Monitoring Surface Elevation Changes in BOP Coastal Wetlands

Installation of Rod Surface Elevation Tables

Prepared for Bay of Plenty Regional Council

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Climate, Freshwater & Ocean Science

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Executive summary

The Bay of Plenty Regional Council (BoPRC) approached NIWA to assist with implementing Rod Surface Elevation Table (RSET) benchmarks for measuring surface elevation changes in coastal wetlands as part of BoPRC's estuarine monitoring programme.

A report commissioned by BoPRC (Fitzgerald et al. 2019) identified that estuarine saltmarsh and mangrove ecosystems in the Bay of Plenty are potentially susceptible to submergence and habitat loss due to sea level rise (SLR). The long-term persistence of saltmash and mangrove in estuaries depends on their capacity to accrete sufficient sediment to maintain their position in the mid–upper intertidal zone relative to sea level. This requirement relates to the inability of saltmarsh and mangroves to tolerate continuous tidal immersion (e.g., Bird 1986, Clarke and Myerscough 1993, Baker et al. 2015). Fitzgerald et al. (2019) recommended extending the existing BoPRC monitoring programme to include RSET monitoring of surface elevation changes. The overall objectives of the coastal wetland monitoring require a sampling strategy that considers the ecological values and significance of coastal wetlands in Bay of Plenty estuaries and implementation of appropriate field methods to enable changes in wetland vegetation to be monitored over time.

The key objective of the RSET monitoring is to determine surface-elevation trends in representative saltmarsh and mangrove habitats in BoP estuaries. These elevation-trend data will be used by BoPRC to:

- Identify wetland habitats that maybe at risk of loss under present-day or future SLR scenarios.
- Enable mitigation strategies to be developed in a timely manner.
- Provide accurate validation data for testing predictions of future wetland habitat changes in BoP estuaries.

This report describes the installation of RSET benchmarks, including the installation of marker horizons (MH) and mesh plates for monitoring surface elevation and sediment accretion. The report also includes information on site selection, site layouts and training provided to BoPRC staff.

Mangrove and saltmarsh habitats in Athenree estuary (Tauranga Harbour) and Nukuhou Inlet, (Ohiwa Harbour) were selected following consultation with BoPRC (Figure 2-1, Figure 2-2). Three sites were identified for RSET benchmark installation in each habitat (mangrove and saltmarsh) at both locations with twelve RSET benchmarks installed in total.

1 Introduction

1.1 Background

The Bay of Plenty Regional Council are in the process of expanding their existing monitoring programme for coastal wetlands. A report commissioned by BoPRC (Fitzgerald et al. 2019) presented a strategy and methodology to extend the existing monitoring programme. The objectives of this scoping study were:

Development of a sampling strategy that considers the ecological values and significance of estuarine wetlands in the BoP.

Develop appropriate field methods to enable changes in wetland vegetation to be monitored over time.

As shown in Figure 1-1, estuarine wetlands occur in the numerous estuaries fringing Tauranga Harbour and in the Maketu, Little Waihi, Whakatane, Ōhiwa, Waiōtahe, Opotoki and Waiaua estuaries that indent the Bay of Plenty coastline (Fitzgerald et al. 2019).

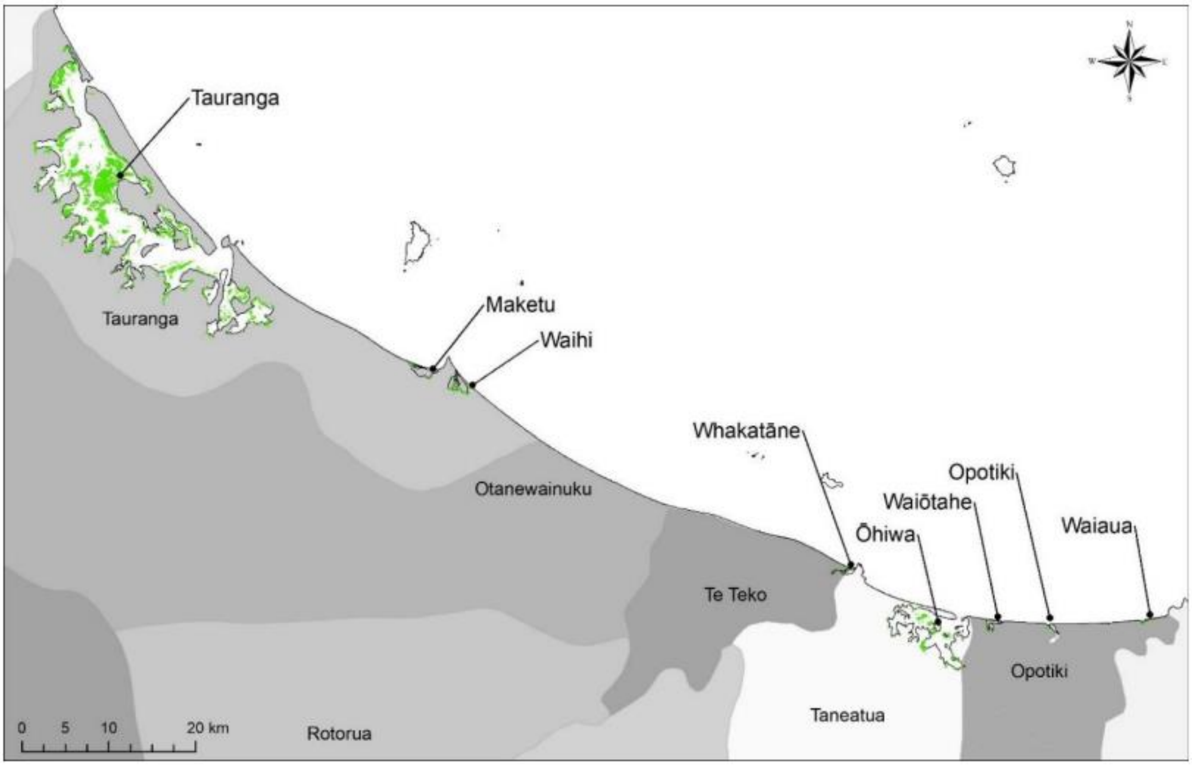


Figure 1-1: Estuaries, saltmarsh and ecological districts in the Bay of Plenty Region. Source: Fitzgerald et al. (2019).

1.1.1 Surface Elevation Tables – monitoring SLR Effects

The threat of rising sea levels to the long-term persistence of the Bay of Plenty's estuarine wetlands was also identified by Fitzgerald et al. (2019). Saltmarsh and mangrove ecosystems are particularly susceptible to sea level rise (SLR) as they must maintain their position in the upper intertidal zone relative to sea level due to their physiological intolerance to continuous tidal immersion (e.g., Bird 1986, Clarke and Myerscough 1993, Baker et al. 2015).

Coastal wetlands may adapt to SLR by landward migration upslope and/or vertical accretion of intertidal flats by sedimentation. In many estuaries, however, landward wetland migration is constrained by coastal infrastructure (e.g., stopbanks, roads, railway lines) resulting in coastal squeeze (Woodroffe et al. 2016). Landward migration may also be constrained by natural topographic features (Figure 1-2).

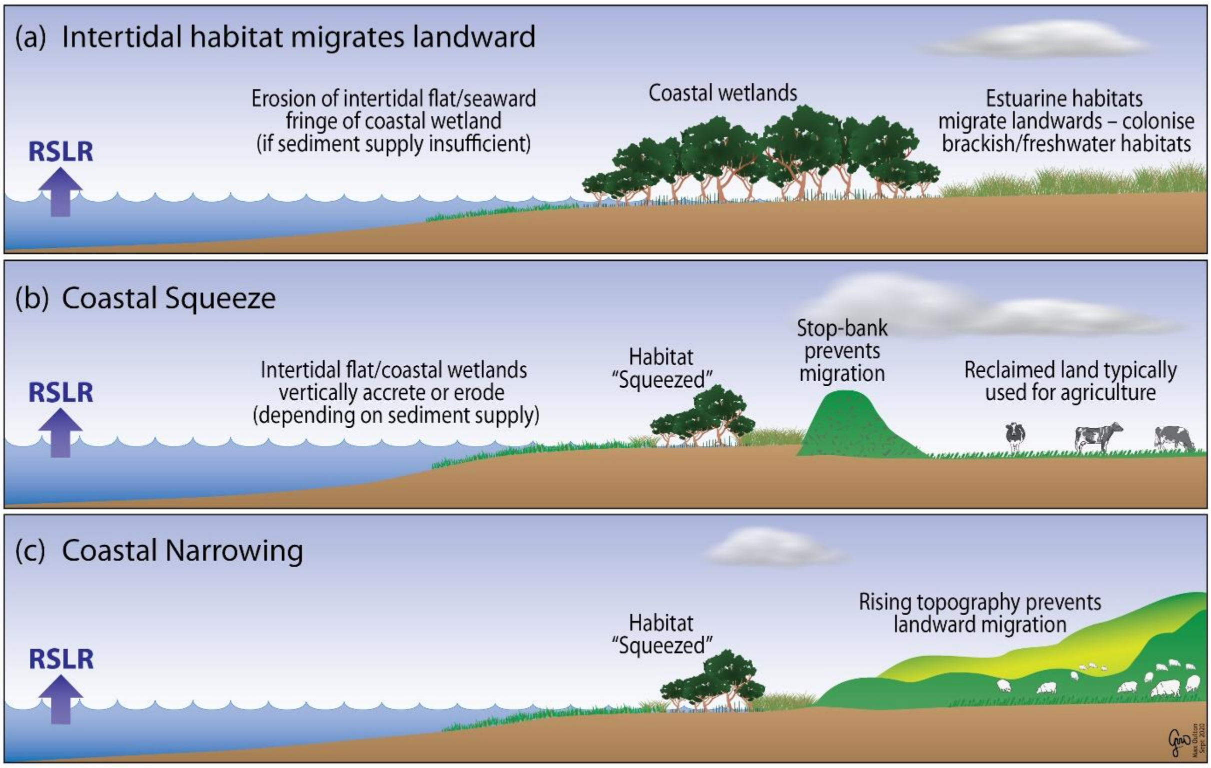


Figure 1-2: Potential coastal wetland responses to sea level rise: (a) habitats naturally migrate landwards to displace brackish/freshwater habitat where there are no physical barriers; 9b) coastal squeeze occurs where natural landward migration of wetland habitats is prevented by hard protection structures and/or reclamation; and (c) migration is prevented by rising land topography (i.e., coastal narrowing). Source: Swales et al, 2020).

The relative contribution of the various processes controlling substrate surface elevations in estuarine wetlands vary with local environmental conditions. Surface processes include deposition and erosion of mineral sediments (i.e., primarily supplied by rivers), sediment desiccation, and seasonal variations in leaf litter and microbial mat production (e.g., Woodroffe 1985, McKee 2011, Webb et al. Swales et al. 2015; 2019). Subsurface processes include regional tectonic processes that influence vertical land motion (VLM) (Kaye and Barghoorn 1964, Cahoon et al. 1995, Cahoon 2015,), shallow and deep subsidence associated with sediment compaction by dewatering (Swales et al. 2016, Woodroffe et al. 2016), as well as fluctuations in groundwater storage associated with evapotranspiration, seasonal rainfall and tidal cycle recharge and discharge (Cahoon et al. 2011, Rogers et al. 2014). In highly organic soils, root growth and decay and net organic matter accumulation can also influence shallow subsidence or expansion (McKee 2011, Krauss et al. 2014).

Many of the insights regarding the role of biophysical processes and feedbacks controlling surface-elevations in coastal wetlands have come from studies employing the Surface Elevation Table and Marker Horizon (SET-MH) method (Boumans and Day, 1993, Cahoon et al. 1995, Webb et al. 2013, Krauss et al. 2014). The SET-MH and improved Rod Surface Elevation Table (RSET, Cahoon et al. 2002) techniques have been applied in studies of saltmarshes and mangrove forests dominated by peat sediment and mineral sediment deposition at hundreds of sites around the globe (Webb et al. 2013).

The RSET has largely replaced the earlier SET (pipe benchmark) system due to a number of advantages of the RSET method. These include the high precision, the lightweight mechanical levelling device and capacity to drive the rod benchmark to a range of depths not possible for the SET due to pipe/sediment friction. Thus, RSET benchmarks can be installed to monitor shallow (i.e., 1 m) and deep (i.e., driven to refusal) sedimentary processes. For example, they enable measurement of change in sediment elevation over shallower (e.g., the root zone) and deeper depths of the sediment profile than is possible with the SET method (Cahoon et al. 2002). In New Zealand, RSET monitoring of surface elevation trends, including coastal subsidence, has been conducted by NIWA since 2007 in partnership with Waikato Regional Council, in the extensive mangrove forest of the southern Firth of Thames. A schematic diagram of the Firth of Thames installation is shown in Figure 1-3 (Swales et al. 2019).

The vertical stability of RSET benchmarks, in terms of the potential for the structure to settle through the sediment column, has been evaluated by Swales et al. (2016) for 18-m deep RSET installed in the mangrove forest in the southern Firth of Thames. Specifically, the bearing capacity of the benchmark within the unconsolidated sediments (i.e., skin friction resistance) was estimated relative to the force exerted by the benchmark mass and the potential point settlement. These calculations yielded a bearing capacity that was a ~100-times larger than the downward force exerted by the mass of the RSET benchmark. The potential (point) settlement of the RSET benchmarks in the substrate was estimated as ~0.03 mm from the general sediment properties and the RSET benchmark specifications. Thus, any measurable vertical motion of the RSET benchmark can be attributed the vertical land motion (i.e., sediment column compaction, tectonic processes) (Swales et al., 2016).

As part of the proposed coastal wetland monitoring design for BoPRC, Fitzgerald et al. (2019) recommended installation of RSET benchmarks "*in at least three representative vegetation monitoring plots in each of the main vegetation types (determined after vegetation sampling) in the monitored estuaries*". Installation of RSET benchmarks in saltmarsh and mangrove habitat in two BoP estuaries was proposed following discussions with Shay Dean (BoPRC Environmental Scientist). Preliminary scoping of candidate sites for RSET installation included a visit to wetlands in several BoP estuaries (S. Dean & A. Swales): Athenree, estuaries fringing the western shore of Tauranga Harbour, Little Waihi and Ohiwa estuaries on 11 May 2021.

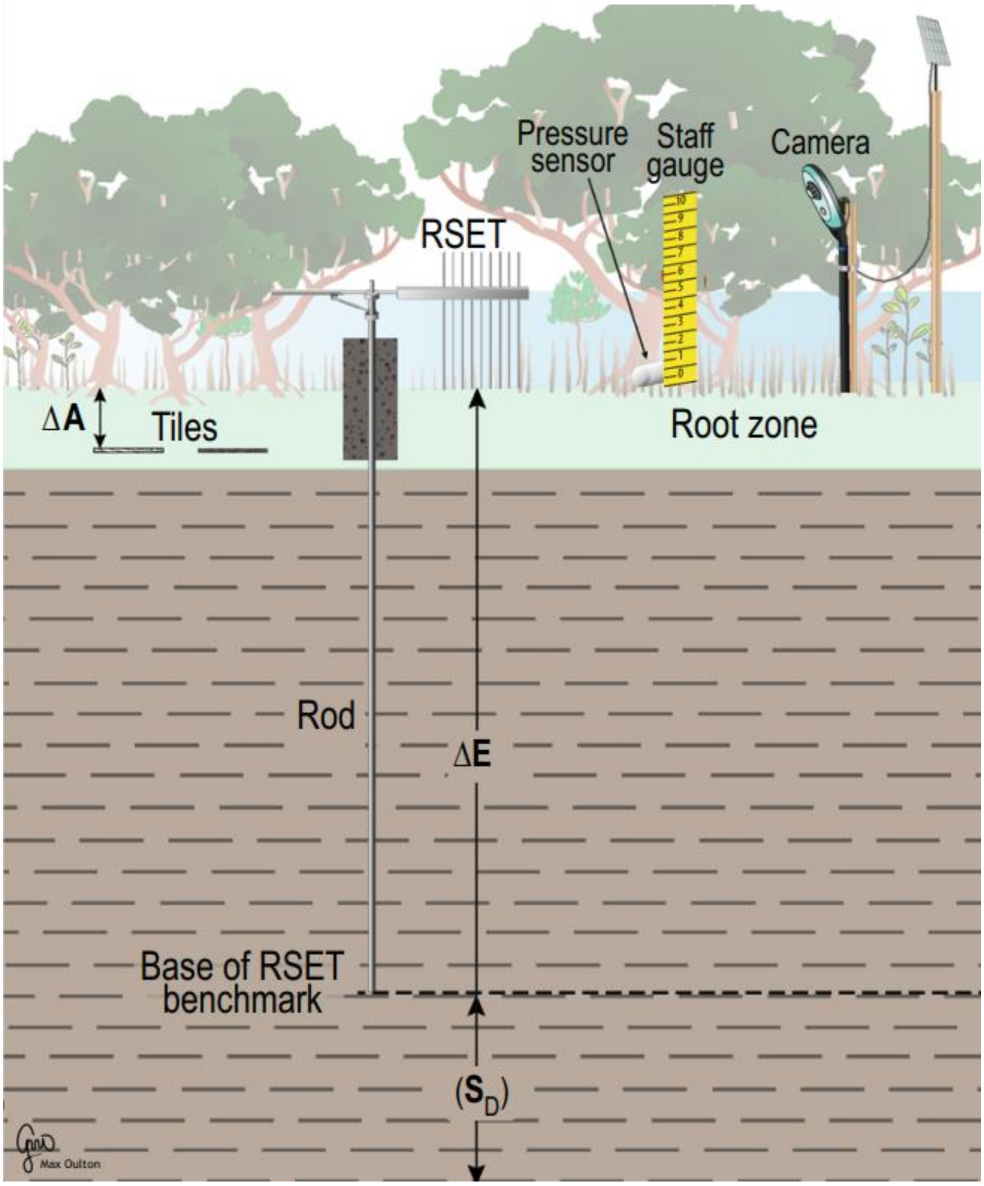


Figure 1-3: Schematic of RSET Benchmark and sediment accretion mesh/tiles. Definitions: Sediment accretion (ΔA), surface-elevation change (ΔE) and hydroperiod measurements made at RSET stations. Shallow subsidence (S_D) and ΔE are measured relative to the base of the stainless steel RSET benchmark. Additionally, cameras and pressure sensors can be used for site specific measurement of hydroperiods. Source Swales et al (2019).

1.2 Objectives

The key objectives of the present project are to:

- install RSET benchmarks in Athenree Estuary and the Nukuhou arm of Ohiwa Harbour, and
- train BoPRC staff in the RSET benchmark installation process and measurement methods for monitoring sediment accretion and surface-elevation trends in these representative saltmarsh and mangrove habitats.

These trend data will be used by BoPRC to:

- Identify wetland habitats that maybe at risk of loss under present-day or future SLR scenarios.
- Enable mitigation strategies to be developed in a timely manner.
- Provide accurate validation data for testing predictions of future wetland habitat changes in BoP estuaries.

BoPRC engaged NIWA on 23 February 2022 to install a total of 12 RSET benchmarks and associated sediment accretion plates and marker beds in two estuaries in saltmarsh and mangrove habitats at/in close vicinity to sites selected by the BoPRC for long-term wetland monitoring.

The project included:

a. RSET benchmark site selection in two target estuaries i.e., Anthenree and Ohiwa following consultation with BoPRC,

b. planning and preparation for RSET installation,

c. RSET benchmark and sediment accretion mesh/plate installation,

d. BoPRC staff training in sediment accretion and surface elevation measurements and data processing for the purpose of monitoring sediment accretion and surface elevation trends, and

e. delivery of a short technical report that described and summarized the project background, objectives, RSET benchmark installation, site locations, site layout and BoPRC staff training.

2 Methods

2.1 Site Selection

RSET benchmark sites were selected in mangrove and saltmarsh habitat in Athenree Estuary on 14 April 2022 and Ohiwa Harbour (Nukuhou River Inlet, Ohope) on 4 April 2022. Site selection was undertaken by NIWA (A. Swales, M Smith) and BoPRC (J. Crawhaw, S. Dean and H. MacKenzie). This followed preliminary scoping of candidate wetland sites in several BoP estuaries by S. Dean & A. Swales. All of the selected RSET benchmark sites were marked with 2-m PVC conduit pipe and pink flagging tape (i.e., 'no-walk' area).

The overall strategy regarding site selection was to include 3 RSET benchmarks in each saltmarsh and mangrove habitat. The primary reason for this approach was to provide information on the spatial variability in rates of sediment accretion and surface elevation changes within each habitat. Key drivers of these processes include hydroperiod, which varies with position in the intertidal zone, and proximity to suspended fine sediment sources. Unvegetated mudflats and river channels are primary proximal sources of suspended sediment.

Vegetation types at Athenree saltmarsh RSET sites were dominated by Oioi (*Apodasmia similis*) with some *Juncus* sp. Athenree mangrove RSET sites had mangroves ranging in height from 1.2-2.0m. In Ohiwa Harbour, mangroves ranged in height from 0.8-2.1m at RSET sites. Vegetation types at Ohiwa Harbour saltmarsh sites were dominated by Oioi.

Site selection criteria within the saltmarsh and mangrove habitats included:

- Site accessibility, including over the long term.
- Proximity to existing BoPRC coastal wetland monitoring sites.
- Apparent position in the intertidal zone – distance from high-tide shoreline used as a proxy measure.
- Distance from river and/or immediate downstream tidal channel (i.e., fine sediment source).

To this end, the selected RSET benchmark site locations varied across the mid to upper intertidal zone and distance from river and/or tidal channels to capture the range of conditions influencing sedimentation and plant growth.

The locations of installed RSET benchmarks in Athenree Estuary and Nukuhou arm of Ohiwa Harbour are shown in Figure 2-1 and Figure 2-2. GPS coordinates for the twelve RSET sites are provided in Table 2-1.

Table 2-1: GPS coordinates for RSET benchmarks installed in the Bay of Plenty in 2022. NZTM 2000 Format. Athenree benchmarks installed 23-24 August 2022 and Nukuhou benchmarks installed 13-14 September 2022.

Site ID	Vegetation Type	Easting	Northing
Athenree Estuary			
ATH-1	Saltmarsh	1861204	5852528
ATH-2	Saltmarsh	1861338	5852476
ATH-3	Saltmarsh	1861368	5852604
ATH-4	Mangrove	1861963	5852701
ATH-5	Mangrove	1861922	5852612
ATH-6	Mangrove	1861982	5852581
Nukuhou			
NUK-1	Mangrove	1960401	5784328
NUK-2	Mangrove	1960461	5784332
NUK-3	Mangrove	1960314	5784340
NUK-4	Saltmarsh	1960087	5783837
NUK-5	Saltmarsh	1960018	5783907
Nuk-6	Saltmarsh	1960141	5783777

Figure 2-1: Location of RSET sites at Athenree, western end of Tauranga Harbour, Bay of Plenty. Three RSET sites in the saltmarsh are identified as ATH-1, ATH-2 and ATH-3. Three RSET sites in the mangroves are identified as ATH-4, ATH-5 and ATH-6.

Figure 2-2: Location of RSET sites at Ohiwa Harbour, Nukuhou Inlet, Ohope, Bay of Plenty. Three RSET sites in the saltmarsh are identified as NUK-4, NUK-5 and NUK-6. Three RSET sites in the mangroves are identified as NUK-1, NUK-2 and NUK-3.

2.2 Installation of RSET Benchmarks

The Rod Surface Elevation Table (RSET) method employs a portable mechanical device that provides high-precision measurements of relative elevation change in wetland sediments or shallow water bottoms relative to the depth of the RSET benchmark. Elevation changes integrate the above and below ground biophysical processes occurring in the wetland system that include sediment accretion, consolidation, subsidence, and biomass production (i.e., litter, root growth) over time.

The RSET method also provides a scientifically robust and standardized set of guidelines for non-destructive measurement of elevation change and vertical accretion in coastal wetland habitats.

The RSET benchmarks, consist of 1.5 m or 1.0 m long sections of threaded 14.2-mm diameter stainless steel rod. The rod sections are threaded together and driven vertically into the substrate. The rod is driven “to refusal” which occurs when either (1) the rod contacts underlying bedrock or (2) frictional resistance of the rod with the substrate inhibits further rod penetration. A GPS monitoring campaign can subsequently be used to establish the vertical stability of the RSET benchmarks relative to each other and/or an established datum, as may occur due to vertical land motion (VLM) (e.g., subsidence, Swales et al. 2016). The RSET instrument receiver is bolted to the top of the rod and encased in concrete, to minimise horizontal motion during measurements.

A detailed description of the SET/RSET methodology is provided by the US Department of the Interior (US Geological Survey and NOAA) publication (USDI, 2015): *The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics* (https://www.usgs.gov/centers/eesc/science/surface-elevation-table) and downloaded at: DataStore - Published Report - (Code: 2225005) (nps.gov).

Further information pertaining to the RSET installations at Athenree or Ohiwa are provided in subsequent sections, accompanied by photos and figures.

2.2.1 RSET Benchmark Site Layout

The layout of the RSET site is shown in Figure 2-3.

The RSET benchmark stations installed at the BoPRC sites consists of the following:

- A 'no walk' quadrat (dimensions: 6 x 2.5 m) with corners marked by PVC electrical conduit pipe. Walking within this zone is prohibited to prevent substrate disturbance. Measurements of sediment accretion and elevation changes are made with the quadrat as follows (Figure 2-6).

- RSET measurement area – the area within which the RSET benchmark is located and point-elevation measurements are taken. This circular area extends approximately 0.6 m in every direction from the RSET benchmark. The layout of a site benchmark is depicted in Figure 2-3. The grey circle with red outline represents the 0.15 m benchmark itself. No other sampling occurs within this area to avoid any disruption of the wetland surface measured by the SET instrument.

- Sediment accretion measurements – two independent methods are employed. Sediment accretion plots were located in the half quadrat not occupied by the RSET benchmark (Figure 2-3):

  a. Plastic mesh plates (Swales and Lovelock, 2020). Mesh plates are installed at three locations within each quadrat to provide information about small scale variability in sediment accretion and subsidence rates. Plastic mesh plates provide an accurate, repeatable and rapid method to measure sediment accretion. At mangrove sites, plastic plates 0.3 x 0.3 m were installed and held in place using geotextile pins. The plastic mesh plates are composed of a 2 mm aperture woven mesh (Nytal HD 10-2000 micron, product code 06-2000/53-158) supplied by SEFAR Filter Specialists Ltd, 24G Allright Place, Mt Wellington, Auckland.

  b. b. Marker horizons (Cahoon et al., 2015). Typically, feldspar clay powder is employed. The application can be problematic at sites with rapid sediment mixing due to bioturbation (e.g., mud crabs, Swales and Lovelock). The feldspar marker horizon method has been successfully employed in US saltmarshes (USDI, 2015).

The Potash Feldspar (200 F) employed in this project was supplied by CCGNZ Group, Triton Drive, Albany (Auckland).

In the present project, three marker plots (30cm x 30cm) with a marker horizon (blue boxes in Figure 2-3) for measuring vertical accretion are installed. Plots are typically located inside the quadrat perimeter but within arm's reach.

The exact locations of the plastic mesh plates and feldspar marker horizons relative to the RSET benchmark and/or quadrat corner PVC pipe markers were determined using a distance and magnetic bearing or (x,y) co-ordinates. A map should be prepared for use in the field during surveys and updated as required (Figure 2-4).

- Platform – all RSET measurements are made from temporary raised platform in order to avoid disruption of the wetland surface. NIWA typically employs 3-m aluminium planks (supplier: Ulrich Aluminium, Hamilton).
- RSET orientation – In general, RSET measurements are taken in 4 directions, (typically every 90 degrees although this may vary depending on site conditions. The RSET instrument can be used to make measurements in up to 8 different directions so it's important to mark or record where the measurements are being taken. The RSET data record sheets developed by NIWA include the magnetic bearings of each RSET arm direction used for repeat measurements. Each direction can be marked by a plastic straw, although the direction should always be confirmed using a hand-held magnetic compass (Figure 2-5).

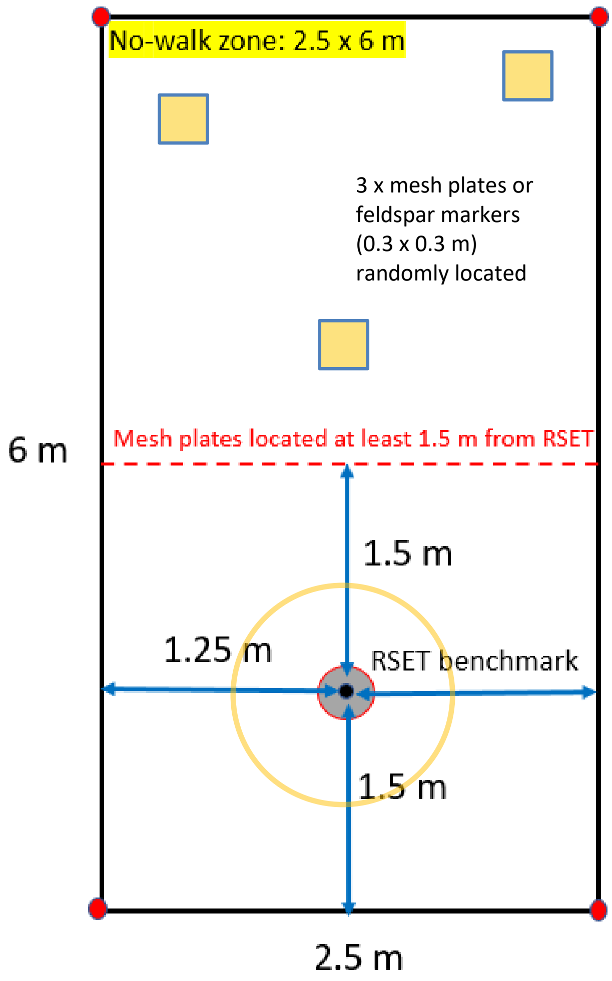
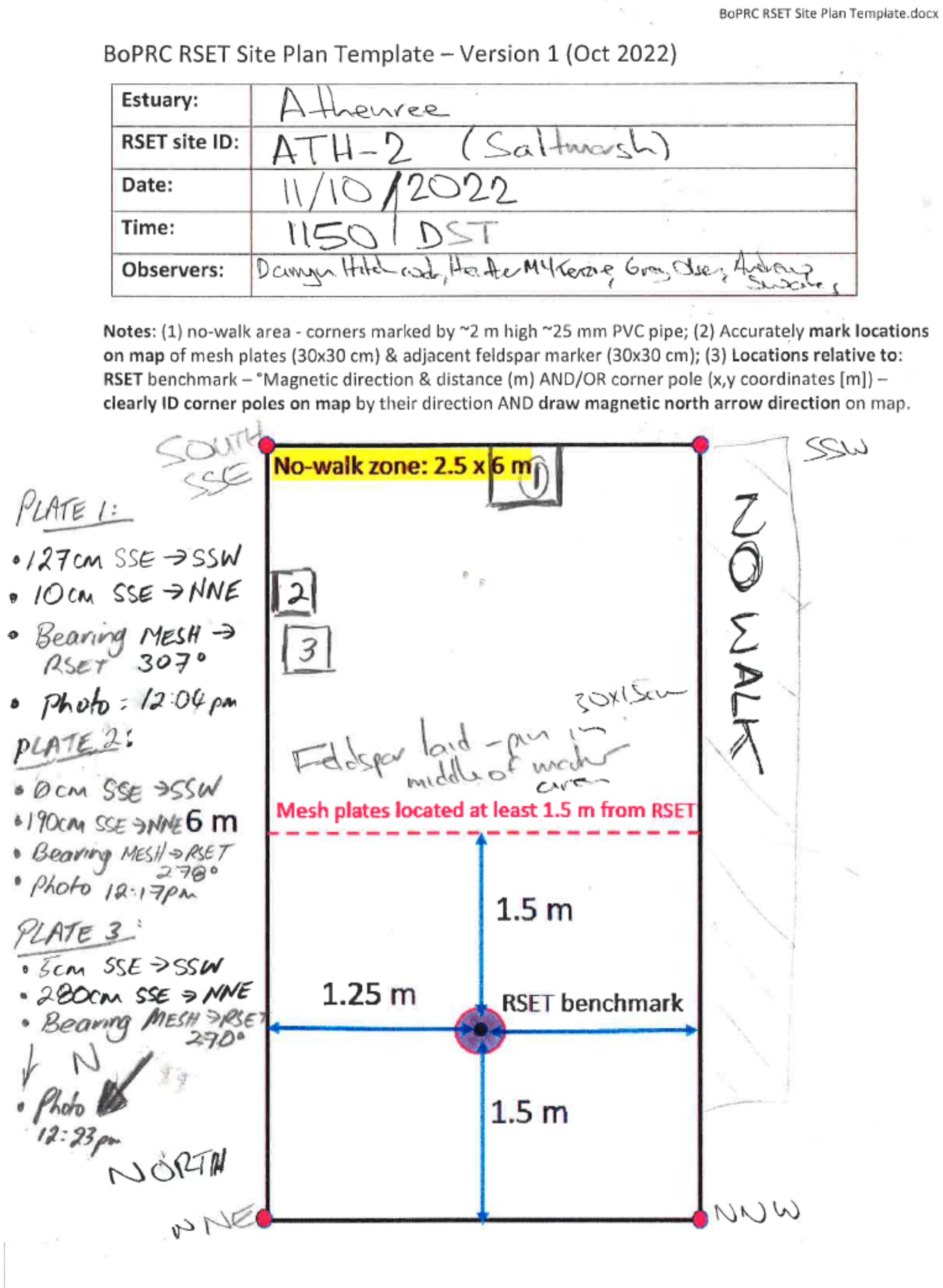


Figure 2-3: Schematic of RSET Installation layout. Included in RSET installation template document reproduced in Appendix A. Corners of the sample station no-walk area (2.5 x 6.0 m) were marked with ~1.5-2 m high PVC pipe (red circles); Each corner pole on the schematic was also identified by direction, e.g NW, SE, etc. A magnetic north arrow direction was drawn on the template document. The RSET measurement area is depicted by the orange circle (approx. 0.6 m diameter) which extends beyond the RSET benchmark. Locations of random mesh plates (30x30 cm) & adjacent feldspar markers (30x30 cm) were also marked and accurately drawn on the template document when installed.

A sample station area of 2.5 x 6.0 m was chosen as a no-walk zone to protect vegetation and the sediment surface from damage during installation and monitoring. Corners of the no-walk zone were first marked by 25 mm diameter PVC pipe ~1.5-2.0 m high (Figure 2-3 and Figure 2-6).

All materials and equipment used for the installations were flown to the RSET sites via helicopter. All installation and subsequent sampling activities take place using temporary platforms installed above the wetland surface. Two x 3 m aluminium scaffolding planks were carefully placed on either side of the RSET benchmark installation point, with each plank supported by either 2 x plastic step stools or 2 x plastic baskets (Figure 2-7). This equipment needs to be as lightweight as possible because it may need to be carried in/out for RSET monitoring.


BoPRC RSET Site Plan Template.docx

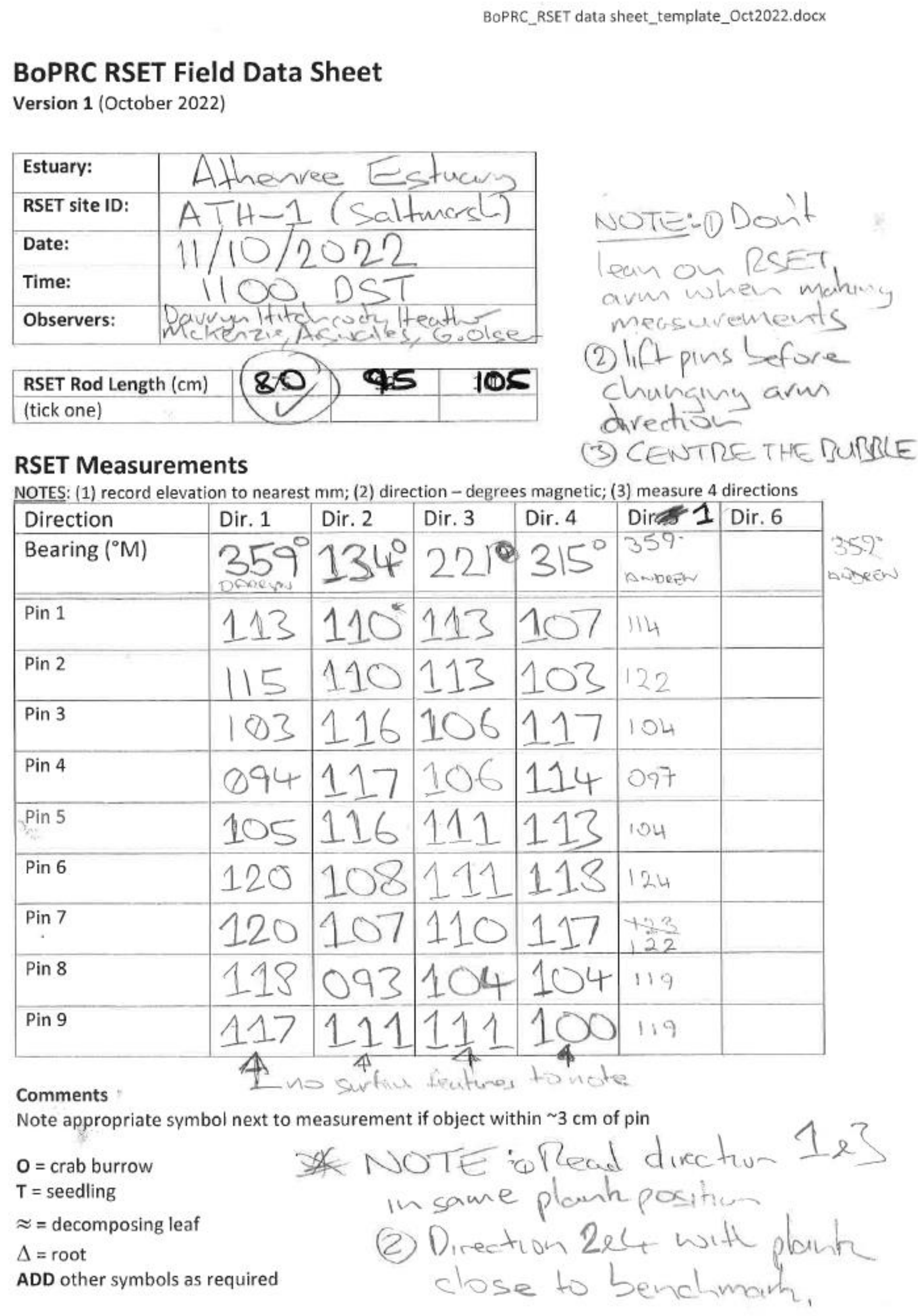
BoPRC RSET Site Plan Template – Version 1 (Oct 2022)

Estuary:	Athenree
RSET site ID:	ATH-2 (Saltmarsh)
Date:	11/10/2022
Time:	1150 / DST
Observers:	[illegible]

Notes: (1) no-walk area - corners marked by ~2 m high ~25 mm PVC pipe; (2) Accurately **mark locations on map** of mesh plates (30x30 cm) & adjacent feldspar marker (30x30 cm); (3) **Locations relative to: RSET** benchmark – °Magnetic direction & distance (m) AND/OR corner pole (x,y coordinates [m]) – **clearly ID corner poles on map** by their direction AND **draw magnetic north arrow direction** on map.

Figure 2-4: Example of initial site map - site ATH-2 (saltmarsh habitat).

Plastic mesh plates and feldspar marker beds installed at first RSET survey, several weeks after RSET benchmark installation. Location of plates and feldspar beds recorded. Map should be updated as required. Note 'No Walk' area also extend to one side of quadrat to reduce site disturbance.


BoPRC_RSET data sheet_template_Oct2022.docx

BoPRC RSET Field Data Sheet
Version 1 (October 2022)

Estuary:	Athenree Estuary
RSET site ID:	ATH-1 (Saltmarsh)
Date:	11/10/2022
Time:	1100 DST
Observers:	Darryn Hitchcock, Heather McKenzie, A. Swales, G. Olsen

RSET Rod Length (cm) (tick one)	80 ✓	95	105

NOTE: (1) Don't lean on RSET arm when making measurements (2) lift pins before changing arm direction (3) CENTRE THE BUBBLE

RSET Measurements
NOTES: (1) record elevation to nearest mm; (2) direction – degrees magnetic; (3) measure 4 directions

Direction	Dir. 1	Dir. 2	Dir. 3	Dir. 4	Dir. 1	Dir. 6
Bearing (°M)	359° DARRYN	134°	221°	315°	359° ANDREW	
Pin 1	113	110*	113	107	114	
Pin 2	115	110	113	103	122	
Pin 3	103	116	106	117	104	
Pin 4	094	117	106	114	097	
Pin 5	105	116	111	113	104	
Pin 6	120	108	111	118	124	
Pin 7	120	107	110	117	~~123~~ 122	
Pin 8	118	093	104	104	119	
Pin 9	117	111	111	100	119	

359° ANDREW

↑ no surface features to note

Comments
Note appropriate symbol next to measurement if object within ~3 cm of pin

O = crab burrow
T = seedling
≈ = decomposing leaf
Δ = root
ADD other symbols as required

* NOTE (1) Read direction 1 & 3 in same plank position (2) Direction 2 & 4 with plank close to benchmark.

Figure 2-5: Example of completed RSET data record sheet. Site ATH-1 (Athenree Estuary) saltmarsh habitat, survey 1 (11 October 2022). Data for four RSET instrument arm directions and cross check for direction 1 (359°M).

Figure 2-6: Measurements and marking of the no-walk area for the RSET site. A piece of white PVC pipe is installed at each corner of the no-walk zone 2.5 m x 6.0m.

Figure 2-7: Photo of aluminium plank placed either side of the RSET benchmark point during installation. The aluminium planks are 3.0 m in length and supported by plastic baskets or step stools on each side of the no-walk area.

2.2.2 RSET Benchmark Installation

A RSET benchmark is designed to provide a vertical reference point from which elevation measurements can be collected for many years. Figure 1-3 showed the cross section of the RSET benchmark installation.

A RSET benchmark is installed using stainless-steel (SS) rods driven into the wetland sediment 'to refusal'. In practice this means that the RSET SS rod is driven to bedrock or more typically until the surface friction between the rod and the surrounding sediment prevents or significantly reduces the rate of rod penetration. In the present project, a rate of 1 cm/s (i.e., 150 s for 1.5 m rod length) or less was used as a threshold value for rod "refusal'. A custom-built receiver, which couples with the RSET instrument, is securely attached to the top of the stainless-steel rod.

It is recommended that a team of at least 3 people are available to install RSET benchmarks. Any less than three is not efficient considering all the gear that must be transported from station to station. NIWA's standard approach is to deliver materials to each benchmark site at the start of the field work using a helicopter – this has been a highly efficient/cost-effective method.

The general procedure for installing a deep RSET benchmark is as follows:

- Install a temporary or permanent platform to work on.
- Excavate a circular hole of appropriate diameter and depth and insert a PVC pipe casing. A hand-held battery-powered Ryobi post-hole auger was used to excavate a 0.8 m deep x 0.15 m diameter hole.
- Drive multiple lengths of threaded stainless-steel rod into the ground
- Cut the rod (if necessary) after driving to refusal. The rod may need to be cut to ensure that the top of the SS rod is below the top of the PVC pipe casing. This ensures that the rod and the RSET receiver (attached subsequently) are fully encased in concrete and enclosed by the PVC pipe collar.
- Attach the receiver to the rod.
- Fill PVC pipe with concrete.

Supplies for Installing a Deep RSET Benchmark

- SS Rods – the benchmark consists of 1.5 m or 1.0 m long sections of 14.2-mm diameter marine grade 316 SS rod that are threaded together. Rods are connected and driven to refusal. In the present project the maximum depth achieved at each RSET benchmark site ranged from 11.6 to 20 m (Athenree) and 11 to 15 m (Nukuhou). Some 18m of SS rods (8 x 1.5m and 6 x 1.0 m) were delivered to each deep RSET benchmark. The surplus SS rod was returned to BoPRC for future use.
- A hand-held post-hole driver and Makita 40V MAX XGT BL AWS 40 mm battery-powered rotary hammer drill (model code HR005GM204) were used for installing the SS rod benchmark. The rod was driven vertically "to refusal" which occurs when either (1) the rod contacts underlying bedrock or (2) frictional resistance of the rod with the substrate inhibits further rod penetration (Figure 2-13).

- Driving head (Milwaukee SDS Max Rod Driver 16.5x260mm, product code 4932451355.) – is attached to the top-most SS rod (threaded) (Figure 2-12). and protects the 1.5m and 1.0m SS rod sections from being deformed by the driver or hammer drill impact. When the SS rod length was driven to the level of the PVC pipe casing, the driving head was removed before a new rod length was attached. Rod sections are chemically welded together using a thread lock fluid, such as Lock-tight (Figure 2-11). The driving head is re-attached to the top of the new rod length and this step is repeated until the rod is driven to refusal.
- Angle grinder – used to cut any surplus rod that extends above the top of PVC pipe casing. A battery powered angle grinder is used to cut the rod at the wetland surface.
- Battery powered post hole auger – to excavate 150mm diameter x 0.8 m deep hole for the PVC casing (Figure 2-9). A trowel and bucket are used to collect sediment attached to the auger and this sediment is removed from the site.
- RSET receivers –custom-built from marine grade 316 stainless steel. Receivers are designed to bolt onto the top section of rod and couples with the RSET instrument (Figure 2-8). The receiver allows for a fixed and repeatable position in space (x,y,z) so that the RSET instrument is measuring exactly the same points on the ground within the quadrat. One receiver is needed for every deep RSET benchmark.
- Concrete – “Quickcrete” concrete (with stones) or mortar (without stones) was used to encase the attached receiver and rod benchmark within the PVC casing. Approximately 1.5 bags of 20kg Quickcrete Rapidset concrete was used to construct each RSET benchmark.
- PVC collar – 15cm diameter PVC pipe- 1.0 m long. The PVC casing lines a circular hole to 0.8 m depth before the SS rod is installed (Figure 2-9). After the receiver is attached to the rod, the PVC pipe is filled with concrete (Figure 2-15). This concrete-filled PVC casing stabilises the top of the RSET benchmark.
- A SS marker ID is inserted at the end to clearly identify the RSET benchmark (Figure 2-15)
- Tools/Gear: Vice Grips (2), adjustable wrenches, spanners, small sledgehammer, bucket, trowel, hacksaw, paper towels, tap and die for SS threads, CRC 556, Silicone Spray, duct tape, electrical tape, cable ties, hand bilge pump, gloves, hearing & eye protection, thread locker glue, dust mask, compass, funnel for 150mm pipe, GPS. Spare lithium-ion batteries for post-hole borer, grinder or hammer drill.

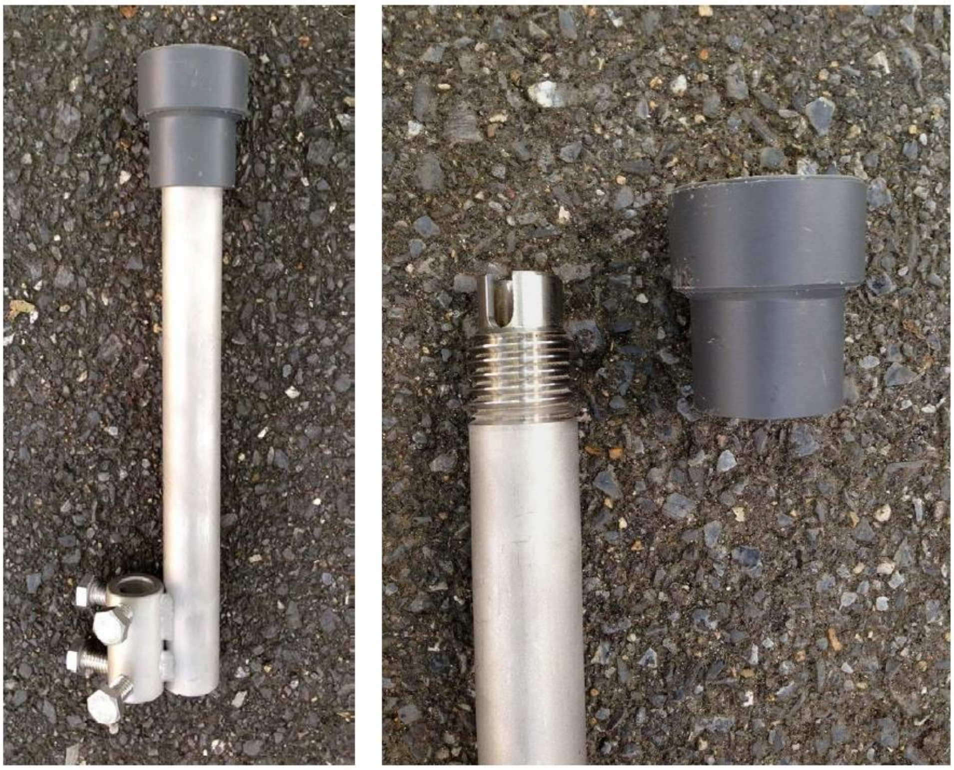


Figure 2-8: RSET Receiver fitted to the top of SS rod. Reproduced from US Geological Survey publication: The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics. *Figure 3.6*.

Instructions for installing the deep RSET benchmark

The installation is best done by a team of 3-4 people depending upon location and access to sites:

- Ensure temporary platforms are in position to safely operate equipment and avoid disrupting the wetland sediment surface.
- Excavate the hole for the PVC casing: Determine the location of the deep mark. Using a post-hole auger, excavate a 150mm diameter hole (the diameter of the PVC collar) to 0.8 to 0.85 m depth (Figure 2-9). Note that pore water may seep into the hole. This is normal.
- The depth of the hole is determined by the length of the PVC Collar. In the present project the 1.0-m long PVC casing was instated with ~0.2 m protruding above the sediment surface (i.e., 0.8 m in the ground). Place the excavated soil from the hole into a bucket and remove it from the immediate area of the RSET benchmark quadrat.
- Install PVC Collar – Push the 150mm PVC pipe into the hole. Step on it and/or use a sledgehammer and block of wood to knock it down to the appropriate depth, i.e., 0.80 to 0.85m (Figure 2-9, Figure 2-10). Try to get the bottom of the PVC pipe into the sediments below the bottom of the hole to improve stability. The top of the PVC pipe should stick up at least 150mm above the wetland surface.

Figure 2-9: Battery powered post-hole borer used for installing hole for the PVC collar. A bucket and trowel is used to collect sediment removed from the hole for disposal away from the sample station.

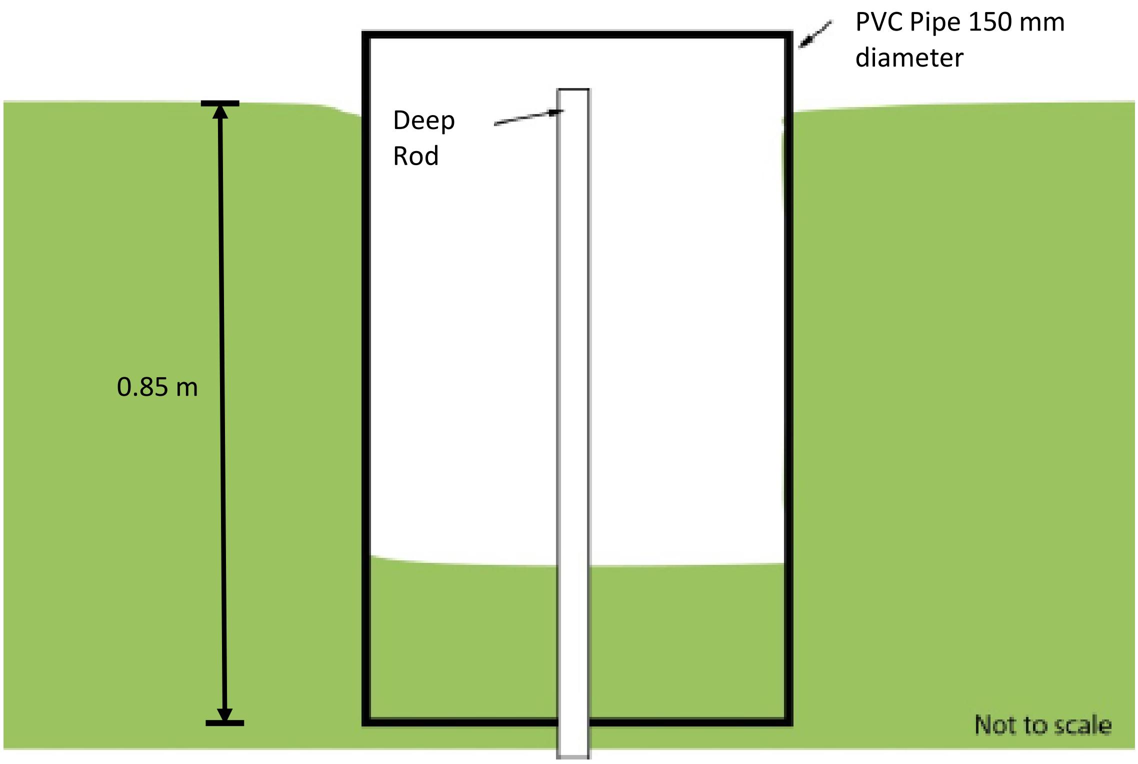


Figure 2-10: Schematic of PVC collar in the ground. Reproduced from US Geological Survey publication: The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics. SOP-3, *Figure 3.18*.

- Drive the SS rods into the ground: Screw together the first two sections of SS rod. Apply thread locker to both sides of the threads on the stud (Figure 2-11). You can install a driving point on the leading edge, but this is not always necessary.

Figure 2-11: Thread locker applied to threads of SS rods.

- Make sure the rod is vertical and push it into the centre of the excavated hole. The first few rods can usually be pushed in by hand.
- Attach the driving head which is a short piece of SS rod that will take the blows from the pounder or hammer drill (Figure 2-12). The hammer drill driving bit and driving rod become very hot (wear gloves).

Figure 2-12: RSET Driving head installed to the top of the SS rod before hammering.

- Start driving the rods into the ground with the hammer drill. Be sure to wear gloves, a hardhat, hearing and eye protection. Stop driving each SS rod section when the driving head is about 150mm above the wetland surface. Remove the driving head. Add a new rod (use thread lock), attach the driving head, tighten with vice grips, wrenches or spanners and resume pounding (Figure 2-13). Repeat this process until significant resistance is met or the rod hits bedrock. Significant resistance to rod penetration occurs when the surface friction between the rod and sediment substantially reduces the rate of penetration. In the present project a threshold rate of 1 cm/s or less was used to determine when the 'to refusal' depth had been reached (i.e., 150 s or more to drive a 1.5m rod). Once the RSET benchmark is installed this should provide a very stable base for taking high-precision measurements of elevation change using the RSET instrument.
- When finished installing the deep mark, remove the rod driving head. The final rod in the ground should be at the wetland surface or approximately 50-100 mm above it.

Figure 2-13: Battery Powered Hammer Drill used for driving SS rods into the sediment.

- Be sure that the top of the SS rod remains below the top of the PVC pipe. It is also very common to have water in the bottom of the hole. Remove excess water in the PVC pipe with a hand bilge pump or small plastic cup.

- Attach the receiver – The plastic cap covering the receiver thread is removed and the thread is sprayed liberally with Silicon 808 spray before reattaching the cap. Slide the SS receiver over the rod and into the hole (Figure 2-14). Tighten the bolts on the receiver with an adjustable wrench or 1/2” spanner, thereby attaching it to the deep mark. Make sure the rods are snug and tight before attaching the receiver. The top of the receiver should by 100 mm above the top of the PVC pipe or 250mm above the sediment surface. Use the notch in the top of the receiver to align the receiver in the desired orientation for the RSET measurements. Once the receiver is attached to the deep rod and encased in cement, the directions available for RSET measurements will be fixed. It is important to be aware of the directions prior to attaching the receiver and adding cement to the PVC pipe.

- Fill the pipe with cement– It is normal for there to be water inside the hole. Remove as much of the seawater as possible from within the PVC pipe using the hand-held bilge pump. Attach a suitable funnel to the PVC pipe and add some dry cement to the bottom of the pipe if there is a lot of water which can’t be removed. Incrementally add cement (concrete or mortar mix) and small amounts of fresh water to the PVC pipe and stir. Saltwater will work if fresh water is not available. Fill the PVC pipe with cement. Shake the receiver (attached to the rod) and use a stick to stir as you progress. This will help settle the concrete and remove air bubbles. Fill the PVC pipe to the top with cement and make a dome at the top using a trowel to allow water to run off (Figure 2-15).

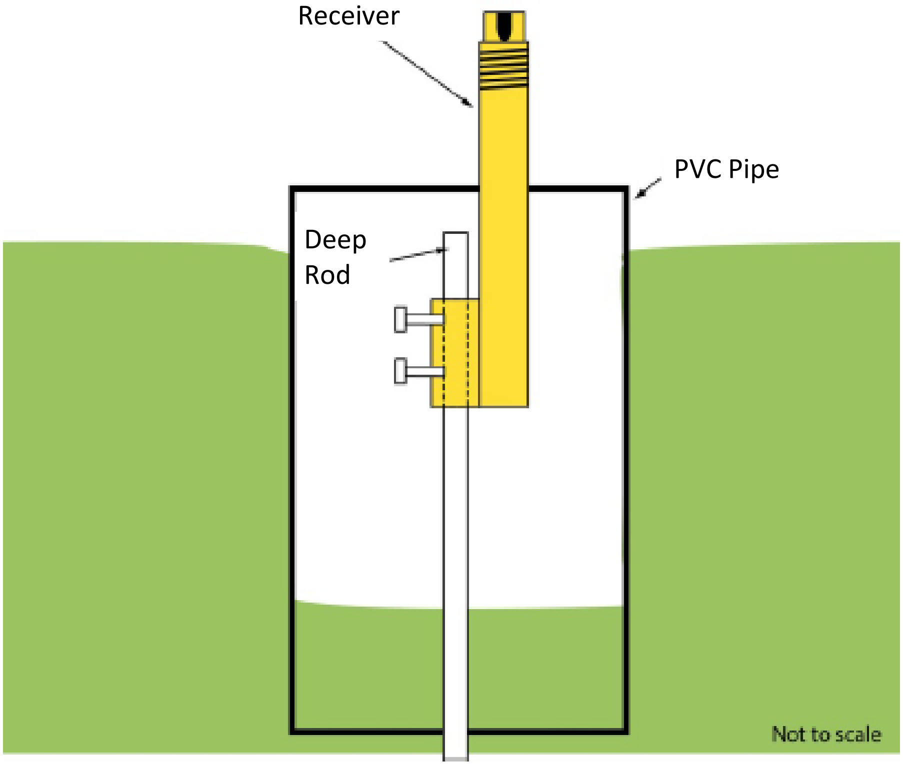


Figure 2-14: Receiver (yellow) attached to the RSET rod (white). Reproduced from US Geological Survey publication: The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics. SOP-3, *Figure 3.22*.

Figure 2-15: Completed RSET benchmark with stainless steel identification tag. The receiver is fixed to the RSET rod that is encased in concrete inside the PVC collar.

- Add an SS ID marker, place it into the cement before it sets. Note that markers are for ID purposes and are not to be used for surveying.
- Installation of the RSET benchmark is complete. If possible, wait 4-8 weeks before taking the first measurements with the RSET instrument.

The process of installing a RSET mark goes relatively quickly once the equipment and installation team are in place. In terms of logistics, it should be straightforward to install at least 3 RSET benchmarks during a single 8-hour day.

This will depend to some extent on the relative locations of the sites and the time required to move between them. Three RSET benchmarks installed per day is a minimum number under most circumstances.

2.3 Sediment accretion measurement methods

Two methods have been implemented in the present project to measure sediment accretion rates:

- Feldspar marker horizons (USDI, 2015).
- Plastic mesh plates (Swales and Lovelock, 2020).

The marker horizon and mesh plates are installed adjacent to each other at three replicate sites within each quadrat and provide independent methods for sediment accretion measurement.

Marker Horizons (MH) are artificial soil layers established on the surface of the wetland to measure vertical accretion. Under ideal conditions, the MH is gradually buried by deposition of natural sediment and is not subsequently disturbed due to processes such as bioturbation or resuspension by currents or waves. The latter process is unlikely to occur in low-energy wetland environments as plants are effective at dampening currents and attenuating wave heights. Sediment mixing and disturbance of the marker horizon, due to bioturbation, is much more likely to occur when crabs, in particular, are present. For example, the mud carb (Helice crassa) is common in mangrove forests whereas this may not be the case in saltmarsh where a dense root mat makes construction of borrows more difficult.

Numerous materials such as sand, feldspar, brick dust and glitter are used as marker horizons. Powdered white feldspar clay is the most common; its main advantages are that it is bright white and easily distinguishable from surrounding sediments, has a higher density than water, and forms a colloidal layer when wet (so it can be deposited as a contiguous layer even in open water). Cores are taken through this layer, and the thickness of the sediment (both mineral and organic) accumulated above the layer is measured as vertical accretion. Accretion rates are typically expressed as millimetres of accretion per year. Marker horizons primarily provide data on surface processes of sediment deposition and erosion (Figure 2-16). When used together with RSET measurements, the SET-MH techniques make it possible to distinguish between the contributions of surface and subsurface processes to elevation change.

NIWA has modified the sediment accretion measurement method by incorporating customisable plastic-mesh plates that may be used along with feldspar-marker horizons (i.e., USGS publication). In our experience, the feldspar marker horizons can be affected by rapid sediment mixing associated with the burrowing and feeding activities of mud crabs. The mixing results in poor accuracy and eventual loss of marker horizons, typically over several months. The plastic-mesh plate method for sediment accretion measurement is described by Swales and Lovelock (2020). In the present project, replicate (x3) plastic mesh plates and feldspar were installed within each RSET benchmark quadrat. This occurred during RSET survey 1, which occurred several weeks after the RSET benchmark installation.

Examples of the positions for the MH within each RSET site quadrat are shown in Figure 2-3 and a template for MH and plastic mesh plate installations is provided in Appendix B. These may be installed at any accessible point within the 3.0 x 2.5m area of each quadrat not occupied by the RSET benchmark. The locations selected should be representative of vegetation cover within the quadrat and provide a good spatial coverage and be accessible from outside the boundary off the quadrat (i.e., within arms-length). Feldspar (approx. 1 kg) is evenly sprinkled on the surface of the wetland (approx. 30 x 30 cm area) within each MH plot., upon which sediments naturally settle and accrete. Plastic-mesh plates (approx. 30 x 30cm) were installed adjacent to feldspar areas and held in place with 4 steel pins. At saltmarsh sites, the mesh plates were cut in half (i.e., 0.15 x 0.3 m) so they could be more readily accommodated in natural gaps in the saltmarsh. The plastic mesh can be customised to each site by cutting holes in it to accommodate roots (e.g., mangrove pnumatophores). In some cases, pnumatophores may need to be removed at bed level using secateurs. Over time, any artifacts in measurements resulting from the mesh installation become negligible as the mesh is progressively buried by natural sedimentation (Swales and Lovelock, 2020).

Each side of the MH and mesh plates are identified by inserting a small plastic rod into the sediment (Figure 2-17). MH are typically established 4-8 weeks after the RSET benchmark installation and at the same time the first baseline RSET measurements are taken.

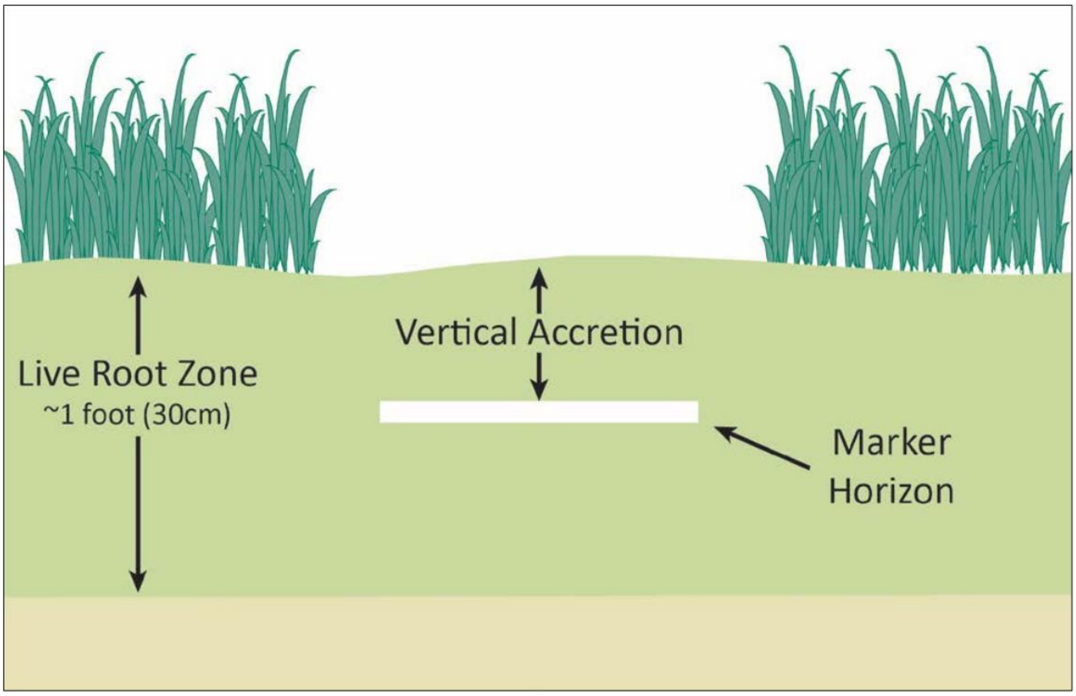


Figure 2-16: Schematic diagram showing the marker horizon and the vertical accretion occurring above it. Reproduced from US Geological Survey publication: The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics. *Figure 7*.

Figure 2-17: Marker horizon plot showing plastic mesh installed in Saltmarsh. Mesh installed in saltmarsh was 15 x 30 cm. Feldspar was also sprinkled alongside the plastic mesh. Plastic yellow straws or white rods are used to demarcate areas.

Be sure to draw a detailed map in the template for MH installations showing the relative locations of the feldspar plots in case the rods are lost or destroyed. Record details of locations relative to RSET benchmark – Magnetic direction & distance (cm) AND/OR corner pole (x,y coordinates [m]) and clearly identify corner poles on map by their direction. Draw magnetic north arrow direction on the template document.

2.4 Baseline RSET Measurements

The first measurements taken at an RSET benchmark are called the "baseline" readings and are the values to which subsequent readings will be compared. Prior to taking the first measurements, it is important to establish the sampling directions, consider the sampling schedule and have an appropriate plan to record the data collected. Be sure to work from a stable platform when reading the RSET instrument.

RSET surveys are best conducted at or around low tide. Typically, you will have at least a 6 hour window for making measurements (i.e., low tide $\pm$ 3 hours) as RSET benchmarks are generally located in the upper intertidal zone. Consult tidal predictions (e.g., LINZ, Tide predictions | Toitū Te Whenua - Land Information New Zealand (linz.govt.nz); NIWA Tides) to plan your field work. Low tides occurring from mid-morning to mid-afternoon are ideal. Consult weather forecasts several days before the planned survey and postpone if poor weather is likely. Making high quality measurements is best achieved during fair weather.

Consider the 8 directions (every 45 degrees) that are available when the RSET instrument is attached to the receiver (Figure 2-18). Choose one direction then select the remaining 3 directions (e.g., B, C, and D, Figure 2-18). The four directions are typically 90 degrees apart from each other. Actual positions selected may be influenced by presence of vegetation (e.g., large branches or roots of mangroves). Different positions may need to be selected and/or light pruning of vegetation may be undertaken, providing the impact is minimal. Bungee cords can also be used to temporarily change the position of mangrove-tree branches which RSET surveys are being conducted.

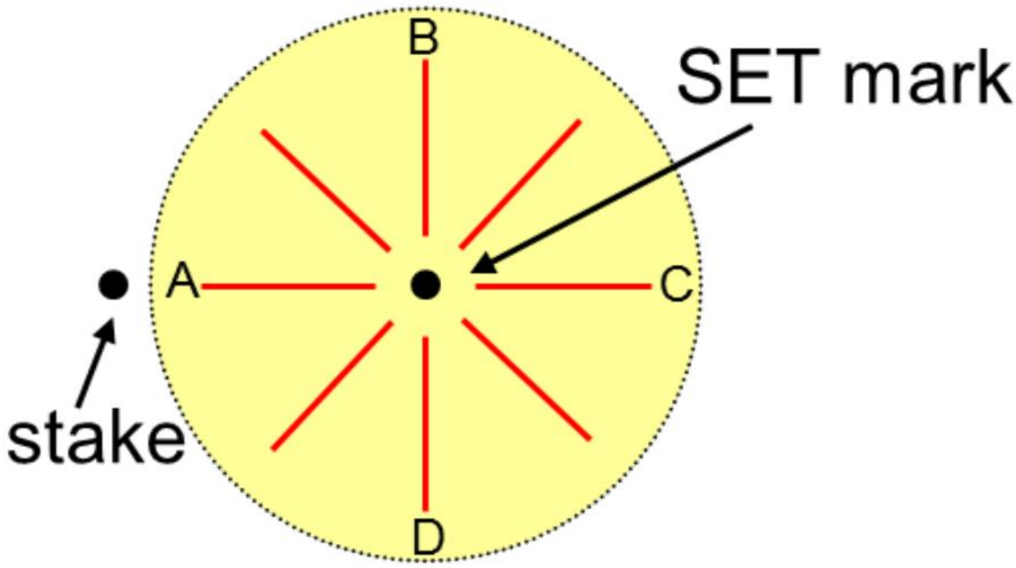


Figure 2-18: Schematic diagram showing the eight RSET measuring directions. In this example only ABCD directions are measured. These are typically 90 degrees apart. A stake may be used to identify position A.

Draw a map of the RSET benchmark quadrat (Template in Appendix B, Figure 2-4), showing the locations of the marker horizons, mesh plates and RSET arm directions and stake positions (if used) and any other features that will help to clearly define the layout. Record the bearing of each of the 4 directions with a compass (Appendix D). The point of recording all this information is to clearly note and distinguish the 4 sampling directions so that the RSET can be properly oriented on subsequent visits. It is essential that the RSET arm is in the same orientation from reading to reading.

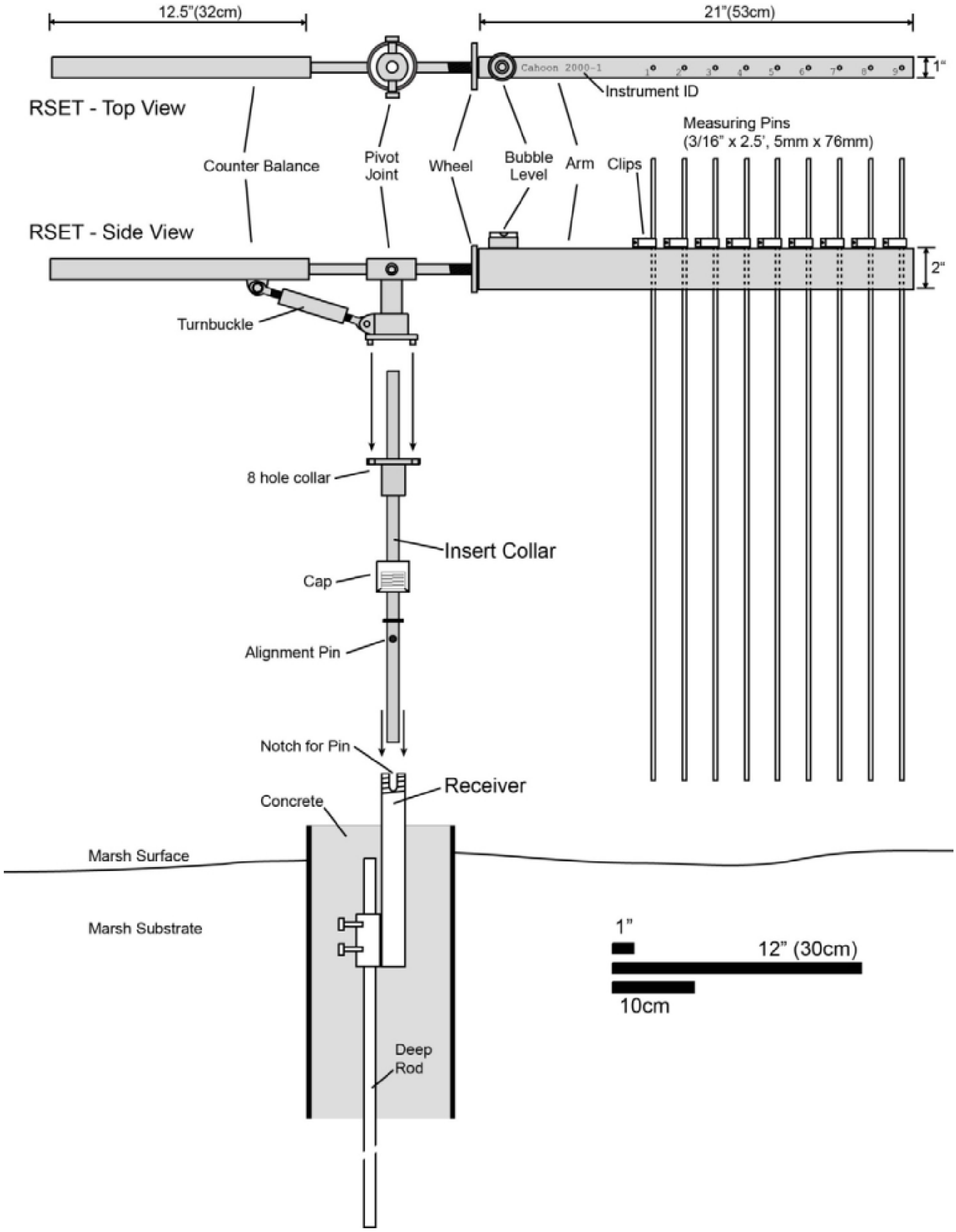


Figure 2-19: Schematic diagram of the Rod Surface Elevation Table (RSET) showing the SET arm, insert collar, and receiver. From Callaway et al. 2013.

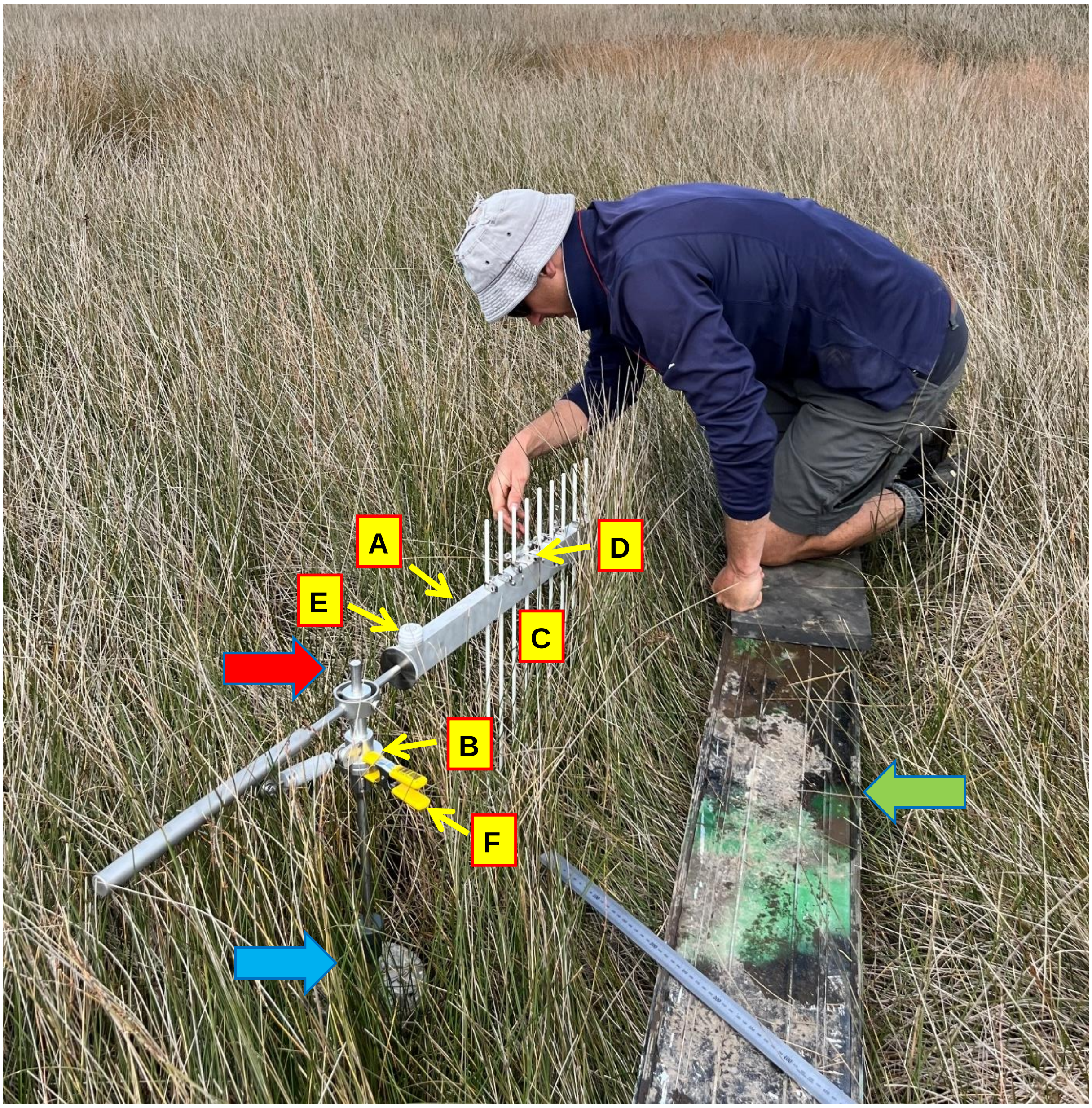


Figure 2-20: Setup of the RSET instrument on a benchmark- Athenree Saltmarsh. Blue arrow indicates the benchmark with receiver. The RSET instrument (red arrow) is mounted onto the receiver. The observer accesses the measurement area using an elevated aluminium plank (green arrow) that is temporarily deployed during each survey. This approach minimises disturbance of the wetland sediment surface in the vicinity of the base station during measurements. Key: A = horizontal arm, B = instrument base, C = fibreglass pins x9, D = badge clips, E = Bubble level, F = Pony clamp x2.

2.4.1 RSET baseline readings

The first measurements or "baseline" readings taken with the RSET are the values to which subsequent readings will be compared. RSET data and measurements are recorded using template supplied (Appendix D).

Equipment required for RSET measurements of substrate surface elevations include plank and stools for creating a stable platform, RSET instrument, metric ruler (minimum 50cm), template data sheets for recording, pencils, camera, compass, secateurs.

Set up the RSET instrument for measurements as follows:

- After installing the raised plank access platform, remove the plastic cap from the receiver on the RSET benchmark. Lightly coat the RSET receiver thread with Silicone spray before and/or after readings.
- Attach the RSET insert collar to the RSET benchmark receiver, making sure the alignment pin on the insert collar slides into the notch on the receiver. Screw the insert collar cap onto the base of the receiver (Figure 2-21).

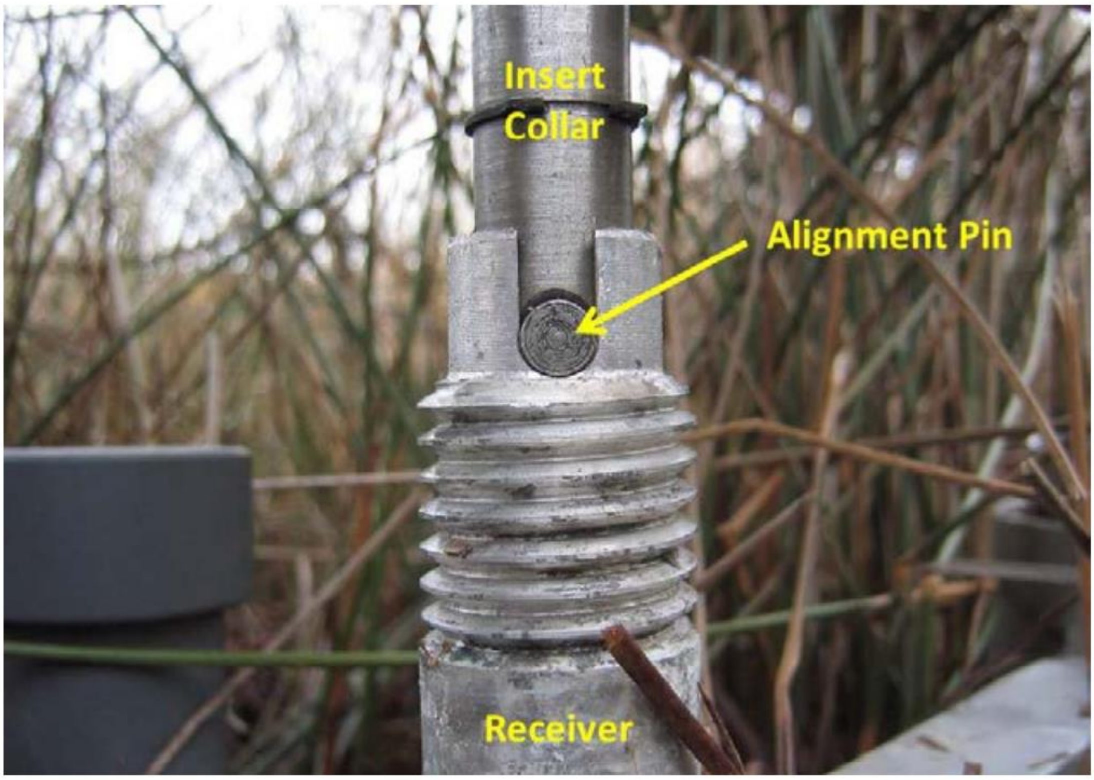


Figure 2-21: The base of the RSET instrument connects to the receiver on the RSET benchmark using an alignment pin. Reproduced from US Geological Survey publication: The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics. SOP-4, *Figure 4.14*.

- Remove the RSET instrument from the carry case and install it onto the insert collar. Secure the instrument to the collar using the two large pony clamps.
- Insert each of the 9 fibre glass pins into the matching holes on the instrument arm. Do not allow the pins to fall to the wetland surface - use the small alligator clips or badge clips to secure/suspend the pins well above the substrate surface.
- Note: prior to first use of the RSET instrument, label the top of each fiberglass pin with a unique number (i.e., 1 through 9). These pins will be matched to each of the nine numbered holes on the instrument arm. Place the numbered pins into their corresponding numbered holes.
- Lift and rotate the horizontal arm to the first measurement direction, as described earlier and fix to the insert collar using the two pony clamps (Figure 2-20).

- Level the horizontal arm in the two horizontal axes using the bubble level (Figure 2-20), turnbuckle and wheel (Figure 2-19).
- Record the direction or bearing on the data recording sheet (Appendix B) and/or draw a diagram along with metadata (i.e, date, time, observers, RSET ID, tide, etc.) (see example in Appendix D).
- To begin the measurements, slowly lower each of the nine fibre glass pins by releasing the badge clips until the pin just touches the sediment surface and replace the badge clip once in position. When the wetland surface is dry this can be done visually – RSET surveys are best conducted when sites are exposed (i.e., low tide ±3 hours). If the substrate surface is submerged, placing the pin relies on touch and/or the feel of the pin hitting the firm surface of the wetland. Do not lean on the horizontal arm during this procedure.
- At many wetland sites, the vegetation, roots or other structures are pushed aside when placing pins. In addition, some sites will undoubtedly have detritus, leaves and other materials on the surface. A decision needs to be made on what to remove and what to leave in place. It is normal to remove any materials which are not attached to or incorporated into the sediment. For example, remove dead vegetation laying on top of the soil surface. Do NOT remove something like a mussel, shell or branch which is partially buried in the sediment. If a pin rests on an unusual surface, such as a branch or in a crab hole, recording the pin height may not be required. Be sure to make a note in the template document (BoPRC RSET Field Data Sheet Template). After measuring the pins, return any moved materials back to their original location.
- NIWA recommended practice is to remove leaves and twigs that have not substantially decomposed or partially incorporated into the substrate (i.e., mangroves). The RSET data recording sheet also includes codes for recording meta data (i.e., proximity [within ~2 cm] to burrows, seedlings, on decomposing leaves).
- Determining the actual sediment surface can be a subjective decision, depending on the type of wetland environment being assessed. In general, saltmarsh and mangrove forests dominated by mineral sediment deposition are more straightforward and easier to make measurements. Sites with more organic sediments (fresh and brackish marshes), can be more difficult for pin placement due to the uneven nature of the surface. When the wetland surface is dry, pins are placed visually by the person taking measurements. If the wetland surface is under water, use your fingers to locate the surface and assist in properly placing the pins.
- Regardless of the environment and conditions being worked in, it's important that to be consistent from sample to sample in determining the wetland surface. Establish a protocol and follow it. Record detailed notes in the template document.
- **Measuring RSET pin heights**: when all of the pins have been placed on the substrate surface and clipped in place, record the pin heights **to the nearest millimetre** (make sure the ruler starts at zero) on the data sheet. Pin height is the distance of the pin above the horizontal bar of the RSET (Figure 2-22, Figure 2-23). Take care to lift pins above the substate surface before moving the instrument arm from one position to another. Once all measurements have been collected for all four directions, carefully

lift pins and remove the SET instrument from the insert collar. Move vegetation back to original position and/or remove bungee cords restraining mangrove tree branches, if relevant.

- Remove pins, unscrew the insert collar from the receiver and transfer components to the carry case. Spray the receiver thread with silicone and reattach the receiver cap. Remove plank and stools, taking care to avoid disturbing the sediment surface by the RSET station "no-walk" zone.

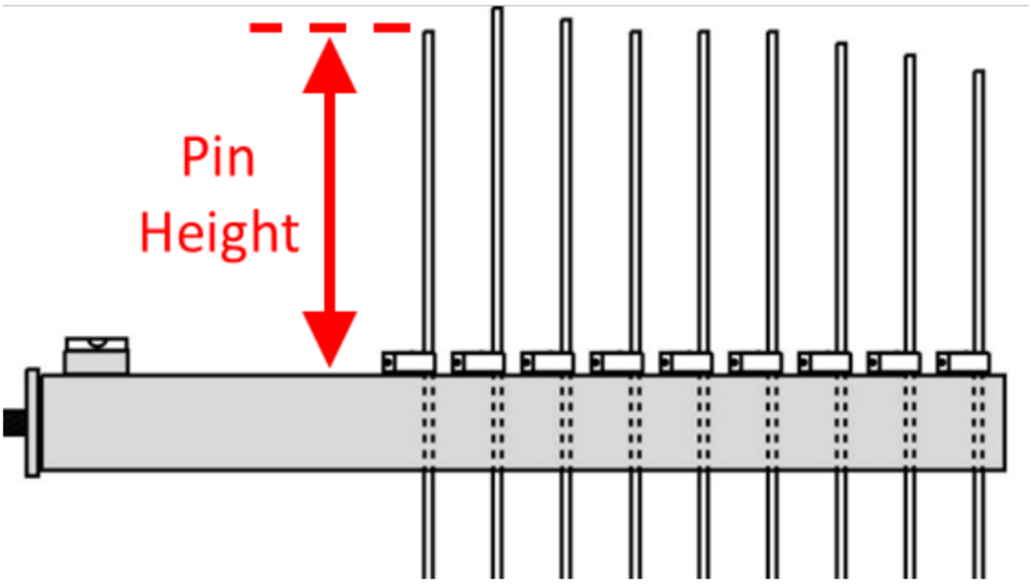


Figure 2-22: Measurement of SET pin heights. Reproduced from US Geological Survey publication: The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics. SOP-4, *Figure 4.19*.

Figure 2-23: Reading the pin heights for SET instrument. Reproduced from US Geological Survey publication: The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics. SOP-4, *Figure 4.20*.

2.4.2 Recommended Sample Schedule for RSET and MH measurements

Sample at consistent time intervals from year to year. For example, if surveys are conducted every 6 months, then late summer (Feb/March) and late winter (August) can be good options in terms of weather conditions. A recommended approach to build a statistically robust data set as quickly as possible to determine elevation trends is as follows:

- Years 1 and 2: seasonal surveys (four per year).
- Years 3-5: six-monthly surveys (two per year).
- Year 6 onward: annual surveys - long-term trend monitoring.
- Post-event surveys: infrequent high magnitude events (river floods, storm) surge can substantially increase sediment supply to coastal wetlands. Post-event surveys can provide important insights into the relative role of fairweather processes versus extreme events on coastal wetland elevation changes (e.g., Swales et al., 2019).

Using this monitoring strategy, surface elevation trends can generally be determined after three years, whereas annual surveys would require a decade of data or more to have confidence in the trend. This primarily reflects the sample size and bear in mind that a three-year record is a minimum. In general, a longer record will sample more extreme events that strongly influence sedimentation in coastal wetlands by supplying fine sediment and elevating water levels (i.e., river floods, storm surges). Long gaps between surveys (i.e., > annually) should be avoided.

It is recommended that a single operator make all SET measurements because there will be a degree of operator bias in the surface elevation measurements (i.e., placement of the pin on the surface, reading the ruler). In practice, having 2–3 experienced operators fully conversant with the RSET surface-elevation measurement method is prudent. This approach recognises that a single operator may not always be available or may leave the organisation.

Double Read: If there is a change in the primary RSET observer, then a “double read” of the RSET measurements is recommended. A double read is where the primary observer takes their final reading at each site and the replacement primary RSET onserver makes their first reading immediately after the original primary observer on the same survey date. Ideally the replacement primary observer will have participated in many RSET surveys as a data recorder, for example.

To maintain the competency of the data recorder(s), it is recommended that they make a reading of the RSET arm for at least one RSET arm direction at 2-3 sites in every survey. Figure 2-5 shows the field data sheet for Athenree RSET ATH-1 (saltmarsh) for the initial October 2022 survey. A double reading by the primary observer and data recorder for one arm direction (359°M) shows that the individual measurements of the two observers are within 1-2 mm of each other. The average and standard deviation values for the primary observer (111.7±9.0 mm) and data recorder (113.9±9.8 mm) are also similar, although the ~2mm difference in the average values measured by the two observers suggests a small measurement bias. Conducting a small number of double measurements during an RSET survey therefore keeps multiple observers competent as well as providing insights into potential bias.

3 Training of BoPRC Staff

RSET Benchmark installation: Darryn Hitchcock (BoPRC) accompanied NIWA staff during the installation of RSET benchmarks in Athenree on 23-24 August and Heather MacKenzie also assisted with RSET installations in Nukuhou Inlet (Ohiwa Harbour) on 13-14 October 2022.

RSET Survey One – including installation of plastic mesh plates and feldpsar marker: BoPRC science and field staff undertook training in RSET survey methods (i.e., survey 1) with NIWA staff. BoPRC was represented by Shay Dean, Darryn Hitchcock, Heather McKenzie, Erin Fox and Josie Crawshaw. Installation of marker horizons and plastic mesh plates was also conducted. The training included demonstrations of measurement techniques and record keeping for on-going surface elevation and sediment accretion monitoring at the BoPRC RSET sites. The initial RSET surveys and training were conductedat Athenree Estuary on 10-11 November 2022 (Athenree).

4 Site Access

When undertaking the services in Athenree Wildlife Refuge Reserve, Nukuhou Saltmarsh Conservation Area or Uretara Island Scenic Reserve; the contractor must comply with conditions of Department of Conservation Authorisation Number: 87667-FLO.

Access to either the mangrove RSET sampling sites at Athenree (ATH 4-6) or the saltmarsh RSET sampling sites at Nukuhou Inlet (NUK 4-6) was possible without crossing private land (Figure 2-1and Figure 2-2).

Access to Athenree saltmarsh RSET sampling sites (ATH 1-3) and Nukuhou mangrove RSET sampling sites (NUK 1-3) was only possible with permission from private landowners.

4.1 Athenree Site information

Sites ATH 4-6 (mangrove habitat) were accessible from the end of Waiiti Ave (off Seaforth Rd) in Waihi Beach as shown in Figure 4-1.

Sites ATH 1-3 (saltmarsh habitat) is shown in Figure 4-1 and is accessible from 133 Koutunui Rd with permission from:

Shona and David Evans, 133 Koutunui Road, Athenree.
Email: wildwestdisco@gmail.com
Phone: 027 252 4741 (Shona Evans); 07 863 4282

Note: Property is being sold so the new landowner may need to be identified to request permission for access in the future.

Figure 4-1: Access routes for Athenree wetland habitats. Green line indicates vehicle route to shed on Shona and David Evan's Property adjacent to saltmarsh sites ATH 1-3. Red line indicates public access via Waiiti Ave to mangrove habitat ATH 4-6.

4.2 Nukuhou Inlet, Ohiwa Harbour Site information

Sites NUK 4-6 (saltmarsh habitat) were accessible via trap lines running along the NW edge of the Nukuhou River just off the Pacific Coast Highway between Ohope and SH2 as shown in Figure 4-2.

Sites NUK 1-3 (mangrove habitat) is accessible from Burke Rd as shown in Figure 4-2 with permission from:
Mr David (Dave) Gee, 158 Burke Road.
Email: gees.motuore@nettel.net.nz
Phone: 027 271 0158

Note: Access to farmland adjacent to the mangrove habitat is via an unsealed farm track and is steep and slippery in places. Use of a 4WD is strongly recommended. Some areas at the bottom of the farm track can also be very wet and there is a risk of getting a vehicle stuck. The mangrove sites can also be accessed via the pest-control trap line that follows the shoreline. The trap line can be accessed from the public reserve at the entry to Burke Road or via private land, with permission. Figure 4-2 shows access to the gate off Burke Rd and 4WD route to land adjacent to mangrove habitat.

Figure 4-2: Access routes for Nukuhou Inlet wetland habitats in Ohiwa Harbour. Yellow line indicates walking route via trap line to sites NUK 4-6. Orange line indicates 4WD track to paddock adjacent to mangrove habitat on David Gee's property.

5 Acknowledgements

We thank the following individuals for their assistance. Site access: Mr David Gee, Burke Road, (Nukuhou) and Mrs Shona Evans, Koutunui Road (Athenree). NIWA staff involved in field work preparation, RSET installation and training: Mark Smith, Barry Greenfield, Rochelle Petrie and Gareth van Assema. We also thank BoPRC Shay Dean, Heather Mackenzie, Darryn Hitchcock and Josie Crawshaw for providing site information for project planning and their assistance with RSET benchmark installation and survey.

6 Glossary of abbreviations and terms

BoP	Bay of Plenty
BoPRC	Bay of Plenty Regional Council
MH	Marker Horizons
RSET	Rod Surface Elevation Table
SET	Surface Elevation Table
SET-MH	Surface Elevation Table and Marker Horizon
SLR	Sea level rise

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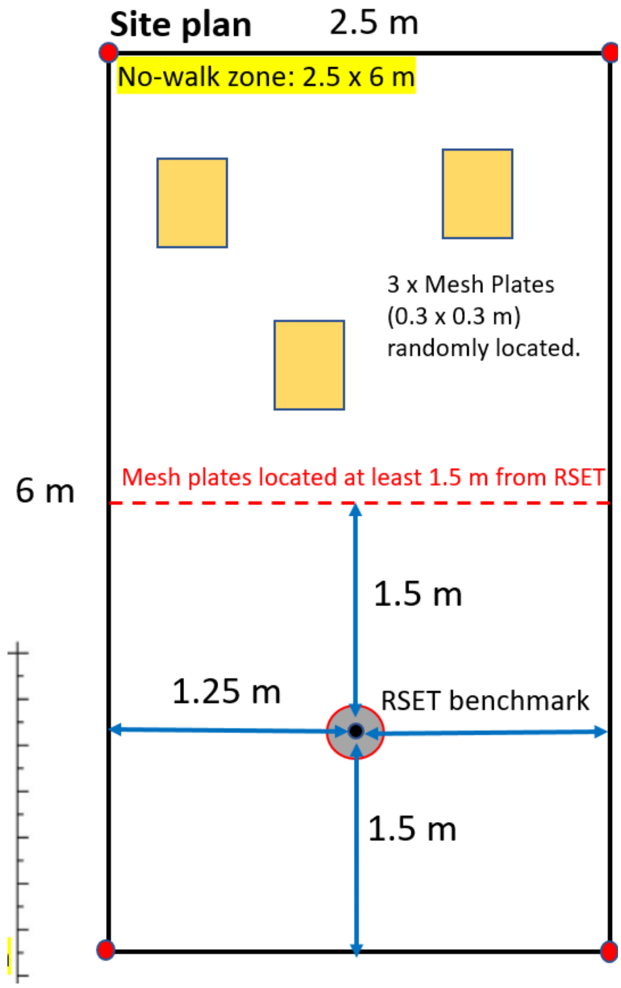
Appendix A Template RSET Installation Record Sheet

Estuary:	**Data**	**Comments**
Date:		
Time:		
Observer:		
Site ID:		
GPS Co-ods:		
PVC Liner: total length in ground (m):		Target: 0.8 m in ground
Total number & type/lengths of stainless-steel rod driven:		1.5 and 1.0 m lengths
Total length of rod driven (m)		Target: **at least 15 m** or to refusal.
Photographs:		
Notes: Please photograph each sheet when compete and email to Andrew.Swales@niwa.co.nz same day.	**Mangrove sites**: Ensure RSET benchmark is located **at least 1 m** from tree trunks.	**Max height of PVC liner** above ground: **0.2 m** **Max height of RSET receiver** above ground: **0.25 m**

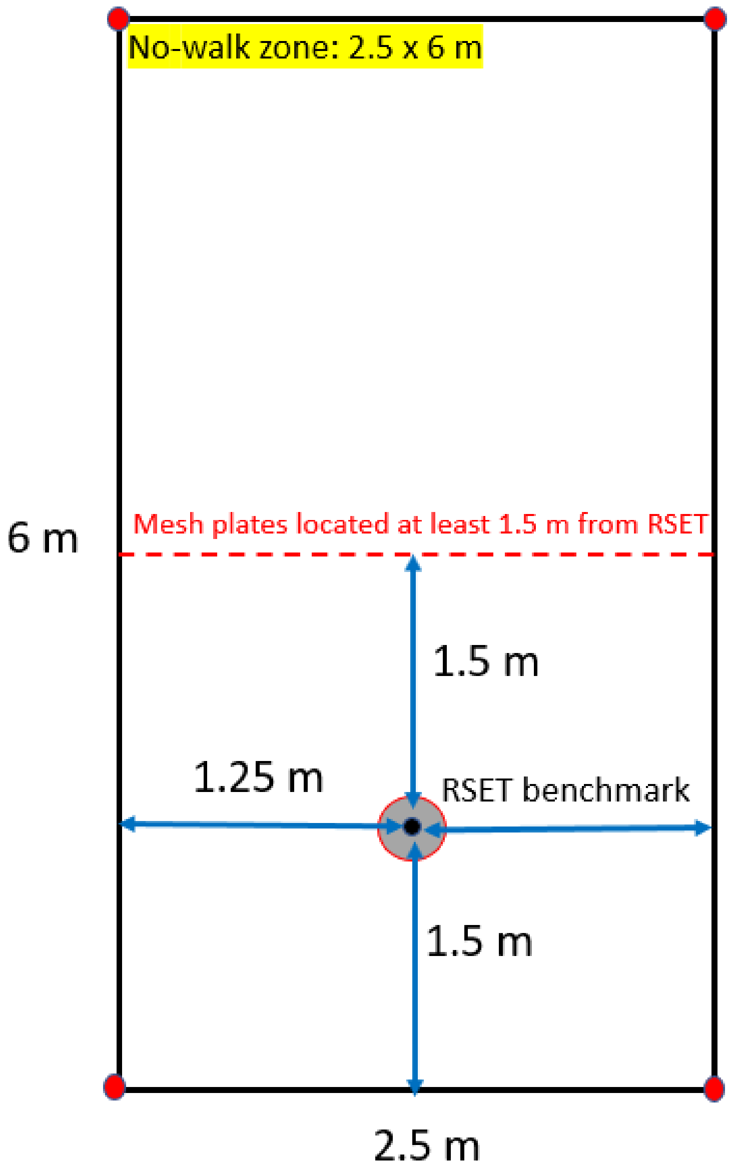


Site plan
2.5 m
No-walk zone: 2.5 x 6 m
3 x Mesh Plates
(0.3 x 0.3 m)
randomly located.
6 m
Mesh plates located at least 1.5 m from RSET
1.5 m
1.25 m
RSET benchmark
1.5 m

Appendix B Template MH and Mesh Plate Installation Record Sheet

Estuary:	
RSET site ID:	
Date:	
Time:	
Observers:	

Notes: (1) no-walk area - corners marked by ~2 m high ~25 mm PVC pipe; (2) Accurately **mark locations on map** of mesh plates (30x30 cm) & adjacent feldspar marker (30x30 cm); (3) **Locations relative to**: **RSET** benchmark – °Magnetic direction & distance (m) AND/OR corner pole (x,y coordinates [m]) – **clearly ID corner poles on map** by their direction AND **draw magnetic north arrow direction** on map.


No-walk zone: 2.5 x 6 m
6 m
Mesh plates located at least 1.5 m from RSET
1.5 m
1.25 m
RSET benchmark
1.5 m
2.5 m

Appendix C BoPRC – Sedimentation Accretion Field Data Sheet Template

Estuary	
RSET site ID:	
Date:	
Time:	
Observers:	

Plastic mesh plate measurements (units – mm)

Notes: (1) confirm plate ID from site map; (2) measure sediment depth to nearest mm; (3) minimum of **5** measurements per mesh plate.

	North	South	Centre	East	West
Plate 1					
Plate 2					
Plate 3					

Feldspar measurements (units – cc on syringe)

Notes: (1) confirm marker bed ID from site map; (2) minimum of **3 cores**/marker bed; (3) re-lay feldspar periodically (~1-cm thick) as required if layer mixed/bioturbated; (4) use cut-off plastic syringe as mini-corer.

	Core 1	**Core 2**	**Core 3**	**Comments**
Sediment surface				
Feldspar –top				
Feldspar – bot				

Appendix D BoPRC RSET Field Data Sheet Template

Estuary:	
RSET site ID:	
Date:	
Time:	
Observers:	

RSET Rod Length (cm)	80	95	105
(tick one)			

RSET Measurements

NOTES: (1) record elevation to nearest mm; (2) direction – degrees magnetic; (3) measure 4 directions

Direction	Dir. 1	Dir. 2	Dir. 3	Dir. 4	Dir. 5	Dir. 6
Bearing (°M)						
Pin 1						
Pin 2						
Pin 3						
Pin 4						
Pin 5						
Pin 6						
Pin 7						
Pin 8						
Pin 9						

Comments

Note appropriate symbol next to measurement if object within ~3 cm of pin

O = crab burrow

T = seedling

≈ **=** decomposing leaf

Δ = root

ADD other symbols as required

Example of BoPRC RSET Field Data Sheet-Athenree ATH-1

BoPRC RSET Field Data Sheet

Version 1 (October 2022)

Estuary:	Athenree Estuary
RSET site ID:	ATH-1 (Saltmarsh)
Date:	11/10/2022
Time:	1100 DST
Observers:	Darryn Hitchcock, Heather McKenzie, A Swales, G. Olsen

RSET Rod Length (cm) (tick one)	80 ✓	95	105

NOTE: ① Don't lean on RSET arm when making measurements
② lift pins before changing arm direction
③ CENTRE THE BUBBLE

RSET Measurements

NOTES: (1) record elevation to nearest mm; (2) direction – degrees magnetic; (3) measure 4 directions

Direction	Dir. 1	Dir. 2	Dir. 3	Dir. 4	Dir. ~~5~~ 1	Dir. 6
Bearing (°M)	359° DARRYN	134°	221°	315°	359° ANDREW	
Pin 1	113	110*	113	107	114	
Pin 2	115	110	113	103	122	
Pin 3	103	116	106	117	104	
Pin 4	094	117	106	114	097	
Pin 5	105	116	111	113	104	
Pin 6	120	108	111	118	124	
Pin 7	120	107	110	117	~~123~~ 122	
Pin 8	118	093	104	104	119	
Pin 9	117	111	111	100	119	

352° ANDREW

↑ no surface features to note

Comments

Note appropriate symbol next to measurement if object within ~3 cm of pin

O = crab burrow

T = seedling

≈ = decomposing leaf

Δ = root

ADD other symbols as required

* NOTE ① Read direction 1 & 3 in same plank position
② Direction 2 & 4 with plank close to benchmark.