Makara Estuary Monitoring: Effects-based monitoring within a degraded, yet dynamic, coastal environment.

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Abstract

Makara Estuary is the southernmost estuary on the north-western coast of Wellington, New Zealand. The steep catchment surrounding Makara Estuary is predominantly utilised for farming and forestry. Monitoring of the benthic ecology, sedimentation rates and identifying regions of erosion within the Makara Estuary has been undertaken over the last 3 years, as part of resource consent condition monitoring for Meridian Energy's Mill Creek wind farm development.

Baseline pre-construction surveys at 3 sampling locations within the estuary revealed a degraded estuary characterised by anoxic surficial sediments, together with low diversity and abundance of infanual and epifaunal organisms. Various sites of active erosion both within and upstream of the estuary proper were also apparent, making effects-based assessments difficult. Subsequent monitoring of the estuary has revealed a suite of stressors that are negatively impacting the ecological integrity and functioning of the estuary. Many of these are associated with poor land-use practices; although, natural disturbance events associated with large-scale macroalgal deposition also impacts the estuary. The rate of sedimentation has been estimated to be around 14 mm/yr, which while relatively high, is in line with estuaries that have forestry production in their catchment. While infaunal community composition and the abundance of several polychaete species changed (increased and decreased) over the course of monitoring and differences between pre-construction and construction-phase surveys were apparent, there was no completing evidence that wind turbine construction has significantly altered benthic community composition or accelerated rates of sedimentation within the estuary.

In this paper we present results from biological and physical monitoring, discuss the difficulties of undertaking effects-based monitoring in a degraded, yet dynamic, estuarine environment and outline ways in which the impacts to the estuary could be reduced with focused initiatives. Outside of the context of resource consent monitoring, it is anticipated that results of benthic and physical sampling will provide important information on the on-going state of the Makara Estuary to regulatory authorities and the wider Makara community.

Keywords: Monitoring, wind farm construction, benthic ecology, sedimentation

1. Introduction

Meridian Energy Ltd (MEL) was granted resource consent in 2011 to construct a total of 26 wind turbines within the Ohariu Valley – known as the Mill Creek wind farm. As part of resource consent conditions imposed by the Greater Wellington Regional Council, MEL was required to undertake environmental monitoring of the Makara Estuary located adjacent to the proposed works area (41°13'11.95"S: 174°42' 55.69"E). Monitoring was necessary in order to detect and evaluate any environmental impacts, primarily relating to sedimentation. Sedimentation was anticipated as being of potential concern given the proximity of the works to the estuary and steep hilly nature of the catchment. Monitoring was to be undertaken prior to (baseline data collection), during, and following the construction of the wind turbines. This paper presents the main findings of the monitoring to date, which encompasses 2 pre-construction and 4 construction-phase surveys.

1.1 Makara Estuary

The Makara Estuary is a lagoon-type estuary [5] and encompasses approximately 15 ha in area from the base of the Makara River to Ohariu Bay (Tasman Sea). The Makara River connects to the Ohariu River further upstream and both rivers flow through a combination of high and low producing pasture and forestry. The estuary proper is surrounded by farmland, patchy scrub-land and low-density housing. The wider Ohariu catchment is hilly with the catchment geology comprised of greywacke, alluvium, peat and sand [8;9]. The Makara Estuary is an intrinsic part of Wellington's natural heritage and the estuary and surrounds are listed as a conservation site in Wellington's District Plan.

1.2 Sampling locations

For the initial pre-construction survey a total of 3 locations within the Makara Estuary were sampled (Figure 1). These same locations were re-sampled for all subsequent construction-phase surveys. The 3 locations were:

1. the inner entrance and lagoon;
2. 400 m upstream of the entrance; and,
3. 800 m upstream of the entrance.

Figure 1. Biological and physical monitoring locations within the Makara Estuary. L1 – entrance (41° 13' 12.94" S; 174° 42' 56.51" E); L2 – 400m upstream from entrance (41° 13' 22.19" S; 174° 42' 50.07" E); and L3 – 800m from entrance (41° 13' 30.59" S; 174° 42' 57.70" E).

2. Methods and materials

2.1 Biological sampling

At each location biological and physical sampling was undertaken. To obtain data on epifaunal and infaunal abundance, community composition, and overall species diversity (taxa richness) at each of the three locations, a total of 12 haphazardly placed 0.25 m^2 quadrats and 12 infaunal cores (130 mm diameter 150 mm deep) were sampled from predetermined sampling points. Such an approach was necessary to: 1) achieve adequate dispersion across each sampling location; 2) reduce the possible influence of previous sampling events; 3) reduce biases associated with spatial autocorrelation. Resultantly, individual quadrats and cores were not positioned within a 4 m radius from one another during a specific sampling event, or from any samples collected over the previous 12 months.

Epifaunal species occurring in quadrats were generally identified in the field with data recorded onto paper forms. For infanual cores, all sediment was rinsed through a 0.5 mm sieve with seawater, with material retained on the sieve placed in individually labelled containers with residues stained in Rose Bengal and preserved in 70% isopropyl alcohol in seawater. Samples were then identified to the lowest possible taxonomic level and enumerated. Observations of the sediment surface and sediment characteristics at each location were also made.

2.1.1 Data analysis

Data presented in this paper includes taxa richness, community data and polychaete worm abundance. Data for taxa richness and dominant polychaetes are presented as mean values with associated measurements of variation around the sample mean e.g., standard deviation (SD) or standard error (SE), whereas soft-sediment community data are presented as a multivariate ordination.

To visualise any changes in community assemblages in multivariate space (epifaunal and infaunal counts combined), Principal coordinates analysis (metric MDS) using PRIMER-6 & PERMANOVA+ statistical software [1;3] was run on log(x+1) transformed abundance data) using a Bray-Curtis similarity measure [2].

To test for any differences in community composition among locations and across surveys, two-factor PERMANOVA analysis within the PRIMER-E routine [1] was undertaken. The multivariate null-hypothesis (*Ho*) tested was for no statistically significant differences in infaunal assemblages among sample locations and across surveys. Both factors were treated as 'fixed' within the model, which was based on 4999 permutations (α=0.05) of log(x+1) transformed data. Where statistically significant differences for the main factors (Location and Survey) were apparent in the main model, *a posterori* pair-wise analysis was undertaken, again using PERMANOVA and based on 4999 permutations. Tests of this nature enabled comparisons of pre-construction and construction-phase surveys.

Additional univariate tests were run on polychaete count data. Again two-factor PERMANOVA analysis within the PRIMER-E routine was employed (as above). The univariate null-hypothesis (*Ho*) tested was for no statistically significant difference in the abundance of individual polychaete species (e.g., *Capitella capitata*) among locations or across surveys. Individual analyses were run on Log(x+1) abundance data using a Euclidean resemblance (distance) measure.

2.2 Physical sampling

In order to evaluate sedimentation rates within the estuary over the course of monitoring, two 40 cm x 40 cm stainless steel plates were deployed at each of the three monitoring locations. Along with GPS positions, a set of measurements from prominent local features were photographed and the depth relative to stable bench marks were recorded with a dumpy level. Once positioned, disturbed sediment was put back into place over each plate to as near as possible to the original level with the average depth of sediment measured. In order to remove biases due to sediment and sediment plate settlement/stabilisation, measurements made 6 month later (spring 2012) were used as the pre-construction baseline. At each sampling period thereafter, the depth of sediment above each plate was measured. Sediment depths were then collated (*n*=6 per plate), averaged and graphically presented for each location.

To document erosion within the estuary over the course of the monitoring programme, the estuary/river banks were video surveyed along its 1.5 km length. Any areas of active erosion were measured (± 10cm), mapped using GPS and photographed using easily identified benchmarks for reference purposes, thus providing additional information of sources of sediment input into the estuary.

3. Results

Biological and physical monitoring results for key components are presented across the 3 locations for the 2 baseline (pre-construction) surveys undertaken in autumn (March) and spring (September) 2012 and the 4 construction-phase surveys (March 2013 – September 2014).

3.1 Pre-construction phase surveys

The first two pre-construction phase surveys revealed an extremely degraded estuary. This was evident at all 3 locations, which were characterised by homogeneous, fine, anoxic, silty mud; patches of decaying macroalgae (Location 1); various states of bank erosion (active, slow and historic) throughout the estuary; and, *ad hoc* reclamation (Location 3). Average taxa richness (epifauna and infauna combined) was uniformly low at all locations being < 3 species.core^{-1} for both surveys (Figure 2). Polychaete fauna enumerated from infaunal cores were also synonymous of degraded environments (Figure 3). There was widespread deposition of fine sediment on intertidal cobble habitat and mudflats at Location 1 during the second pre-construction survey, suggesting that sedimentation was impacting the estuary prior to wind farm development (Figure 4).

3.2 Construction-phase surveys

All construction-phase surveys continued to support the notion of the Makara estuary being a degraded environment within faunal diversity benthic community composition and abundances of polychaetes remaining low and highly variable across locations and surveys (Figures 2, 3 and 5). The autumn 2014 construction-phase survey was particularly notable, as the entire intertidal and subtidal sample area at Location 1 was covered in an extremely dense cover of drift macroalgae (up to 0.5m in vertical height in places). The macroalgae (multiple species) had presumably been deposited into the estuary from the adjacent coastline during a recent storm event or tidal flood, with the algae in various stages of decay.

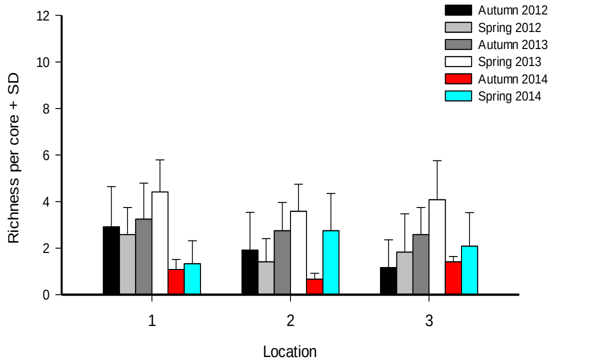

Figure 2. Biodiversity (epifauna and infauna combined) presented as mean taxa richness + SD at three locations within the Makara Estuary. Surveys undertaken in 2012 were pre-construction, whereas surveys undertaken between 2013 and 2014 were all construction-phase surveys.

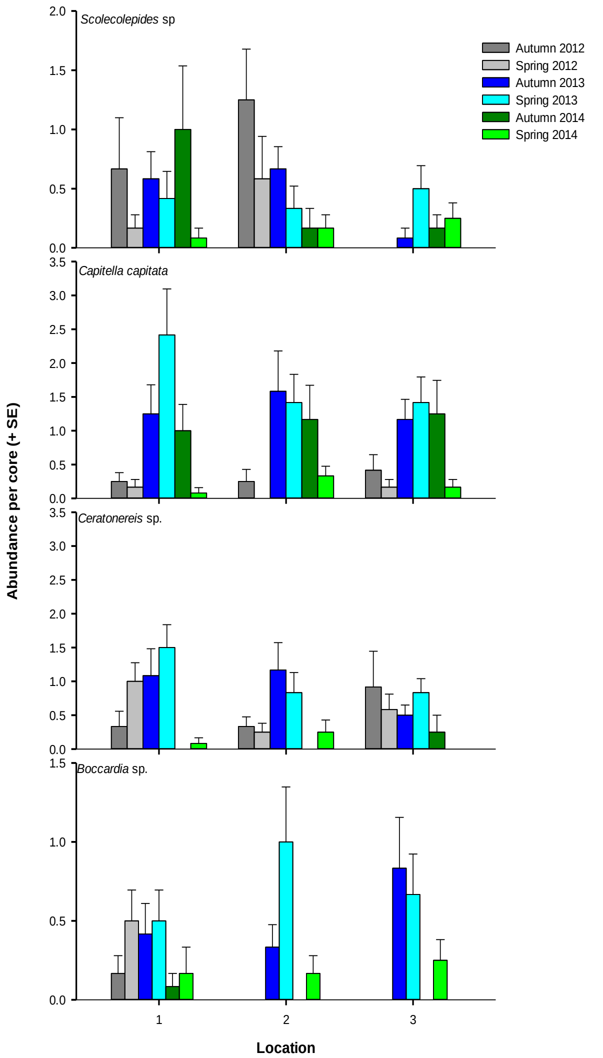

Figure 3. Mean abundance (+ SE) of polychaete species per core (*n*=12) for three survey locations within the Makara Estuary. *Note*: Y-axis scale differs among plots. Surveys undertaken in 2012 were pre-construction, whereas surveys undertaken between 2013 and 2014 were all construction-phase surveys.

Similar but reduced effects were also evident at Location 2 with deposition of drift macroalgae on intertidal mudflats. There was further evidence of very recent tidal emersion of the terrestrial vegetation lining the northern and southern banks coupled with small slips ~10m in length.

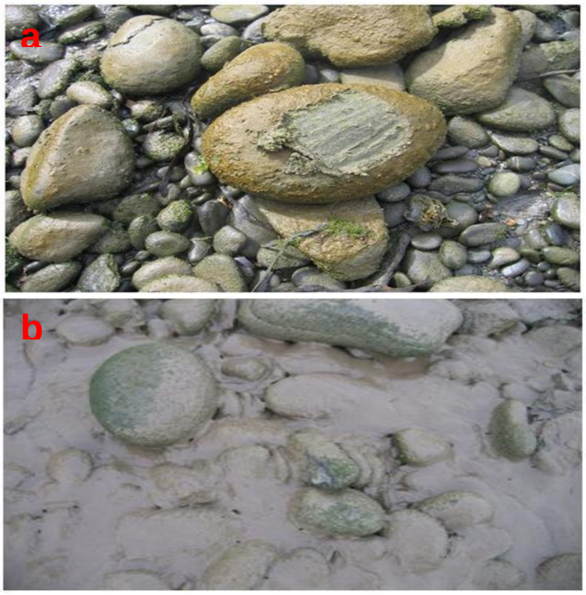

Figure 4. Intertidal cobble habitat at Location 1 illustrating nature of sedimentation between autumn 2012 (a) and spring 2012 (b) pre-construction phase surveys.

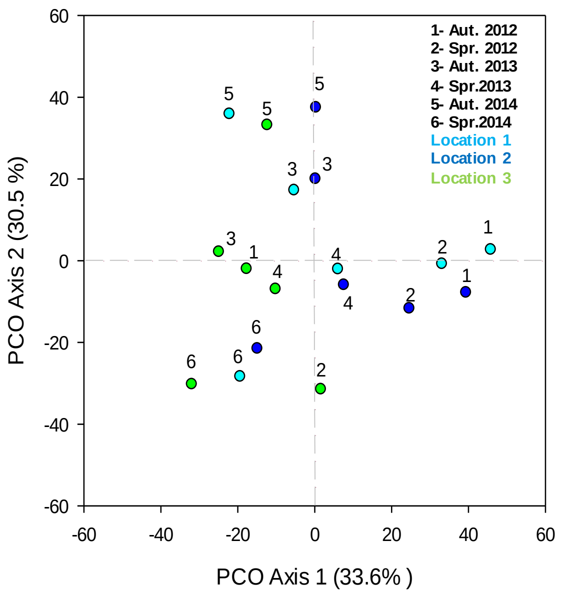

Figure 5. Principal Coordinates (PCO) analysis of epifaunal and infaunal species (16 taxa) across the three sampling locations (1,2,3) for autumn and spring surveys. Surveys undertaken in 2012 were pre-construction, whereas surveys undertaken between 2013 and 2014 were all construction-phase surveys.

3.3 Benthic community and species-specific variation

At a community level, PERMANOVA analysis of benthic data indicated a statistically significant difference for the factor Location and a statistically significant difference for the factor Survey (Table 1). There was also a statistically significant Location×Survey interaction implying that variation of benthic communities were not equivalent across locations and surveys. *A posterori* pairwise tests for main factors revealed that benthic communities at all locations (1, 2, and 3) were statistically different from one another. For the factor Survey, benthic communities representing the two pre-construction surveys were not statistically different from one another, whereas communities from post-construction surveys (3, 4, 5 and 6) were statistically different from one another and the two pre-construction surveys. Results of this nature infer a continuous change in community composition between pre-construction and construction-phase surveys.

Table 1. Results from PERMANOVA analysis to test for A: statistical differences in faunal communities (16 taxa) among sample locations (Lo) across Surveys (Su); and, B: *A posterori* pairwise tests for Location (1-3) and Survey(1-6). Statistically significant *P*-values at the 5% level are shown italicised and in bold.

A: PERMANOVA - multispecies

Source	df	SS	MS	Pseudo-*F*	P(perm)
Lo	2	24172	12086	4.6706	***0.0002***
Su	5	112910	22582	8.7266	***0.0002***
L x S	10	42380	4238	1.6377	***0.0024***
Res	198	512360	2587.7		
Total	215	691820			

B: PERMANOVA - *A posterori* pair-wise tests

Location	*t*	P(perm)
1, 2	1.5935	***0.0254***
1, 3	2.6065	***0.0002***
2, 3	1.8942	***0.0058***

Survey	*t*	P(perm)
1, 2	1.475	0.0712
1, 3	3.0548	***0.0002***
1, 4	3.2971	***0.0002***
1, 5	2.3941	***0.0008***
1, 6	2.7687	0.0694
2, 3	2.8033	***0.0002***
2, 4	2.7354	***0.0002***
2, 5	2.9894	***0.001***
2, 6	2.4514	***0.0002***
3, 4	2.2133	***0.0002***
3, 5	3.2035	***0.0002***
3, 6	3.3809	***0.0002***
4, 5	4.2506	***0.0004***
4, 6	3.705	***0.0004***
5, 6	3.2947	***0.0002***

PERMANOVA analysis is supported by a PCO ordination (*metric* MDS) (Figure 5), which illustrates a change in infaunal assemblages at Locations 1 and 2 accross all surveys depicted by the movement of points from right to left across the ordination through time. This was less obvious for Location 3 which has remained to the left of the ordination and in most cases negatively asscoiated with PCO Axis 2. While variation of this nature helps explain the statisticaly significant

Location×Survey interaction it also suggest that infaunal communities are continually changing throughout the estuary rather than changes being principally location-specific.

For the polychaetes *Scolecolepides sp, Capitella capitata, Ceratonereis sp* and *Boccardia sp* there was a general pattern of either increased or reasonably stable abundances across locations between the two pre-construction phase and the first two construction-phase surveys (Figure 3). This was followed by a decline in many of the polychaete species in 2014. It is worth noting that rainfall recorded for the catchment in 2013 was lower than average (data not presented), whereas autumn 2014 was characterised by the extreme storm event/tidal flood that deposited large amounts of macroalgae throughout the estuary and 2014 had higher rainfall than 2013. Both of these factors may account for the reduced abundances of many species.

PERMANOVA analysis of single-species abundance data (not presented) indicated a statistically significant difference for the factor Location for *Scolecolepides sp*; whereas *Scolecolepides sp, Capitella capitata, Ceratonereis sp,* and *Boccardia sp* abundances were statistically different across surveys. The lack of any Location × Survey interaction for all species suggests that directional changes (increases or decreases in abundance) for many species were equivalent across locations.

3.4 Sedimentation monitoring

Over the 30 month period of settlement plate deployment, i.e., from spring 2012 (excluding the 6 month period to settle and bed down) a total of 28 mm and 28.5 mm of sediment had accumulated over the plates for Locations 1 and 2 respectively. This equates to an annual sedimentation rate in the estuary since spring 2012 of ~14 mm/yr, which is relatively high; although, consistent with catchments in forestry production [6]. Moreover, while the monitoring has only been undertaken for 2.5 year there has been no obvious trend of accelerating sedimentation attributable to development of the Mill Creek wind farm within the adjacent Ohariu Valley. Figure 6 presents averaged plate depth at each location over the monitoring period. *Note:* the sediment plates at Location 3 were buried by *ad hoc* reclamation between autumn and spring 2013 survey and have been irrecoverable.

3.5 Erosion monitoring

Routine assessments made over the monitoring period identified a range of erosion types (historic, slow and active) throughout the Makara estuary and upper Makara River.

Initial pre-construction phase surveys documented evidence of historical erosion, which was mostly observed in the lower estuary between Locations 1 and 2. Slow erosion was restricted to low-lying mud islands capped with glasswort, in the lower estuary towards the entrance and three areas of active erosion (15-20 m long) were observed in the upper area of the estuary upstream from Location 3. The only change recorded between the two 2012 pre-construction surveys was an additional area of active erosion observed on the northern bank at Location 3. This area was measured to encompass an area 5 m long, 0.5 m high and ~0.5 m wide and was estimated to have provided an additional 1.25-2.0 m^3 of sediment to the lower estuary. The three areas of active erosion observed upstream of Location 3 in autumn 2012 had all stabilised by spring 2012 and have been not observed to be actively eroding in subsequent surveys.

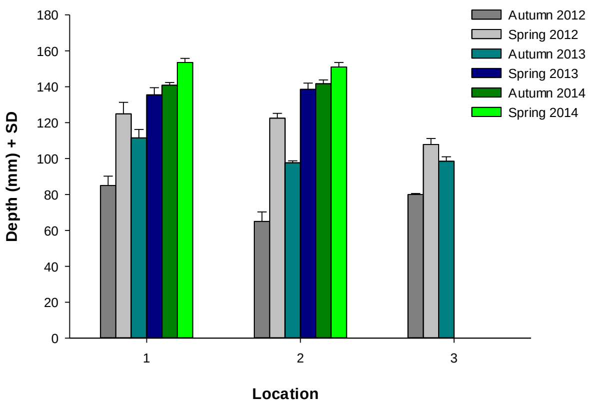

Figure 6. Average plate depth at each location over the 6 surveys, i.e. cumulative deposition. The difference between autumn and spring 2012 pre-construction surveys equates to initial plate settlement.

Several small areas of new erosion were been observed on the northern and southern banks adjacent Location 2 in 2014, although all have been less than 10 m in length. These features are best described as small slips rather than actively eroding estuary margins and in total these areas represent relatively small sediment inputs into the estuary. Causes of the slips are hypothesised to be related to the storm or tidal inundation that preceded the autumn 2014 survey.

4. Discussion

Biological and physical surveys of the Makara Estuary as part of resource consent monitoring have indicated that much of the estuary is degraded, with impacts consistent with long-term (decadal), and persistent sedimentation. There is also evidence that dynamic, yet intermittent, natural events (e.g., storms/tidal inundation *etc*) that push large volumes of macroalgae into the estuary where it subsequently gets trapped and decays, negatively impact the lagoon-region (entrance) of Makara Estuary. While sediment deposition continues to occur throughout the estuary there is no conclusive evidence that the low biological diversity, and measured rates of sedimentation are due to the Mill Creek wind farm construction. Rather the dilapidated state appears to be symptomatic of the poor land-use practices contained within the wider Makara Estuary catchment.

Over the course of sampling the extent of degradation continues to be apparent in both biotic and abiotic measures, for example: 1) uniformly low biodiversity across sampling locations over consecutive sampling periods; 2) the nature of species and community composition encountered during sampling; 3) the persistent and thin cover of fine silty mobile sediment on intertidal mudflat coupled with extremely anoxic sediments for all locations and surveys; 4) pockets of active erosion and small slips along estuary margins; and, 5) historical data documenting poor water quality associated with both the Makara and Ohariu streams that feed directly into the estuary [9].

Any changes to infaunal communities that we have documented have been greatest and reasonably synchronous at Locations 1 and 2 and to a lesser degree at Location 3. However, available evidence suggests that factors influencing infaunal community structure (sedimentation *etc*) are predominatly estuary-wide rather than location-specific.

The four main polychaete species identified in this study – *Scolecolepides* sp, *Ceratonereis sp, Boccardia* sp and *Capitella capitata* are all common to estuaries and harbours throughout New Zealand. Of these, *Scolecolepides* sp, *Capitella capitata* and *Boccardia* sp are synonymous with impacted sites characterised by anoxic sediments and organic enrichment [4]. Furthermore, the uniformly low faunal diversity detected in this study parallels similar studies from other sediment-impacted estuaries with relatively high anoxic levels [7;8]. Unfortunately due to a lack of long-term monitoring within this estuary, the full extent of habitat degradation or possible change in species diversity and abundance that may have occurred over the last 25+ years remains unknown.

Given the degraded nature of the estuary prior to undertaken monitoring, detecting effects associated with wind farm construction against the background of historic and present-day erosion was always going to be challenging. However, what the monitoring programme has generated is contemporary data on the state of the estuary. This can be used as a baseline for both regulatory authorities and local community conservation groups (Makaracarpas) to target the most vulnerable areas impacting the estuary and to gauge the effectiveness of any restoration efforts, particularly riparian planting.

Erosion has previously been highlighted as being problematic to the estuary (Makaracarpa's Restoration Plan 2007) and since the initiation of the current monitoring programme erosion mediation in the form of riparian planting along parts of the southern shore has been a directive of the Makara community and MEL. While such initiatives are worthwhile they will possibly have limited effect until the most-problematic areas particularly areas of the northern bank are given attention. This will require a mix of fencing to keep stock away from the edges of the waterway, planting of species to reduce surface flow during extreme rain events (e.g., flaxes and sedges) and planting of lowland shrubs and trees with significant root systems tolerant of inundation (likely both native and exotic).

At the time of writing encouragingly there has been additional riparian planting within many of the problematic areas above Location 3 since the spring 2014 survey. Continued riparian planting throughout the whole catchment would, in our view, lead to the improved health and ecological integrity/functioning of the estuary through time.

5. References

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