was probably more widespread than was apparent, the deeper seafloors being poorly resolved. Seagrass had decreased in extent by 2009, but then became increasingly widespread to 2020. Further, the main localities of seagrass remained the same irrespective of the level of surface manifestation.

3.4 Motukiekie Channel

Motukiekie Channel is 1500 m long and up to 600 m wide. The channel centre reaches depths of 5 m, with a steep drop-off to > 8 m at the southeastern platform margin. Although open in the northwest to northerly swells, the southeastern half, where sampling took place, is sheltered (Figures 1 and 7; Section A1.4 of Appendix 1). Tidal currents are probably weak. The seafloor comprises mainly sand and shell hash, becoming muddier with depth.

Although seagrass was noteworthy only on Transect M1 and M5, to depths of 2.5 m (Figure 7), this biome was patchily distributed over 4.90 ha of the 66.87 ha of waters ≤ 5 m deep. Algal turf was widespread (38.12 ha within the 5 m contour), but also extended to at least 8 m. At all depths, corallines were most abundant, and the biodiversity index was 'medium' to 'high'. *Caulerpa flexilis* plants were sparsely widespread amidst constricted areas of dense worm fields (see Figure 4) at 9–10 m on

Transect M5. Dense beds and ridges of shell hash exist, particularly along Transect M5, but the overall visible biodiversity was 'low'.

Seagrass had variable presence in the historical aerial images, but it occurred in the same general localities over time. In 1951 it appeared to be confined to a small patch in the north, it was remarkably widespread and dense in 1980, it had become sparse by 2009, and by 2020 it was again reappearing (Section A2.4 of Appendix 2). The algal turf seems to have been extensively distributed over time.

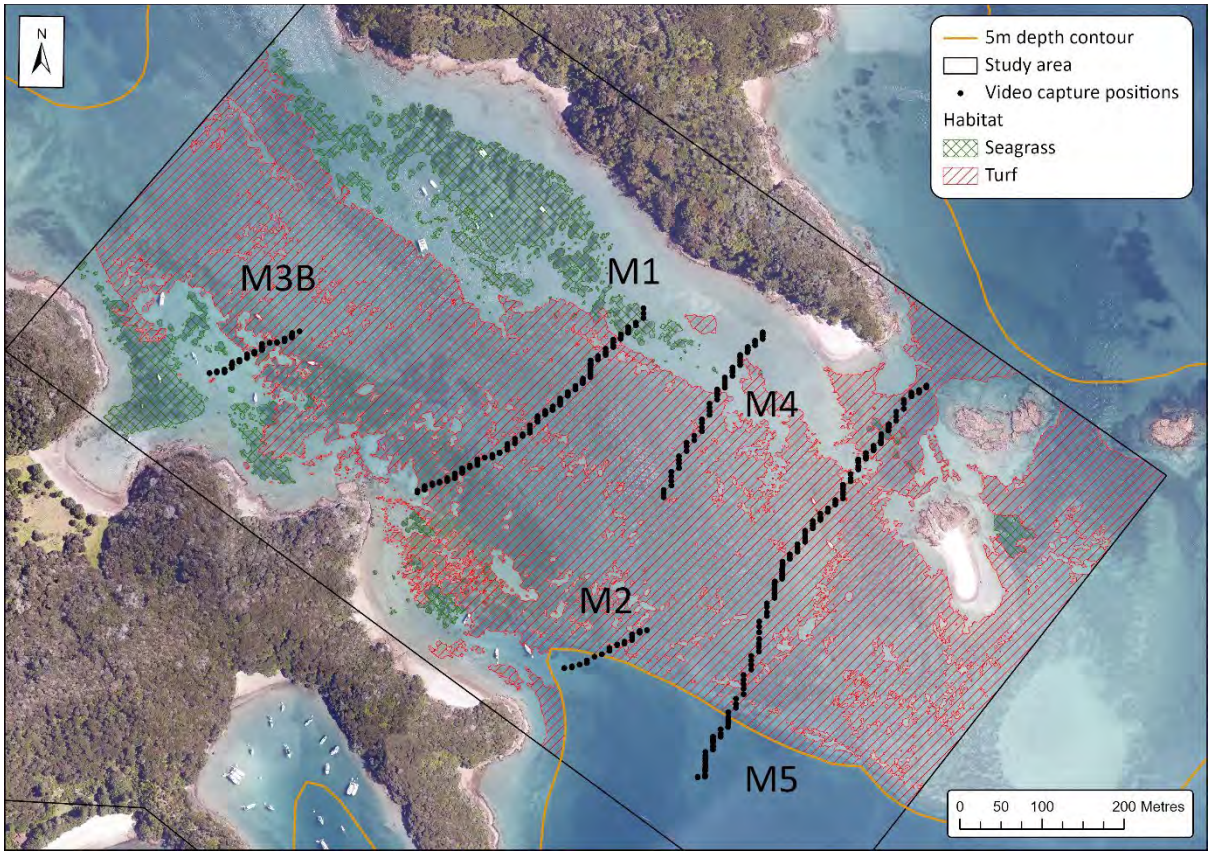


Figure 7: Video-camera transects and indicative distribution of the putative seagrass (green) and algal-turf (red) biomes, to 5 m depth (Section A1.4 of Appendix 1), Motukiekie Channel, 2020.

3.5 Summary of the soft-bottom biomes of Ipipiri Platform, mid-1900s to present

Three ecological biomes—two biogenic—are prominent today on the soft seafloors of Ipipiri Platform. Although not entirely without overlap, they are primarily characterised surficially by either seagrass or algal turf, amidst the underpinning, often shell-hash-populated sand flats. The seagrass biome 1) occupies sandy flats and gentle slopes to depths of about 2.5 m; 2) exhibits significant patchiness; 3) comprises few macroalgae (apart from coincident clumps of algal turf, especially near patch margins); and 4) harbours few other macro-constituents. Based on the four study sites, this biome presently covers about 5% of the shallow waters of the platform.

The algal-turf biome 1) is generally from 1 m to ≥ 10 m on sandy flats and slopes; 2) is generally less clumped but, even when at its most widespread, exhibits a fragmented appearance; 3) comprises primarily low-profile red algae most obviously characterised by geniculate corallines, but with significant presence of foliose species as well in Okahu Passage; and 4) is accompanied by more, nevertheless a limited array, of other macro-constituents. It covers at least 38% of the seafloor ≤ 5 m deep, but, importantly, the turf extended below the depth where it was routinely discernible in the aerial imagery and in places even beyond the deepest video footage (15 m).

Key characteristics of the sand plains supporting these vegetated habitats are that they 1) appear for the most part to comprise medium-to-coarse grains; and 2) show little in the way of other surficial macro-constituents. Reef (stones, cobbles, pebbles—often supporting smallish clumps of coralline turf similar in appearance to that on the sand) was present on some transects and, when extensive enough, was discernible in the aerial imagery (see Figure 3).

Although formal estimates of the areal extent of the biomes at the study sites over time, based on the historical aerial imagery, were not attempted because of highly-variable image quality, it was evident that 1) seagrass showed greater variation than did the algal turf, with 1980 being the year in common when seagrass was most apparent on Ipipiri Platform, and 2009 the lowest; and 2) the two biomes nevertheless tended to be present in their same respective general localities over time.

4. DISCUSSION

The islands of Ipipiri and their surrounding waters have long been of immense cultural and seafood-harvesting significance to the peoples of eastern Bay of Islands. The most ancient midden layers in the beach dune at Mangahawea Bay (see Figure 1), probably among the earliest-settled locations in the country (AD early-1300s), demonstrated a deep-seated fishing tradition and strong connections to the surrounding waters (Robinson et al. 2019). With islands set amidst clear, shallow, sheltered waters adjacent to the open sea, Ipipiri Platform was physically not dissimilar to the tropical east-Pacific context from which the first settlers had travelled. And the numerous later middens on the platform and nearby demonstrated an enduring reliance on local marine fish and shellfish (Booth 2017).

The shallow, soft-bottom communities of Ipipiri Platform are almost certainly far closer to their pristine, immediately-prehuman state than those in many inner parts of the Bay of Islands where recent sedimentation has brought about dramatic ecological change (Swales et al. 2012, Booth 2020, 2021). Although there are apparently no sediment cores for Ipipiri Platform, the persistence of silt-intolerant seagrass since at least 1950–80 is consistent with relatively low levels of terrestrially derived siltation. Other evidence for low rates of sediment accumulation include 1) ≤ 1–2 m post-Glacial sediment thickness of much of the platform, compared with 3–4 m elsewhere in the Bay of Islands (Bostock et al. 2010); 2) in a context of little or no tectonic activity and only about 20 cm of sea level rise, the apparent absence of substantial generalised or localised shallowing having taken place on Ipipiri Platform between the first comprehensive bathymetric chart of 1849 (Hydrographic Office 1857) and the present one, 170+ years on; and 3) a geomorphologist's observation of little or no mud, and low shoreline accretion, in shallow waters off western Okahu and Waewaetorea islands, and northwest Urupukapuka (Gibb 2012).

Seagrass and associated species Seagrass beds provide low-lying, three-dimensional structure that stabilise sediments and offer canopy cover for invertebrates and fishes (e.g., Morrison et al. 2014b, Anderson et al. 2019). Around and near the islands of Ipipiri there are nine significant and/or recovering subtidal beds, with several smaller, more-ephemeral patches (Figure 1). This high incidence of subtidal seagrass is presumably brought about by the shallow and relatively silt-free and sheltered seafloors, and high turnover of clear and fresh seawater. Subtidal seagrass is presently rare elsewhere in the Bay of Islands (Booth 2021).

Subtidal seagrass along our video transects extended to depths of 2.5 m. Although forming extensive meadows (≥ 1 ha) on certain parts of Ipipiri Platform, a defining feature along most of our transects was its clumpiness—a growth pattern yet to be explained. A rich macrofauna—much of it infaunal—is typically associated with northern subtidal seagrass (e.g., Grace & Whitten 1974, Grace & Grace 1976, Hayward et al. 1981), but mainly because of our sampling methodology, indices of diversity were 'low'. The most prominent and widespread macroinvertebrate was the speckled whelk (*Cominella adspersa*) that is typical of muddy reefs and certain sand flats, often existing unseen buried in the substrate (Morton & Miller 1968). The speckled whelk's sturdy shell can be expected to persist intact long after

death in these sheltered waters, but, on the other hand, its abundance is almost certainly understated on account of buried live shells.

Algal turf and associated species The widespread algal-turf biome (mainly the coralline *Corallina berteroi* but, particularly in Okahu Passage, foliose species like '*Gigartina*' *atropurpurea* as well) also provide stability and shelter. Algal turf was widespread on our video transects, typically with a fragmented, wavy surface manifestation. It occurred from 1 m to depths beyond the deepest sampling (15 m), and often well beyond what was visible in the aerial imagery. In Te Miko Channel, the only other intensively investigated site in eastern Bay of Islands, similar algal turf was present amidst the rhodolith beds (Nelson et al. 2012). Biodiversity indices of algal turf on Ipipiri Platform were 'medium' to 'high'. The most noticeable, and widespread, macroinvertebrate was, again, the speckled whelk.

Similar algal-turf seafloors appear to exist elsewhere in the Bay of Islands. They were particularly apparent in aerial imagery of mainland localities south of Ipipiri, from Paroa Bay to Albert Channel, and including parts of Manawaora Bay. But we know of no other similar, extensive, algae-dominated subtidal beds described from elsewhere in New Zealand (overviews of MacDiarmid et al. 2009, 2012a,b, 2013, Morrison et al. 2009, 2014a, Rowden et al. 2012, Jones et al. 2016, Anderson et al. 2019). However, MacDiarmid et al. (2012b) reported red-algae (*Adamsiella*) beds in inner Wellington Harbour, and Neill et al. (2012) and Neill & Nelson (2016) referred to reasonably extensive red-algae meadows in Otago Harbour. The algal-turf biome, dominated by geniculate reds, described here for the eastern Bay appears to be confined largely to the northeast of the country, with an apparently similar community also present 80 km north, in Doubtless Bay (Vince Kerr, pers. obs.).

Sand flats and associated species Although diversity values were 'low' among the larger of the visible surficial taxa, subtidal sand and muddy sand are typically rich in interstitial macrofauna (e.g., Morton & Miller 1968). Such was seen in Poroporo Channel in 1980 (Hayward et al. 1981) with numerous polychaetes and a particularly wide variety of bivalves.

The prominent, ecologically defining, embedded macroinvertebrate of Ipipiri Platform is almost certainly the filter-feeding tawera, evidenced primarily by its sheer abundance and wide distribution as recently dead shells on the shore and in shallow waters. Indeed, the finding of Hayward et al. (1981) of > 16 000 m^{-2} of live tawera in Albert Channel may be among the densest recorded (Morrison et al. 2014a). Packed beds of essentially immobile filter feeders like tawera assist in stabilising the seabed and clearing the water of organic particles—and are themselves food for predators. The next most obvious infaunal macro-mollusc on Ipipiri Platform is tucetona (but probably the small dog cockle *Glycymeris modesta* too). These shells often collect in sometimes large, post-mortem deposits, which in turn become important long-lived biogenic features (e.g., Dewas & O'Shea 2012). Albeit defining taxa, live dog cockles are, however, almost certainly numerically less abundant than smaller buried bivalves like the basket shell *Corbula zelandica*, or the white nut shell *Nucula hartvigiana* and its sister species *N. nitidula* (e.g., Hayward et al. 1981).

Sandy areas often had associated vegetative debris—particularly, accumulations of detached coralline algae but also sparse fronds of macroalgae such as ecklonia. Living macroalgae on sandy seafloors were, however, generally sparse and most often represented by an occasional *Codium fragile* and ecklonia. And at depth on Transect S1, S1A, and M5 (Figures 6 and 7), patchy *Caulerpa flexilis* was reasonably widespread, extending beyond our sampling.

Other defining taxa Certain other macroinvertebrates are frequently considered key indicator species of community type and health (e.g., Morrison et al. 2014a). Live horse mussels (*Atrina zelandica*) were unexpectedly absent in our sampling, although were represented by occasional, often still-articulated valves. The only location where horse mussels were reasonably common live in the 2009 Bay of Islands Ocean Survey 20/20 was in the deeper (> 10 m) waters of Te Rawhiti Inlet (Figure 1) (Bowden et al. 2010).

Scallops (*Pecten novaezelandiae*) were also sparse in 2020, despite the significance of the local recreational fishery in recent decades (Williams et al. 2008, Williams 2009, Hewitt et al. 2010, Fisheries New Zealand 2019). These beds have displayed the high interannual and spatial variability in abundance typical of pectinids, but the impression is that legal-sized scallops (those ≥ 100 mm) have now been scarce for almost a decade. In our sampling, a total of only three live scallops were identified, just-undersized. Consistent with this, scallop abundance on Ipipiri Platform in early-2021 was the lowest recorded[10].

The gastropod most commonly seen live in 2020 was the predatory speckled whelk, usually as individual animals, but sometimes in large egg-laying groupings (Figure 4). Notably, Hayward et al. (1981) reported greater abundance and wide distribution of the smaller *Cominella quoyana* over *C. adspersa* in Poroporo Channel in 1980, whereas in 2020 it was *C. adspersa* throughout (Bruce Marshall, Te Papa, pers. comm.). *Cominella adspersa* is likely a keystone predator and scavenger in Ipipiri waters (Stewart & Creese 2004) and is also implicated in scallop predation (Talman et al. 2004).

Polychaete worms (as well as certain unsegmented worms like nemerteans) are almost certainly a major component of the deposit- and suspension-feeding fauna of Ipipiri Platform not well captured in our imaging. In 2020, various simple holes and depressions, particularly in deeper, finer substrates, may have represented worm activity, with larger excavations more likely to be crustacean. Encrusted and unencrusted calcareous worm tubes were common among algal-turf clumps. Occasional, confined fields of small erect worm siphons (Figure 4) were possibly spionids (Geoff Read, NIWA, pers. comm.). The leathery tubes of parchment worms were common and widespread, the worm particularly apparent both live and dead among the seagrass on Transect S1 (Figure 6). That the parchment worm was unreported in 1980 (Hayward et al. 1981) suggests a substantial range extension of what may be a non-indigenous species (NIS) (Morrison et al. 2014a). However, no recognised NIS (animal or plant) was observed.

What was probably microphytobenthic film appeared to 'cement' extensive areas of sand surface (Figure 4). Such film, often diatom-dominated and mucus-bound, plays significant roles in system productivity and trophic dynamics, carbon sequestration, and seabed stabilisation (e.g., MacIntyre et al. 1996, Gillespie et al. 2000, Lelieveld et al. 2003).

Less-common taxa Live echinoderms were uncommon, most often represented by comb sea stars *Astropecten polyacanthus* and 11-armed starfish *Coscinasterias muricata*. Fish encountered were a single porcupine fish *Allomycterus jaculiferus* and a smooth leatherjacket *Parika scaber*, together with occasional pelagic fish that probably included kōheru *Decapterus koheru*. Presumably other fishes had been spooked.

Soft-bottom, subtidal biomes prominent in other parts of New Zealand (some being obvious elsewhere in the Bay of Islands) that were not encountered to any extent in our sampling included 1) rhodoliths, at least the larger individuals of which are more typically seen among coarser substrates in areas of stronger currents (10–20 m s^{-2}; Nelson et al. 2012); 2) habitat-forming sponge gardens (e.g., Morrison et al. 2014a); 3) bryozoan-dominated reefs (e.g., Grange et al. 2003); 4) habitat-forming abundances of tubeworms (e.g., Morrison et al. 2014a); 5) brachiopods providing stability and structural complexity (e.g., MacDiarmid et al. 2013); 6) anemone-bound seafloors (e.g., Lamarche et al. 2020); 7) substrates dominated by ophiuroids or holothuroids (e.g., Lamarche et al. 2020); and 8) extensive, stabilising beds of green-lipped mussels *Perna canaliculus* (e.g., Morrison et al. 2014a).

Changes in biogenic cover over time Marine ecosystems have inherent dynamism that can involve significant changes over short time frames, through to remarkably little change over the scale of decades. Only since synoptic aerial imagery encompassing several decades has recently become available has it been possible to routinely follow static or slow-changing communities.

[10] https://www.mpi.govt.nz/consultations/review-of-sustainability-measures-2022-april-round/

The putative areal cover of algal turf appears to have been remarkably steady over the past 50–70 y in our study sites, although often-poor resolution at depth among the historical imagery makes this conclusion tentative in some instances for algal turf. Red-algae turfs are often viewed locally (e.g., Alestra et al. 2014) and worldwide (e.g., Filbee-Dexter & Wernberg 2018) to represent a recent, stable, degraded state; many kelp forests globally have been recently replaced by turf algae. It appears, however, that coralline turf on the soft substrates of Ipipiri is part of a long-existing climax state.

In contrast, the surface manifestation of the shallower, putative seagrass biome showed considerable areal variation (Appendix 2), the common peak year being 1980, and the nadir 2009. Changes in sedimentation rates and turbidity, and ocean-climate factors, have been implicated in such changes in the Bay of Islands (Booth 2019). That the seagrass appeared to come and go from the same general localities suggested remnant root structure persisted, even if there was little leaf growth.

Taken together, our work suggests that the bottom-stabilising seagrass and algal-turf biomes are the predominant long-term surficial ecological communities of Ipipiri Platform of recent geological times.

Overarching synthesis We have characterised the main biomes—seagrass, algal turf and sand—of the shallow, soft seafloors of Ipipiri Platform. However, almost certainly there is more complexity present spatially and temporally than our imagery has revealed. For example, accumulations of small, live and dead rhodoliths were observed among the shallow algal turf in Poroporo Channel in February 2020 (Booth 2021) yet rhodoliths were not discerned in our November 2020 imagery.

The vegetated biomes of the shallow waters of Ipipiri Platform rank highly in their ecological values and are of fishery significance, and the locality is culturally pre-eminent. Further, both above and below the sea surface the area has High Natural Character (high levels of environmental naturalness). But there are threats to the endurance of such biomes. The integrity and persistence of shallow (2–9 m) areas of sand on sheltered shores, and their associated surficial life, are affected by 36 significant threats (MacDiarmid et al. 2012a). They are particularly vulnerable to the effects of ocean acidification, with other major threats being sedimentation, bottom trawling, shellfish dredging, increased sea temperature, sand and gravel abstraction, and increased turbidity. For Ipipiri Platform, sedimentation and increased turbidity are probably the immediate key pressures. Of particular concern is that within Te Rawhiti Inlet, between the islands of Ipipiri and the mainland (Figure 1), is the largest silt sink for the entire Bay of Islands. With most silt deriving from the largest source of sediment in the Bay, the Taumarere/Kawakawa river system, fine sediments have been accruing in this relatively deep, fetch-limited basin at 4.9 mm y^{-1} over the past century (Swales et al. 2012). And, with among the most rapid loss of sediment accommodation space in the Bay, this area is predicted to experience early, large-scale environmental change such as the loss of certain subtidal habitats.

Recent, heavy exploitation of key fish species in the Bay of Islands (Booth 2017) is unlikely to have had much direct impact on the vegetated biomes of Ipipiri. And apart from the use of light (about 5 kg) recreational dredges for scallops, the only harvesting techniques used on Ipipiri Platform today are the relatively benign hand-netting, -lining and -gathering. The platform's seagrass and algal turf are probably not even under significant physical threat from the dredging; thick meadows would quickly foul dredges, although tufts and small patches adjacent to the main beds may be susceptible. The few tracks identified in the aerial imagery that might have resulted from dredging (Section A3.2 in Appendix 3) appear as narrow lines passing through dark-coloured biogenic seafloor features in situations where there seems no other explanation. Tows over sand, however, are less likely to have left an aerially-visible signature so the imagery may lead to underestimated recreational dredge impact. In our assessment, however, the greater physical impact on the soft-bottom biodiversity on Ipipiri Platform comes from boating. Incessant propeller wash can lead to dramatic, and presumably long-lasting, damage (Section A3.1 in Appendix 3). On the other hand, thousands of boat anchor nights take place every summer in Otiao Bay (Figure 1), yet the seagrass beds, although scarred, remain vibrant. This is probably because of the sheltered environment with anchoring being localised and intense over a short summer period, with the macrobenthos recovering to an extent over the remainder of the year (as, for example, at Kawau Island; Backhurst & Cole 2000).

Ipipiri Platform today probably contains the most significant, soft-bottom, subtidal biogenic communities of the Bay of Islands, represented by seagrass and algal-turf beds. These rare biomes presumably persist through the relatively shallow and silt-free seafloors, the gradients of exposure and associated seafloor types, the clear and clean waters, and, in many places, reasonably-strong tidal currents. In turn, Rimu aria Rakaumangamanga, together with the subtidal seagrass, underpins what is probably the most widely promoted representation and allure of the Bay of Islands today whereby not only people on boats and from the air draw wonderment, but swimmers and divers are inspired too. Here we have made a start on characterising these ecologically significant biomes by providing a 2020 baseline of their composition and extent.

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6. REFERENCES

Alestra, T.; Tait, L.W.; Schiel, D.R. (2014). Effects of algal turfs and sediment accumulation on replenishment and primary productivity of fucoid assemblages. *Marine Ecology Progress Series 511*: 59–70.

Anderson, T.J.; Mark Morrison, M.; MacDiarmid, A.; Clark, M.; D'Archino, R.; Nelson, W.; Tracey, D.; Gordon, D.; Read, G.; Kettles, H.; Morrisey, D.; Wood, A.; Anderson, O.; Smith, A.M.; Page, M.; Paul-Burke, K.; Schnabel, K.; Wadhwa, S. (2019). Review of New Zealand's key biogenic habitats. (NIWA Client Report No. 2018139WN prepared for the Ministry for the Environment.) https://environment.govt.nz/assets/Publications/Files/NZ-biogenic-habitat-review.pdf

Backhurst, M.K.; Cole, R.G. (2000). Biological impacts of boating at Kawau Island, north-eastern New Zealand. *Journal of Environmental Management 60*: 239–251.

Booth, J.D. (2017). Characterising fisheries and other marine harvesting in the Bay of Islands, with ecological consequences, from first human settlement to the present. *New Zealand Aquatic Environment and Biodiversity Report No. 186*. 86 p.

Booth, J.D. (2019). Recent (post-1930) changes in the extent of subtidal seagrass (*Zostera muelleri*) beds of the eastern Bay of Islands, New Zealand. *New Zealand Journal of Marine and Freshwater Research 53*: 113–127.

Booth, J.D. (2020). Reviewing the far-reaching ecological impacts of human-induced terrigenous sedimentation on shallow marine ecosystems in a northern-New Zealand embayment. *New Zealand Journal of Marine and Freshwater Research 54*: 593–613.

Booth, J.D. (2021). Reviewing recent (mainly post-1950) changes in nature and extent of shallow-water, soft-seafloor biological communities of New Zealand's Bay of Islands: causes, consequences and persisting threats. (Unpublished report to Bay of Islands Maritime Park Inc.) https://www.fishforever.org.nz/images/ff/documents/reports/BOOTH_Soft_seafloors_of_the_Bay_of_Islands.pdf

Bostock, H.; Maas, E.; Mountjoy, J.; Nodder, S. (2010). Bay of Islands OS20/20 survey report. Chapter 3: Seafloor and subsurface sediment characteristics. ftp://ftp.niwa.co.nz/os2020/boi/Final_chapters/Chapter_03_Seafloor_substrate.pdf

Bowden, D.; et al. (2010). Bay of Islands OS20/20 survey report. Chapter 9: Seafloor assemblage and habitat assessment using DTIS. ftp://ftp.niwa.co.nz/os2020/boi/Final_chapters/Chapter_09_DTIS.pdf

Brook, F.J.; Carlin, G.L.F. (1992). Subtidal benthic zonation sequences and fish faunas of rocky reefs in Bay of Islands, northern New Zealand. Department of Conservation, Northland Conservancy.

D'Archino, R.; Schimel, A.C.G.; Peat, C.; Anderson, T. (2021). Automated detection of large brown macroalgae using machine learning algorithms—a case study from Island Bay, Wellington. *New Zealand Aquatic Environment and Biodiversity Report No. 263*. 36 p.

Dewas, S.E.A.; O'Shea, S. (2012). The influence of *Tucetona laticostata* (Bivalvia: Glycymeridae) shells and rhodolith patches on benthic-invertebrate assemblages in Hauraki Gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research 46*: 47–56.

DOC (Department of Conservation) (2008). Marine Protected Areas classification, protection standard and implementation guidelines. https://www.doc.govt.nz/globalassets/documents/conservation/marine-and-coastal/marine-protected-areas/mpa-classification-protection-standard.pdf

Farr, T.; Broom, J.; Hart, D.; Neill, K.; Nelson, W. (2009). Common coralline algae of northern New Zealand: an identification guide. *NIWA Information Series No. 70*.

Filbee-Dexter, K.; Wernberg, T. (2018). Rise of turfs: a new battlefront for globally declining kelp forests. *BioScience 68*: 64–76.

Fisheries New Zealand (2019). *Fisheries Assessment Plenary, November 2019: stock assessments and stock status*. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 579 p.

Francis, M.P.; Evans, J. (1992). Immigration of subtropical and tropical animals into north-eastern New Zealand. *In*: Battershill, C.N.; et al., (Eds.) Proceedings of the Second International Temperate Reef Symposium, 7–10 January 1992, Auckland, New Zealand. pp. 131–136.

Francis, M.P.; Worthington, C.J.; Saul, P.; Clements, K.D. (1999). New and rare tropical and subtropical fishes from northern New Zealand. *New Zealand Journal of Marine and Freshwater Research 33*: 571–586.

Froude, V.A. (2016). Rare and special marine and estuarine sites of the Bay of Islands, New Zealand. A report prepared for Bay of Islands Maritime Park Inc. Fish Forever Working Group. Pacific Eco-Logic Ltd, Russell. https://www.fishforever.org.nz/

Gibb, J.G. (2012). Application of geology and physical oceanography to marine reserve determination, Ipipiri, eastern Bay of Islands, Northland, New Zealand. Kerikeri: Coastal Management Consultancy Ltd.

Gillespie, P.A.; Maxwell, P.D.; Rhodes, L.R. (2000). Microphytobenthic communities of subtidal locations in New Zealand: taxonomy, biomass, production, and food-web implications. *New Zealand Journal of Marine and Freshwater Research 34*: 41–53.

Grace, R.V.; Grace, A.B. (1976). Benthic communities west of Great Mercury Island, north-eastern New Zealand. *Tane 22*: 85–101.

Grace, R.V.; Whitten, R.F. (1974). Benthic communities west of Slipper Island, north-eastern New Zealand. *Tane 20*: 5–20.

Grange, K.R.; Tovey, A.; Hill, A.F. (2003). The spatial extent and nature of the bryozoan communities at Separation Point, Tasman Bay. *Marine Biodiversity Biosecurity Report No. 4.* 22 p.

Hayward, B.W.; Grace, R.V.; Brook, F.J. (1981). Soft-bottom benthic macrofaunal communities of the eastern Bay of Islands, northern New Zealand. *Tane 27*: 103–122.

Hewitt, J.; Chiaroni, L.; Hailes, S. (2010). Bay of Islands OS20/20 survey report. Chapter 11: Soft-sediment habitats and communities. ftp://ftp.niwa.co.nz/os2020/boi/Final_chapters/Chapter_11_Soft_sediment_communities.pdf

Hydrographic Office (1857). Bay of Islands surveyed by Commander G.H. Richards and P.W. Oke Master's Assistant under the direction of Captain J.L. Stokes H.M.S. *Acheron*.

Jeong, S.Y.; Maneveldt, G.W.; Gabrielson, P.W..; Nelson, W.A.; Won, B.Y.; Cho, T.O. (2022). *Phymatolithopsis* gen nov. (Hapalidiales, Corallinophycidae, Rhodophyta) based on molecular and morpho-anatomical evidence. *Journal of Phycology 58(1)*: 161–178.

Jones, E.G.; Morrison, M.A.; Davey, N.; Hartill, B.W.; Sutton, C. (2016). Biogenic habitats on New Zealand's continental shelf. Part I: Local Ecological Knowledge. *New Zealand Aquatic Environment and Biodiversity Report No. 174*.

Kerr, V.C.; Grace, R.V. (2015). Marine habitats of the proposed Waewaetorea Marine Reserve. A report prepared for Fish Forever, Bay of Islands. https://www.fishforever.org.nz/

Lamarche, G.; Laferriere, A.; Geange, S.; Gardner, J.; Pallentin, A. (2020). Inner shelf habitat surrounding the Kapiti Marine Reserve, New Zealand. Chapter 22, pp. 403–419. *In*: Harris, P,T.; Baker, E. (Eds), *Seafloor geomorphology as benthic habitat* (Second edition). https://doi.org/10.1016/B978-0-12-814960-7.00022-1

Lelieveld, S.D.; Pilditch, C.A.; Green, M.O. (2003). Variation in sediment stability and relation to indicators of microbial abundance in the Okura Estuary, New Zealand. *Estuarine, Coastal and Shelf Science 57*: 123–136.

MacDiarmid, A.; et al. (2009). Ocean Survey 20/20. Bay of Islands Coastal Project. Phase 1 – Desk top study. https://dc.niwa.co.nz/niwa_dc/srv/eng/catalog.search#/metadata/0648ae77-153b-41af-a5af-9e110ed425fb

MacDiarmid, A.; Bowden, D.; Cummings, V.; Morrison, M.; Jones, E.; Kelly, M.; Neil, H.; Nelson, W.; Rowden, A. (2013). Sensitive marine benthic habitats defined. (NIWA Client Report No. WLG2013-18.) https://environment.govt.nz/assets/Publications/Files/sensitive-marine-benthic-habitats-defined.pdf

MacDiarmid, A.; McKenzie, A.; Sturman, J.; Beaumont, J.; Mikaloff-Fletcher, S.; Dunne, J. (2012a). Assessment of anthropogenic threats to New Zealand marine habitats *New Zealand Aquatic Environment and Biodiversity Report No. 93*.

MacDiarmid, A.; Nelson, W.; Gordon, D.; Bowden, D.; Mountjoy, J.; Lamarche, G. (2012b). Sites of significance for indigenous marine biodiversity in the Wellington region. (NIWA Client Report No. WLG2012-19.) https://www.gw.govt.nz/assets/Documents/2021/10/NIWA-REPORT-Sites-of-significance-for-indigenous-marine-biodiversity-in-the-Wellington-region.pdf

MacIntyre, H.L.; Geider, R.J.; Miller, D.C. (1996). Microphytobenthos: The ecological role of the "secret garden" of unvegetated, shallow-water marine habitats. I. Distribution, abundance and primary production. *Estuaries 19*: 186–201.

Matheson, F.; Wadhwa, S.; Taumoepeau, A.; Smith, J. (2010). Seagrass in the eastern Bay of Islands: past and present abundance, threats and management options. (NIWA Client Report HAM2010-043.) https://www.nrc.govt.nz/media/1slctxz2/easternboiseagrassreportniwa.pdf

Morley, M.S.; Hayward, B.W. (1999). Inner shelf Mollusca of the Bay of Islands, New Zealand, and their depth distribution. *Records of the Auckland Museum 36*: 119–140.

Morrison, M.A.; Lowe, M.L.; Parsons, D.M.; Usmar, N.R.; McLeod, I.M. (2009). A review of land-based effects on coastal fisheries and supporting biodiversity in New Zealand. *New Zealand Aquatic Environment and Biodiversity Report No. 37*.

Morrison, M.A.; Lowe, M.L.; Grant, C.M.; Smith, P.J.; Carbines, G.; Reed, J.; Bury, S.J.; Brown, J. (2014b). Seagrass meadows as biodiversity and productivity hotspots. *New Zealand Aquatic Environment and Biodiversity Report No. 137*.

Morrison, M.A.; Jones, E.; Consalvey, M.; Berkenbusch, K. (2014a). Linking marine fisheries species to biogenic habitats in New Zealand: a review and synthesis of knowledge. *New Zealand Aquatic Environment and Biodiversity Report No. 130*.

Morton, J.; Miller, M. (1968). *The New Zealand sea shore*. Auckland: Collins.

Mountain Harte, H.; Hook, A.; Henare, P. (2010). Te Kupenga Manawahuna: a baseline study for traditional and customary fisheries practices in Te Rawhiti – CUS 2007–2008. Ministry of Fisheries. http://www.ngatikuta.maori.nz/about/

Neill, K.; D'Archino, R.; Farr, T.; Nelson, W. (2012). Macroalgal diversity associated with soft sediment habitats in New Zealand. *New Zealand Aquatic Environment and Biodiversity Report No. 87*.

Neill, K.F.; Nelson, W.A. (2016). Soft sediment macroalgae in two New Zealand harbours: biomass, diversity and community composition. *Aquatic Botany 129*: 9–18.

Neill, K.F.; Nelson, W.A.; D'Archino, R.; Leduc, D.; Farr, T.J. (2015). Northern New Zealand rhodoliths: assessing faunal and floral diversity in physically contrasting beds. *Marine Biodiversity 45(1)*: 63–75.

Nelson, W. (2020). *New Zealand seaweeds: an illustrated guide*. Wellington: Te Papa Press.

Nelson, W.; Dalen, J.; Neill, K. (2013). Insights from natural history collections: analysing the New Zealand macroalgal flora using herbarium data. *PhytoKeys 30*: 1–21.

Nelson, W.; D'Archino, R. (2010). Bay of Islands OS20/20 survey report. Chapter 12: Attached benthic macroalgae. ftp://ftp.niwa.co.nz/os2020/boi/Final_chapters/Chapter_12_Macroalgae.pdf

Nelson, W.A.; Neill, K.; Farr, T.; Barr, N.; D'Archino, R.; Miller, S.; Stewart, R. ((2012). Rhodolith beds in northern New Zealand: characterisation of associated biodiversity and vulnerability to environmental stressors. *New Zealand Aquatic Environment and Biodiversity Report No. 99*. 102 p.

Nelson, W.A.; Twist, B.A.; Neill, K.F.; Sutherland, J.E. (2019). Coralline algae of New Zealand: a summary of recent research and the current state of knowledge. *New Zealand Aquatic Environment and Biodiversity Report No. 232*.

Ngati Kuta ki Te Rawhiti Hapu Management Plan 2011. Fifth edition. https://www.scribd.com/document/16770402/Ngati-Kuta-Hapu-Management-Plan

Robinson, J.; Blanchard, A.; Clendon, M.; Maxwell, J.; Sutton, N.; Walter, R. (2019). Mangahawea Bay revisited: a reconsideration of the stratigraphy and chronology of site Q05/682. *Journal of Pacific Archaeology 10*: 45–55.

Rowden, A.A.; Berkenbusch, K.; Brewin, P.E.; Dalen, J.; Neill, K.F.; Nelson, W.A.; Oliver, M.D.; Probert, P.K.; Schwarz, A-M.; Sui, P.H.; Sutherland, D. (2012). A review of the marine soft-sediment assemblages of New Zealand. *New Zealand Aquatic Environment and Biodiversity Report No. 96*. 165 p.

Stewart, M.J.; Creese, R.G. (2004). Feeding ecology of whelks on an intertidal sand flat in north-eastern New Zealand. *New Zealand Journal of Marine and Freshwater Research 38*: 819–831.

Swales, A.; Gibbs, M.; Hewitt, J.; Hailes, S.; Griffiths, R.; Olsen, G.; Ovenden, R.; Wadhwa, S. (2012). Sediment sources and accumulation rates in the Bay of Islands and implications for macro-benthic fauna, mangrove and saltmarsh habitats. Report prepared for Northland Regional Council. https://www.nrc.govt.nz/media/ywokthwr/sedimentsourcesandaccumulationratesintheboiandimplicationsswales2012.pdf

Talman, S.G.; Norkko, A.; Thrush, S.F.; Hewitt, J.E. (2004). Habitat structure and the survival of juvenile scallops *Pecten novaezelandiae*: comparing predation in habitats with varying complexity. *Marine Ecology Progress Series 269*: 197–207.

Twist, B.A.; Neill, K.F.; Bilewitch, J.; Jeong, S.Y.; Sutherland, J.E.; Nelson, W.A. (2019). High diversity of coralline algae in New Zealand revealed: knowledge gaps and implications for future research. *PLOS ONE 14(12)*: e0225645.

Walls, K. (1987). Estuarine and coastal freshwater wetlands of the Bay of Islands. Whangarei: Northland Harbour Board.

Williams, J.R. (2009). Abundance of scallops (*Pecten novaezelandiae*) in Northland and Coromandel recreational fishing areas, 2007. *New Zealand Fisheries Assessment Report 2009/62*.

Williams, J.R.; Tuck, I.D.; Carbines, G.D. (2008). Abundance of scallops (*Pecten novaezelandiae*) in Northland and Coromandel recreational fishing areas, 2006. *New Zealand Fisheries Assessment Report 2008/34*.

Yoon, H.S.; Hackett, J.D.; Bhattacharya, D. (2002). A single origin of the peridinin-and fucoxanthin-containing plastids in dinoflagellates through tertiary endosymbiosis. *Proceedings of the National Academy of Science 99*: 11724–11729.

APPENDIX 1: Characterising biodiversity

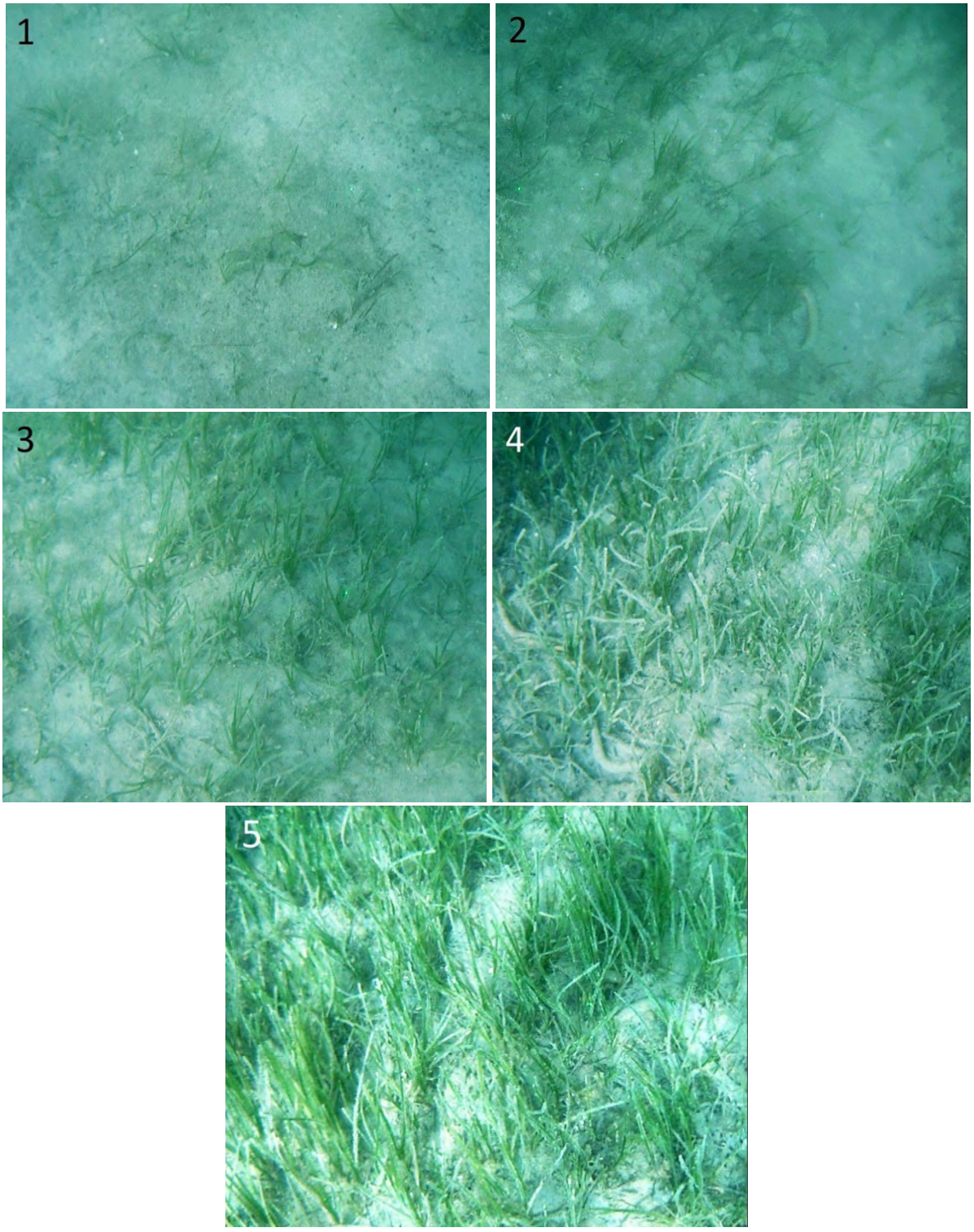
This appendix summarises the field sampling undertaken in November 2020. It characterises the biological and physical features of the seafloor along each of the 2–5 transects of the four study sites, based primarily on the towed-video imagery, and displayed over the essentially coincident aerial imagery of the seafloor. One-second images from each video transect were viewed individually by one of us (JDB) and salient features noted. Every 10th second image (10 s, 20 s, 30 s, etc.) was then characterised according to 1) seagrass cover (null, plus five categories), 2) algal turf cover (null, plus five categories), and 3) sediment (null, plus five categories, based primarily on the extent of the tawera shell hash present). A further 'Other' category allowed mapping of additional seafloor types encountered: cobble/rock, muddy seafloors, areas of what appeared to be microphytobenthos film (typically characterised by a cemented appearance and green tinge), areas of bottom bioturbation and possible shellfish siphons, and any significant presence of detached fronds of macroalgae. Each transect was then subdivided into its composite sections based on these four groupings. Because the video camera was under tow up to 5 m behind the position of the video control on the vessel, and the video software itself displays the stations in vertical sets, the recorded GPS positions may not always align directly with the sampling point. Drop-camera imagery (no time stamp) at representative points along many of the transects allowed additional categorisation of seabed features. All depths are Multibeam Chart Datum depths.

Representative imagery associated with certain sections of each transect follows, in large format and at high resolution in the hope they are usefully discriminative for other researchers. Downloaded images were enhanced where necessary using Adobe Photoshop. Not all sections warranted imagery being presented here, but the entire video footage is archived at NIWA (Greta Point, Wellington) and accessed through the Marine Biologist (seaweed). Abbreviations used: AT, algal turf; MPB, microphytobenthos film; SG, seagrass.

Categories recorded for the 10-second video imagery

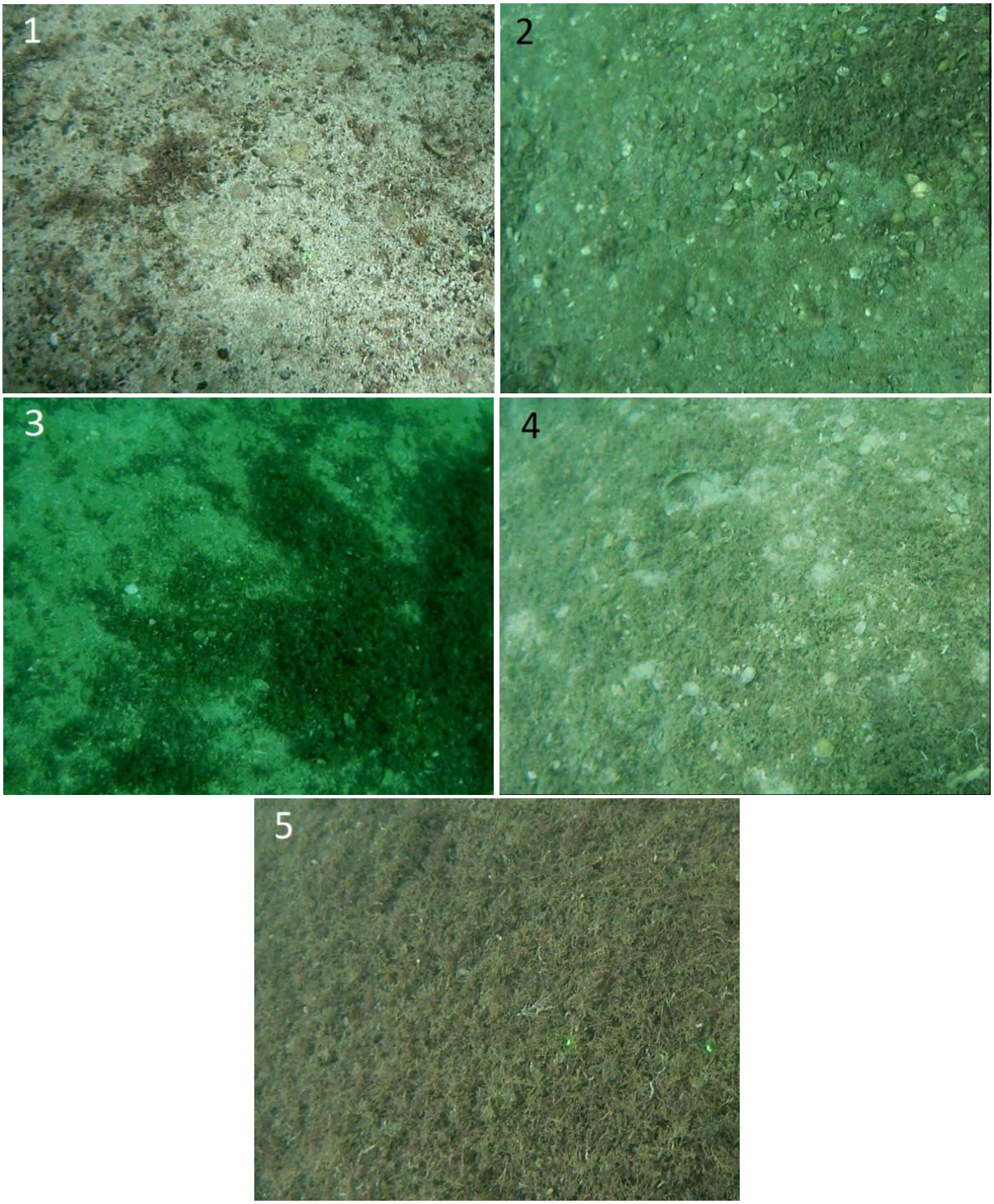
Seagrass

	Category 1	Category 2	Category 3	Category 4	Category 5
Seagrass	Wispy	Straggle	Widespread	Near continuous	Continuous & dense



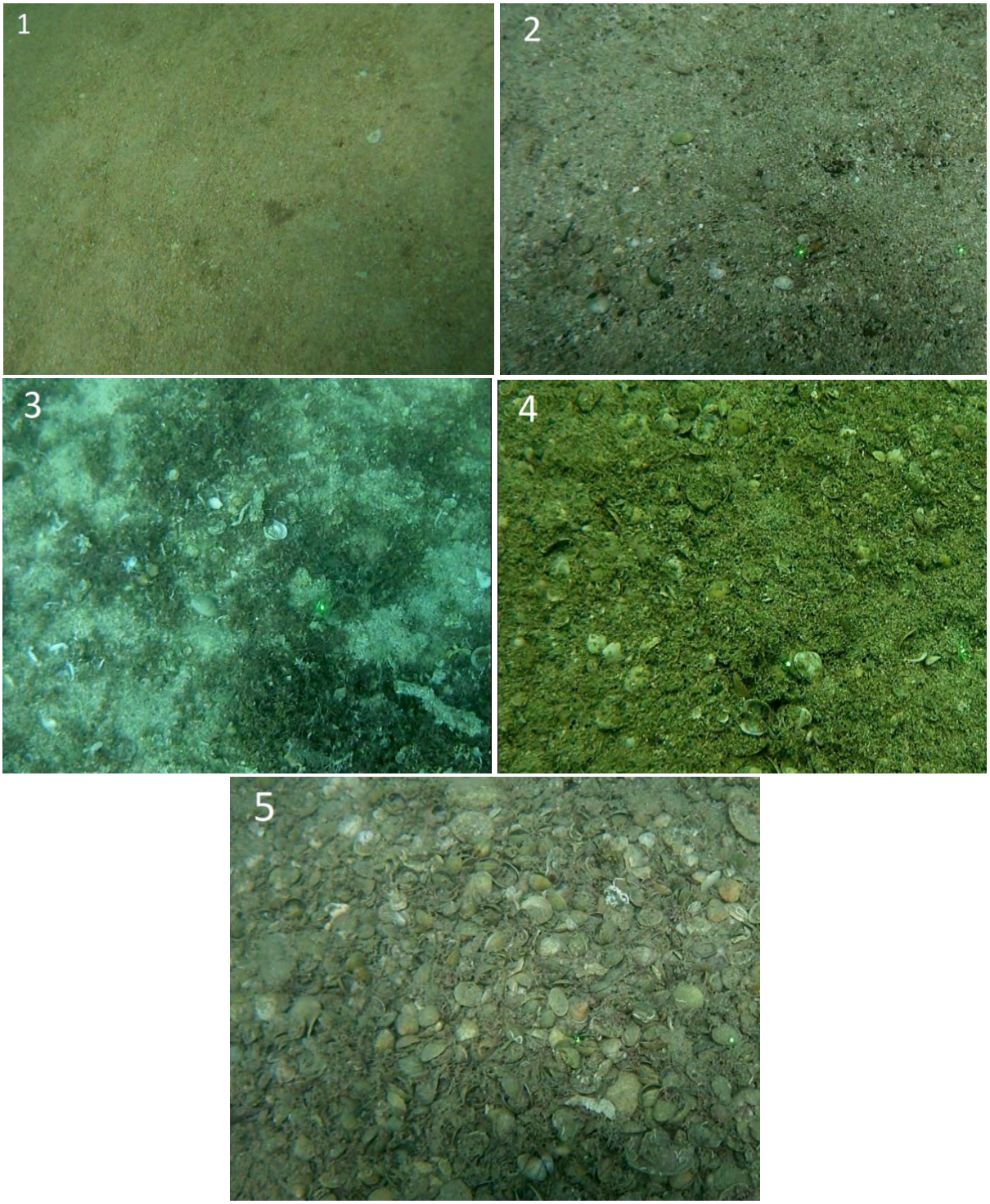
Algal turf

	Category 1	Category 2	Category 3	Category 4	Category 5
Turf	Tiny growths	Clumps	Extensive clumps	Near-continuous	Continuous

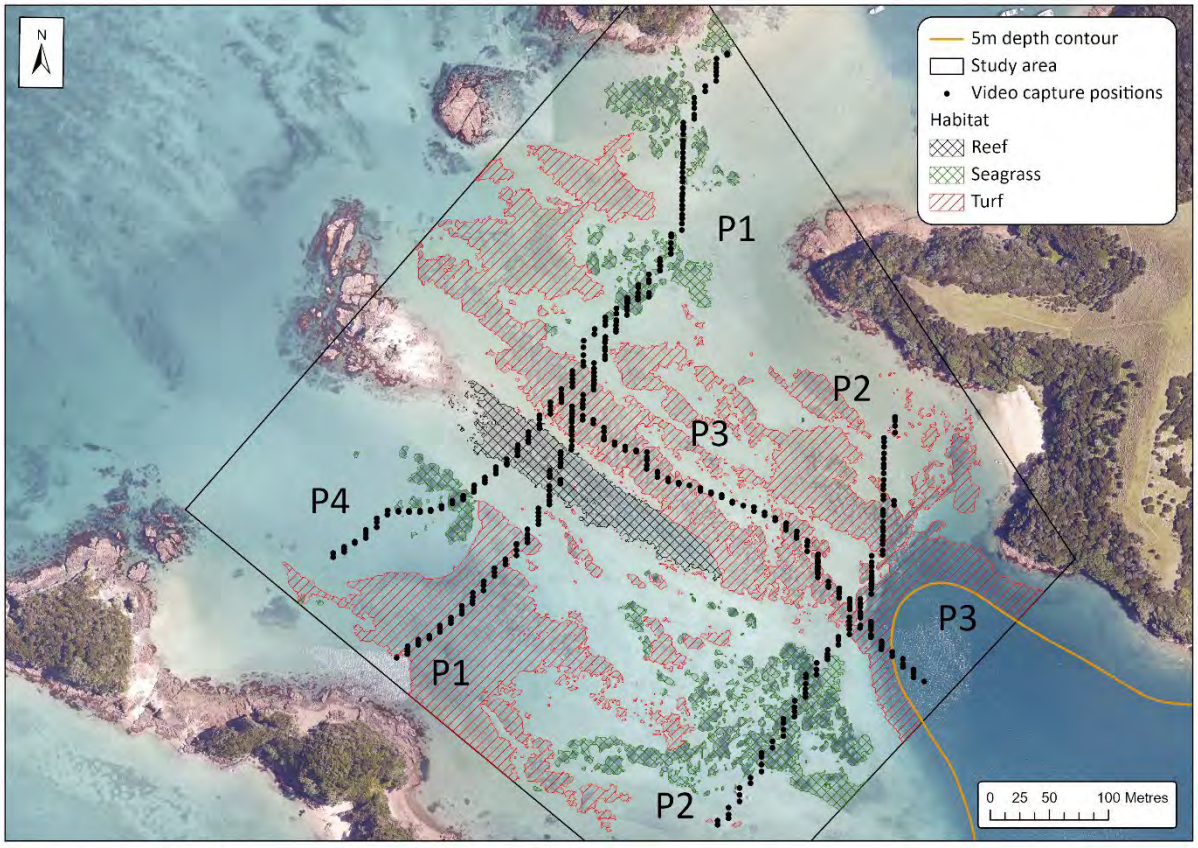


Substrate

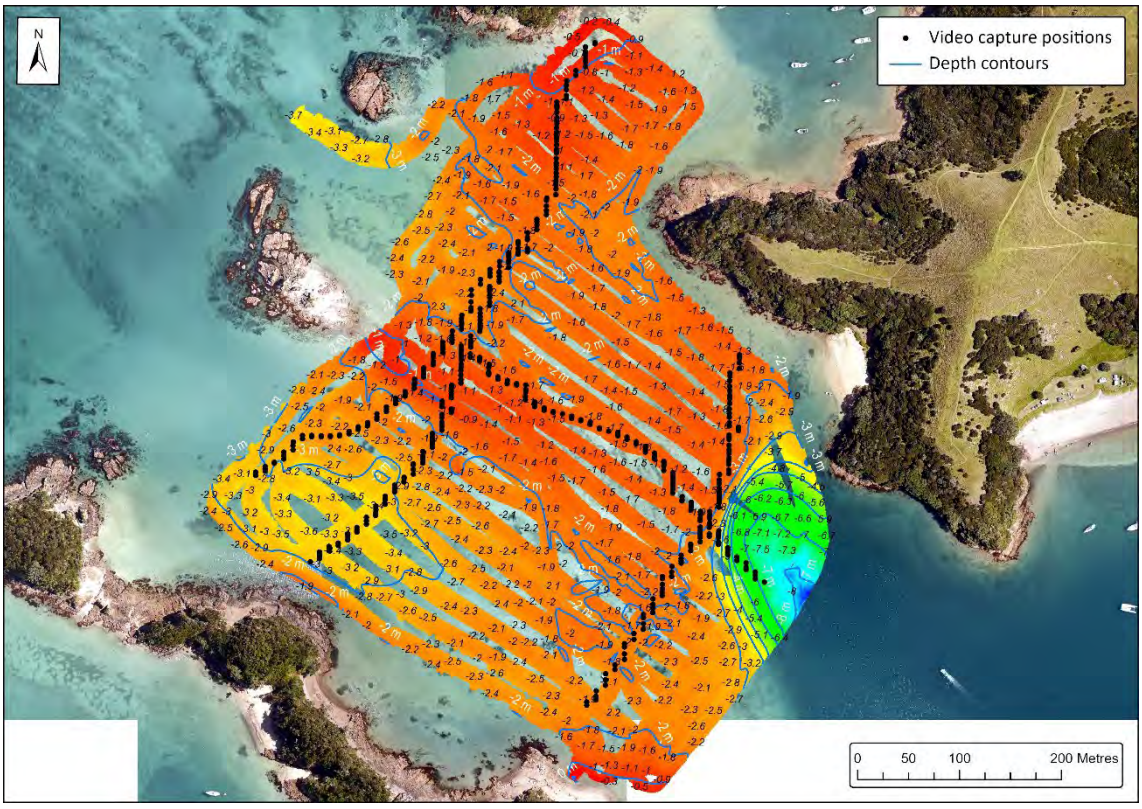
	Category 1	Category 2	Category 3	Category 4	Category 5
Substrate	Clean sand	Shell fragments	Scattered whole tawera	Extensive tawera hash	Ridges of tawera hash



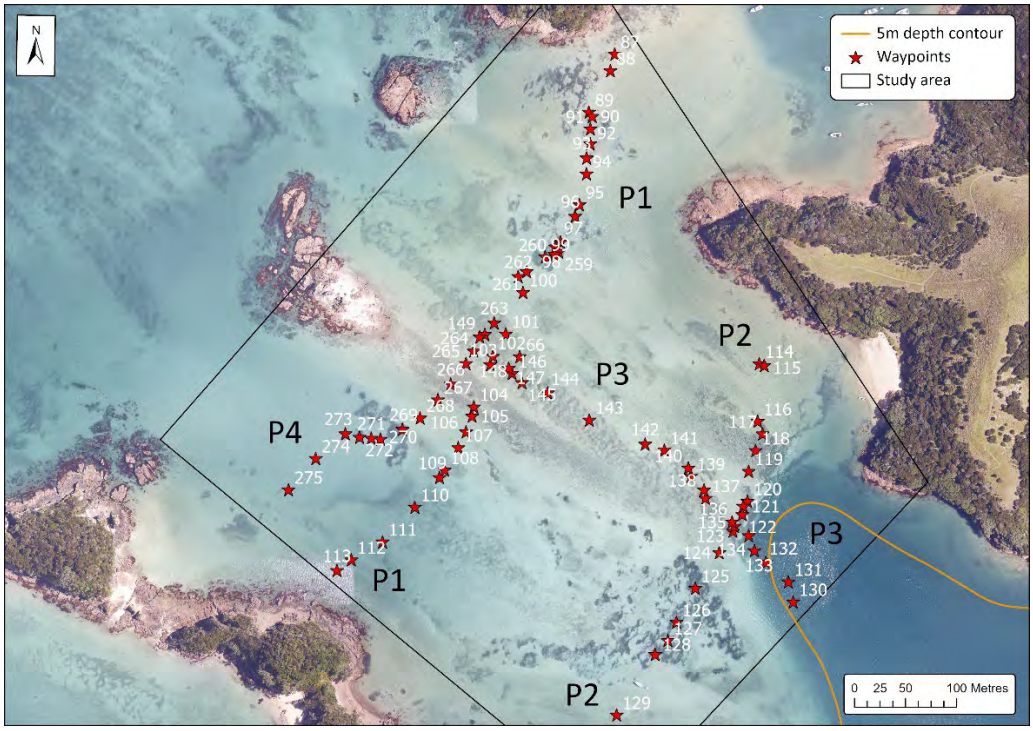
A1.1 Poroporo Channel



Video-camera transects and indicative distribution of the putative seagrass (green) and algal-turf (red) biomes, and reef (black), to 5 m depth, Poroporo Channel, 2020.



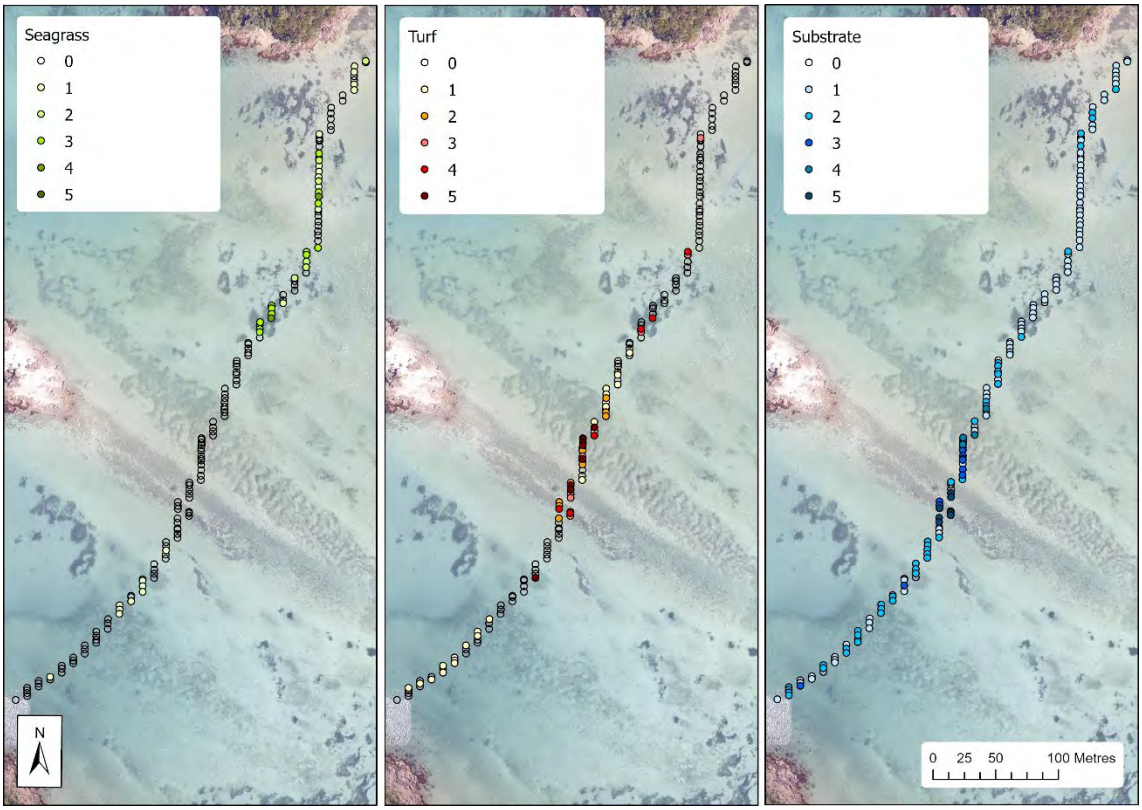
Multibeam Chart Datum depths and depth contours, Poroporo Channel, 2020.



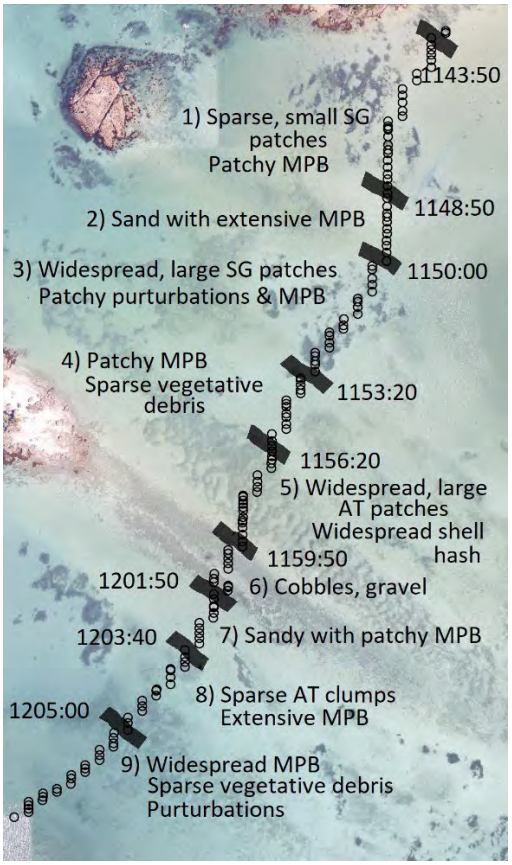
Poroporo Channel waypoints, 2020.

Transect P1

Transect P1 (625 m long; Waypoints 87–113) traverses the northwestern part of Poroporo Channel. It progresses south from water depths of 0.5 m down to 2.1 m before shoaling to 1.1 m, and then deepening again, to 3.3 m. Drop-camera imagery was at Waypoints 93, 95, 99, 103, & 107.



Characterisation of Transect P1 based on 10-second video imagery.



Overall characterisation by section of Transect P1. Times given are from video frames.

Representative imagery for P1

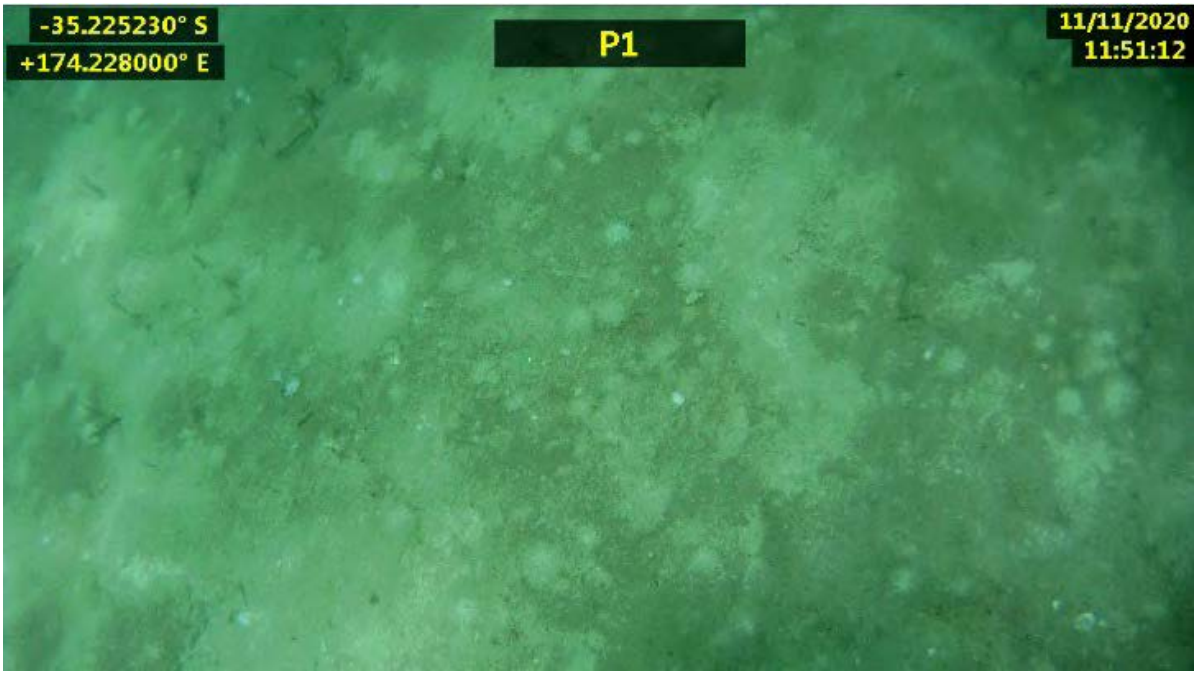
Section 1



Characterising imagery for Section 1 of Transect P1 (MPB).

Section 3





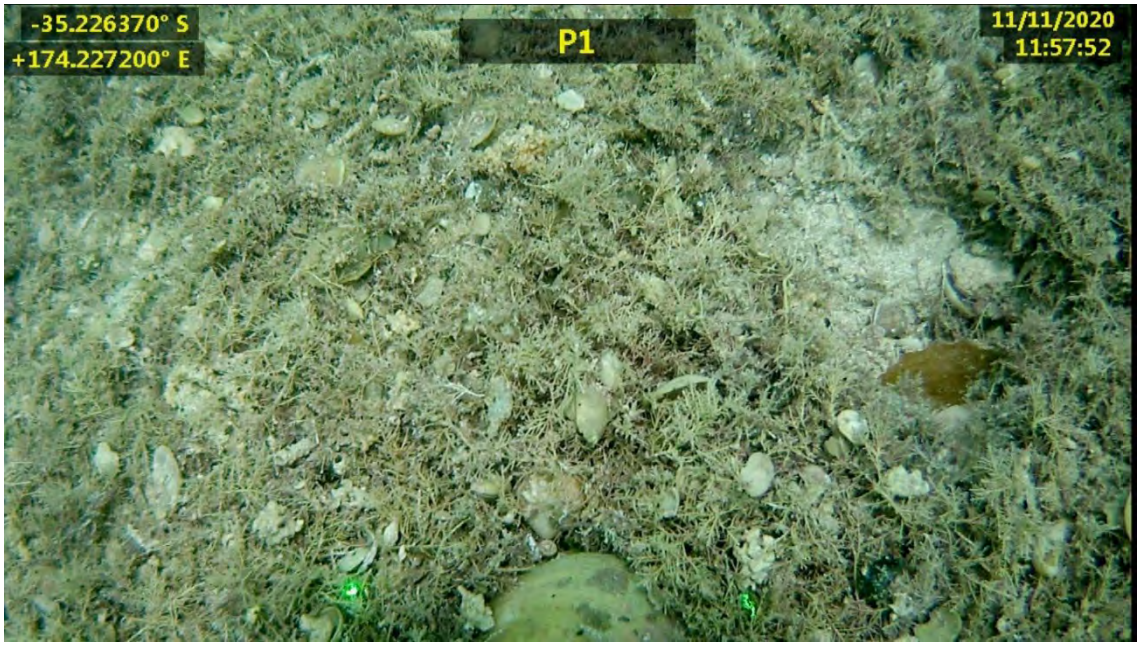
Characterising imagery for Section 3 of Transect P1 (seagrass, perturbations, MPB).

Section 4



Characterising imagery for Section 4 of Transect P1 (MPB, vegetative debris).

Section 5

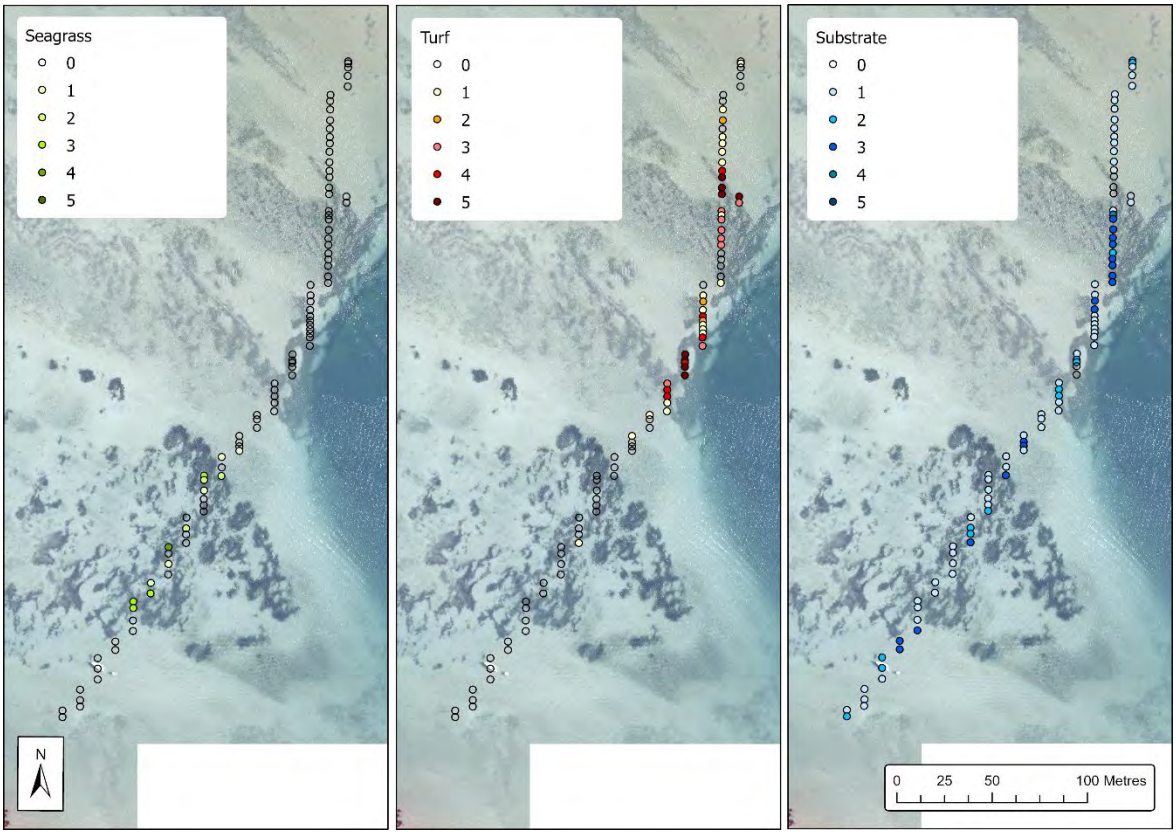




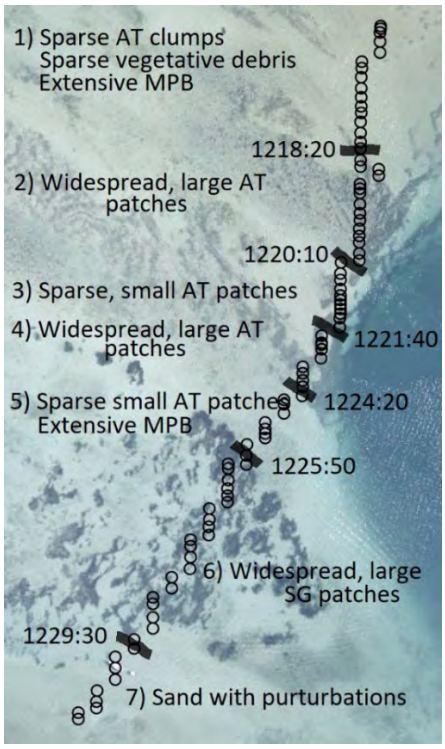
Characterising imagery for Section 5 of Transect P1 (algal turf, vegetative debris, shell hash).

Transect P2

Transect P2 (500 m long; Waypoints 114–129) traverses from the north the southeast part of the channel. It starts in 1.5 m of water and shelves to 2.1 m. There was drop-camera imagery at Waypoints 116, 117, 120, 122, 125, and 128.



Characterisation of Transect P2 based on 10-second video imagery.



Overall characterisation by section of Transect P2. Times given are from video frames.

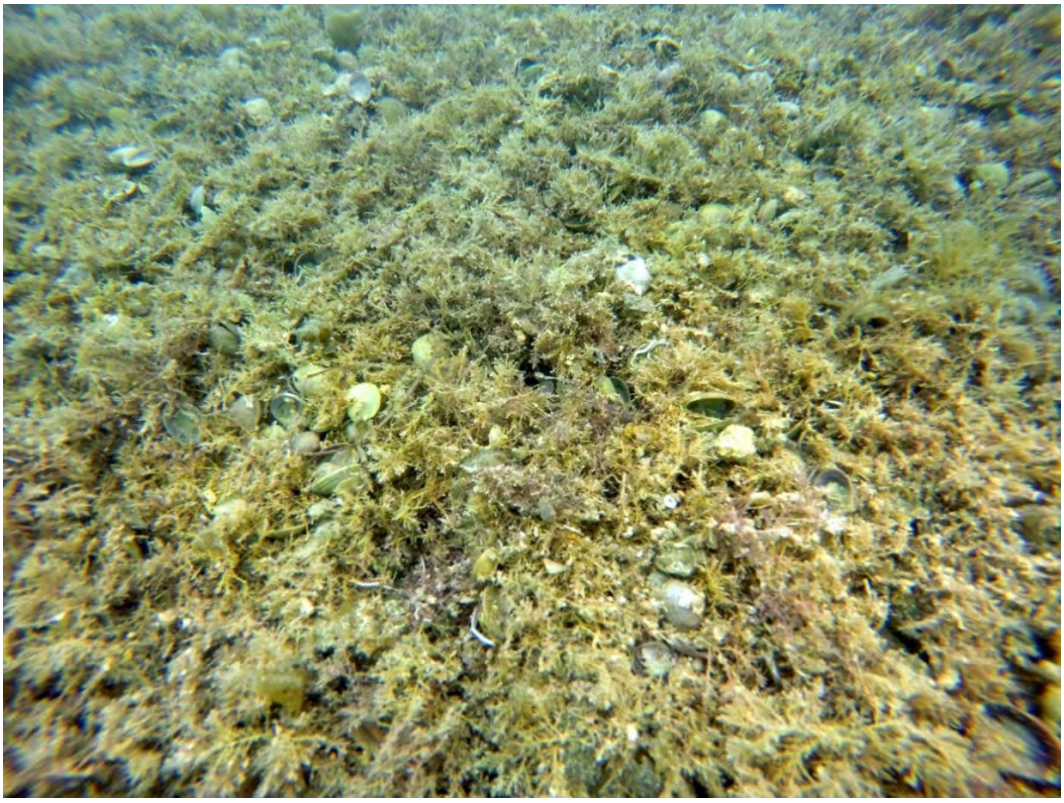
Representative imagery for P2

Section 1



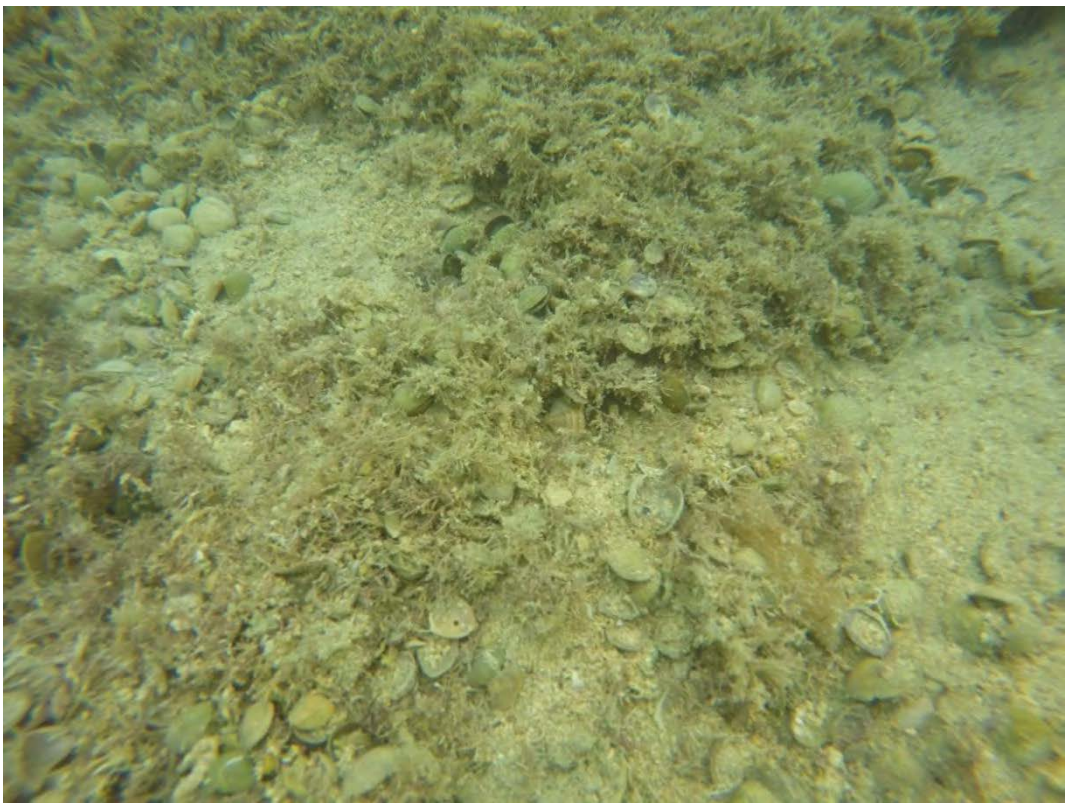
Characterising imagery for Section 1 of Transect P2 (algal turf).

Section 2



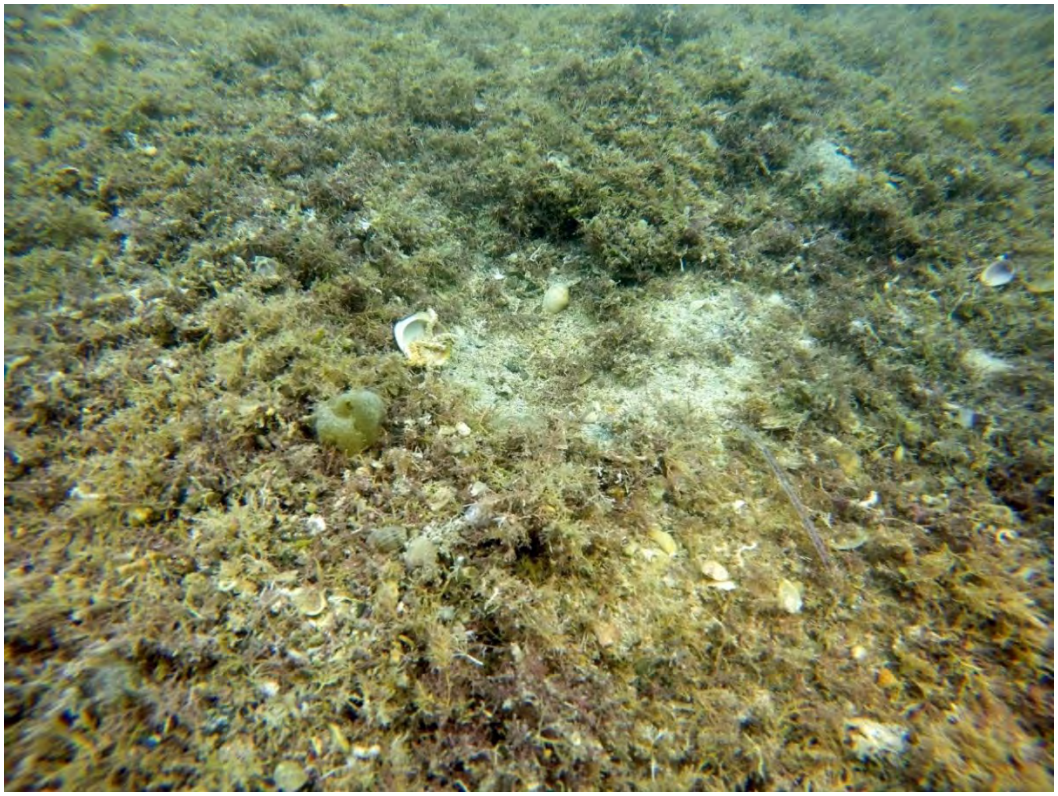
Characterising imagery for Section 2 of Transect P2 (algal turf).

Section 3



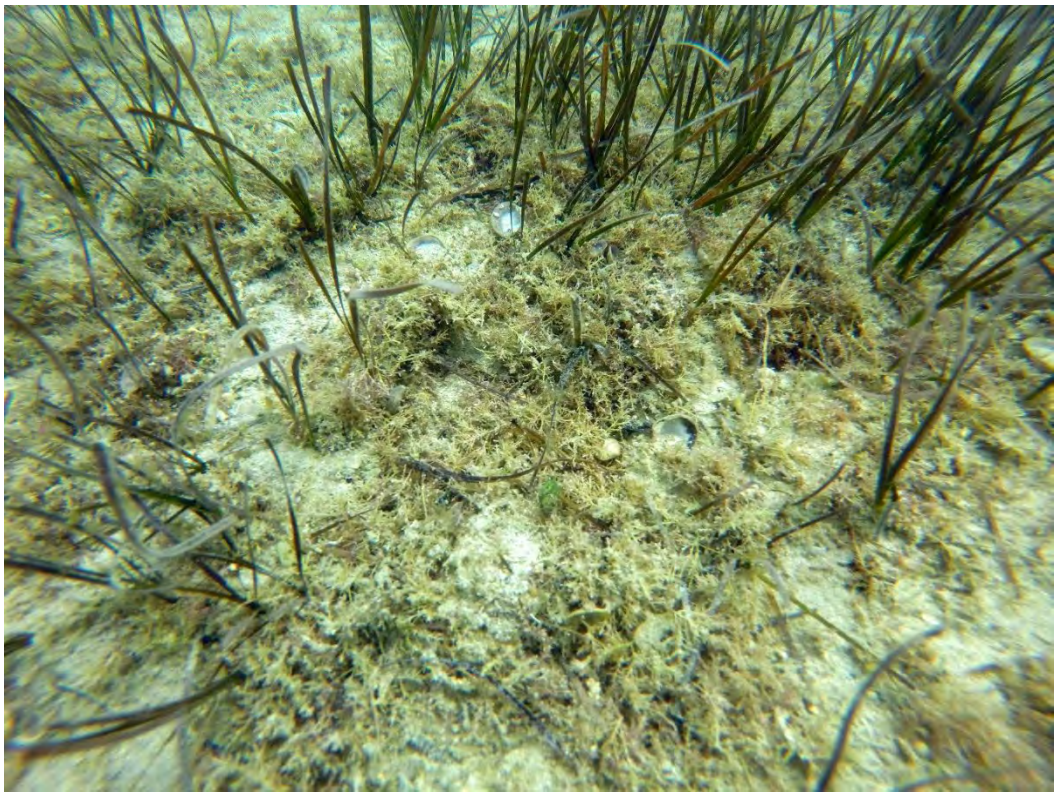
Characterising imagery for Section 3 of Transect P2 (algal turf, shell hash).

Section 4



Characterising imagery for Section 4 of Transect P2 (algal turf).

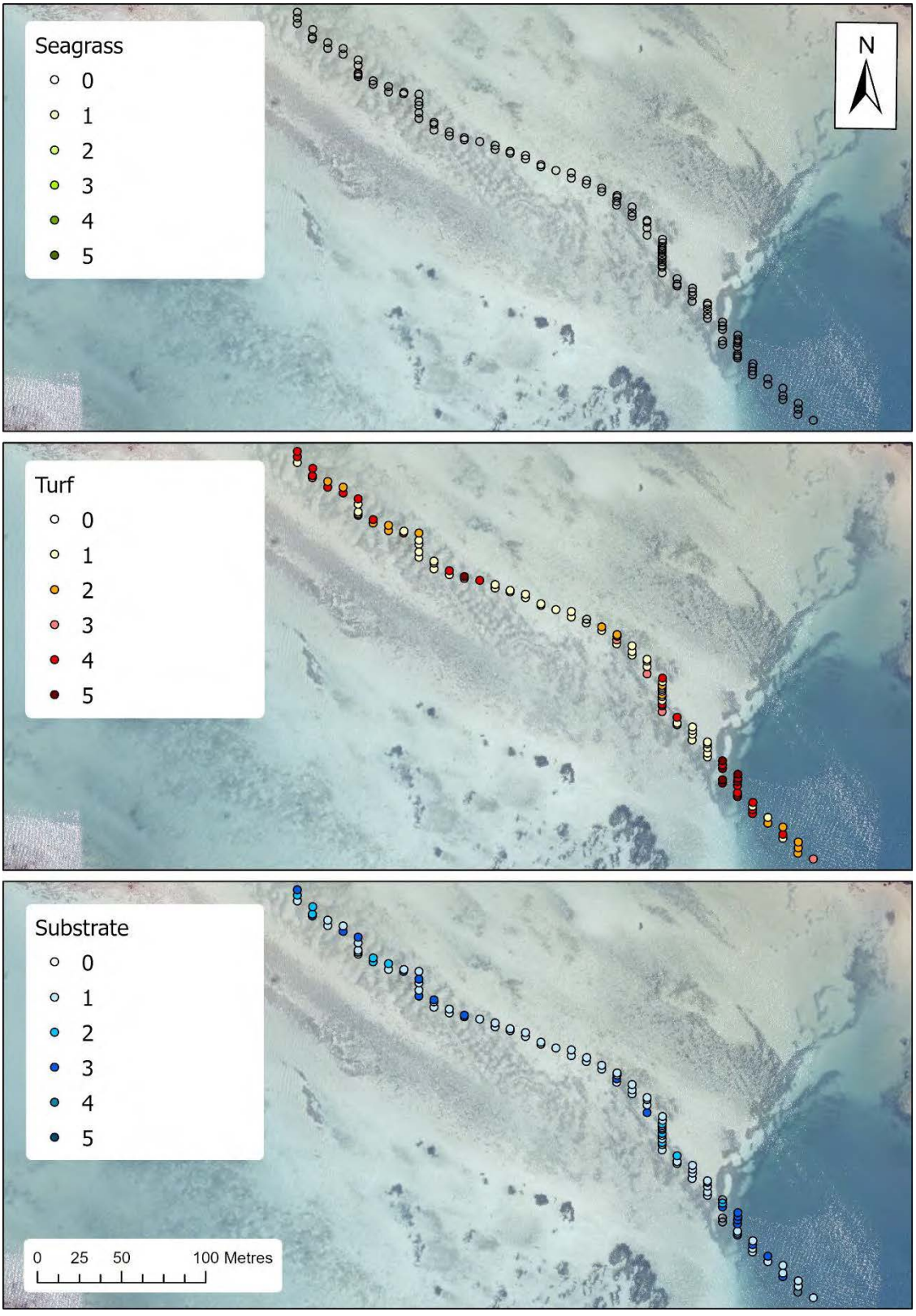
Section 6



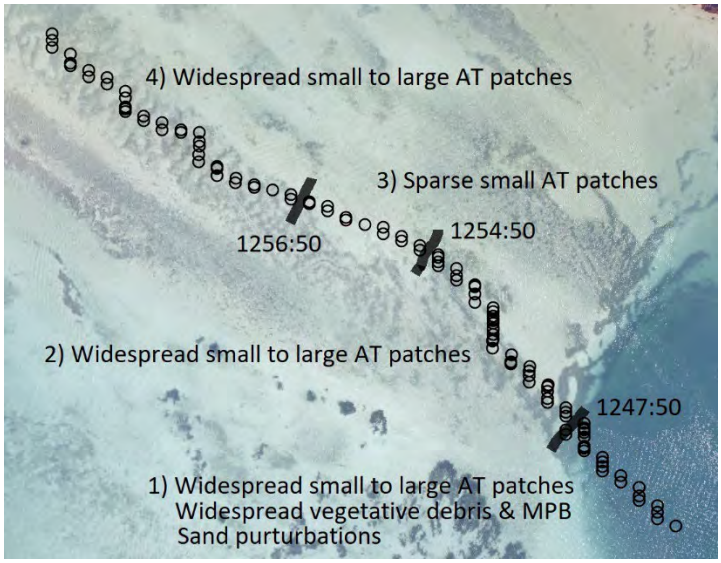
Characterising imagery for Section 6 of Transect P2 (seagrass, algal turf).

Transect P3

Transect P3 (460 m long; Waypoints 130–149) bisects the channel from the southeast, shallowing rapidly from water depths of 6.7 to 2.5 m before shoaling to 1.3 m. There was no drop-camera imagery.



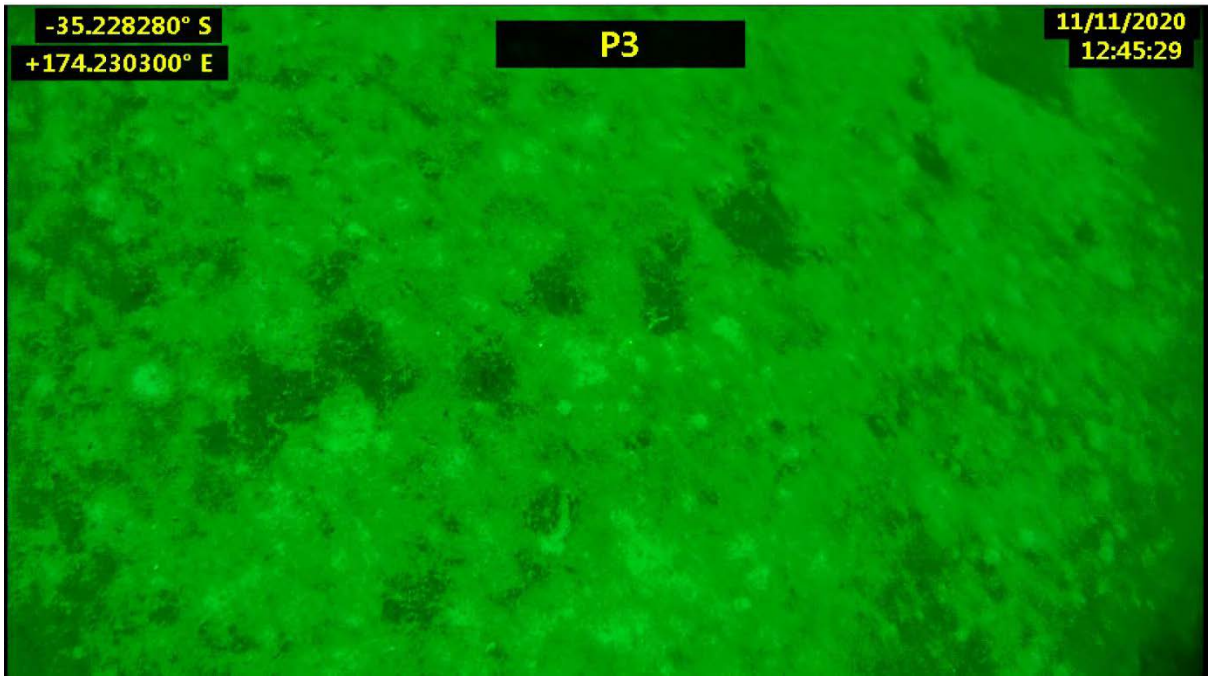
Characterisation of Transect P3 based on 10-second video imagery.



Overall characterisation by section of Transect P3. Times given are from video frames.

Representative imagery for P3

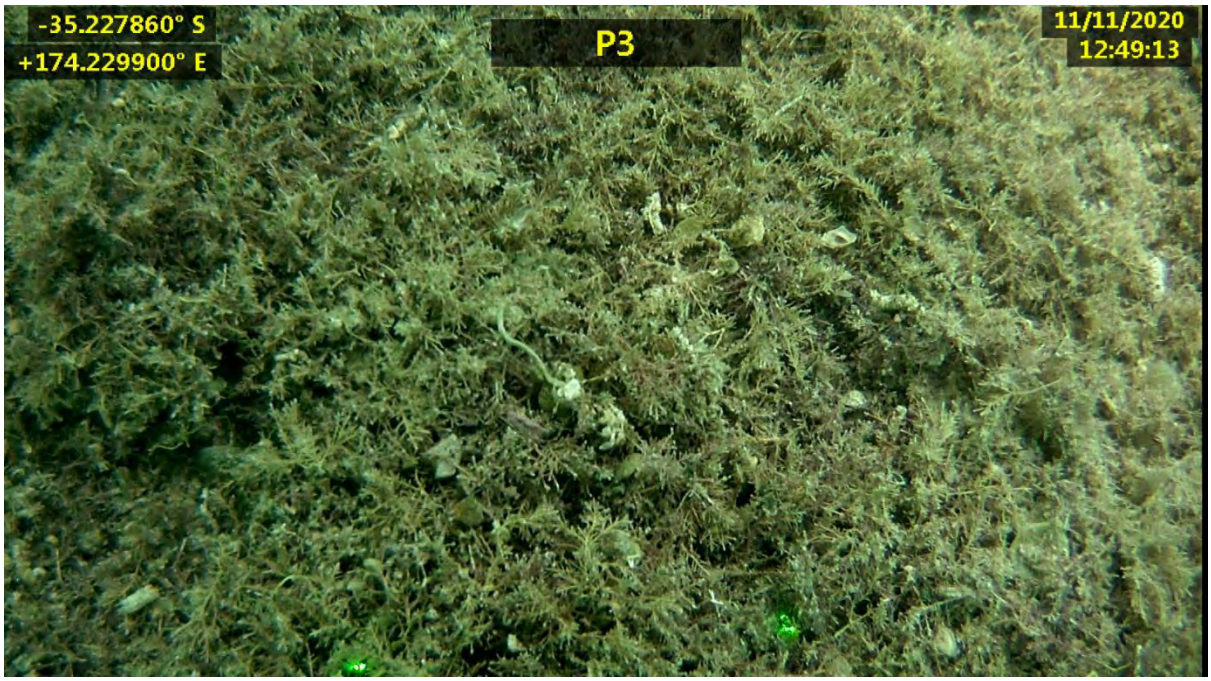
Section 1





Characterising imagery for Section 1 of Transect P3 (vegetative debris, perturbations, MPB, algal turf).

Section 2



Characterising imagery for Section 2 of Transect P3 (algal turf).

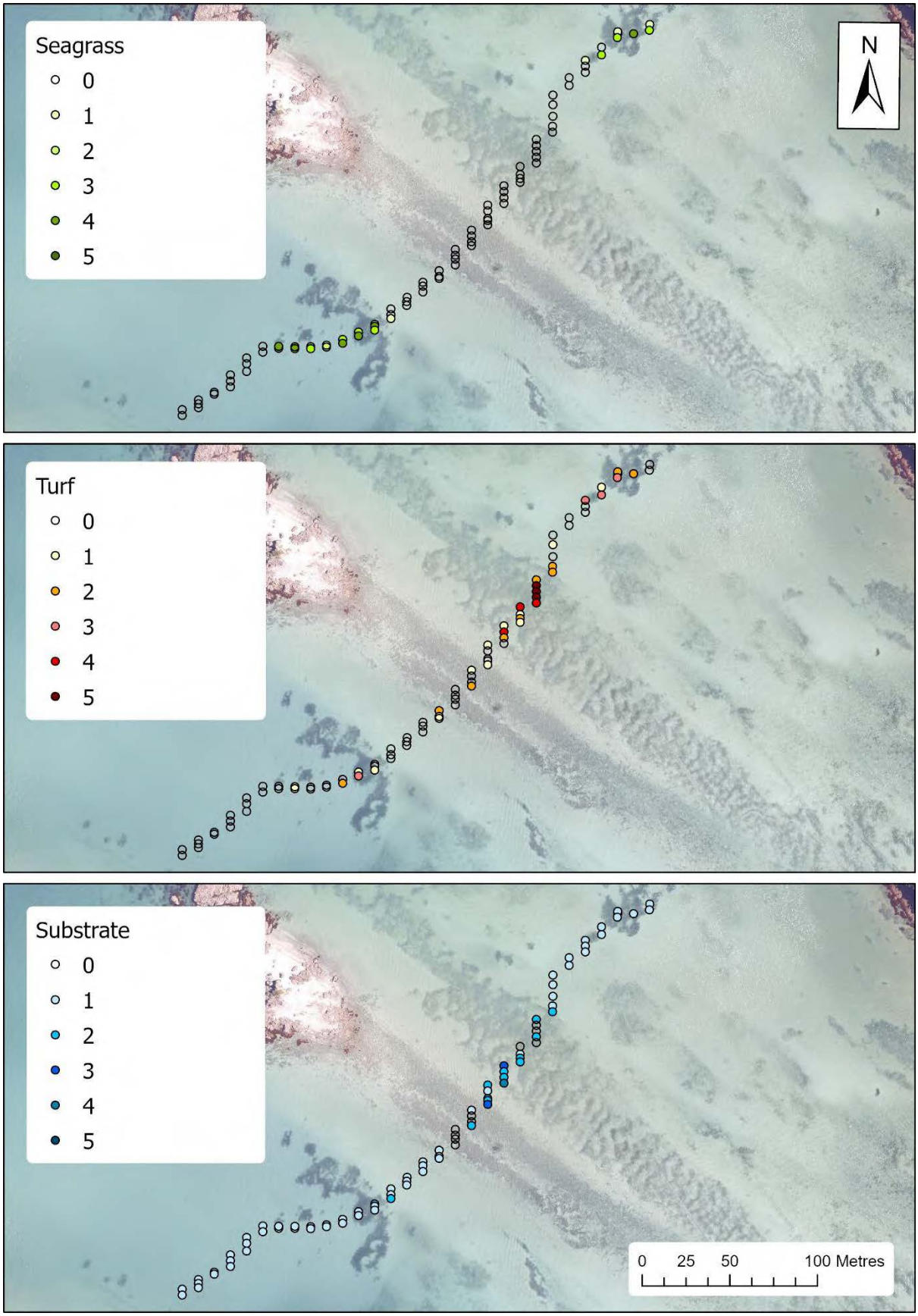
Section 4



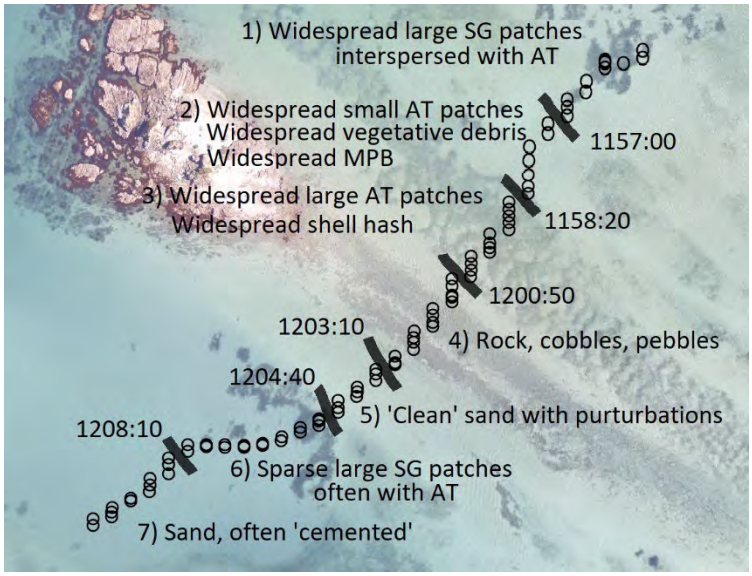
Characterising imagery for Section 4 of Transect P3 (algal turf).

Transect P4

Transect P4 (390 m long; Waypoints 259–275) traverses southwestward the northwestern part of Poroporo Channel from its intersection with Transect P1. It deepens from depths of 2.3 m to 3.3 m. There was drop-camera imagery at Waypoints 260, 264, 270, and 274.



Characterisation of Transect P4 based on 10-second video imagery.

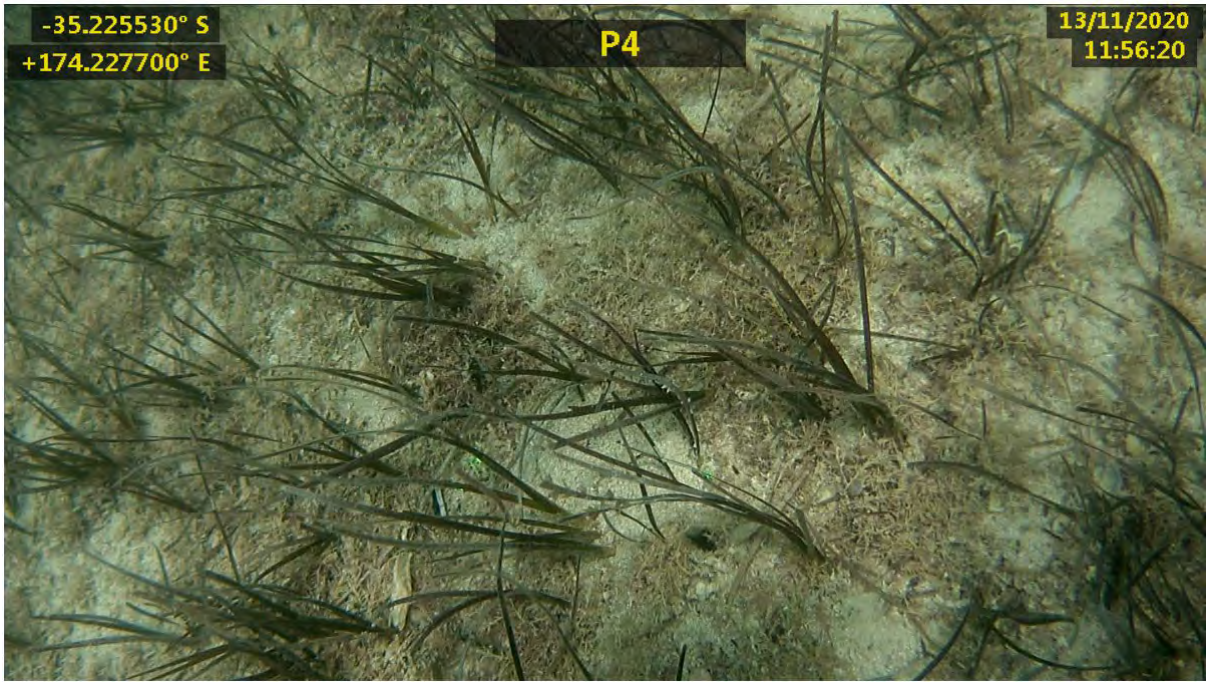


Overall characterisation by section of Transect P4. Times given are from video frames.

Representative imagery for P4

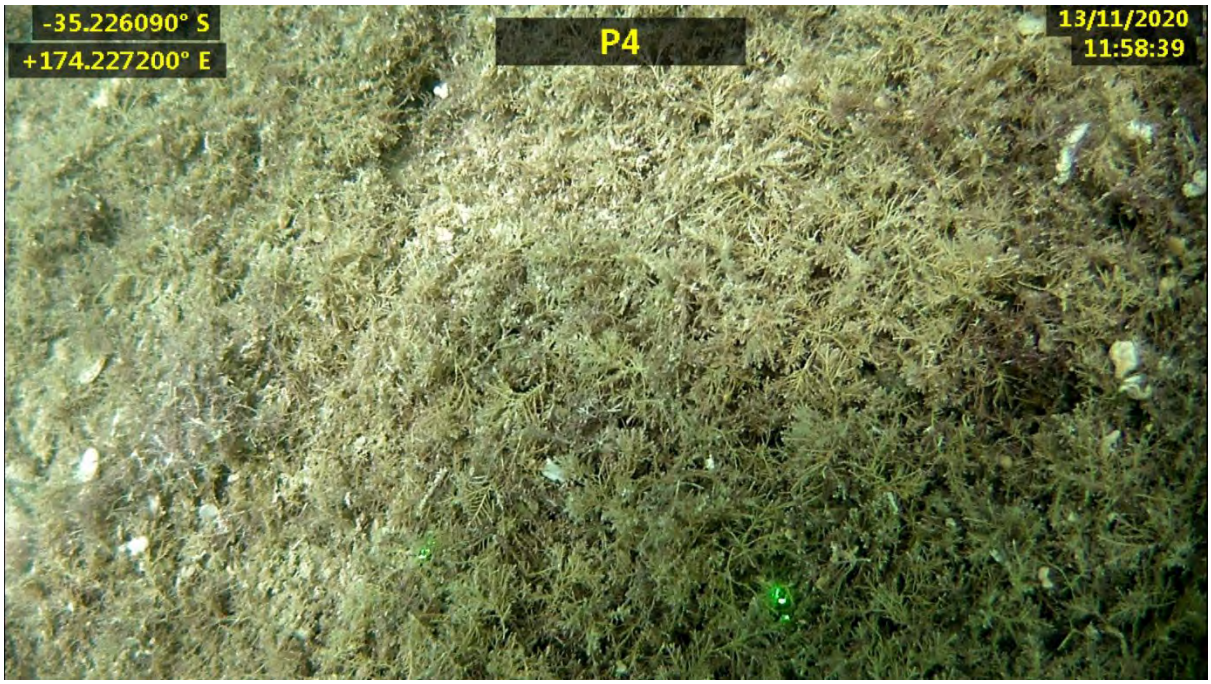
Section 1

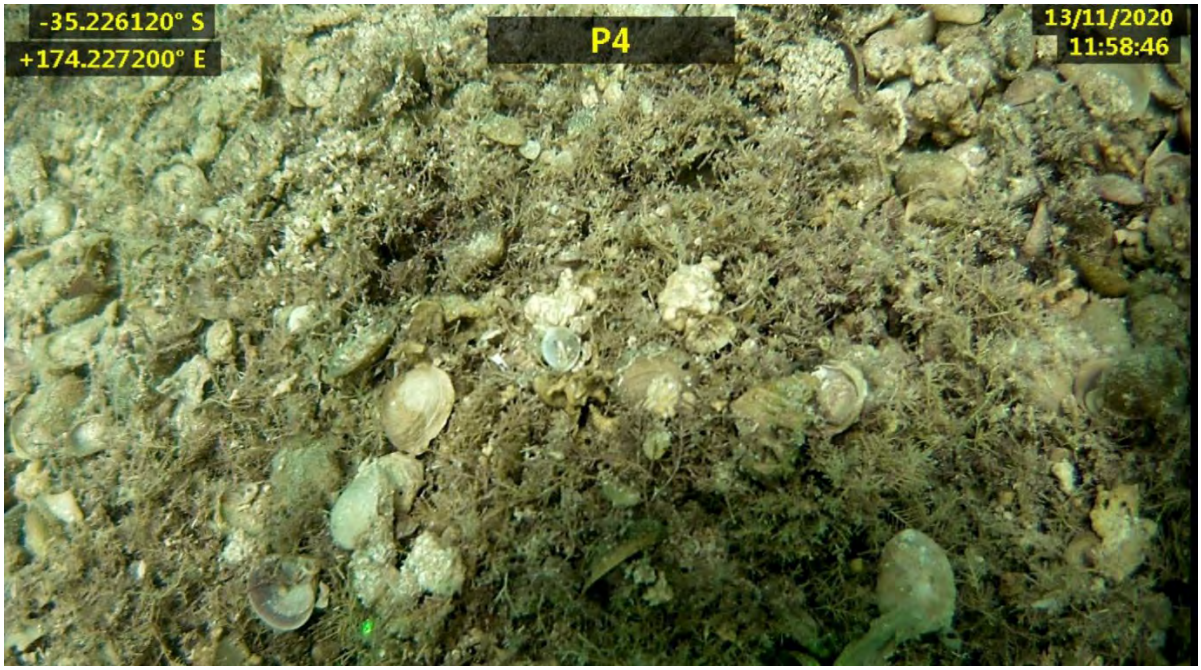




Characterising imagery for Section 1 of Transect P4 (seagrass, algal turf).

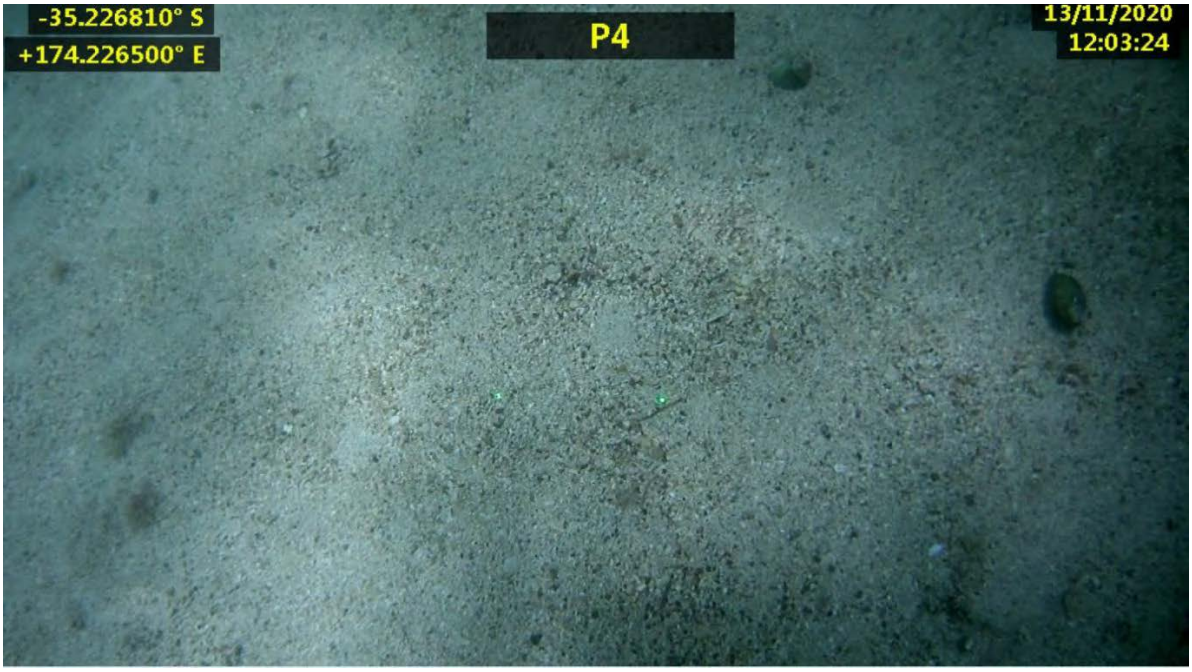
Section 3

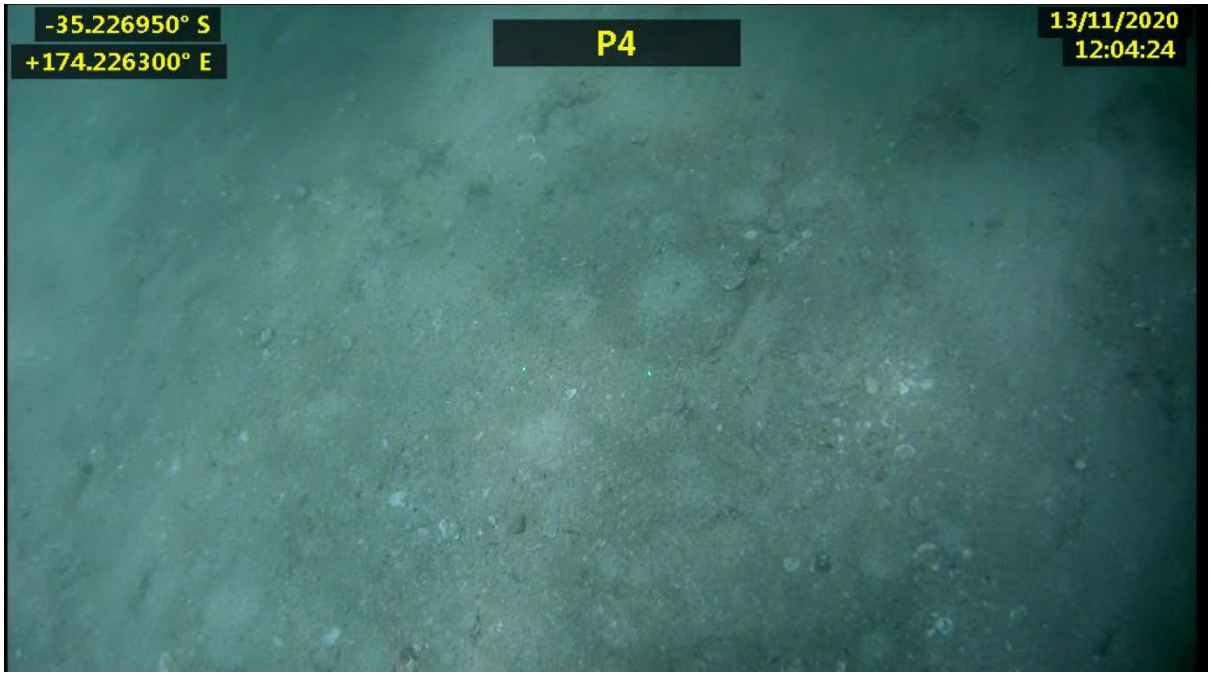




Characterising imagery for Section 3 of Transect P4 (algal turf, shell hash).

Section 5





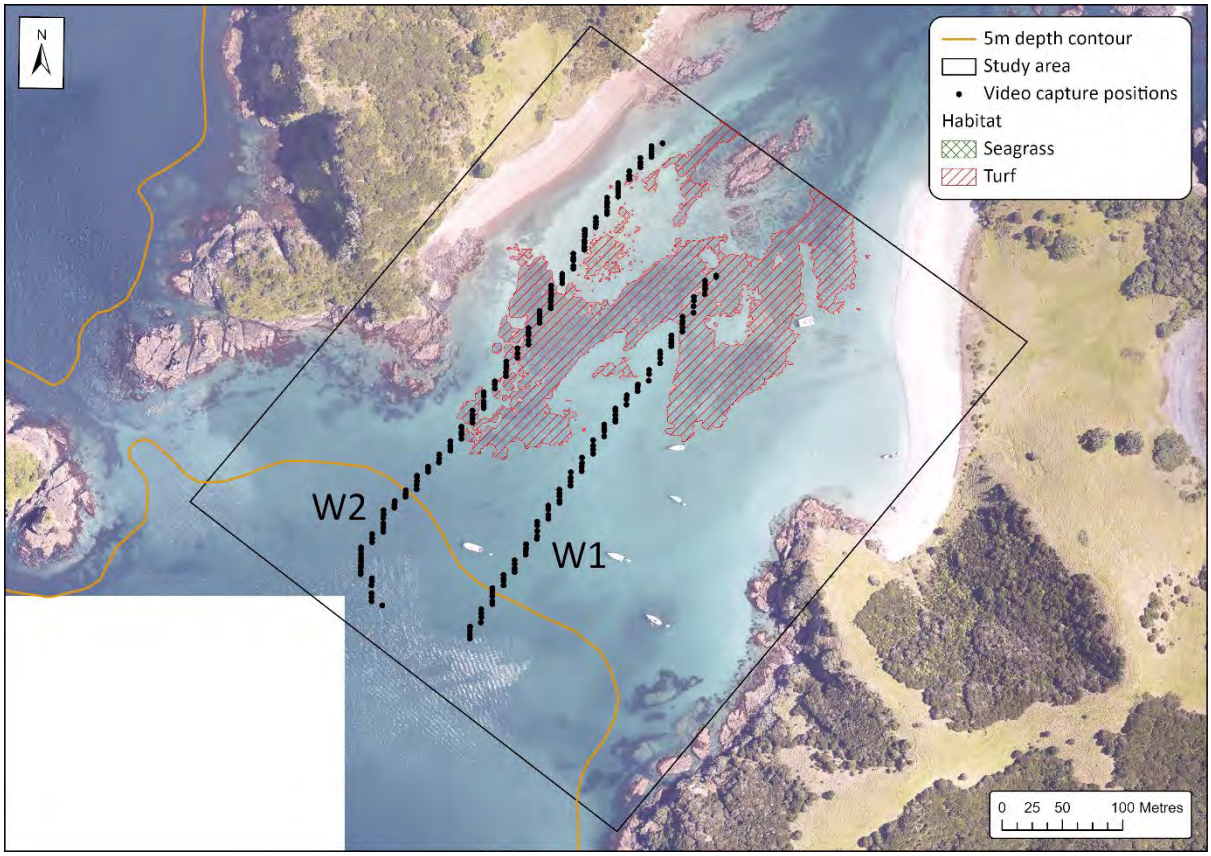
Characterising imagery for Section 5 of Transect P4 (‘clean’ sand, pertubations).

Section 7

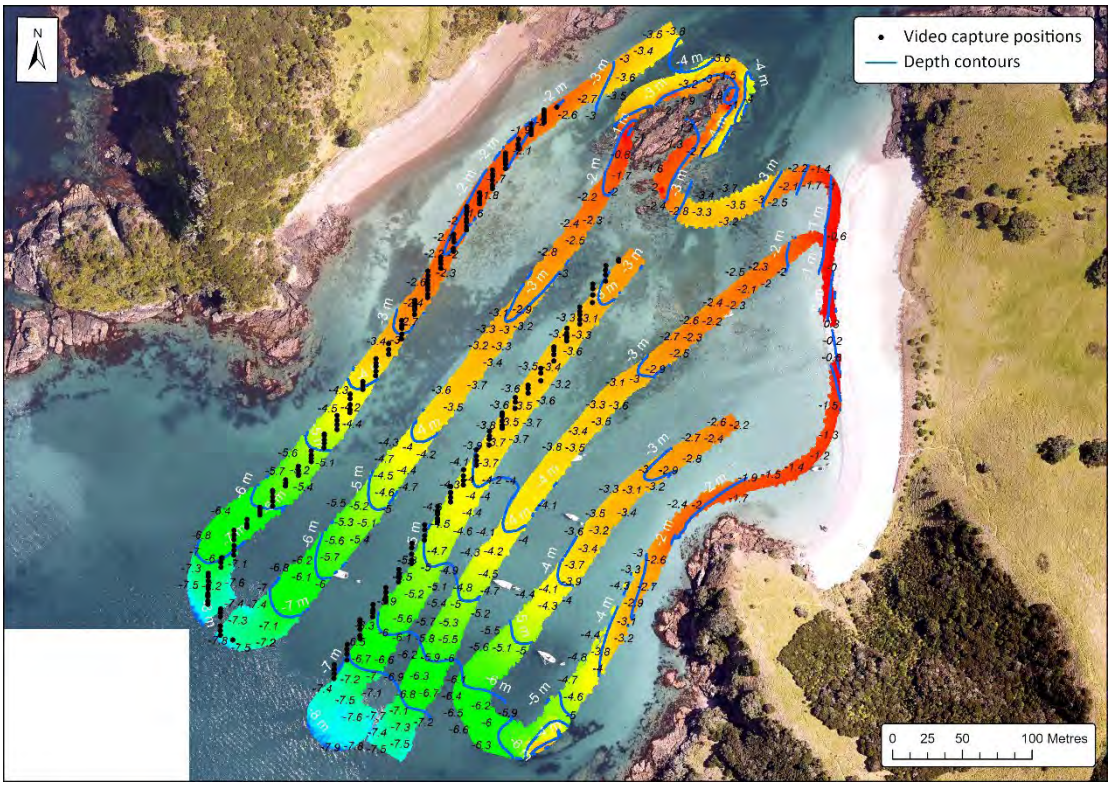


Characterising imagery for Section 7 of Transect P4 (sand, MPB).

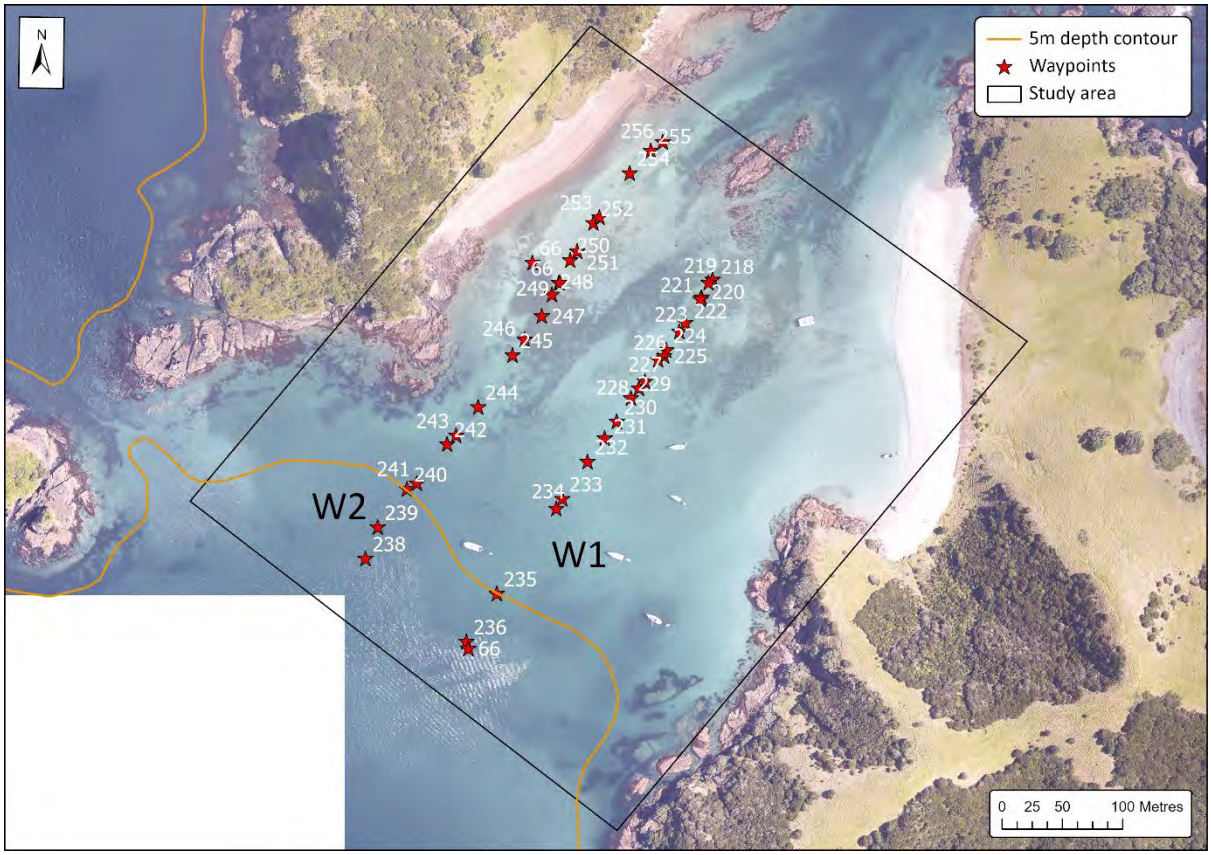
A1.2 Okahu Passage



Video-camera transects and indicative distribution of putative algal-turf biome (red), to 5 m depth, Okahu Passage, 2020.



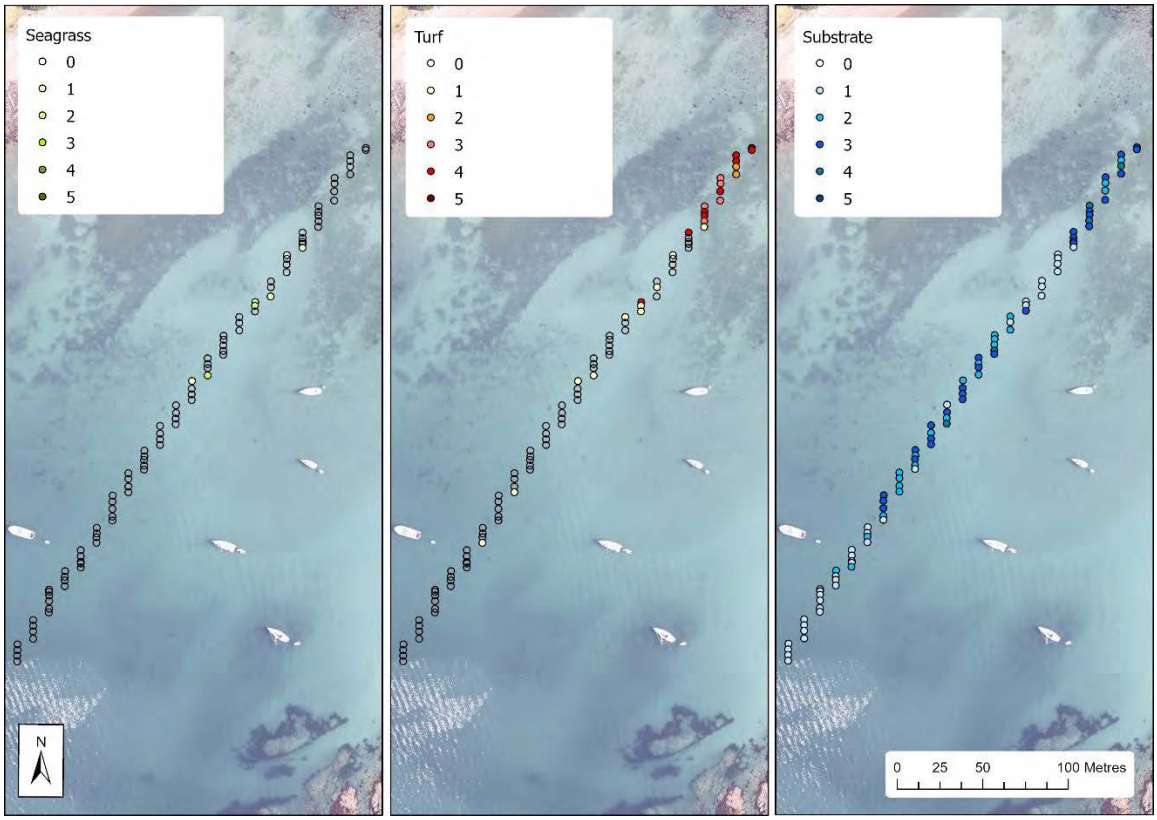
Multibeam Chart Datum depths and depth contours, Okahu Passage, 2020.



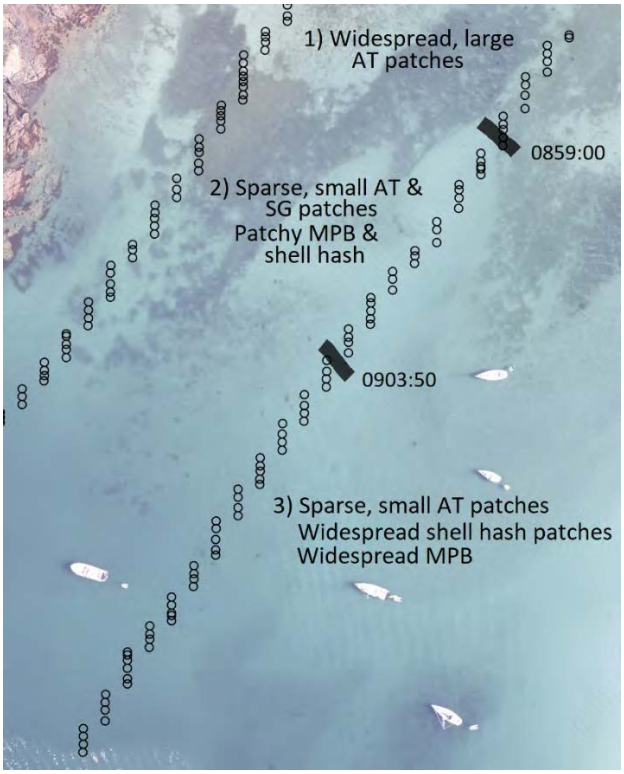
Okahu Passage waypoints, 2020.

Transect W1

Transect W1 is the right-hand (southeastern), 360-m long, transect between Okahu and Waewaetorea islands (Waypoints 218–236). The water deepens gradually from 2.6 to 5.5 m, before falling off to 7.4 m. There was no drop-camera imagery.



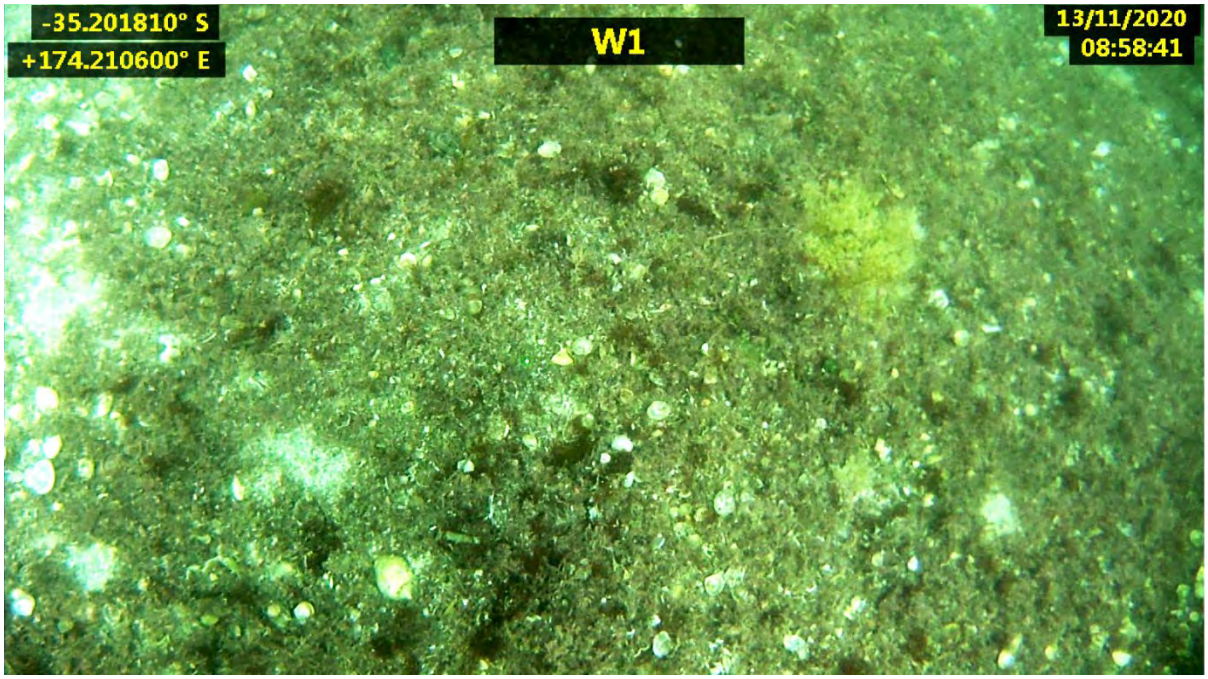
Characterisation of Transect W1 based on 10-second video imagery.



Overall characterisation by section of Transect W1. Times given are from video frames.

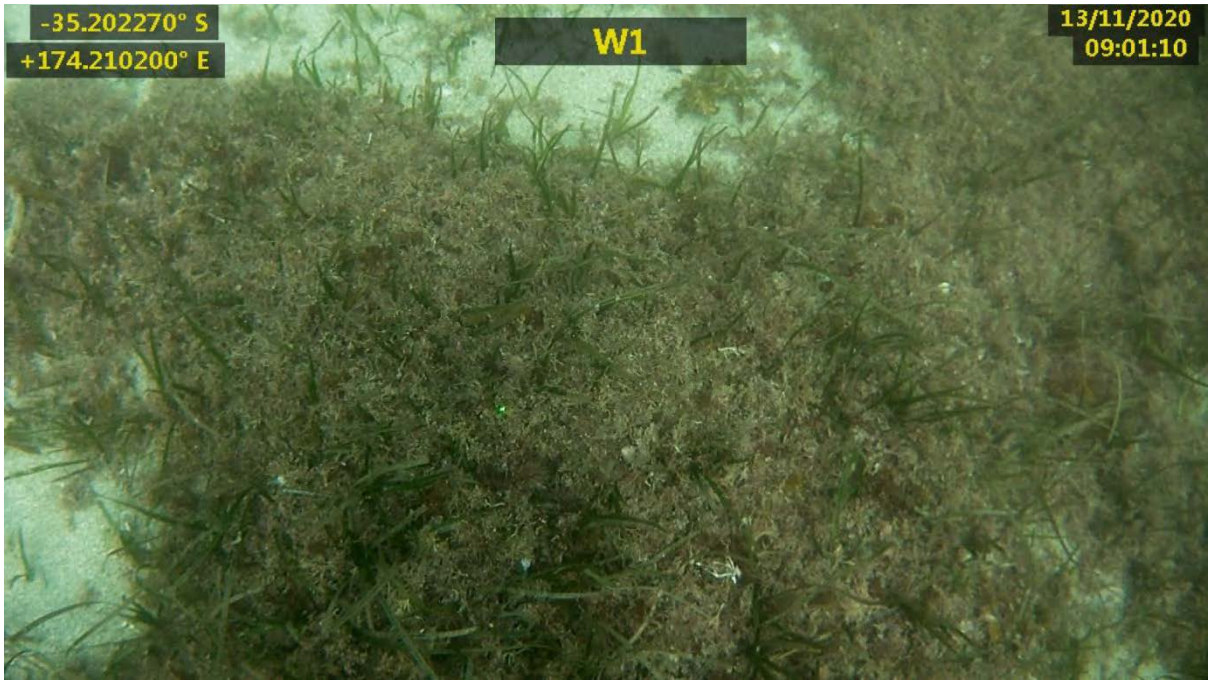
Representative imagery for W1

Section 1

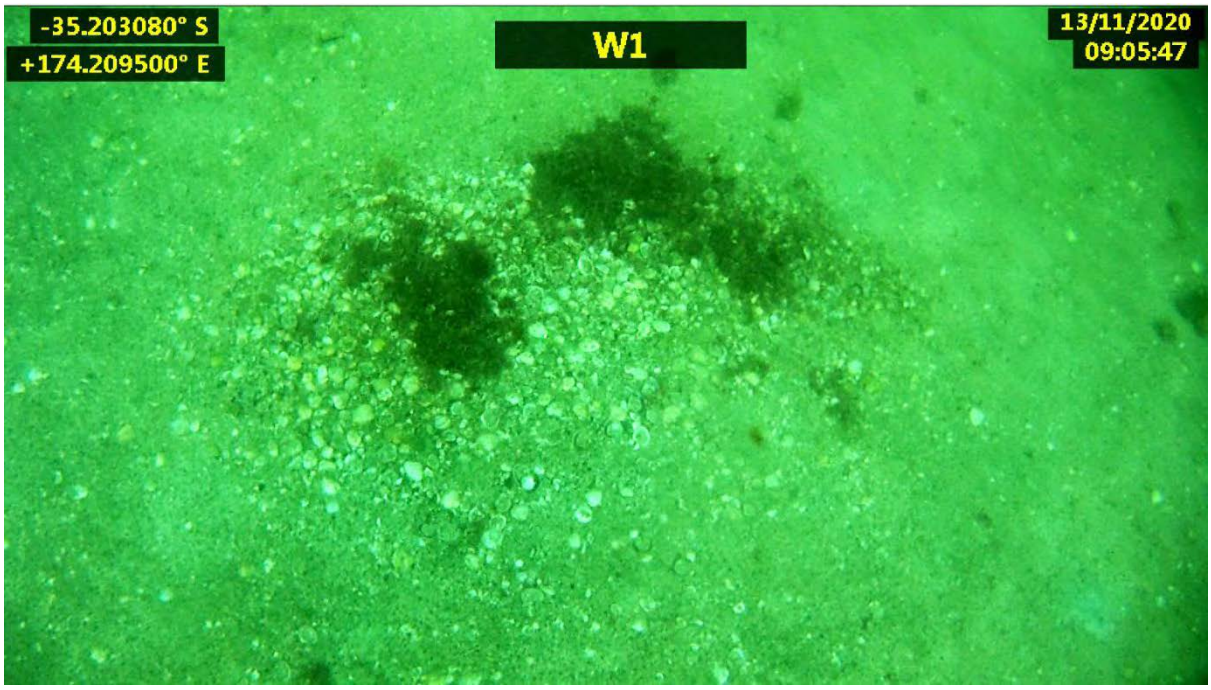


Characterising imagery for Section 1 of Transect W1 (algal turf).

Section 2



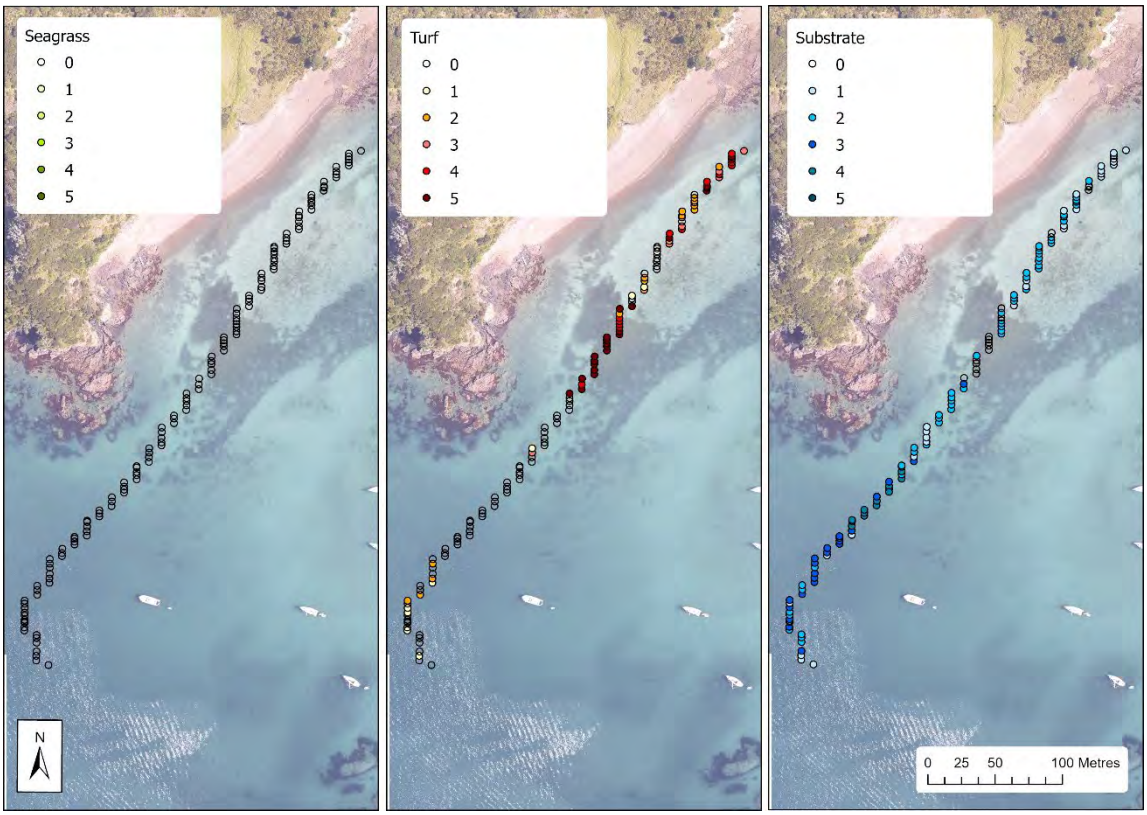
Characterising imagery for Section 2 of Transect W1 (algal turf, seagrass).



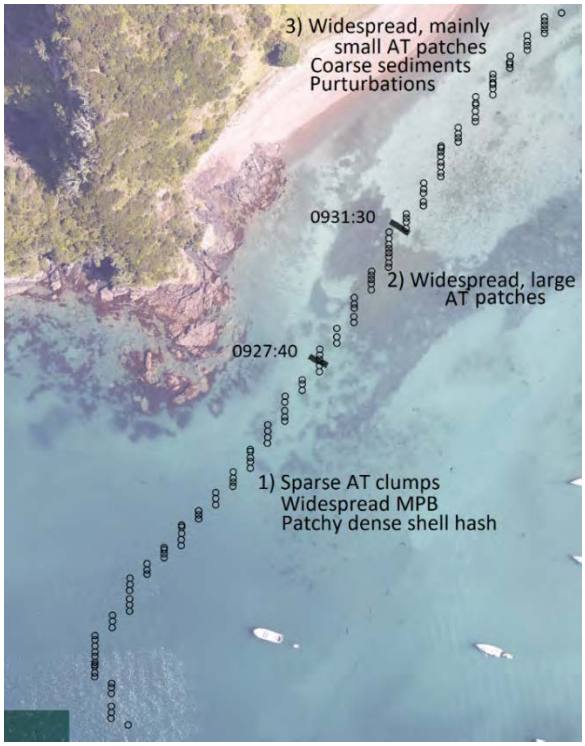
Characterising imagery for Section 3 of Transect W1 (algal turf, shell hash, MPB).

Transect W2

Transect W2 is the northwestern, 490-m long, transect (Waypoints 238–255). Water depths shallow rapidly from 7.6 to 2.7 m before shoaling to 1.6 m and then deepening slightly to 2.2 m. There was drop-camera imagery at 247, 249, 250, 253–255, and 258.



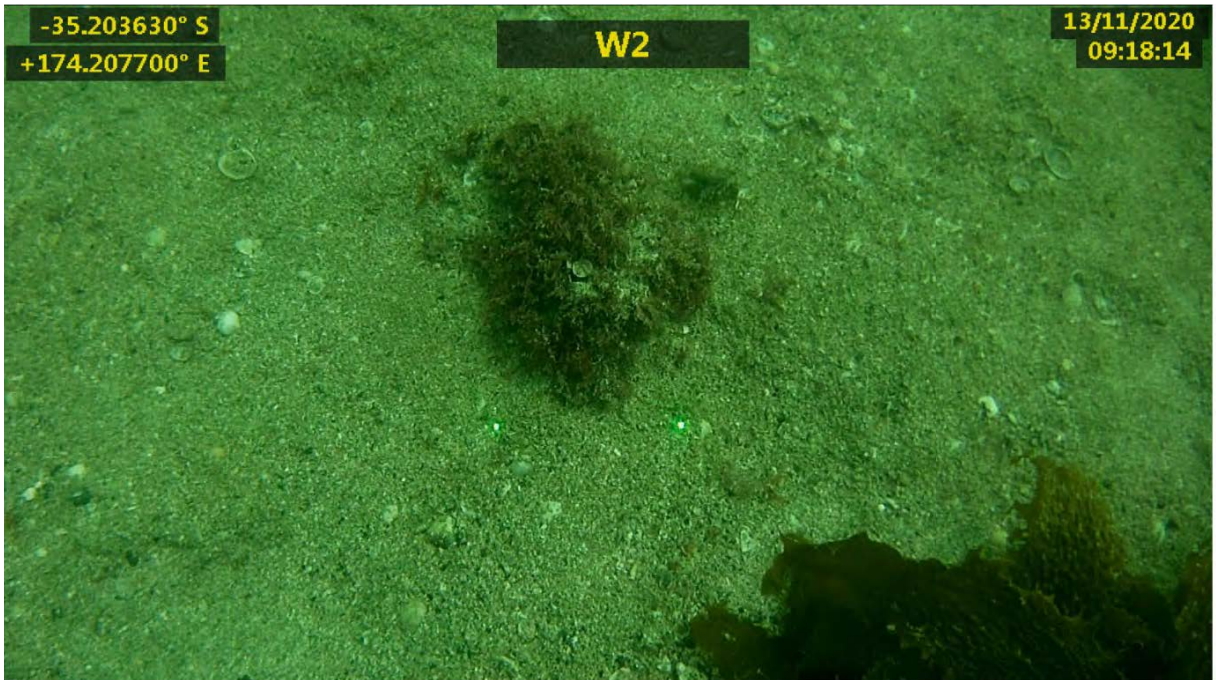
Characterisation of Transect W2 based on 10-second video imagery.

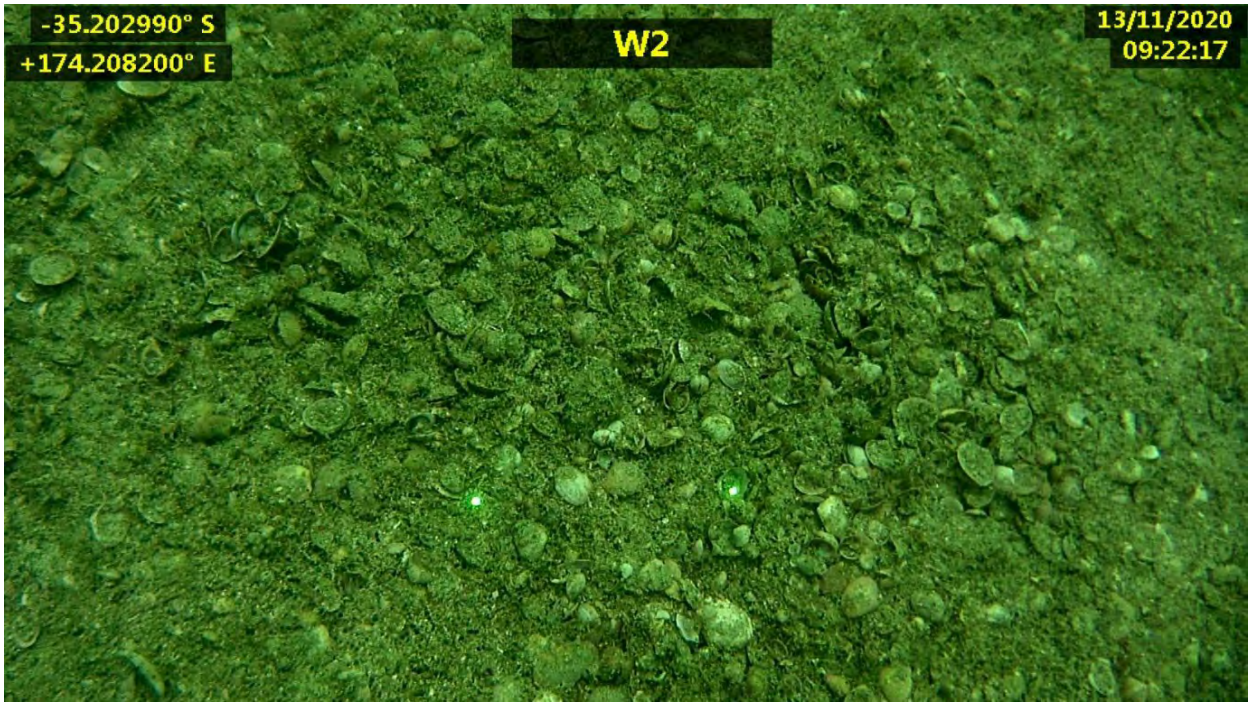


Overall characterisation by section of Transect W2. Times given are from video frames.

Representative imagery for W2

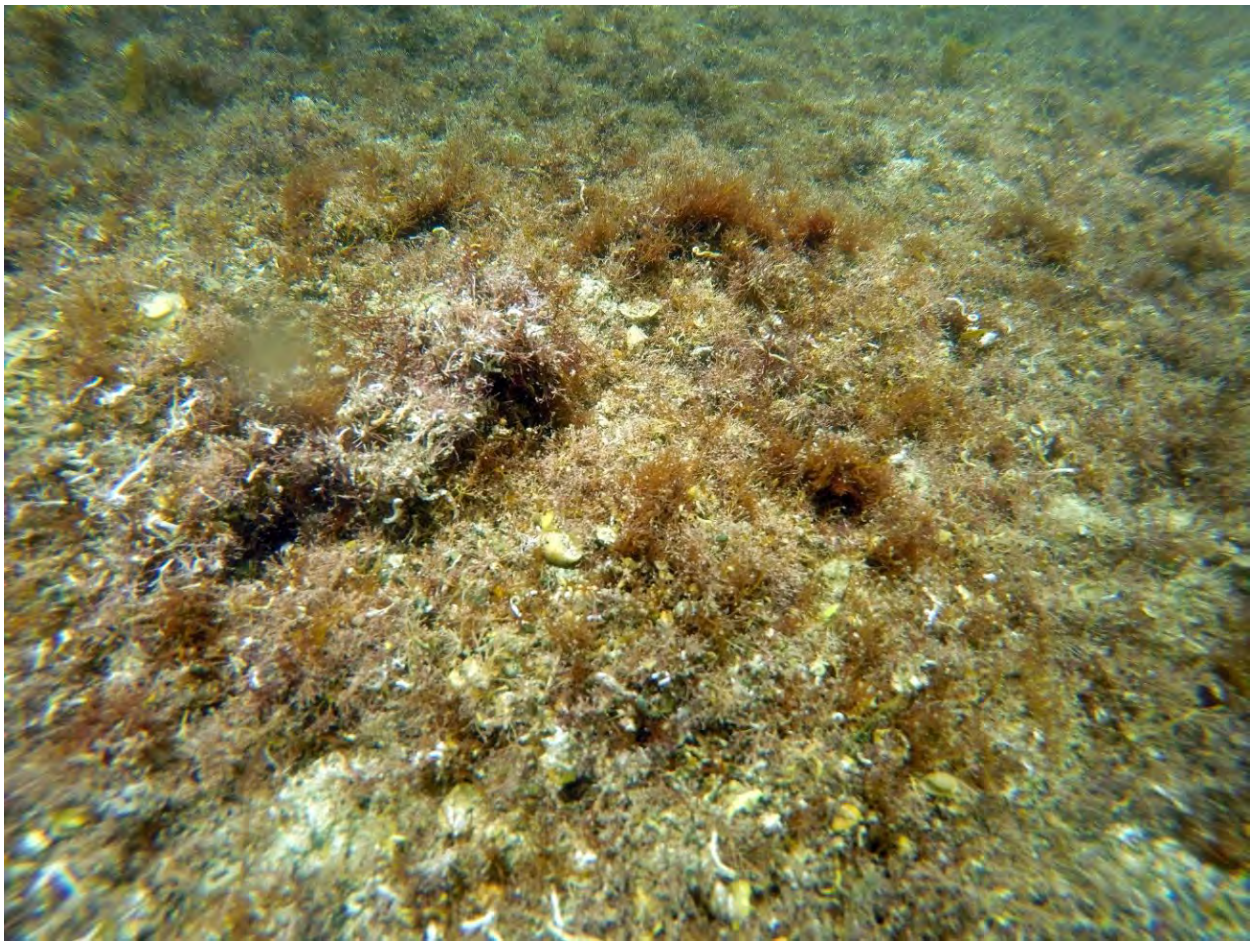
Section 1





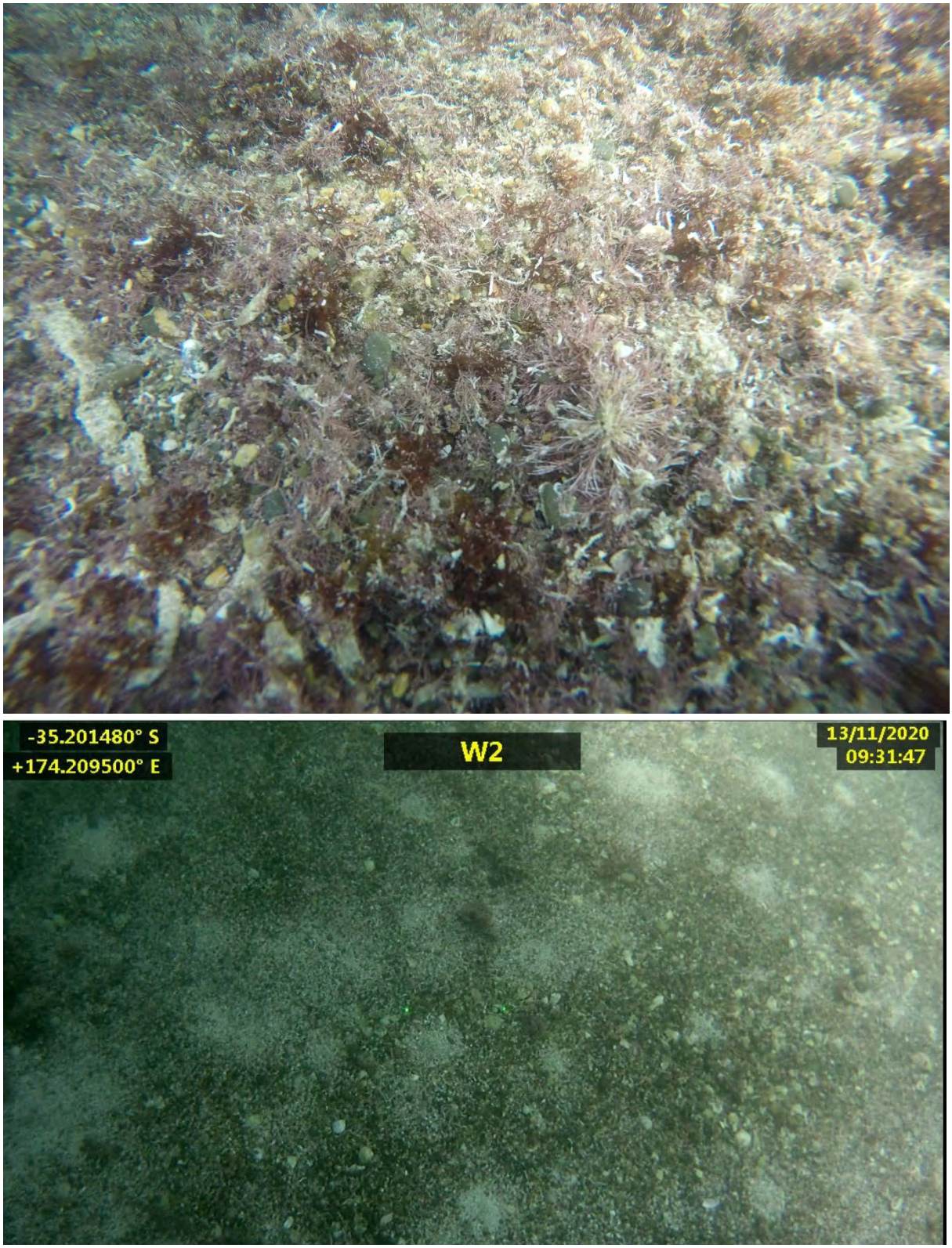
Characterising imagery for Section 1 of Transect W2 (algal turf, shell hash).

Section 2



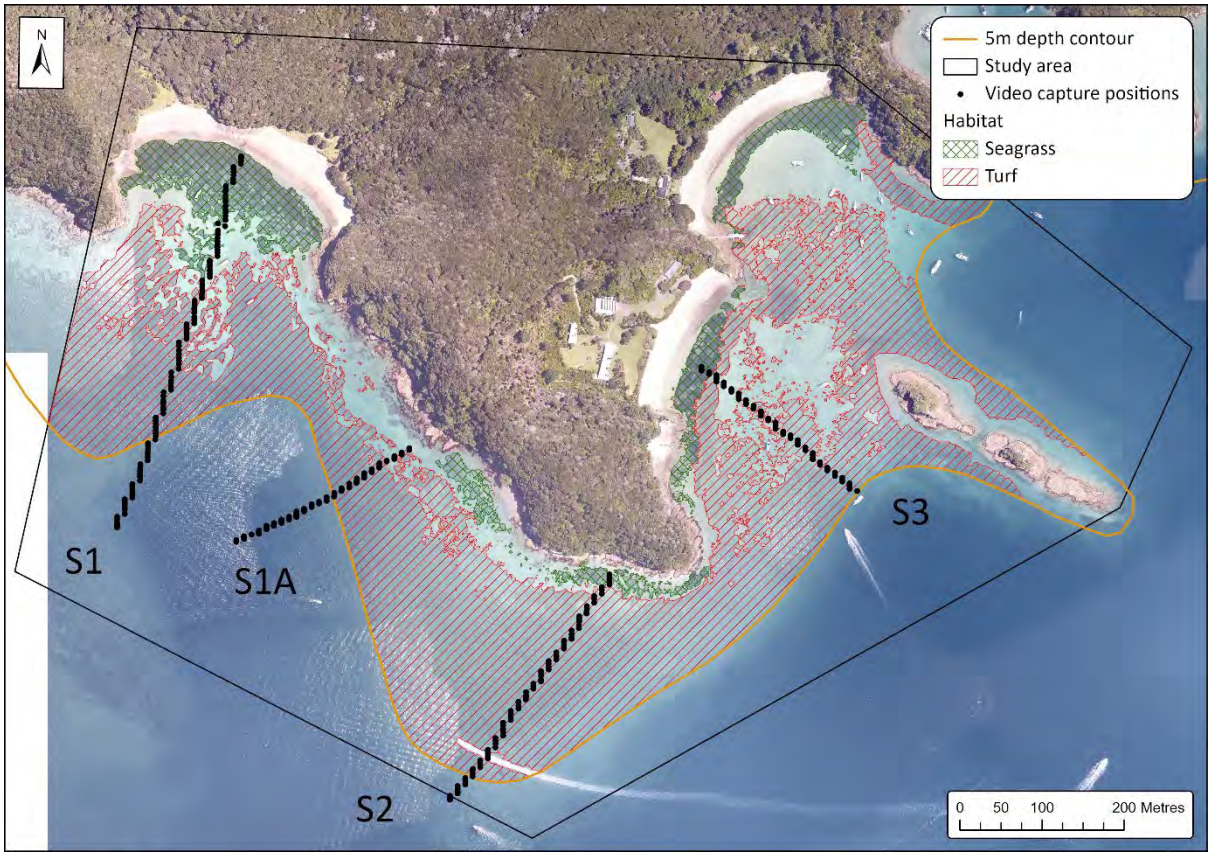
Characterising imagery for Section 2 of Transect W2 (algal turf).

Section 3

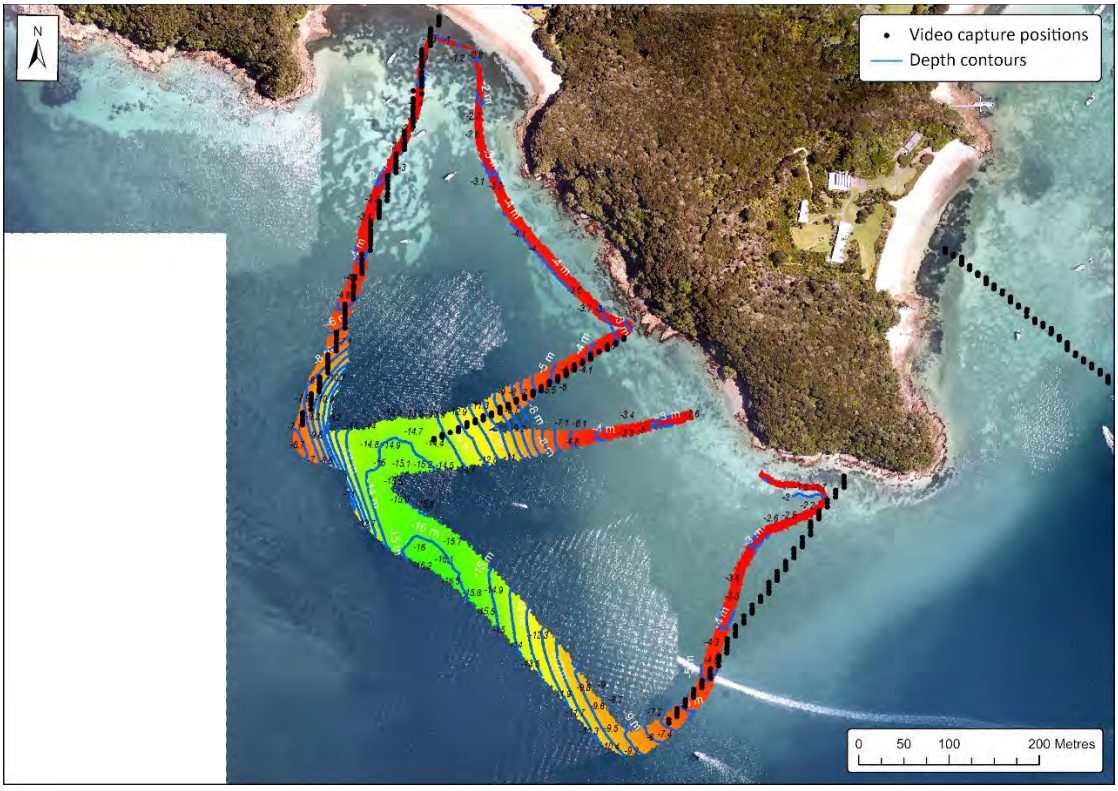


Characterising imagery for Section 3 of Transect W2 (coarse sediments, algal turf, perturbations).

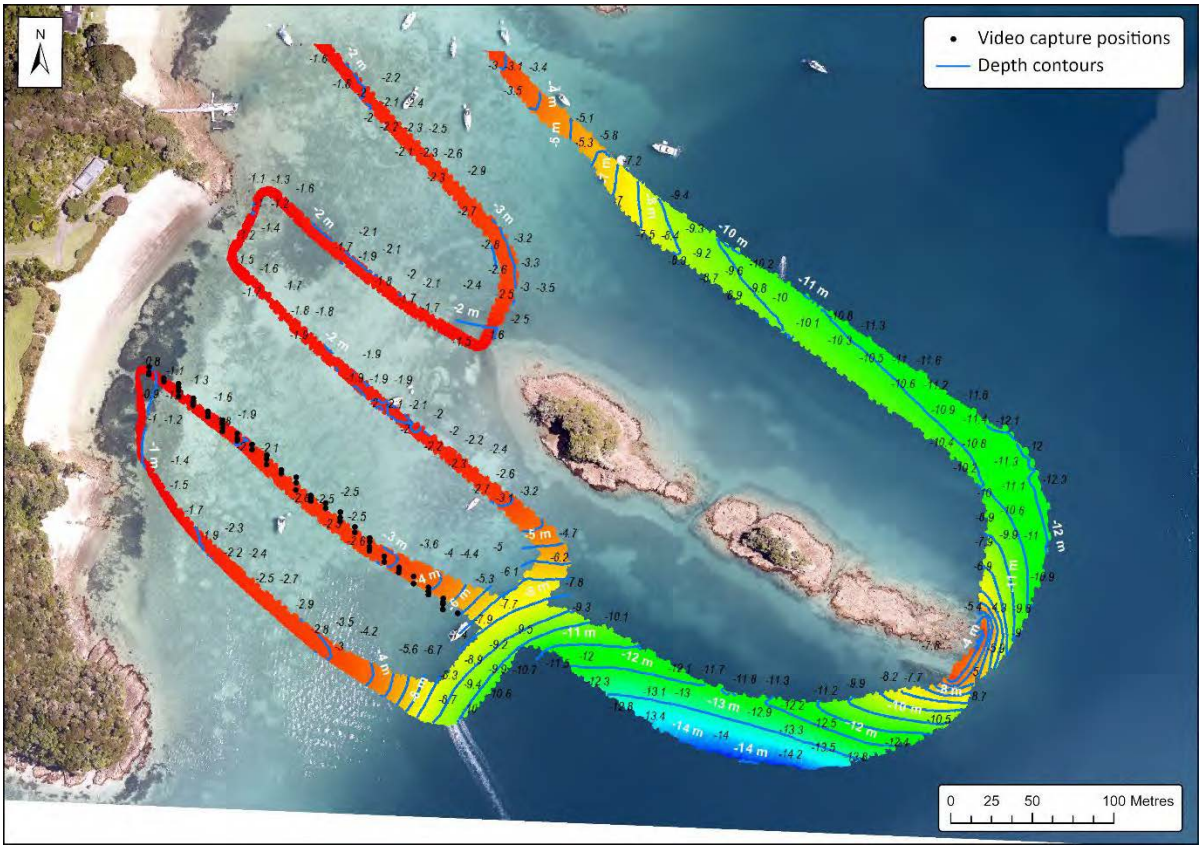
A.1.3 SE Moturua



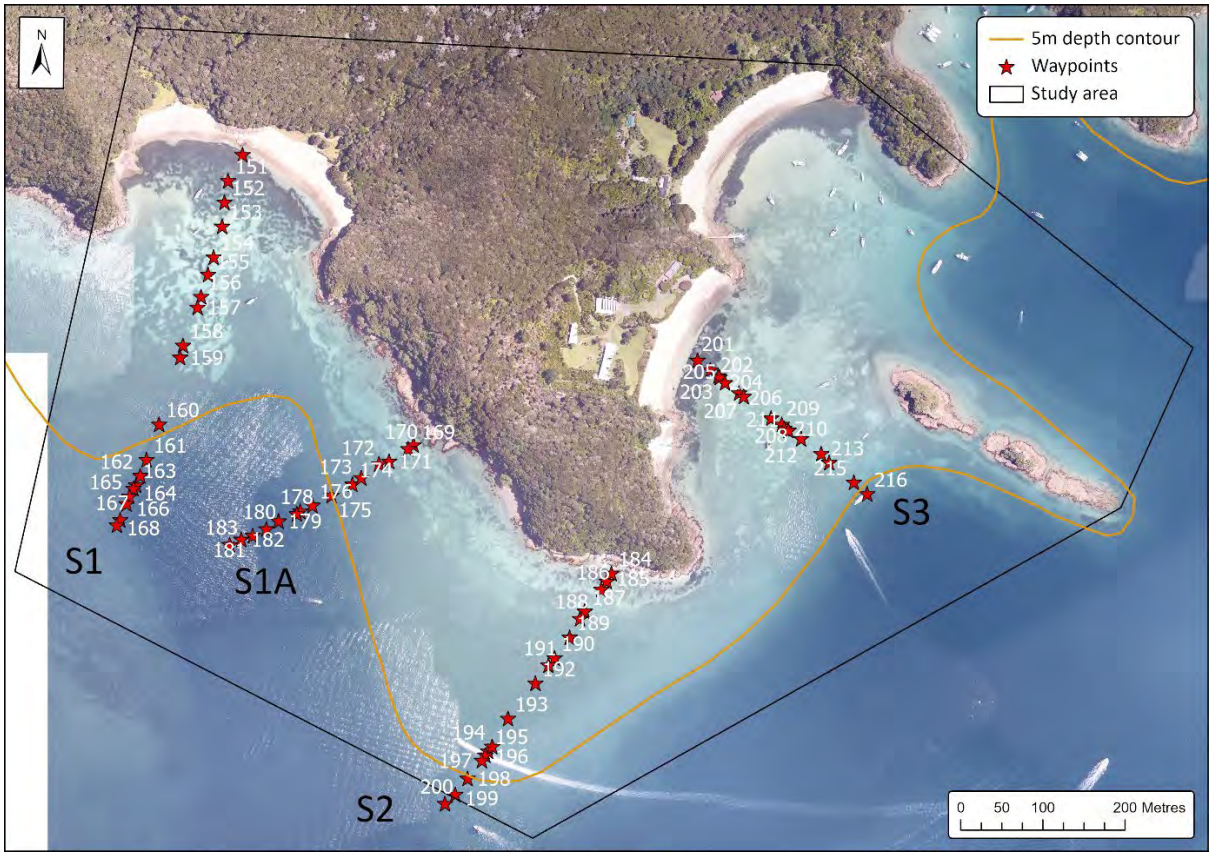
Video-camera transcects and indicative distribution of the putative seagrass (green) and algal-turf (red) biomes, to 5 m depth, Southeast Moturua, 2020.



Multibeam Chart Datum depths and depth contours, western part of Southeast Moturua, 2020.



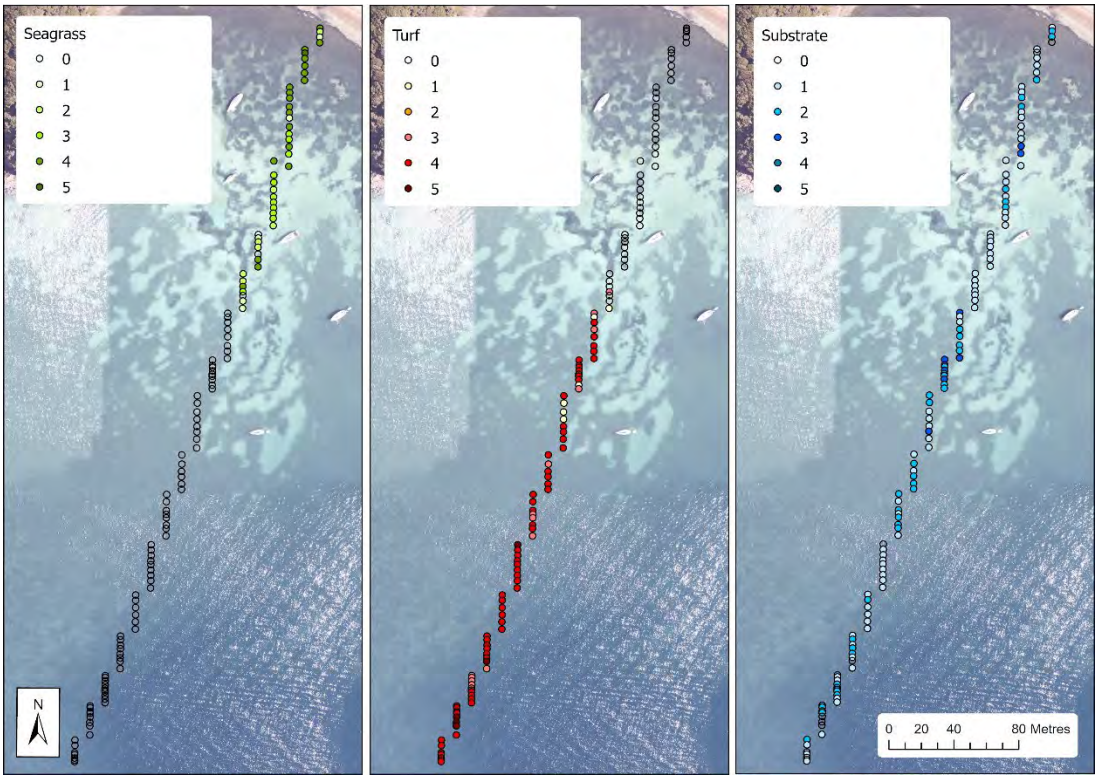
Multibeam Chart Datum depths and depth contours, eastern part of Southeast Moturua, 2020.



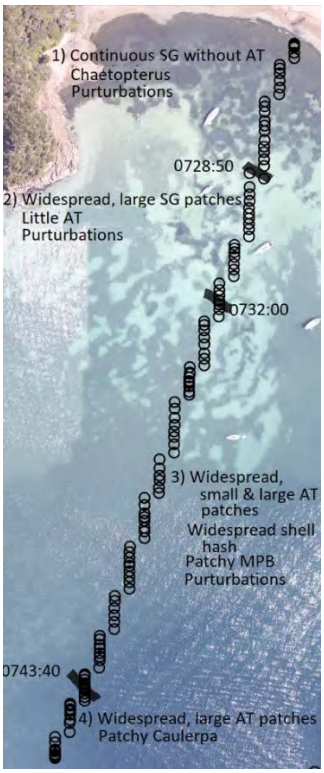
SE Moturua waypoints, 2020.

Transect S1

Transect S1 (480 m long; Waypoints 151–168) traverses Waipao Bay southwest from the shore, deepening gradually to 5 m and then more steeply to 8.5 m. There was drop-camera imagery at Waypoints 158, 163, 165, & 168.



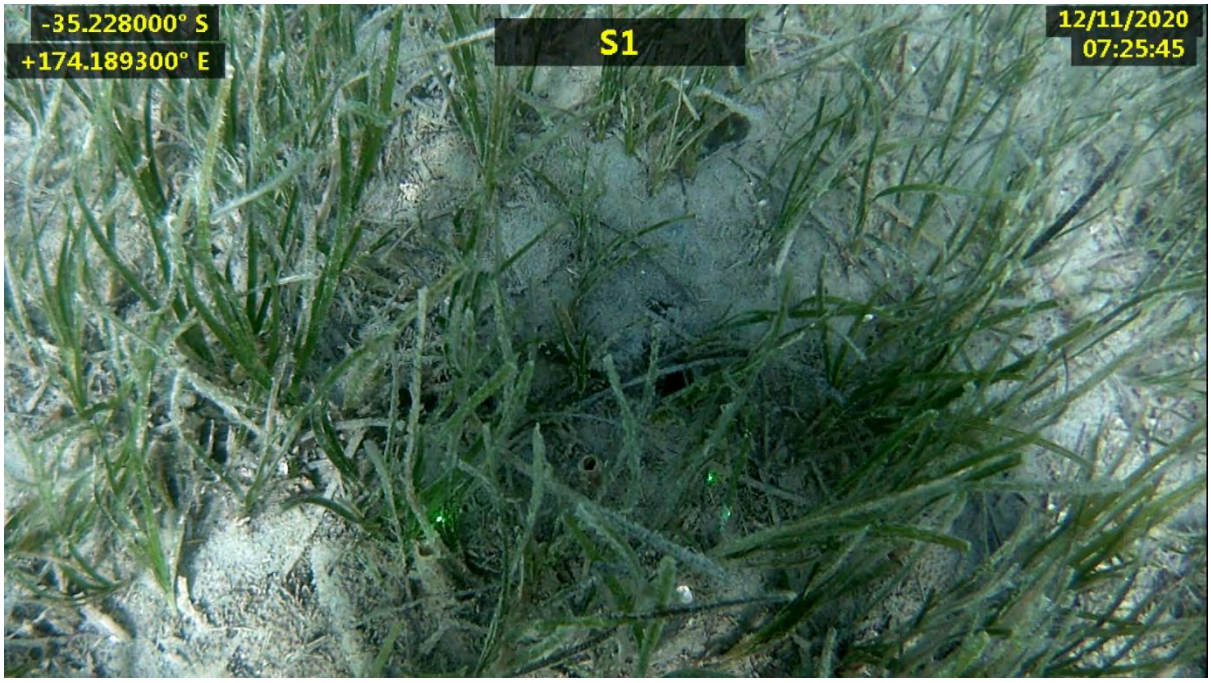
Characterisation of Transect S1 based on 10-second video imagery.



Overall characterisation by section of Transect S1. Times given are from video frames.

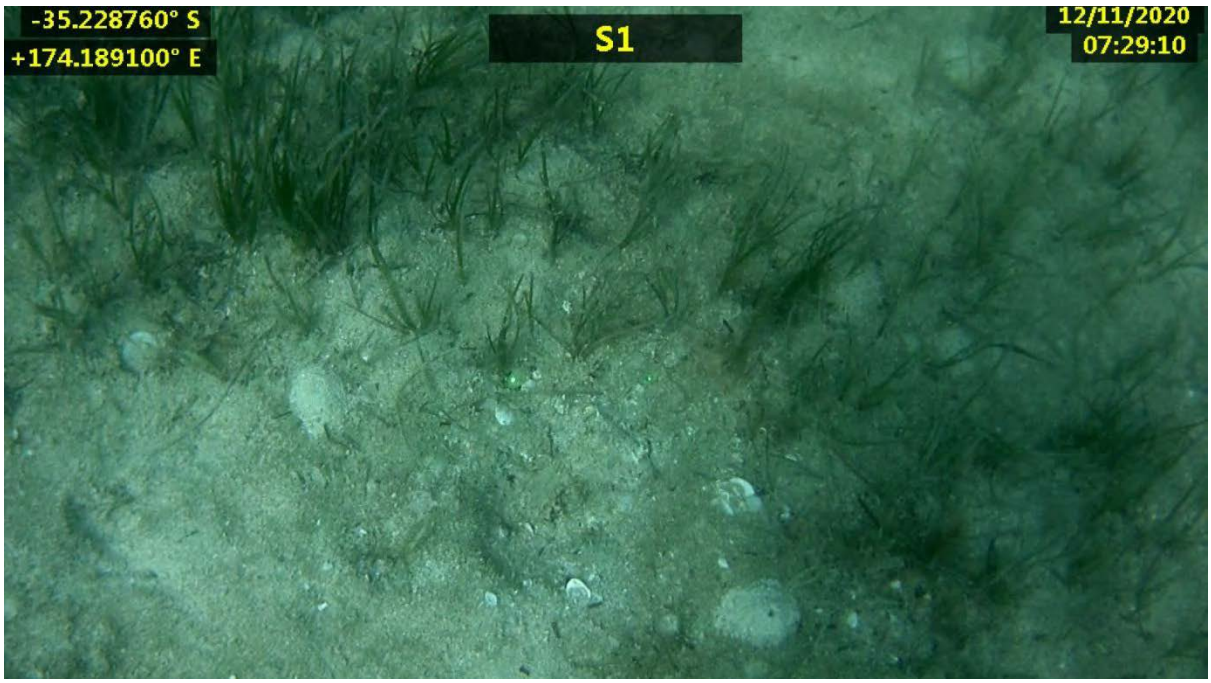
Representative imagery for S1

Section 1



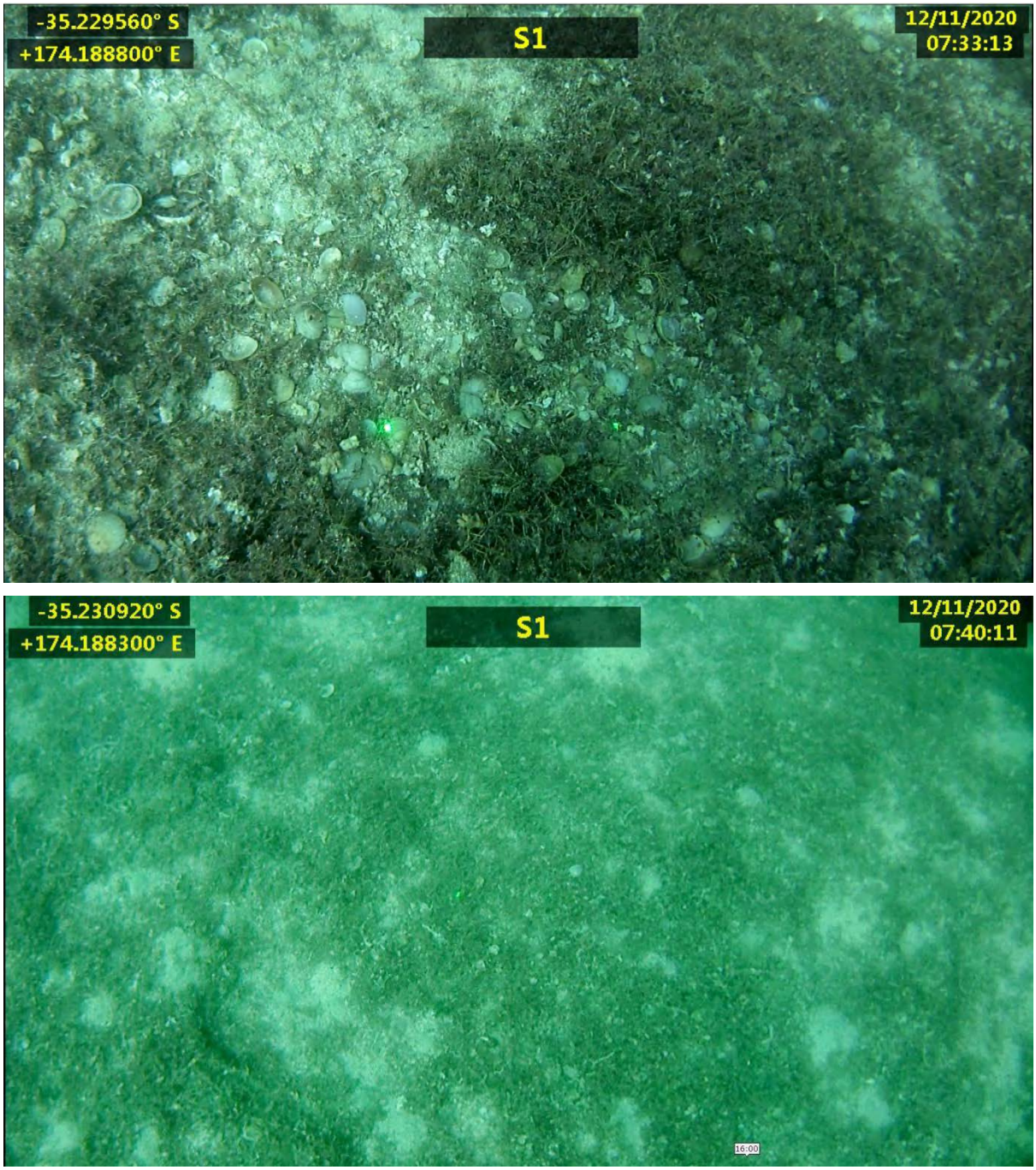
Characterising imagery for Section 1 of Transect S1 (seagrass, *Chaetopterus*, pertubations).

Section 2

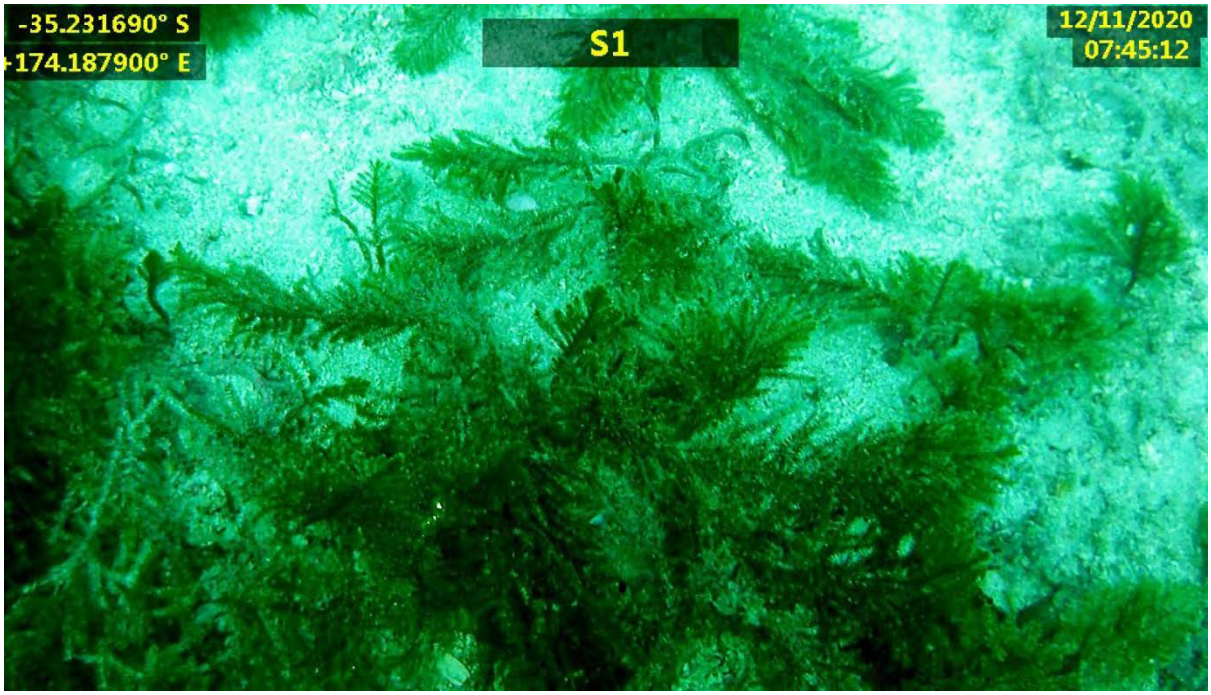


Characterising imagery for Section 2 of Transect S1 (seagrass, pertubations).

Section 3



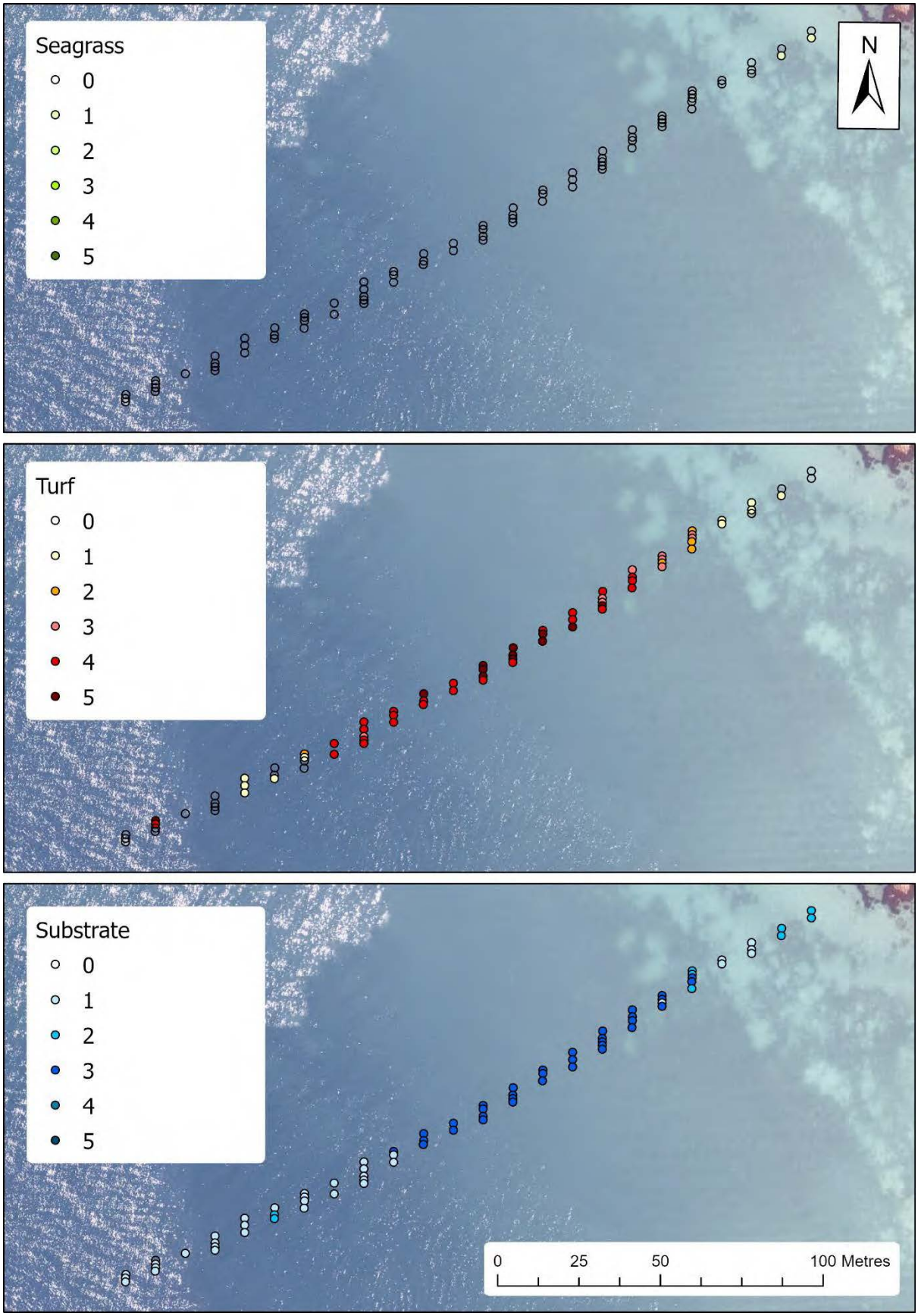
Characterising imagery for Section 3 of Transect S1 (algal turf, shell hash, perturbations).



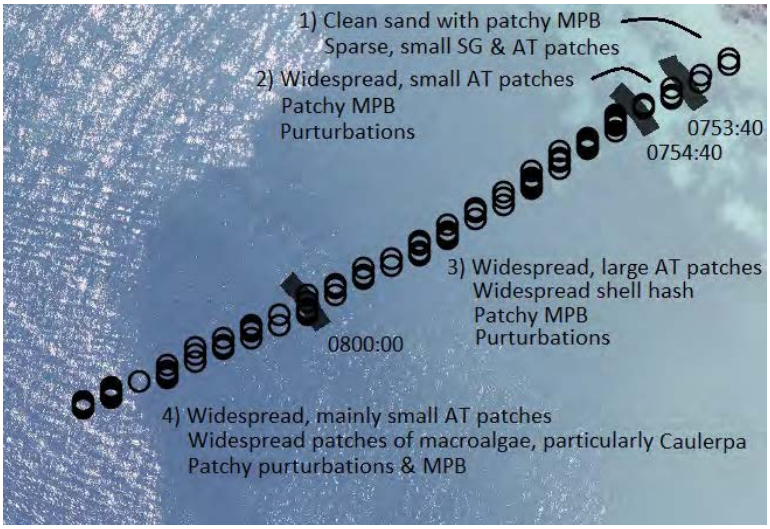
Characterising imagery for Section 4 of Transect S1 (algal turf, *Caulerpa*).

Transect S1A

Transect S1A (260 m long; Waypoints 169–183) extends southwest from the shore, gradually deepening to 6 m, more steeply to 14 m, and then gradually to 15.2 m. There was drop-camera imagery at Waypoints 171, 173, 174, 176, 178, and 179.



Characterisation of Transect S1A based on 10-second video imagery.



Overall characterisation by section of Transect S1A. Times given are from video frames.

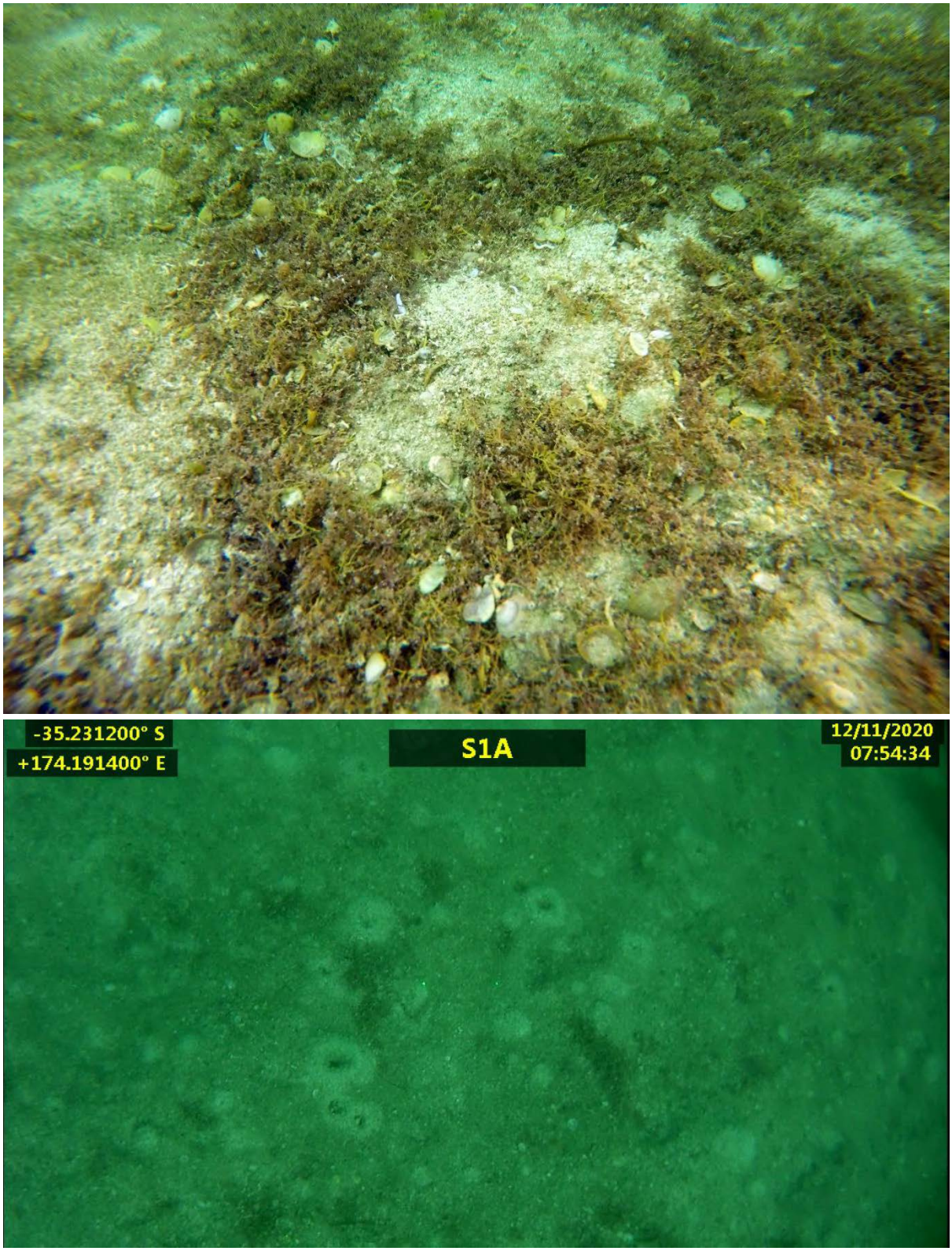
Representative imagery for S1A

Section 1



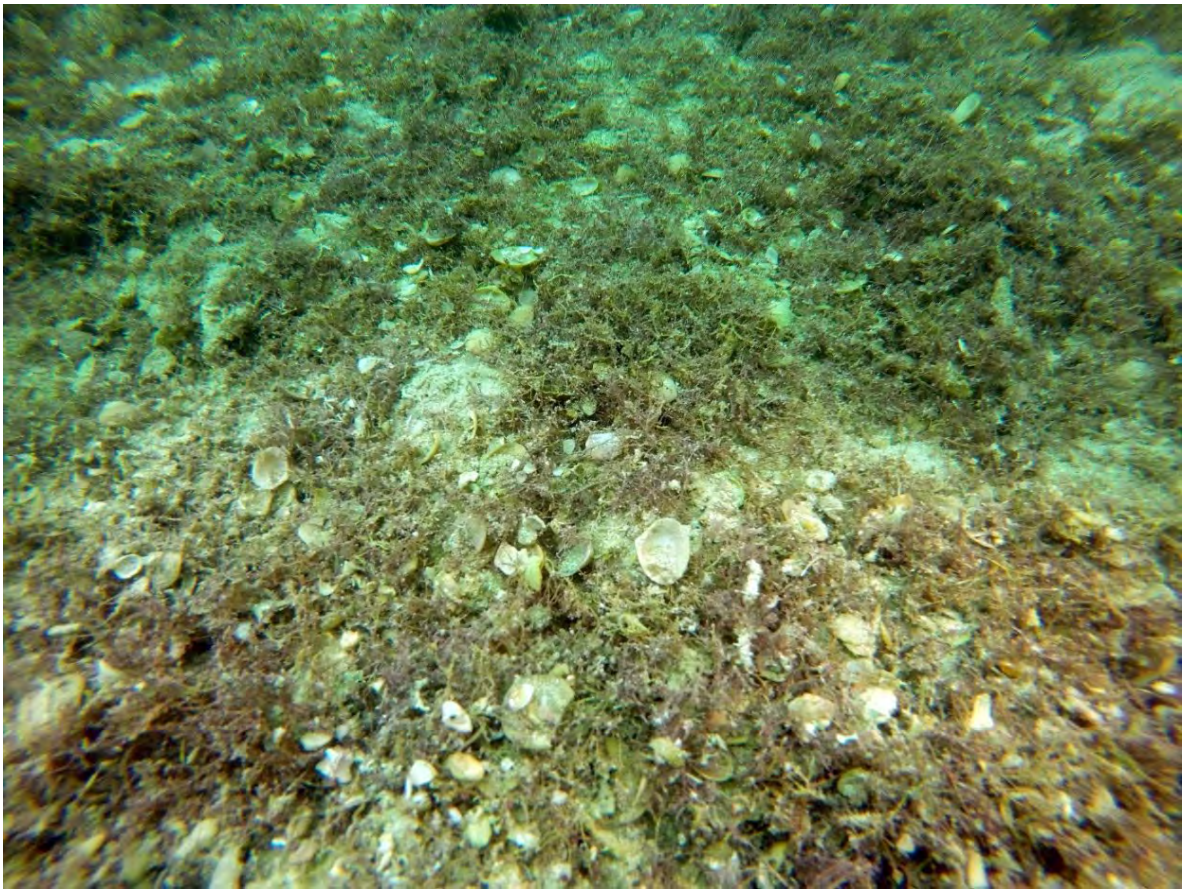
Characterising imagery for Section 1 of Transect S1A (seagrass).

Section 2



Characterising imagery for Section 2 of Transect S1A (algal turf, MPB, perturbations).

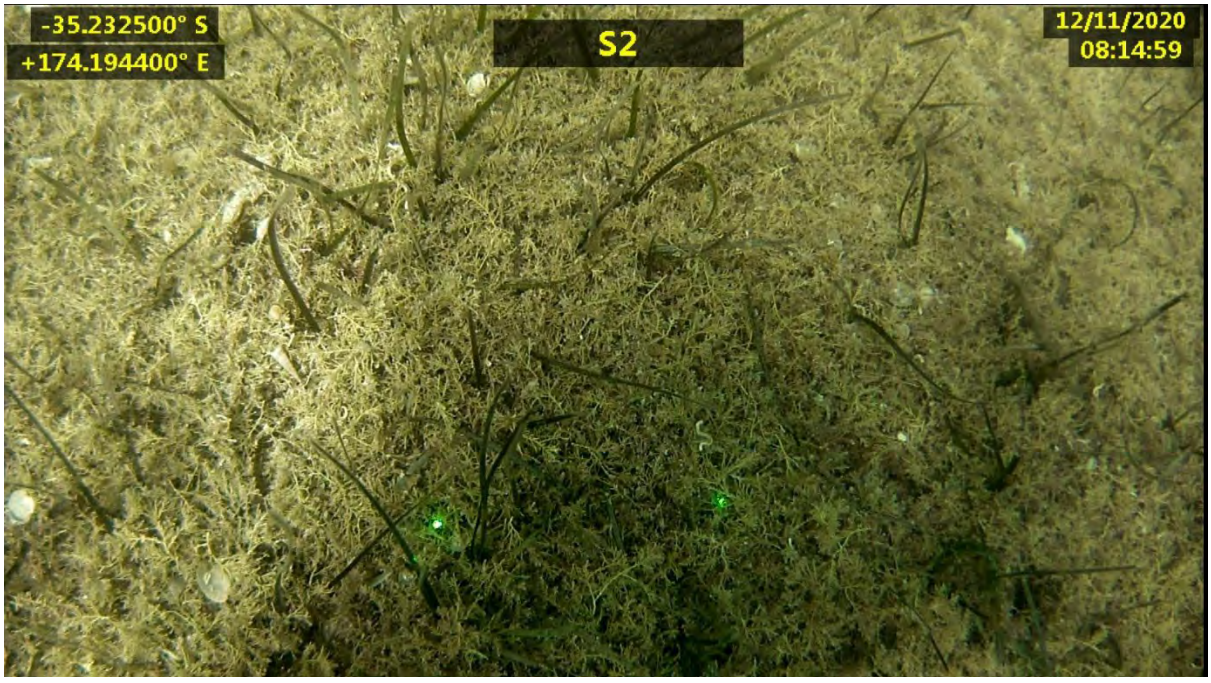
Section 3



Characterising imagery for Section 3 of Transect S1A (algal turf, shell hash).

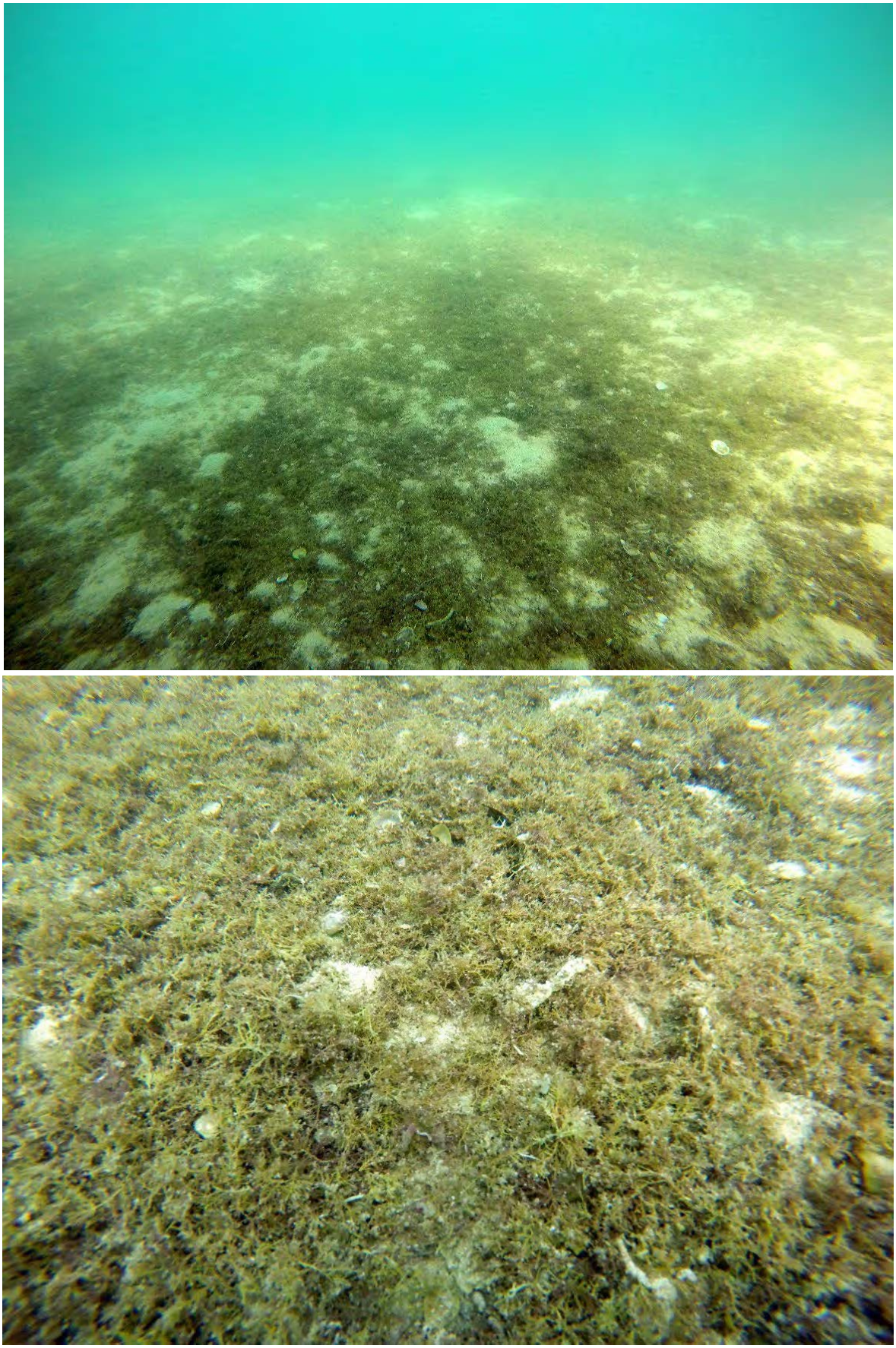
Representative imagery for S2

Section 1



Characterising imagery for Section 1 of Transect S2 (seagrass, algal turf).

Section 2



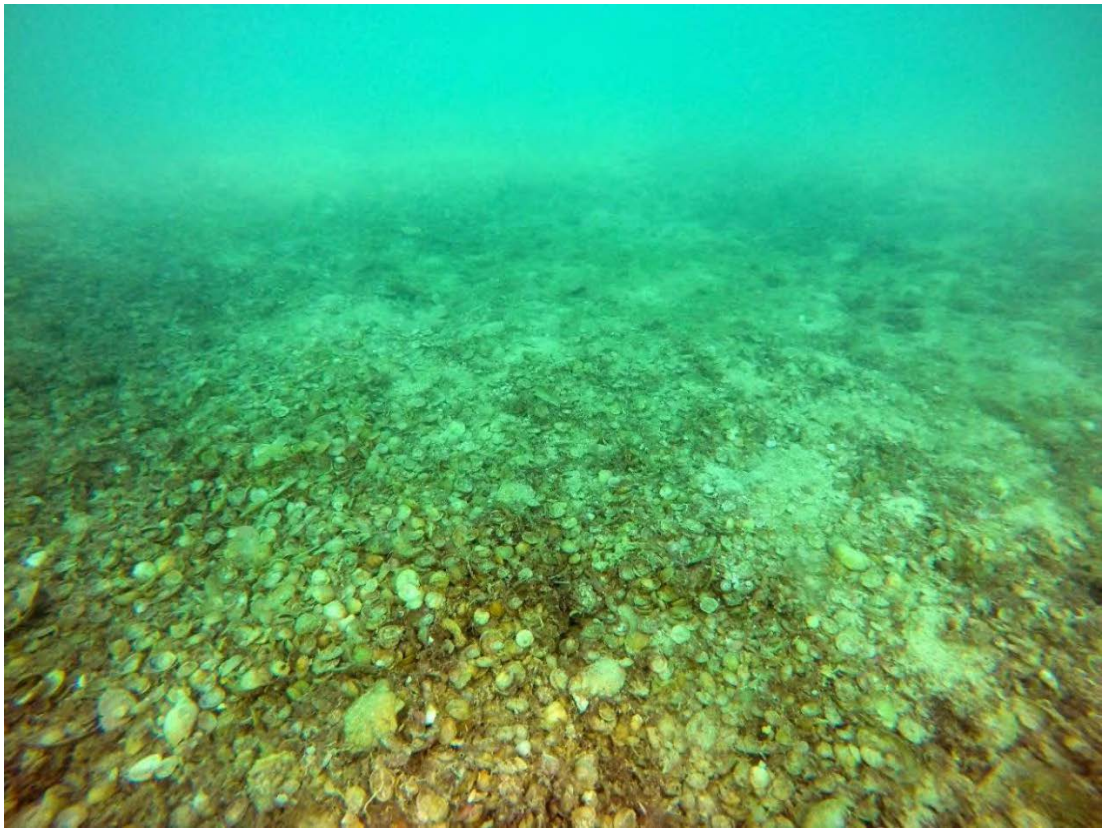
Characterising imagery for Section 2 of Transect S2 (algal turf, perturbations).

Section 3

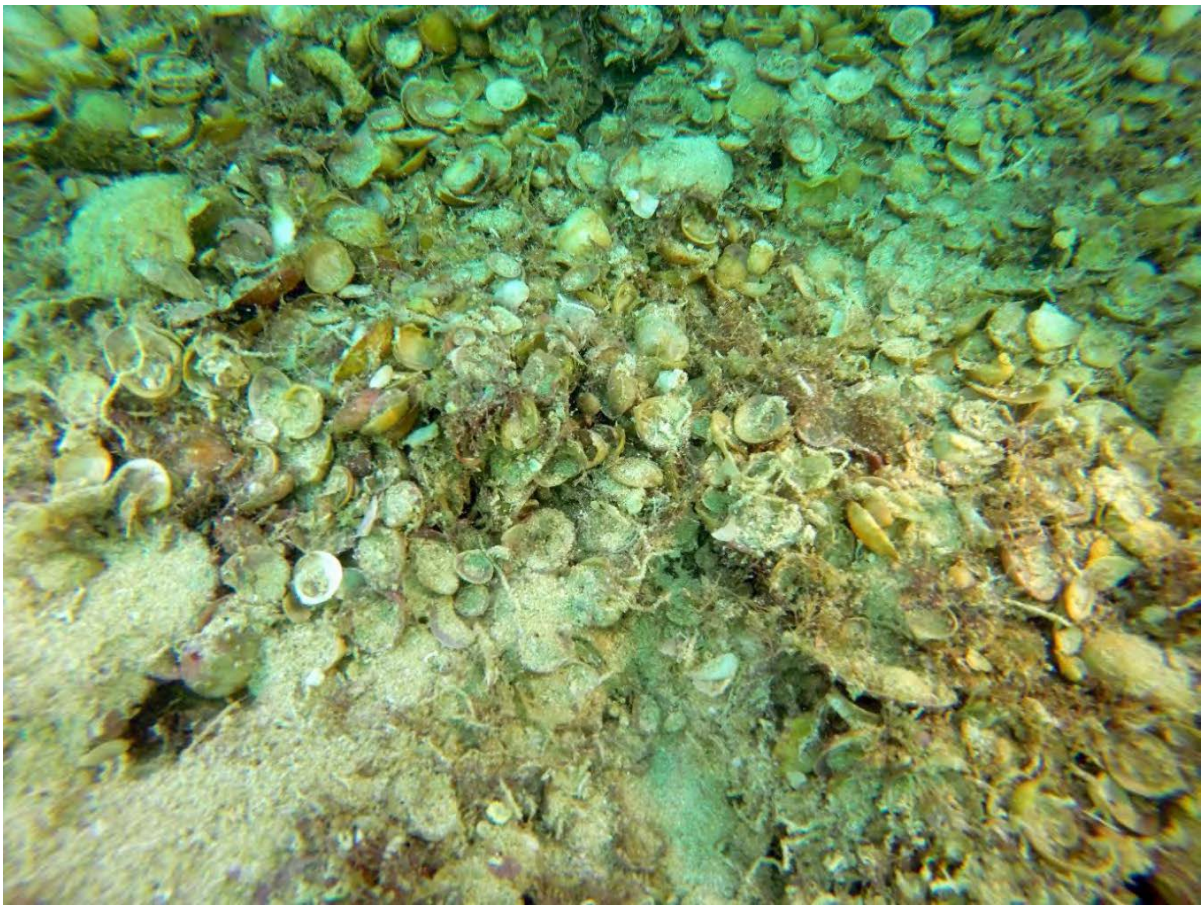


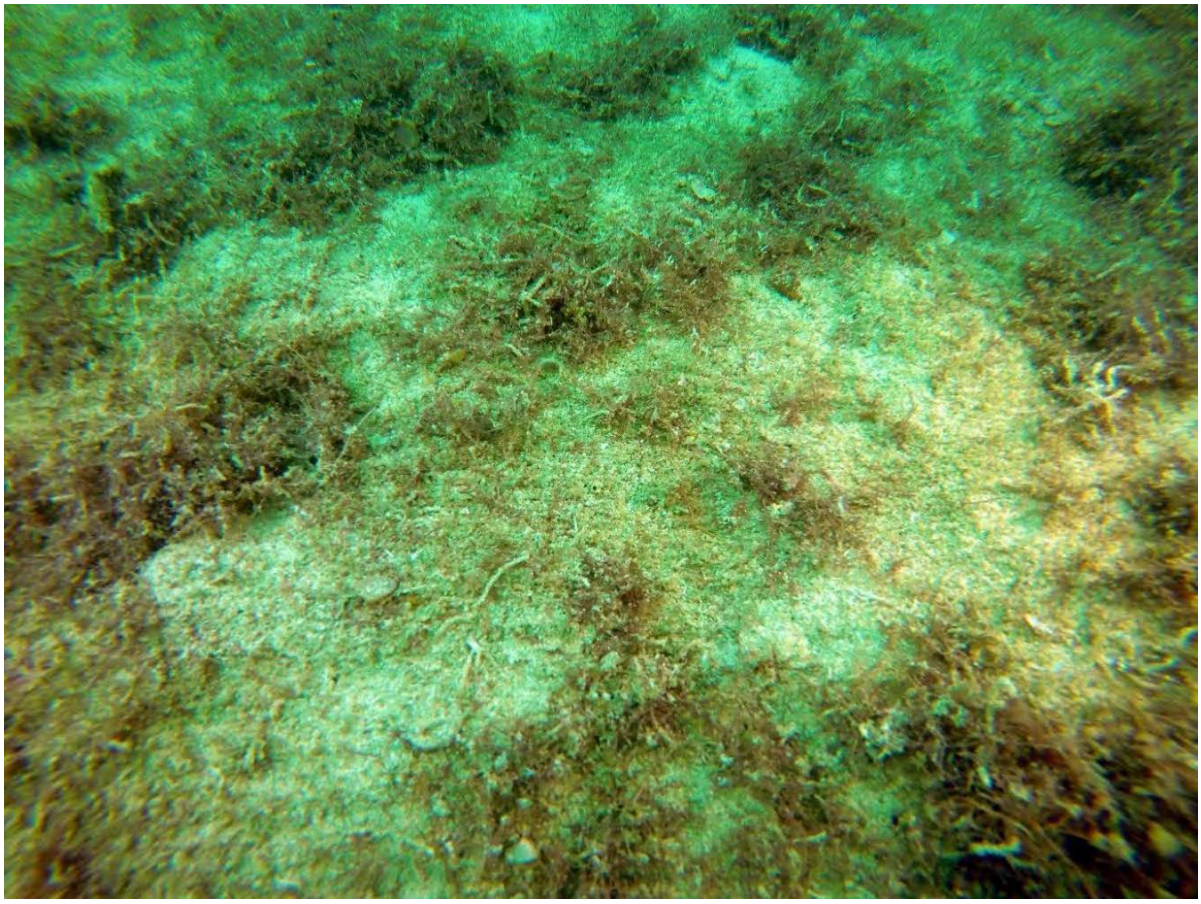
Characterising imagery for Section 3 of Transect S2 (algal turf, perturbations).

Section 4





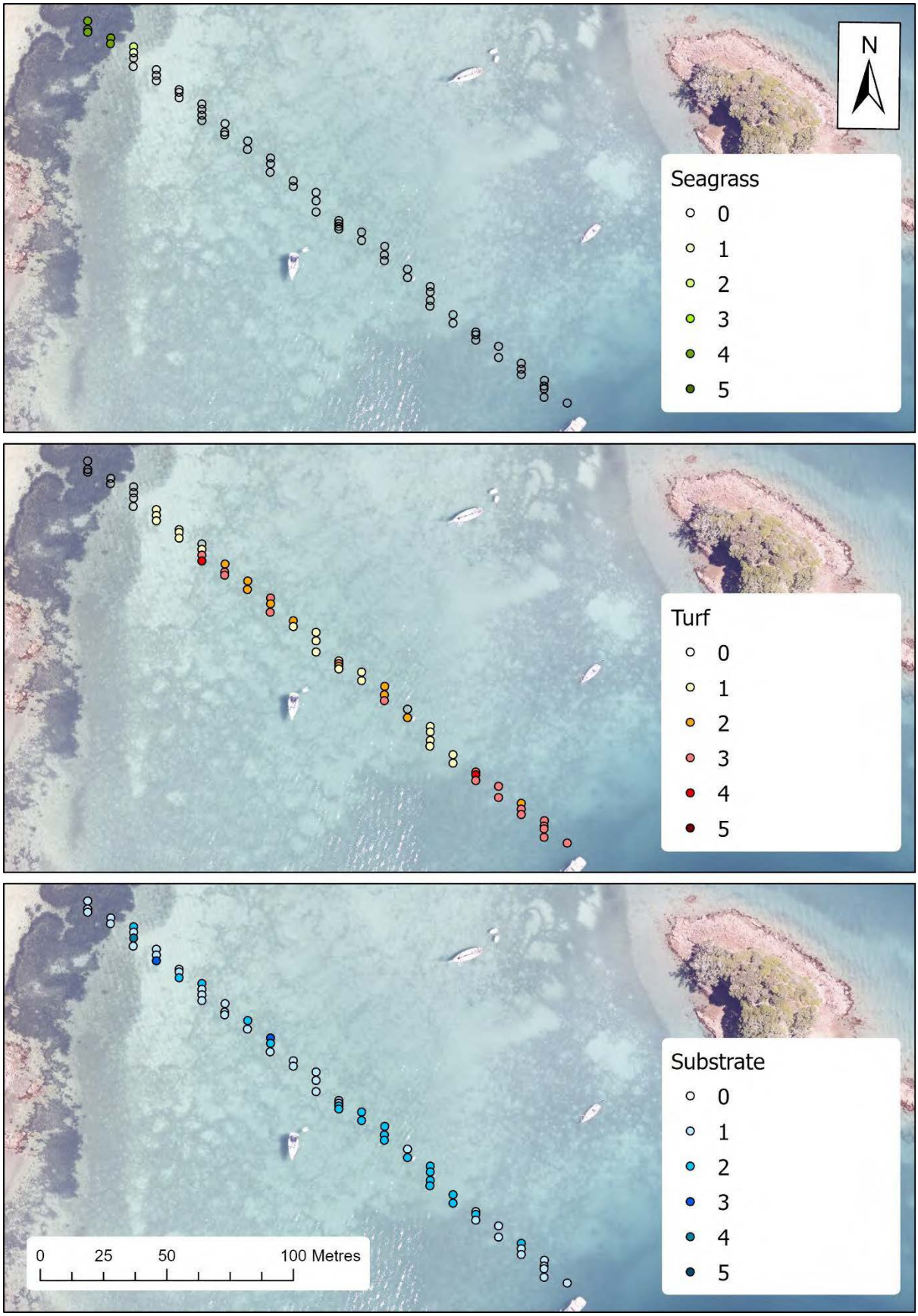




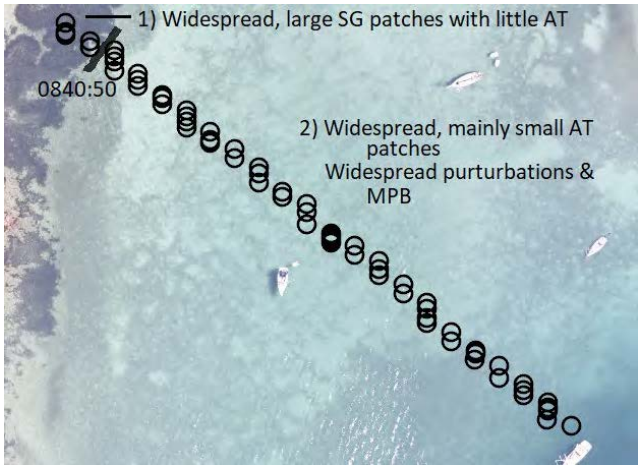
Characterising imagery for Section 4 of Transect S2 (algal turf, shell hash, perturbations).

Transect S3

Transect S3 (250 m long; Waypoints 201–216) extends southeast from the shore, gradually deepening to 5 m and then more steeply to 6.2 m. There was drop-camera imagery at Waypoints 201, 203, 206, 210, 215, and 217.



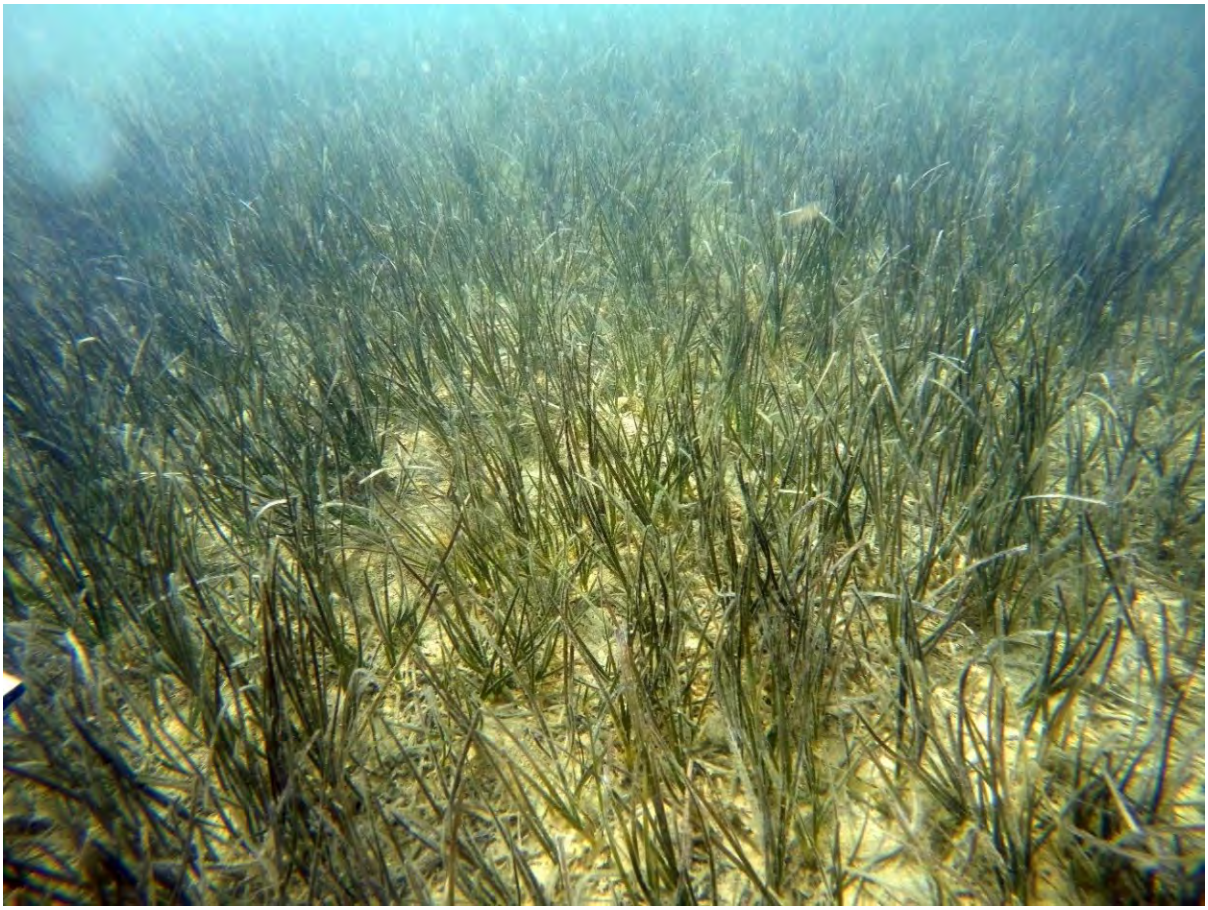
Characterisation of Transect S3 based on 10-second video imagery.



Overall characterisation by section of Transect S3. Times given are from video frames.

Representative imagery for S3

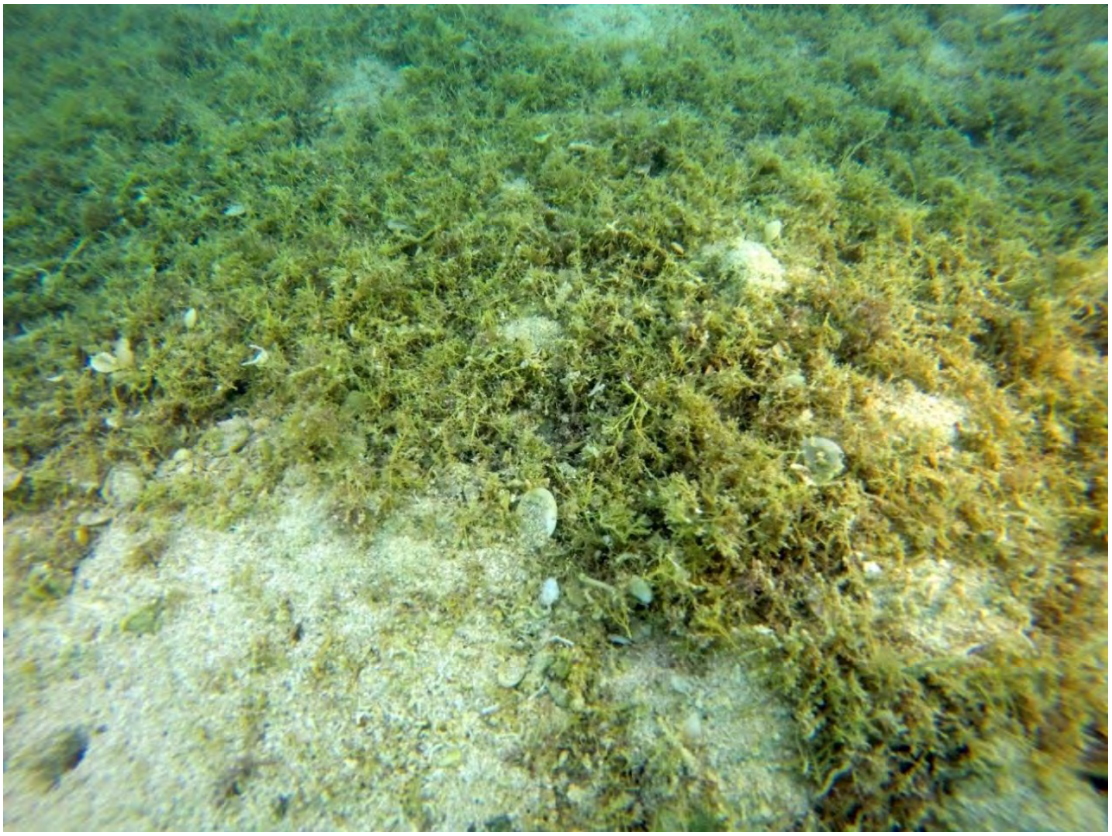
Section 1



Characterising imagery for Section 1 of Transect S3 (seagrass).

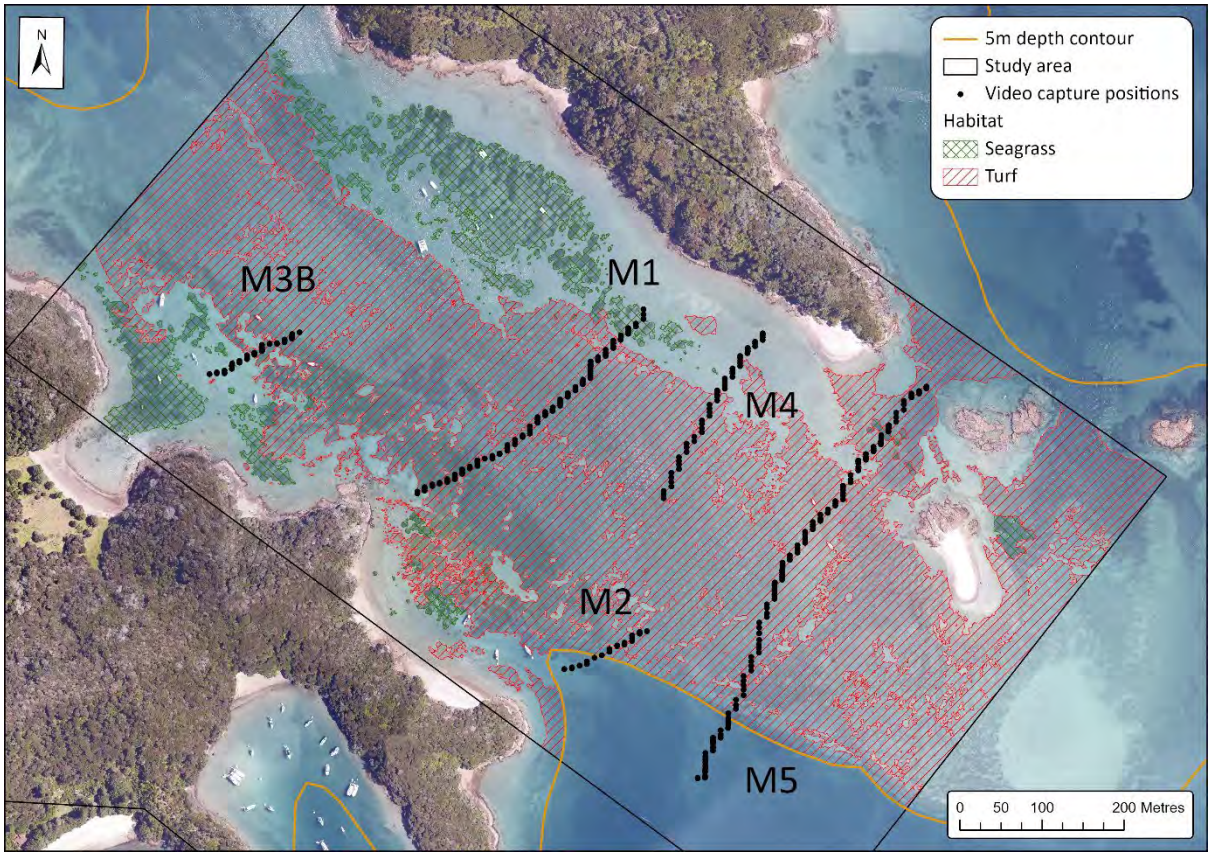
Section 2



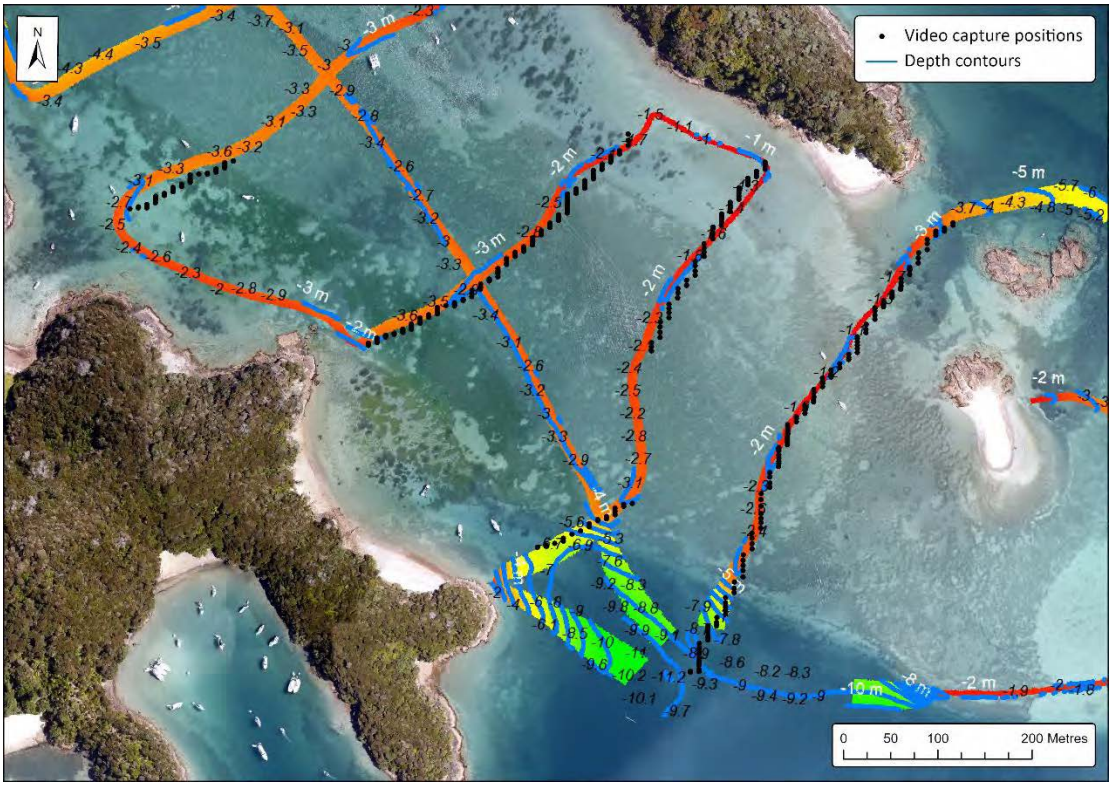


Characterising imagery for Section 2 of Transect S3 (algal turf, perturbations).

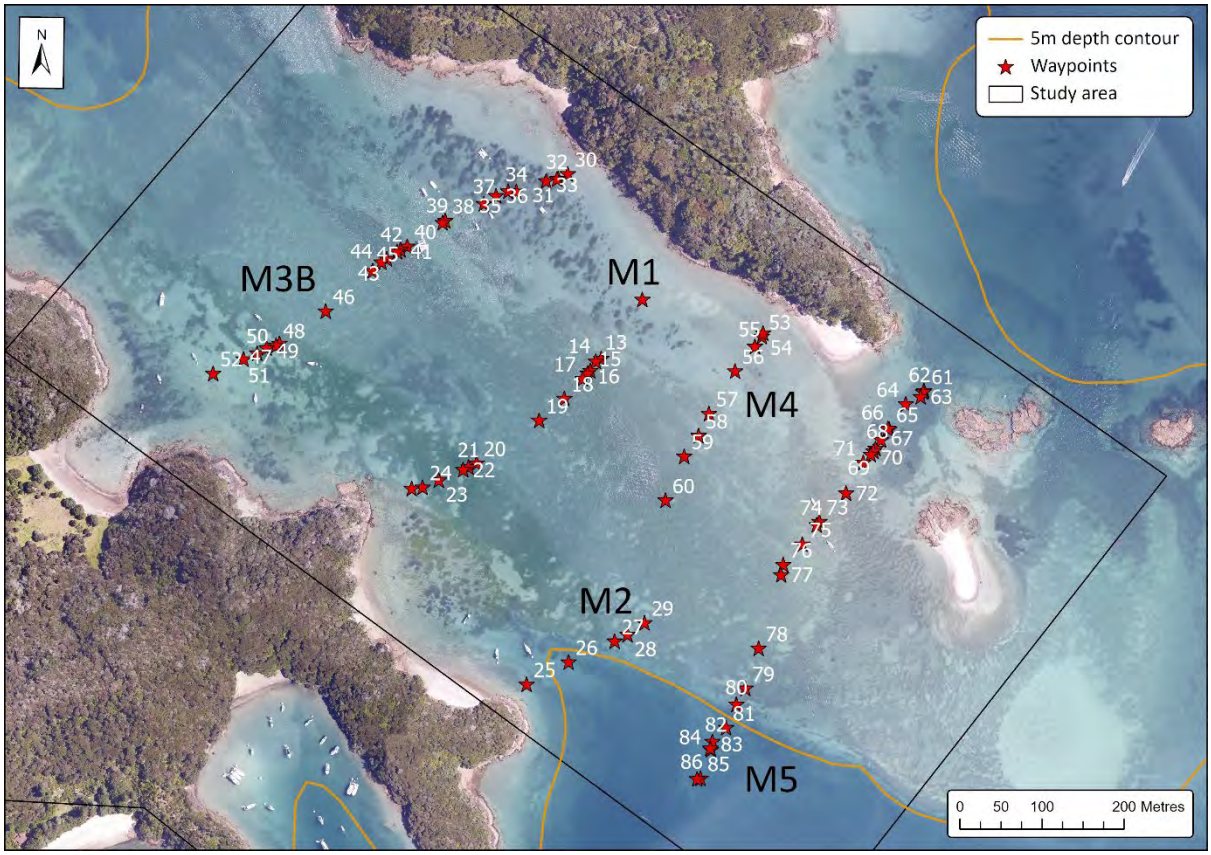
A1.4 Motukiekie Channel



Video-camera transects and indicative distribution of the putative seagrass (green) and algal-turf (red) biomes, to 5 m depth, Motukiekie Channel, 2020.



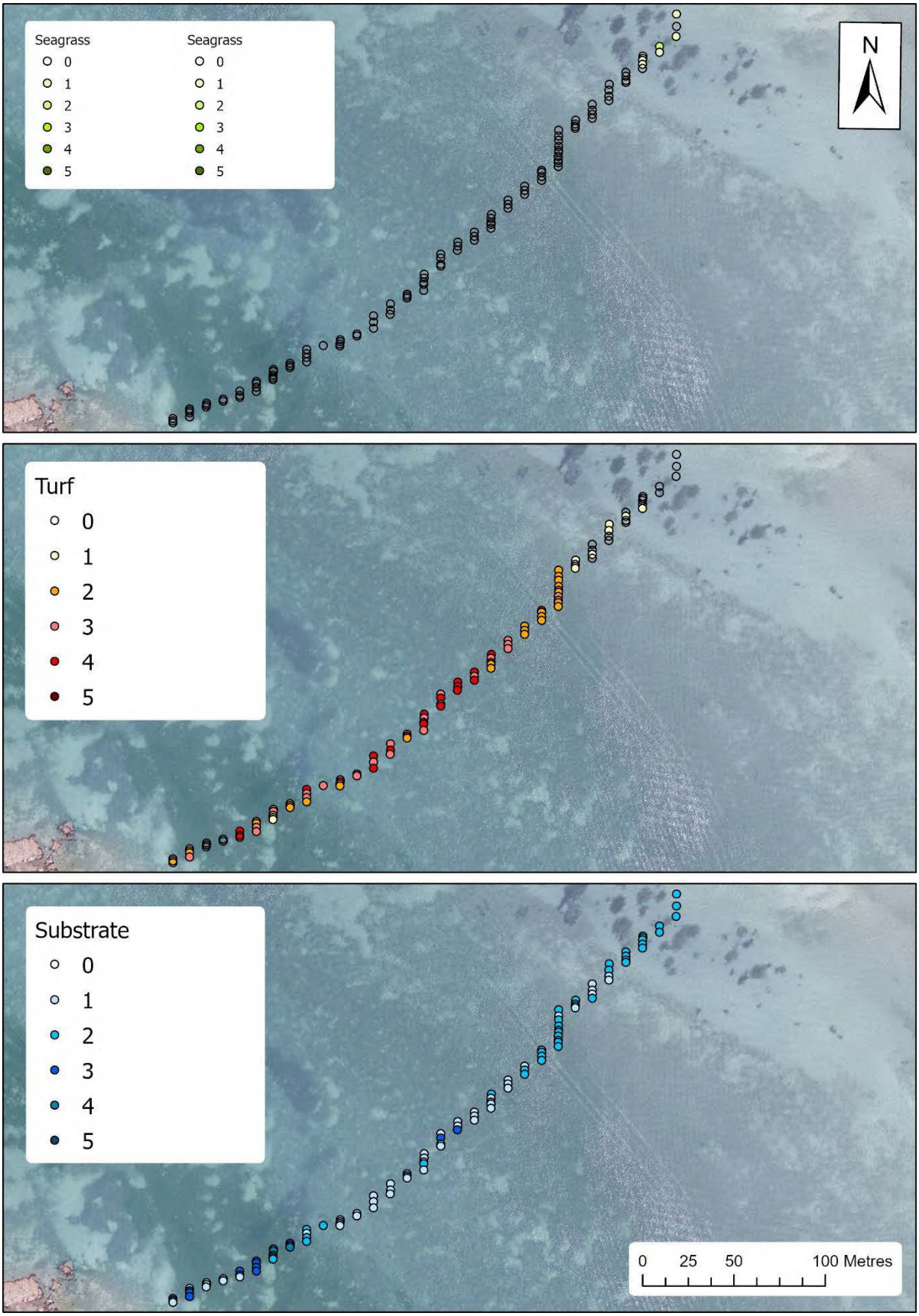
Multibeam Chart Datum depths and depth contours, Motukiekie Channel, 2020.



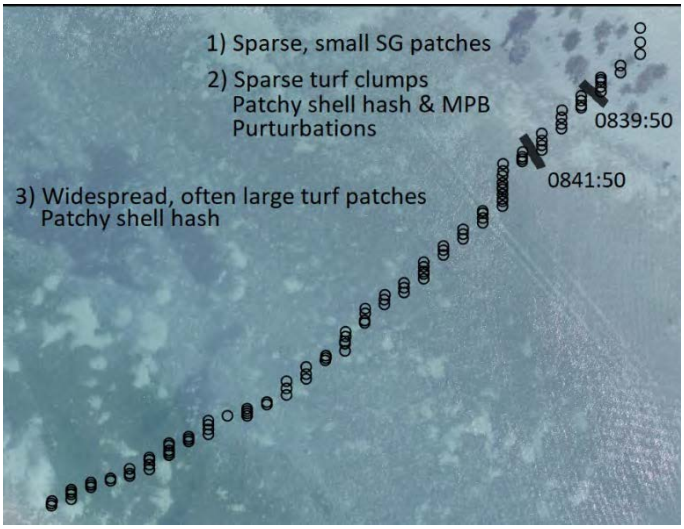
Motukiekie Channel waypoints, 2020.

Transect M1

Transect M1 (390 m long; Waypoints 13–24) traverses Motukiekie Channel, gradually deepening from 1.5 to 3.2 m. There was drop-camera imagery at Waypoints 15, 19, 21, & 24.



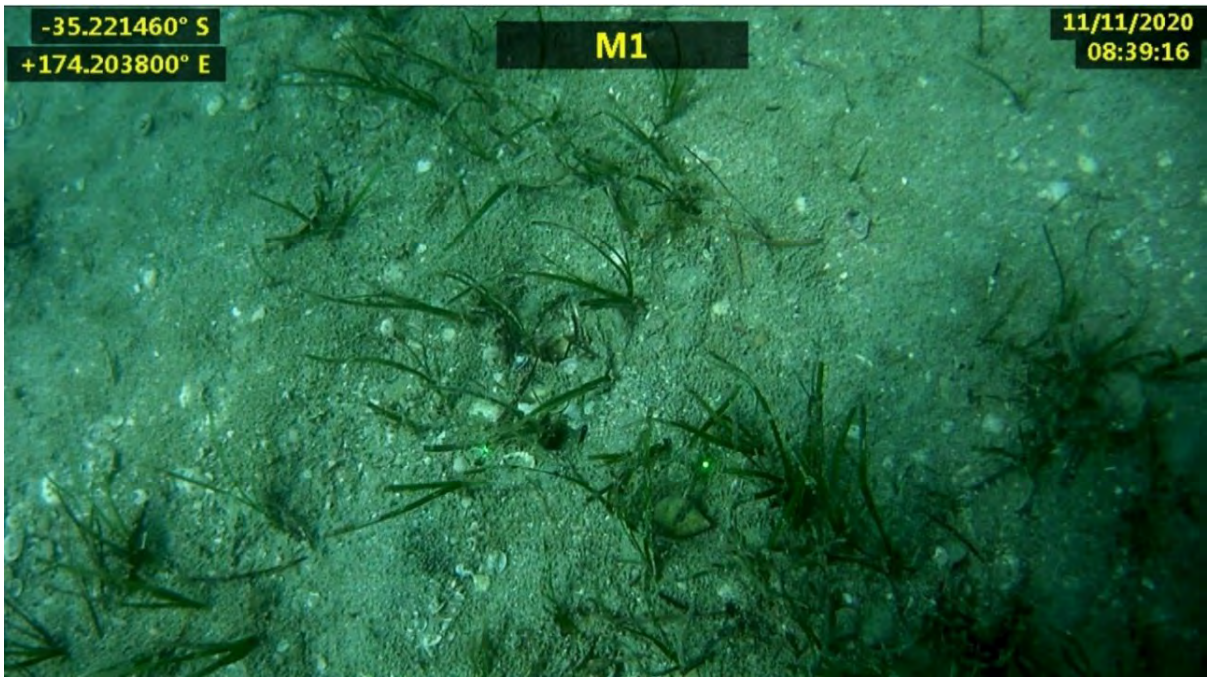
Characterisation of Transect M1 based on 10-second video imagery.



Overall characterisation by section of Transect M1. Times given are from video frames.

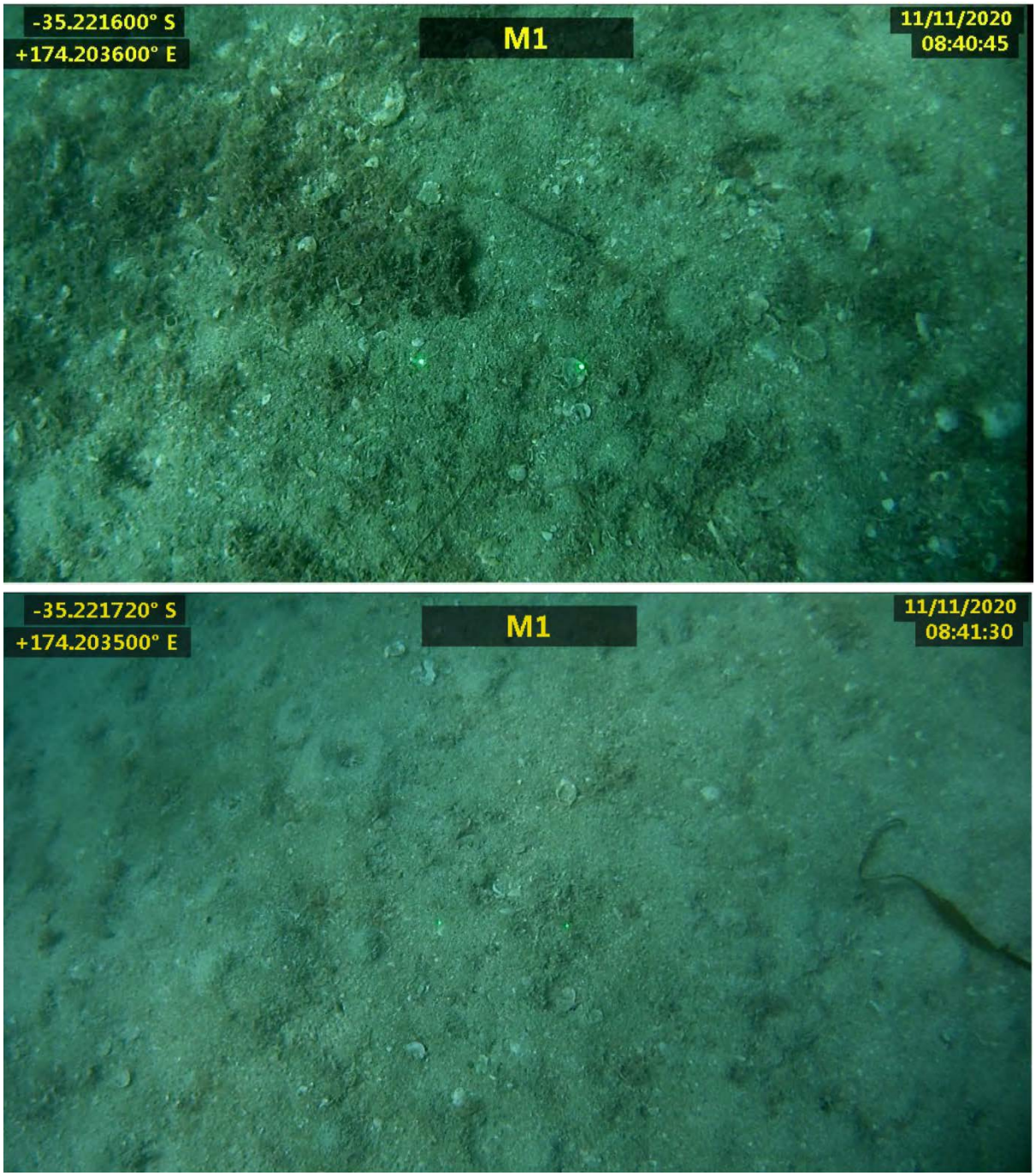
Representative imagery for M1

Section 1



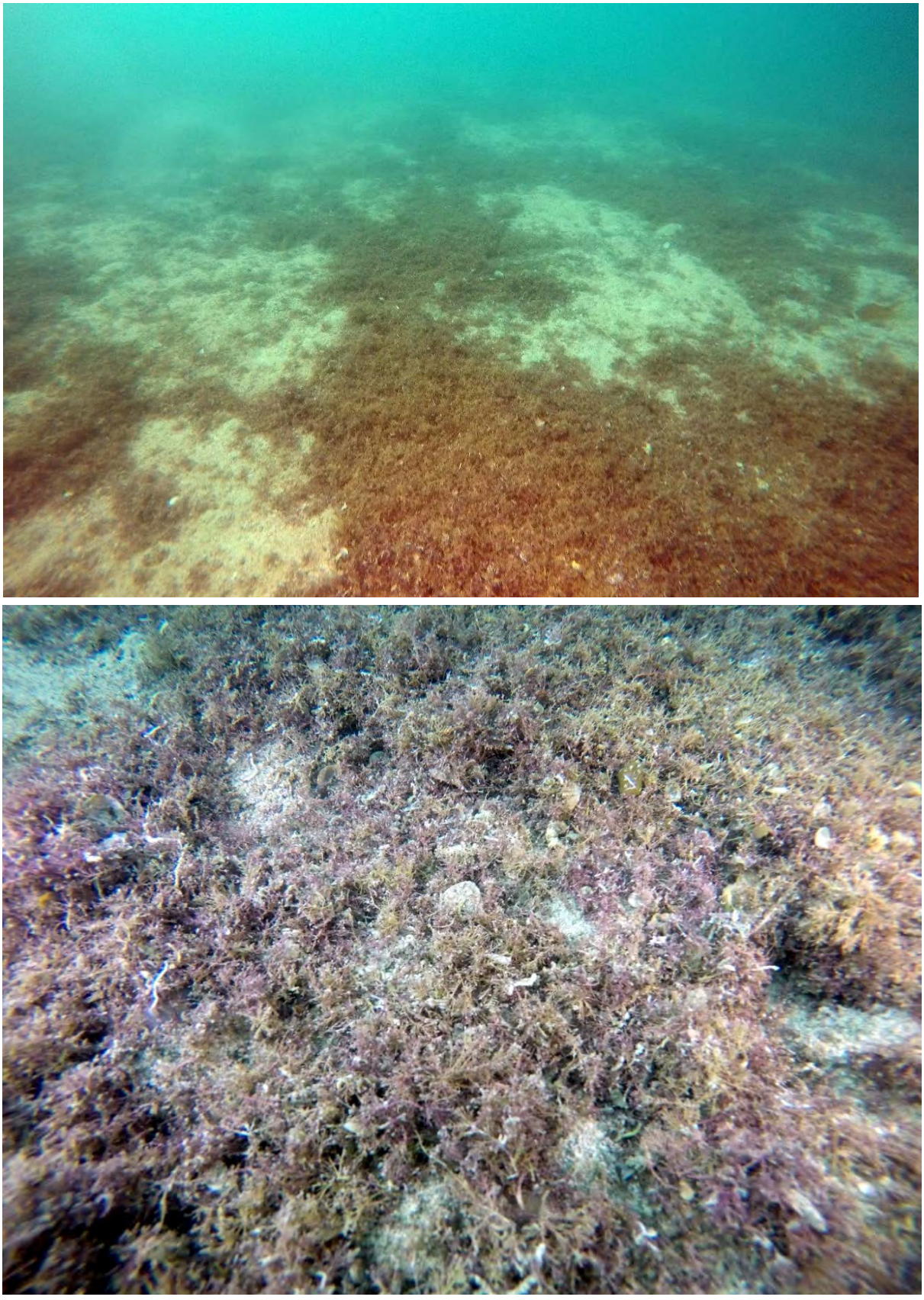
Characterising imagery for Section 1 of Transect M1 (seagrass).

Section 2



Characterising imagery for Section 2 of Transect M1 (algal turf, shell hash, perturbations).

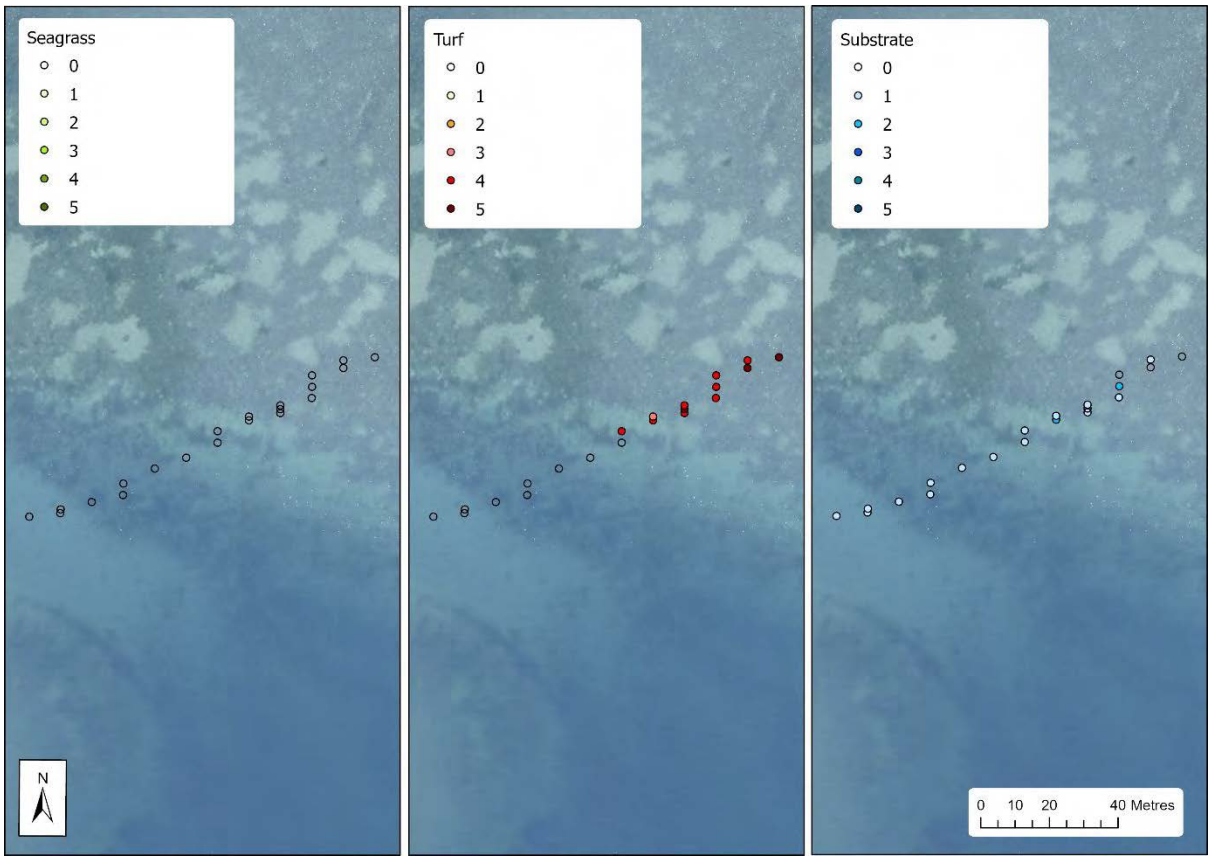
Section 3



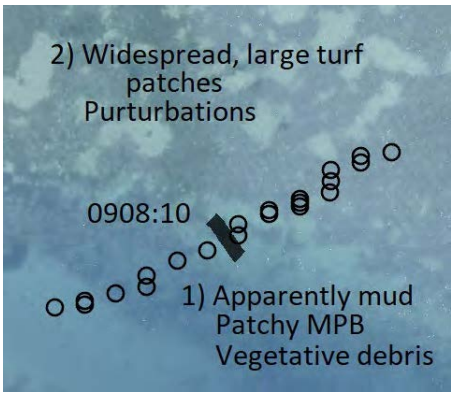
Characterising imagery for Section 3 of Transect M1 (algal turf, shell hash).

Transect M2

Transect M2 (130 m long; Waypoints 26–29) is a short run from 6.4 m to 3.1 m depth, where the shallow Motukiekie Channel rapidly deepens in the south. The first few minutes of video were not well focused, and in later parts the camera was on its side. There was no drop-camera imagery.



Characterisation of Transect M2 based on 10-second video imagery.



Overall characterisation by section of Transect M2. Times given are from video frames.

Representative image for M2
Section 1



Characterising imagery for Section 1 of Transect M2 (MPB, vegetative debris).

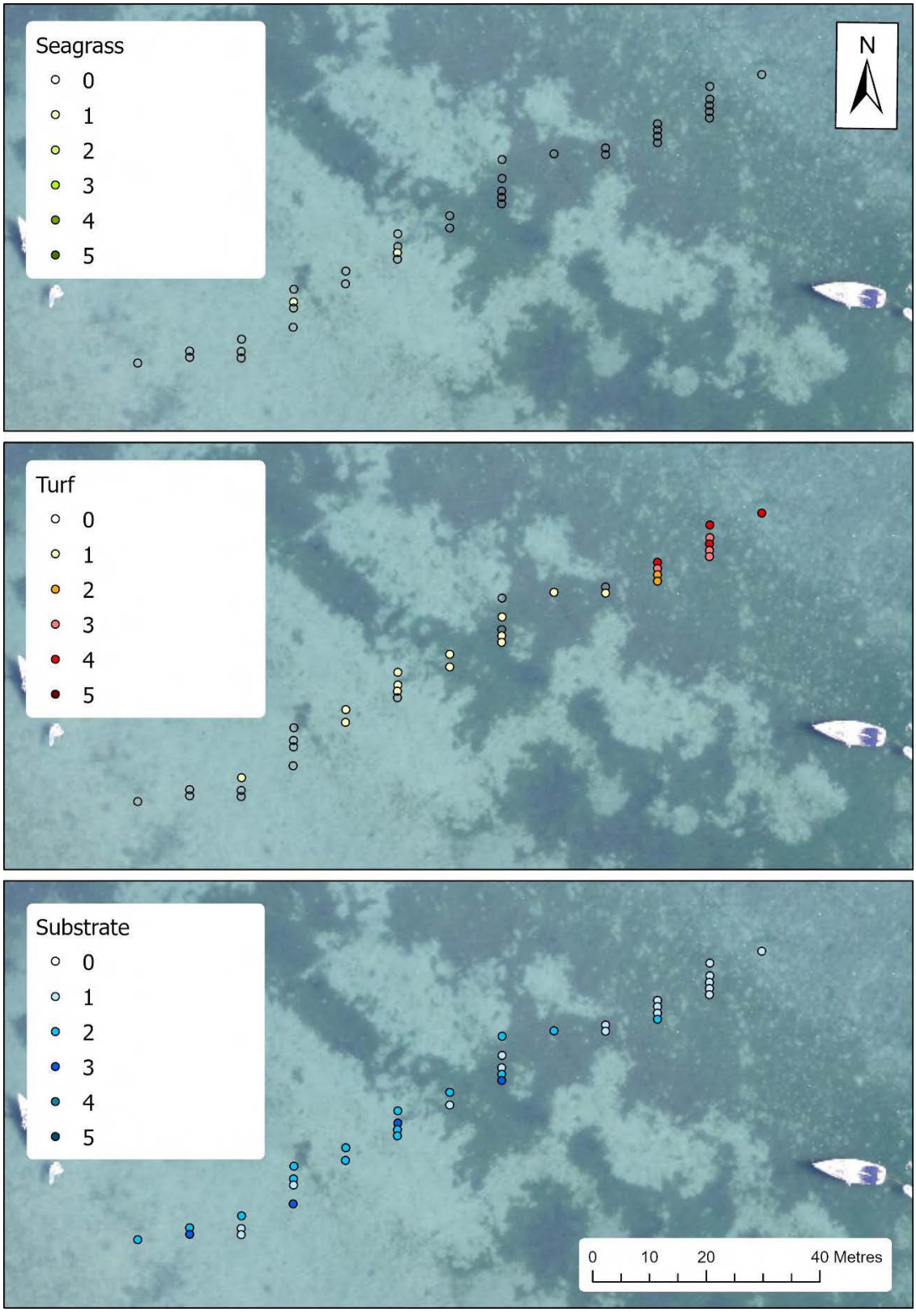
Section 2



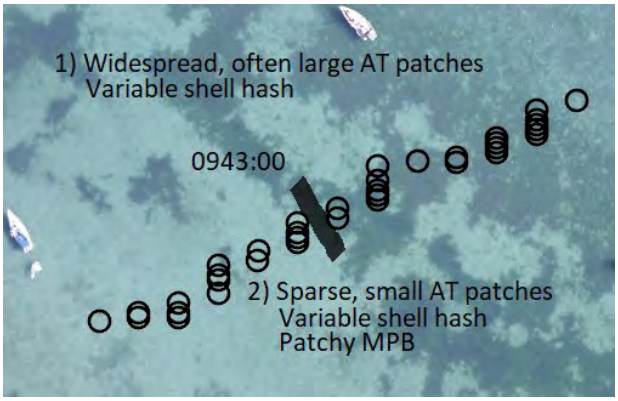
Characterising imagery for Section 2 of Transect M2 (algal turf, perturbations).

Transect M3B

Transect M3B (130 m long; Waypoints 46–52) runs southwest from near the middle of the channel towards the northern shore of Moturua, from 3.2 m depth to 2.8 m. There was no drop-camera imagery.



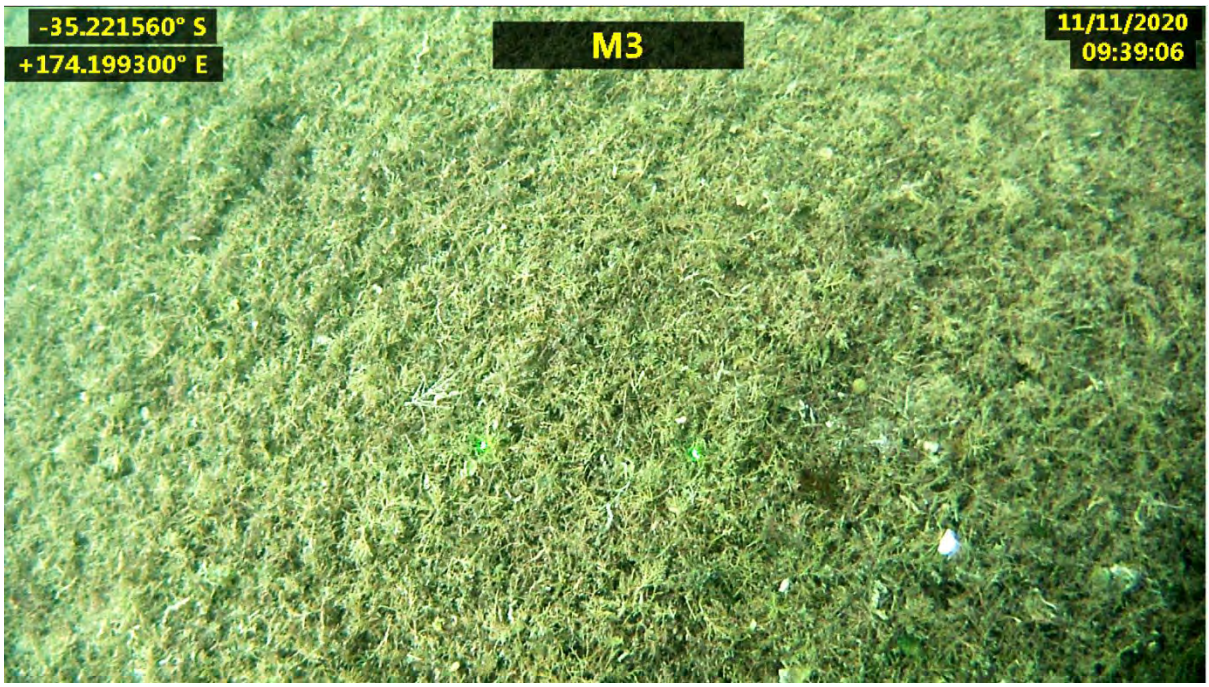
Characterisation of Transect M3B based on 10-second video imagery.



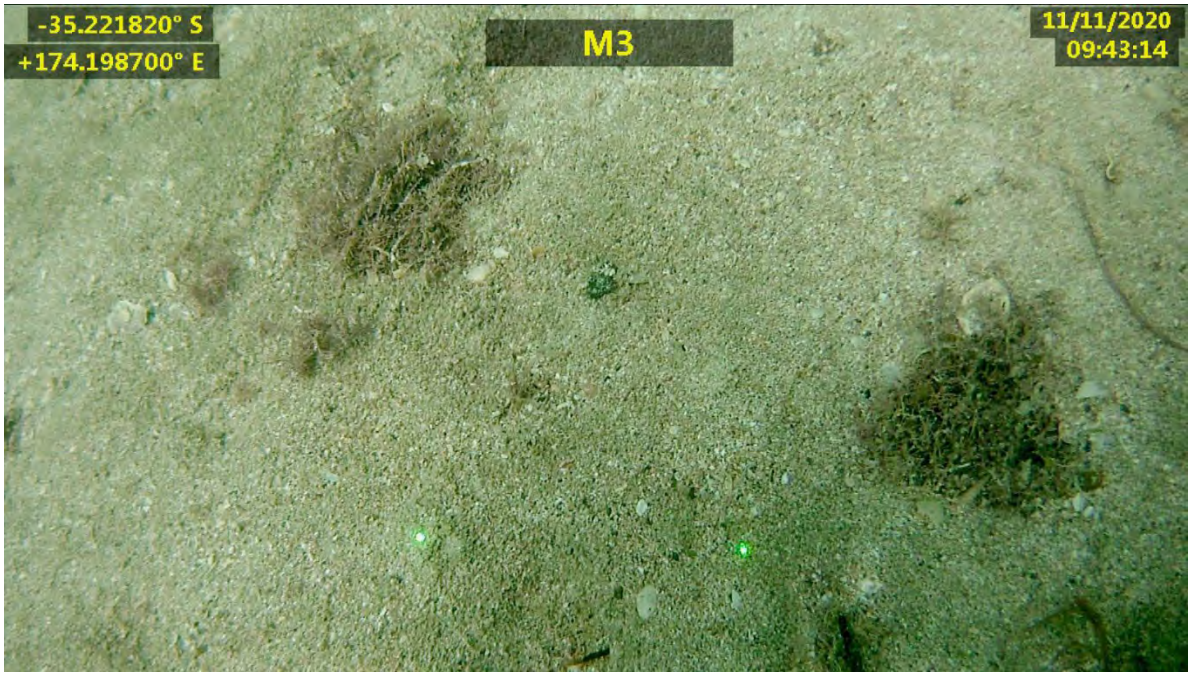
Overall characterisation by section of Transect M3B. Times given are from video frames.

Representative imagery for M3B

Section 1



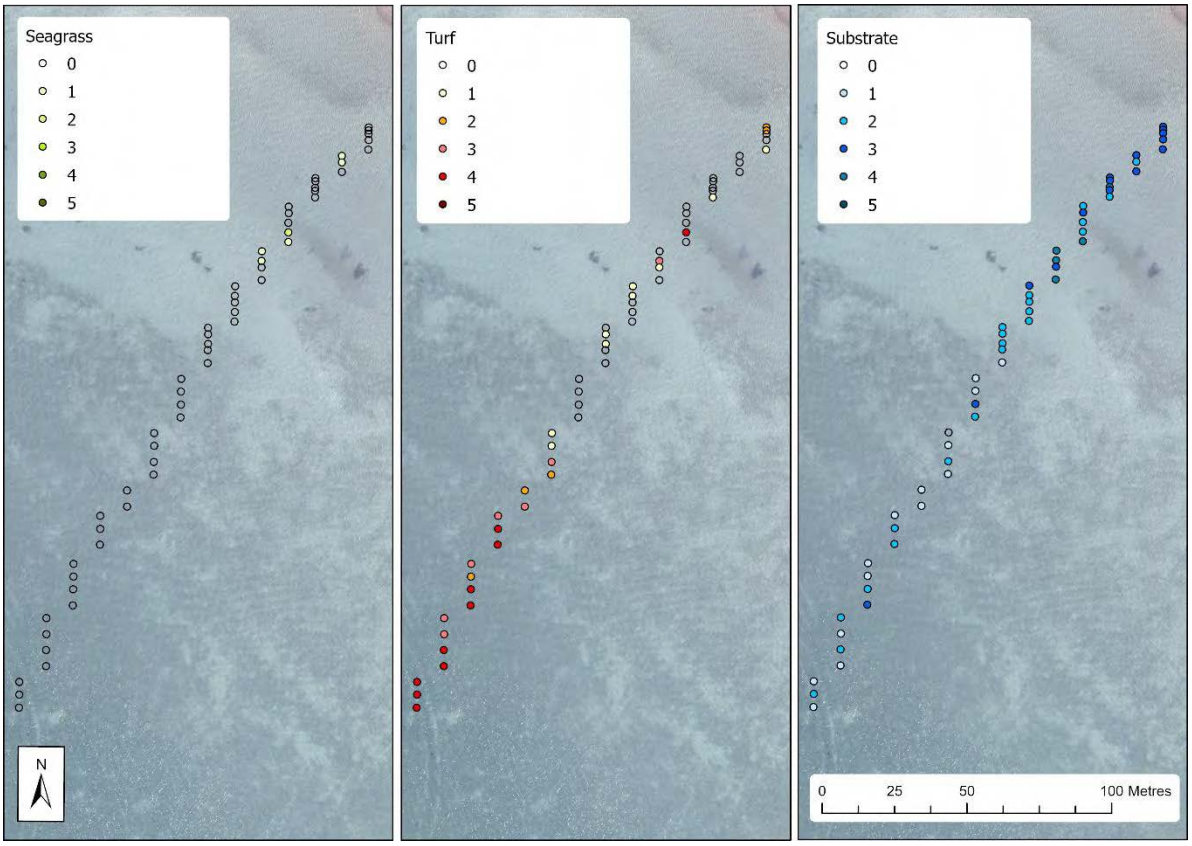
Characterising imagery for Section 1 of Transect M3B (algal turf).



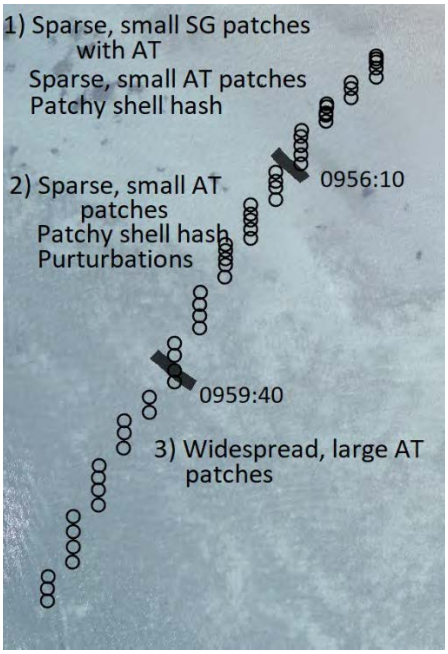
Characterising imagery for Section 2 of Transect M3B (algal turf, MPB).

Transect M4

Transect M4 (270 m long; Waypoints 53–60) is, in effect, the northern part of the transect across the channel that began with M2. It deepens gradually from 0.8 to 2.4 m. There was no drop-camera imagery.



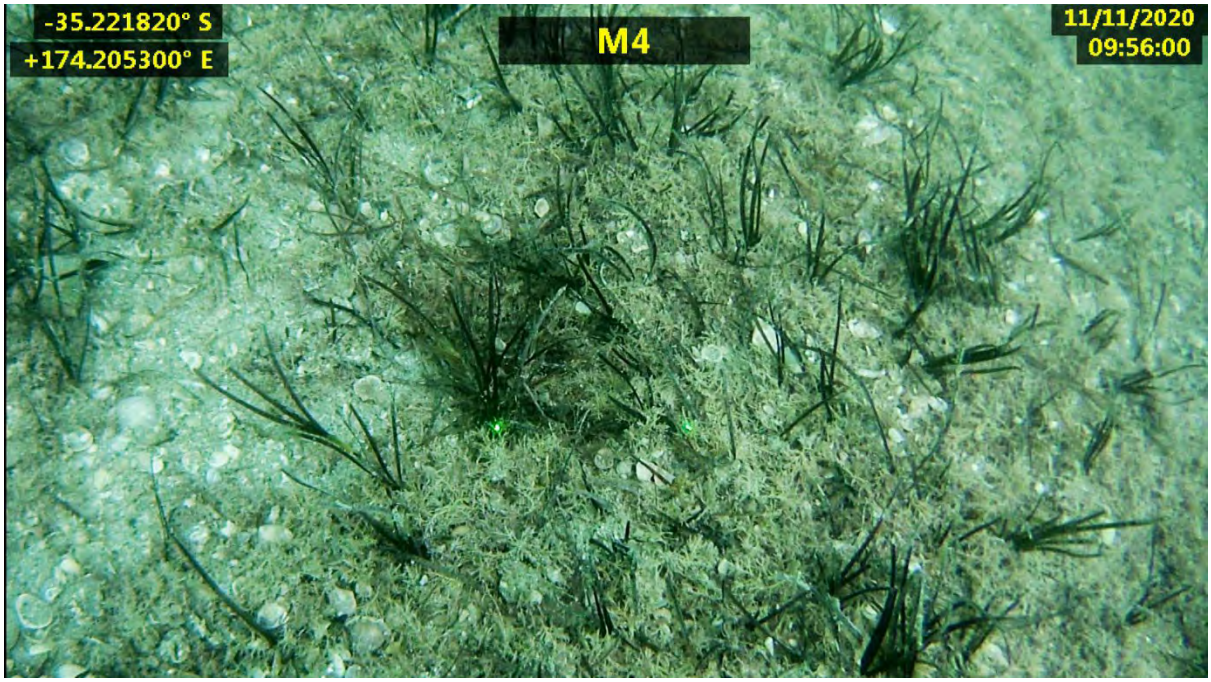
Characterisation of Transect M4 based on 10-second video imagery.

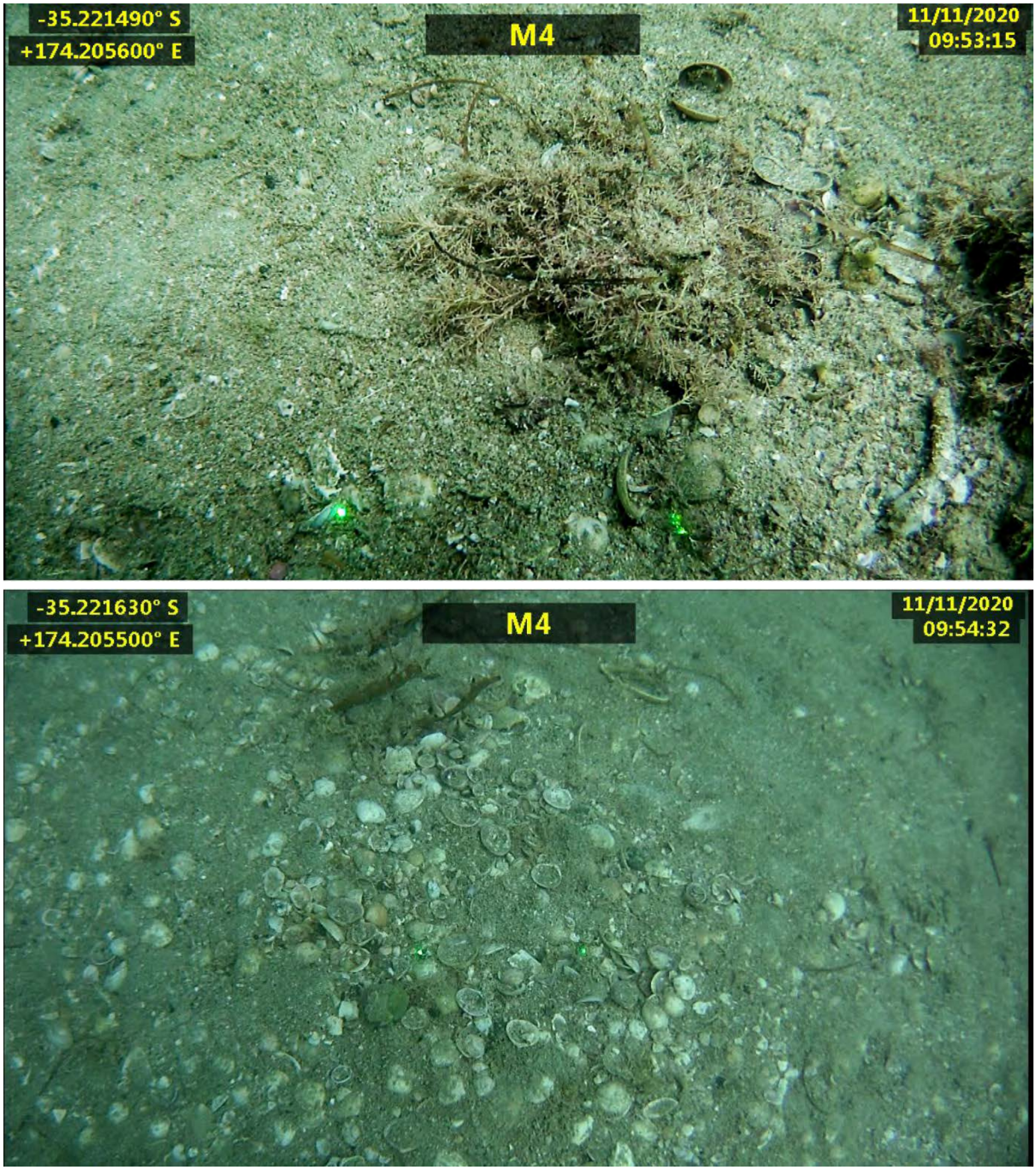


Overall characterisation by section of Transect M4. Times given are from video frames.

Representative imagery for M4

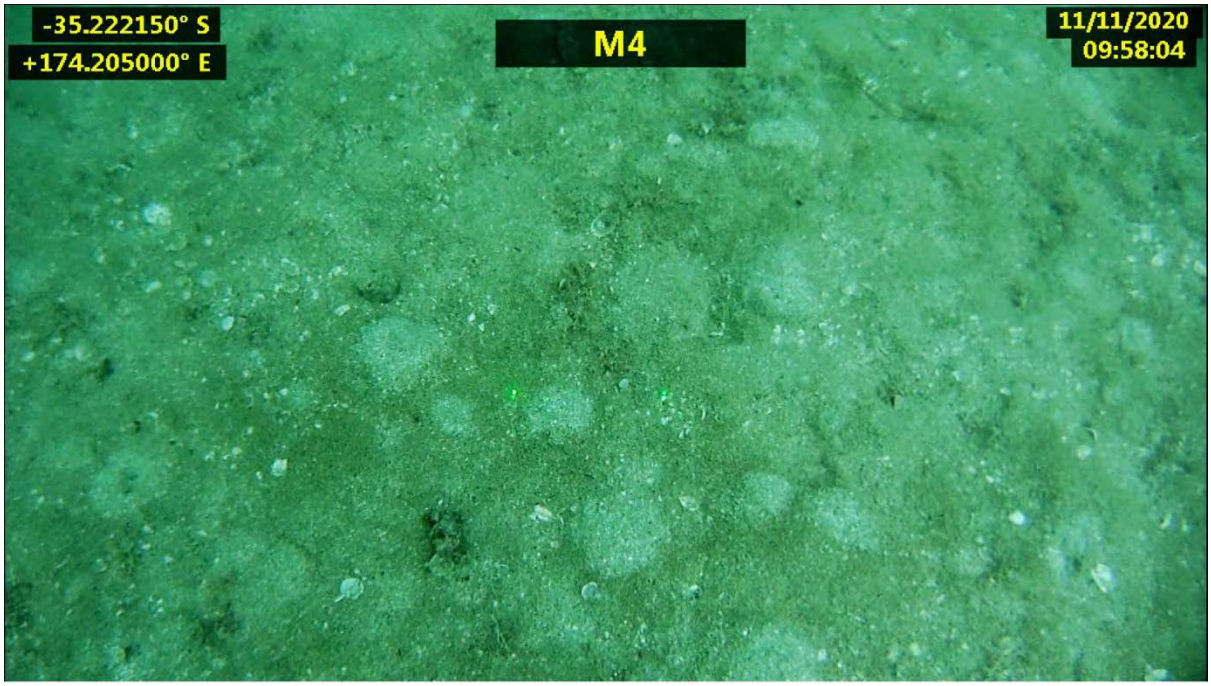
Section 1





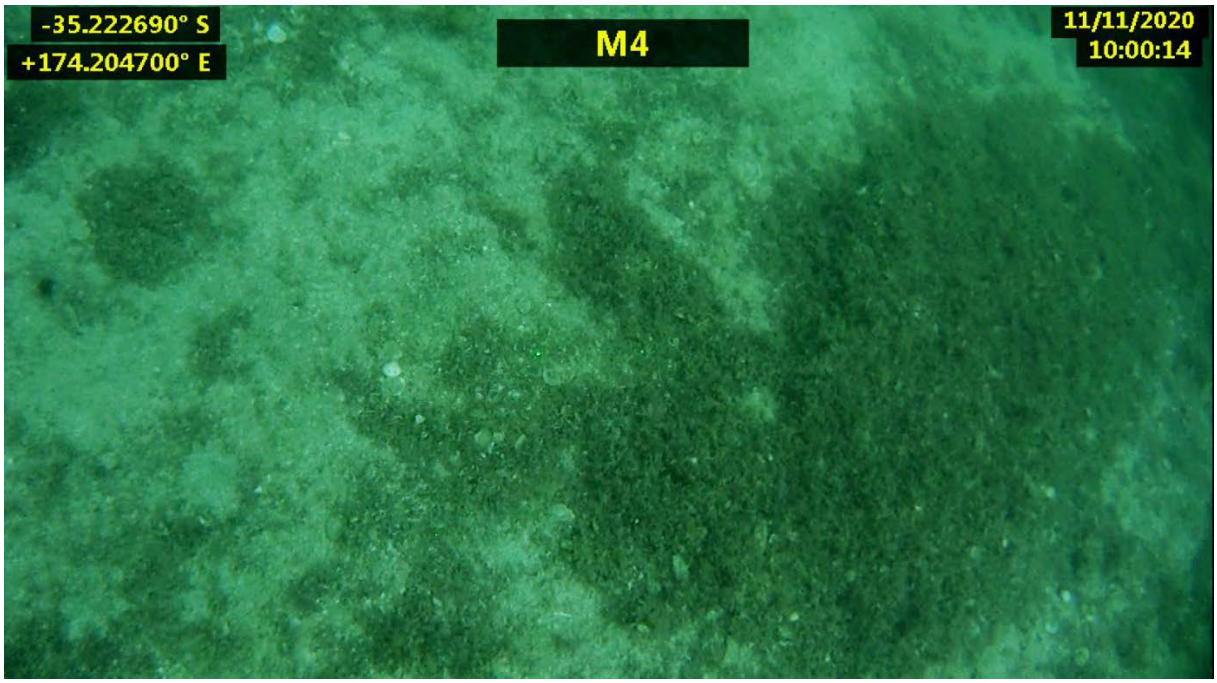
Characterising imagery for Section 1 of Transect M4 (seagrass, algal turf, shell hash).

Section 2



Characterising imagery for Section 2 of Transect M4 (algal turf, shell hash, perturbations).

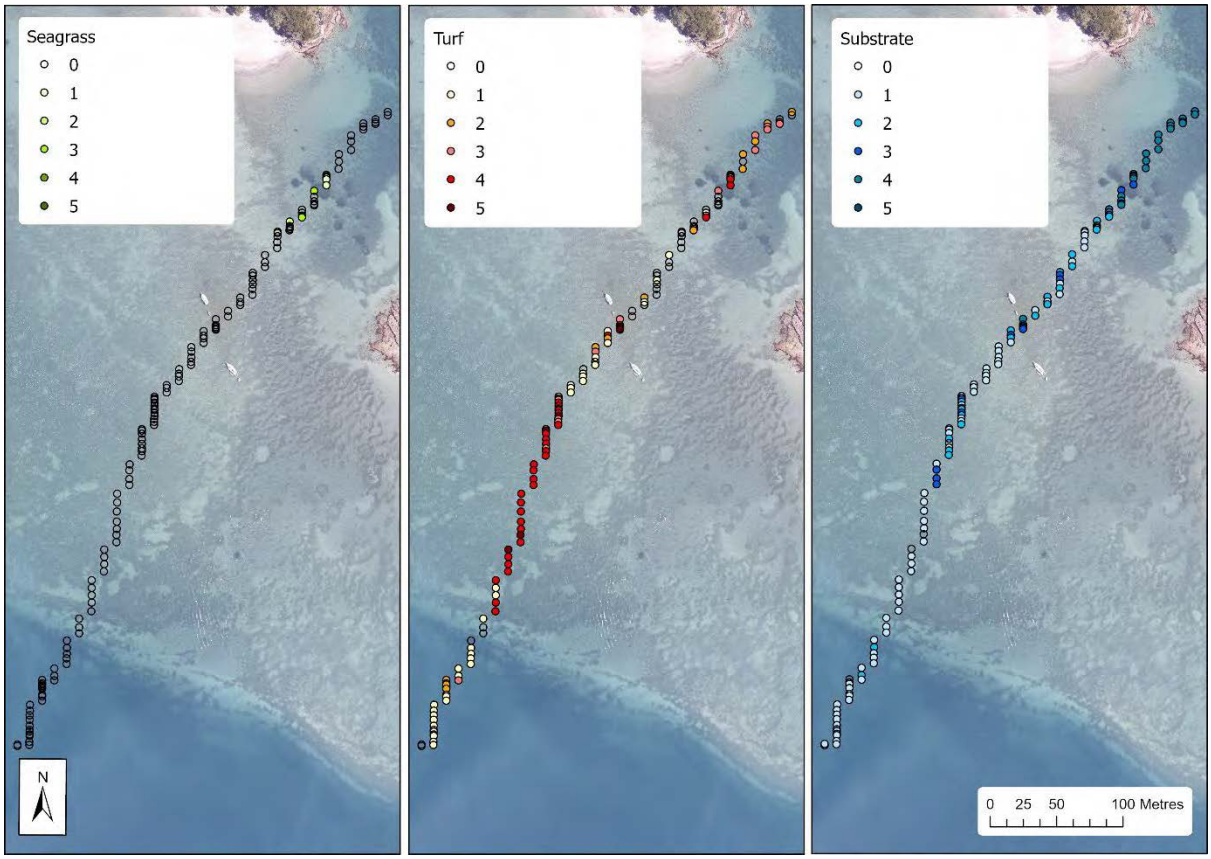
Section 3



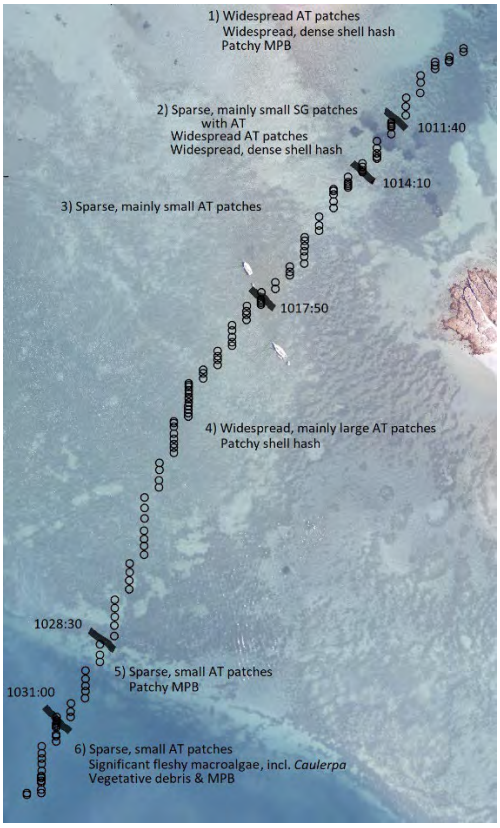
Characterising imagery for Section 3 of Transect M4 (algal turf, shell hash).

Transect M5

Transect M5 (590 m long; Waypoints 61–86) extends southward across the eastern part of Motukiekie Channel. It begins at 3.4 m depth, shoals gradually to 1.0 m before deepening gradually to 4.0 m, deepening steeply to 9 m, and then dropping gradually to 10.6 m. There was drop-camera imagery at Waypoints 63, 65, 67, 70, 77, and 79.



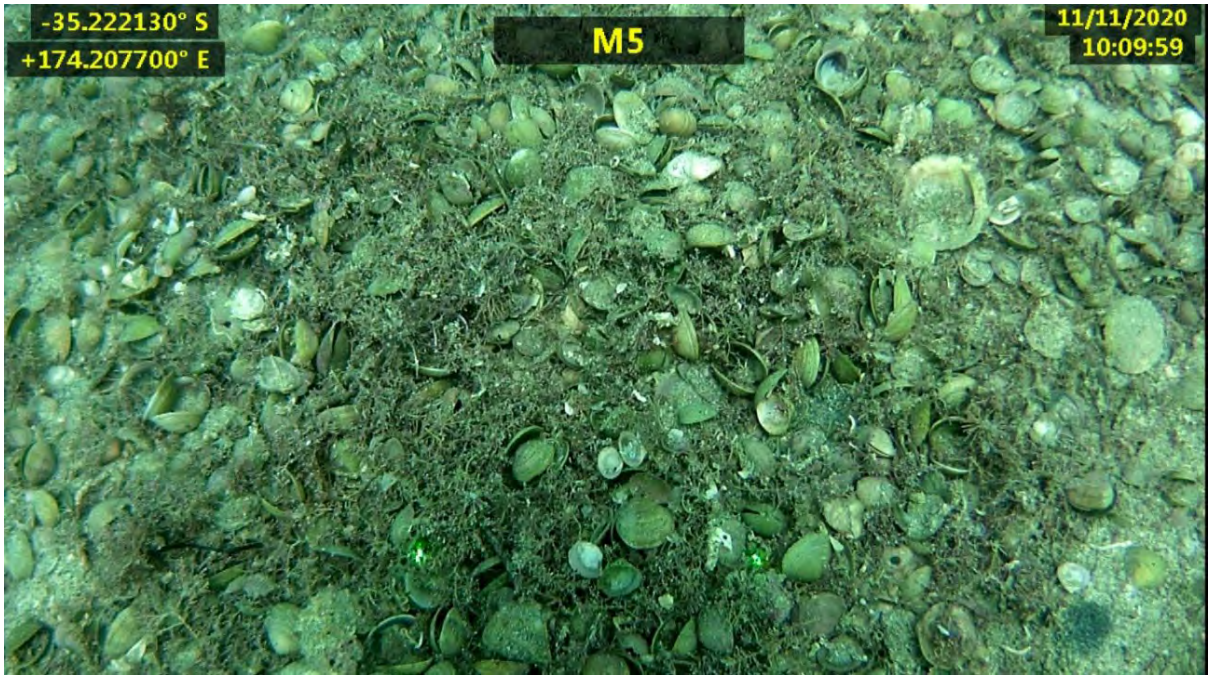
Characterisation of Transect M5 based on 10-second video imagery.



Overall characterisation by section of Transect M5. Times given are from video frames.

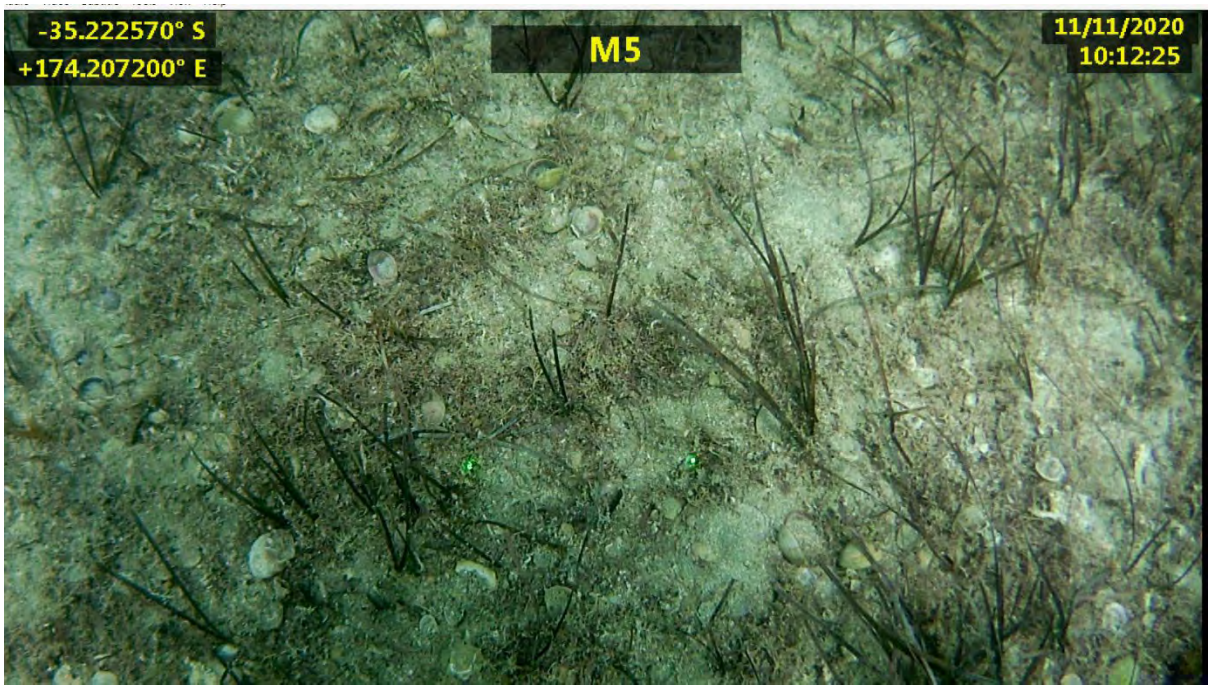
Representative imagery for M5

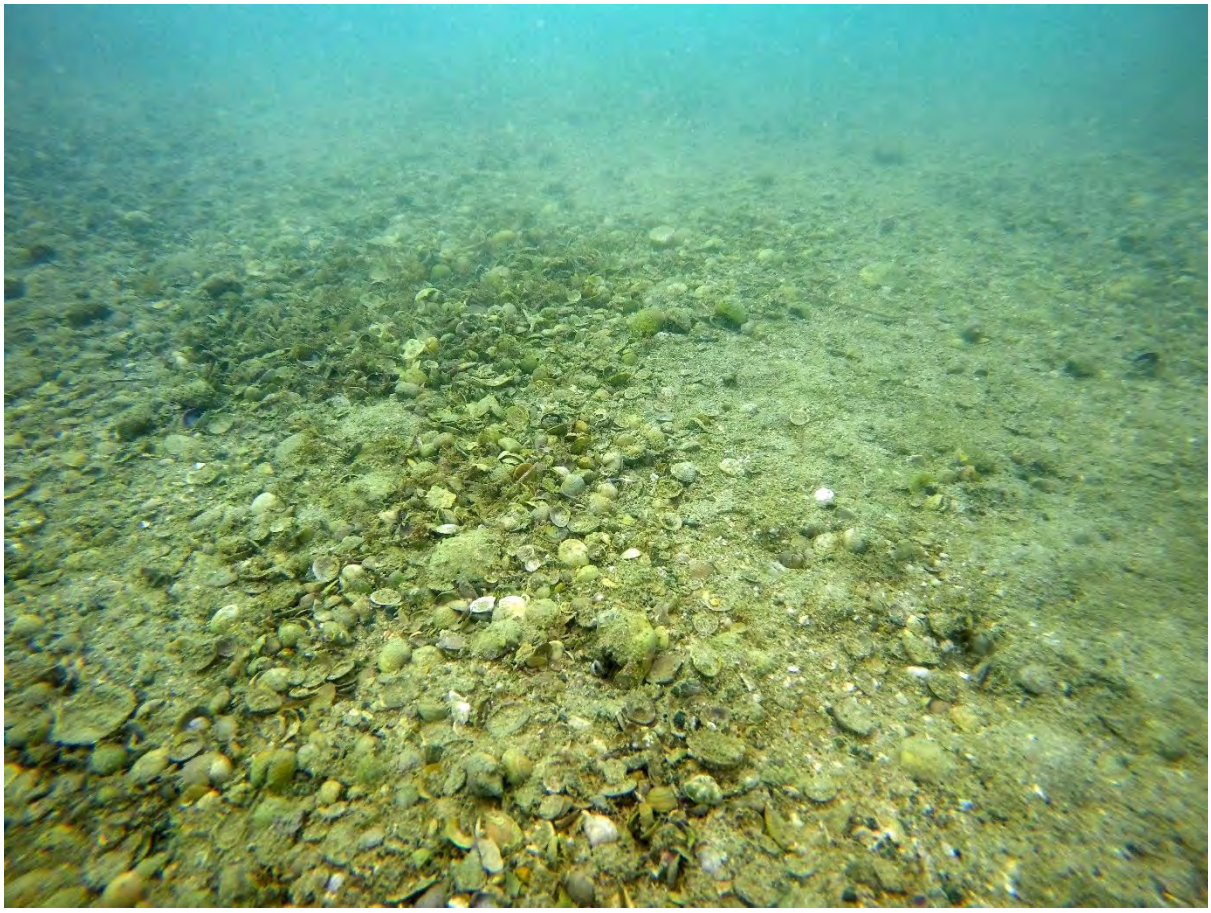
Section 1



Characterising imagery for Section 1 of Transect M5 (algal turf, shell hash).

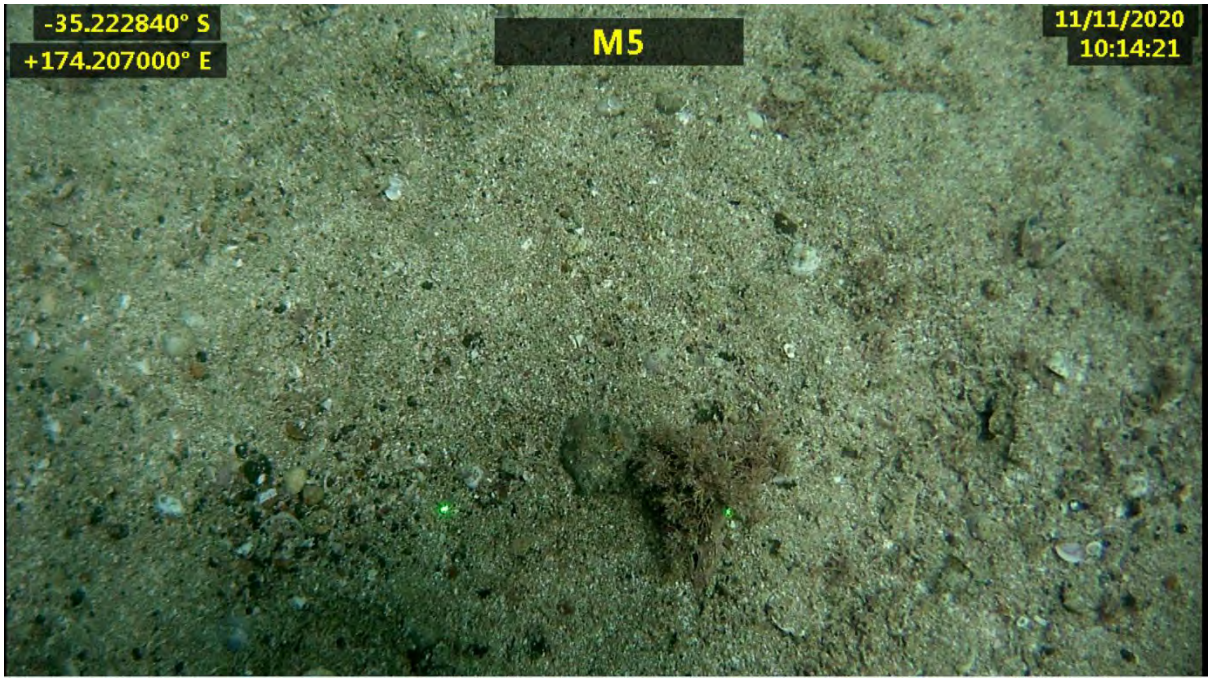
Section 2





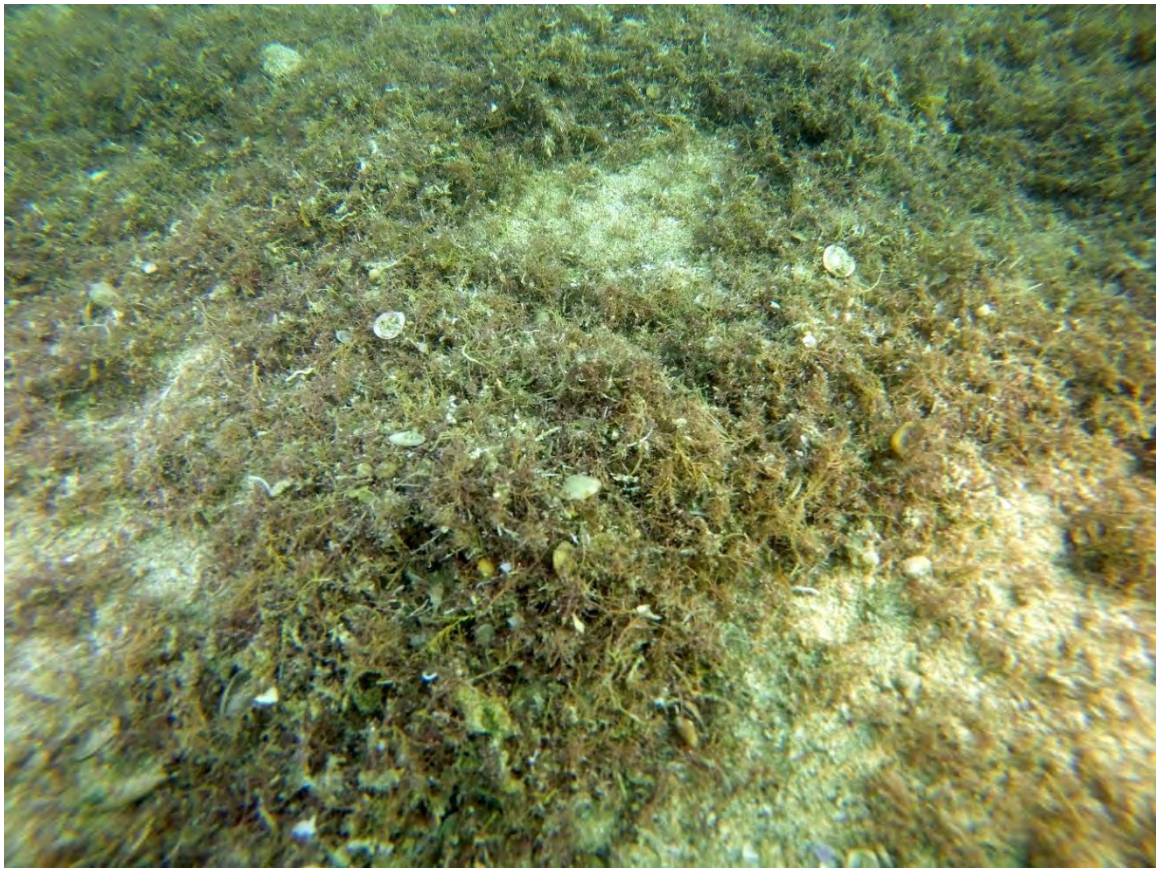
Characterising imagery for Section 2 of Transect M5 (seagrass, algal turf, shell hash).

Section 3



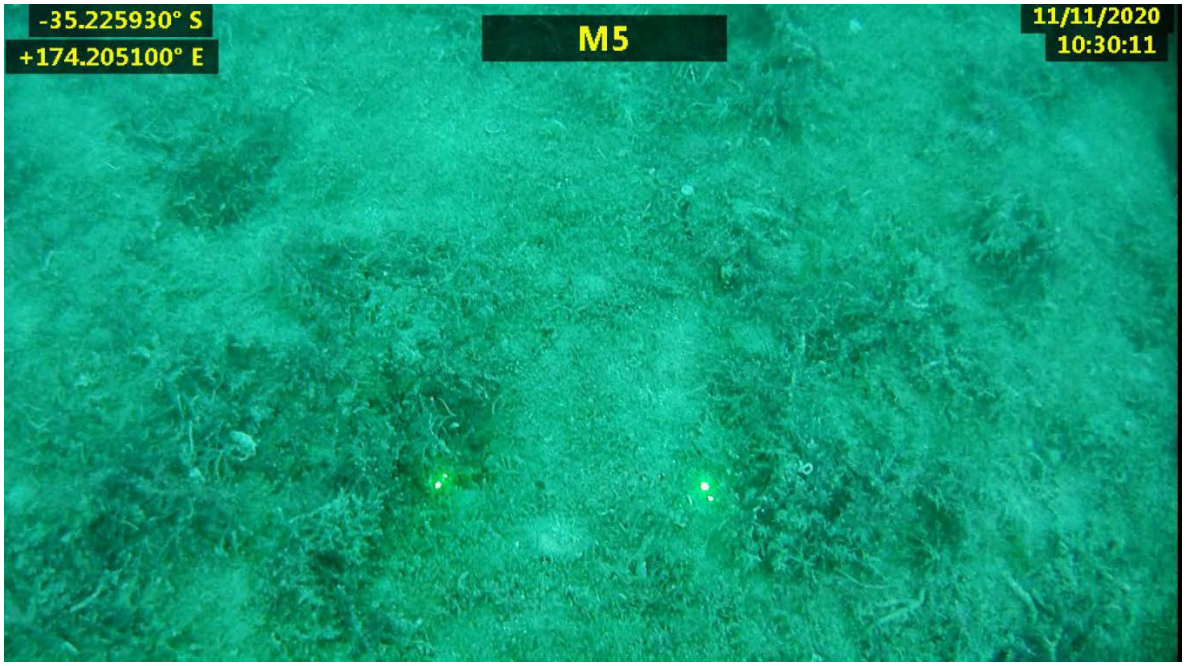
Characterising imagery for Section 3 of Transect M5 ('clean' sand, algal turf).

Section 4



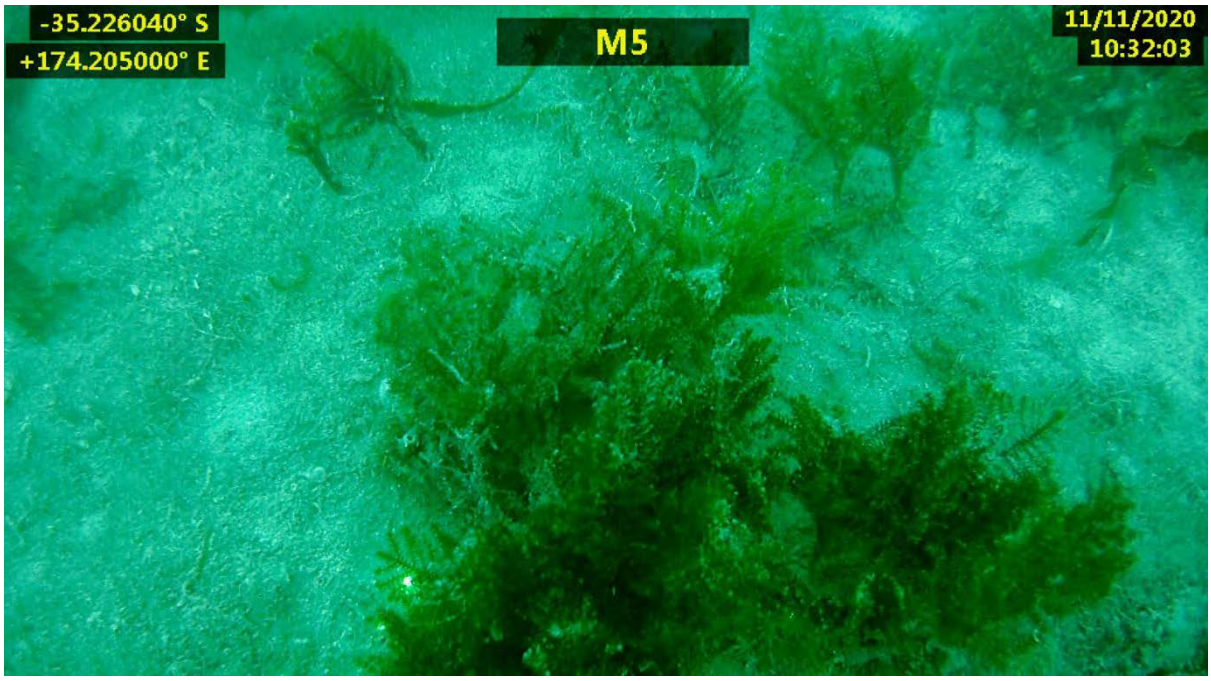
Characterising imagery for Section 4 of Transect M5 (algal turf).

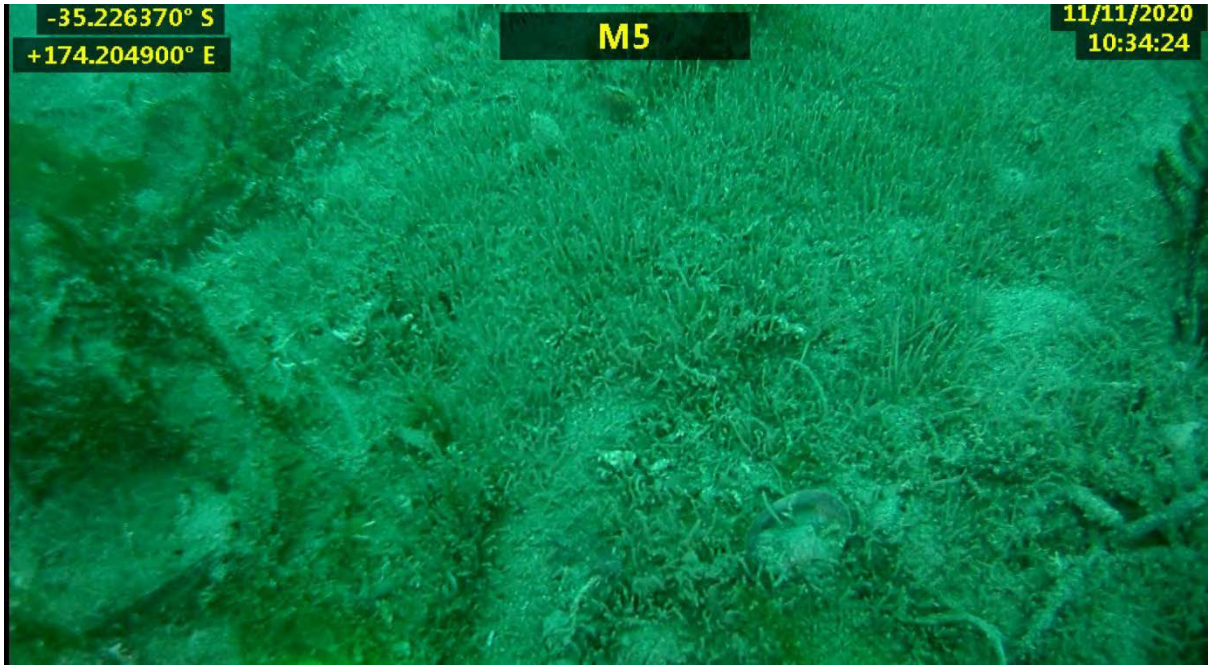
Section 5



Characterising imagery for Section 5 of Transect M5 (algal turf).

Section 6





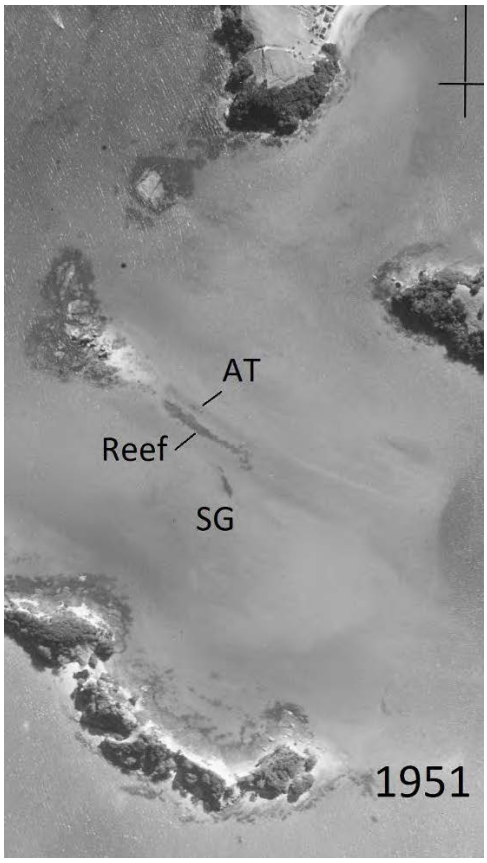
Characterising imagery for Section 6 of Transect M5 (macroalgae, worm field).

APPENDIX 2: Historical distribution of putative biomes

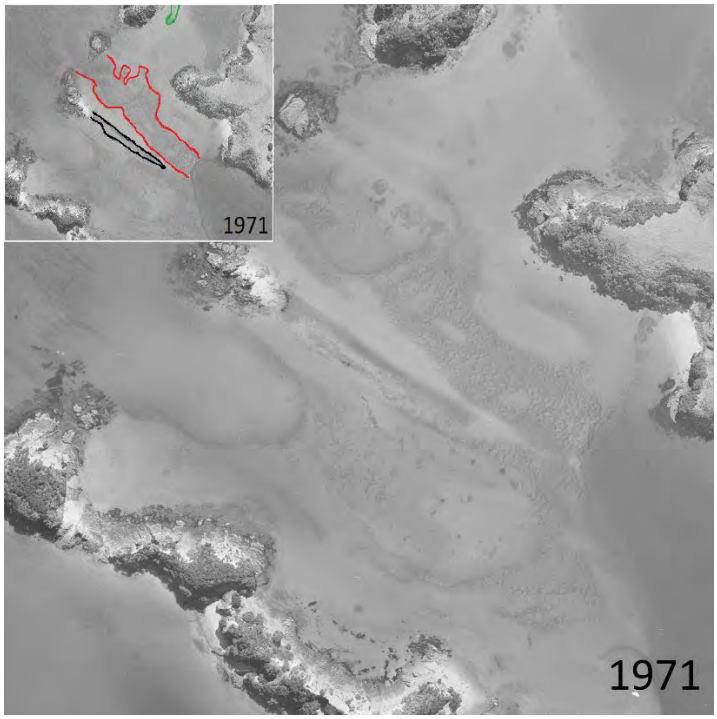
This section uses representative, synoptic aerial imagery to qualitatively establish changes in extent over time in the distribution of the putative seagrass and algal-turf biomes. Each historical image is accompanied by an interpretation of the distributions of biomes visible. Image quality varies considerably and was generally insufficient to allow areal extents to be calculated with any precision. Also, the timing of useful images was different for each study site. Finally, the generally-shallow seagrass shows more darkly in the imagery than the algal turf, so there is more confidence around its changes in extent over time. Unsurprisingly, older images are least-well represented, with the earliest located being from 1942, for SE Moturua. The pre-1990 images shown here are the only useful ones known to exist. There are, however, later (mainly post-2000) images that have not been used (e.g., historical Google Earth), but examination of many of these did not suggest anything different in the biome distributions from that shown here. The 'Crown' images are available at https://retrolens.co.nz/.

A2.1 Poroporo Channel

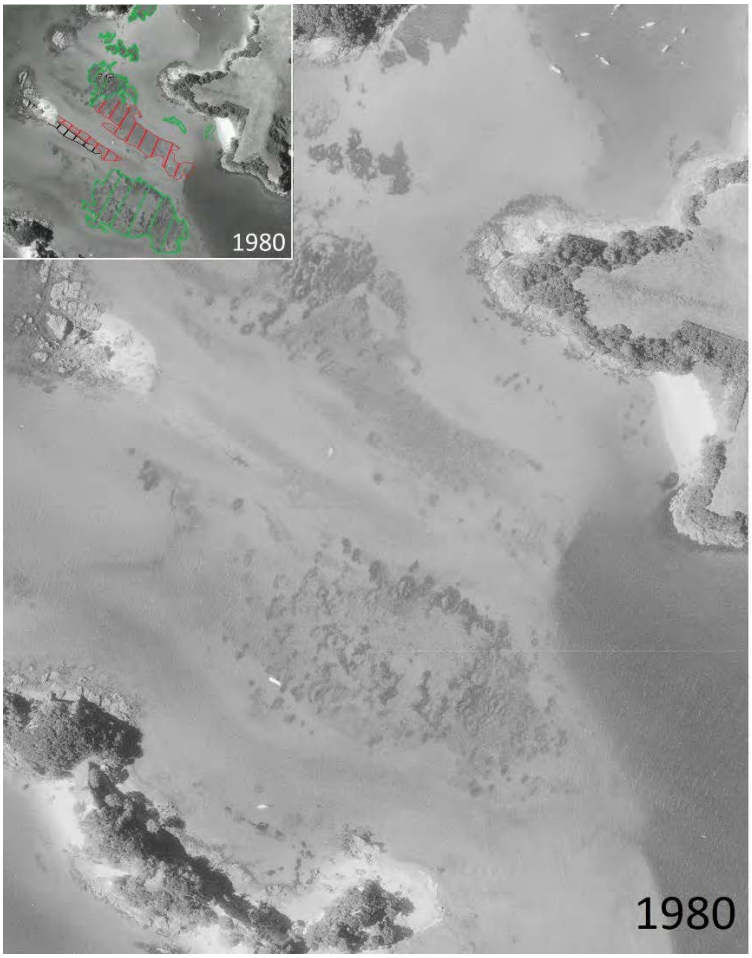
The resolution of the earliest image (1951) is such that seafloor biological and physical features cannot be determined with confidence. However, the impression is that the nature and orientation of contrasting light/darker features correspond with the distribution of biomes seen today. From 1980, the putative seagrass and algal turf, and reef, are distinguishable. The images then suggest relative stability over time in the distribution of the algal turf, but with greater changes in the extent of the surface expression of the seagrass. Seagrass was widespread in 1980, had become greatly diminished in extent in 2009, and was then obvious from 2014–16 onwards. The main localities of seagrass remained the same irrespective of the surface manifestation, suggesting root systems remained intact over time. The northwest/southeast orientation of at least the algal-turf biome is probably attributable to tidal currents.



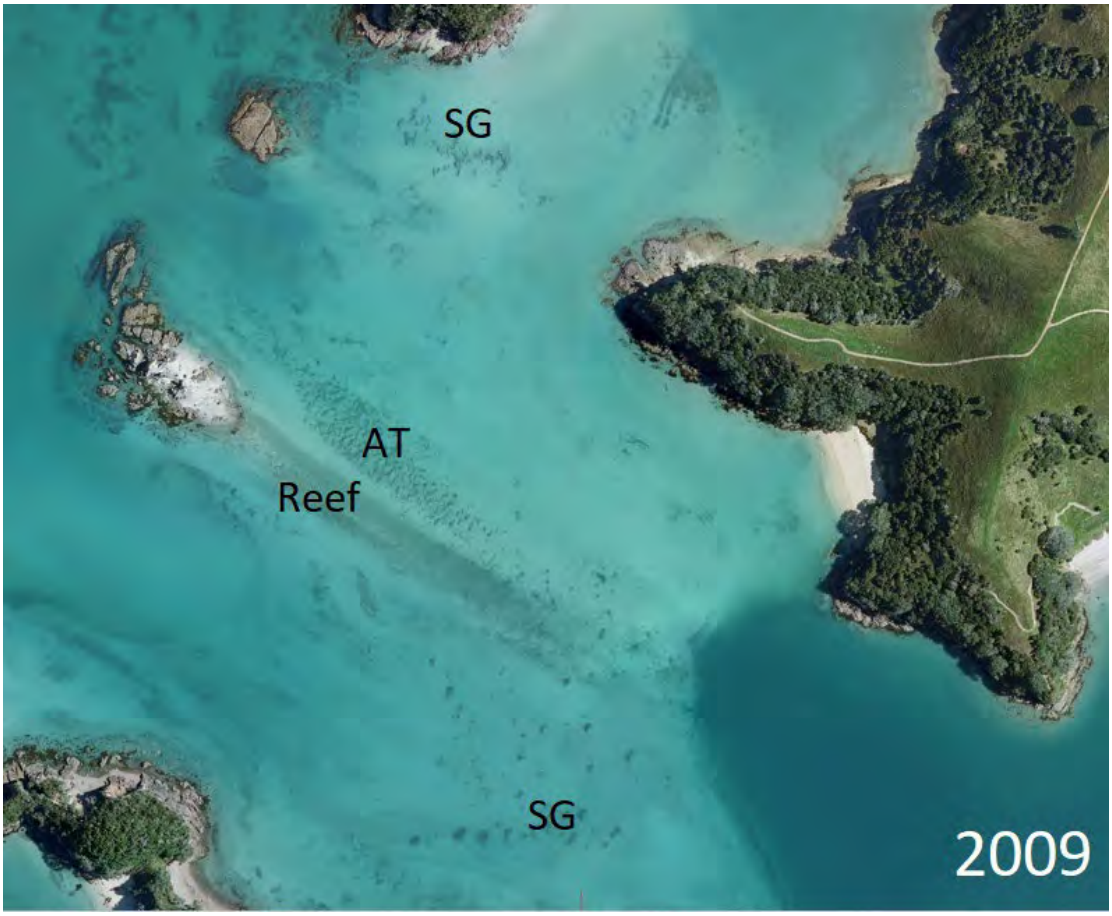
Poroporo Channel aerial image in 1951 (Crown_209_543_21). AT, algal turf; SG, seagrass.



Poroporo Channel aerial image in 1971 (Crown_3406_4478_19). The inset provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf; black, reef.



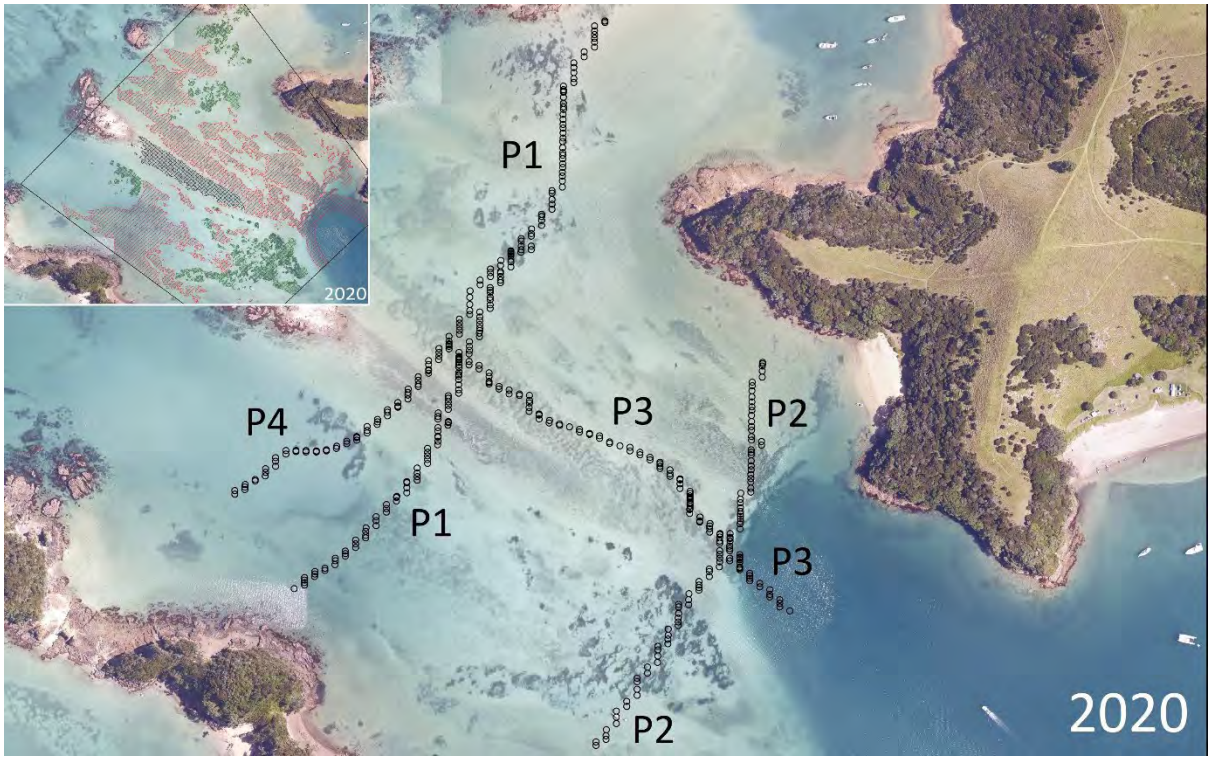
Poroporo Channel aerial image in 1980 (Crown_5651_J_6). The inset provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf; black, reef.



Poroporo Channel aerial image in 2009 (Bay of Islands Ocean Survey 20/20). AT, algal turf; SG, seagrass.



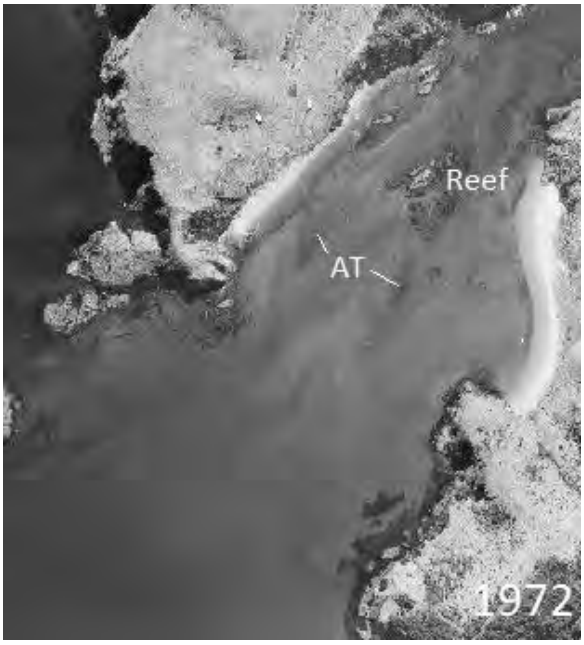
Poroporo Channel aerial image in 2014-16 (NRC). The inset provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf; black, reef.



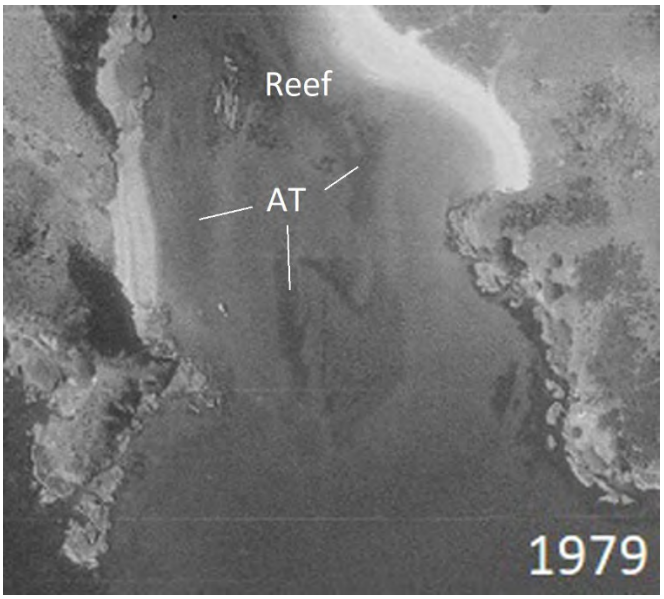
Poroporo Channel aerial image in 2020 (present study). The inset provides our interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf; black, reef.

A2.2 Okahu Passage

The resolution of the earliest images (1972 and 1979) is such that seafloor biological and physical features cannot be determined with confidence. Only algal turf and reef are distinguishable in the later imagery; seagrass would be expected to show more darkly. Accordingly, although the images suggest stability over time in the distribution of the algal turf, it is unlikely there has been extensive seagrass coverage here in recent times.



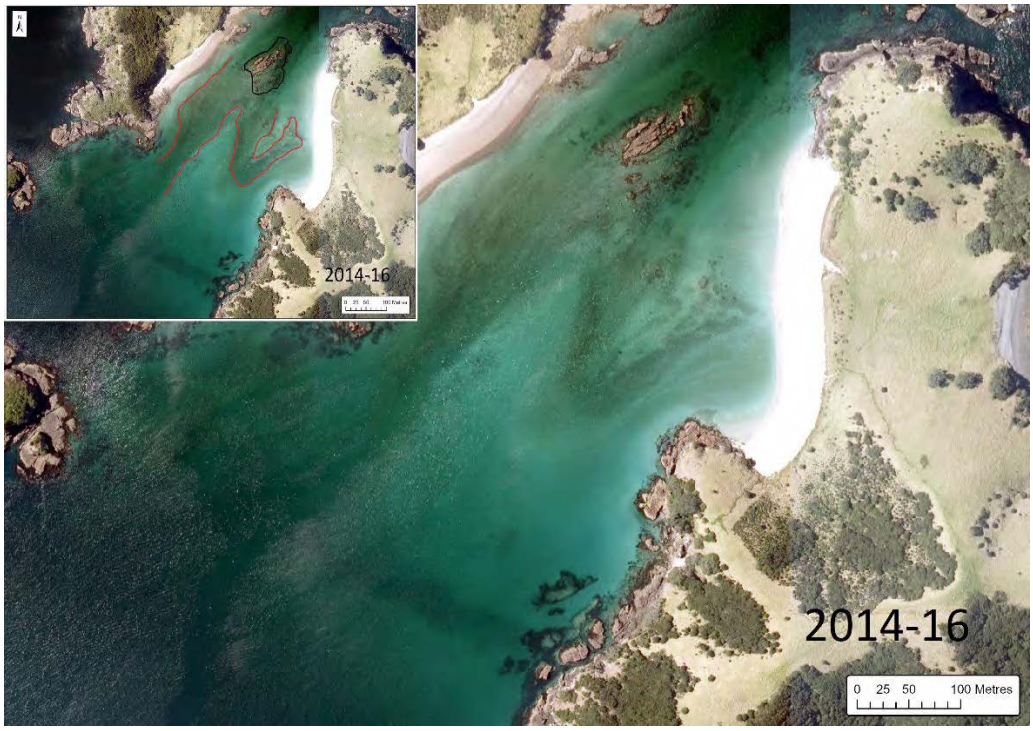
Okahu Passage aerial image in 1972 (Crown_3406_4477_24).



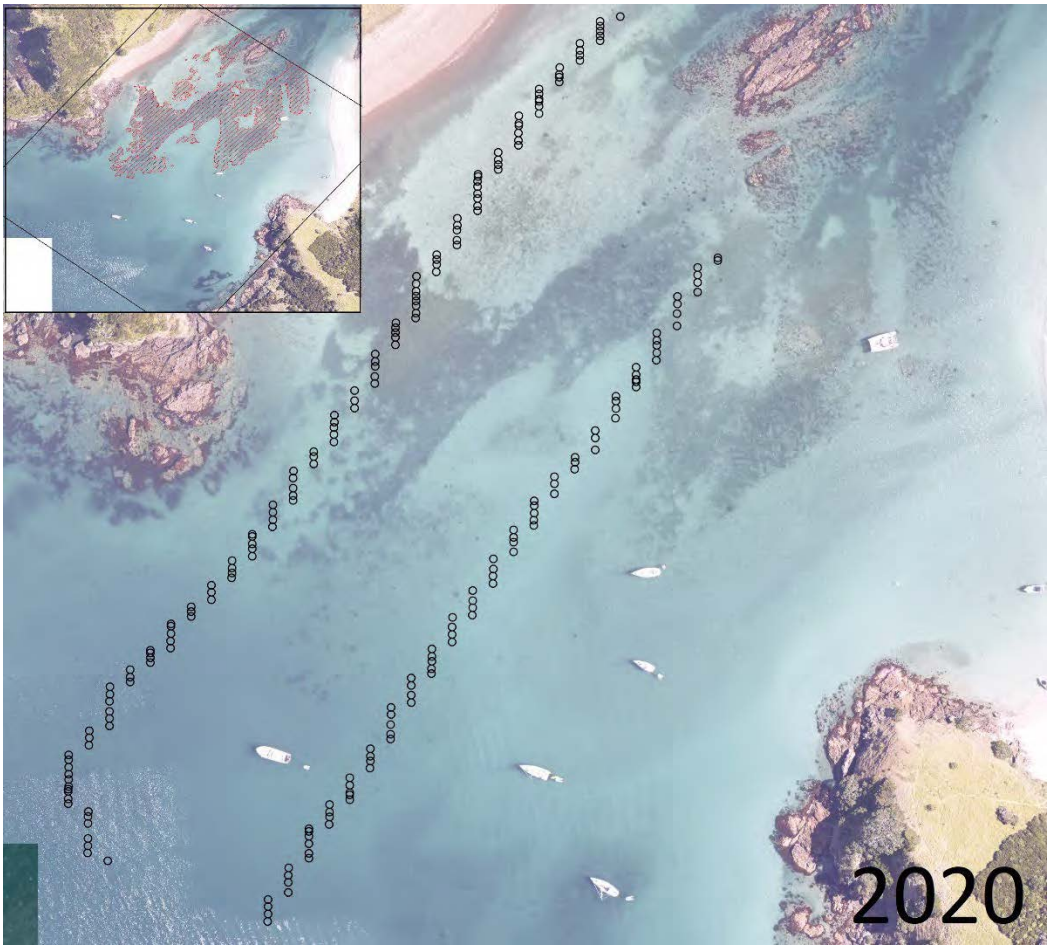
Okahu Passage aerial image in 1979 (Crown_5006_J_3_1).



Okahu Passage aerial image of biomes in 2009 (Bay of Islands Ocean Survey 20/20). The inset provides an interpretation of the distribution of biomes. Red, putative algal turf; black, reef.



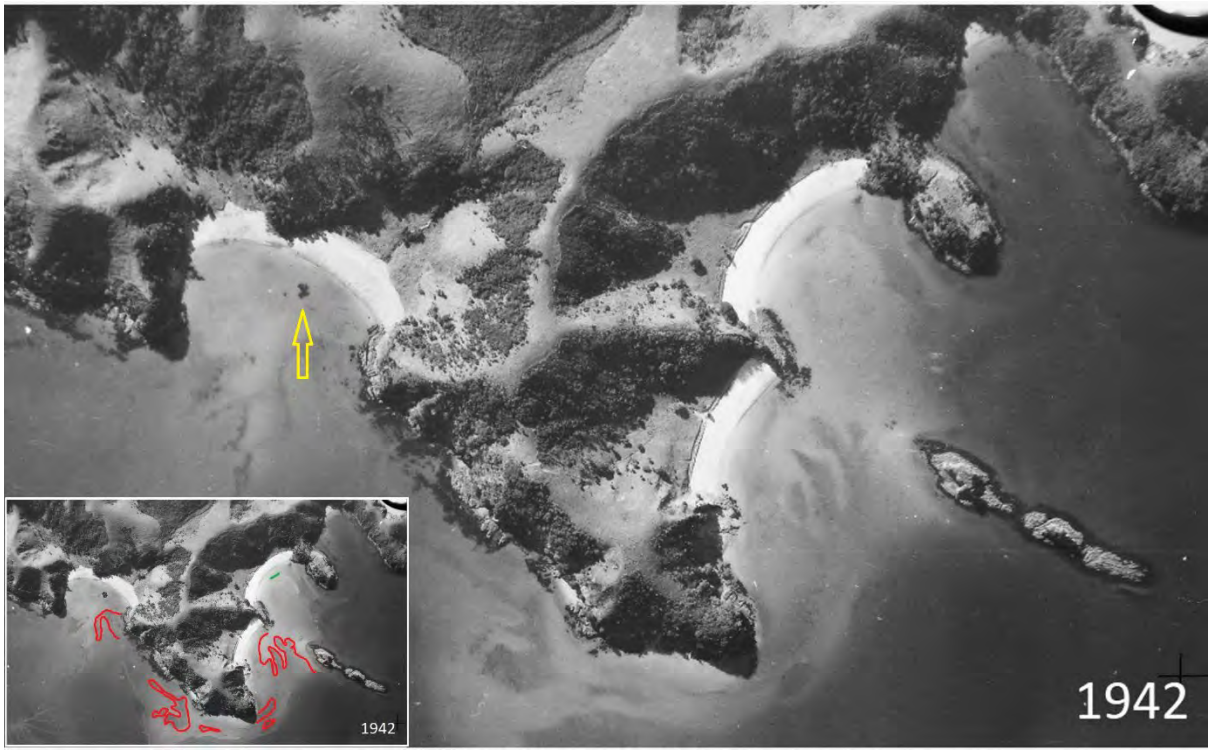
Okahu Passage aerial image of biomes in 2014-16 (NRC). The inset provides an interpretation of the distribution of biomes. Red, putative algal turf; black, reef.



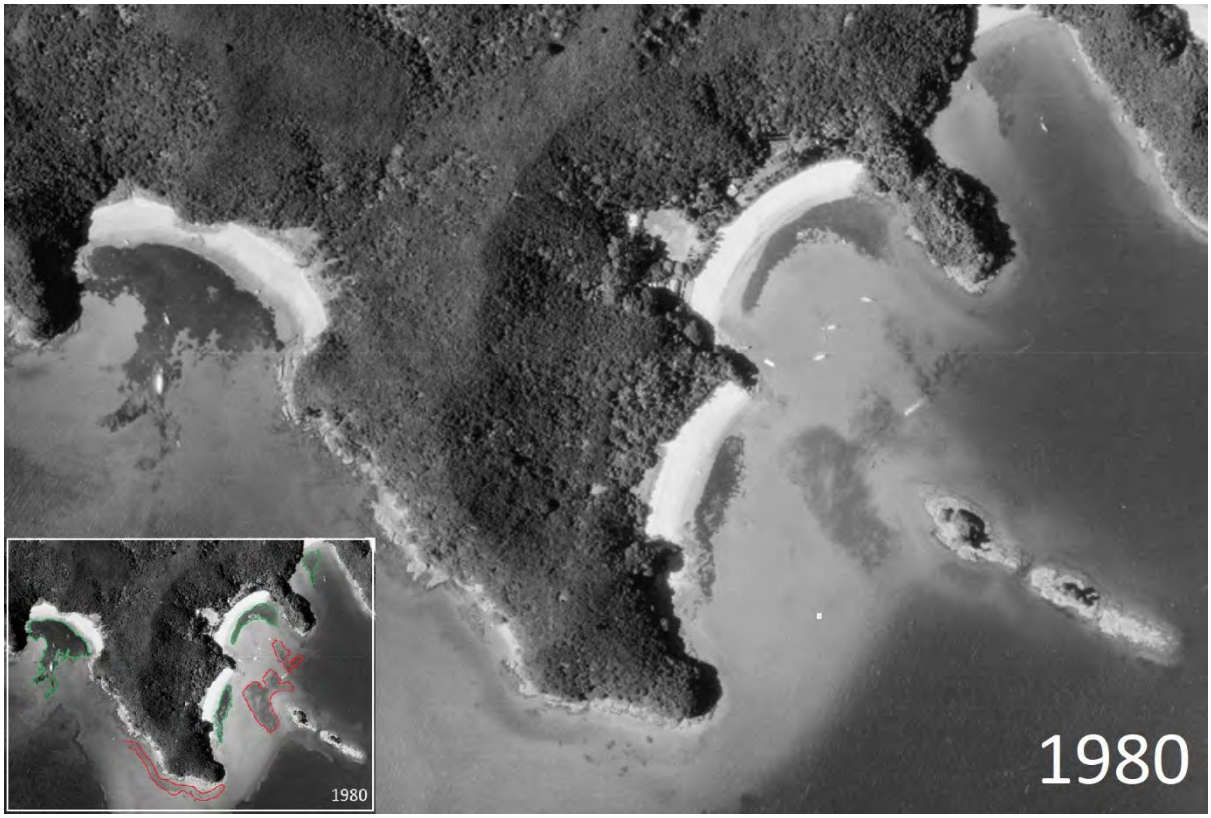
Okahu Passage aerial image in 2020 (present study). The inset provides our interpretation of the distribution of biomes. Red, putative algal turf; black, reef.

A2.3 SE Moturua

In general, the nature and orientation of contrasting light/dark features suggest concurrence in the distribution of the putative biomes over time. In 1942, however, there was little evidence for seagrass, and the algal turf is difficult to distinguish. By 1980, there was extensive seagrass in all the bays, but – again – the algal turf was probably much-more widespread than apparent. Seagrass had decreased in extent by 2009, but had became increasingly widespread to 2020. Further, the main locations of seagrass remained the same irrespective of the level of surface manifestation.



SE Moturua aerial image of biomes in 1942 (Air Force Museum of New Zealand: enlNZAMtin138frameA5). The small dark patch in the bay to the left is kelp-covered rock (arrowed). The insert provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf.



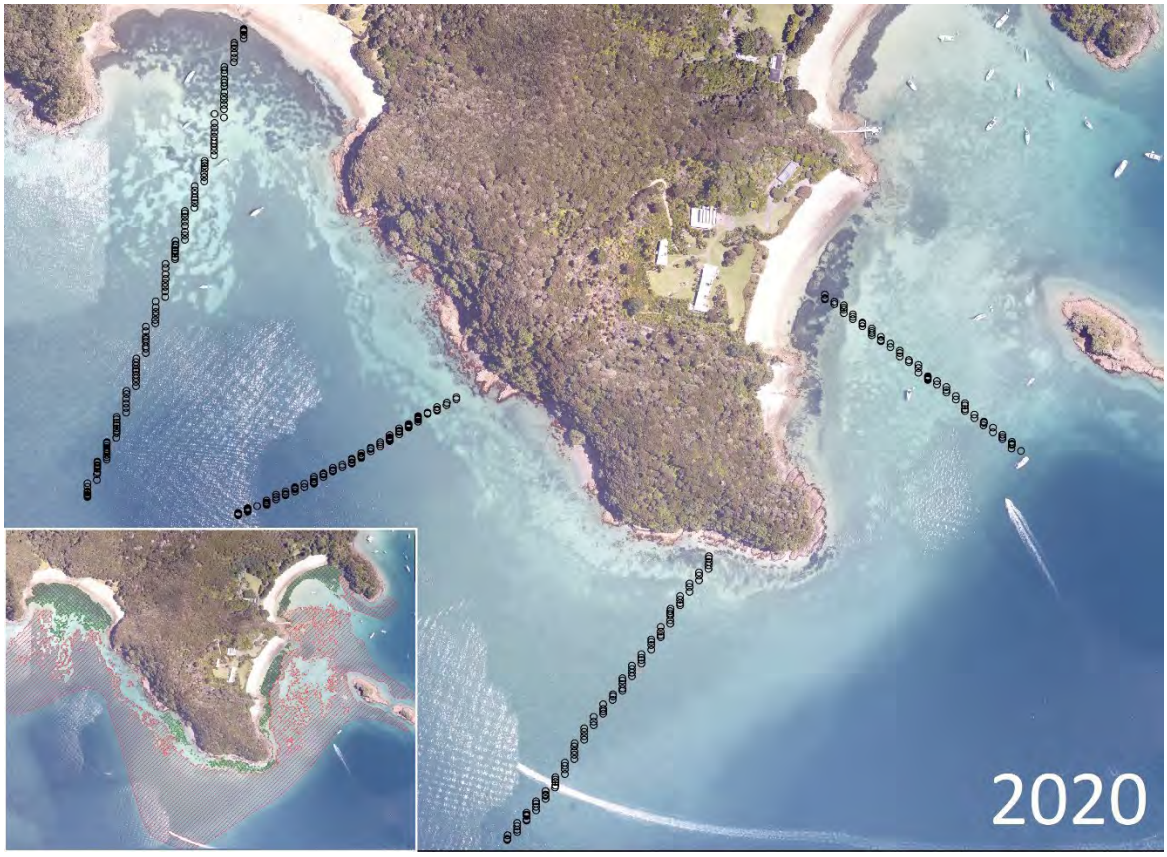
SE Moturua aerial image of biomes in 1980 (Crown_5651_J_4). The insert provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf.



SE Moturua aerial image of biomes in 2009 (Bay of Islands Ocean Survey 20/20). Green, putative seagrass; red, putative algal turf.



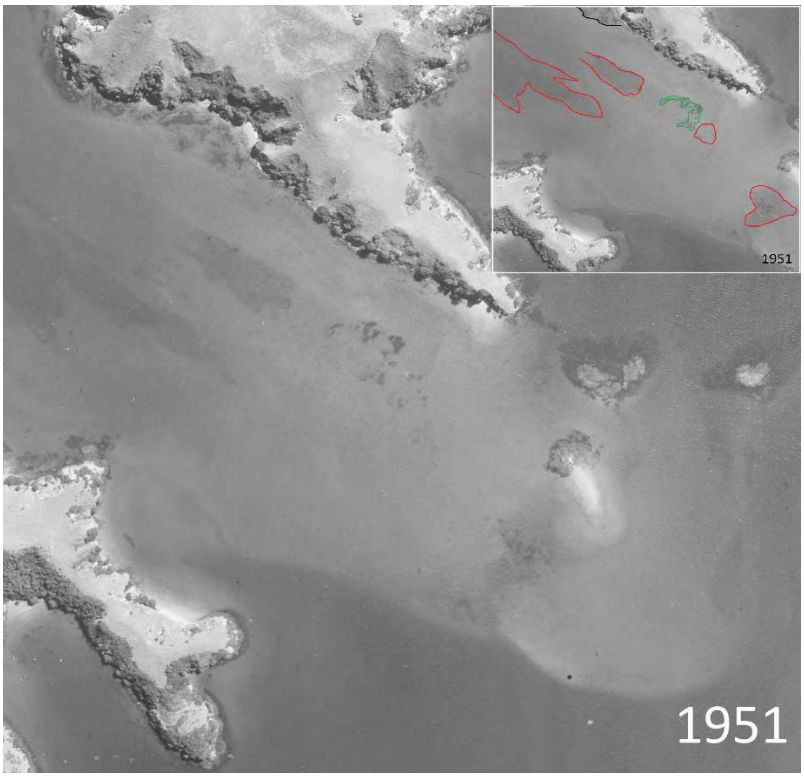
SE Moturua aerial image of biomes in 2014–16 (NRC). The insert provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf.



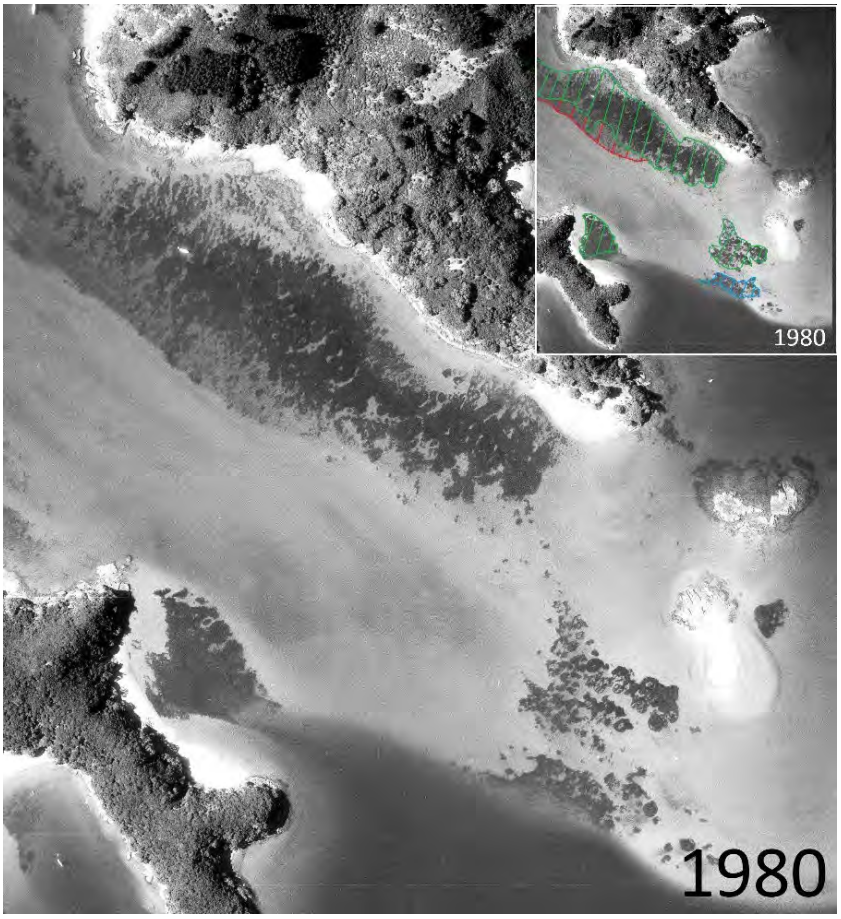
Southeast Moturua aerial image in 2020 (present study). The insert provides our interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf.

A2.4 Motukiekie Channel

The nature and orientation of contrasting light/dark features suggest general concurrence in the distribution of biomes over time – but image resolution is variable. At least since 2009, the algal turf has been similarly distributed in the channel. The seagrass biome appeared to exhibit variability in extent over time, being widespread in 1980 and possibly extending to considerable depths in the southeast. It had then decreased in extent by 2009, but became increasingly widespread to 2020. The main localities of seagrass remained the same irrespective of the level of surface manifestation.



Motukiekie Channel aerial image of biomes in 1951 (Crown_209_542_17). The insert provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf.



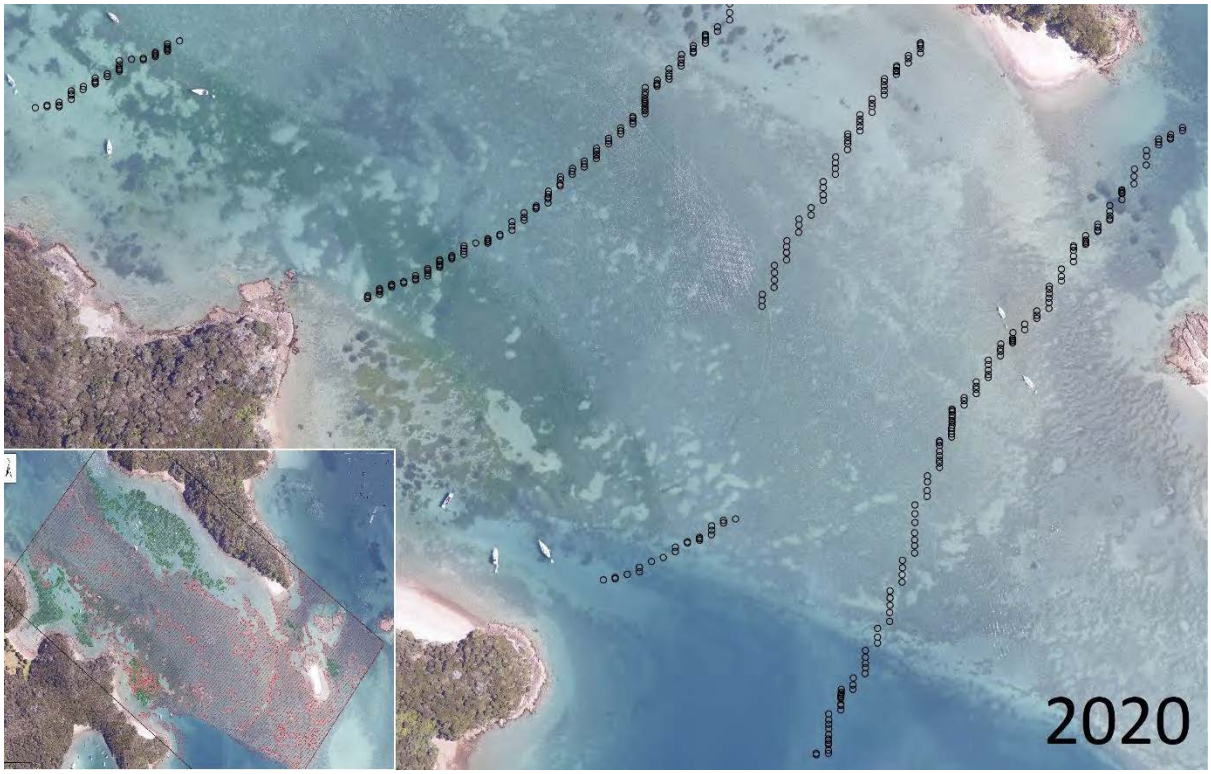
Motukiekie Channel aerial image of biomes in 1980 (Crown_5651_J_4). The insert provides an interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf; blue, unresolved.



Motukiekie Channel aerial image of biomes in 2009 (Bay of Islands Ocean Survey 20/20). The insert provides an interpretation of the distribution of biomes. Red, putative algal turf; black, reef.



Motukiekie Channel aerial imagery showing the indicative distribution of biomes in 2014-16 (NRC). The insert provides an interpretation of the distribution of biomes. Red, putative algal turf.

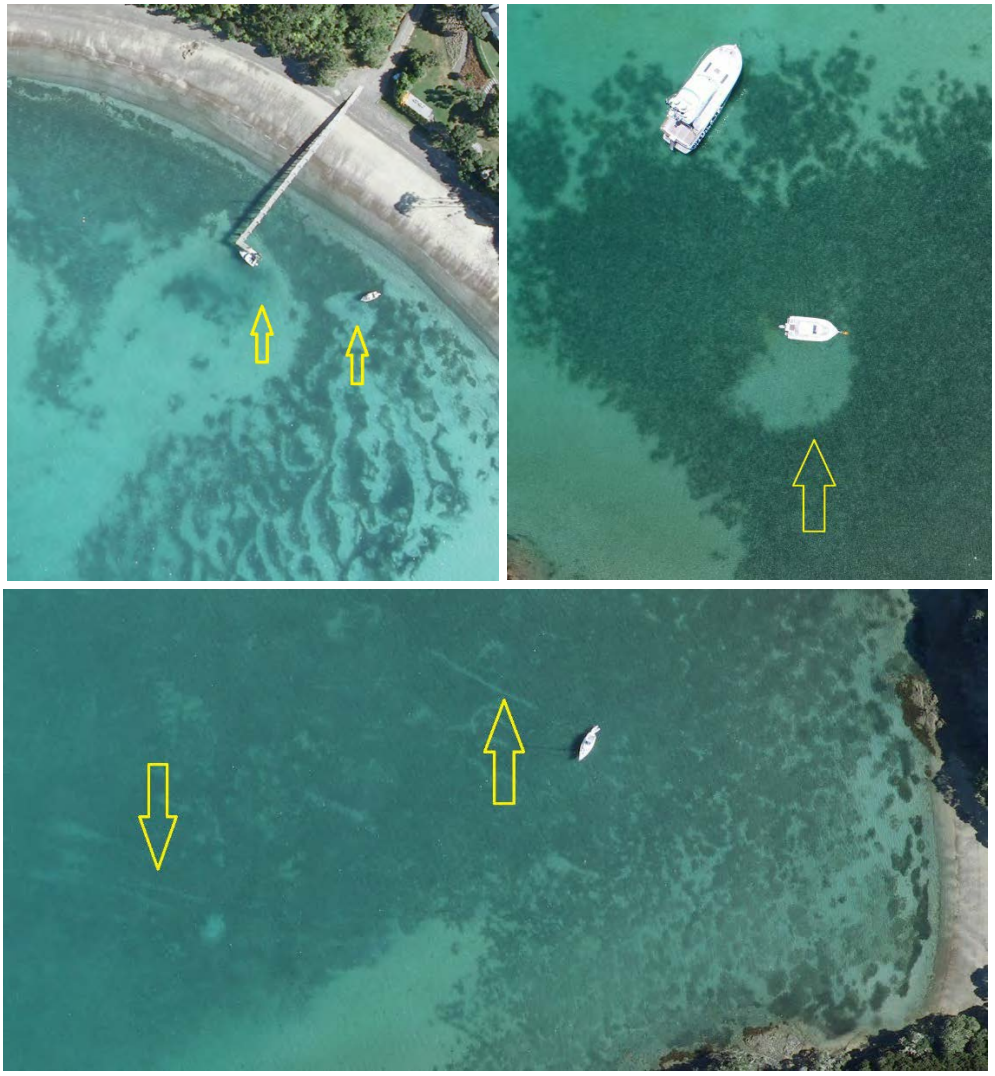


Motukiekie Channel aerial image of biomes in 2020 (present study). The inset provides our interpretation of the distribution of biomes. Green, putative seagrass; red, putative algal turf.

APPENDIX 3: Human impacts on biomes

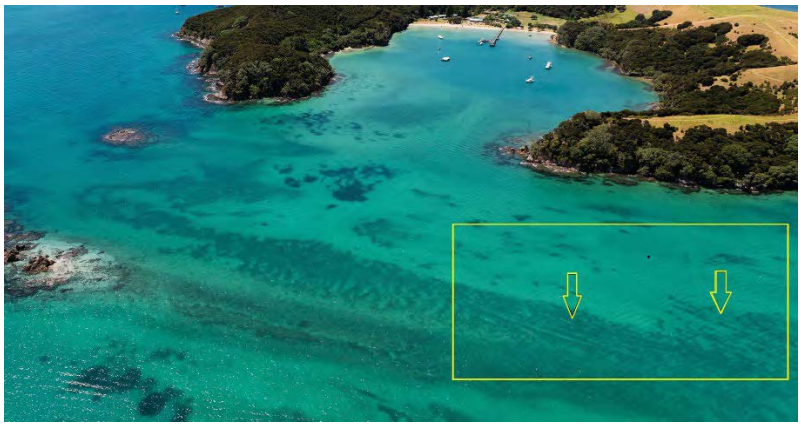
This section offers serendipitous imagery that has come to our attention and which shows human-mediated factors apparently impacting the integrity of the seagrass and algal-turf biomes of Ipipiri Platform (yellow arrows). Illustrative images are submitted in the expectation that they may provide a basis for further investigation of human impacts.

A3.1 Boat manoeuvring, mooring, and anchoring

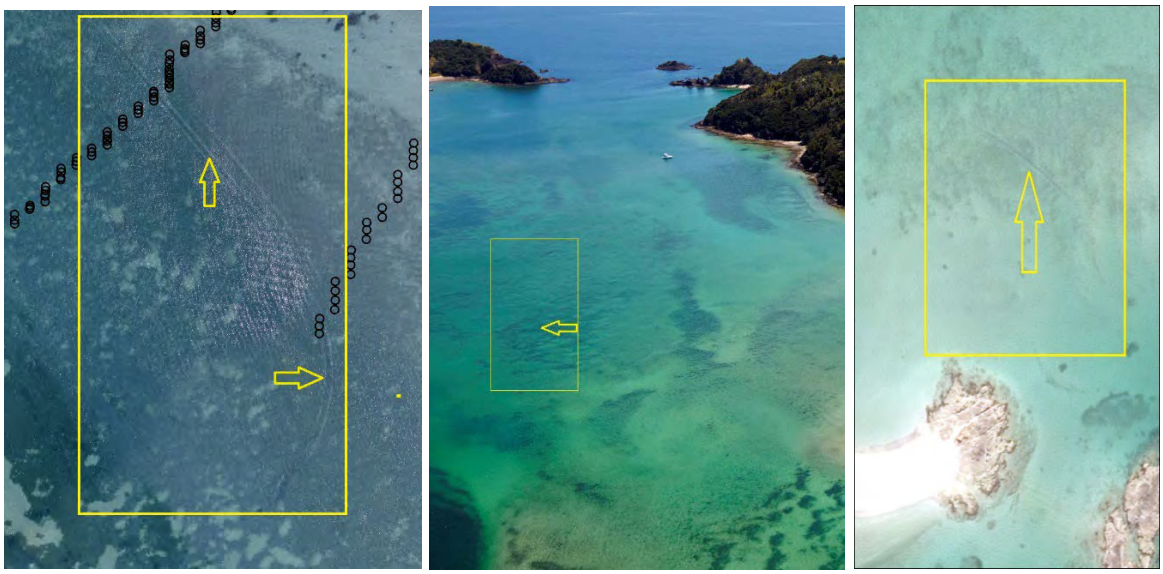


Otarepo Bay, Motuarohia, 2009 (Bay of Islands Ocean Survey 20/20). Seagrass possibly impacted by boat manoeuvring near end of wharf, and a swing mooring to the right (upper left). Moturua, 2020 (NRC). Swing mooring (upper right). Otiao Bay, Urupukapuka Island, 2009 (Bay of Islands Ocean Survey 20/20). Anchor drags (lower).

A.3.2 Boat passaging and/or dredging

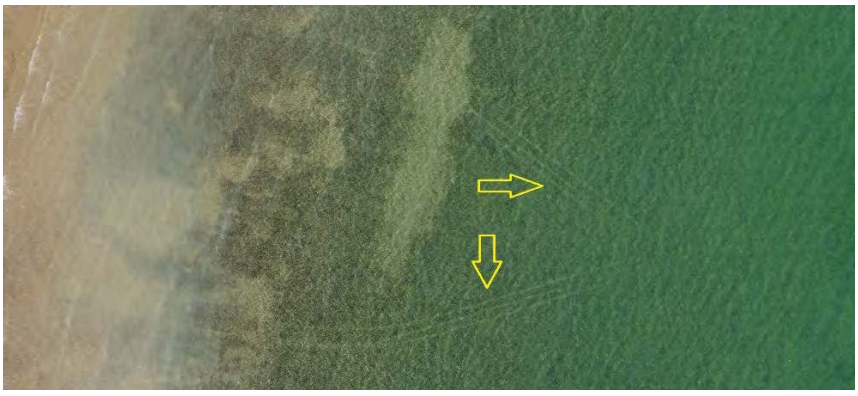


Poroporo Channel, 2017 (Dean Wright Photography, with permission). Probably boat passaging.



Motukiekie Channel, 2020 (present study). Probably boat passaging (left). Motukiekie Channel, 2011 (Lara.Kay Photography, with permission). Possibly dredging (middle). Motukiekie Channel, 2015 (NRC). Possibly dredging (right).

A3.3 Vehicle passaging



Mainland cove, 2020 (Tim Booth, with permission). Three-wheeled vehicle/craft over subtidal seagrass.