Ecological Status of Mangrove Removal Sites in the Auckland Region

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Ecological Status of Mangrove Removal Sites in the Auckland Region

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Executive summary

We surveyed trends in sediment characteristics and benthic communities after removal of mangroves at twenty sites in the Auckland region. At all sites, quantitative visual assessments (including density of seeds and seedlings), and measurements of sediment characteristics and remaining vegetative biomass were made, with analyses of macrofaunal community structure at a subset of thirteen representative sites. Three positions were surveyed at each site: two within the removal area (Removal Positions: 'Edge' located within 10m of the pre-mapped seaward edge of the removal zone; 'Centre' located 20-50m from the seaward edge of the removal zone), and one position within neighbouring sandflat or mudflat habitat ('Unvegetated'). If sites had adjacent mangrove forests remaining, sediment was also sampled inside mangroves within 100m of a clearing.

Few sites showed recovery towards a typical sandflat (either in sediment characteristics or benthic community composition) over periods ranging from three months to eight years.

- At most sites, substantial vegetative biomass still remained post removal, with dense root mass often found just below or at the sediment surface.
- Perimeters of removal areas were generally obvious, with limited erosion of sediment, or change to sandier substrate, except at some Edge positions.
- While there was high variability in macrofaunal community composition between estuaries, composition at sites where mangroves had been removed generally differed from that in unvegetated habitats <10m away. Edges of sandier removal sites were more likely to increase over time in similarity to adjacent unvegetated habitats than muddier sites.
- Sites where mangroves were removed by mechanical means and where mangrove cuttings were left on site exhibited less change toward sandier substrates and macrofaunal communities than sites with non-mechanical methods and where all cut biomass had been removed offsite.
- Faster trends toward recovery were associated with smaller sized clearings, non-mechanical removal techniques, and removal of above ground vegetation. The seaward edges of mangrove clearings were most likely to show changes toward sandier sediments and macrofaunal communities.
- Seedlings were present at fewer sites than expected, though seedling removal by community groups could explain this pattern. Sites with high seedling colonisation were generally adjacent to intact mangrove forest.

The general lack of full recovery suggests that change to a sandier non-mangrove state will require at least a decade, if not far longer, for erosion of muddy sediment and dispersal or decomposition of remaining mangrove vegetative biomass. In sheltered locations, change to a sandier state appears unlikely.

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1.0 Background

Within New Zealand, mangroves occur in four regions in the upper half of the North Island: Northland, Auckland, Waikato and Bay of Plenty. In the past half century, mangroves have increased in extent throughout estuaries and tidal creeks in these regions (Morrisey et al. 2010). This increase in mangrove abundance, as well as the perception that mangroves result in the accumulation of fine sediment, has resulted in an increasing number of consent applications for mangrove removals, with goals of returning estuarine areas to sandier, unvegetated states (Lundquist et al. 2014). Legal and illegal removals have occurred in recent decades in all four New Zealand regions where mangroves occur.

The Proposed Auckland Unitary Plan 2013 includes provisions to enable mangrove removal back to the extent that existed in 1996 to reinstate navigation, access and amenity values, subject to the methods of removal and disposal having only minor adverse effects on the coastal marine area (CMA) (Auckland Council 2013). Removal is also permitted in areas identified in the plan as significant wading bird areas, and in other areas where it enables the operation, maintenance, use and functioning of existing lawful structures, infrastructure and drainage systems. However, monitoring of existing mangrove clearances has been limited, and it is unclear whether mangrove removals in most locations have successfully resulted in a return to a ‘desired state’, i.e., to sandflat habitats that existed prior to 1996, which provide kaimoana and/or are suitable for recreational access and/or desired aesthetics.

Mangrove removal (both consented and illegal clearings) has occurred at dozens of sites in the Auckland Region, using a range of different removal methodologies, and at sites varying in exposure and sediment mud content. This allows for examination of different methodologies and site-specific characteristics on rates of return to sandier substrates and their associated benthic communities. It also allows examination of the time required for sites to return to sandflat (if at all), and an assessment of the likelihood that mangrove removal sites are rapidly (within a decade) recolonised by mangroves. The pre-defined proxy for desired state in this study is that a mangrove removal site returns to sandflat or sandy substrates.

Here, we examine 20 sites in the Auckland region to determine: 1) if a successful return from mangrove forest to sandier substrates has occurred at each site; 2) if there is variability in the time or degree of return; and 3) if so, what aspects of mangrove removal or site characteristics explain the observed differences. Sites were selected to cover the variety of methods used to remove mangroves (e.g., manual chain-saw cutting, mechanical mulching using tractors), and a range of exposures from sheltered tidal creeks or other sites with man-made barriers which impact flow (i.e., causeways, breakwaters), to high tidal movement or exposure to wind waves. Sites were also selected to cover a range of sizes and shapes of mangrove clearings and periods since mangrove removal. The

focus of this study was on the benthic ecology and physical recovery of the sites. Aspects such as bird abundance and social outcomes were not part of this analysis.

This study is part of a broader mangrove research programme, which includes additional sites across Northland, Waikato and Bay of Plenty regions, although this report covers the findings from sites sampled within the Auckland region only. Combined, it is envisioned that the broad scale review of mangrove removals will enable better guidance for community groups and regional and district councils on methods that are cost-effective, and that maximise the potential for sediment erosion and decomposition of mangrove vegetative biomass and a return of the area to a more desired state, i.e., sandflat.

2.0 Methods

2.1 Site selection

With the assistance of Auckland Council staff, Department of Conservation staff and others familiar with mangrove removal locations, we compiled information on existing consented and illegal clearings in the Auckland Region. Information on consented removals was provided by Auckland Council, though available information varied between consents, and the database rarely included specific information on methodology, or when removals actually occurred. We assumed that removals occurred within one year of consent granting, unless information was available to suggest otherwise. Identification of illegal removals was provided by Auckland Council staff, NIWA staff, Department of Conservation staff and local residents, based on knowledge of location or existence of mangrove removals. Exact locations of illegal removals were confirmed when practicable, for sites that were identified as likely candidates for sampling for this project. Due to the small scale (< a few dozen trees) of many illegal removals, locating many of the sites was not possible without intensive field efforts that were beyond the scope of this project. It is likely that the compiled list does not include all mangrove removals in the Auckland region in recent decades.

For consented clearings, consent information was used to identify size and location of removal, removal method used, and approximate time of removal. For illegal clearings, location, timing, and methodology were often anecdotal or unknown. For each site, we also compiled information on physical characteristics (usually broadly based on the entire estuary and catchment where a removal occurred) to assist in choosing a representative set of sites based on physical exposure and estuary size (Hume et al. 2007). We compiled information on a total of ~40 consented and illegal mangrove removals in the Auckland region (Table 2-1), and used this information to select 20 sites for field sampling (see Section 3: Site descriptions). Selected sites span a range of removal techniques, times since removal, and site-specific variation in exposure and sediment type.

Table 2-1 Table of consented and illegal mangrove removals from which the sampled sites were selected. Consent data and broad positional locations provided from Auckland Council database and have not been ground truthed. Illegal removals provided by various sources (Auckland Council, National Institute of Water and Atmospheric Research Ltd., Department of Conservation). *Some consents (e.g., Gibbs, Panmure, Waiuku) included multiple removal sites, and information on area of removal per site was not specified

Location	Estuary	Latitude	Longitude	Consent #	Removal area (m^2)	Consent Status	Years since consent granted	Consent Granted or date of removal (if available)
Orewa	Orewa	5949165	1751356	32301	700-950	Surrendered	7	Jul-06
Lucas Creek	Waitemata	5928458	1748759	20966	~10	Issued	19	Feb-94
Whau River	Waitemata	5915123	1749774	21097	~10	Issued	17	Dec-96
Whau River	Waitemata	5919266	1747707	20836	200	Issued	17	Aug-96
Henderson Creek	Waitemata	5923170	1746526	32759	400	Expired	7	Nov-06
Hobson	Waitemata	5918919	1760721	13884	50	Expired	18	Jul-95
Hobson	Waitemata	5920275	1759408	37713	100	Issued	3	May-10
Catalina Bay	Waitemata	5926785	1749266	37976	1500	Issued	3	Aug-10
Beachlands	Tamaki	5916378	1776900	20871	444	Cancelled	16	Feb-97
Panmure	Tamaki	5913737	1764723	36219	3500	Issued	5	Dec-08
Panmure	Tamaki	5913967	1764282	36219	3500	Issued	5	Dec-08
Gibbs Sculpture Park*	Kaipara Harbour	5957651	1727591	39908	600000*	Issued	1	Jun-12

Location	Estuary	Latitude	Longitude	Consent #	Removal area (m^2)	Consent Status	Years since consent granted	Consent Granted or date of removal (if available)
Gibbs Sculpture Park*	Kaipara Harbour	5956543	1727485	39908	600000*	Issued	1	Jun-12
Airport	Manukau	5904254	1761512	20872	80	Surrendered	17	Nov-96
Airport	Manukau	5902887	1757480	38862	130000	Issued	2	Mar-11
Mangere*	Manukau	5910734	1759230	40809	12370*	Issued	1	Sep-12
Mangere*	Manukau	5910107	1763049	40017	12370*	Expired	1	Jan-12
Mangere	Manukau	5911865	1758093	39605	n/a	Issued	1	Sep-12
Mangere	Manukau	5912085	1758186	36693	43000	Issued	4	Apr-09
Waiuku*	Manukau	5876993	1753270	37547	90923.5*	Issued	3	Apr-10
Waiuku*	Manukau	5876656	1753530	37547	90923.5*	Issued	3	Apr-10
Waiuku*	Manukau	5876770	1753355	37547	90923.5*	Issued	3	Apr-10
Waiuku*	Manukau	5878024	1751514	37547	90923.5*	Issued	3	Apr-10
Waiuku*	Manukau	5877226	1752653	37547	90923.5*	Issued	3	Apr-10
Waiuku*	Manukau	5877324	1753365	37547	90923.5*	Issued	3	Apr-10
Waiuku	Manukau	5876324	1753436	32474	4800	Issued	7	Jun-06
Pahurehure	Manukau	5897660	1769481	32781	50	Surrendered	7	Oct-06

Location	Estuary	Latitude	Longitude	Consent #	Removal area (m^2)	Consent Status	Years since consent granted	Consent Granted or date of removal (if available)
Pahurehure	Manukau	5896957	1771335	32458	34057	Expired	7	Jun-06
Pahurehure	Manukau	5896611	1771951	35053	276000	Issued	5	Dec-08
Whangateau	Whangateau	5976455	1758120	Illegal	2600			2009
Whangateau	Whangateau	5976569	1757942	Illegal	300			2007
Weiti	Weiti	5943233	1754203	Natural	n/a			n/a
Matipo Road, Te Atatu	Waitemata	5921959	1745970	Illegal	<200			n/a
Shelly Beach	Kaipara	5951942	1723389	Illegal	~600			n/a
Awhitu Regional Park	Manukau	5895636	1747207	Illegal	<50			n/a
Mangere Inlet	Manukau	n/a	n/a	Illegal	<50			n/a
Conifer Grove/Wattle Downs, Pahurehure	Manukau	5898138	1767801	Illegal	<50			n/a
Keywella Drive, Pahurehure	Manukau	5898548	1769499	Illegal	~2000			~Dec-2012
Hingaia Islands, Pahurehure	Manukau	n/a	n/a	Illegal	<50			n/a
Waiuku Estuary	Manukau	n/a	n/a	Illegal	<50			n/a

2.2 Sampling methodology

At each site, mangrove removal areas were pre-identified using maps and approximate GPS coordinates as provided by the Auckland Council consent database, if available, to determine initial boundaries of removal locations. When no maps were available, removal areas were located from anecdotal descriptions of sites, and identified visually using remaining mangrove stumps and pneumatophore zones to locate approximate initial boundaries. Three positions were sampled to characterise the removal zone at each site: neighbouring 'Unvegetated' habitats were located within 10m of the seaward edge of the mangrove removal zone, and included a range in sediment from sites dominated by medium or fine sands sites dominated by silt and clay (>80% mud content); 'Mangrove Edge' sampling positions were located ~10m inside the seaward edge of the mangrove removal zone; and 'Mangrove Centre' sampling positions were located at approximately midway between the seaward and shoreward edge of the removal zone, generally 20-50m inshore of the seaward edge of the removal. Generally the Unvegetated habitat had not previously been occupied by mangroves. However if no Unvegetated habitat occurred adjacent to a mangrove zone (i.e., the mangrove zone filled all available intertidal habitat as occurred for at least one site), then Unvegetated samples were taken from the sparse mangrove fringe zone at the edge of a channel. The Centre and Edge positions are collectively referred to as "Removal Positions" when grouped together. For small removals (<10m in width), only Edge samples were collected. In addition sediment samples were taken from adjacent mangrove forests, if any remained within 100m of a removal site to approximate mud content at removal positions prior to removal. Samples taken from adjacent mangroves, while likely to be similar to mangrove forest sediments prior to mangrove removal, are only an approximation of likely baseline sediment characteristics prior to removal. However, baseline (pre-removal) samples were not available for most sites.

2.2.1 Visual assessment of mangrove removal sites

2.2.1.1 Perimeter mapping

Perimeters of mangrove removal zones were mapped by walking within 1 m of the visible perimeter of the area still identifiable as containing mangrove biomass based on presence of stumps and pneumatophores. Positions were recorded using a hand-held GPS unit (Garmin GPSMap78SC). Perimeters were imported into ArcGIS (v10.1) and the area of each removal zone was calculated, and compared to maps available from consent documents to determine if erosion of removal boundaries was occurring.

2.2.1.2 Quadrat sampling

At each site, three quadrats (0.5 m x 0.5 m) were sampled at each position (neighbouring Unvegetated, mangrove removal Edge, and mangrove removal Centre) for visual information on physical and ecological characteristics indicative of recovery after mangrove clearance (e.g., presence and abundance of epifauna, presence of macroalgae, colonisation by mangrove seeds and seedlings, presence and location of remaining vegetative biomass (mulchate, pneumatophores, root mass), and sediment oxic depth). After visual assessments were completed, quadrats were hand-raked to determine the abundance of the infaunal bivalves.

The following metrics were recorded for each 0.5m x 0.5m quadrat:

- Number of visible crab or other burrows.
- Number and species of epifauna on the surface, primarily gastropods *Amphibola crenata, Zeacumantus lutulentus, Diloma subrostrata,* and *Cominella glandiformis.* Counts of *Potamopyrgus estuarinus* were not included in visual measurements, as they were not recorded reliably due to their small size.
- Number of infaunal bivalves >10mm, including primarily *Austrovenus stutchburyi* and *Macomona liliana.*
- Depth and density of root biomass.
- Proportion of surface covered by mangrove leaf litter.
- Number of pneumatophores.
- Proportion of surface covered by woody debris, and depth of debris layer (mm).
- Number of mangrove seeds and seedlings.
- Proportion of surface covered by macroalgae.
- Depth of sediment oxic layer (mm).
- Sinkability, i.e., depth of footprints (cm) of an adult individual with a body weight of 70-100kg.

Mangrove stumps were counted at the Centre and Edge positions (where stumps were visible) at each site within a 10m x 10m area to estimate approximate density of mangroves prior to removal.

2.2.2 Sediment analyses

Sediment characteristics (i.e., sediment particle size analysis, organic content and photopigments (chlorophyll *a* and phaeophytin)) were assessed at each position at each site. At each sampling position (Unvegetated, Edge, Centre), sediment was randomly

sampled using two composite sediment cores (2cm deep, 2cm diameter), one to determine sediment particle size and organic content and one for chlorophyll *a* and phaeophytin analysis. At sites where adjacent mangroves occurred, we collected sediment samples from 10m inside the edge of the mangrove forest. The cores were kept frozen in the dark prior to being analysed as described below. At a subset of sites, we collected three replicate samples to ensure variability between positions was greater than variability within a position.

Grain size: The samples were homogenised and a subsample of approximately 5g of sediment was taken and digested in ~ 9% hydrogen peroxide until frothing ceased to remove organics. The sediment sample was then wet sieved through 2000μm, 500μm, 250μm and 63μm mesh sieves. Pipette analysis was used to separate the <63μm fraction into >3.9μm and <3.9μm. All fractions were then dried at 60^{o}C until a constant weight was achieved (fractions were weighed at ~ 40h and then again at 48h at which time all samples were at a constant weight). Grainsize fractions were calculated as percentage weight of gravel/shell hash (>2000μm), coarse and very coarse sand (500 – 2000μm), medium sand (250 – 500μm), fine and very fine sand (63 –250μm), silt (3.9 – 62.9μm) and clay (<3.9μm). Mud content was calculated as the sum of the silt and clay content.

Chlorophyll *a* and phaeophytin: Within one month of sampling, sediment samples were freeze dried, then homogenised and a subsample (~5g) was weighed and taken for analysis. Chlorophyll *a* was extracted by boiling the sediment in 90% ethanol, and the extract processed using a spectrophotometer (Shimadzu UV1800). An acidification step was used to separate phaeopigments from chlorophyll *a*.

Organic content: Approximately 5g of sediment was placed in a dry, pre-weighed tray. The samples were then dried at 60^{o}C until a constant weight was achieved (the samples were weighed after ~ 40h and then again after 48h at which time all samples were at a constant weight). The samples were then ashed for >5.5h at 400^{o}C (Mook and Hoskin 1982) and reweighed. Organic content was calculated as the percent difference in weight between dry weight and ash-free dry weight.

2.2.3 Macrofaunal analyses

Thirteen of the twenty sites surveyed during this project were prioritised for macrofaunal analysis. These sites were chosen to provide representation across the different mangrove removal methods, estuaries, physical characteristics, exposures, and times since mangrove removal. At each of three sampling positions (Unvegetated, Edge, Centre) per site, six randomly placed macrofaunal cores (13cm diameter, 15cm depth) were collected within 1 m of quadrats sampled for visual information. Macrofaunal cores were sieved through a 500μm mesh and the residues stained with rose bengal and preserved in 70% isopropyl alcohol in seawater. Unvegetated samples were then rinsed and sieved through

a series of nested sieves, and sorted and stored in 50% isopropyl alcohol. Macrofauna were identified to the lowest taxonomic level practicable, usually to species. Analysis of three macrofaunal cores allowed sufficient statistical power for data analysis, so additional cores were not analysed.

Due to the generally large amount of vegetative material, mangrove Centre and Edge samples were extensively rinsed and sieved on a 500µm mesh to remove as many macrofauna as possible from vegetative material. Larger vegetative material, for which rinsing and sieving successfully removed 100% of macrofauna, was removed from root material and set aside and all macrofauna identified. The remaining root mass was subsampled and the macrofauna identified and counted. The subsample proportion varied between samples, with most subsamples consisting of 14-25% of the remaining root mass (subsample range: 9-100%). Macrofaunal abundance from root material was estimated by multiplying the counts within the subsample by the proportion of the root material that was sorted. Total abundance was calculated as the total of the macrofaunal abundance from the larger vegetative material plus the estimated macrofaunal abundance from the root material.

2.2.4 Vegetative biomass

As mangrove removals may be associated with slow decomposition of remaining vegetative biomass (including roots, pneumatophores, stumps, and in some cases, mulch), we quantified the vegetative biomass in macrofaunal cores (13cm diam., 15cm depth) for 3 replicate samples at each position. After sorting, all vegetative material was air dried for one week on aluminium trays, and then oven dried at 70 ºC for approximately 4 days until dry weight stabilised. Weights for each mangrove constituent were then recorded. Above ground biomass included >2 mm diameter vegetation such as pneumatophores and woody debris; below ground biomass included fine root mass.

2.2.5 Statistical analyses

Community composition: All community analyses were performed on both the individual replicate cores, and on the average of the three replicate cores collected at each position (Unvegetated, Edge and Centre) at each estuary site. Multivariate ordination of data was performed using nonmetric multidimensional scaling (MDS) based on Bray Curtis similarities (Primer v. 6.1.15; Clarke 1993). MDS was used to determine whether community composition was similar across positions, and if mangrove removal areas were trending toward neighbouring unvegetated habitats over time, and if different sites and different removal methodologies showed similar trends among sites and times. Multivariate plots also allowed for examination of similarity in trends between sites and if temporal trends in recovery were apparent based on time since mangrove removal occurred. Ordinations of raw, square root transformed, log transformed and presence/absence data

were conducted. Only the raw data ordinations are presented in this report as no differences in interpretation of patterns were apparent with the different transformations. Dissimilarities were calculated between sampling positions at each site using raw, untransformed data using the SIMPER procedure in Primer. Community composition at each site was also described based on the five most numerically dominant taxa.

Biodiversity: Univariate measures of macrofaunal community structure were also calculated for each position at each estuary site. Number of taxa, number of individuals across all taxa, and the Shannon-Weiner diversity index were calculated for each of three replicates, then averaged.

Factors influencing differences in recovery rates: Multiple regression was used to identify the role of mangrove removal methodologies and site characteristics in explaining the observed rates of change for sediment characteristics, vegetative biomass, and community dissimilarities. A backwards selection procedure was used to determine the subset of environmental variables that best explained the observed variability for each metric for Removal Positions (both Edge and Centre positions). Environmental variables in the analysis included a subjective ranking of exposure (Moderate, Sheltered) based on broad estuary physical characteristics from the Estuary Environments Classification (Hume et al. 2007) and site evaluation by NIWA staff; sediment characteristics at neighbouring unvegetated habitats (% mud content); mangrove removal methodology (use of mechanical (i.e., vehicles in the coastal zone) or non-mechanical (i.e., hand-clearing via chainsaw); disposal of vegetative biomass (onsite or offsite); and size of the cleared area (ha). Multiple regressions were performed using the REG procedure in SAS (v. 9.3). P values <0.05 were determined to be significant.

3.0 Site descriptions

Twenty mangrove removal sites were chosen for sampling (Figure 3-1); of these, higher resolution macrofaunal samples were analysed at 13 sites representative of the range of methods, exposures, and times since mangrove removal.

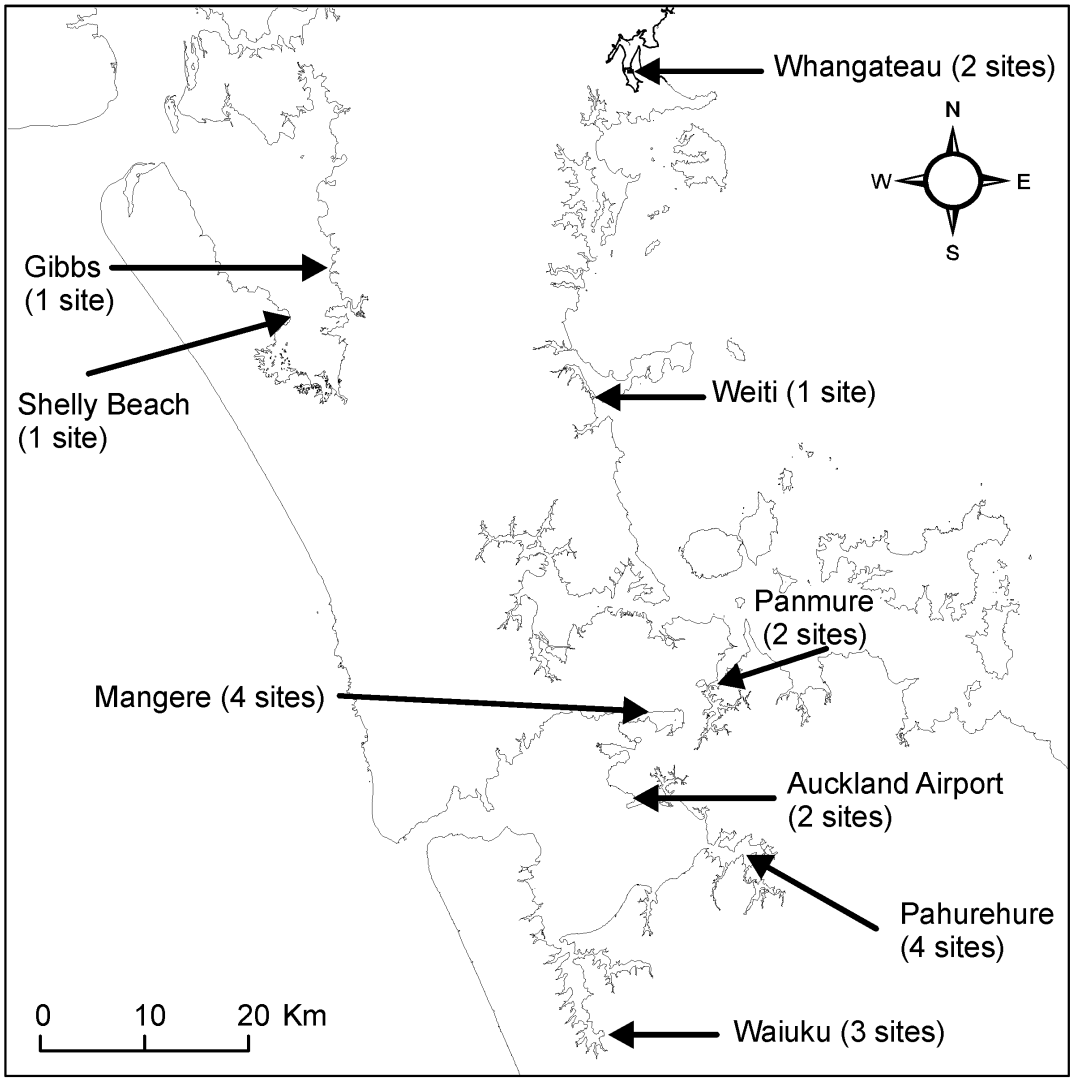

Figure 3-1 Map of mangrove removal sites sampled (Table 3-1).

Table 3-1 GPS coordinates of sampling locations at each site. Descriptions indicate approximate date of removal and removal method used. * indicates sites where macrofaunal samples were analysed

Site location	Year removed	Position	Latitude (NZTM)	Longitude (NZTM)	Exposure	Removal Method	Disposal of vegetation	Size (ha)
Shelly Beach	2013	Unvegetated	5951942	1723389	Moderate	Chainsaw, likely with vehicle access for debris removal	Offsite	0.06
		Edge	5951942	1723389				
		Adj. Mangroves	5951942	1723389				
Gibbs 1*	2012	Unvegetated	5956546	1727306	Moderate	Mechanical	Mulch, onsite	2.06
		Edge	5956544	1727395				
		Centre	5956543	1727485				
		Adj. Mangroves	5956543	1727485				
Auckland Airport 1*	2011	Unvegetated	5902888	1757391	Moderate	Mechanical	Mulch, onsite	13.86
		Edge	5902887	1757480				
		Centre	5902998	1757482				
Auckland Airport 2	2011	Unvegetated	5902776	1757478	Moderate	Mechanical	Mulch, onsite	13.86
		Edge	5902774	1757567				
		Centre	5902885	1757569				
Mangere 1*	2013	Unvegetated	5911180	1759149	Sheltered	Chainsaw, with vehicle	Mostly offsite	0.06

Site location	Year removed	Position	Latitude (NZTM)	Longitude (NZTM)	Exposure	Removal Method	Disposal of vegetation	Size (ha)
		Edge	5911180	1759149		(Argo) for debris removal		
		Centre	5911180	1759149				
		Adj. Mangroves	5911180	1759149				
Mangere 2	2011	Unvegetated	5910734	1759230	Sheltered	Chainsaw	Offsite	0.04
		Edge	5910734	1759230				
		Adj. Mangroves	5910734	1759230				
Mangere 3	2013	Edge	5910732	1759319	Sheltered	Chainsaw	Offsite	0.05
Mangere 4*	2011	Edge	5910223	1762784	Sheltered	Chainsaw	Offsite	0.58
		Centre	5910219	1762962				
		Adj. Mangroves	5910334	1762786				
Pahurehure 1*	2012	Unvegetated	5898550	1769410	Sheltered	Chainsaw	Woody debris onsite	0.19
		Edge	5898548	1769499				
		Centre	5898548	1769499				
		Adj. Mangroves	5898548	1769499				
Pahurehure 2*	2008	Unvegetated	5896619	1771595	Sheltered	Chainsaw	Offsite via	5.21

Site location	Year removed	Position	Latitude (NZTM)	Longitude (NZTM)	Exposure	Removal Method	Disposal of vegetation	Size (ha)
		Edge	5896619	1771595			helicopter	
		Centre	5896508	1771593				
Pahurehure 3*	2012	Unvegetated	5897293	1771164	Sheltered	Mechanical	Offsite	4.21
		Edge	5897291	1771253				
		Centre	5897291	1771253				
Pahurehure 4	2012	Unvegetated	5896962	1771069	Sheltered	Mechanical	Offsite	5.28
		Edge	5896964	1770980				
		Centre	5896964	1770980				
Waiuku 1*	2006	Unvegetated	5876435	1753438	Sheltered	Mechanical	Mostly offsite	2.53
		Edge	5876435	1753438				
		Centre	5876435	1753438				
Waiuku 2	2010	Unvegetated	5876657	1753442	Sheltered	Mechanical	Mostly offsite	4.57
		Edge	5876657	1753442				
Waiuku 3*	2010	Unvegetated	5876881	1753357	Sheltered	Mechanical	Mostly offsite	4.57
		Edge	5876881	1753357				
		Centre	5876881	1753357				
Weiti 1*	~2012	Unvegetated	5943342	1754294	Sheltered	Natural mortality event	Woody debris	3.48

Site location	Year removed	Position	Latitude (NZTM)	Longitude (NZTM)	Exposure	Removal Method	Disposal of vegetation	Size (ha)
		Edge	5943120	1754290			onsite	
		Centre	5943233	1754203				
Whangateau 1*	2009	Unvegetated	5976566	1758122	Moderate	Chainsaw	Woody debris onsite	0.26
		Edge	5976455	1758120				
Whangateau 2*	2007	Edge	5976569	1757942	Moderate	Chainsaw	Woody debris onsite	0.03
		Adj. Mangroves	5976678	1758034				
Panmure 1	2008	Unvegetated	5913740	1764545	Sheltered	Chainsaw	Mostly offsite	0.28
		Edge	5913740	1764545				
		Centre	5913740	1764545				
Panmure 2*	2008	Unvegetated	5913855	1764369	Sheltered	Chainsaw	Mostly offsite	0.52
		Edge	5913855	1764369				
		Centre	5913855	1764369				
		Adj. Mangroves	5913855	1764369				

3.1 Shelly Beach, Kaipara Harbour (one site)

An unconsented clearance at Shelly Beach was noted by NIWA staff undertaking Kaipara Harbour Ecological Monitoring fieldwork in late 2013. A small (~20m wide, ~30m long) strip of mangroves was removed from the middle of the mangrove stand directly north of the jetty from shore to sea to create an access way through the mangroves (Figure 3-2, Appendix). The mangrove clearing was most likely cleared via chainsaw, with some evidence of a minor amount of mechanical access by tractor, mostly likely for the process of removing above ground biomass from the site.

Large amounts of coarse sand have been naturally deposited on the clearance site, such that it was difficult to spot buried stumps, and large rocks were present at the sand/clearance boundary. Remaining below ground biomass (moderate density) was visible just underneath the sediment surface. Sediments at the site consisted of primarily firm sand, dominated by coarse and medium sand fractions. Low density *Macomona liliana* siphon tracks (<5 tracks $0.25m^{-2}$) were visible on the sediment surface at the Unvegetated position.

Sampling protocol was adjusted as there was only a small strip of mangrove removal; no Centre habitat was sampled. Edge samples were taken approximately 15m inside the seaward edge of the clearing (Figure 3-2). Unvegetated samples were collected approximately 10m beyond the seaward edge of the clearing, outside the pneumatophore zone.

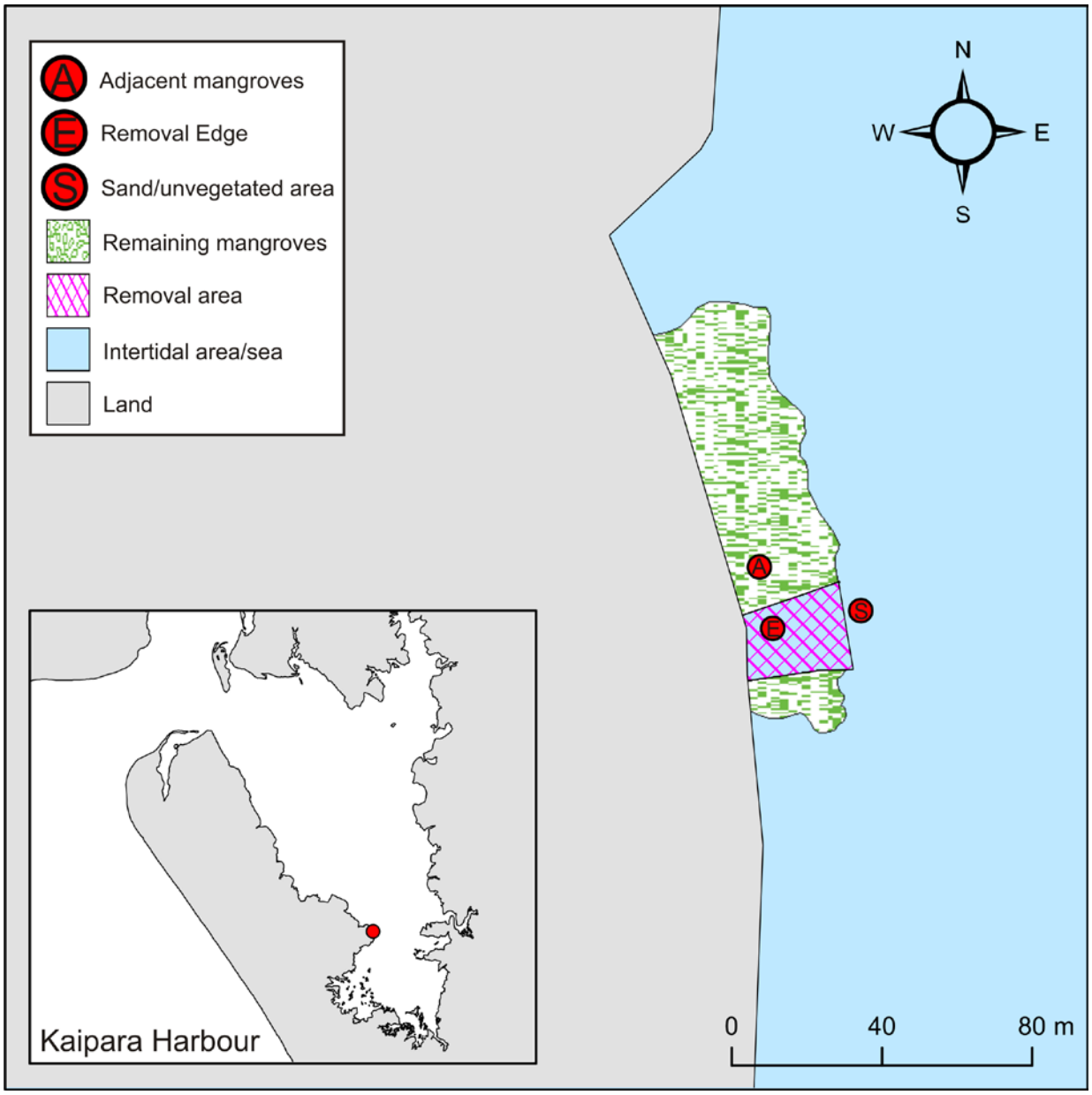

Figure 3-2 Map of Shelly Beach, Kaipara Harbour mangrove removal area.

3.2 Gibbs Sculpture Park, Kaipara Harbour (one site)

This clearance is not publicly accessible from land and required approval and escort from Joanna Sunde (Environmental consultant with Barker and Associates Ltd.). This site is located at the Gibbs Sculpture Park in the southern Kaipara Harbour, and is part of a large consented removal (consent #39908) for a total of 60.5 ha at two locations in the Kaipara Harbour. Sampling for this survey occurred within one large block (2.06 ha; perimeter of clearance tracked using a handheld GPS) of mangroves (Figure 3-3, Appendix). This mangrove removal was carried out in 2012, via mechanical mulching of the above ground biomass. The mulchate was left on site. Sampling occurred in the southern area of the

consented removal area, with mangrove removal in the northern area still in progress in November 2013.

Large amounts of mulched material (consisting of large branches covered with a thick layer of smaller mulched material) were still present on site approximately a year after mulching, and large patches of sea lettuce (*Ulva spp.*) were also observed. The underlying sediment had a shallow oxic layer (<1mm) and black anoxic liquid seeped out of footprint holes (sinkability generally <3cm). At the seaward side, salt marsh plants were present on the edge of the clearance area, including the invasive saltwater paspalum. A large seagrass patch was located adjacent to the clearance, and appeared to be in good health. The remaining mangroves at the southern edge of the cleared area were large and healthy.

Standard protocol was followed, with three positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre) and four positions sampled (including adjacent mangroves) for sediment particle size, organic content and chlorophyll *a* (Figure 3-3). The Unvegetated samples were collected 10m seaward of the clearance area and within 5-10m of the large seagrass patch. Edge samples were located approximately 10m into the removal area and Centre samples were collected from the centre of the clearing, approximately 100m from shore.

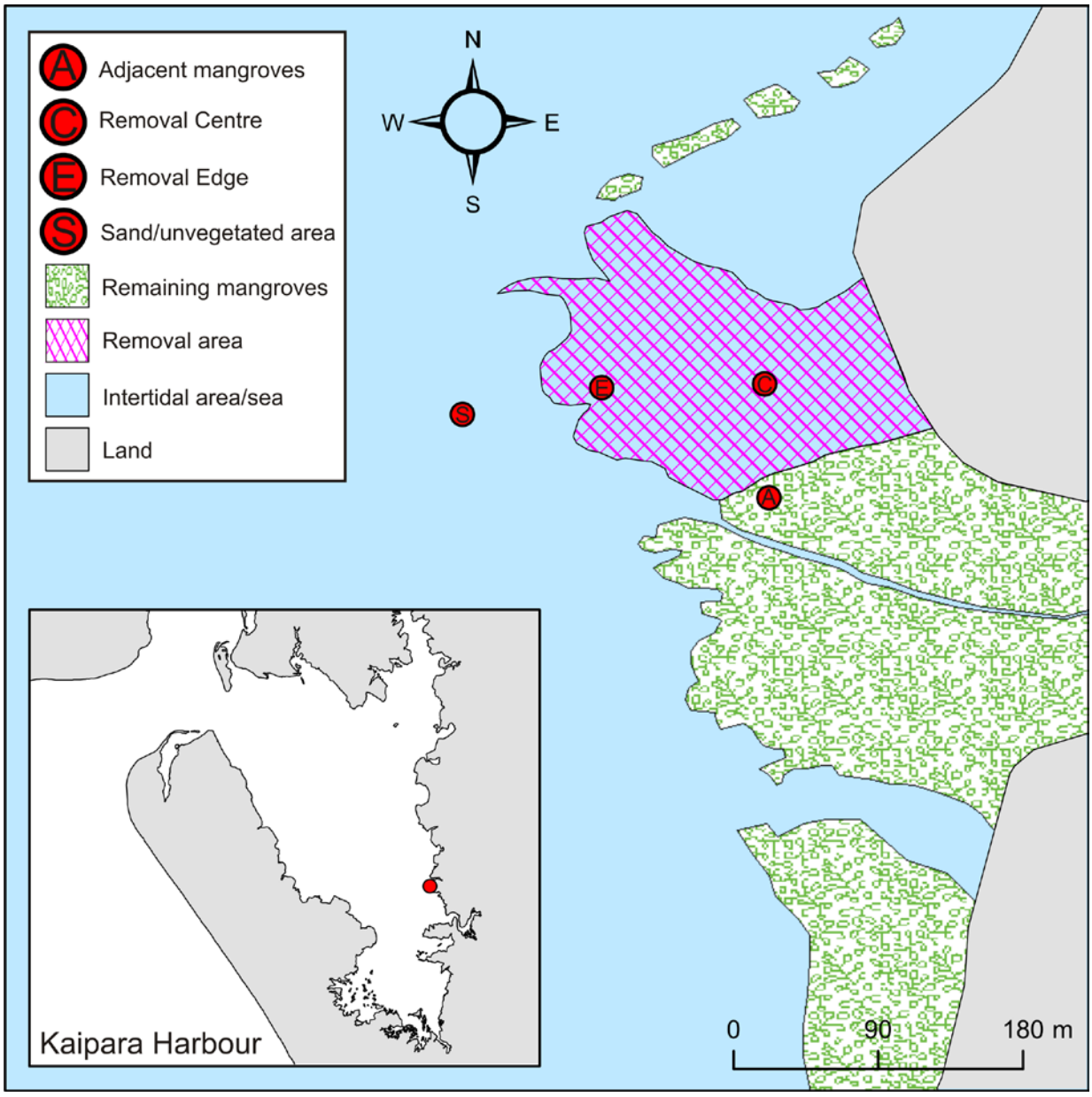

Figure 3-3 Map of Gibbs Sculpture Park, Kaipara Harbour mangrove removal area.

3.3 Auckland Airport, Manukau Harbour (two sites)

This site is a consented clearing (No. 38862) granted in March 2011, and mangroves were mechanically removed with the mulch deposited directly onsite. The site is large (13 ha), and the perimeter of the mapped mulched area was still visible Figure 3-4, Appendix). The mangrove removal edge was patchier in tree density (measured by stump density) than the inner area of the clearing with densities of 16 and 32 stumps $100m^{-2}$, respectively, for Edge and Centre positions.

The general character of the site showed deep finer mulch material deposited inshore (and likely covering/resulting in death of adjacent saltmarsh habitat which is now covered in 30-40cm minimum of mulch of 5-10m width on the edge of the clearing area) (Figure 3-5).

There is also a large ridge (1-2 m in height) of mulch material at the seaward edge of this inshore mulch deposition zone (Figure 3-5). This inshore area consists of primarily fine mulch material. Significant mulch material does remain on site, primarily on the shoreward half (~6.5 ha) of the site (mainly large branches and woody debris >1cm diameter).

Sampling protocol was standard, with three positions sampled. No intact mangrove remained at the site. Due to the large size of this removal two transects were sampled on either side of the site to incorporate potential within site variability. Auckland Airport 1 was located closer to the runway of Auckland Airport. Auckland Airport 2 was located approximately 150m west-northwest of Auckland Airport Site 1 (Figure 3-4). The left side of the clearance area had a much lower density of mangroves, and the site curved around in a rough crescent shape. Core samples for the Unvegetated position were sampled within 10m of the seaward edge in hard-packed fine sand. Edge samples were located approximately 10m into the removal area and Centre samples were collected from the centre of the clearing, approximately 100m from shore.

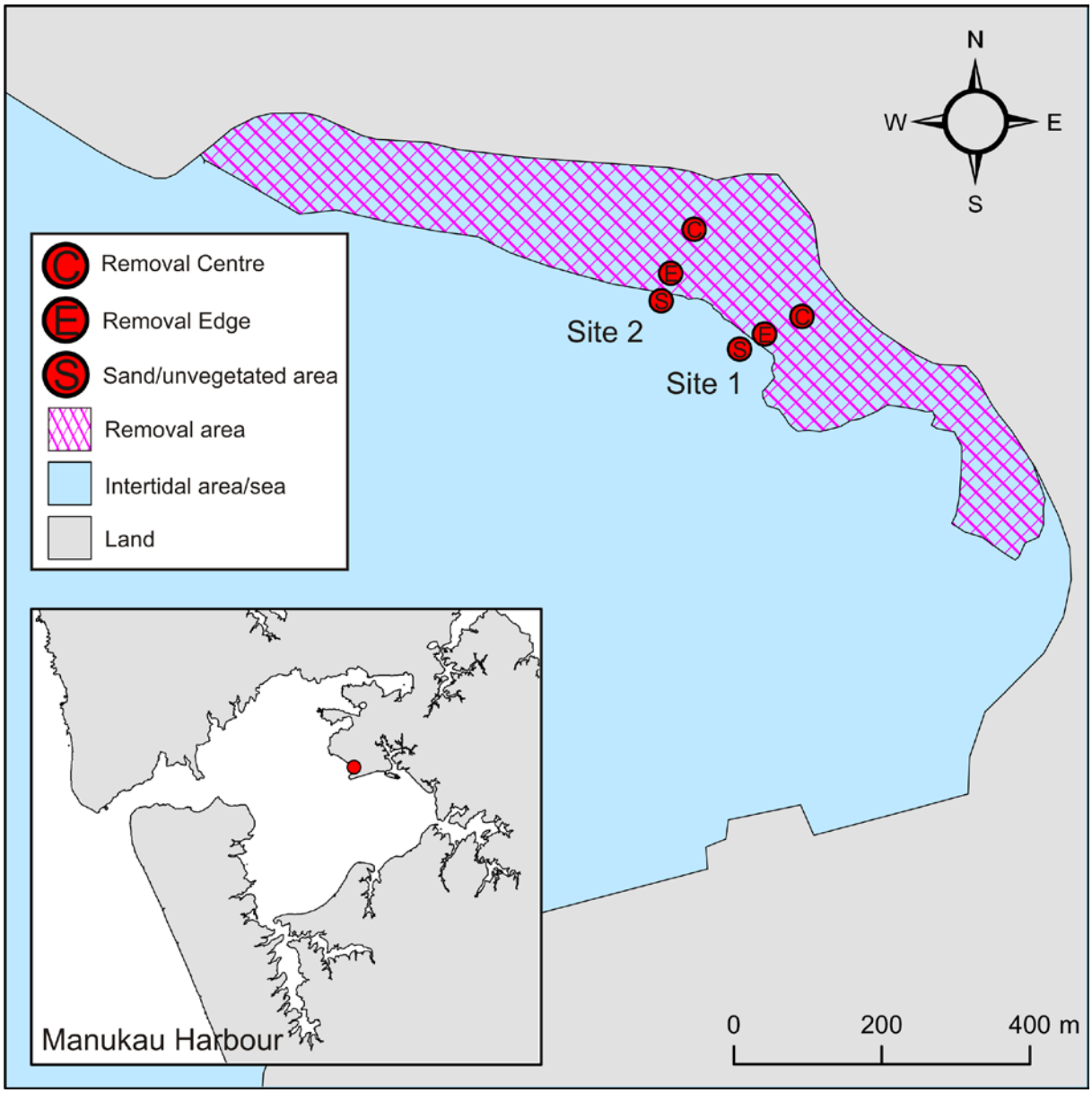

Figure 3-4 Map of Auckland Airport, Manukau Harbour mangrove removal area.

Figure 3-5 Mulch debris accumulating at inshore region of Auckland Airport Site.

3.4 Mangere Inlet, Manukau Harbour (four sites)

Mangere Site 1

This consented mangrove removal is located on the northern side of the motorway just seaward of the new Mangere Bridge. This site was cleared in August 2013, and is a small clearing of roughly 20m x 30m (Figure 3-6, Appendix). The site is very sheltered, with a breakwater built parallel to shore. The primary clearing is within an unnatural bay formed between the natural shoreline and the breakwater. The mangroves within the current removal area were very tall (~3m). Remaining mangroves (of which removal is included in the consent, but the consent holders ran out of funding this year) are also tall (~3m) with a mix of unusual, tall and minimally branched mangroves very close together, along with mangroves of more standard morphology with larger canopies closer to the main inlet. Most vegetative biomass was removed offsite, though a narrow band (~3m wide) of branches was left on the seaward entrance to the small embayment. The site is on the edge of a causeway off-ramp, and is an area of minimal natural character with often high

amounts of rubbish deposited, and general industrial character in the neighbouring terrestrial area. Machinery was used (Argonaut vehicle) to access the site and pull branches to shore.

Machine tracks were clearly apparent at three months post-removal, covering a strip in the middle of this small clearing. Within machinery tracks, mud was thigh depth, whereas mud depth at much of the rest of the site was approximately calf deep. Sediments within the clearing were generally black and anoxic, typical of mangrove clearings within a few months of clearing (Felsing 2006; Stokes 2009; Lundquist et al. 2012).

Adjacent mangroves were sampled approximately 5 m inshore of the clearing. The Centre position was located in the main centre of the removal patch, though 2-3 m inshore to avoid the machinery tracks (Figure 3-6). The Edge position was located just inside the band of remaining branches, approximately 5-10m from the edge. The Unvegetated position was located at the mouth of the breakwater embayment, an area of high mud content that was difficult to access. Unvegetated samples were collected within 10m of the seaward edge of the band of branches.

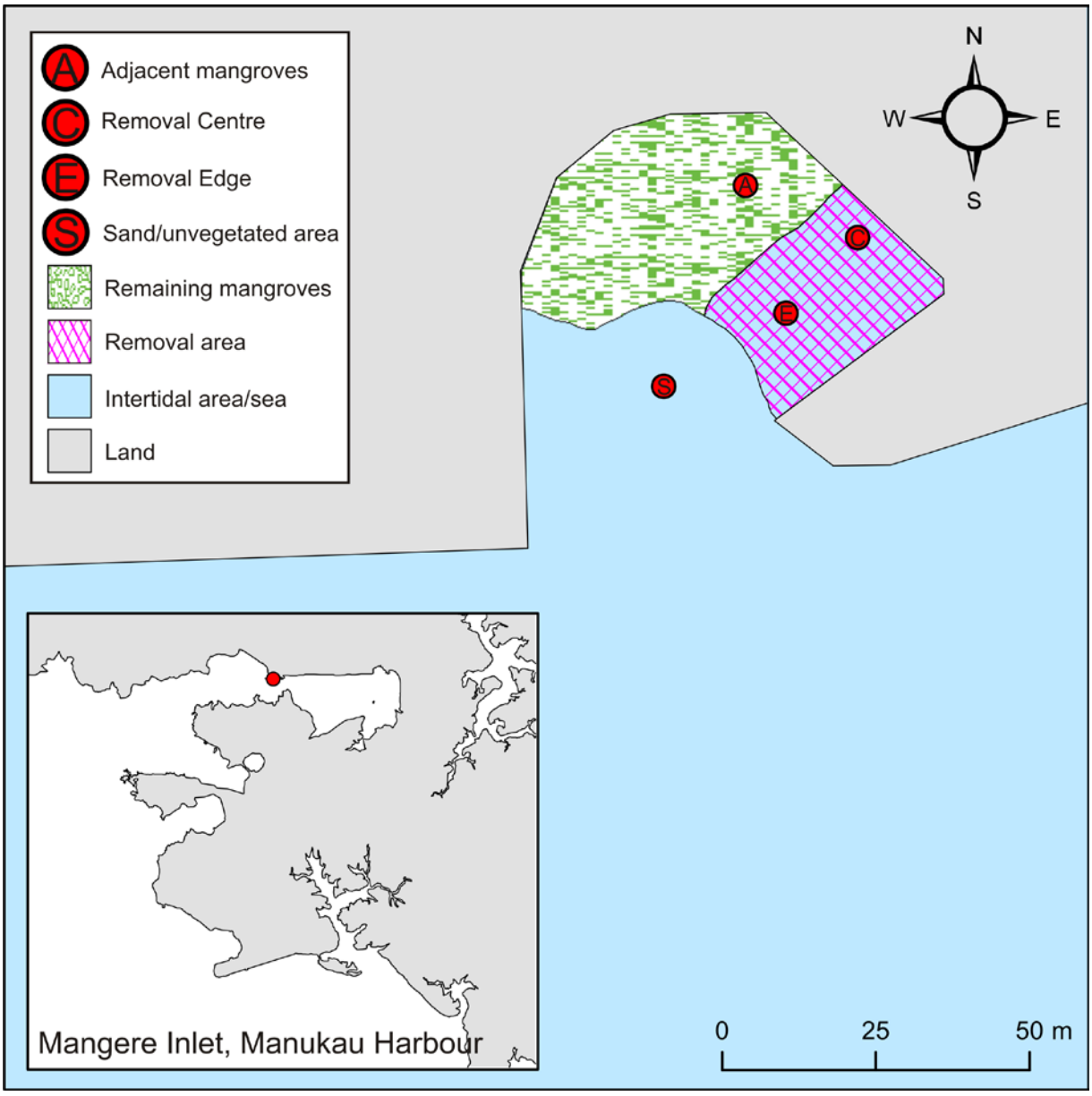

Figure 3-6 Map of Mangere Inlet Site 1, Manukau Harbour mangrove removal area.

Mangere Sites 2 and 3

This consented removal is located on the southern side of the motorway between the new and the old Mangere bridges (Figure 3-7, Appendix). Site 2 is located in the 'old' clearing, completed in approximately 2011. This clearing was to provide recreational access, and was centred in proximity to a new boat ramp. Rough dimensions of this clearing are 3-5 m seaward from shore (a grassy area), and alongshore for approximately 50m. Site 3 is located in the 'new' clearing, which occurred in August 2013. This clearing is similar in total dimensions to Site 2, with an approximately 3-5m wide strip, a bit wider alongside the new Mangere Bridge, and stretching approximately 80m from the edge of Site 2 to the side of the new Mangere Bridge.

At site 2 within the removal zone, the sediment texture was muddy (sinking ankle deep). Low density pneumatophores (average 33 pneumatophores 0.25 m^{-2}) and old oyster shells attached to rocks and pneumatophores littered the sediment surface. Crustacean burrows were also observed but to a lesser degree than at Site 3 (10 and 37 burrows 0.25m^{-2} at sites 2 and 3, respectively). At Site 3, both pneumatophores (average 67 pneumatophores 0.25m^{-2}) and dead oyster shells were recorded, but in higher densities than at Site 2. The clearance boundaries of both sites were still clearly defined, and a minor amount of woody mangrove debris (i.e., the remains of cut branches) remained on the sediment surface.

Standard protocol was adjusted due to the narrow width of the clearings, and no Centre mangrove samples were taken from either Site 2 or Site 3 (Figure 3-7). Only one Unvegetated and one adjacent mangrove position were sampled to represent both Site 2 and 3 due to the close proximity of the two clearings. The sediment at the Unvegetated position was very muddy and soft (sinking at least 50cm) and the topography of the surface was primarily characterised by low density crustacean burrows (average 10 burrows 0.25m^{-2}). The adjacent mangrove site was 10m inside of the nearest intact strip, located further from the mouth of Mangere Inlet toward the old Mangere Bridge. Tree heights were 2-3 m, and consisted of large trees with wide canopies. The Unvegetated position was located near the boat ramp near the middle of the Site 2/3 boundary, approximately 5-10m from mangrove removal area. Edge positions for both Site 2 and Site 3 were located at the centre of each strip clearing.

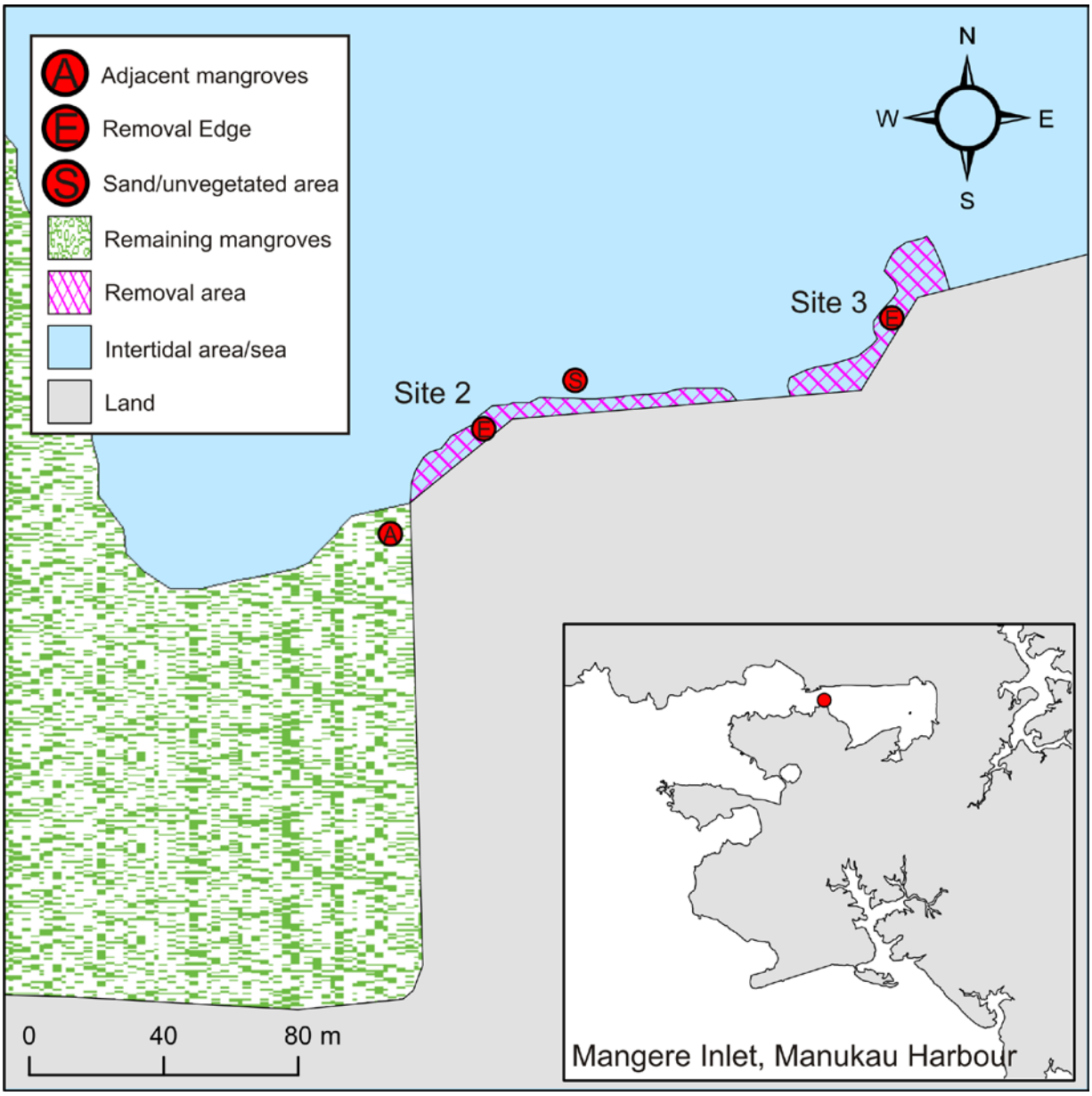

Figure 3-7 Map of Mangere Inlet Sites 2 and 3, Manukau Harbour mangrove removal areas.

Mangere Site 4

This consented mangrove removal is located at the KiwiRail site. Mangrove removal occurred in summer 2011/12 with the objective of allowing access through the mangrove forest for a February 2012 waka ama event. The clearing is an odd shape, somewhat funnel like, with the widest section (~30m) inshore near the rail yard. The clearing narrows to a small pathway of approximately 10m in width that stretches approximately 300m from shore to sea, with majority of the clearing being within the 10m thin path to allow for waka access (Figure 3-8, Appendix). The initial clearing occurred two years ago, using a chainsaw with hand removal of vegetation offsite, but no machinery (tractors) on site. In

January 2014, an Argonaut vehicle was on site going through the centre of the path to sea, leaving clear areas of disturbance (seedlings trampled/removed) in the Argonaut path. At the time of sampling, the community group was in process of removing additional mangroves and widening the strip by approximately 5m to provide for waka ama access for the biannual event that took place in February 2014.

Standard protocol was adjusted, with two positions sampled for macrofauna and visual observations (Edge and Centre) and three positions sampled (including adjacent mangroves) for sediment particle size, organic content and chlorophyll *a* (Figure 3-8). No Unvegetated site was sampled due to difficulty with seaward access through this long mangrove clearing. The Centre position was sampled within the inshore wider section of the removal, approximately 10-20m from shore within an area undisturbed by the Argo vehicle. The Centre position had sediments resembling thick terrestrial clay; the clay was an orange hue for a few centimetres before turning grey below the oxic layer. Seedling density was high and consistent within this patch, and no community seedling removal had occurred here during the two years since mangrove removal. The Edge position was located about 150m toward sea, within a patch of relatively undisturbed seedlings alongside the Argo path. This Edge position was located a reasonable distance (>100m) from the seaward edge of the clearing due to access difficulties with the site consisting of at least thigh deep mud. Community volunteers suggested that similar sediments were present between the Edge sampling position and the seaward edge of the removal, except that near the seaward edge was an area of volcanic sediments covered by mud. The Edge position showed a shallower oxic layer, and consisted of deep, muddy sediments. Areas with obvious disturbance (i.e., tracks) from the recent Argo vehicle had very shallow (1-2mm) oxic depths, and sediments were black in colour; core sample positions avoided these recently disturbed tracks. Adjacent mangroves were sampled at the same distance along the strip as the Edge position.

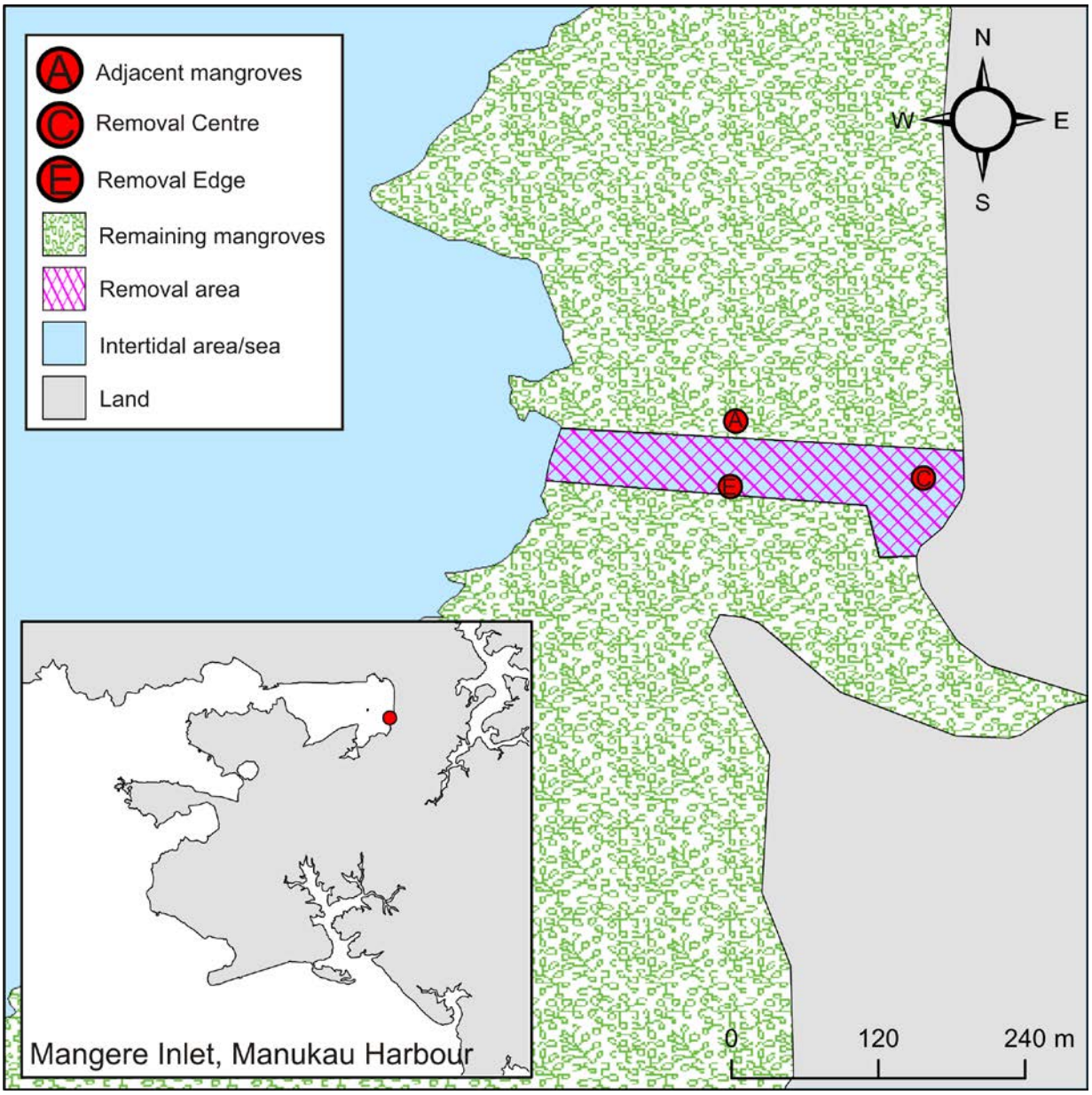

Figure 3-8 Map of Mangere Inlet Site 4, Manukau Harbour mangrove removal area. *Unvegetated site was not sampled due to accessibility.

3.5 Pahurehure Estuary, Manukau Harbour (four sites)

Pahurehure Site 1

This site is an illegal clearance that occurred in approximately December 2012, detected during the sampling of one of NIWA's long-term mangrove monitoring sites, accessed via Keywella Drive. The site was visited ~monthly from December 2011 to April 2013 by NIWA staff, and again, as part of this AC survey, in November 2013. The mangrove clearance area dimensions were approximately 30m x 60m (0.19ha), located between mangrove and

a grassy shoreline where some restoration management has occurred recently with mowing and/or removal of invasive pampas in approximately 2012 (Figure 3-9, Appendix). The mangroves appeared to have been removed via chainsaw, and all branches were left on site. Most of the trees were cut at levels of about 0.5-1 m height. A prior illegal mangrove clearance occurred in summer 2011/2012 located toward the centre of the mangrove forest, and GPS boundaries for both clearings were included in the perimeter mapping.

The site is located alongside a small channel, which previously was not completely infilled with sediment during low tides. The channel is now mostly infilled with sediment, although this may not be a result of the mangrove removal, as the new sediment showed the orange-hued characteristics of terrestrial clays. The sediment alongside the site prior to the time of the removal event was previously mostly fine sediment, with staff sinking to calf depth. The upstream portion of neighbouring sediment now has a thick clay layer, whereas additional cores positioned more ‘seaward’ were increasingly finer sediments that did not have a dense clay layer underneath. Stump sprouting was observed in April 2013 from most stumps >0.5 m in height. However, few of the stump sprouted trees were alive in November 2013, with only about half a dozen trees having live branches sticking out through forest litter. Branches were intact with little evidence of decomposition and they covered roughly three quarters of the removal site. Pneumatophores and root mass showed little evidence of decomposition. The site was covered (near 100% cover) with green macroalgae (*Ulva* sp. (tubular)). Algae was also present covering the rocks on the edge of the site and in the non-vegetated sediment.

Standard protocol was followed, with three positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre) and four positions sampled (including adjacent mangroves) for sediment particle size, organic content and chlorophyll *a*. Core samples for the Edge position were sampled approximately 5-10m of the seaward edge. Centre samples were collected from within 15 m of the inner edge of the clearing, at least 10m inshore of the Edge position. Unvegetated samples were collected in a line parallel to the removal edge. The adjacent mangrove area (mangroves of approximately 2.5-3.5m in height) was sampled approximately 10m from the edge of the removal site.

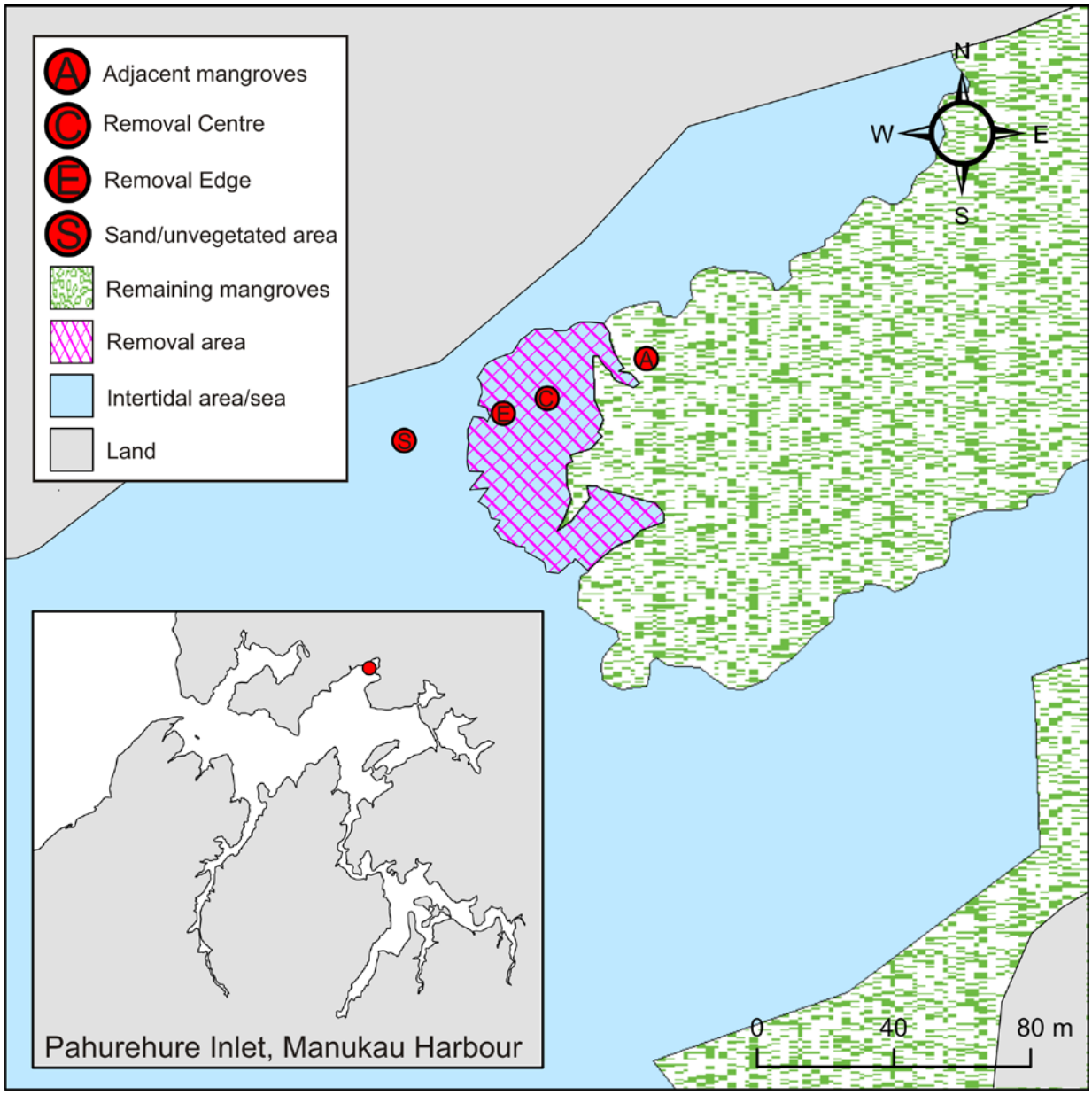

Figure 3-9 Map of Pahurehure Estuary Site 1, Manukau Harbour mangrove removal area.

Pahurehure Site 2

This site is a consented clearing (No. 35053), representing one of the trial clearing areas done as part of the initial consent in 2008 (site T2 in the consent documentation) and was accessed via Westholm Way. Here, above ground mangrove biomass was removed using chainsaws and carried offsite by helicopter. The site was approximately 5.21 ha and is approximately 100m in width from shore to the edge of the intertidal where the survey samples were collected, though the shape of the removal area is irregular at this site (Figure 3-10, Appendix). The removal area stretches alongshore for approximately 350m. At the edge of the removal area is a very muddy (thigh depth) channel.

The boundary of the cleared area was still apparent, with stumps and pneumatophore zone still visible. Stump counts at the Edge and Centre positions differed markedly with many more (smaller diameter) stumps present within 10m from the edge of the clearance area (900 per 100m^2 compared to 175 per 100m^2 at the Centre position). The below ground mangrove biomass remaining on site was located at the sediment surface and included dense root mats. Within the cleared area, the sediment had low sinkability (5-10cm foot print depth) due to the presence of the root mat. However, at the Unvegetated position the sediment was very silty and deep (sinking up to thigh depth). The mud snail *Amphibola crenata* was present in high abundance at all positions. Crustacean holes were abundant at the Edge and Unvegetated positions, but rare at the Centre position.

Standard protocol was followed, with three positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre) (Figure 3-10). No intact mangroves remained at the site. Core samples for the Edge position were sampled within 10m of the seaward edge. Centre samples were collected from the centre of the clearing, approximately 50m from shore. Unvegetated samples were located approximately 10m into the deep muddy channel from the edge of the removal.

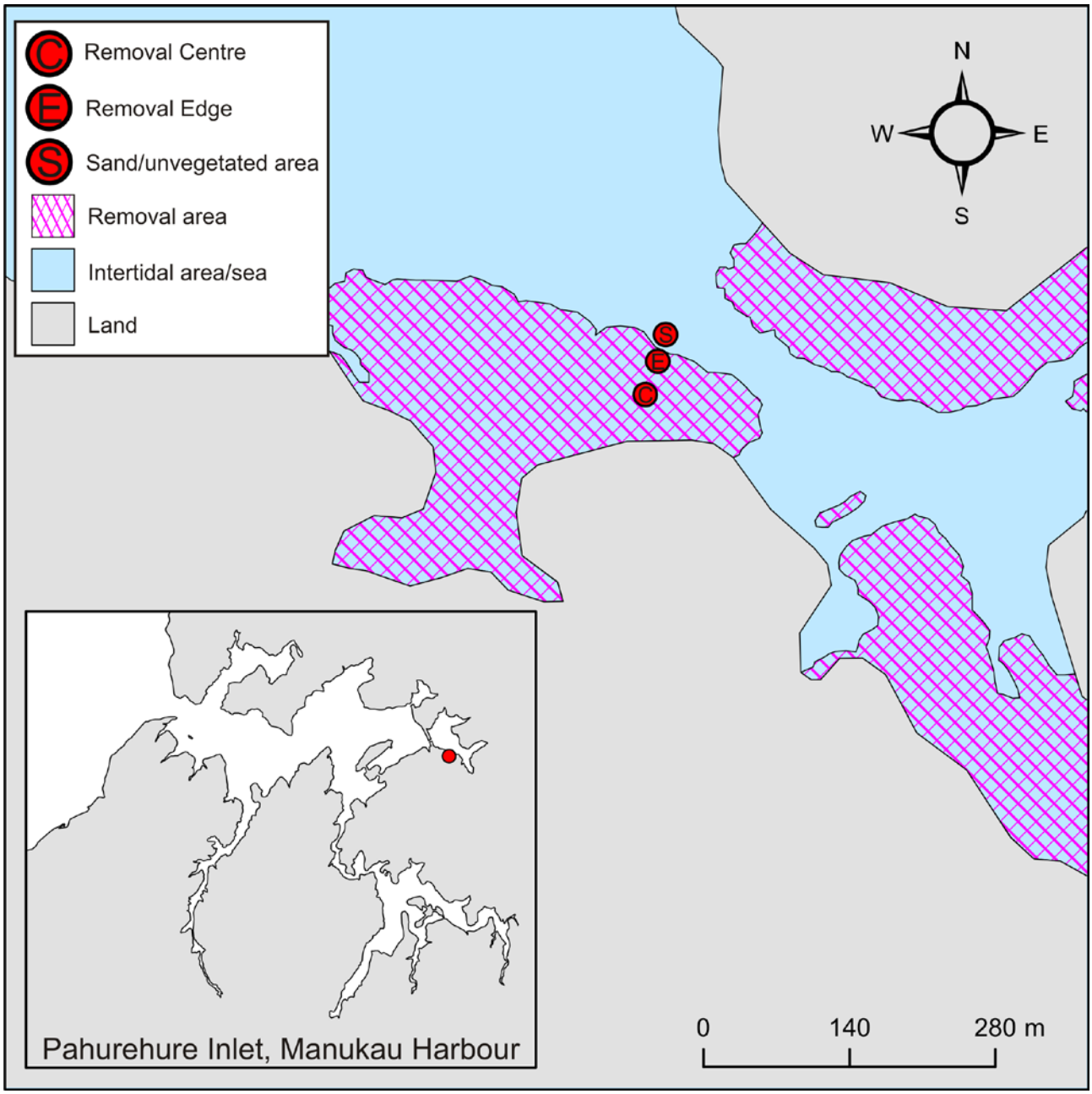

Figure 3-10 Map of Pahurehure Estuary Site 2, Manukau Harbour mangrove removal area.

Pahurehure Site 3

This site is a consented clearing, carried out in 2012 using mechanical (tractor) removal with all above ground biomass removed offsite. This site is located upstream of site C1 in the consent documentation maps from the original trial clearance report. Near site C1 is the likely area of illegal removals identified by AC staff, though this only consisted of a few dozen trees (based on remaining stumps). Pahurehure Site 3 was large, located inshore of another similar sized clearing area, and was adjacent to intact mangroves that were not sampled (due to the distance (>200 m) from the locations sampled near the centre of the

clearance area). The approximate dimensions of this ~6 ha removal area are 215 m alongshore x 280m upstream (estimated based on consent documentation, as the boundary was not GPSed at the time of sampling due to large size of the clearing) (Figure 3-11, Appendix).

The boundary of the cleared area was still apparent, with stumps and pneumatophore zone still visible. The sediment at this site and across sampling positions was predominately of low sinkability (foot print depths between 5-10cm). Within the clearance area, the below ground biomass was moderately dense and at the sediment surface. Counts of the remaining stumps indicated that the pre-existing mangrove stand was very dense (500 stumps per $100m^2$ at both Centre and Edge positions) and stumps were also visible at low density (<10 stumps per $100m^2$) in the narrow unvegetated area adjacent to the clearing.

Standard protocol was followed, with three positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre). Only three positions were sampled for sediment particle size, organic content and chlorophyll *a*. No intact mangroves were sampled, as they were determined to be located far enough from the clearing to be experiencing different hydrodynamic conditions (Figure 3-10).The Unvegetated position was located in a narrow area alongside a deep (but dry during low tide) channel. We noted that the mangroves were sparse within this unvegetated area (see definition of Unvegetated in section 2.2) prior to removal based on visible stumps, and some pneumatophores were visible during sampling, but at very low density compared to the Edge and Centre positions. As such, we expect this unvegetated area is likely closer to 'mangrove edge' in actual quality. The Edge position was located within 10m of the apparent edge of the clearing. The Centre position was located midway to shore, approximately 100m from the channel.

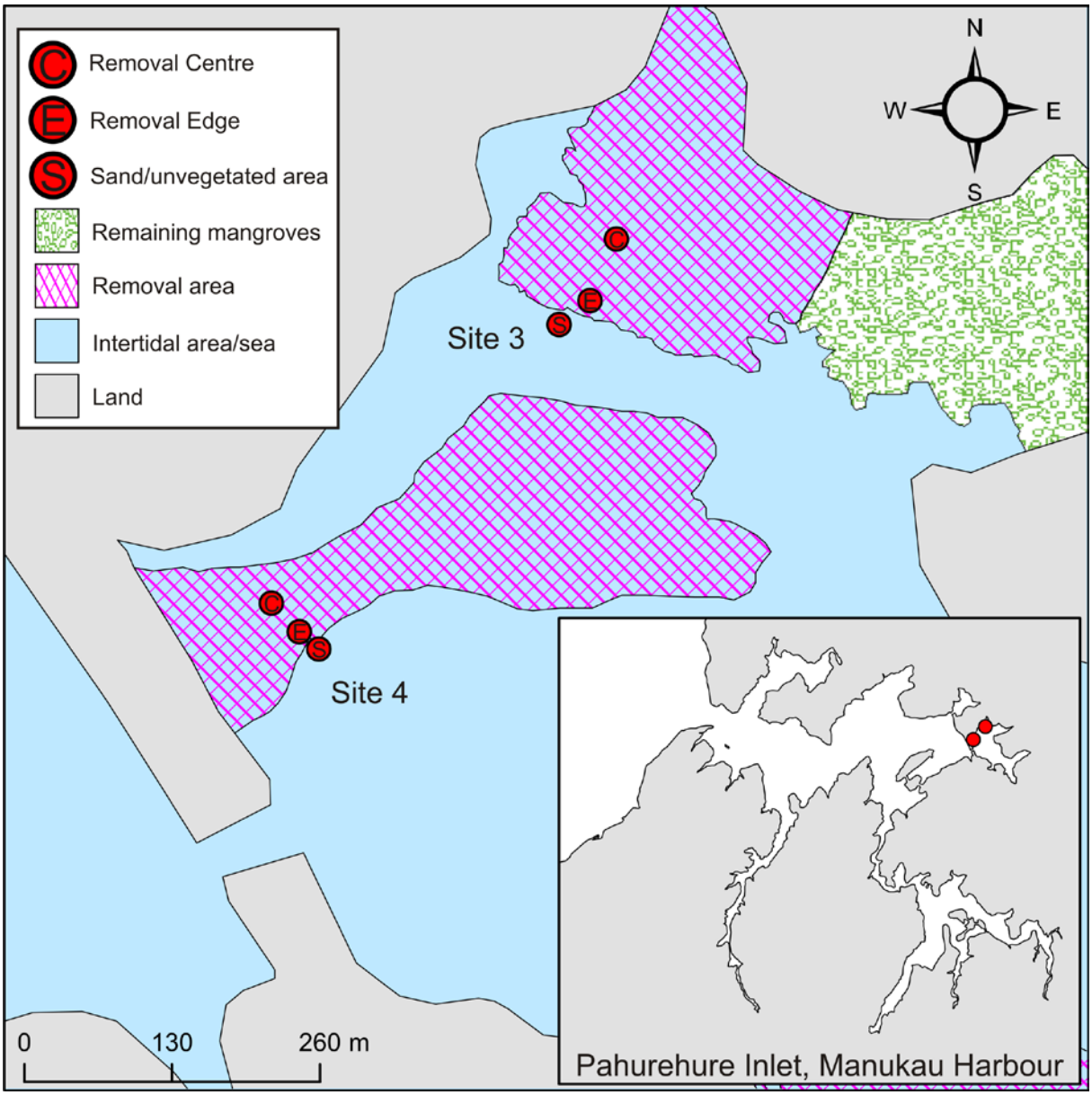

Figure 3-11 Map of Pahurehure Estuary Sites 3 and 4, Manukau Harbour mangrove removal area.

Pahurehure Site 4

This site is a consented clearing (site C1 in Consent No. 35053), representing one of the later clearing areas in Pahurehure Inlet. This removal area is approximately 5.3 ha (Figure 3-11, Appendix). Removal of mature mangroves occurred via mechanical (tractor) removal, with all above ground biomass removed offsite. The site is located next to and parallel to Auckland's Southern Motorway, and historically has shown extensive macroalgal blooms occurring through much of the clearance area, though blooms were much reduced in extent in 2013 from the prior year (Carolyn Lundquist, NIWA, personal observation).

The site was accessed from Morewa Place and there was a riparian strip of newly planted grasses, marshes and shrubs on the shoreward side of the clearance. The cleared area where the sampling was conducted was approximately 80m wide (transect running shore to sea) and the extent of the clearance is still visible due to remaining stumps (100 and 65 stumps $100m^{-2}$ at Centre and Edge positions, respectively) and pneumatophores (average 200 and 180 pneumatophores per $0.25m^{-2}$ at Centre and Edge positions, respectively). Remaining below ground mangrove biomass was dense and visible on the surface.

Standard protocol was followed, with three positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre). Only three positions were sampled for sediment particle size, organic content and chlorophyll *a,* as there was no intact mangrove remaining at the site. The Edge position was located within 10m of the seaward edge (Figure 3-11). The Centre position was sampled from the centre of the clearing, approximately 40m from shore. The Unvegetated position was located approximately 10m from the edge of the removal site.

3.6 Waiuku Estuary, Manukau Harbour (three sites)

Waiuku Estuary is located southwest of Auckland. Starting at Waiuku town, the intertidal area of Waiuku River extends for 12km before meeting Manukau Harbour. Six sites were consented for mangrove removal in 2006 and 2010; three of these sites were surveyed (Figure 3-12).

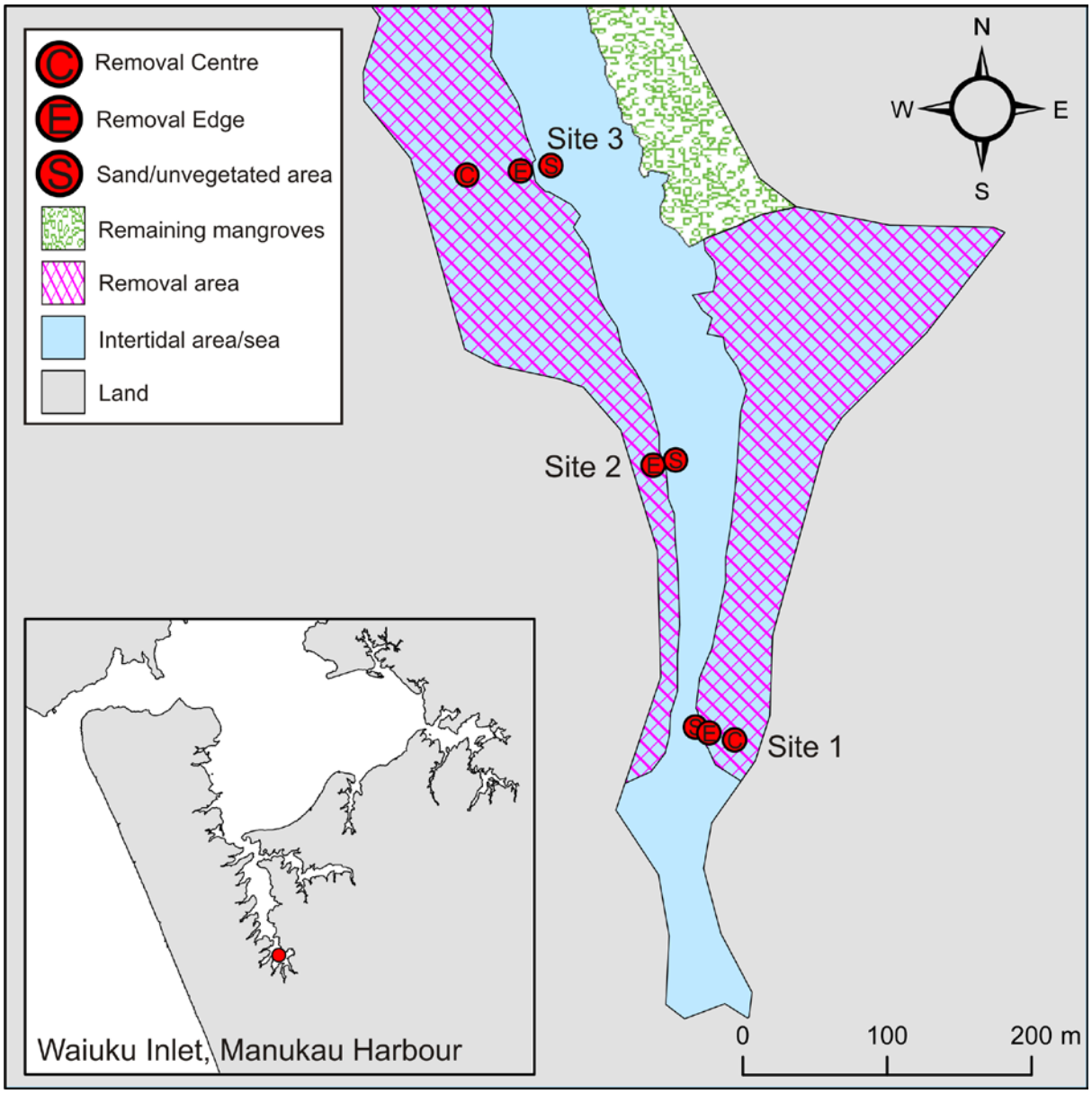

Figure 3-12 Map of Waiuku Estuary Sites 1, 2 and 3, Manukau Harbour mangrove removal areas.

Waiuku Site 1

Site 1 is located closest to the township of Waiuku and is the most sheltered of the sites sampled. The area sampled here corresponds to area/site 2 on the aerial image included in the consent application (No. 37547), where approximately 1.654 ha was cleared in 2006 and no mangroves were left in the immediate vicinity (Figure 3-12, Appendix). The mangroves were removed mechanically and cut off 10cm below the sediment surface, and then the holes were filled with sediment. The site is accessed from the road by the traffic bridge on King Street.

At the time of sampling, the sediment across the site was very firm, dry and cracking. The sediment composition was also very clay-like rather than silty. The sediment within 5 m either side of Waiuku River was fine sediment, sinking to approximately thigh depth. The site was covered with household rubbish and was bordered by a small 'stream' coming from a drainage pipe from the adjacent catchment, which was growing filamentous green algae.

Standard protocol was followed, with three positions sampled for macrofauna, sediment properties, chlorophyll *a* and visual observations (Unvegetated, Edge and Centre). No adjacent mangroves were present. The cleared area where Centre and Edge sampling was conducted was approximately 50m wide, whilst the intertidal area available for Unvegetated sampling and observations was only approximately 5-10m wide. The Unvegetated position was located within 5 m of the edge of the cleared mangrove area.

Waiuku Site 2

This consented removal at Site 2 is located in Area/Site 1 on the aerial map included in the consent application. In 2010, approximately 1.3ha was mechanically cleared, and a small amount of mulch left on site (Figure 3-12, Appendix). This clearance area is the second most exposed of the three sites sampled in Waiuku Estuary, and consists of a small strip clearing located between the high cliffs of the catchment and the main channel of the Waiuku River. The sediment across the entire site consisted of hard-packed clay. Collecting macrofauna cores was problematic and the material sampled had to be forcibly dug out from the plastic corer. There was minimal mulch on site and the appearance of the sediment surface was cracked and dry and dotted with a high density of crustacean burrows.

Due to the size and shape of the removal, sampling protocol was adjusted, with samples and observations only collected in the Edge of the clearance (~10m from seaward edge) and in the adjacent 2-5 m strip of intertidal flat for the Unvegetated position (Figure 3-12). No adjacent mangroves were present at Site 2.

Waiuku Site 3

This consented removal is located in Area/Site 3 on the aerial map included in the consent application. In 2010, approximately 2.825ha of mangroves were mechanically removed, with none remaining (Figure 3-12, Appendix). Mechanical removal involved cutting the stumps down to 10cm below the sediment surface and the holes were filled in with sediment. The area cleared is a similar shape to other clearings sampled in Waiuku Estuary (strip from the land down to the main channel), but is the biggest clearance and most exposed of the three surveyed sites (width of clearance from land towards channel is approx. 80-100 m). There was minimal mulch on site and the sediment composition of this site was similar to that observed at site 2.

Standard protocol was followed, with three positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre) and three positions sampled for sediment particle size, organic content and chlorophyll *a.* The Centre position was sampled in the centre of the clearing, approximately 40m from the edge of the clearing. The Edge position was located within 10m of the seaward edge of the clearing. The Unvegetated position was located in a thin strip of sediment, approximately 10m wide. There was a large population of *Amphibola crenata* at this site.

3.7 Weiti Estuary (one site)

The site, while not a mangrove removal, represented an area where mangroves had naturally died off due to the enclosure of the area by a sand bar during a storm event in ~2012 (Figure 3-13, Appendix). The site is located close to the mouth of the Weiti River on the southern side. Access is via a reserve managed by the Department of Conservation. NIWA staff were informed of this site by Auckland Museum staff, as it was a location where a large bloom of *Percursaria percursa* (a green macroalgae that had not been documented on the North Island prior to 2011; Pratt et al. (2013)) had been found. The site is also a protected dotterel area, and stoats and rats are trapped by a local who runs the holiday park near the entrance to the reserve. He emailed a picture of the area (before the die-off) taken in 1954 showing historical density and height of mangroves at the site.

The mangroves were large (1-2m) and the dead trees are still present in a pond of stagnant water, approximately 3.5ha in area. There is a large bloom of *P. percursa* draped over all the dead trees and a thick algal mat in the water was present. The sediment was firm at the edge of the mangrove mortality area (sinking < 1 cm) and there was a shallow oxic layer present (ranging between 1 and 3mm in depth) on top of black anoxic sediment. The surface topography was flat, with low density plant debris (i.e., leaves, woody material) and a moderate coverage of *P. percursa* observed throughout the site.

Standard protocol was followed, though positions were not along a transect due to the nature of the site (Figure 3-13). Three positions (Unvegetated, Edge and Centre) were sampled for macrofauna and for sediment particle size, organic content and chlorophyll *a*. Visual observations were taken at only two positions, as the Centre position was completely under water (approximately 30 cm) within the dead mangrove stand. Sediment was anoxic under the thick algae, with a sinkability of approximately 20-30cm. The Edge position was located at the water's edge adjacent to Centre sampling position on a narrow strip between the water and "beach" sand nearby. The Unvegetated position was located toward the end of the lagoon. A pipi (*Paphies australis)* bed was visible on the surface of the sediment at the Unvegetated sampling position. The Unvegetated sediment was firm, and appeared to be relatively well oxygenated (oxic layer of 1-3cm).

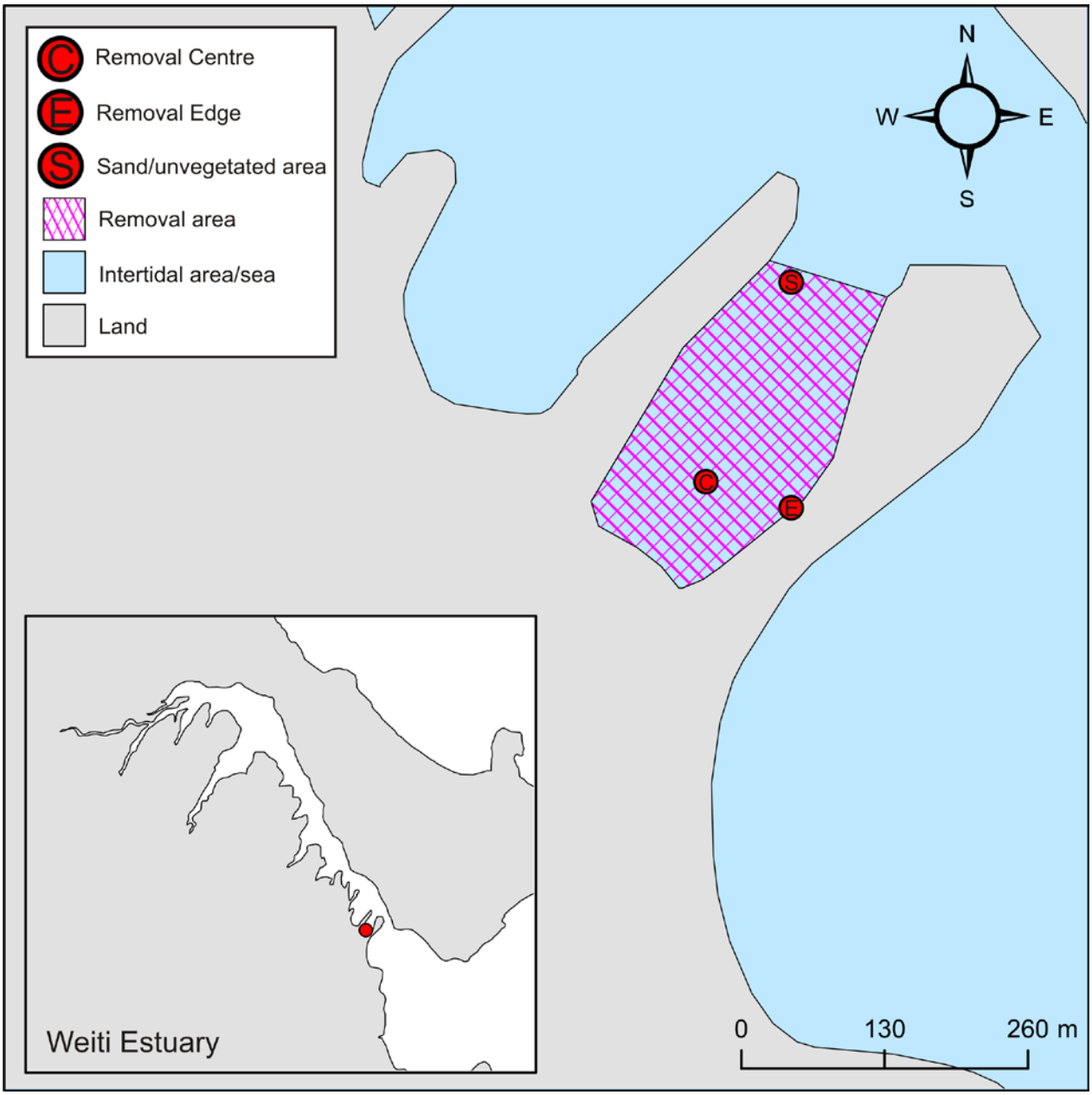

Figure 3-13 Map of Weiti Estuary natural mangrove mortality event area.

3.8 Whangateau Estuary (two sites)

This estuary had two illegal clearances which occurred in 2007 and in 2009. The clearance sites, located south of the causeway, are very small and the mangroves stands cleared were sparse in density. Site 1 was within 50m of the shore, and Site 2 was very close to shore. The two sites were separated by approximately 120m and Sites 1 and 2 were approximately 0.26 and 0.03ha, respectively (Figure 3-14, Appendix). Trees were cut (presumably using a chainsaw) approx. 0.5-1m above ground and debris left on site. Some of these stumps are now sprouting.

Sediment was generally firm sand within the 2009 clearance area (Site 1), but sinkability increased to a maximum of 5cm within the 2007 clearance area (Site 2), where sediment was generally black just below the surface, with a shallow oxic depth.

At the 2009 (Site 1) clearance, large stumps were still visible and large branches and tree debris were left onsite. The sediment in the 2009 clearance was predominantly sandy and had minimal root material present. The 2007 (Site 2) clearance site was dominated by woody biomass on the surface and up to 10cm in depth, but had little evidence of root mass left. Within the 2007 clearance, the top 10cm of the sediment layer was rust coloured, and had abundant peat/bark-like woody particles within the sediment.

Protocol was adjusted to accommodate the two small historical clearances, with Edge positions only collected for both sites, with the 2007 clearing identified as Site 2 and the 2009 clearing identified as Site 1 (Figure 3-14). The Unvegetated position was located between the two sites. Intact mangroves north of the clearances were sampled for grainsize, organic content, and chlorophyll *a*.

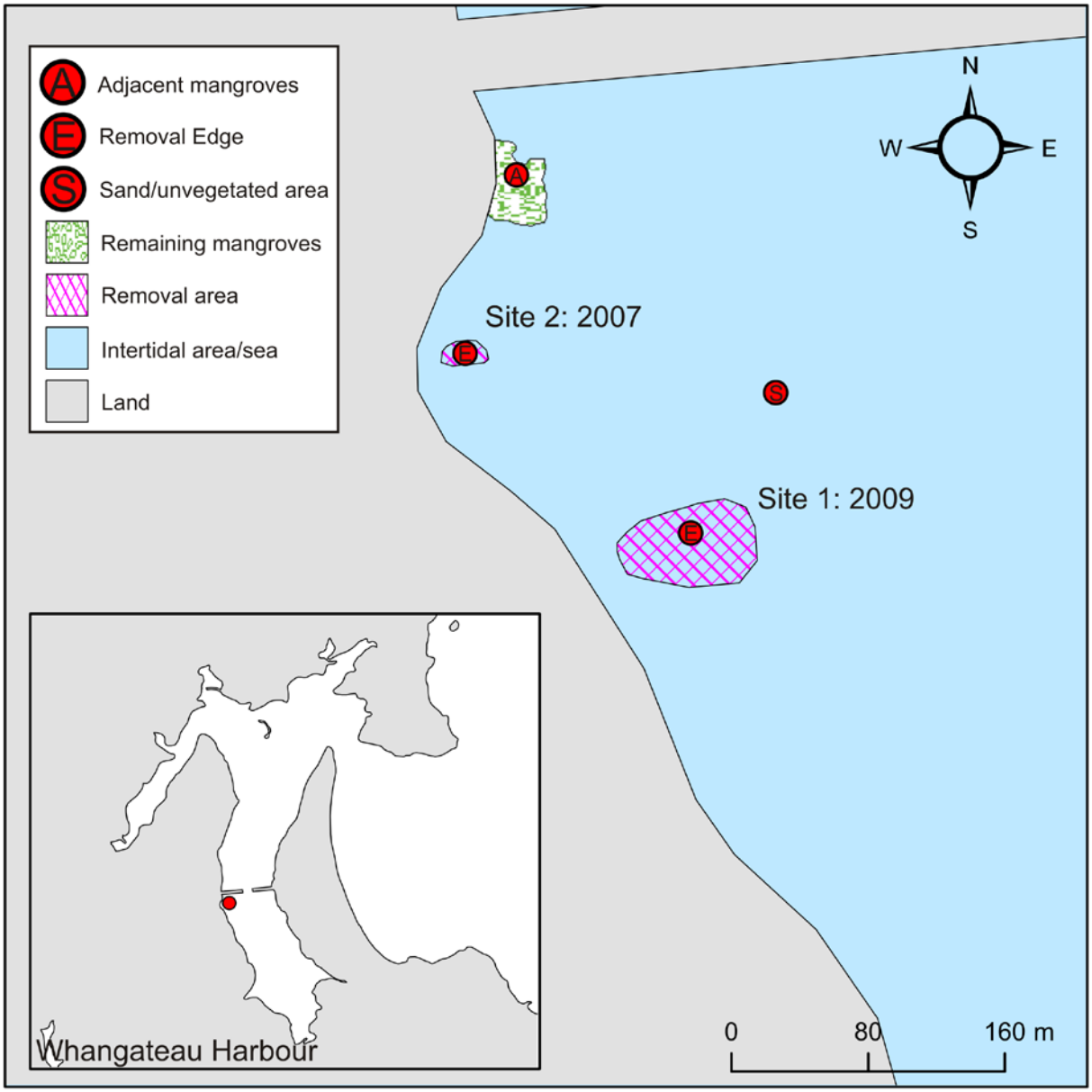

Figure 3-14 Map of Whangateau Estuary Sites 1 and 2 mangrove removal areas.

3.9 Panmure Basin (two sites)

Panmure Basin is a sheltered and enclosed sub-estuary of the Tamaki Estuary, with a highly built up urban catchment. On site, there was rubbish (i.e., bottle, plastics and bricks) at the high tide mark. Storm water drains discharge close to the surveyed sites. Directly behind the remaining mangroves and cleared areas, there is a public walkway with parks and buildings adjacent. The areas are readily accessible via stairs or an approximate 1 m drop. The mangroves removed from both sites 1 and 2 were completed in 2008 (No. 36219) and approximately 3.5 ha was removed by hand using chainsaws (Figure 3-15,

Appendix). While consent database suggested vegetation was disposed of offsite, a few dozen whole trees remained on the removal site. The remaining mangrove trees are healthy looking and tall (2.5-3 m).

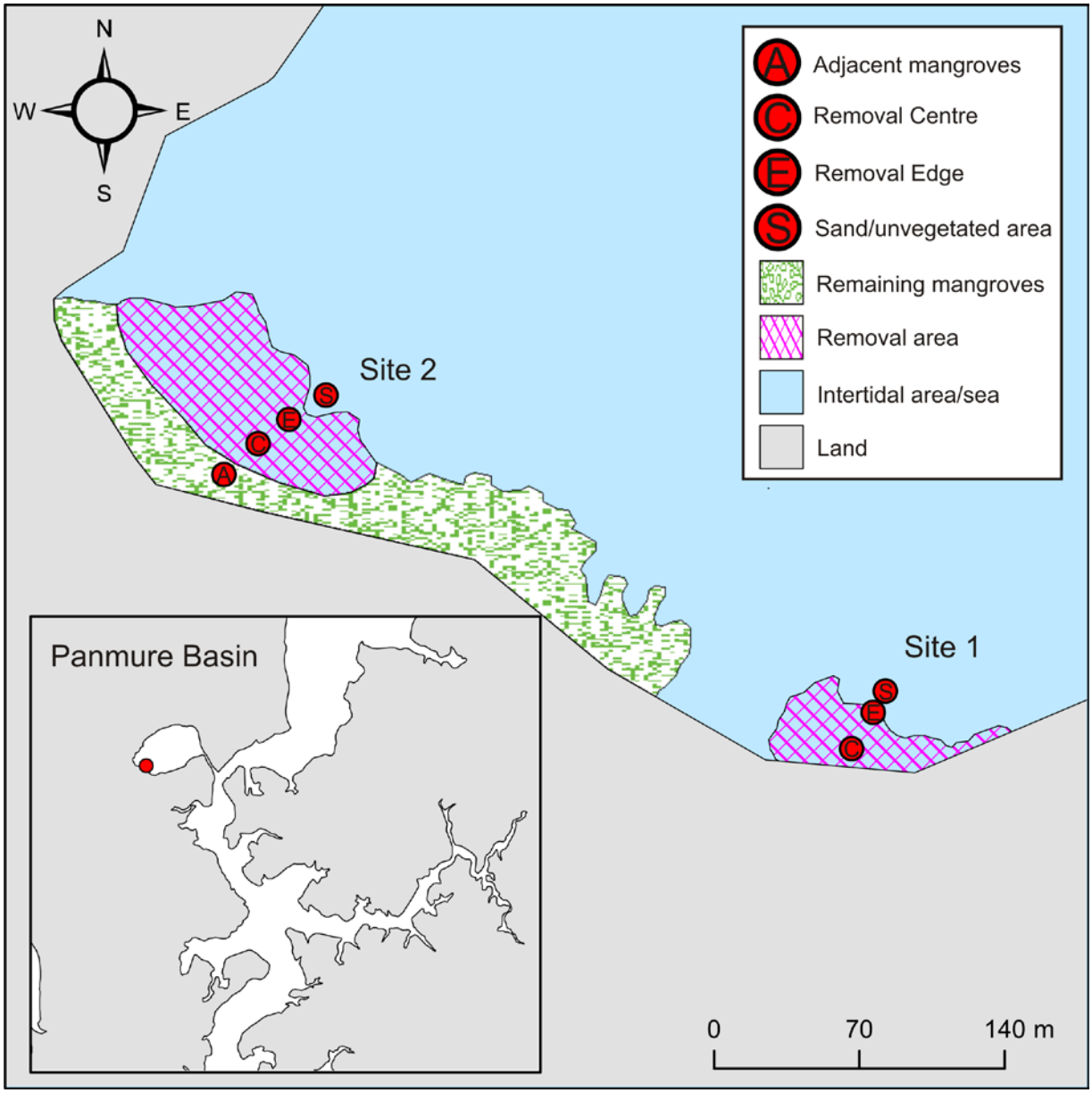

Figure 3-15 Map of Panmure Estuary Sites 1 and 2 mangrove removal areas.

Panmure Site 1

Site 1 is on the southern side of Panmure Basin (Figure 3-15, Appendix). The site is a small strip (~40m in width) next to the seawall and access is via stairs from waterfront walkway. The sampled area corresponds to Area 6 on the aerial map included in the consent documents. The sediment consists of deep mud (up to calf in places in the

cleared area and to the knee or greater in the Unvegetated area sampled. Oysters are present and attached to pneumatophores and old stumps left on site. Some woody debris (primarily branches and twigs) was observed on site.

The clearance area was difficult to access, due to the deep mud found at the site (sinking an average of 30 and 50cm at the Centre and Edge sampling positions, respectively) and relatively high density of dead oyster shells (up to 10% cover). The below ground mangrove biomass was moderately dense and sat underneath a surficial sediment layer of approximately 3-5cm in depth. The mangrove removal had low density (<5% coverage) of woody debris remaining on site, a moderate density of pneumatophores, and a high density of crustacean burrows. The Unvegetated position was dominated by crustacean burrows, and there was a muddy layer overlaying a firmer gravel/pebble sediment mix at approximately 30cm below the sediment surface.

Standard protocol was followed, with three positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre) and three positions sampled (no adjacent mangroves were present) for sediment particle size, organic content and chlorophyll *a* (Figure 3-15). The Centre position was located within 10m of the seaward edge of the clearance. The Edge position was located at the approximate centre of the clearing, roughly 20m from the seaward edge. The Unvegetated position was located 10m seaward of the edge of the removal.

Panmure Site 2

Site 2 is located northwest of Site 1 in Panmure Basin and accessed via the walkway adjacent to the park (Figure 3-15, Appendix). The sampled area corresponds to Area 2 on the aerial map included in the consent documents. Approximately 3.5ha of mangroves were removed, with dimensions of approximately 50m x 120m. The remaining mangroves between the removal area and seawall were tall (approx. 2.5-3m) and healthy looking.

Within the removal area, remaining branches and twigs were associated with black anoxic sediments. The muddy sediment deposited on the cleared area was hummocked around stumps and tree debris on site. Oysters, attached to pneumatophores and woody debris, were also common within the cleared section. As observed at Site 1, crustacean burrows and pneumatophores were observed at high densities at Centre and Edge positions. The below ground mangrove biomass remaining was dense, occurring underneath a layer of muddy surficial sediment ranging between 3-4cm deep. The sediment at the Unvegetated position consisted of deep mud (sinking up to 70cm), with abundant crustacean burrows.

Standard protocol was followed, with 3 positions sampled for macrofauna and visual observations (Unvegetated, Edge and Centre) and 4 positions sampled (including adjacent mangroves) for sediment particle size, organic content and chlorophyll *a* (Figure 3-15).

The Centre position was located near the centre of the removal area, approximately 20m from the shoreward edge. The Edge position was located within 10m of the seaward edge of the clearance. The Unvegetated position was located outside the clearance at approximately 10m from the edge into the muddy unvegetated sediments.

4.0 Results

Sampling sites were chosen to cover a range of available combinations of mangrove removal methodology, time since removal, and exposure, to allow examination of importance of methodology, exposure, and time since removal in driving site and benthic community characteristics.

We focused our analysis on five key questions that might be used to determine the success of mangrove removals in terms of longer term changes in sediment and benthic community composition: 1) Do muddy sediments erode after mangrove removal? 2) Does vegetative biomass decompose or disperse after mangrove removal? 3) Is there organic enrichment at mangrove sites? 4) Are benthic communities trending toward neighbouring unvegetated habitats? and 5) Are mangrove removals rapidly recolonised by mangroves? For each question, we investigated whether there were trends associated with time since removal, or differences associated with removal methodology (mechanical versus manual removal), disposal of vegetative biomass (onsite or offsite), physical characteristics of the location (exposure and sediment mud content of neighbouring habitats), and size of clearing.

4.1 Do muddy sediments erode after mangrove removal?

A common objective of mangrove removals is for areas to return to sandflat habitats that were present at a site decades prior to mangrove colonisation. However, at many sites where mangroves have colonised, sediment deposition has resulted in muddier sediments both in areas where mangrove forests have colonised, and in neighbouring unvegetated areas. Results showed the mangrove removal areas we observed generally had higher mud contents than neighbouring unvegetated areas ($p < 0.0001$; Wilcoxon paired rank test). Post removal of mangroves, this mud may erode away and it would be expected that this would happen faster at the edges of the removal than at the centre. While we do not have a time series of samples after removal at the sites, we can determine whether this erosion is occurring by testing whether the mud content of Centre positions are more like that of adjacent mangroves, while the mud content of the Edge positions are more similar to Unvegetated positions.

To determine if variability in grain size within habitats at a site was sufficiently small to allow use of single replicate sediment samples in detecting trends in sediment grain size between positions and between sites, we collected three replicate sediment samples at three sites representing the range of sediment types found in the study (Auckland Airport 1, Pahurehure 1, Mangere 1). Standard errors were calculated for each of six sediment grain size components (% gravel, % coarse sand, % medium sand, % find sand, % silt, % clay). Mean standard errors within habitats ranged from 0.4 to 3.2%, with highest variability at Edge Removal positions. Variability within positions was small relative to variability

between positions, suggesting further analysis using only one replicate was sufficient to detect differences in sediment characteristics. All further analyses present sediment grain size calculations based on one replicate only.

Across all sites, Adjacent Mangrove sites and Centre locations had similar sediment characteristics, with 1-5% difference in mud content between Adjacent Mangrove and Centre locations (Figure 4-1). For many sites, the expected spatial pattern in mud content was observed, with a decreasing trend from Centre (and adjacent mangroves, if present) to Edge to Unvegetated positions (Figure 4-1).

Patterns in sediment composition and trends differed among sites depending on whether sites were in exposed or sheltered locations. For moderately exposed sites, some (Gibbs, Auckland Airport Site 1 and 2) showed large differences in percent mud content between Centre and Unvegetated positions, with removal areas dominated by muds (up to 80% mud content), and neighbouring unvegetated sediments dominated by fine and medium sands (Figure 4-1). Removal positions at these exposed sites still had high mud content at Centre positions, though Edge positions were trending toward reduced mud content (Figure 4-1). The Shelly Beach site was most different from others, dominated by coarse and medium sands, though the mangrove removal Edge position did show higher mud content (~10%) compared to the Unvegetated position. Sediment composition at the Whangateau Edge positions at both Sites 1 and 2 was similar to that of both Adjacent Mangrove and Unvegetated positions, with all positions dominated by fine sands. The Weiti site, though sheltered from wind-waves, showed similarities in sediment characteristics to the exposed sites, with removal areas dominated by high mud content, and neighbouring unvegetated sediments dominated by fine and medium sands (Figure 4-1).

All other sites (Pahurehure, Mangere, Waiuku, Panmure) were sheltered tidal creeks and embayments with high mud content (>80% mud content) across all positions, including the Unvegetated position (Figure 4-1). Mud content was typically >90% in adjacent mangroves and Centre positions in sheltered sites, with mud content decreasing below 90% within Removal Positions only at Panmure 1 and Pahurehure 1 of the sheltered sites. Unvegetated positions at sheltered sites generally had mud content of approximately 80%. Spatial patterns of decreasing mud content from Adjacent Mangrove/Centre positions to Edge to Unvegetated positions were apparent at some sheltered sites (Panmure 1, 2, Mangere 1, 2, 3, Pahurehure 1), though these changes were all relatively small in magnitude. Patterns were not apparent at other sheltered sites, with high mud content observed at all positions.

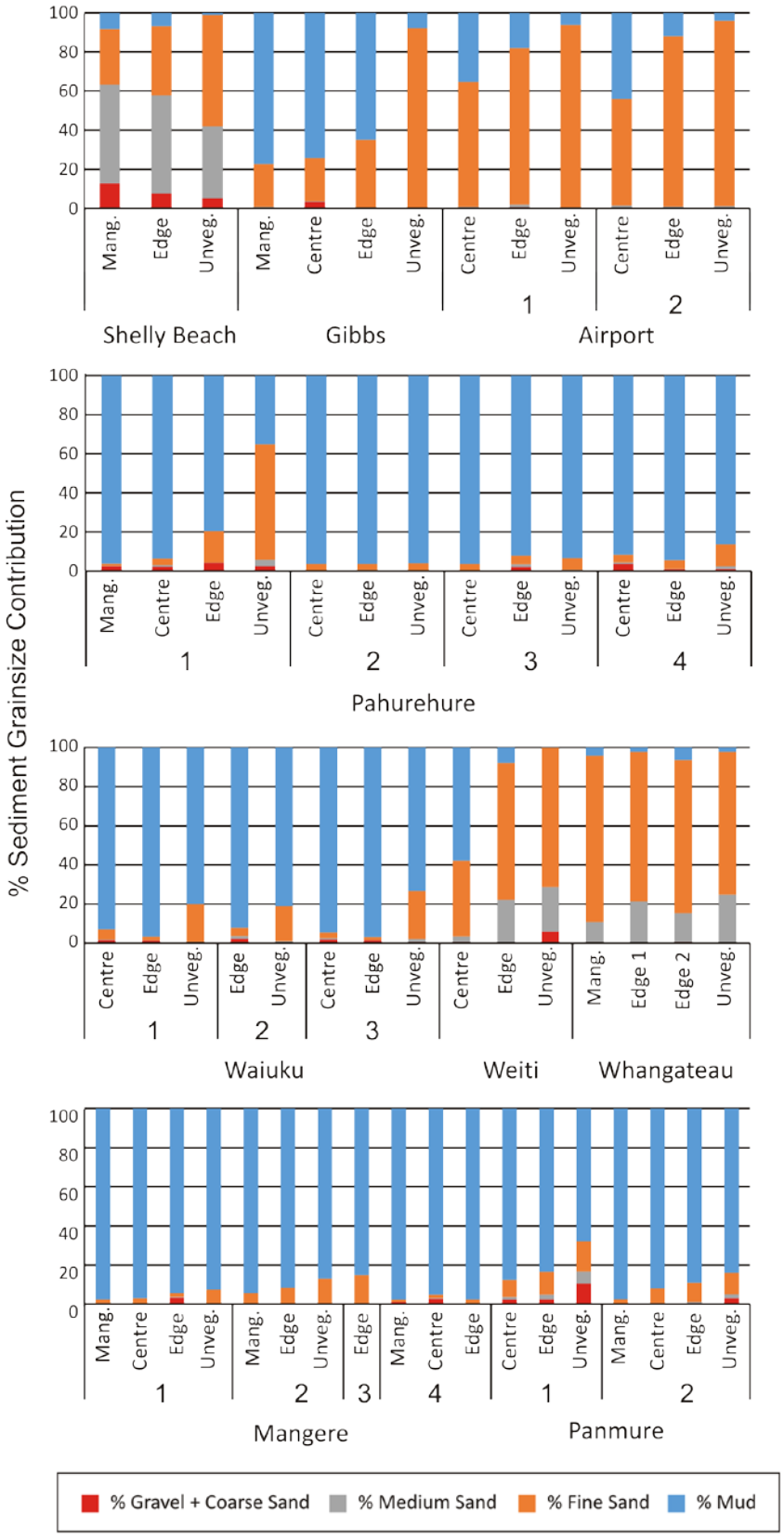

Figure 4-1 Percent sediment grain size contribution of Gravel + Coarse sand (>500µm), Medium Sand (250 - 500µm), Fine Sand (63 – 250µm) and Mud (<63µm) at all sites. Sites with moderate exposure include Shelly, Gibbs, Airport 1, Airport 2, and Whangateau; all other sites were relatively sheltered.

To assess changes in sediment characteristics associated with removal of mangroves, the differences in mud content between Edge and Centre sites (Removal Positions) and Unvegetated sites were tested. These differences in mud content showed a decreasing trend with time since removal for the four sandier sites; which were generally exposed sites (Figure 4-2). Mud content differences decreased faster for Edge than for Centre positions, and two older mangrove removal sites (Whangateau Sites 1 and 2) showed little difference in mud content relative to neighbouring Unvegetated positions after 5 years (Figure 4-2). Trends at more sheltered, muddier sites were less clear, partially due to the high mud content at the Unvegetated position at most of these sites (Figure 4-2). No clear decreasing trend was apparent for either Edge or Centre positions at muddier sites.

Removal methodology showed a consistent effect, with Mechanically cleared sites (Gibbs, Auckland Airport, Pahurehure Sites 3 and 4, Waiuku Sites 1, 2 and 3) showing consistently larger differences in mud content (i.e., less removal of mud) than hand cleared sites. However, disposal off site was also important. The two non-Mechanical sites with highest differences in mud content were both sites where all biomass (including branches) was left on site; these were Weiti, a natural mortality event, and Pahurehure 1, an illegal clearing where chainsaws lopped branches off but left all mangrove biomass in situ.

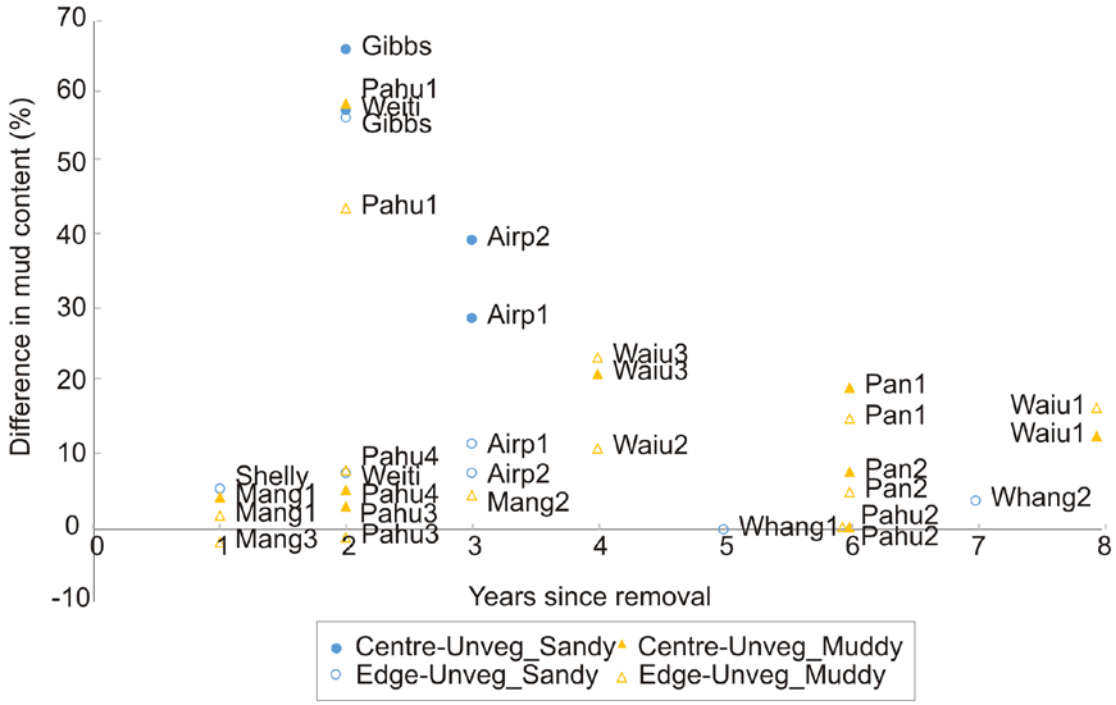

Figure 4-2 Difference in percent mud content between Edge and Centre positions and neighbouring unvegetated position with time since removal.

Multiple regression analyses suggest that aspects of mangrove removal methodology (both use of mechanical methods and vegetation disposal), and size of clearing were significant drivers of decreasing mud content across all sites, whereas time since removal and exposure were not significant in the multiple regression analysis for either differences in mud content between Edge and Unvegetated positions, and between Centre and Unvegetated positions (Table 4-1). Factors associated with more similar mud content between mangrove removal positions and unvegetated sediments (i.e., increased mud removal) were non-mechanical methods, offsite disposal, and smaller rather than larger clearings (Table 4-1). The lack of temporal trends (i.e., more similar mud content at sites with longer time since removal) is surprising, but matches observations of inconsistent trends in mud content, particularly at muddier, sheltered sites (Figure 4-2).

Table 4-1 Multiple regression analysis of the difference in mud content between Edge and Unvegetated habitats, and between Centre and Unvegetated habitats. Variables with significant values >0.10 are not included in the table.

Source	Mean Square	F	Pr > F	Estimate	Direction of effect
Centre-Unvegetated					
Model	2116.15	48.97	**<0.0001**		
Error	43.21				
Size	896.75	20.75	**0.0010**	-2.50	Large > small
Mechanical	173.89	4.02	0.0727	-8.79	Mech > non-mech
Veg Disposal	6277.47	145.2	**<0.0001**	-49.99	Onsite > offsite
Edge-Unvegetated					
Model	607.76	4.07	**0.0251**		
Error	149.29				
Size	928.40	6.22	**0.0240**	-2.49	Large > small
Mechanical	1153.15	7.72	**0.0134**	-21.13	Mech > non-mech
Veg Disposal	1078.94	7.23	**0.0162**	-16.65	Onsite > offsite

4.2 Does vegetative biomass decompose or disperse after mangrove removal?

Vegetative biomass (both above and below ground) is also expected to decrease with time since mangrove removal, and show faster rates of decrease at Edge compared to Centre

positions. Above ground biomass included >2 mm diameter vegetation such as pneumatophores and woody debris; below ground biomass included fine root mass. Any vegetative biomass left in situ would be included in this calculation, with the exception of large mangrove branches that could not be sampled with the sampling gear used (13cm corer).

Here we present differences in the amount of vegetative biomass collected in cores between Edge and Centre positions (Figure 4-3). One caveat in comparing between Edge and Centre positions in this study is that initial vegetative biomass is unknown, and it is likely that Centre positions had higher mangrove density (and thus, higher root mass and pneumatophore density) than Edge positions prior to removal, confounding our interpretation of spatial differences in remaining vegetative biomass. We expect any differences between the Edge and Centre positions could result from a combination of enhanced rates of erosion and decomposition at Edge positions, as well as the possibility of lower pre-removal density (i.e., sparser mangrove stands at the fringe of mangrove forests) at Edge positions.

Higher mangrove vegetative biomass was found at sites where above ground biomass was left onsite, including mulched sites (Gibbs, Auckland Airport Sites 1 and 2) and unconsented sites where intact branches were left on site (Pahurehure Site 1, Whangateau Sites 1 and 2), though there was lower biomass at Weiti which also had intact trees remaining on site (Figure 4-3). Lower biomass was observed at all Mangere and Panmure sheltered sites relative to Pahurehure and Waiuku sites. Baseline information is not available to determine whether this difference is due to differences in removal methodology, or differences in the density of mangrove biomass at each site prior to removal.

Pneumatophores were still abundant and visible protruding above the sediment surface at most sites, with no consistent trend between Edge and Centre positions (Figure 4-4). Highest pneumatophore density was observed at Pahurehure Sites 3 and 4 and Waiuku Site 1.

Stumps were also generally visible at mangrove removal sites, showing little evidence of decomposition (Table 4-2). At some sites stumps were not visible at the sediment surface, and it is possible that sediment deposition buried the top of the stumps, making them difficult to observe (e.g., as found at Shelly Beach). This is more likely than rapid decomposition of stumps, due to the estimated slow rates of decomposition of woody mangrove debris in New Zealand estuaries (Gladstone-Gallagher et al. 2014). Most sites had higher stump density at Centre positions, though a few sites had high densities of smaller stumps observed at Edge positions (e.g., Pahurehure 2) (Table 4-2).

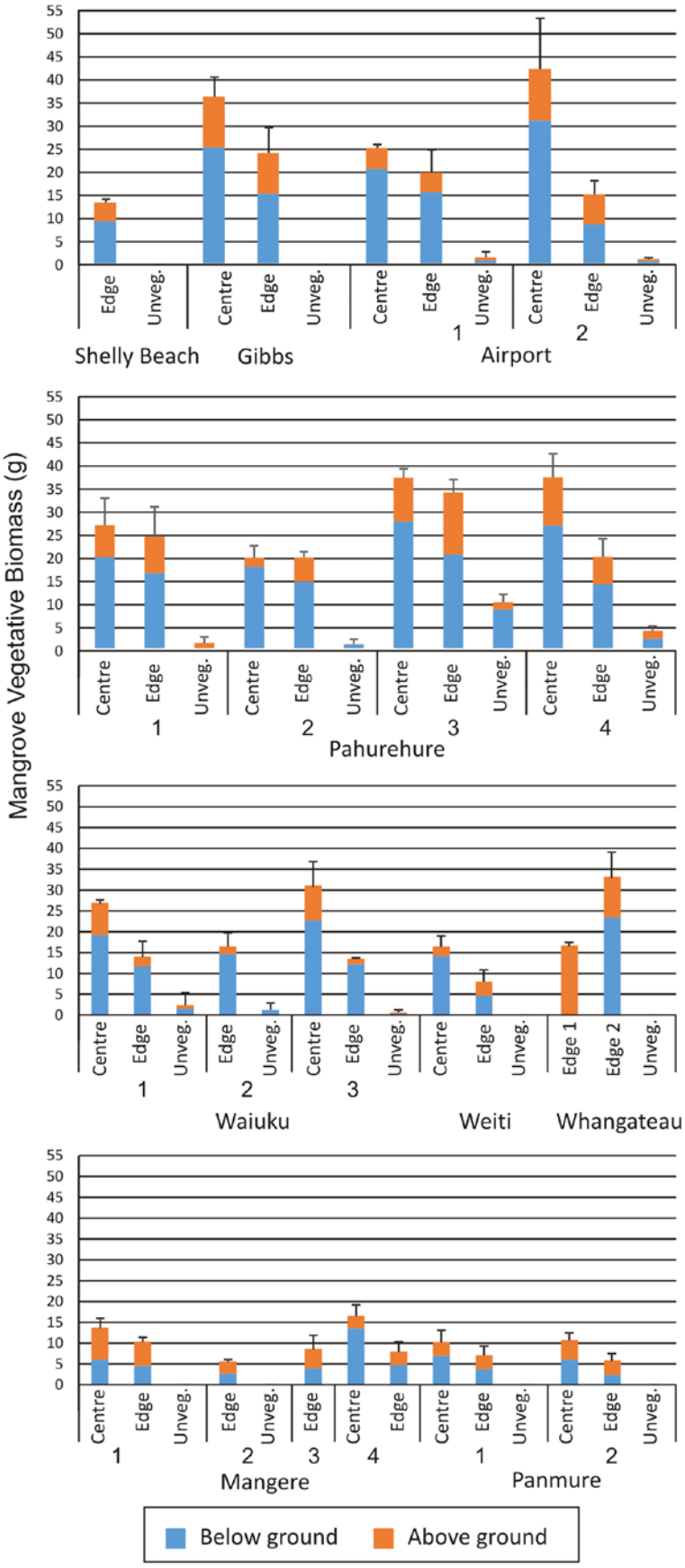

Figure 4-3 Mean total mangrove biomass per 13cm diam., 15cm deep macrofaunal core (+SE).

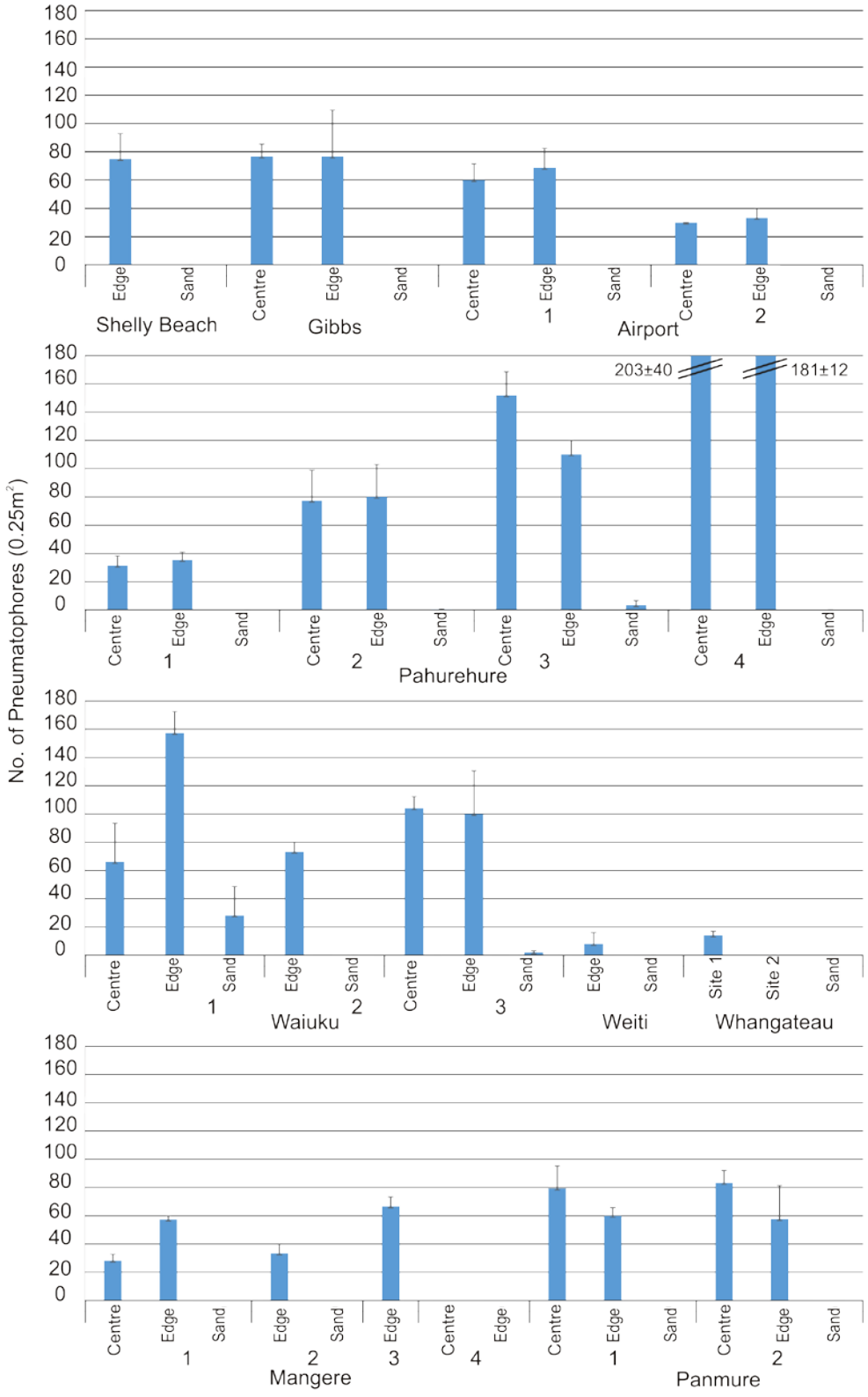

Figure 4-4 Total number of pneumatophores in a 0.25 m^2 quadrat at each position at all sites (+ SE)

Table 4-2 Total number of stumps per 100 m^2 at the edge and centre of all sites (NV = not visible).

Estuary	Site	Edge	Centre
Shelly Beach	1	NV	-
Gibbs	1	175	125
Airport	1	16	32
	2	10	29
Pahurehure	1	NV	28
	2	900	175
	3	500	500
	4	65	100
Waiuku	1	17	3
	2	NV	-
	3	NV	8
Weiti	1	3	5
Whangateau	1	11	-
	2	1	-
Mangere	1	NV	7
	2	100	-
	3	125	-
	4	NV	15
Panmure	1	2	5
	2	NV	15

The relative proportion of different components of remaining vegetation (root biomass versus woody above-ground debris) appeared to be similar between sites, though Centre positions generally had higher overall biomass compared to Edge positions (Figure 4-3). In general, the high amount of remaining biomass, even for sites that were eight years post-removal, was surprising, and suggests long-term retention of both above and below ground vegetation after mangrove removals.

Sites where above ground vegetative biomass was not removed showed no clear trend at sandier sites; all exposed sites either had mulched biomass (Gibbs, Auckland Airport) or intact biomass (Weiti, Whangateau) remaining on site (Figure 4-5). These sites with larger

woody debris showed no clear decreases in vegetative biomass over time, though Centre positions generally had larger quantities of vegetative biomass than Edge positions. Sheltered, muddier sites also showed larger relative quantities of vegetative biomass at Centre compared to Edge positions, and no clear trends with time since removal (Figure 4-5).

Mechanically cleared sites and those with biomass left in situ were both associated with high differences in vegetative biomass in cores (Figure 4-5). High amounts of remaining biomass were potentially associated with both mechanical clearing methodology (i.e., compression of sediments which limits potential for sediment erosion and decomposition), and the amount of in situ biomass deposition at a site after the clearing event, including both mulched and intact biomass. Sites without Mechanical clearing or in situ deposition (Mangere 1, 2 and 3; Shelly Beach, Pahurehure 2, Panmure 1 and 2) had lower remaining biomass than those sites with Mechanical clearing (Waiuku, Pahurehure 3 and 4), those with in situ deposition (Whangateau Sites 1 and 2; Weiti) or those with both Mechanical clearing with in situ deposition (Gibbs, Auckland Airport) (Figure 4-5).

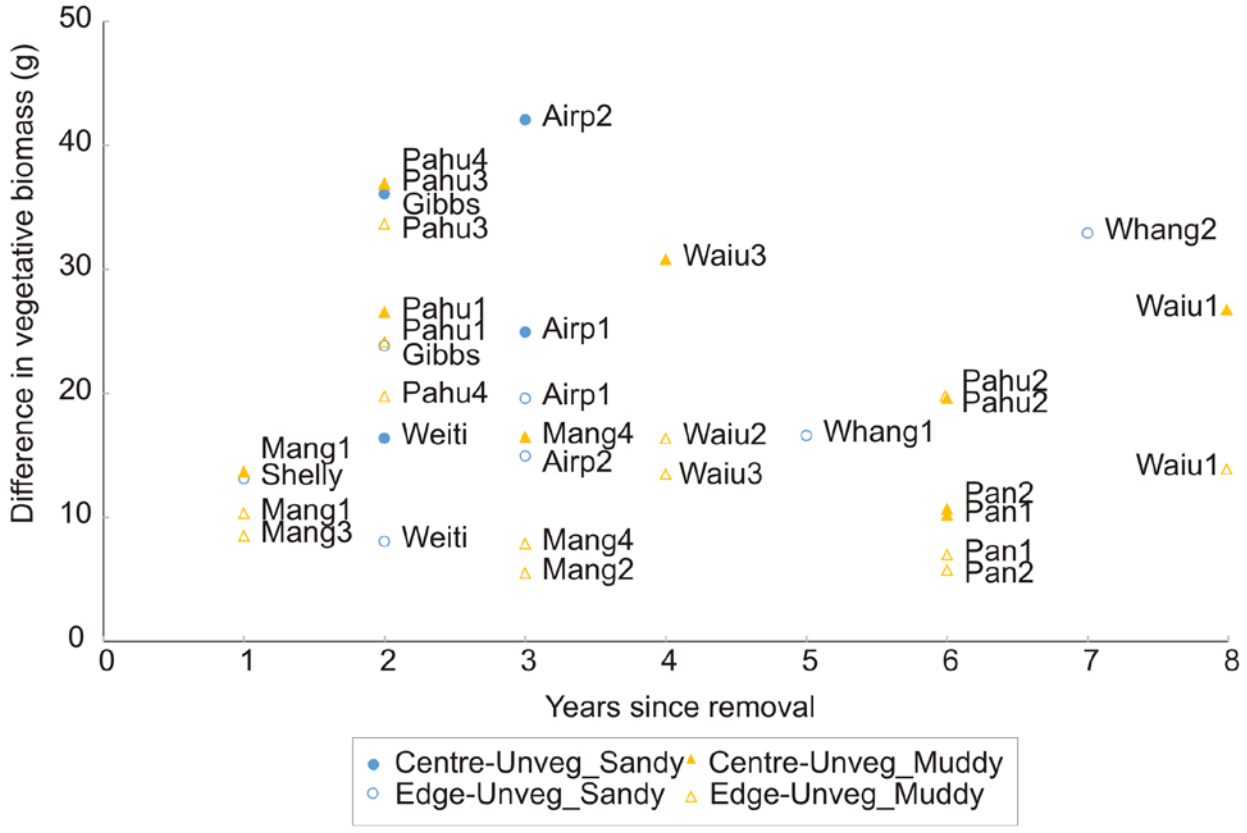

Figure 4-5 Remaining vegetative biomass (including both below and above ground biomass) at Edge and Centre positions versus time since removal.

Multiple regression analyses suggest that the use of mechanical removal was the primary factor associated with higher amounts of both above and below ground biomass, with the

mechanical variable appearing as significant ($p<0.05$) in all four multiple regressions (Centre and Edge positions, below and above ground biomass) (Table 4-3). The method of disposal (onsite or offsite) was also significant in two of the four vegetative biomass regression models (Centre-Below Ground Biomass, Edge-Above Ground Biomass), with onsite disposal (of both mulch and larger woody debris) associated with higher amounts of vegetative biomass than offsite disposal (Table 4-3). Site characteristics were only significant for Edge-Above Ground Biomass, with moderate exposure, size of clearing, and sandier neighbouring sediments all associated with lower vegetative biomass (Table 4-3).

Table 4-3 Multiple regression analysis of the difference in below and above ground biomass between Edge and Centre habitats. Variables with significant values >0.10 are not included in the table.

Source	Mean Square	F	Pr > F	Estimate	Direction of effect
Centre-Below ground biomass					
Model	252.21	13.10	**0.0012**		
Error	19.25				
Mechanical	340.70	17.70	**0.0015**	-9.98	Mech > non-mech
Veg Disposal	98.02	5.09	**0.0454**	-5.58	Onsite > offsite
Edge- Below ground biomass					
Model	106.22	11.32	**0.0056**		
Error	5.07				
Mechanical	106.22	3.37	0.0829	-4.70	Mech > non-mech
Centre-Above ground biomass					
Model	57.39	48.97	**<0.0001**		
Error	43.21				
Mechanical	57.39	48.97	**<0.0001**	-4.05	Mech > non-mech
Edge- Above ground biomass					
Model	38.59	4.69	**0.0118**		
Error	8.22				
Size	49.75	6.05	**0.0266**	-0.42	Large > small
Veg Disposal	64.71	7.87	**0.0133**	-7.73	Onsite > offsite
Exposure	62.62	7.61	**0.0146**	7.44	Sheltered > Moderate
Sediment	46.92	5.71	**0.0305**	0.11	Sand > mud

4.3 Is there organic enrichment at mangrove sites?

Organic enrichment is a potential adverse impact of mangrove removals, with some mangrove removals being previously associated with high nutrient levels in pore water, and large macroalgal blooms (Lundquist et al. 2012). Mangrove sediments often have naturally higher levels of organic content and chlorophyll *a* compared to adjacent vegetated sediment. As such, a decreasing trend in organic content or chlorophyll *a* would be expected over time since mangrove removal. While we cannot compare temporal trends in organic enrichment at each site, we use individual sites with varying times since removal as a surrogate for measuring declines in organic content over time since mangrove removal. We also investigate spatial differences within sites, with faster change expected at Edge compared to Centre positions.

Spatial patterns showing decreases from Centre to Edge to Unvegetated positions were observed at most sites for both chlorophyll *a* and organic content, although this was not as pronounced with phaeophytin (Figure 4-6, Figure 4-7). At some sites where adjacent mangroves were sampled (Pahurehure 1, Mangere 1 and 4, Gibbs), chlorophyll *a* and/or organic content values were higher in mangrove removals than at the Adjacent Mangrove position, suggesting these increases were associated with either disturbance impacts from removal activities or from remaining biomass. For example, high levels of chlorophyll *a* were likely due to near 100% cover of macroalgal blooms at Pahurehure Site 1 and Weiti (Figure 4-6). Organic content was generally higher at sheltered muddy sites compared to sandier, exposed sites (Figure 4-7).

Macroalgae growing on the surface of mangrove removal sites was observed at 12 of the 20 sites. Six of the sites (Mangere Site 1, Pahurehure Sites 2 and 4, Whangateau Site 1, and Panmure Sites 1 and 2) had low abundance (generally ~1% cover within sampling quadrats). Six other sites (Auckland Airport Sites 1 and 2, Pahurehure Sites 1 and 3, Weiti, and Gibbs) had larger quantities of macroalgae, ranging from 5-100% cover within sampling quadrats. Macroalgae was generally patchy across most removal areas (e.g., Auckland Airport, Gibbs), though percent coverage of macroalgae at Weiti and Pahurehure Site 1 was consistently high (>50% cover) throughout most of the site. Most sites with high coverage of macroalgae had either mulch deposited on the surface of the removal area, or intact woody debris left onsite.

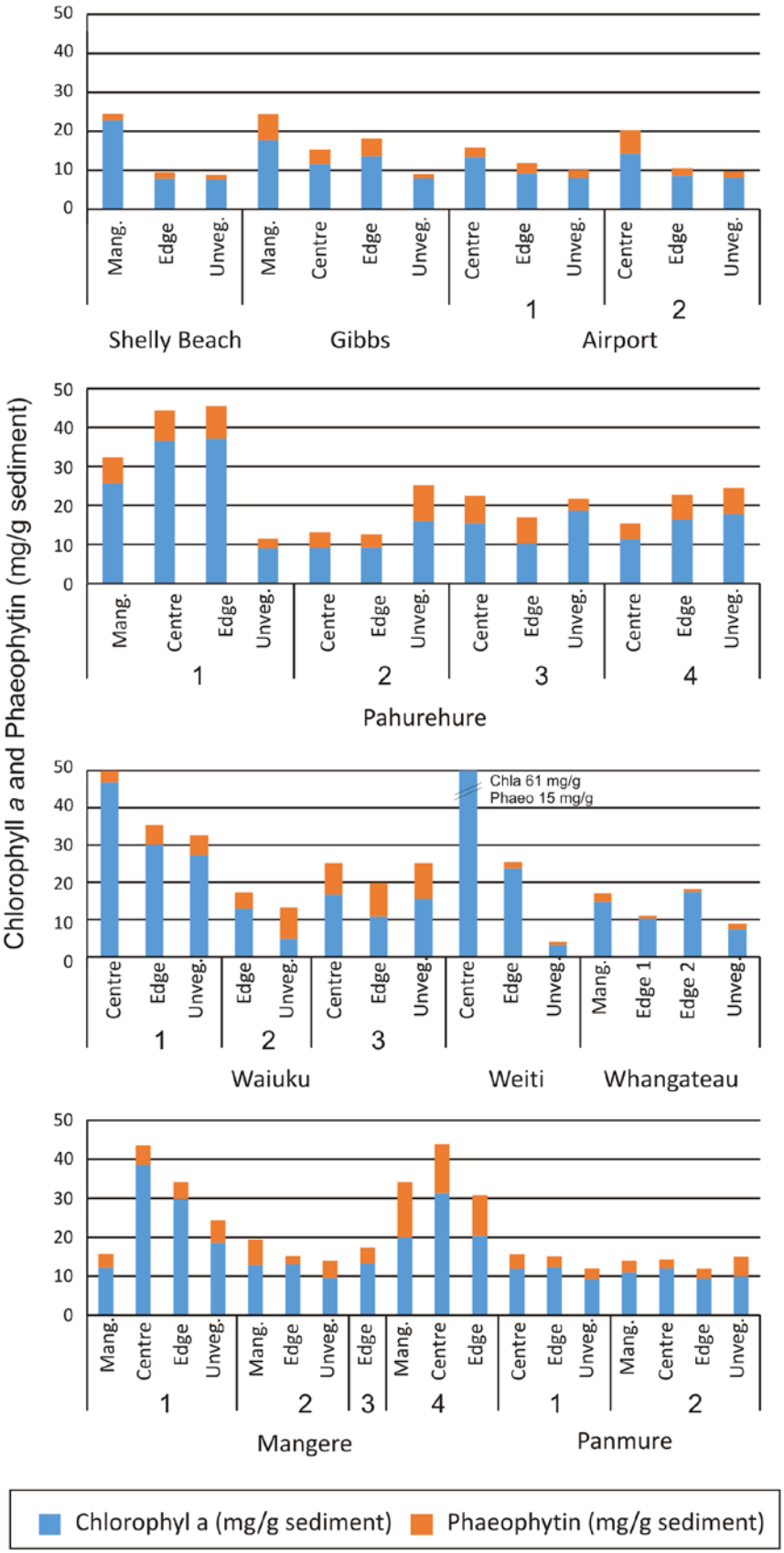

Figure 4-6 Chlorophyll *a* and Phaeophytin (mg/g) at each position at all sites.

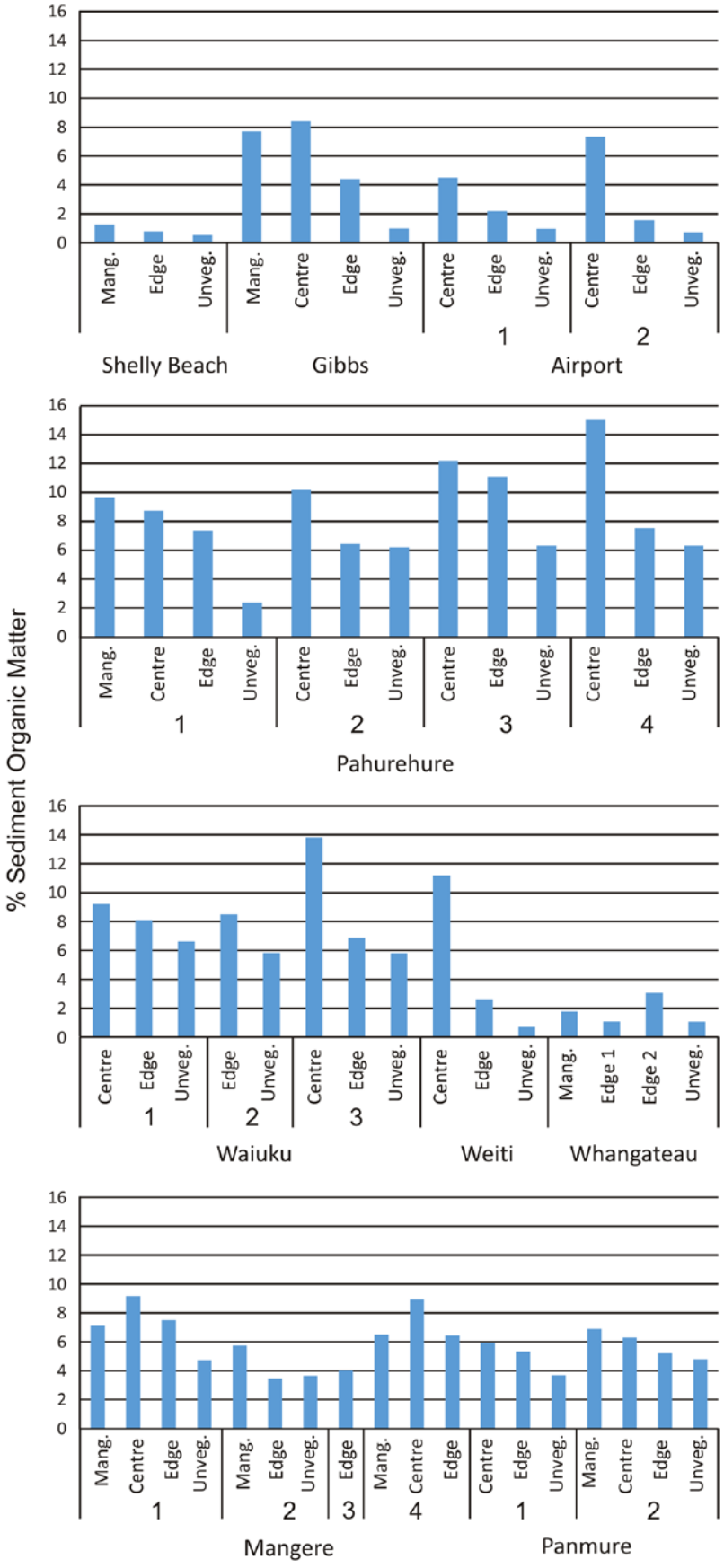

Figure 4-7 Percent sediment organic matter at each position at all sites.

Spatial patterns in organic content were similar to that of mud content, with large decreases in organic content from Centre to Edge Removal Positions to Unvegetated positions particularly for sandier (more exposed) sites. Organic content decrease, relative to Unvegetated positions, was higher for Edge than for Centre positions at sandier sites, with both Whangateau sites again showing little difference in organic content across positions after five years (Figure 4-8). Decreases in organic content, relative to Unvegetated positions, with time since removal at muddier sites were not apparent, presumably due to the higher organic content associated with the muddier sediments at the Unvegetated position at most of these sites (Figure 4-8). No clear effects associated with removal methodology were observed, though largest differences in organic content were found at sites with either Mechanical removal or with all above ground biomass left in situ (Pahurehure 1, Pahurehure 4, Gibbs, Weiti). However, sites showed a large range of values of organic content differences, with values between 1 and 10% for Mechanical sites and/or in situ deposition (Figure 4-8). Non-Mechanical sites (Shelly Beach, all Mangere sites, Pahurehure Sites 1 and 2, Whangateau Sites 1 and 2, Panmure Sites 1 and 2, but with the exception of Weiti and Pahurehure 1) generally showed a smaller range of values, having less than 4% difference in organic content between Removal Positions and Unvegetated positions.

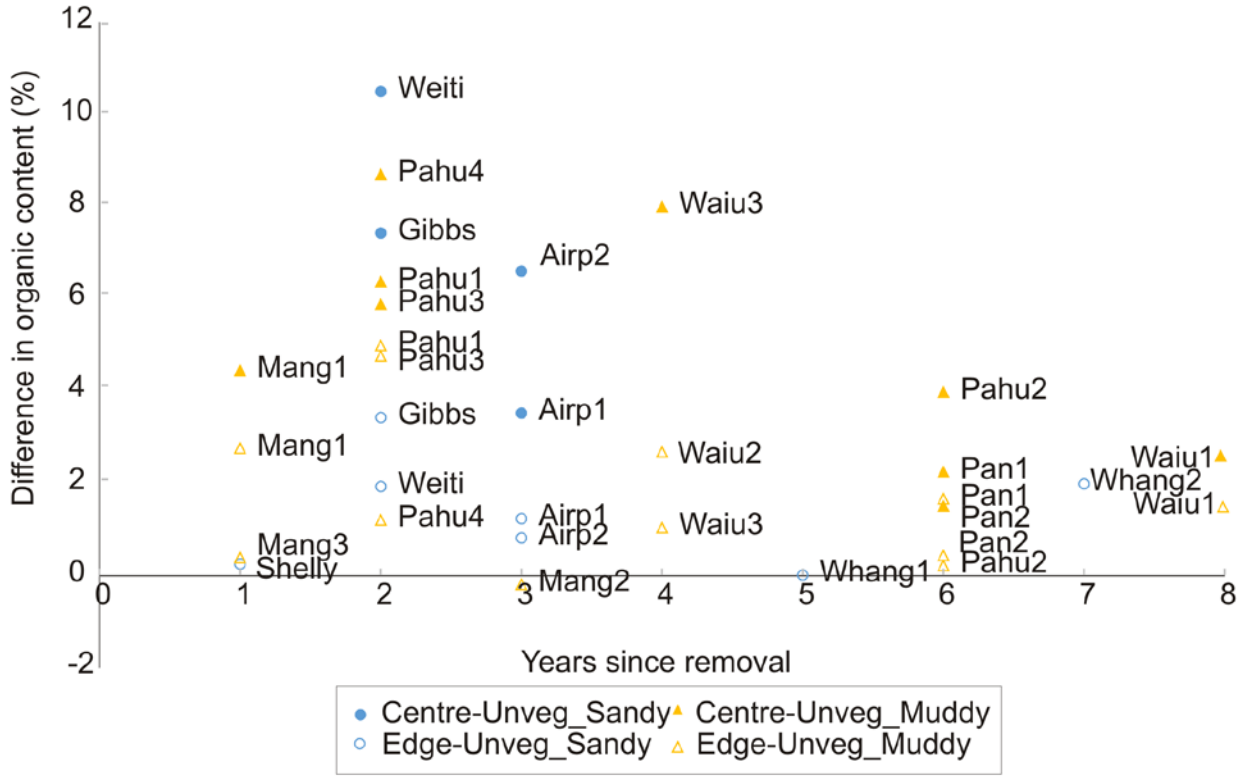

Figure 4-8 Difference in percent organic content between Edge and Centre positions and neighbouring Unvegetated position versus time since removal.

Trends in differences in chlorophyll *a* with time since removal were generally not apparent, with high values observed at two sites where macroalgal blooms were present (Weiti, Pahurehure 1) (Figure 4-9). However, no clear trends either in position (Centre versus Edge) or in exposure (exposed/sandier sites versus sheltered/muddier sites) with time since removal were apparent. In contrast to mud content and organic content, chlorophyll *a* had the smallest differences between removal and Unvegetated positions at Mechanical sites (Figure 4-9).

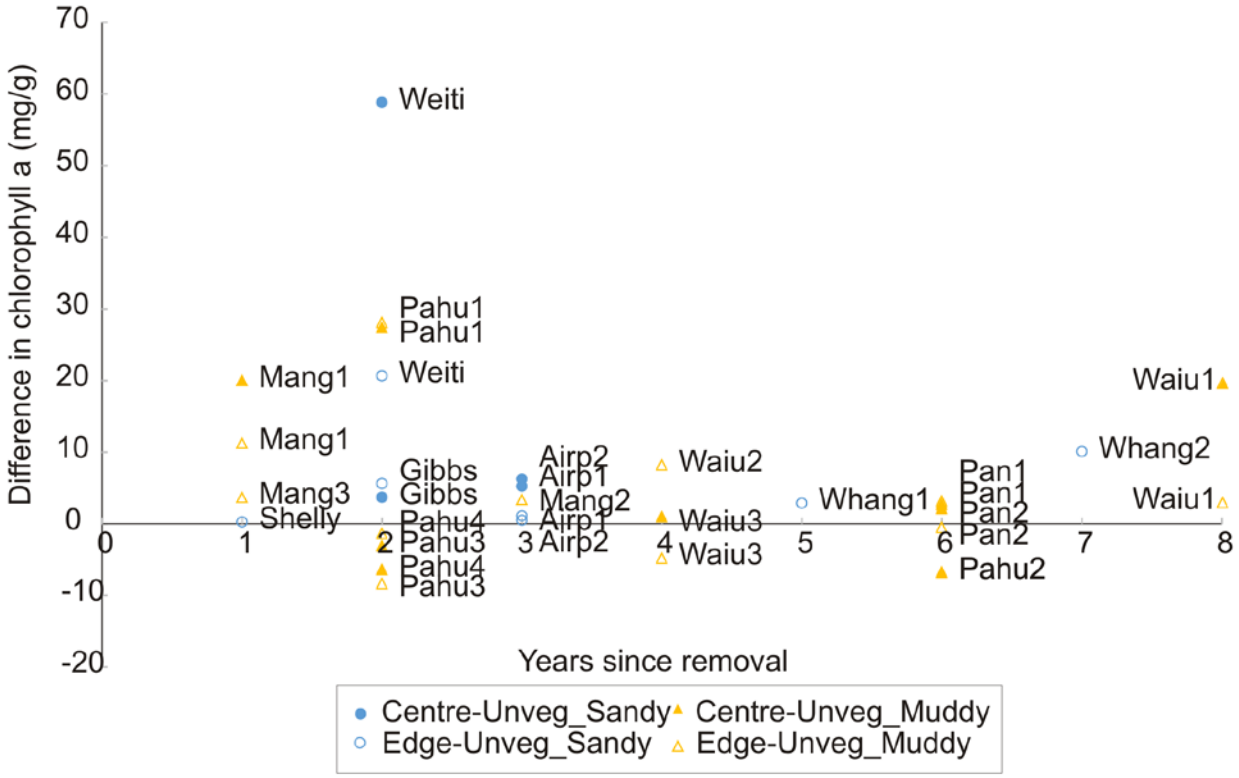

Figure 4-9 Difference in chlorophyll a (mg/g) between Edge and Centre positions and neighbouring unvegetated position versus time since removal.

Multiple regression analyses showed few significant factors affecting organic content, with no significant drivers for Edge-Unvegetated differences in organic content at all (Table 4-4). Time since removal was the only significant variable for the Centre-Unvegetated differences in organic content (Table 4-4). A larger number of factors affected the difference in chlorophyll *a* content between Removal Positions and Unvegetated positions, with disposal method and exposure being significant drivers for both Edge and Centre positions (Table 4-4). The size of the clearing was also significant for the Edge chlorophyll *a* analysis. As with mud content and vegetative biomass, higher values of chlorophyll *a* content were associated with onsite disposal (of both mulch and larger woody debris), sheltered exposures, and larger sized clearing areas (Table 4-4).

Table 4-4 Multiple regression analysis of the difference in organic content and chlorophyll a between Edge and Unvegetated habitats, and between Centre and Unvegetated habitats.

Source	Mean Square	F	Pr > F	Estimate	Direction of effect
Organic Content					
Centre-Unvegetated					
Model	43.06	9.01	**0.0110**		
Error	4.78				
Time since removal	43.06	9.01	**0.0110**	-0.87	Older > younger
Edge-Unvegetated	**No significant variables**				
Chlorophyll a					
Centre-Unvegetated					
Model	1164.23	6.51	**0.0136**		
Error	178.79				
Veg Disposal	2167.49	12.12	**0.0051**	-36.39	Onsite > offsite
Exposure	1736.59	9.71	**0.0098**	-38.04	Sheltered > moderate
Edge-Unvegetated					
Model	309.33	6.89	**0.0034**		
Error	44.89				
Size	262.73	5.85	**0.0278**	-0.95	Large > small
Veg Disposal	755.75	16.84	**0.0008**	-17.42	Onsite > offsite
Exposure	315.44	7.03	**0.0174**	-11.71	Moderate > sheltered

4.4 Are benthic communities trending toward neighbouring unvegetated habitats?

Another common objective of mangrove removals is that benthic communities, in addition to sediments, will return to those communities associated with sandier sediments that were historically present in an area, including shellfish. We lack baseline information on both historical benthic community composition and abundance, and recent community composition and abundance just prior to removals. However, we can determine if

mangrove removals are trending toward neighbouring unvegetated (both muddy and sandy) habitats by looking at different components of macrofaunal diversity.

First, are species colonising the removal sites? If mangrove removal areas have anoxic sediments or dense root biomass or above ground vegetative biomass on site, these factors may affect colonisation by macrofauna.

Second, are key bioturbating species present such as crabs or other crustaceans that form burrows and bioturbate sediments? Presence of these taxa is likely to speed up the process through which muddier sediments may erode, and vegetative biomass may decompose or disperse. To address these questions, we used both visual survey observations and macrofaunal core samples to determine differences in the presence and abundance of different macrofaunal taxa at each site and position. We examined indicators of faunal colonisation, including numbers of epifauna, crab burrows, and infauna, from visual quadrats. While visual quadrat surveys allow cost-efficient measurements of colonisation of mangrove removals by large macrofauna (i.e., count and sizing of bivalves), particularly those at the surface, analysis of macrofaunal community composition from sediment cores allows for more detailed analysis of trends in macrofaunal communities. Variables such as the number of taxa, number of individuals, and Shannon-Weiner diversity were examined to assess recovery dynamics over time. Multivariate analyses were used to investigate changes in macrofaunal community composition to determine if mangrove removal areas were trending toward neighbouring unvegetated habitats.

4.4.1 Survey data

Visual surveys allowed for cost-efficient estimates of whether larger animals (e.g., gastropods, bivalves, crab or other crustacean burrows) were present within both removal and neighbouring positions at each site. Expected patterns for mangrove removals would be that colonisation is initially higher at Edge compared to Centre positions, that macrofaunal numbers become more similar to those in neighbouring Unvegetated areas over time, and that numbers are higher for sites that have had a longer time since removal.

Epifaunal counts were quantified from visual quadrat surveys. The common estuarine gastropod *Potamopyrgus estuarinus* was not included in these counts as its small size makes it difficult to quantify in quadrats; rather, estimates of this species were quantified in macrofaunal cores. Epifaunal densities were highest at Pahurehure Sites 1, 2 and 3 (Figure 4-10). Most sites showed the expected pattern of increasing epifaunal density from Centre to Edge positions. One exception was Pahurehure Site 1, for which large quantities of macroalgae were associated with high densities of the gastropod *Amphibola* at both Centre and Edge positions (Figure 4-10). *Amphibola* was the dominant bivalve at all Pahurehure Inlet and Waiuku sites and Mangere 4, whereas other gastropods (primarily

Zeacumantus lutulentus) were abundant at Gibbs and Auckland Airport sites. No epifaunal gastropods were found at Mangere Sites 1-3, but live oysters were present at Site 3, attached to pneumatophores and woody debris. Abundance of epifauna was variable at Unvegetated positions, and did not show any patterns between sandier and muddier substrates (Figure 4-10).

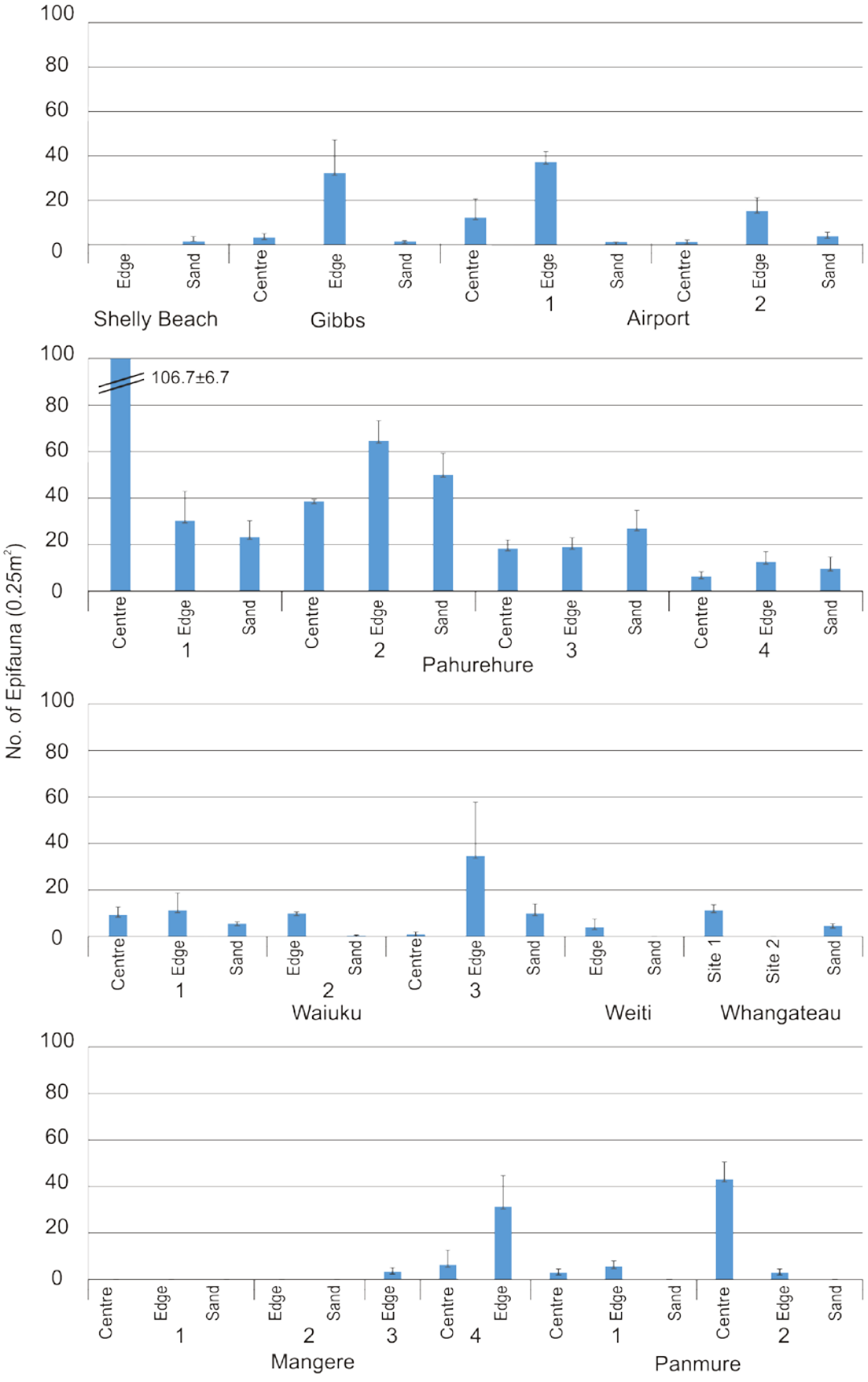

Figure 4-10 Mean number of Epifauna in a 0.25 m^2 quadrat at each position at all sites (+ SE).

Crustacean burrows (primarily crabs) were quantified from visual quadrat surveys. Presence of crab holes varied between sites; sandier sites generally had low burrow abundance at (Auckland Airport, Whangateau, and Weiti), though low abundance at Airport sites could also be due to abundant root mass that made it difficult for crustaceans to burrow (Figure 4-11). High densities of burrows were observed at many muddier sites, with densities of 200-600 per 0.25 m^2 quadrat at some sites in Panmure, Waiuku and Pahurehure (Figure 4-11). All sites except Waiuku 1 and Gibbs had higher abundance of crab burrows at Edge positions compared to Centre positions, though these differences were not always significant.

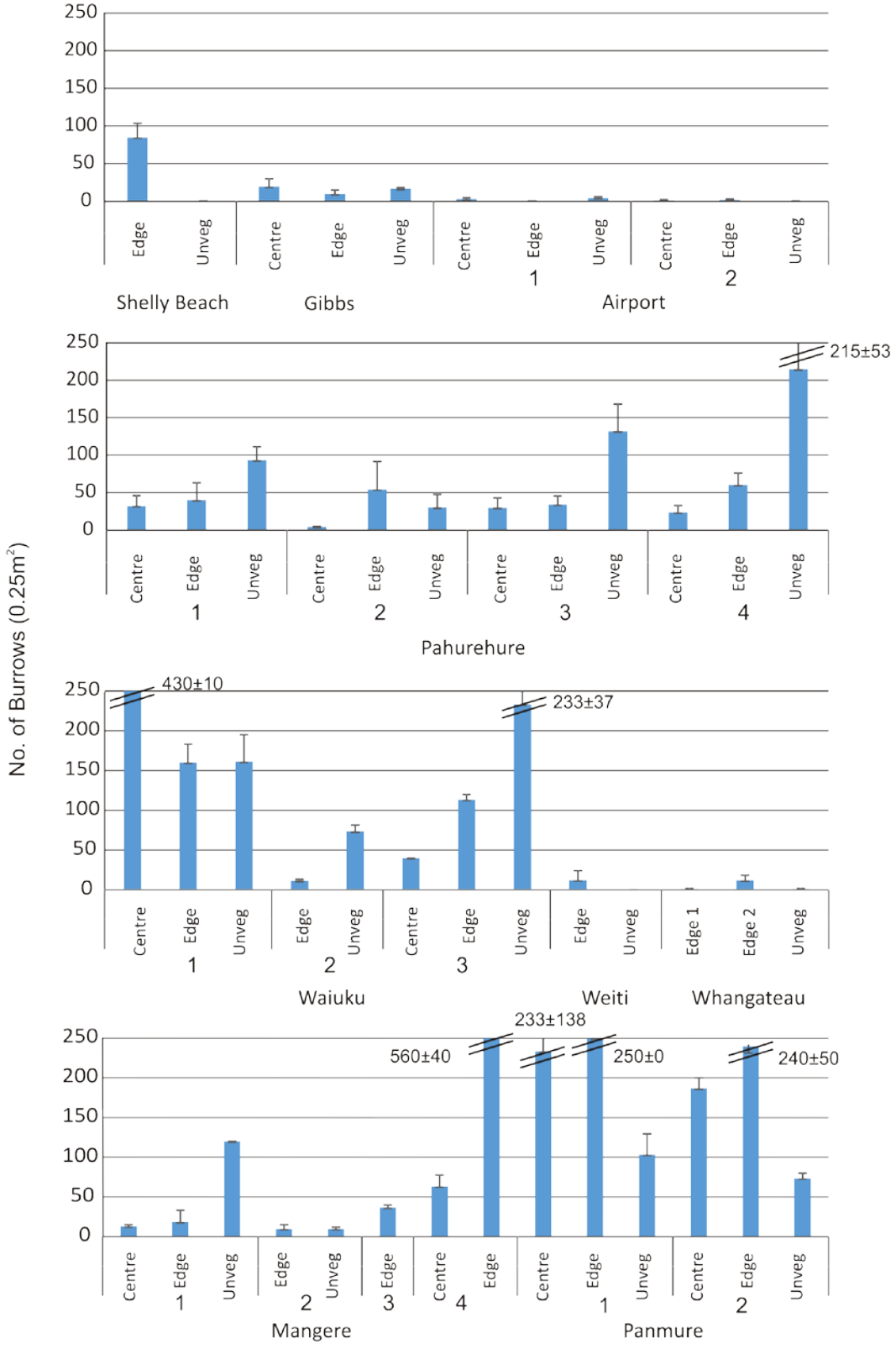

Figure 4-11 Mean number of burrows in a 0.25 m^2 quadrat at each position at all sites (+ SE).

Infaunal bivalve abundance was quantified from hand-raking of quadrats sampled for visual surveys. Hand-raking is generally successful at finding bivalves >10 mm and does not accurately find smaller juvenile bivalves. No infaunal bivalves were found in quadrats in any of the positions at the Mangere, Waiuku, and Panmure sites. A total of one bivalve (*Austrovenus stutchburyi*) was collected from all positions at the four relatively muddy Pahurehure sites (at the Unvegetated position). In contrast, bivalves were present in quadrats at the Unvegetated positions at all sandier sites (Gibbs, Auckland Airport Sites 1 and 2, Weiti, Whangateau, Shelly Beach), with densities ranging from 4 per quadrat to >200. Cockles (*Austrovenus stutchburyi*) were the most abundant bivalves at all sites except Weiti, where both cockles and pipis (*Paphies australis*) were found at the Unvegetated position. Bivalves were only found in mangrove removal areas at three sandier sites (Gibbs, Auckland Airport Sites 1 and 2) at low abundances, with a total of 20 and 25 cockles in three quadrats at Auckland Airport Site 1 at Edge and Centre sites, respectively, and four and zero cockles in three quadrats at Auckland Airport Site 2 at Edge and Centre sites, respectively. However, these high numbers (at least at Auckland Airport) are a bit misleading, as all live cockles were found lying on the sediment surface, in association with abundant dead cockle shells. It appears that these cockles were transported onto the removal site after removal occurred; however, it is unlikely that these cockles will survive as they are unable to bury at this site due to the dense root biomass and remaining mulch at the surface. At the Gibbs site, a total of seven cockles in three quadrats were found at the Edge position, and no cockles were found at the Centre position.

4.4.2 Macrofaunal cores

We first present three common univariate measures of macrofaunal communities: number of taxa, number of individuals, and Shannon-Weiner diversity. While these are commonly used for examining trends in macrofaunal communities, they are not capable of detecting changes in community composition, for example, shifts from opportunistic species that are quick to colonise disturbed habitats to competitive dominants that often occupy less disturbed sites. Therefore, we also present multivariate analysis of macrofaunal communities using MDS to better evaluate whether mangrove removals are trending toward neighbouring Unvegetated flats in terms of community composition.

Total number of taxa exhibited the expected increasing trends of Centre to Edge to Unvegetated at only three of the sites sampled (Gibbs, Pahurehure 1, Mangere 1); these were all recent mangrove removals (within 2 years of removal) (Figure 4-12). No consistent pattern in number of taxa with position was seen across other sites (Figure 4-12) Total number of individuals also showed no consistent trend among sites or positions (Figure 4-13). Highest number of individuals across all taxa were found within mangrove removal positions, though these abundances generally consisted of high

numbers of few opportunistic taxa. For example, in one macrofaunal core at Weiti Edge position, a total of 848 individual *Capitella* spp. were counted. While the Weiti Centre position also had abundant *Capitella* spp., a total of seven individuals of *Capitella* spp. were counted from all three Unvegetated macrofaunal cores combined at this site. Oligochaetes were also common at both Edge and Centre mangrove removal positions, driving spatial patterns in the number of individuals. Over 50 oligochaetes per core were counted at Pahurehure Site 1 and 3, Panmure Site 2, Mangere Site 1, and Waiuku Sites 1 and 3, with a maximum of 401 oligochaetes in one Centre sample at Pahurehure Site 1. A third taxa that occurred in high abundance in mangrove removal positions was the gastropod *Potamopyrgus estuarinus*, with highest abundance of 1530 individuals per core found in an Edge core at Pahurehure Site 1, and cores with more than 100 individuals found at Gibbs, Pahurehure Sites 1, 2, and 3, and Waiuku Sites 1 and 3.

Shannon-Weiner diversity also generally showed inconsistent trends with position, though more sites (Gibbs, Mangere 1, Pahurehure Sites 1 and 2, Panmure 2, and Weiti) did show expected patterns of increasing diversity from Centre to Edge to Unvegetated. This reflects that this diversity index is based on both the number of taxa, and the relative number of individuals in each taxon. Highlighting that samples dominated by large numbers of one or a few taxa would have lower values than samples with even distributions of individuals across species (Figure 4-14).

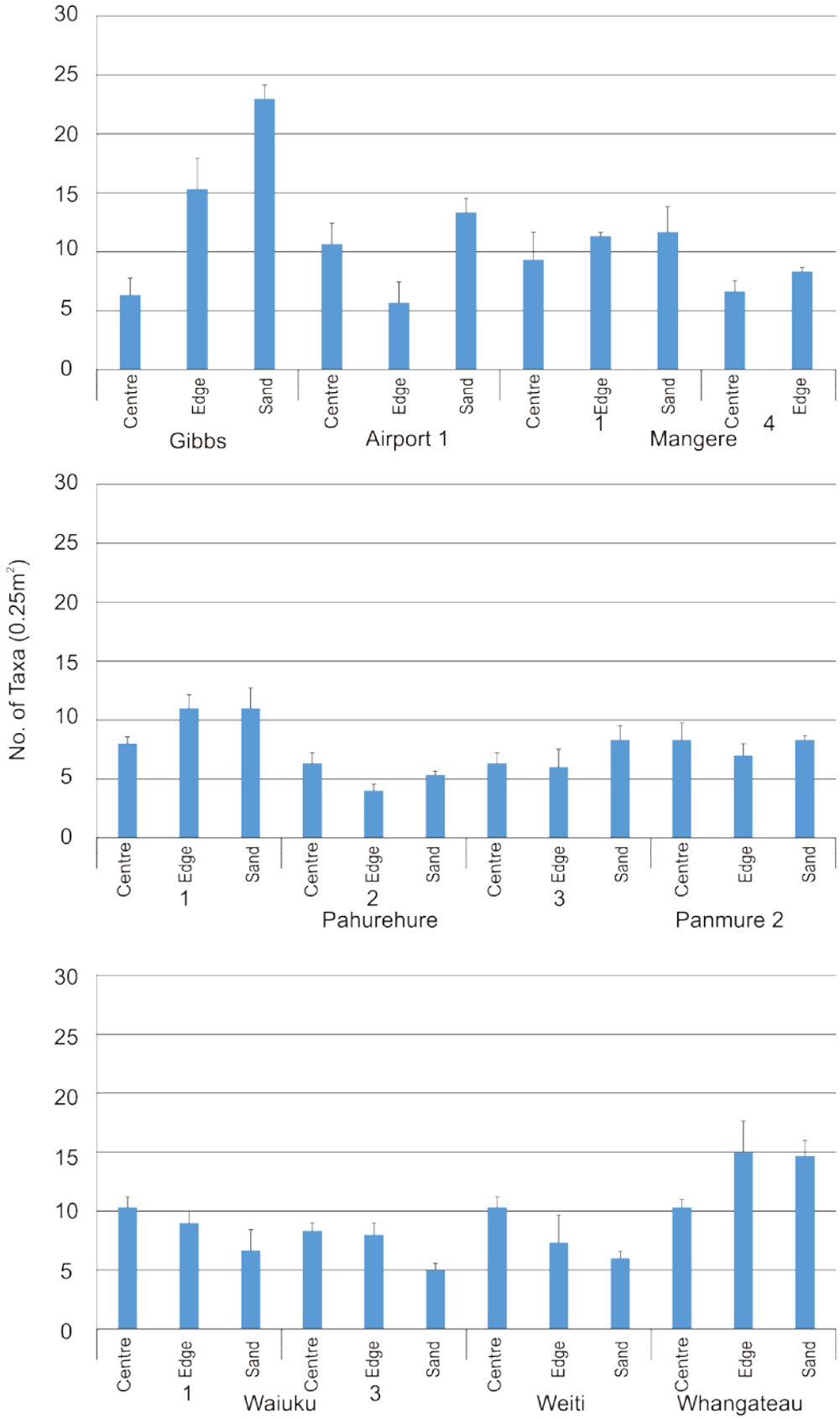

Figure 4-12 Total number of taxa at each position at all sites sampled for macrofauna (+ SE). Abundances represent the mean of three replicate cores (13cm diam., 15cm depth).

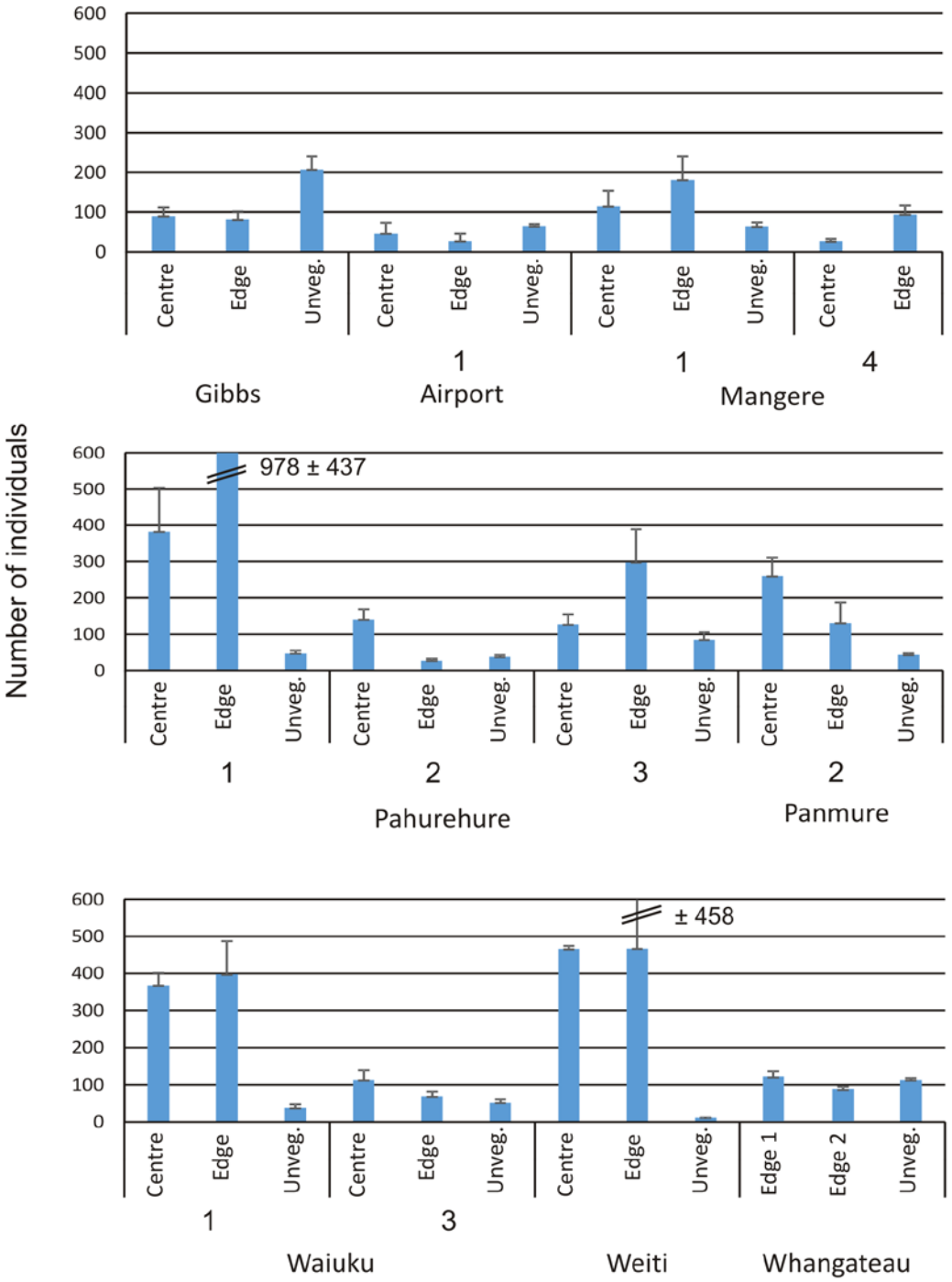

Figure 4-13 Total number of individuals at each position at all sites sampled for macrofauna (+ SE). Abundances represent the mean of three replicate cores (13cm diam., 15cm depth).

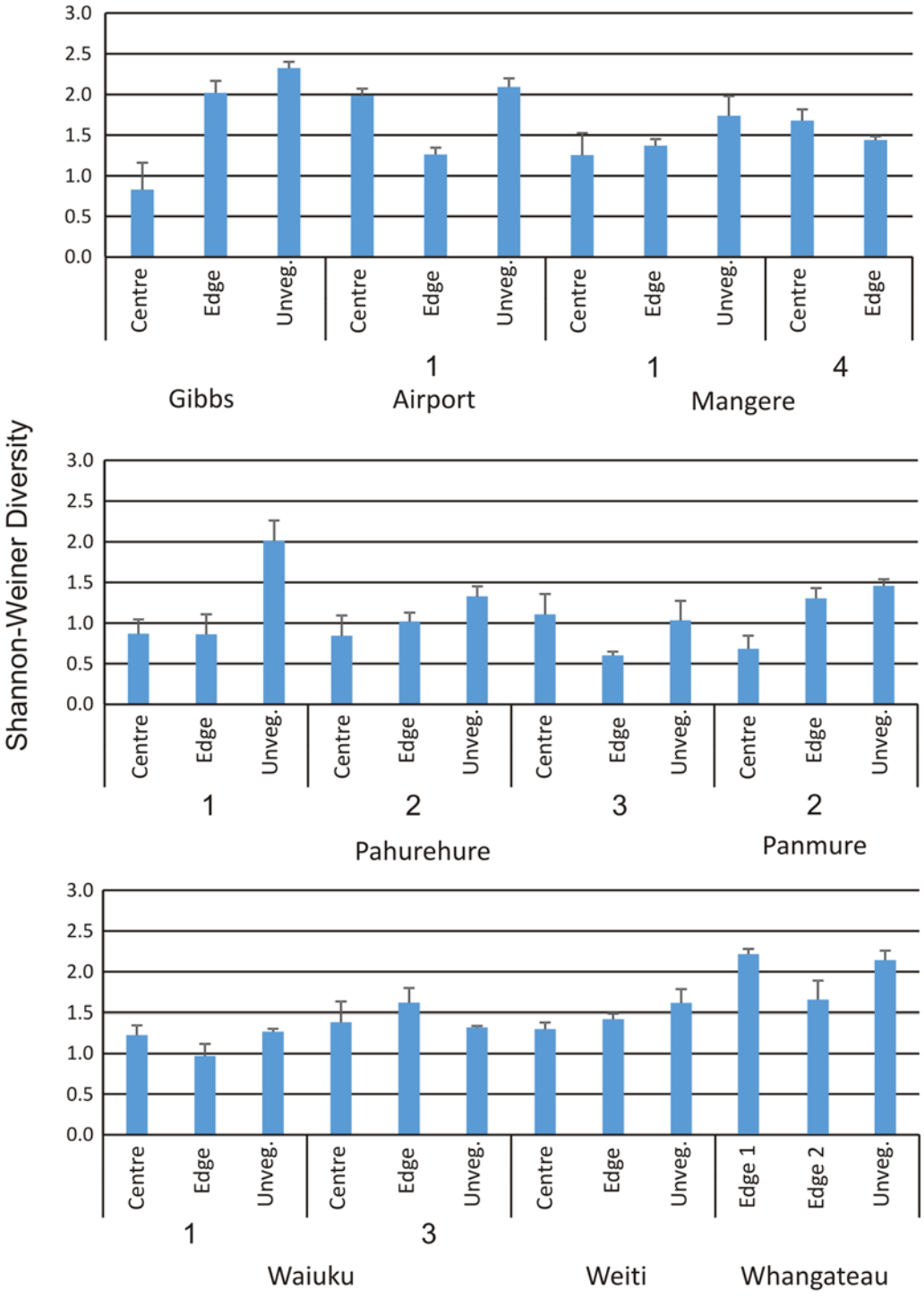

Figure 4-14 Shannon-Weiner diversity at each position at all sites sampled for macrofauna (+ SE). Abundances represent the mean of three replicate cores (13cm diam., 15cm depth).

In contrast to univariate analyses, multivariate ordination shows reasonably consistent differences between the three positions at the 13 sites (Figure 4-15). For some sites (e.g., Panmure 2, Gibbs) Edge positions are placed midway between Unvegetated and Centre sites in the MDS ordination. Assuming that prior to removal Edge positions were more similar to Centres, this suggests that sites (or at least Edge positions) are trending toward Unvegetated over time since mangrove removal (Figure 4-15). At other sites, Edge and Centre positions are more closely spaced whereas Unvegetated positions are located far away from mangrove removal positions in ordination space implying, under the same assumption as above, that these areas may not be becoming more similar to Unvegetated conditions. As sediment composition makes it difficult to interpret, (i.e., Unvegetated positions at muddier sites are similar in composition to mangrove Removal positions at sandier sites, we also performed MDS analyses on sandy and muddy sites separately (Figure 4-16, Figure 4-17). Sandier sites were defined as those with <10% mud content at the Unvegetated position, whereas mud content at muddy sites averaged 80% (range: 35-96%) at the Unvegetated position. Within these separated MDS analyses, trends are more easily visible between sites, with clustering of Unvegetated positions in both muddy and sandy plots (Figure 4-16, Figure 4-17). For sandier sites, most Centre positions are located farther from Unvegetated positions than Edge positions in multi-dimensional space (Figure 4-16). Muddy sites do not show this pattern, such that while Unvegetated positions are clustered together, Edge positions are no closer to Unvegetated positions than Centre positions (with the exception of Waiuku Site 3) (Figure 4-17).

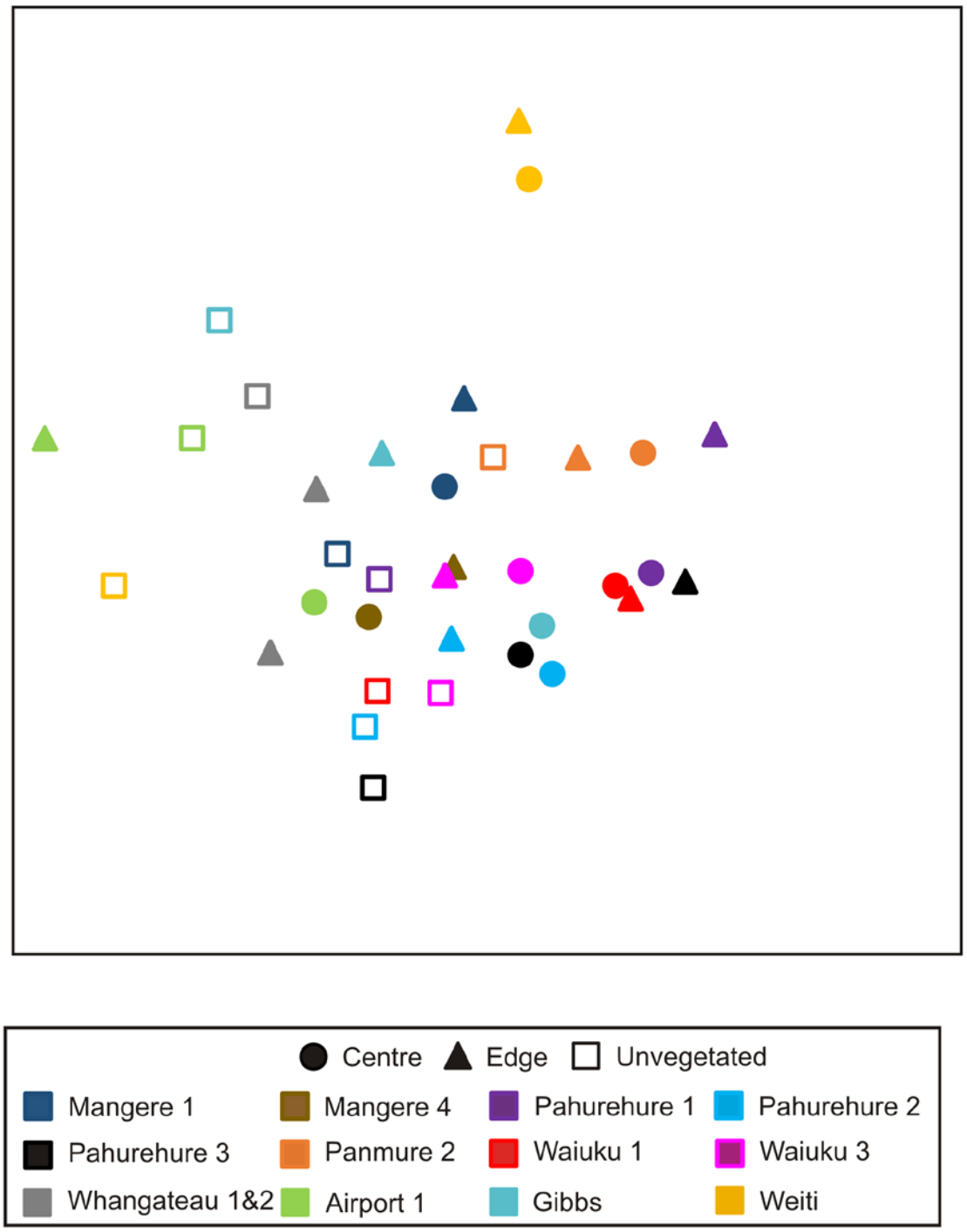

Figure 4-15 Multivariate ordination (non-metric multidimensional scaling, MDS) of macrofaunal community structure at each position at all sites sampled for macrofauna. Macrofaunal community structure is based on the mean of three replicate cores (13cm diam., 15cm depth) at each position (Centre, Edge, Unvegetated) at each site. Two dimensional MDS presented to aid visualisation; stress (2D) = 0.17; stress (3D) = 0.12.

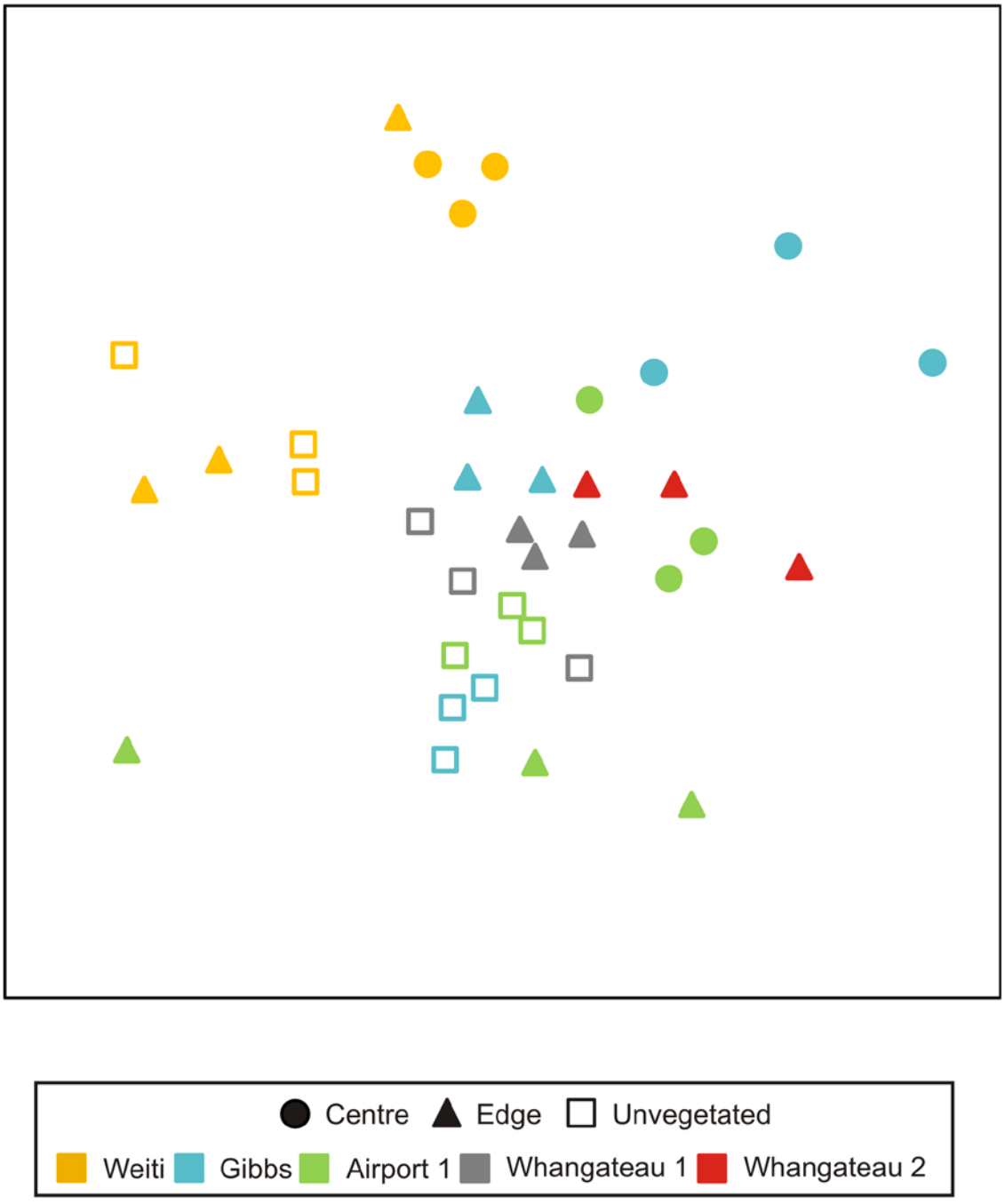

Figure 4-16 Multivariate ordination (non-metric multidimensional scaling, MDS) of macrofaunal community structure at each position at only sandy sites sampled for macrofauna. Macrofaunal community structure is based on three individual replicate cores (13cm diam., 15cm depth) at each position (Centre, Edge, Unvegetated) for each site. Two dimensional MDS presented to aid visualisation; stress (2D) = 0.21; stress (3D) = 0.15.

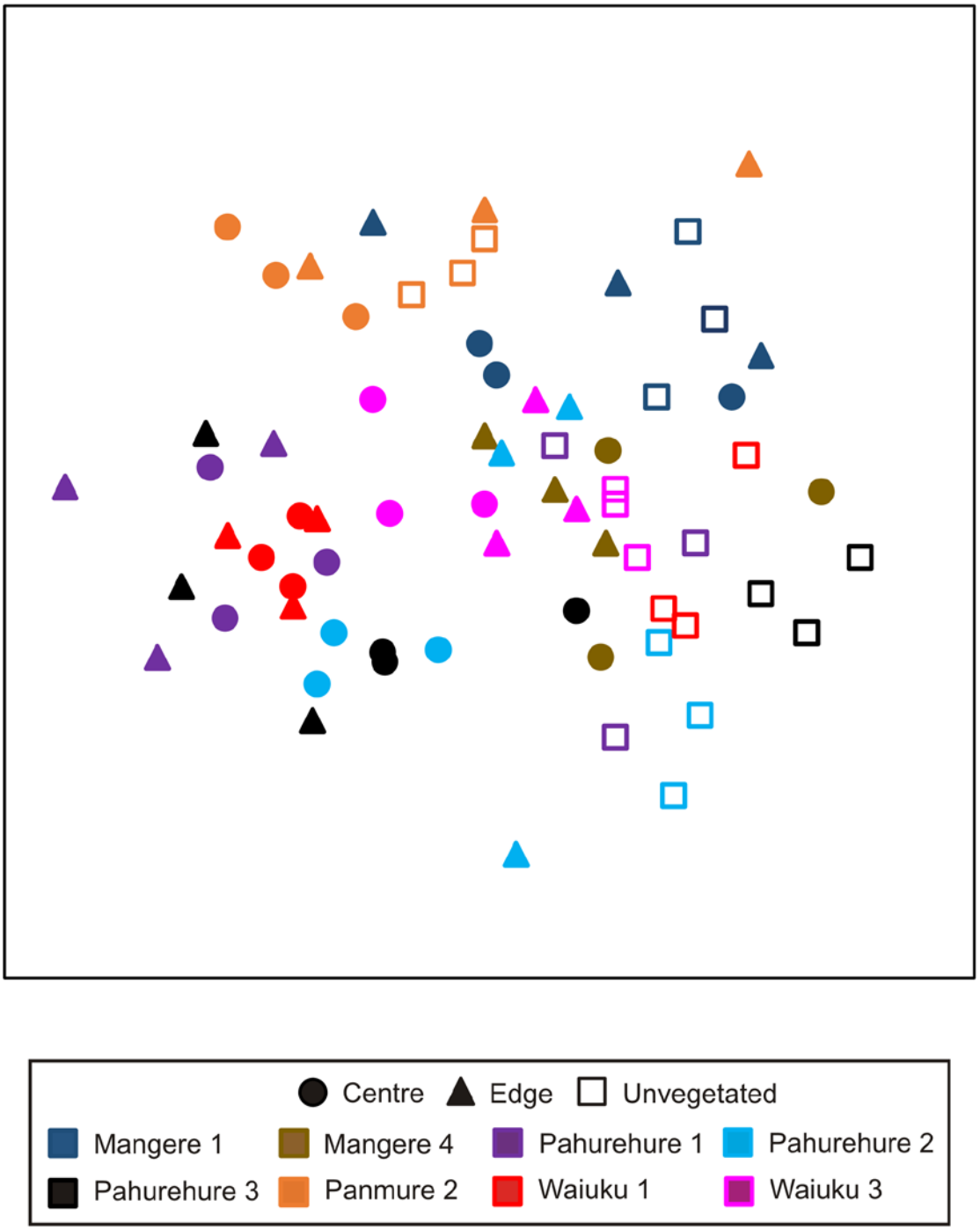

Figure 4-17 Multivariate ordination (non-metric multidimensional scaling, MDS) of macrofaunal community structure at each position at only muddy sites sampled for macrofauna. Macrofaunal community structure is based on three individual replicate cores (13cm diam., 15cm depth) at each position (Centre, Edge, Unvegetated) for each site. Two dimensional MDS presented to aid visualisation; stress (2D) = 0.24; stress (3D) = 0.16.

These trends (or lack thereof at muddier sites) are explained easily when examining the dominant species at each position at each site (Table 4-5). For example, differences in community composition are evident when comparing the five most common species at

each site, with mangrove removal positions (Edge and Centre) often dominated by Oligochaeta, *Capitella* spp., and *Potamopyrgus estuarinus*, whereas Unvegetated positions usually include a number of polychaetes not found or found in low abundance in mangrove removal sites (e.g., the spionid polychaetes *Polydora* sp., *Aonides trifida*, *Prionospio aucklandica*, *Scolecolepides benhami*). At least one bivalve (e.g., *Austrovenus stutchburyi*, *Macomona liliana*, *Paphies australis*) was within the top five species for sandier sites, whereas muddier sites included a range of other common taxa that had higher abundance in Unvegetated positions than in Centre or Edge mangrove removal positions (Table 4-5). In general, as shown in the MDS plots, Edge positions had higher overlap of species with Unvegetated positions than did Centre positions, particularly at sandy sites.

Table 4-5 Top 5 species in order of abundance at each position at all sites sampled for epifauna.

	Centre	Edge	Unvegetated
Gibbs (sandy)	*Potamopyrgus estuarinus* Oligochaeta *Capitella* spp. *Cossura consimilis* *Nicon aestuariensis*	*Capitella* spp. *Perinereis vallata* *Austrominius modestus* *Austrohelice crassa* *Austrovenus stutchburyi*	*Heteromastus filiformis* *Austrovenus stutchburyi* *Arthritica bifurca* *Aonides trifida* *Paradoneis lyra*
Airport 1 (sandy)	*Scolecolepides benhami* *Zeacumantus subcarinatus* *Halicarcinus whitei* *Nicon aestuariensis* *Arthritica bifurca*	*Austrovenus stutchburyi* *Scoloplos cylindrifer* *Torridoharpinia hurleyi* *Zeacumantus subcarinatus* *Amphibola crenata*	*Scoloplos cylindrifer* *Austrovenus stutchburyi* *Macomona liliana* *Aonides trifida* Nemertea
Mangere 1 (muddy)	*Capitella* spp. Oligochaeta *Scolecolepides benhami* *Arthritica bifurca* *Heteromastus filiformis*	*Capitella* spp. Oligochaeta *Heteromastus filiformis* *Pseudopotamilla* sp. *Scolecolepides benhami*	*Paradoneis lyra* *Austrohelice crassa* Oligochaeta *Heteromastus filiformis* *Scolecolepides benhami*
Mangere 4 (muddy)	*Scolecolepides benhami* Oligochaeta *Capitella* spp. *Hemiplax hirtipes* *Potamopyrgus estuarinus*	*Scolecolepides benhami* Oligochaeta *Capitella* spp. *Amphibola crenata* *Austrohelice crassa*	

	Centre	Edge	Unvegetated
Pahurehure 1 (muddy)	*Potamopyrgus estuarinus* Oligochaeta *Scolecolepides benhami* *Amphibola crenata* *Capitella* spp.	*Potamopyrgus estuarinus* *Capitella* spp. Oligochaeta *Torridoharpinia hurleyi* *Austrohelice crassa*	*Torridoharpinia hurleyi* *Arthritica bifurca* Oligochaeta *Amphibola crenata* *Nicon aestuariensis*
Pahurehure 2 (muddy)	*Potamopyrgus estuarinus* *Scolecolepides benhami* Oligochaeta *Amphibola crenata* *Austrohelice crassa*	Oligochaeta *Potamopyrgus estuarinus* *Amphibola crenata* *Nicon aestuariensis* *Scolecolepides benhami*	*Torridoharpinia hurleyi* *Scolecolepides benhami* *Amphibola crenata* *Paracorophium* sp. *Austrohelice crassa*
Pahurehure 3 (muddy)	*Potamopyrgus estuarinus* *Scolecolepides benhami* *Amphibola crenata* *Austrohelice crassa* Oligochaeta	*Potamopyrgus estuarinus* Oligochaeta *Perinereis vallata* *Amphibola crenata* *Austrohelice crassa*	*Pseudopotamilla* sp. *Scolecolepides benhami* *Austrohelice crassa* *Paracorophium* sp. *Prionospio aucklandica*
Panmure 2 (muddy)	Oligochaeta *Boccardia syrtis* *Austrohelice crassa* *Capitella* spp. *Melita awa*	Oligochaeta *Boccardia syrtis* *Polydora cornuta* *Austrohelice crassa* *Capitella* spp.	Oligochaeta *Melita awa* *Hemiplax hirtipes* *Nicon aestuariensis* *Cossura consimilis*
Waiuku 1 (muddy)	*Potamopyrgus estuarinus* Oligochaeta *Paracorophium* sp. *Scolecolepides benhami* *Austrohelice crassa*	*Potamopyrgus estuarinus* Oligochaeta *Paracorophium* sp. *Scolecolepides benhami* *Capitella* spp.	*Scolecolepides benhami* *Paracorophium* sp. Oligochaeta *Amphibola crenata* *Aonides trifida*
Waiuku 3 (muddy)	Oligochaeta *Potamopyrgus estuarinus* *Austrohelice crassa* *Scolecolepides benhami* *Capitella* spp.	Oligochaeta *Scolecolepides benhami* *Amphibola crenata* *Capitella* spp. *Potamopyrgus estuarinus*	*Scolecolepides benhami* *Paracorophium* sp. Oligochaeta *Austrohelice crassa* *Cossura consimilis*

	Centre	Edge	Unvegetated
Weiti (sandy)	*Corophium* sp. *Capitella* spp. *Polydora cornuta* *Perinereis vallata* *Pseudopolydora sp.F*	*Capitella* spp. *Corophium* sp. *Paracalliope novizealandiae* Spirobiidae *Pseudopolydora* sp.F	*Capitella* spp. *Paphies australis* *Corophium* sp. *Perinereis vallata* *Lasaea parengaensis*
Whangateau 1 (sandy)		*Paracorophium* sp. *Ceratonereis* sp. *Scolecolepides benhami* *Lasaea parengaensis* *Perinereis vallata*	*Lasaea parengaensis* *Lumbrinereis* sp. *Perinereis vallata* *Colurostylis lemurum* *Prionospio aucklandica*
Whangateau 2 (sandy)		*Perinereis vallata* *Scoloplos cylindrifer* *Lasaea parengaensis* *Ceratonereis* sp. Oligochaeta	*Lasaea parengaensis* *Lumbrinereis* sp. *Perinereis vallata* *Colurostylis lemurum* *Prionospio aucklandica*

Bivalves were common only at sandier sites, and abundances and trends in positions between Centre, Edge and Unvegetated from macrofaunal cores matched trends from visual assessment in quadrats. Few individual *Austrovenus* were found in Edge and Centre positions compared to Unvegetated positions, and *Austrovenus* were only found at sandier sites (Figure 4-18). *Austrovenus* abundance at Airport Edge sites was relatively similar to that at Airport Unvegetated sites, as previously mentioned, although these cockles were found lying on the sediment surface (Figure 4-18). *Paphies* were only found in cores collected at Weiti Unvegetated positions, with a mean density of 2.3 per core. *Macomona*, not sampled in quadrat hand-raking as they live deeper in the sediment, were found at three sites (Gibbs, Airport 1, Whangateau), and in an order of magnitude lower abundance at Edge sites compared to Unvegetated sites; no *Macomona* were found at Centre positions (Figure 4-19).

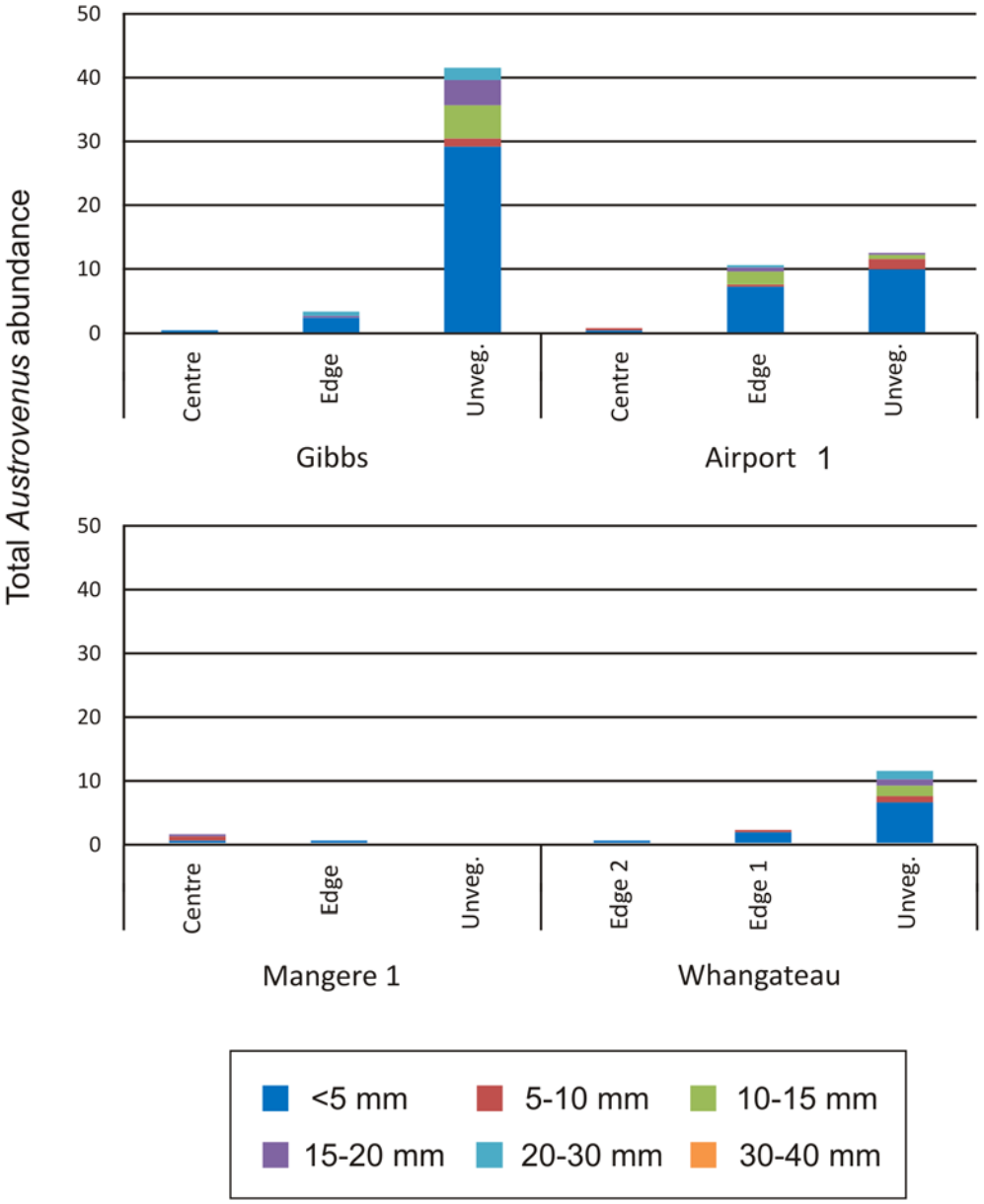

Figure 4-18 Total abundance and size distribution of *Austrovenus stutchburyi*. Abundances represent the mean of three replicate cores (13cm diam., 15cm depth).

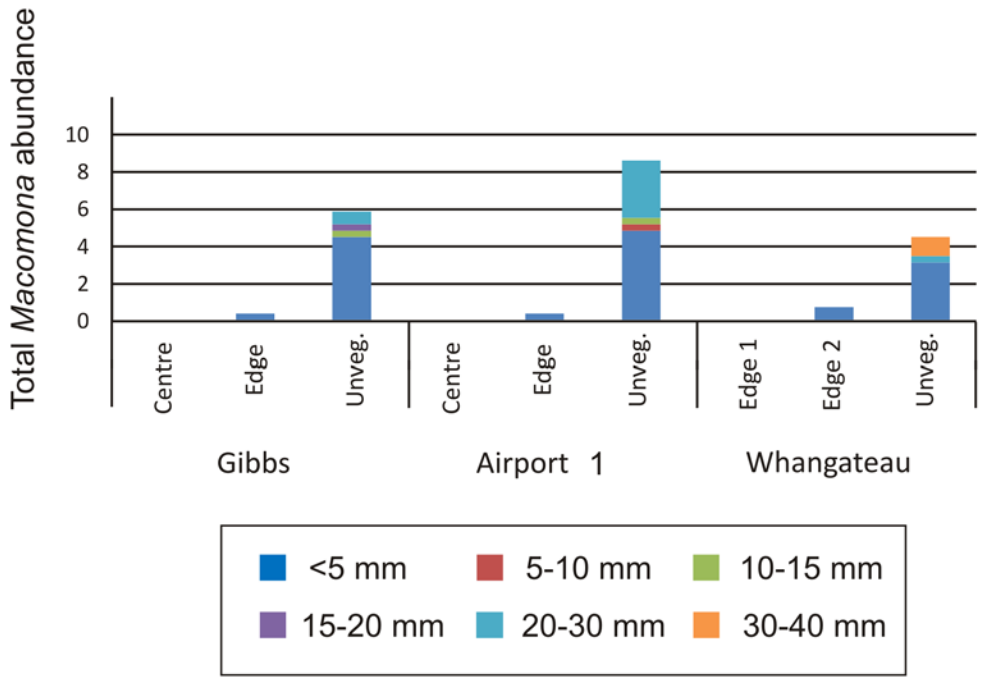

Figure 4-19 Total abundance and size distribution of *Macomona liliana*. Abundances represent the mean of three replicate cores (13cm diam., 15cm depth).

From the multivariate analysis of macrofaunal community composition, there was an observed increase in community similarity (defined by position in multivariate space) over time since removal between mangrove Removal Positions and Unvegetated positions for sandier sites; however, no clear trend with time was observed for muddier sites (Figure 4-20). Edge positions were consistently more similar to Unvegetated positions than Centre positions for sandier sites; this spatial pattern was not consistent for muddier sites, with two of seven sites having larger dissimilarities for Edge compared to Centre positions (Figure 4-20). Multiple regression analyses showed no significant drivers for macrofaunal communities for Edge-Unvegetated dissimilarity scores (results not shown).

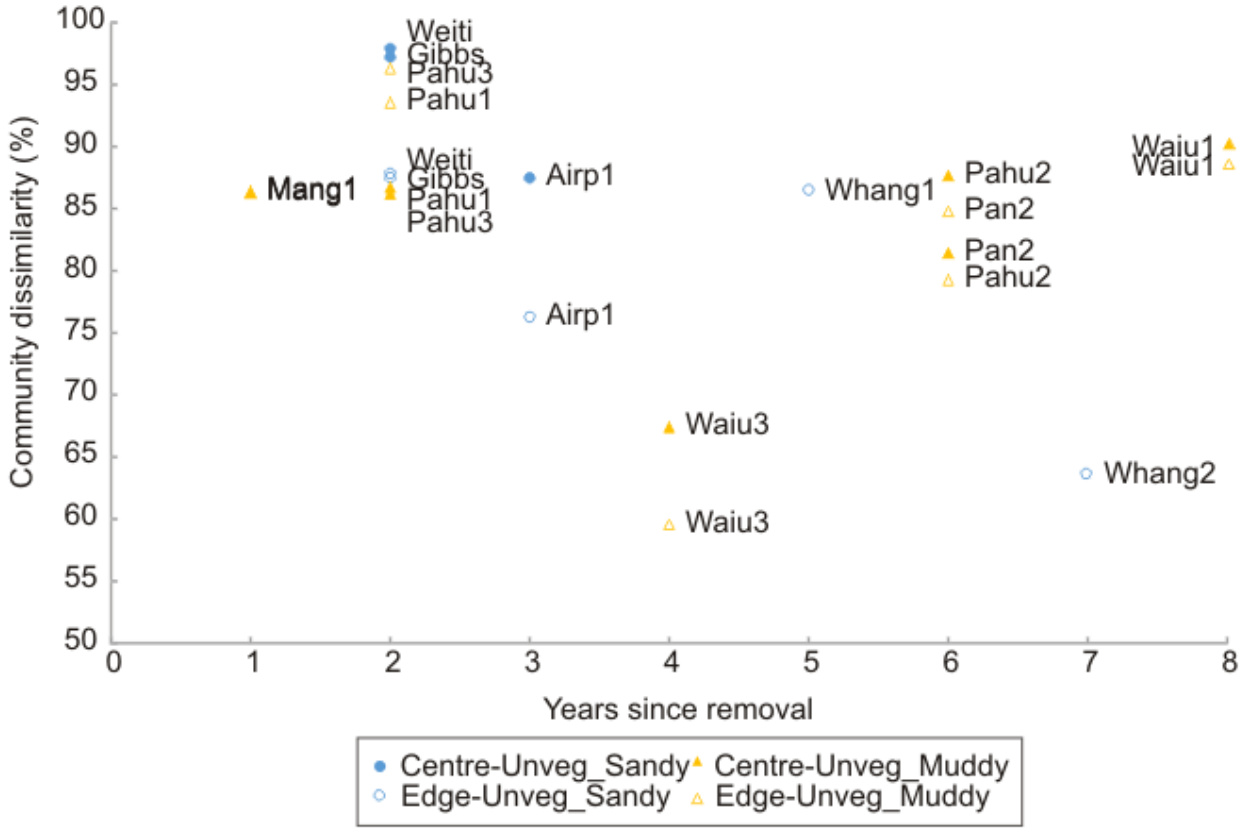

Figure 4-20 Community dissimilarity between Edge and Centre positions and neighbouring Unvegetated position versus time since removal.

4.5 Are mangrove removals rapidly recolonised by mangroves?

While large densities of seedlings were observed at some sites (e.g., Mangere 4), and have been observed anecdotally at a number of clearings, few seeds and seedlings were observed in quadrats at most sites at the time of sampling (November-December 2013 for most sites) (Table 4-6). The lack of colonisation at most sites is potentially due to a sampling occurring prior to seeds being released over summer (Gladstone-Gallagher et al. 2014); some sites have since been colonised by mangroves in dense numbers, e.g., Pahurehure Site 4 alongside the southern motorway, where large bands of seedlings were clearly visible in April 2014. The timing of sampling was specifically chosen to be prior to the main seedling recruitment event, so that recruitment incorporated seasonal seedling mortality; sampling during the seedling recruitment season would potentially be misleading as high mortality is common for mangrove seedlings (Morrisey et al. 2010). Recently, Swales estimated <1% survival over 120 days in the Firth of Thames (Andrew Swales, NIWA, unpublished data) at exposed sites, and Lundquist et al. estimated 40-60% survivorship at two sites in Mangere Inlet (Carolyn Lundquist, NIWA, unpublished data).

Mangrove recruitment is also dependent on the presence of a local source for seeds, such that sites without adjacent or nearby mangroves (e.g., Pahurehure Inlet Sites 2, 3 and 4; Mangere Sites 2 and 3) would be expected to have fewer seedlings (Table 4-6). Anoxic sediments are potentially associated with low survivorship of seedlings if colonisation does occur. As such, more recent clearings might be associated with higher seedling mortality rates than older clearings. Finally, many mangrove removal sites are subject to active seedling removal by community groups (usually included as part of consent applications), which likely confounds our estimates of seedling colonisation at most sites. At the 20 sites examined, the two sites with highest colonisation rates were Pahurehure 1 and Mangere 4; both were sheltered sites, and both were adjacent to or surrounded by large mangrove stands. The local community group at Mangere 4 confirmed that no seedling removal had taken place at this site since adult trees were removed due to it being a restricted access site (KiwiRail).

Table 4-6 Mean number (+ SE) of Seeds/Seedlings in a 0.25 m^2 quadrat at each position at site positions where mangrove seeds or seedlings were found

Site	Centre	Edge	Unvegetated
Auckland Airport 1			0.33 (0.33)
Auckland Airport 2	1.33 (1.33)		
Pahurehure 1	9.00 (1.00)	4.67 (2.67)	
Whangateau 1		0.33 (0.33)	
Panmure 2	2.67 (0.88)	1.00 (1.00)	
Mangere 4	31.67 (7.97)	46.33 (6.67)	

5.0 Discussion

The objective of this survey was to determine the current status of mangrove removal areas in the Auckland region. Comparing community and sediment characteristics at sites to identify site characteristics and methodologies for mangrove removal that were associated with more rapid change to the desired state. As was apparent upon visual inspection of all sites (Appendix), none of the sites have fully recovered to the desired sandier state. Thus, we examined changes in sediment mud content, vegetative biomass, and benthic community composition as indicators of whether or not trends toward sandier substrates and associated communities were occurring, and if these trends could be associated with site characteristics or removal method.

At the sites examined, from clearings ranging in year from 2006 to 2013, there were general consistencies across all sites, including:

- Lack of erosion of muddier sediments at muddy sites, whereas more exposed, sandier sites were more likely to show decreasing mud content.
- Lack of dispersal or decomposition of both above and below ground biomass.
- Slow trends in community change, with slightly higher rates of change for sandier communities than of muddier communities over time.

The lack of erosion of sediments is consistent with most prior surveys of mangrove removals, which showed very slow erosion of sediments and change from muddier to sandier sediments (e.g., Lundquist et al. 2012, Stokes 2009).

The high densities of remaining biomass, both above and below ground, were also consistent with studies of mangrove removals in other regions. Perimeters of mangrove removal zones where mulching occurred are clearly evident at numerous sites in Tauranga Harbour where removal occurred in 2010 and 2011, with some erosion evident on the edge of removal zones, but rarely penetrating further than 10m into a removal area (Lundquist et al. 2012; Lundquist, unpublished data). Decomposition rates have been estimated at different latitudes in New Zealand (Whangarei Harbour, Pahurehure Inlet, Whangamata Harbour), suggesting that wood and root material will take as long as decades to break down (Gladstone-Gallagher et al. 2014; Lundquist et al. 2014; Gladstone-Gallagher et al. unpublished data).

Changes in benthic community were also slow, with trends suggesting slightly faster changes in sediment characteristics and macrofaunal community toward sandier substrates for sandier exposed sites than for muddier sites. Initial differences between mangrove removal sites and their neighbouring unvegetated habitats in muddy systems are often far less than differences observed at sandier, exposed sites. While univariate metrics such as species richness and total number of individuals did show similarities between removal and Unvegetated positions at most sites, examination of species

abundances and multivariate comparisons of benthic community composition suggest that colonising species are primarily disturbance-tolerant species, and that the mangrove removal zones are not trending toward unvegetated community composition at most sites. While some colonisation is occurring, the resulting community at most removal sites (both Edge and Centre removal positions) is formed of opportunistic species such as oligochaetes and *Capitella* sp.

Slow rates of recovery of similar parameters have been observed with many methods of mangrove removal, with the slowest rates of recovery associated with mechanical mulching (e.g., Lundquist, et al. 2012, Park 2012). However, slow rates (>5 years) are also associated with other removal methods, including low impact manual removals (e.g., Stokes 2009, Felsing 2006). Sites with faster rates of recovery generally have sandier sediments, and have had small clearings by non-mechanical methods (e.g., manual clearings in Matua, Waikareao, and Waikaraka estuaries in Tauranga Harbour; Patiki Bay, Whangamata; and Mangawhai Estuary in Northland (Lundquist et al. 2012, Alfaro 2010, Coffey 2002). Of note, the Mangawhai site has since been fully colonised by juvenile mangroves (Ricky Eyre, Northland Regional Council, personal communication). Novel mangrove mechanical removal methods (mechanical tracking in <20% of the total area, and vegetative biomass removed from the site at most locations) have been trialled in Whangamata Harbour at both sheltered and exposed locations. Thus far, these trials have shown only minor adverse impacts, restricted to vehicle tracking disturbance and burn piles remaining in situ (Bulmer and Lundquist 2013). However, it has only been approximately 12 months since these removals, thus no long-term conclusions can yet be drawn from the trials about recovery toward sandier substrates.

We observed few impacts of mangrove removals outside the area of removal across the 20 sites studied in Auckland. No obvious impacts were apparent from mangrove removals in neighbouring unvegetated or seagrass habitats, with changes in community structure from disturbed removal area to unvegetated occurring abruptly within a few metres of the edge of a clearing area. However, at one location (Auckland Airport), significant negative impacts inshore of the site were apparent, where large amounts of mulch biomass had been transported, covering what was likely adjacent salt marsh habitats with depths of 30-40cm of mulch material.

In summary, our quantitative surveys revealed few sites with recovery towards a typical sandflat after mangrove removals (in terms of sediment characteristics or benthic community composition) over times of removal ranging from three months to seven years in the Auckland region. To evaluate the likelihood of success of returning mangrove forest to sandier substrates for future mangrove removal consents, each removal site should be assessed on exposure and sediment characteristics, as these physical aspects were correlated with recovery to a desired state. Minimising disturbance by the removal method and off site deposition of vegetation was also correlated with recovery to a desired state in

this study. We recommend continued monitoring of unrecovered sites until sites return to a desired sate, or it becomes clear this will not occur within a reasonable time frame.

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7.0 References

Alfaro, A. C. 2010. Effects of mangrove removal on benthic communities and sediment characteristics at Mangawhai Harbour, Northern New Zealand. *Journal of Marine Science* 67: 1087-1104.

Auckland Council 2013. *Proposed Auckland Unitary Plan* (notified 30th September 2013) [Online]. Available: http://unitaryplan.aucklandcouncil.govt.nz/. [19 September 2014].

Bulmer, R., Lundquist, C. 2013. Whangamata mangrove removal monitoring: Summary of baseline and 3 month post-removal sampling. *Client report* #HAM2013-114, prepared for Waikato Regional Council project #EVW13215.

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology,* 18: 117-143.

Coffey. B. 2002. Trial clearance of mangroves, Patiki Place Reserve, Whangamata Harbour. *Extended monitoring report.* Report prepared by Brian T. Coffey and Associates Limited for Environment Waikato.

Felsing, M. 2006. Benthic impacts of mangrove removal Whangamata Harbour – analysis of Nov 05 samples. *Environment Waikato Internal Memorandum* #1050229.

Gladstone-Gallagher, R. V., Lundquist, C. J., Pilditch, C. A. 2014. Mangrove (*Avicennia marina* subsp. *australasica*) litter production and decomposition in a temperate estuary. *New Zealand Journal of Marine and Freshwater Research,* 48: 10-27.

Gladstone-Gallagher, R. V., Lundquist, C. J. and Carter, K. R. *Unpublished manuscript*. Latitudinal comparisons of mangrove (*Avicennia marina* subsp. *australasica*) productivity and decomposition in New Zealand estuaries.

Hume, T. M., Snelder, T., Weatherhead, M. and Liefting, R. 2007. A controlling factor approach to estuary classification. *Ocean & Coastal Management,* 50: 905-929.

Lundquist, C. J., Morrisey, D. J. Gladstone-Gallagher, R. V. and Swales, A. 2014. Managing mangrove habitat expansion in New Zealand, in Hakeen K (ed). *Mangrove Ecosystems in Asia: Current Status, Challenges and Management Strategies.* Springer-Verlag: 416-438.

Lundquist, C., Hailes, S., Cartner, K., Carter, K. and Gibbs, M. 2012. Physical and ecological impacts associated with mangrove removals using in situ mechanical mulching in Tauranga Harbour. *NIWA Technical Report* No. 137: 106.

Mook, D. H., Hoskin, C. M. 1982. Organic determination by ignition: caution advised. *Estuarine Coastal and Shelf Science,* 15: 697-699.

Morrisey, D. J., Swales, A., Dittmann, S., Morrison, M., Lovelock, C. E. and Beard, C. 2010. The ecology and management of temperate mangroves. *Oceanography and Marine Biology: An Annual Review*, 48: 43-160.

Park, S. 2012. Benthic macrofauna habitat and diversity associated with mangrove removal sites in Tauranga Harbour – year 2 of monitoring. *Bay of Plenty Regional Council internal memorandum,* File Ref: 4.00198, dated 9 March 2012.

Pratt, S. J., Lundquist, C. J., Nelson, W. and Gemmill, C.E.C. 2013. A new record of *Percursaria percursa* (Ulvaceae, Ulvales) on the North Island, New Zealand. *New Zealand Journal of Botany*, 51:1:71-74.

Stokes, D. 2009. Assessment of physical changes after mangrove removal: Whangamata Harbour 2008. *Environment Waikato Technical Report,* 2009/13.

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8.0 Appendix: Site photographs (separate volume)

Photos were taken of general site characteristics, and of individual quadrats at each mangrove removal station (Edge, Centre, Unvegetated). A site photo and representative quadrat photo from Edge and Centre locations are presented to allow visualisation of the mangrove removal area at each site.

Photos appear in a separate published volume.