Environment Waikato Technical Report 2007/05

The Potential Effect of Sea Level Rise on Estuarine Vegetation

Pilot Study – Coromandel Harbour

www.ew.govt.nz
ISSN 1172-4005

Prepared by:
Meg Graeme (Natural Solutions) and
Jim Dahm (Eco Nomos Ltd)

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

June 2006

ISSN: 1172-4005

Document #: 1151767

Peer reviewed by:
Malene Felsing Date Feb 2007

Approved for release by:
Peter Singleton Date Feb 2007

Disclaimer

Table of Contents

List of Figures

1 Introduction

This pilot study aims to help Environment Waikato identify the potential impact of projected sea level rise on the extent and distribution of estuarine vegetation within Waikato estuaries. In particular, the report examines the potential influence of surrounding land uses on the response of estuarine vegetation to sea level rise.

Coromandel Harbour (Figure 1) was chosen as the pilot study site as it has a range of different land uses around the harbour margin typical of the increasing human pressure on Waikato estuaries – including agricultural and urban land uses. The study investigated the influence of sea level rise and surrounding land use on estuarine vegetation in sites with different wave exposure and an area where estuarine wetland has already been significantly modified by human activities (Figure 1).

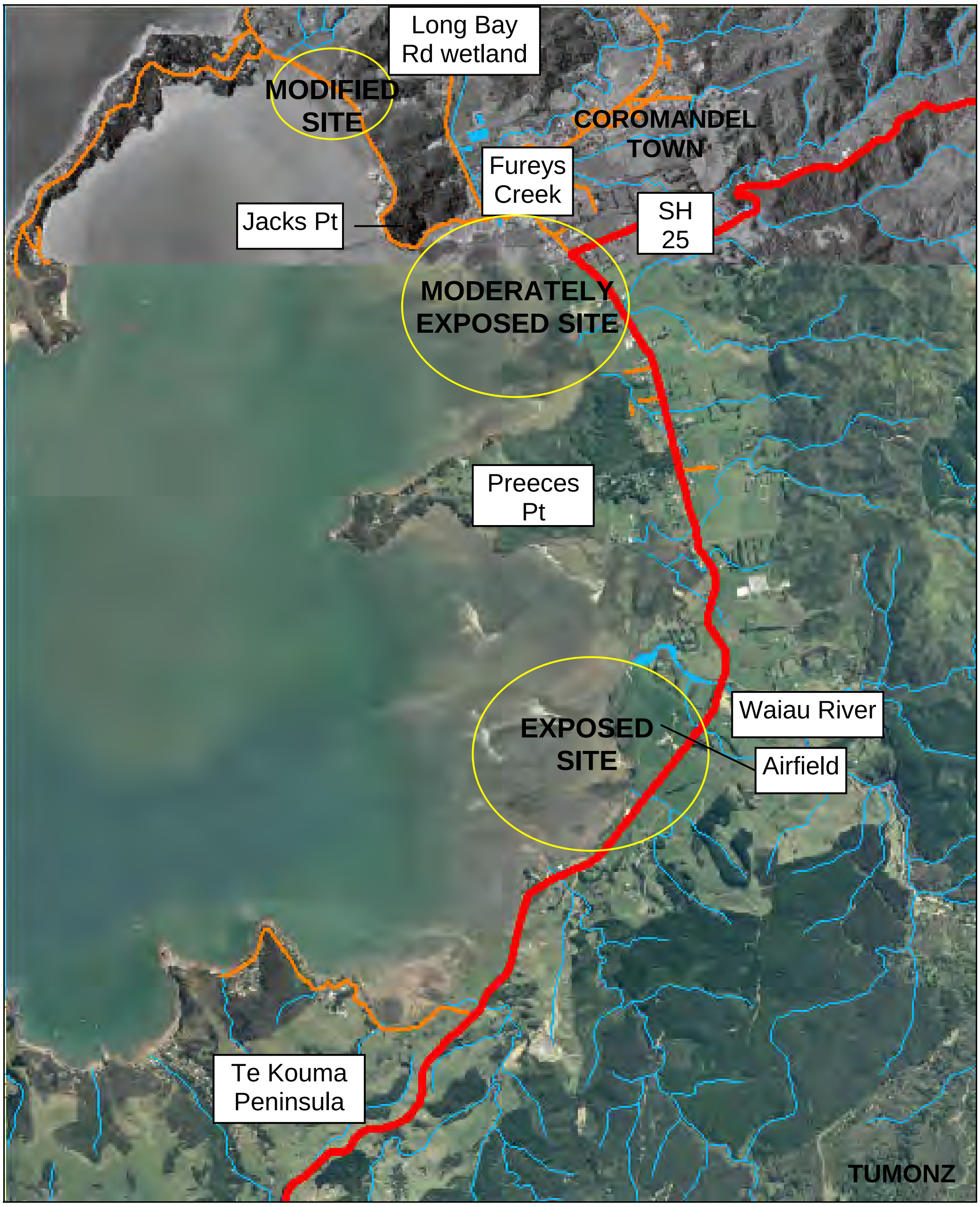


Figure 1: Survey locations within Coromandel Harbour on the Coromandel Peninsula

2 Objectives

The objectives of the pilot study are to:

(a) Identify the factors influencing the boundaries of vegetation communities with existing sea level, particularly bed level and the effect of different wave exposure.

(b) Survey the harbour and low-lying harbour edge to identify areas where wetland vegetation might expand to with predicted sea level rise.

(c) Examine implications of various sea level rise scenarios for wetland loss/expansion.

(d) Identify any relevant recommendations for the management of harbour margin land uses to ensure the protection of estuarine wetland vegetation in the event of projected sea level rise

3 Methods

3.1 Estuarine Vegetation Communities

For the purpose of this investigation, estuarine plant species are split into six groups: seagrass, mangrove, rush and sedgeland, sea meadow, saltmarsh ribbonwood, and riparian shrub communities (see Appendix 1).

Seagrass *(Zostera* sp.) – this is usually a monospecific community.

Mangrove *(Avicennia marina* var. *resinifera)* – this is usually a monospecific community in Coromandel Harbour although seagrass, spartina, saltwater paspalum and sea meadow species can sometimes be found below mature mangrove stands. Mixed mangrove and Juncus communities also occur near the boundaries of these two communities.

Rush and sedgeland – this is composed of sea rush (*Juncus maritimus* var. *australiensis*) and oioi *(Apodasmia similis,* grading landward into more brackish species where there is a greater freshwater influence. The common brackish species are marsh clubrush *(Bolboschenus fluviatilis), Baumea juncea* and tall fescue (*Schedonorus phoenix*).

Sea meadow - the salt meadow community commonly includes sea primrose (*Samolus repens*), remuremu (*Selliera radicans*), glasswort (*Sarcocornia quinqueflora*), and in more brackish areas bachelor's button (*Cotula coronopifolia*), slender clubrush *(Isolepis cernua)*, and arrow grass (*Triglochin striata*). This community is devoid of tall plants such as rushes and saltmarsh ribbonwood, with the exception of silver tussock grass (*Austrostipa stipoides*). However, sea meadow patches are usually quite small in area and mixed within rushland areas.

Saltmarsh ribbonwood (SMR) - this community is identified by the presence of (*Plagianthus divaricatus*), often interspersed with rushes. Small areas of sea primrose, remuremu, the silver tussock grass, and glasswort can also be present.

Riparian shrubs – around Coromandel harbour this community commonly includes the coastal shrub daisy (*Olearia solandri*), mingimingi (*Coprosma propinqua*), manuka (*Leptospermum scoparium*), red matipo (*Myrsine australis*), cabbage tree (*Cordyline australis*) and flax (*Phormium tenax*). Riparian vegetation of this nature provides a very important wildlife habitat and buffer around estuarine wetland areas.

3.2 Surveying and Study Sites

The survey work involved:

- Setting up and checking benchmarks in each of the study areas (Figure 2). Benchmarks were levelled to mean level of sea (MLOS) using high tide levels predicted by the NIWA tide forecaster. At least two different predicted high tides were used to establish the elevation of each datum, with a third predicted tide surveyed if there was a significant difference between the first two measurements. Each datum was established with an accuracy of $\pm$0.01 m. The various benchmarks established are discussed in Section 4.1 and shown in Appendix 2.

- Levelling of spot elevations using a laser level with position fixed by GPS. Spot elevations were taken to define bed levels within and along the boundaries of different vegetation communities and to establish the elevation of low-lying land around the harbour margin (the latter measurements to examine the potential for landward expansion of wetland vegetation with sea level rise).

The study sites adopted included areas of high and moderate wave exposure and an area where the estuarine wetland had been significantly modified by human activities (see Figure 1).

The high exposure area, located in the southern part of the harbour, has a maximum fetch to the west and west-southwest of 27-28 km resulting in significant wave energy (e.g. heights of 0.8-1.2 m, subject to depth limitations, and periods of 4-5 seconds) during periods of sustained strong winds from these directions (among the most common wind directions in this area) where a long south-westerly fetch means a high wave environment is often experienced.

The moderate exposure area, located between Preeces Point and Fureys Creek, has a more restricted fetch typical of the inner harbour. Maximum fetches are generally limited to 3-4 km, with a narrow window exposed to a 6-7 km fetch from the southwest. The lesser fetch results in significantly lower wave energy than the southern part of the harbour. Even during periods of sustained strong winds, maximum wave heights will generally be less than 0.5-0.8 m with wave periods typically only 2-3 seconds.

In both exposure areas, extensive intertidal flats shelter the majority of the vegetation communities from waves at lower stages of the tide.

In addition, the large estuarine wetland on the landward side of the Long Bay Road was also investigated, being an area significantly modified by various human activities – including bunds, a flap-gated culvert, grazing and drainage.

3.3 Analysis

The surveyed bed level data for each of the different vegetation communities was graphed to identify community boundaries and to examine the effect of exposure and, for the Long Bay area, human alteration.

Bed levels were also mapped and a typical cross-section chosen for each of the three surveyed areas. These cross-sections and the established vegetation community boundaries were used to predict the likely wetland vegetation change for different sea level rise scenarios.

The most recent Intergovernmental Panel on Climate Change (IPCC) assessment projects a sea level rise of 0.09 to 0.88 m for 1990 to 2100, with a central value of 0.48 m to 2100 and 0.2 m to 2050 (IPCC, 1991). Therefore, for this study, sea level rise scenarios of 0.2 and 0.5 metres were used, these being the best present estimates of projected sea level rise over the next 50 and 100 years respectively. In addition, the consequences of the worst case (0.88 m) sea level rise projection for the next 100 years was assessed.

On the basis of the above analysis, recommendations were developed to minimise the loss of wetland vegetation in the future.

4 Results

4.1 Survey Benchmarks and Tidal Parameters

Five benchmarks were established around the harbour to provide reference levels for the spot surveys. Details of the benchmarks are provided in Appendix 2. The benchmarks were levelled relative to mean level of sea (MLOS) using predicted high tide elevations from the NIWA tide forecaster – with repeat readings at most sites, apart from Benchmark D which was used for only limited surveying. Details of the readings and the final elevation adopted for each benchmark are summarised in Table 1.

Table 1: Benchmarks used for survey work and elevation relative to mean level of sea (MLOS).

Benchmark	Area	Reading 1	Reading 2	Reading 3	Elevation adopted
A	Long Bay	3.11	3.125	3.115	3.18
D	Mod Exposed	2.59	-	-	2.59
E	Mod Exposed	1.944	1.997	-	1.971
F	Exposed	3.333	3.337	-	3.333
G	Exposed	1.82	1.825	-	1.82

At those sites where repeat readings were conducted, the separate readings are within +0.025 m and generally within + 0.01 m of the elevation adopted for the benchmark (Table 1). Therefore, the benchmarks provide a reasonably accurate datum for the spot surveys.

The predictions used from the NIWA tidal forecaster are predictions for the open coast outside the harbour entrance as the forecaster does not have the bathymetric resolution required for accurate predictions of tidal amplification within estuaries. In other words, the MLOS datum used in this study is MLOS at or near the harbour entrance.

Tidal parameters for Coromandel Harbour relative to mean sea level (msl) were estimated using the tide tables provided by LINZ and are shown in Table 2.

Table 2: Tidal parameters for Coromandel Harbour relative to mean sea level. The estimate of highest astronomical tide (HAT) is approximate only

MHWS=Mean high water spring; MHWN=mean high water neap; MLWN=mean low water neap; MLWS=mean low water spring.

MHWS	MHWN	MLWN	MLWS	Spring Range	Neap Range	MSL	HAT
1.2	0.9	-0.8	-1.1	2.3	1.7	0	1.6-1.7

It is important to note that the MLOS datum used in this study is only an approximation of true mean sea level (MSL). Detailed and expensive surveying would be required to establish a precise mean sea level datum for Coromandel Harbour. Nonetheless, the tidal parameters in Table 2 provide an indicative estimate of these parameters relative to the MLOS datum used in this study (probably within $\pm$0.1 m).

It is also important to realise that waves and storm surge can give rise to extreme sea level elevations higher than those associated purely with astronomical tides.

As yet, a detailed assessment of extreme sea levels has not been conducted for Coromandel Harbour. Nor were we able to locate information on extreme sea levels during major storm events such as those of July 1995 and January 1997 (Cyclone Drena). Nonetheless, it is probable that extreme sea levels arising from the combination of astronomical tides and storm surge effects can reach elevations of RL 2-2.5 m above the MLOS datum used in this study. However, such events are probably relatively infrequent (i.e. have annual probabilities of 5-10% or less).

Wave action can result in low-lying shorelines being overtopped by wave run-up during periods of higher sea level, extending salt-water influences further landward than astronomical tides. Evidence of the influence of wave spray and wave overtopping were noted in several areas during this study – particularly along shorelines in the most exposed study area (e.g. Figure 14).

Figures 3-5 show the bed levels (relative to MLOS) surveyed during this investigation.

4.2 Species Occurrence

The reduced spot levels surveyed for each vegetation community were graphed for each of the three study areas to determine the bed level elevation range for the different estuarine vegetation communities. The results are shown in Figures 6-10.

The following is a brief summary of key findings for each vegetation community:

Seagrass (Figure 6)

i) Seagrass only occurred at the moderately and exposed sites.

ii) The landward edge of these communities consists of isolated patches of seagrass with these patches becoming more dense and continuous seaward. Patches are generally associated with troughs in low-lying sandy bedforms and hollows.

iii) The landward boundary is significantly affected by wave exposure – moving landward with increasing exposure:

iv) The landward edge of patches typically occurs at elevations of RL 0.4m in moderately exposed areas and just under RL 0.7 m in exposed areas.

v) The landward edge of dense seagrass beds typically occurs at about RL 0.1m in the moderately exposed area and RL 0.45 m in the exposed area.

vi) The seaward boundary is about low tide (estimated from aerials).

vii) No seagrass was found at the Long Bay road wetland site.

Mangroves (Figure 7)

i) The seaward boundary of mangroves also occurs at higher elevations with increased wave exposure. In the moderately sheltered area, the seaward boundary of dense mangroves is generally located near MLOS, but increases to about RL 0.4 m in the more exposed area.

ii) Some isolated mangroves were found further seaward in both areas.

iii) The landward boundary is approximately the same in both the exposed and moderately sheltered areas – at RL 1.2 m.

iv) In Fureys Creek the mangroves extend to much lower elevations than noted elsewhere due to the sheltered environment with steeply sloping stream channel margins. Mangroves also extend to higher elevations than normal in drain inverts.

v) The distribution of mangroves in the Long Bay Road wetland is affected by water level control; water levels upstream of the flap-gated culvert typically being about 0.2 m lower than those further seaward. Therefore, the mangroves in this area occur at lower bed levels than noted at the moderately and exposed sites. The data is not representative of natural conditions.

Rush and sedgeland (Figure 8)

i) In the moderate exposure area, rushland covers elevations from RL 0.78 to at least RL 1.82 m, with sea rush and oioi (i.e. salt tolerant species) dominating between RL 1-1.3 m and various mixed communities between 1.3-1.65 m. Above RL 1.65 m only brackish species were found. In very sheltered areas (e.g. behind wide dense mangals) sea rush was noted at elevations as low as RL 0.78 m.

ii) In the exposed area, the rush and sedgeland ranges from RL 1.18 m to at least RL 1.7 m, with salt tolerant species dominant in the range from RL 1.18 to RL 1.45 m and mixed communities from RL 1.45 to RL 1.65 m. The higher elevations noted for the seaward boundary of the salt tolerant and mixed communities relative to the moderate exposed area probably reflects the greater influence of wave action in this area.

iii) The occurrence of sea rush appears to require moderate shelter. In the exposed area, sea rush was only noted in sheltered areas (e.g. in tidal creeks behind chenier ridges). In the moderately exposed area, the seaward edge of sea rush overlaps with mangroves. However, even here, the sea rush generally only occurs behind cheniers and/or wide areas or protective mangroves. The one occurrence of sea rush not sheltered by either mangroves or a chenier ridge was actively eroding (Figure 10). It is possible this area initially formed behind a chenier ridge which has since moved – a large chenier being noted immediately to the north.

iv) The mixed community areas include various species and species mixes, including sea rush, oioi, *Baumea juncea*, marsh clubrush and tall fescue.

v) In both areas, only the brackish species (marsh clubrush, *Baumea juncea*, tall fescue) were noted above RL 1.65m. The seaward edge of the brackish zone coincides reasonably closely with the highest astronomical tide (Table 2).

vi) Therefore, there is an exposure effect on the seaward edge of the salt tolerant and mixed community zone but not on the seaward edge of the brackish species zone.

vii) As with mangroves, isolated plants of sea rush extend down to much lower elevations along the edge of Fureys Creek as a result of the very sheltered environment and steeply sloping gradients.

viii) In the Long Bay Road wetland the sea rush boundary is lower than the moderately exposed site at RL 0.64 but only extends up to RL 1.2. This probably reflects the effect of water level control as noted above.

Sea Meadow (Figure 9)

i) Includes sea primrose, remuremu, glasswort, bachelor’s button, slender clubrush, and arrow grass.

ii) In moderately sheltered areas, sea meadow is found over an elevation range from RL 1-1.55 m and in exposed areas from RL 1.23 m-1.78 m.

iii) There is clear evidence of an exposure effect – with both the landward and seaward boundaries of the zone moving higher (i.e. landward) in more exposed areas. Interestingly, the range of elevations is very similar (about 0.55 m) for both areas.

iv) In general, glasswort and sea primrose extended to lower elevations with remuremu at higher elevations – though glasswort was also noted at higher elevations in wave washed areas (e.g. exposed banks or cheniers subject to wave over-wash or significant wave splashing. See Figure 11).

v) Sea meadow in the Long Bay Road wetland is probably affected by water level control. Readings in deep sheltered drains provide a good indication of the seaward edge of sea meadow in sheltered environments and suggest that species levels in the sheltered Long Bay Road wetland extend 0.2 m lower than would otherwise naturally be the case.

Riparian Vegetation (Figure 10)

i) Species recorded include saltmarsh ribbonwood, coastal shrub daisy, mingimingi, manuka, red matipo, cabbage tree and flax.

ii) Saltmarsh ribbonwood is the most seaward of the riparian species – generally extending from RL 1.17-1.55 m in the moderately sheltered area and from RL 1.37-1.55 m in the exposed site.

iii) Manuka and other coastal riparian species typically occurred above RL 1.5-1.55 m with rare exceptions to RL 1.45 m. These elevations are probably only rarely affected by salt water – e.g. highest astronomical tides or during storm surge events. The landward limit is now restricted by human activities but in natural conditions is probably determined by land slope and exposure – tending to be wider in more exposed and low gradient sites and narrower in less exposed and steeply sloping sites.

iv) The Long Bay Road wetland distributions are quite different and clearly affected by water level control.

Figures 11 and 12 summarise the elevation boundaries of the different estuarine vegetation communities in relation to each other and illustrate the effect of wave exposure on these boundaries. It should be appreciated that these boundaries indicate where the different vegetation communities can occur and not necessarily where they will occur. For instance, there are other undetermined factors that can result in bare intertidal flats occurring despite elevations being suitable for vegetation communities.

4.3 Response to Most Likely Sea Level Rise

The relationships between bed level and estuarine vegetation communities developed above have been used to conduct a preliminary appraisal of the potential response of various estuarine vegetation communities to most likely sea level rise. The currently accepted estimates of projected sea level rise for the next 50 and 100 years (approximately 0.2 m and 0.5 m, respectively – IPCC, 1991) were adopted.

As discussed in Section 3.3, the most recent IPCC assessment provides upper and lower sea level rise estimates of 0.09 to 0.88 m respectively for the period from 1990-2100. The lower level of sea level rise would have impacts that are slightly less severe than the 0.2 m sea level rise. However, the impact of the upper level scenario would significantly differ from the 0.5 m scenario. In view of some recent studies that indicate that climate warming may be occurring more rapidly than earlier thought and/or that sea level may respond more rapidly than anticipated, it is also important to consider the potential impact of this more extreme scenario. Therefore the impact of the worst-case sea level rise of 0.9 m is also considered.

Typical cross-sections for the ‘high exposure’, ‘moderate exposure’, and ‘modified’ study areas were selected to illustrate the effect of sea level rise in these areas. Additional cross-sections for these areas are included in Appendix 3. Locations of the cross-sections are shown on Figures 3 - 5.

While a typical section has been selected to illustrate the response of vegetation communities to sea level rise, it is important to note that the land areas generally have complex and variable topography. Obviously, the exact response of an area to sea level rise will vary with topography and the additional cross-sections in Appendix 3 provide information on this variability. In addition, it is difficult to determine exactly what species may dominate in mixed zone areas (i.e. areas with elevations that could potentially support a variety of communities). There are also other undetermined environmental influences that can result in bare sediment occurring in areas which bed levels alone would suggest are suitable for one or more vegetation communities.

To model sea level rise, bed levels on the cross-sections were reduced in accordance with the projected sea level rise – so all levels are relative to the new MLOS that would pertain with that sea level rise. (For instance, to model a sea level rise of 0.2 m, bed levels were reduced by 0.2 m).

The elevation of MHWS and an estimated extreme storm-surge elevated sea level (RL 2 m) are also shown on each cross-section. As yet, no analysis of extreme sea levels has been conducted for Coromandel Harbour and therefore extreme (e.g. 1-2% Annual Exceedance Probability (AEP)[1]) storm surge elevated sea levels at this site are unknown. However, extreme sea levels of up to RL 2.5 m have been recorded at the head of the Firth of Thames (and possibly up to RL 3 m in 1938) (Dahm and Munro, 2002). As the tidal range in these areas is greater than at Coromandel Harbour, a slightly lesser extreme sea level has been adopted. While it is not yet possible to assign an exact annual probability for such an extreme sea level in the area of Coromandel Harbour, we would estimate it has an annual probability in the range of 2-5%. I.e. it is unlikely to be the highest extreme sea level that can occur in this area.

Sedimentation is a major factor that could influence response of estuarine vegetation to sea level rise – with limited effects possible if sedimentation keeps pace with the rate of sea level rise. However, available information on sedimentation in Coromandel Harbour suggests that net rates of infilling are very low. For instance, Hume and Dahm (1992) found that average rates of infilling prior to human settlement were generally less than 0.1-0.2 mm/yr. While rates were accelerated by catchment disturbance following human settlement, the average rates over the last 150 years were generally 1-2 mm/yr or less - well below the rates required to keep pace with anticipated sea level rise of 0.5 m over the next 100 years. Moreover, it is probable that the highest rates were associated with severe catchment disturbance in the 1800s and early 1900s. Extensive areas of the higher and steeper parts of the catchment now have regenerating forest and, together with improved land management practices over the past few decades, it is likely that rates of sedimentation are now steadily decreasing. Therefore, in considering the impact of sea level rise, we have assumed that the rates of estuarine sedimentation in all environments (i.e. landward and seaward of the existing shoreline) will not increase to keep pace with sea level rise – i.e. that depths will increase. This is the most likely scenario for intertidal flats in the main harbour area seaward of the present shoreline where sedimentation rates are probably most influenced by catchment sediment supply. It is possible that sedimentation may keep pace with sea level rise in small sheltered tidal creeks landward of the shoreline as wave suspended

[1] The annual exceedance probability is the probability that the extreme water level will be equalled or exceeded in any given year.

sediment carried into these areas from the adjacent harbour may enable infilling to keep pace with sea level rise.

Cheniers are wave built features and so it has been assumed that the active chenier along the shoreline will maintain the same elevation relative to MLOS as presently occurs (i.e. at elevations of at least RL 1.4 m). The elevation of relic cheniers inland from the shoreline will be unaffected. As at present, the active chenier will slowly translate landward in response to wave overtopping during storm events. However, the shoreline will prograde as new chenier ridges continue to be generated and to migrate landward towards the shoreline – though this will continue to be a very slow process.

4.3.1 Exposed Site

Current Situation

i) A typical cross-section over this area is shown in Figure 15.

ii) The exposed area seaward of the shoreline is characterised seagrass, mangrove and open intertidal flat environments.

iii) Landward of the shoreline, a complex and biologically diverse chenier vegetation zone occurs due to the highly variable topography associated with active and relic wave-built chenier ridges and intervening intertidal areas.
   - The complex and highly variable topography results in a mosaic of vegetation communities in close juxtaposition – including mangroves and rushland in hollows, sea meadow communities scattered throughout the entire zone, and saltmarsh ribbonwood and other riparian vegetation on the chenier ridges (including *Ficinia nodosa*, generally on the seaward and active chenier).
   - The chenier vegetation zone typically extends from the crest of the most seaward (i.e. active) chenier ridge to RL 1.8 m, the landward edge of estuarine vegetation (i.e. landward edge of saltmarsh ribbonwood and sea meadow).
   - This complex zone varies in width along the shoreline, typically ranging from 50-100 m where it has not been reduced by human activities. In some places, tidal creeks in old chenier swales extend up to 150 m inland. However, this area is very vulnerable to impact from human activities and in some places has been completely eliminated by levelling and infilling.
   - In this exposed area, rush and sedgeland only occurs within the sheltered chenier vegetation zone. Therefore, in this area of the harbour, the complex 'chenier' zone is critical to the occurrence of rush and sedgeland communities.
   - The varying topography provides a range of habitats supporting different sea meadow communities. Therefore, sea meadow would also be much reduced if this chenier zone were lost.
   - Remnant areas of saltmarsh ribbonwood and riparian shrubs still exist – though generally only a narrow strip along the coast and limited in extent. Species include coastal shrub daisy, manuka, and red matipo. The saltmarsh ribbonwood and riparian shrubs occur on relict chenier ridges and therefore the extent of their occurrence is also dependant on this complex chenier zone.

iv) Landward of the chenier zone, a flat coastal plain extends inland up to the foothills of the Coromandel Range. This coastal plain rises to about RL 3-3.5 near State Highway 25. At present, these flats are primarily used for grazing with other uses including the local airfield and scattered houses.

Potential Impact of 0.2 m Sea Level Rise

i) Figure 16 shows a typical cross-section over this area following 0.2 m sea level rise – with elevations relative to the new mean level of sea. The areas in which the various estuarine vegetation communities could occur with the new mean sea level are indicated.

ii) The intertidal seagrass communities will move landward if estuarine sedimentation does not keep pace with sea level rise, but the total area of this vegetation is unlikely to be affected.

iii) There is potential for mangroves to extend landward to the shoreline with the greater depths, but this expansion will probably be balanced by contraction on the seaward margin – with little change overall.

iv) The complex chenier zone will extend slightly further inland. Therefore, assuming the average shoreline position remains in much the same position, there is potential for a slight increase in the width of this zone. However, the mix of communities may change with more mangroves potentially extending into the zone because of greater depths (though greater depths may not occur as sedimentation in these small embayments may keep pace with sea level rise).

v) The small width of remnant riparian shrubs will be compressed between the expanding chenier zone and adjacent land uses and will be significantly reduced or lost unless allowed to expand landward.

The small increase in sea level rise will also result in more frequent and severe coastal flooding of lowland areas than presently occurs. There will also be a slight expansion in the areas affected by flooding relative to the present.

Potential Impact of 0.5 m Sea Level Rise

i) The potential impact of a 0.5 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 17.

ii) Intertidal seagrass communities will move landward in response to increased depths but the total area of this community is unlikely to be affected.

iii) Mangroves will probably contract significantly on the seaward margin, only partially offset by landward expansion. Therefore, there may be an overall contraction of mangroves.

iv) The complex chenier estuarine vegetation zone is likely to expand in width, assuming the average shoreline position is similar to present. However, this will be dependent on maintaining existing topography and the hydraulic connections between the harbour and low-lying swales further inland. If sedimentation within the tidal embayments behind the cheniers does not keep pace with sea level rise, mangroves will become dominant in the deeper outer areas of the zone. Otherwise, rushland will remain dominant in these areas.

v) The riparian zone would move landward if not constrained by land use – otherwise it is likely to be lost.

Coastal flooding of the lowland flats would increase markedly in aerial extent, frequency and severity. For instance, areas that currently have elevations around RL 2 m and which may on average be flooded only once every 20 years or so, would probably be flooded several times a year. Similarly, areas with existing elevations of around RL 3 m which may not currently be affected by flooding could be flooded several times a century. More detailed investigation of existing coastal flood elevations would be required to comment definitively. However, there are clearly questions in regards to the sustainability of coastal subdivision and development in areas with current elevations less than RL 2.5 m (and possibly even higher).

Potential Impact of 0.9 m Sea Level Rise (worst case)

i) The potential impact of a 0.9 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 18.

ii) The increased sea level will move the landward boundary of the estuarine wetlands approximately 300 m inland, provided it is not constrained by human activities.

iii) Intertidal seagrass communities will move landward to the existing shoreline in response to increased depths but the total area of this community is unlikely to be affected.

iv) Mangroves will probably contract significantly on the seaward margin, only partially offset by landward expansion. Therefore, there may be an overall contraction of mangroves.

v) The complex chenier estuarine vegetation zone is likely to expand in width, assuming the average shoreline position is similar to present. However, this will be dependent on maintaining existing topography and the hydraulic connections between the harbour and low-lying swales further inland. If sedimentation within the tidal embayments behind the cheniers does not keep pace with sea level rise, mangroves will become dominant in the deeper outer areas of the zone. Otherwise, rushland will remain dominant in these areas. Further landward rushland and sea meadow will dominate over a width of approximately 300 m, an increase of approximately 170 m over the existing rushland area. Therefore if the expansion of the wetland is not constrained by human activities, the additional rushland will help offset loss in other areas where the topography rises more steeply landward.

vi) The riparian zone would move landward if not constrained by land use – otherwise it is likely to be lost.

4.3.2 Moderately Exposed Site

Current Situation

i) A typical section over this area is shown in Figure 19.

ii) The exposed area seaward of the shoreline typically only has seagrass, mangroves and open intertidal flat environments, similar to that found at the exposed site.

iii) Rushland and other communities generally occur only in sheltered areas landward of cheniers, as at the exposed site. In the only area where rushland presently occurs without a protective chenier, the seaward face of the rushland is actively eroding (Figure 10; See also Appendix 3: Section E). This rushland area probably originally formed behind a chenier, which has since moved (cheniers gradually migrate landward due to wave overtopping). Where it occurs, the rushland zone typically ranges from 50-150 m wide.

iv) Remnant areas of riparian shrubs are generally rare or absent due to grazing and other near-harbour land uses. However, a significant area of manuka dominated riparian and freshwater wetland vegetation remains immediately north of the Huaroa Stream. This manuka-dominated freshwater wetland community is now rare due to land clearance and drainage.

v) The harbour flats rise landward to a high terrace. In some cases this transition occurs abruptly (i.e. on or near harbour margin), while in other areas there are low-lying flats 60-100 m wide on the immediate harbour margin with elevations generally in the range of RL 1.5-2.3 m (Figure 4). These flats would have originally supported riparian coastal communities but are now dominated by pastoral grasses and weeds.

vi) In recent years, grazing is slowly giving way to housing and industrial development along the shoreline. Infilling of low-lying land has also recently started to occur along the landward margin of the harbour and such work may increase in the future

Potential Impact of 0.2 m Sea Level Rise

i) The potential impact of a 0.2 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 20.

ii) Seagrass is likely to move slightly landward (typically less than 30 m) in response to increased depths but the overall area is unlikely to be significantly affected as the seaward boundary will probably translate landward by a similar distance.

iii) The combined width of mangroves and rushland (typically about 300 m) will reduce in width by 40-50 m, particularly where a high terrace on the harbour margin restricts landward movement.

iv) The particular response of mangrove or rushland communities depends on the response of the local topography to sea level rise. For instance, if the tidal embayments behind the protective cheniers accrete in pace with sea level rise, rushland communities are likely to dominate. However, if depths increase, mangrove communities may move landward and dominate these areas.

v) The area of remnant riparian shrubs will move landward if not constrained by land use. However, infilling is currently occurring which could compromise future landward movement of the large remnant of manuka-dominated freshwater wetland near Huaroa Stream. Other low-lying areas of the harbour margin could revert to this wetland type if not constrained by land use (e.g. grazing or harbour margin development).

Low-lying areas adjacent to the harbour will be subject to more regular and deeper sea flooding than presently occurs.

Potential Impact of 0.5 m Sea Level Rise

i) The potential impact of a 0.5 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 21.

ii) Where it occurs (e.g. offshore on Section E), seagrass is likely to move landward by 40-50 m in response to increased depths, though the total area will probably not be significantly affected.

iii) The total width of mangroves and rushland will reduce significantly, typically by 80-110 m. This would equate to a total loss of these wetland types of about 25-30% (7-8 ha) of the existing surveyed area of these estuarine wetland communities. However, if the wetlands are not able to expand landward into adjacent low-lying topography, there is potential for the wetland loss to be increased by about 2-3 ha (i.e. total loss of 9-11 ha or 32-40% of the existing wetland area in this part of the harbour).

iv) Relative loss of rushland and mangroves will depend on response of bathymetry to sea level rise. If depths behind cheniers increase commensurate with sea level rise, mangroves will dominate and rushland will be significantly reduced. In this case, the present lowlands on the harbour margin will be critical to the perseverance of rush communities in this part of the harbour.

v) The area of remnant riparian shrubs will move landward if not constrained by land use. Other low-lying areas of harbour margin could also revert to this wetland type if not constrained by land use (e.g. grazing or harbour margin development). However, if the harbour margin is extensively developed in future years, riparian shrubland will largely be lost.

vi) The low-lying paddocks along this harbour margin will generally be areas of estuarine wetland or riparian vegetation if landward movement of these ecosystems is not constrained by land use.

Areas with existing elevations less than RL 2.5 m (Figure 4) are likely to be affected by coastal flooding several times a century.

Overall, the total area of estuarine wetland vegetation in this area of the harbour will reduce with sea level rise, though this loss could be partially mitigated by protecting low-lying harbour margins (i.e. areas below RL 2.5 m) for future wetland expansion.

Potential Impact of 0.9 m Sea Level Rise (worse case)

i) The potential impact of a 0.9 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 22.

ii) The increased sea level will move the landward edge of the estuarine wetland inland by approximately 60 m, if not constrained by human activities.

iii) Seagrass, where it occurs (e.g. offshore on Section E), is likely to move landward to about the existing shoreline in response to increased depths, though the total area will probably not be significantly affected.

iv) Mangroves will contract and migrate inland, displacing rushland communities landward of the existing shoreline over a width of about 140 m.

v) The total width of rushland will reduce to about 50 m, less than one third of the existing rushland width due to the steeply rising topography. This emphasises the potential for rushland loss in response to sea level rise in areas with steeply rising topography. If landward wetland expansion is prevented by human activities, the rushland would be entirely lost.

vi) The area of remnant riparian shrubs will move landward if not constrained by land use.

vii) The low-lying paddocks along this harbour margin will generally be areas of rushland/sea meadow or riparian vegetation if landward movement of these ecosystems is not constrained by land use.

4.3.3 Modified Area - Long Bay Road Wetland

Current situation

i) A typical section over this area is shown in Figure 23 with the likely boundaries of the vegetation communities if the existing flap-gate were removed.

ii) The former wetland area was approximately 8.3 ha, surrounded by rising topography on the landward margins and a spit (now a road causeway) on the seaward. In recent decades, the estuarine wetland has been extensively drained and bunded and large areas along the landward margin converted to farmland. There is now approximately only 3.8 ha of the original wetland left. A flap-gated culvert, while not completely sealed, limits seawater ingress to the remaining wetland.

iii) Cross-sections indicate that without the flap-gate most of the original wetland area would be flooded on normal tides, restoring the total area of estuarine wetland from 3.8 ha to 8.3 ha.

iv) Surveyed elevations taken near high water indicate that maximum salt-water elevations within the wetland are generally about 0.2 m lower than natural elevations seaward of the flap-gate – so that vegetation community boundaries occur at lower elevations (see discussion in section 4.2). In the absence of the flap-gate, it is probable that the vegetation community boundaries would be similar to those noted in the moderately exposed survey area (Figures 11).

v) At present, the remaining wetland is sheltered along the seaward margin by a causeway, which together with effect of the flap-gate on water levels gives rise to extensive areas of salt marsh.

vi) However, in the absence of the flap-gate, the greater depths would probably result in mangroves dominating the deeper areas, particularly near stream and drain channels. At present, mangroves are limited to the areas adjacent to the main channel for a distance of about 150 m upstream of the flap-gated culvert. Rushland, sea meadow and saltmarsh ribbonwood communities cover most of the remaining area.

Potential Impact of a 0.2 m Sea Level Rise

i) The potential impact of a 0.2 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 24. The vegetation community boundaries shown assume the flap-gate has been removed and the full wetland area has been restored and is subject to natural tidal fluctuations.

ii) It can be seen that the sea level rise would result in only a minor expansion in wetland area because of the rising topography around the margin.

iii) The most likely change is for mangroves to expand at the expense of rushland communities because of the increased depths. However, if sedimentation in the sheltered embayment keeps pace with sea level rise, the expansion of mangroves would be less significant.

iv) Seagrass may also appear in the deeper areas.

v) If it were attempted to maintain the flap-gated culvert and other works (e.g. bunds) to protect the drained wetland areas from inundation, the increased sea level would significantly complicate drainage and flood protection. In the absence of major upgrade of these works, the rise in sea level would result in more frequent and severe stream flooding of low-lying pasture in former wetland areas, particularly with floods coinciding with higher stages of the tide. In addition, the increased salt-water inflows during normal tidal conditions would flood the low-lying pasture in the areas of drained wetland.

vi) Therefore, sea level rise will significantly complicate and increase the cost of maintaining these low-lying pasture areas.

Potential Impact of a 0.5 m Sea Level Rise

i) The potential impact of a 0.5 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 25.

ii) The rise in sea level would result in some wetland expansion but typically by less than 20-30 m due to the rising topography around the wetland margin – though greater expansion (e.g. about 50 m) in some areas (e.g. Section H).

iii) If sedimentation did not keep pace with sea level rise, the major change would be the development of open intertidal flats in deeper areas and further expansion of mangroves towards landward margins. Rushland would be reduced relative to the present situation but would expand relative to the 0.2 m sea level scenario. Seagrass may also become quite widespread.

iv) Riparian vegetation will retreat minor distances up adjacent sloping topography if land use allows.

v) A rise in sea level of this magnitude would necessitate major upgrade of flood protection and drainage works to protect pasture areas from stream flooding and salt water inundation. It is doubtful that these works would be economic given the relatively small areas of pasture to be protected.

Overall, the major impact of sea level rise on estuarine vegetation will be the expansion of seagrass, mangroves and open intertidal flats at the expense of rushland. In addition, the maintenance of low-lying pasture areas will become increasingly expensive and impractical.

Potential Impact of a 0.9 m Sea Level Rise (worst case)

i) The potential impact of a 0.9 m sea level rise on ground elevations (relative to mean level of the sea) and the distribution of estuarine vegetation communities is shown in Figure 26.

ii) The increased sea level will move the landward edge of the estuarine wetland inland by approximately 90 m, if not constrained by human activities.

iii) The majority of the existing wetland would be dominated by seagrass and/or mangroves.

iv) The rushland community would reduce to approximately 90 m compared to the current width of 180 m due to the rising topography landward. If landward expansion of the wetland was constrained by human activities, most of the rushland community would be lost.

v) Riparian vegetation will retreat minor distances up adjacent sloping topography if land use allows.

vi) A rise in sea level of this magnitude would necessitate the elevation of the existing Long Bay causeway being lifted by at least 0.5 m to avoid regular overtopping and storm damage.

5 Conclusions and Management Recommendations

5.1 Summary of Conclusions

The investigation has established that there is a close relationship between bed level and the various estuarine vegetation communities, with the vegetation communities generally only occurring in defined bed level ranges. The nature of the relationship varies with wave exposure and can also be affected by human activities that affect tidal elevations.

The relation between estuarine vegetation communities and bed levels defines where these communities can occur but not necessarily where they will occur, as there are other factors that can determine whether or not the communities occur. For instance, wave shelter appears to be a critical requirement for rush and sedgeland communities.

The relationship between bed level and estuarine vegetation communities for different environments within Coromandel Harbour is used to conduct a preliminary appraisal of the potential response of various estuarine vegetation communities to sea level rise. The best present estimates of sea level rise for the next 50 and 100 years (0.2 m and 0.5 m, respectively – IPCC, 1991) have been used in this study. In addition, the potential impact of the worst-case scenario of 0.9 m sea level rise by 2100 has also been assessed.

The effects of sea level rise on estuarine vegetation communities may be mitigated if sedimentation rates keep pace. However, available data suggests that the existing rates of net sedimentation within Coromandel Harbour are too low to significantly counterbalance sea level rise. Therefore, any mitigating effects of sedimentation have been ignored for the purposes of this preliminary appraisal. There are areas where sedimentation may possibly keep pace with sea level rise – particularly the small sheltered embayments within chenier complexes. If so, existing vegetation communities are likely to be maintained rather than displaced by vegetation adapted to deeper water as projected in this report.

The study found that estuarine vegetation communities will tend to move landward with sea level rise in response to increased water depths. In particular, the study has highlighted the potential for peripheral estuarine vegetation communities (i.e. rush and sedgeland, sea meadow and riparian species) to be significantly reduced in area. In areas where landward topography rises steeply there will inevitably be a significant loss of rushland/sea meadow with projected sea level rise. There is potential for this loss to be balanced by increased areas of rushland/sea meadow where adjacent topography is low-lying - provided landward expansion is not constrained by development or other human activities. The area of mangrove communities is likely to be less significantly impacted by sea level rise, though some reduction may occur. Seagrass communities are unlikely to be reduced in area.

The study has also highlighted that the occurrence of some vegetation communities, especially rush and sedgeland, appears to be critically dependent on shelter. Within Coromandel Harbour chenier ridges are common and provide natural protection for rush and sedgeland. The complex mosaic of active and relict chenier ridges and intervening hollows along much of the harbour shoreline appear to be critical to the occurrence of estuarine rush and sedgeland, especially in more exposed areas of the harbour. The variable topography and exposure in these areas results in very high natural biodiversity and habitat values and, in places, outstanding natural character. Therefore, protection of coastal margin chenier zones and the maintenance of hydraulic connectivity within these areas is important to the protection of these estuarine wetlands.

Overall, the results of the study suggest that protection of both low-lying areas (below about RL 2.5 m) and chenier complexes are critical to the protection of Coromandel Harbour estuarine vegetation communities in the face of sea level rise.

The study also suggests that areas below RL 2.5 m (and possibly even higher) will be subject to coastal inundation with sea level rise. Therefore, from the point of view of coastal hazards it would be wise to avoid future subdivision and development of these areas. Moreover, while pastoral uses of low-lying land (including former wetland areas) presently occur, these uses will become increasingly unsustainable in the face of future sea level rise. If the worst-case sea level rise scenario eventuates these impacts will be considerably more severe.

However, while protection of cheniers and low-lying harbour margins are critical activities, these actions also have the potential to restrict the use of potentially high value coastal land. Therefore, incentives packages to encourage protection of these areas should be considered in addition to land use controls.

It is important to note that while this study has focussed on sea level rise projections for the next 100 years, the existing assessments project that sea level will continue to rise, possibly at accelerating rates, beyond 2100.

Further investigation is required to assess the applicability of these findings to other harbours in the Waikato region. It is probable that similar findings would arise, although there may be additional local factors relevant to the protection of estuarine wetlands in some areas.

5.2 Recommendations

In the light of the above findings, it is recommended that Environment Waikato work closely with Thames Coromandel and other district councils to:

- Provide for landward expansion of estuarine wetlands in response to sea level rise by developing land use controls and targeted incentive provisions that prevent or discourage subdivision and development around harbour margins in areas below about RL 2.5 m.

- Develop strict controls on land use and disturbance around harbour margins to prevent damage or loss of chenier complexes and associated wetlands. These controls should strongly discourage removal of natural vegetation, levelling, infilling, reclamation or the impeding of hydraulic connections.

- Develop targeted incentive provisions to encourage the protection and restoration of chenier complexes and associated wetland environments around harbour margins.

- Develop policy and targeted incentive provisions that encourage restoration of former estuarine wetland areas, including restoration of riparian shrubland around such areas.

Further investigation is also warranted to:

- Assess the applicability of the above findings to other harbours within the Waikato Region

Improve information on extreme sea levels in these areas, especially the maximum likely levels resulting from storm surge and astronomical tides.

Figure 2: A typical surveying set up used to establish local estuarine vegetation boundaries and bed levels

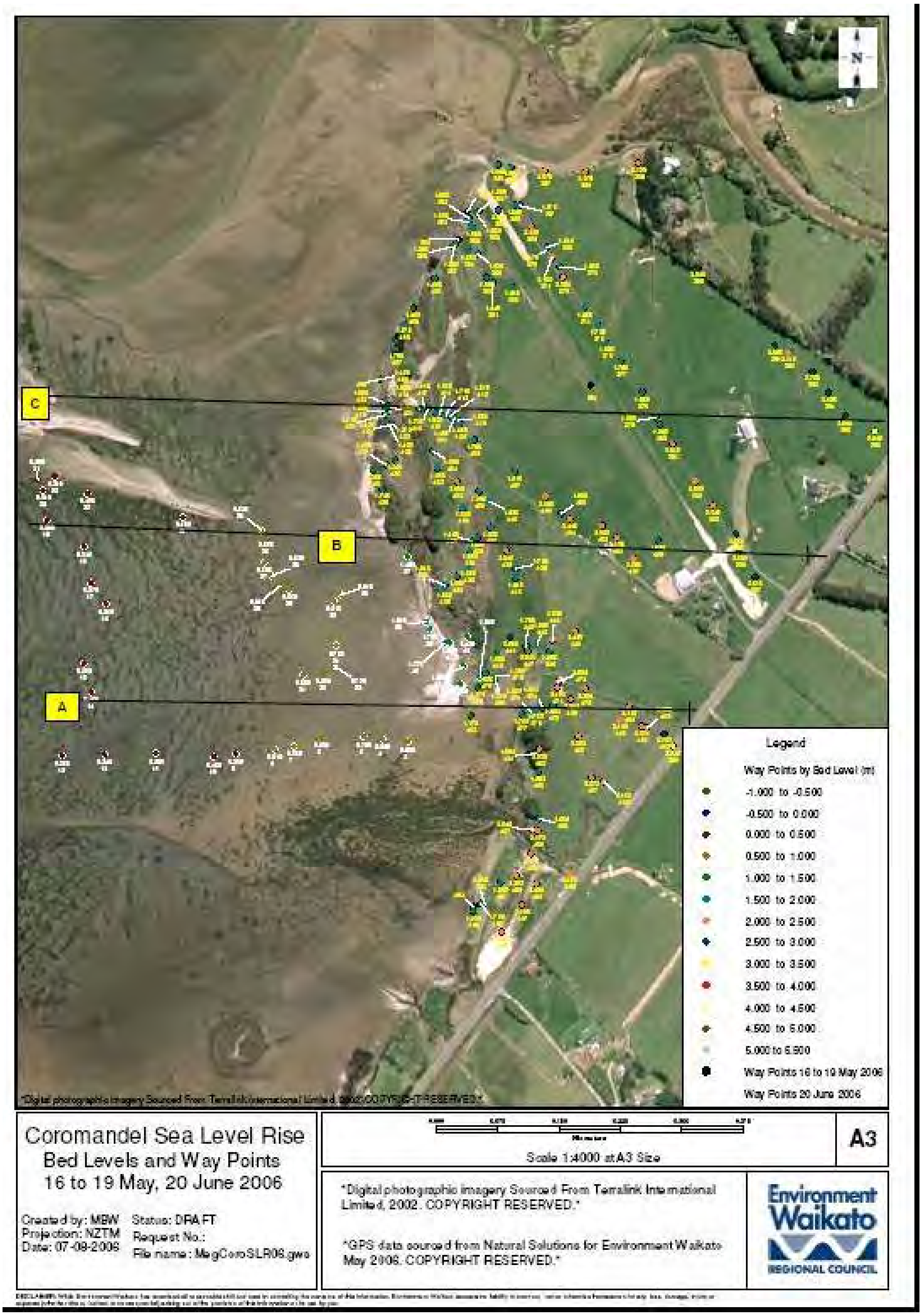


Figure 3: Exposed Area – surveyed bed levels and locations of cross-sections

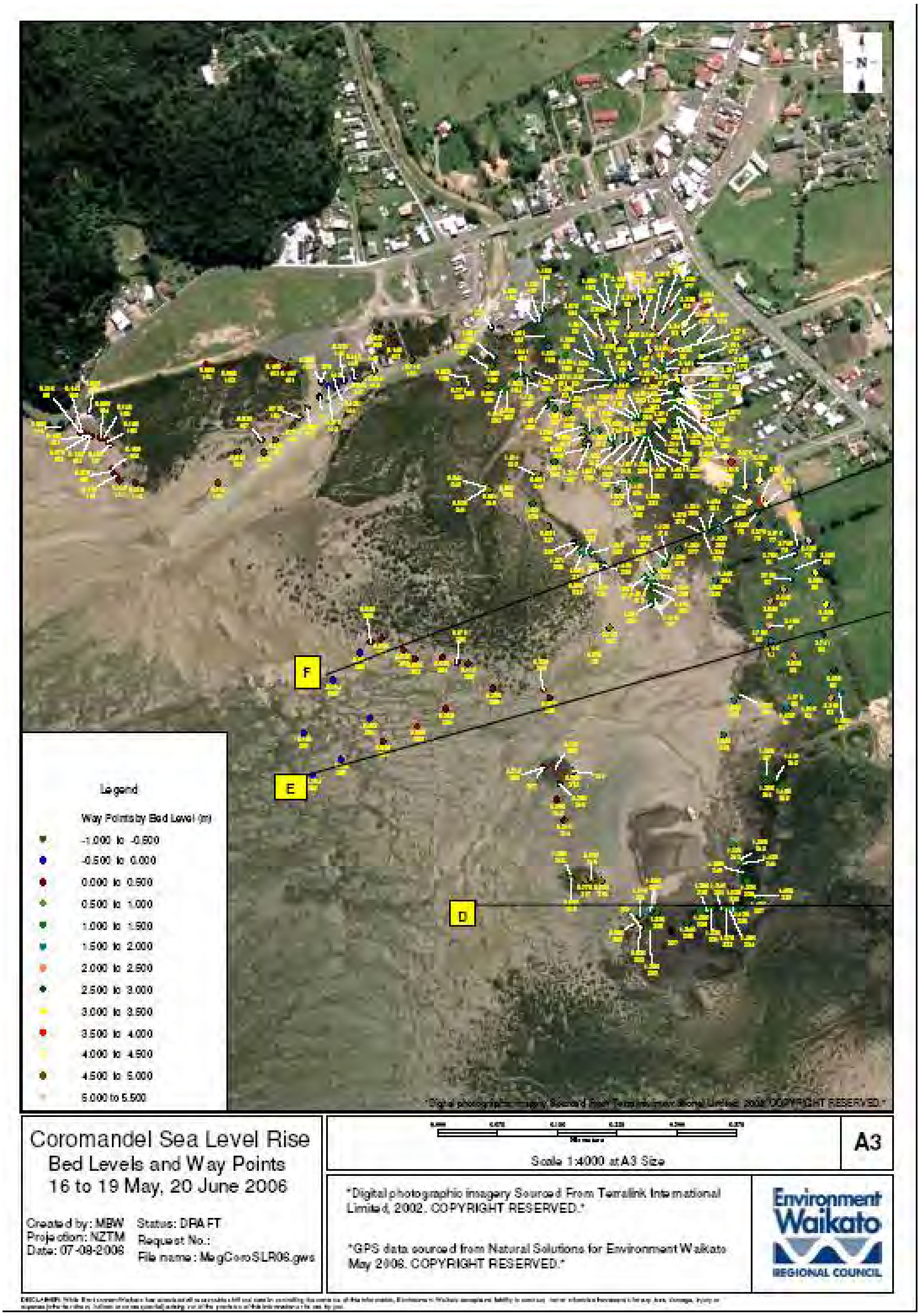


Figure 4: Moderately exposed Area – surveyed bed levels and locations of cross-sections

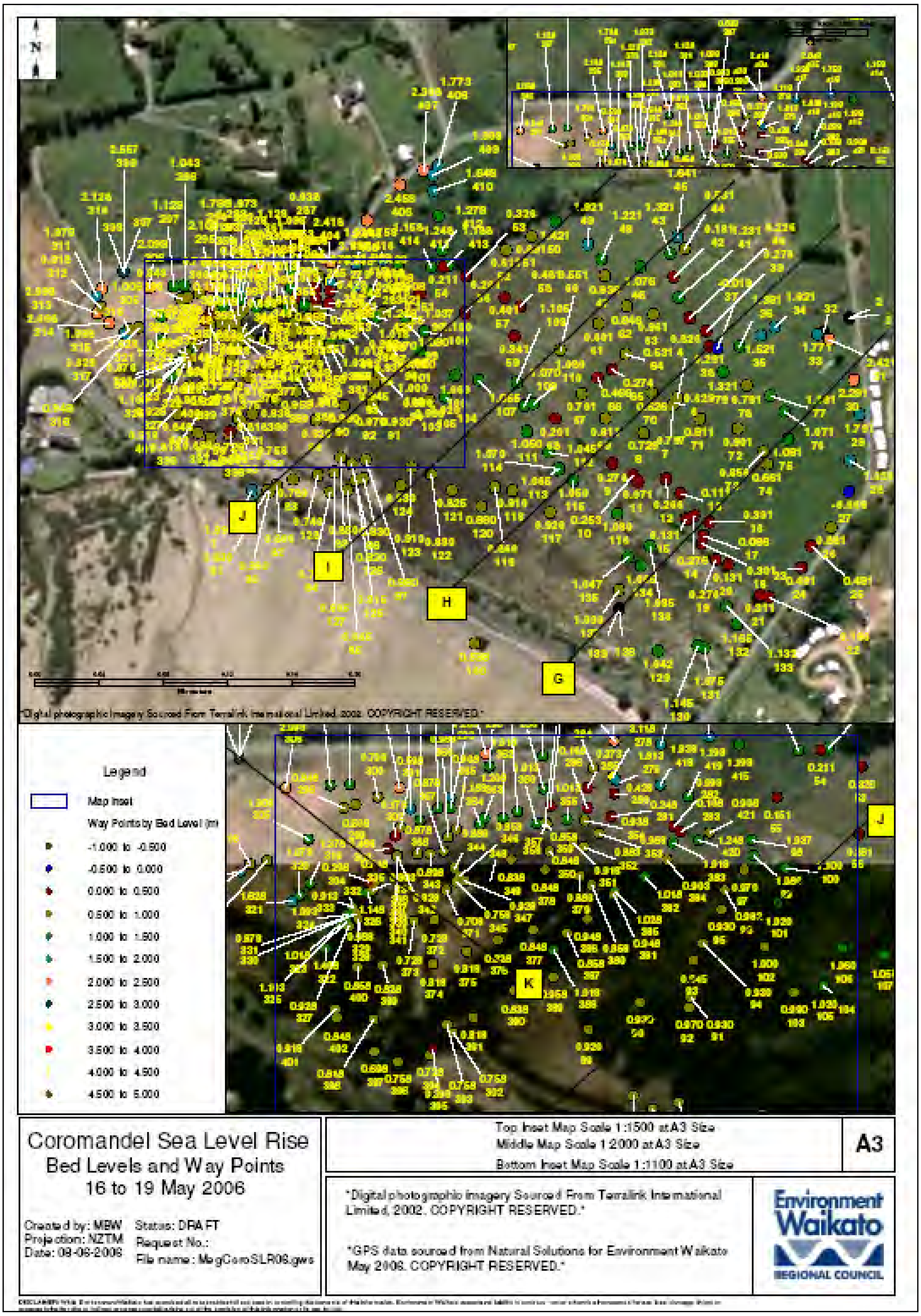


Figure 5: Modified Area – surveyed bed levels and locations of cross-sections

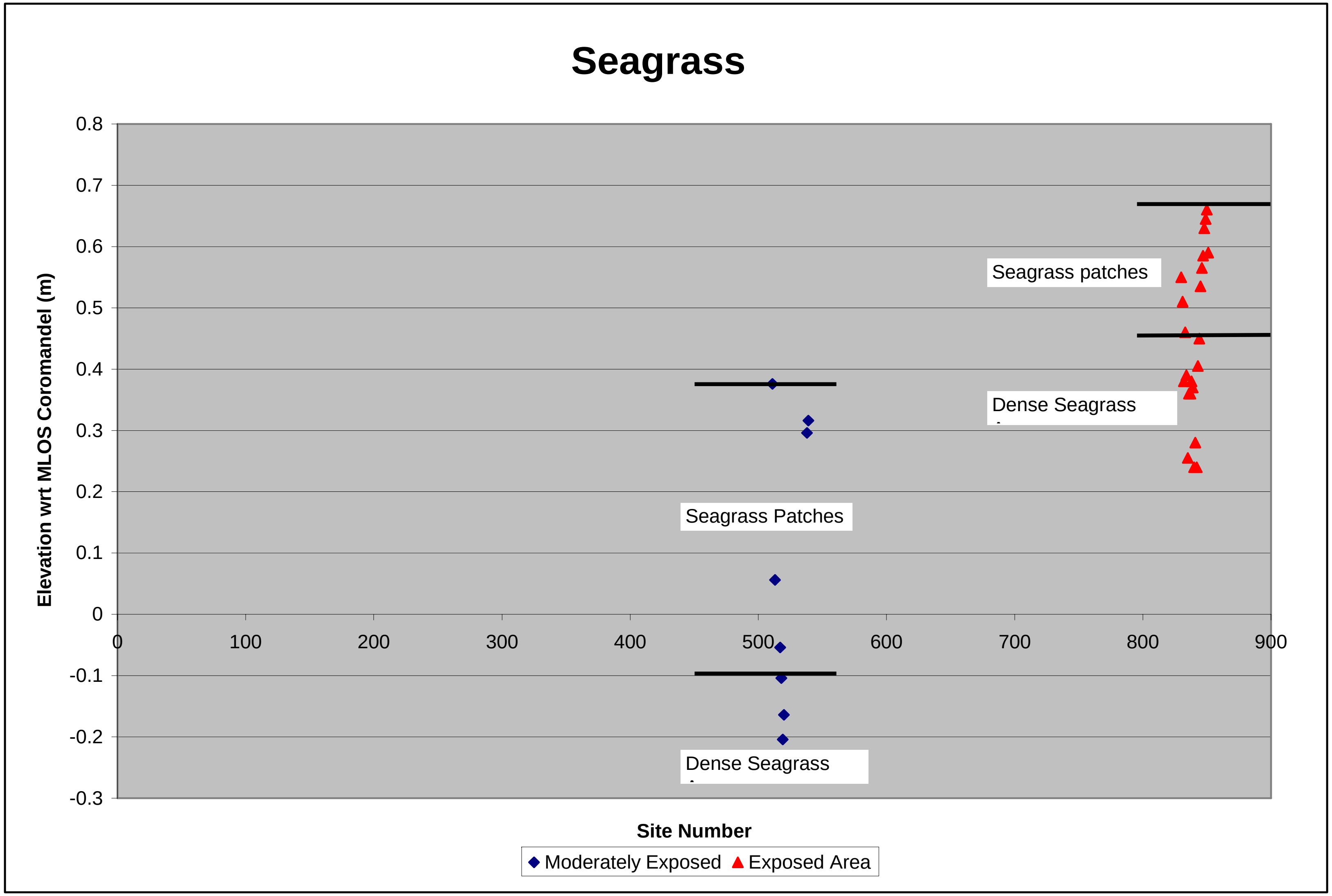


Figure 6: **Occurrence of seagrass with respect to Mean Level of Sea, showing approximate landward and seaward boundaries. The seaward boundary of dense seagrass was not determined**

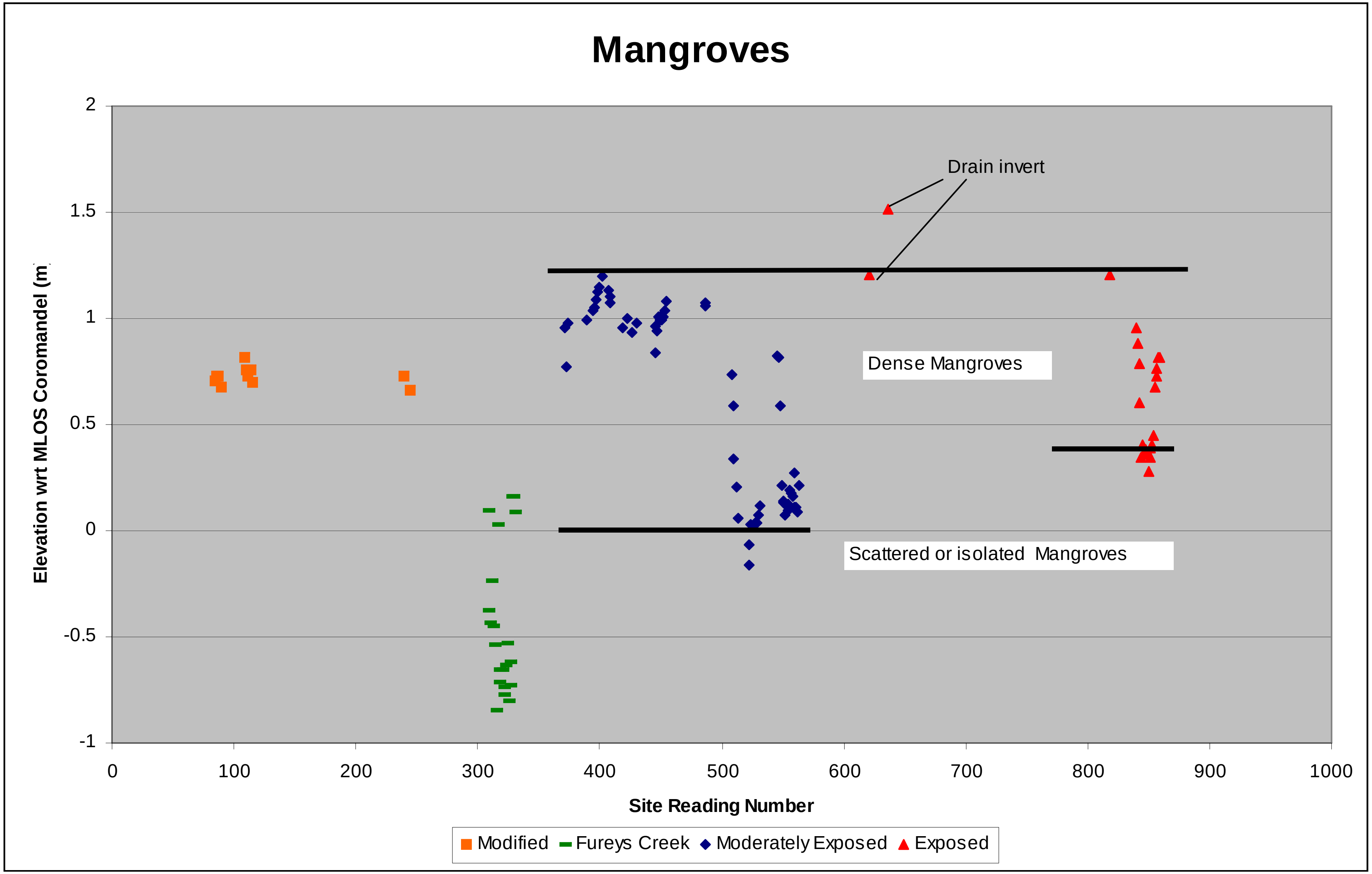


Figure 7: Occurrence of mangroves with respect to Mean Level of Sea, showing approximate landward and seaward boundaries

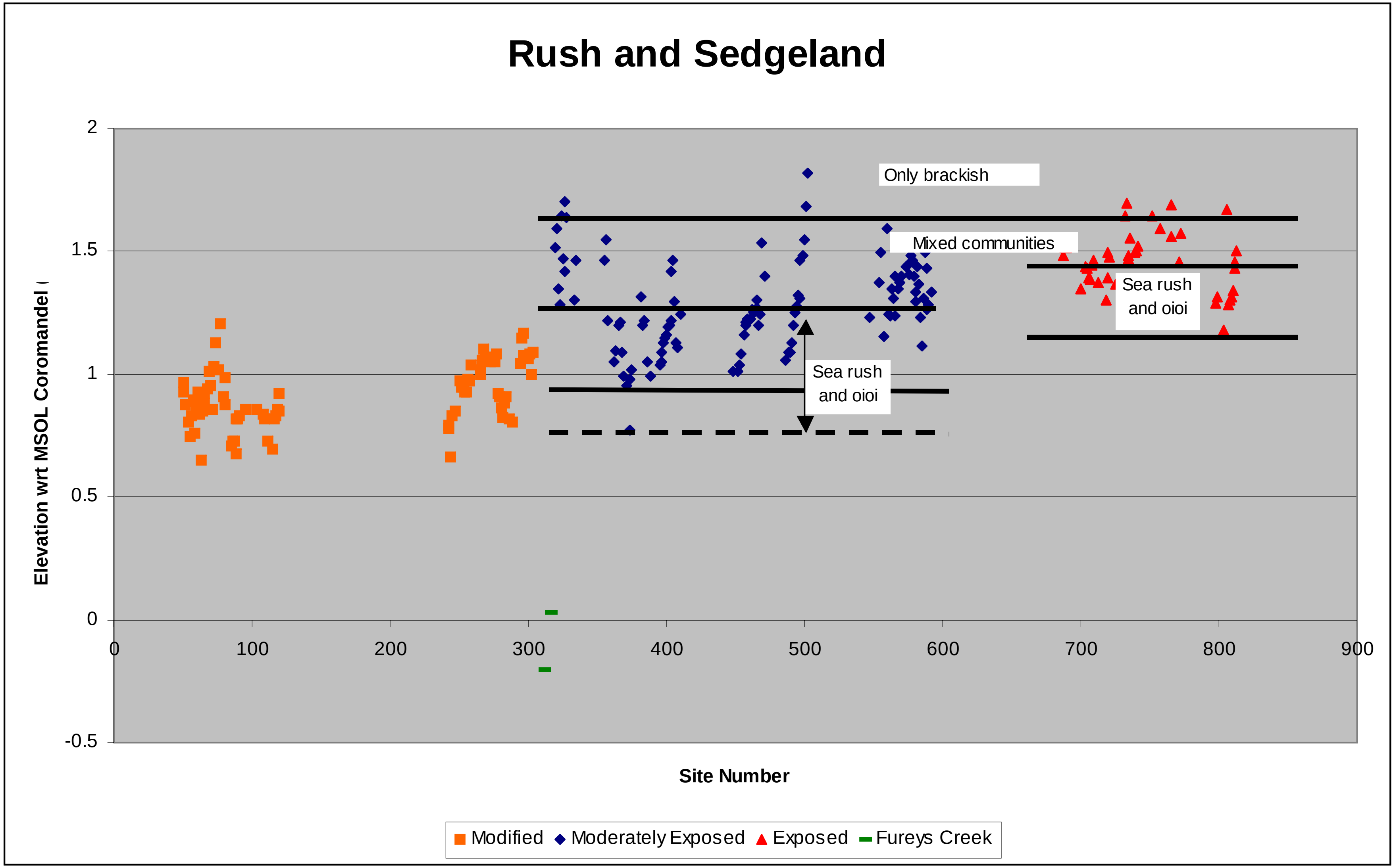


Figure 8: Occurrence of rush and sedgeland with respect to Mean Level of Sea, showing approximate landward and seaward boundaries of community types

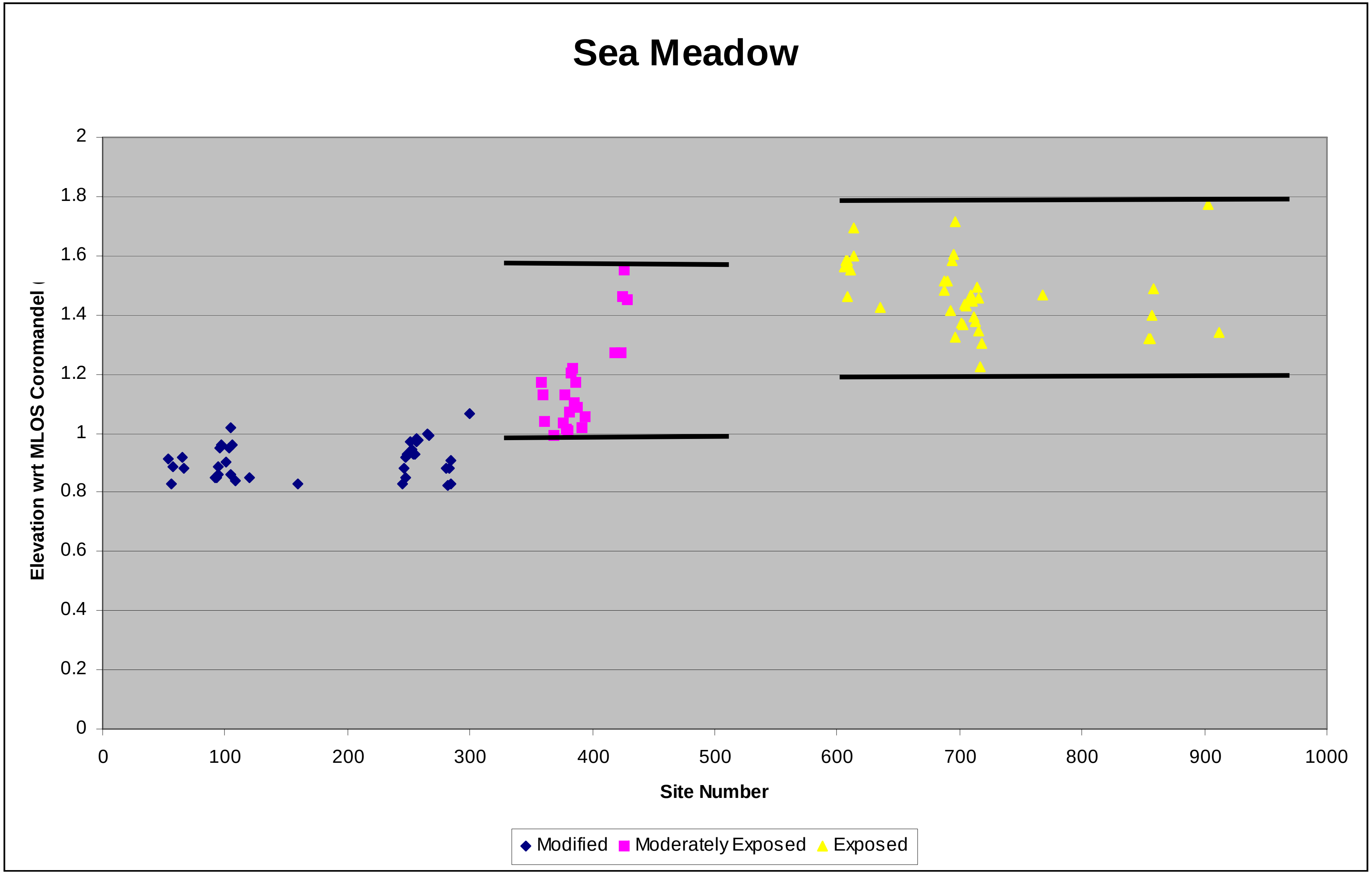


Figure 9: Occurrence of sea meadow with respect to Mean Level of Sea, showing approximate landward and seaward boundaries

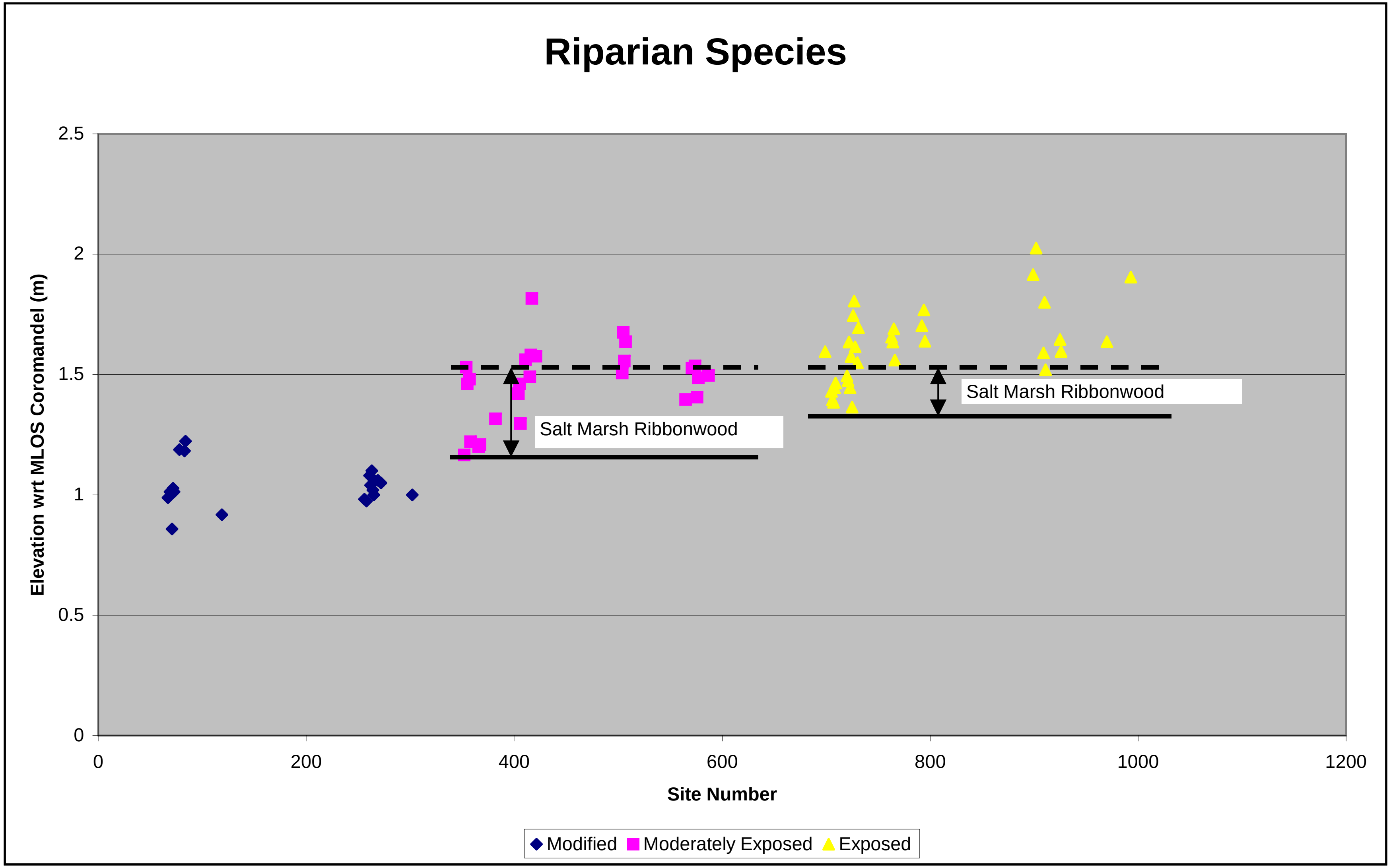


Figure 10: Occurrence of riparian vegetation with respect to Mean Level of Sea. The elevations dominated by saltmarsh ribbonwood are marked, with other riparian species occurring above this elevation:

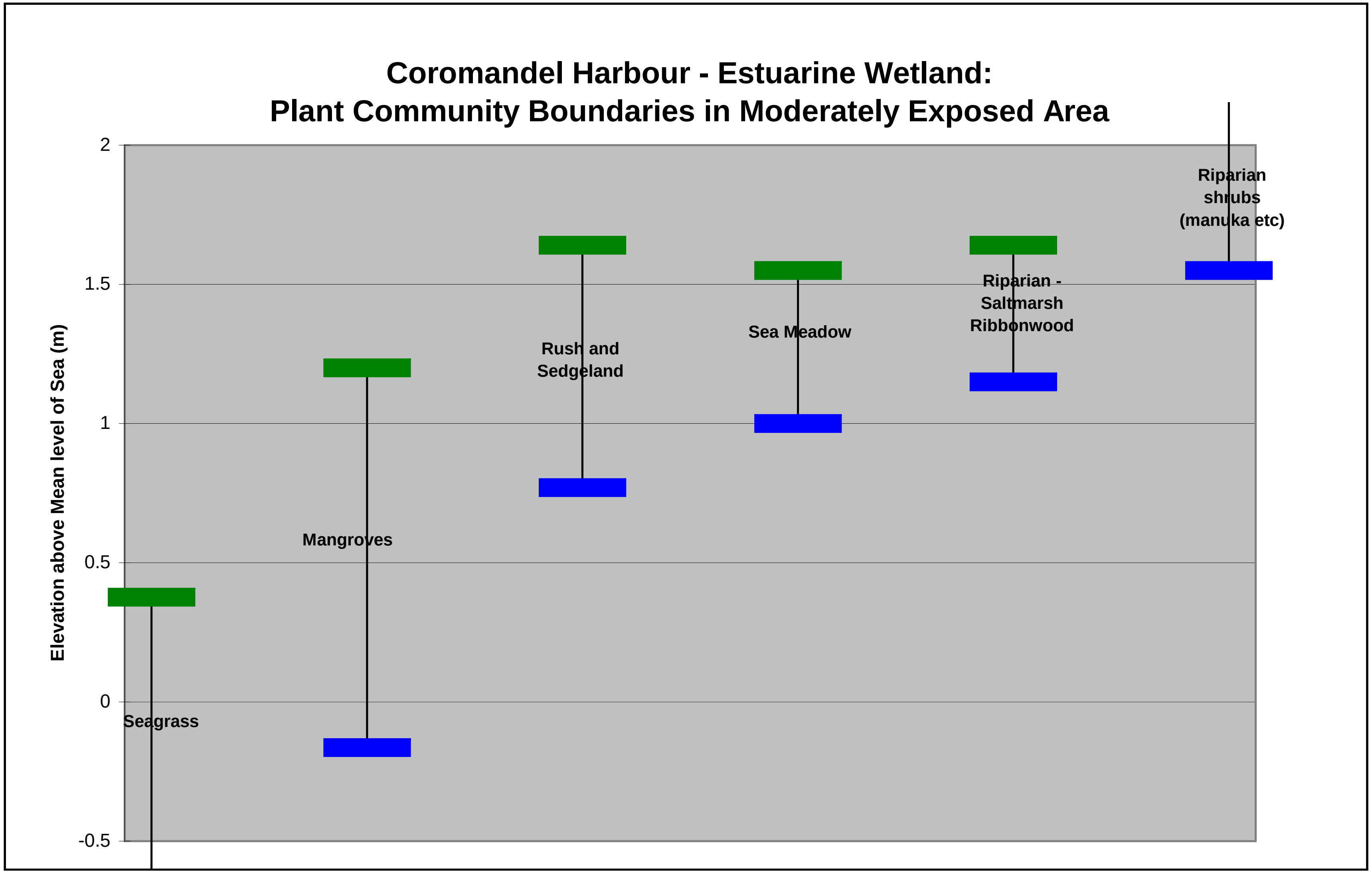


Figure 11: **Plant community boundaries in the moderately exposed area**

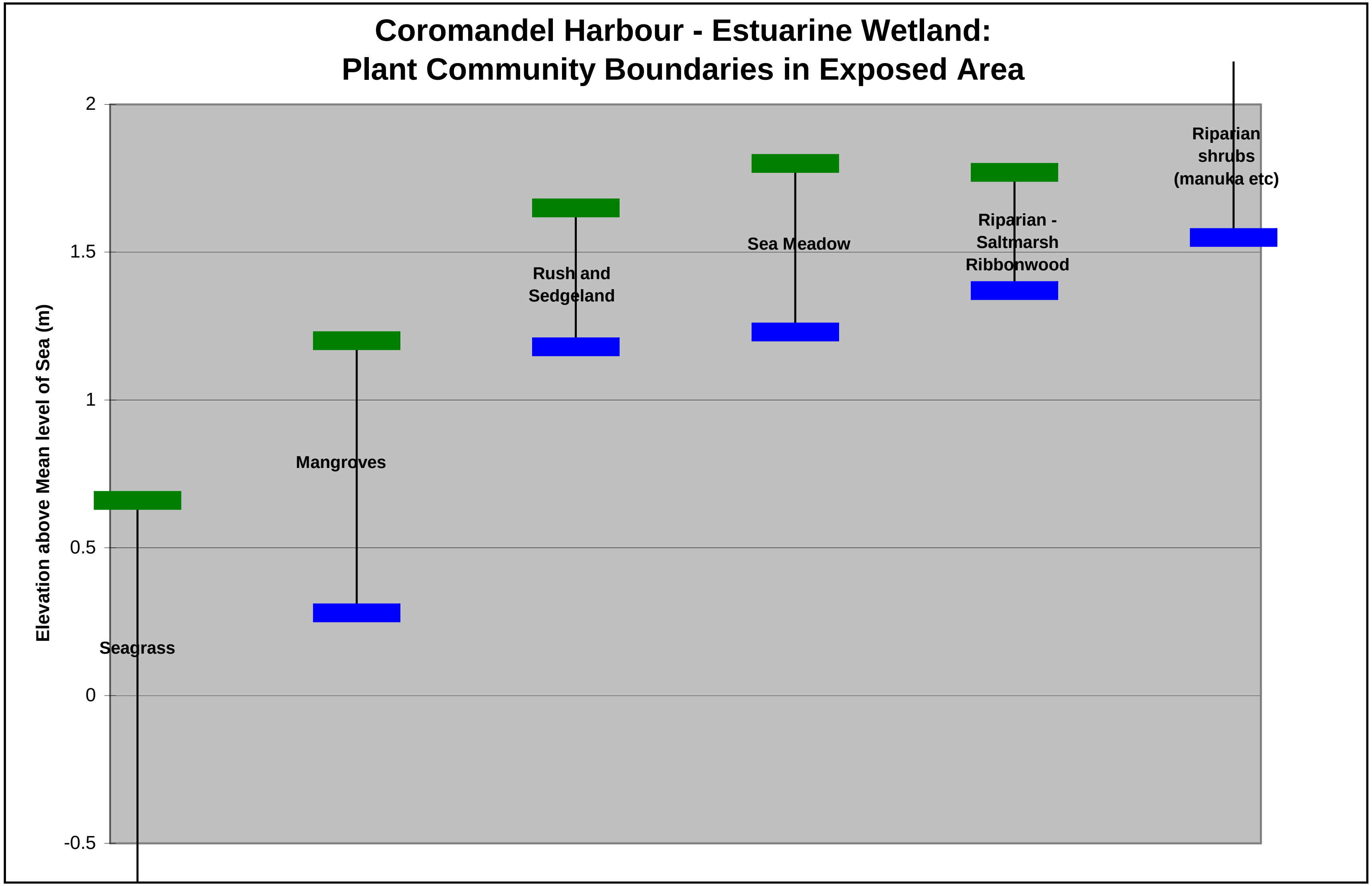


Figure 12: Plant community boundaries in the exposed area

.

Figure 13: An eroding saltmarsh edge (sea rush and patches of glasswort) half way between Jacks Point and Preeces Point, Coromandel Harbour

Figure 14: A wave-washed eroding coastline with sea meadow species (glasswort and remuremu) on the banks, Coromandel airfield

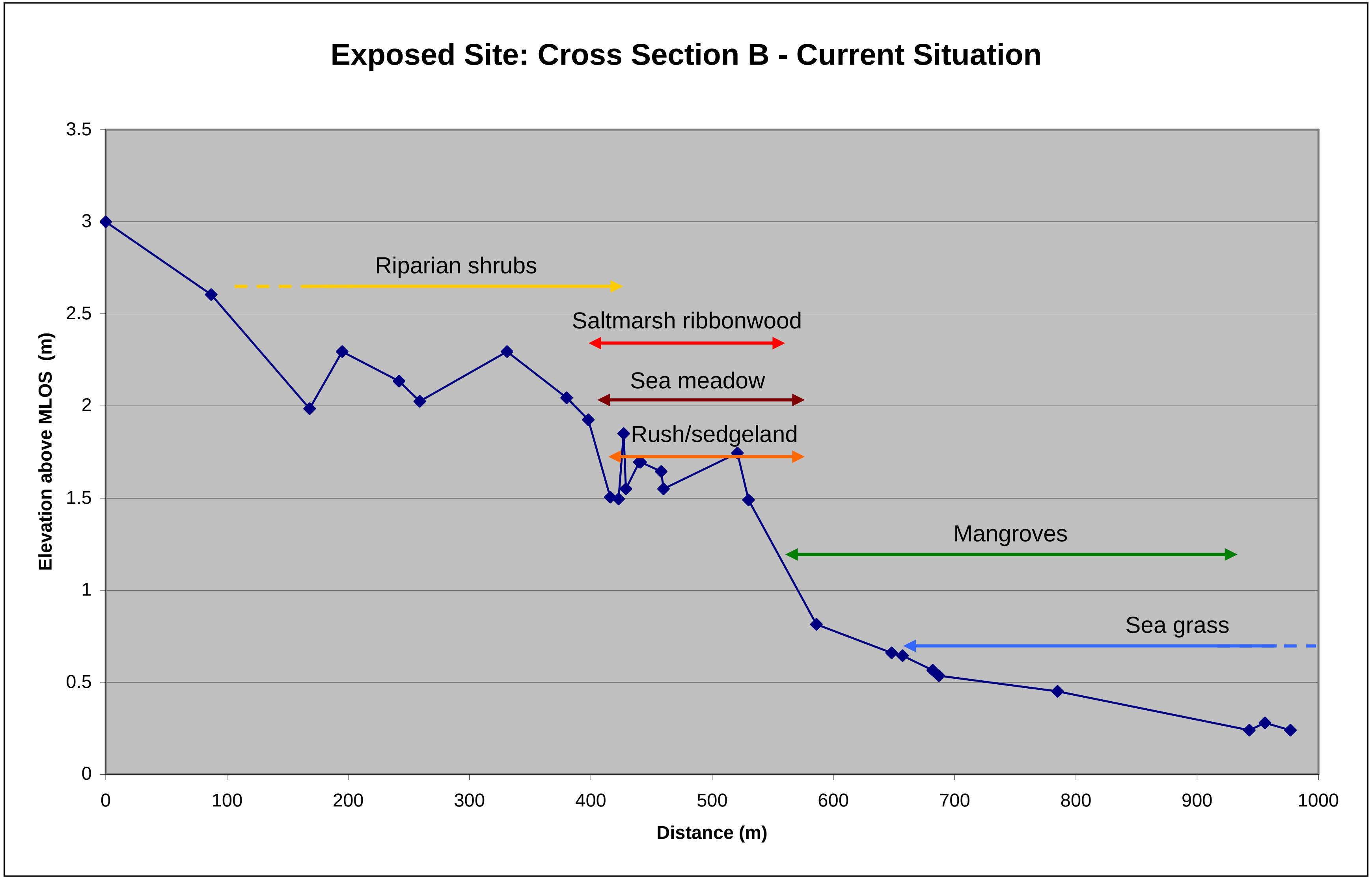


Figure 15: Typical cross-section of Exposed Site (see Figure 3 for location) – current situation. Note that the zone range for each vegetation type is shown but this does not always mean that vegetation type is present (e.g. may be open mud within rush zone)

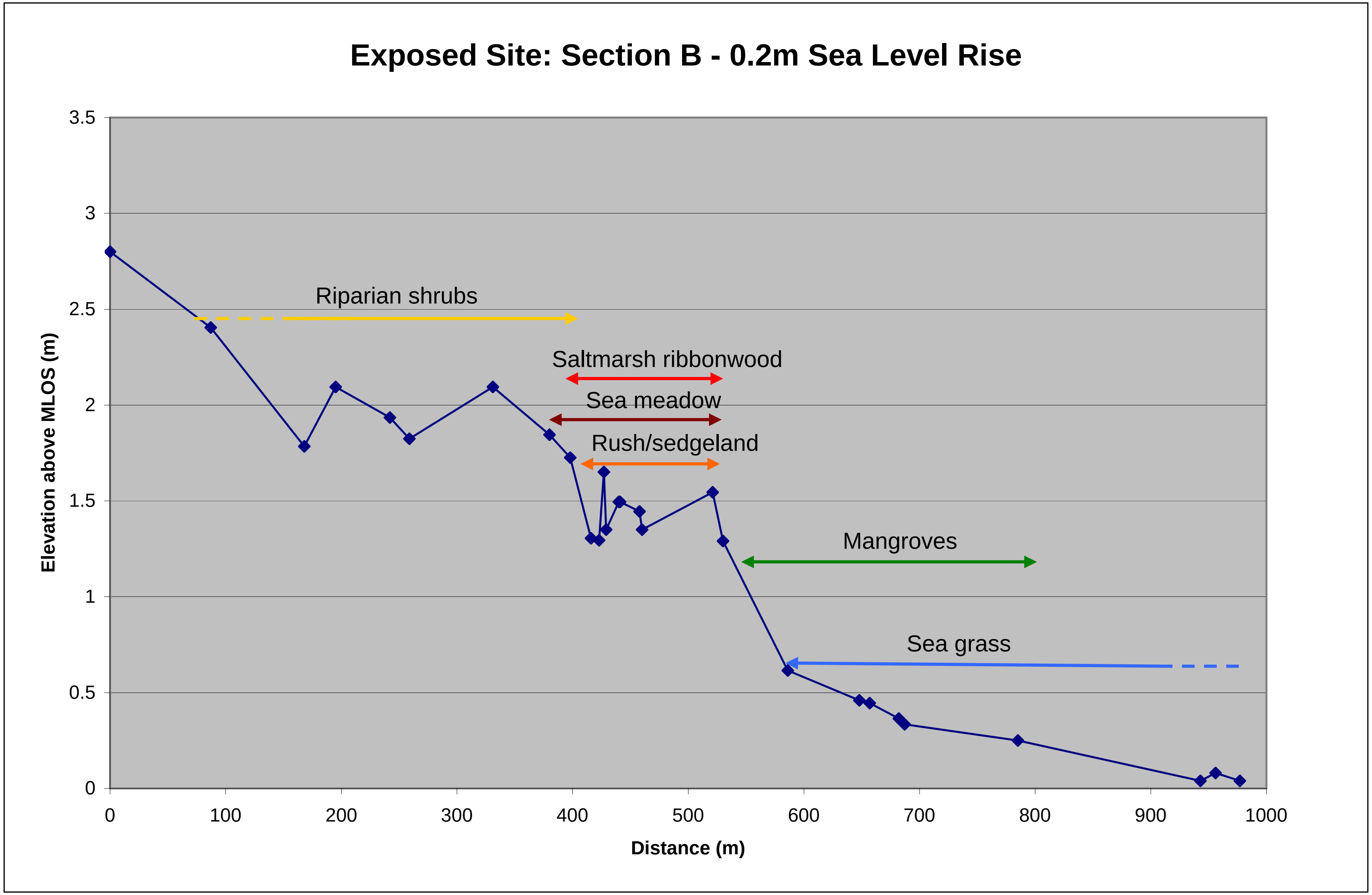


Figure 16: Typical cross-section of Exposed Site (see Figure 3 for location) – 0.2 m sea level rise scenario

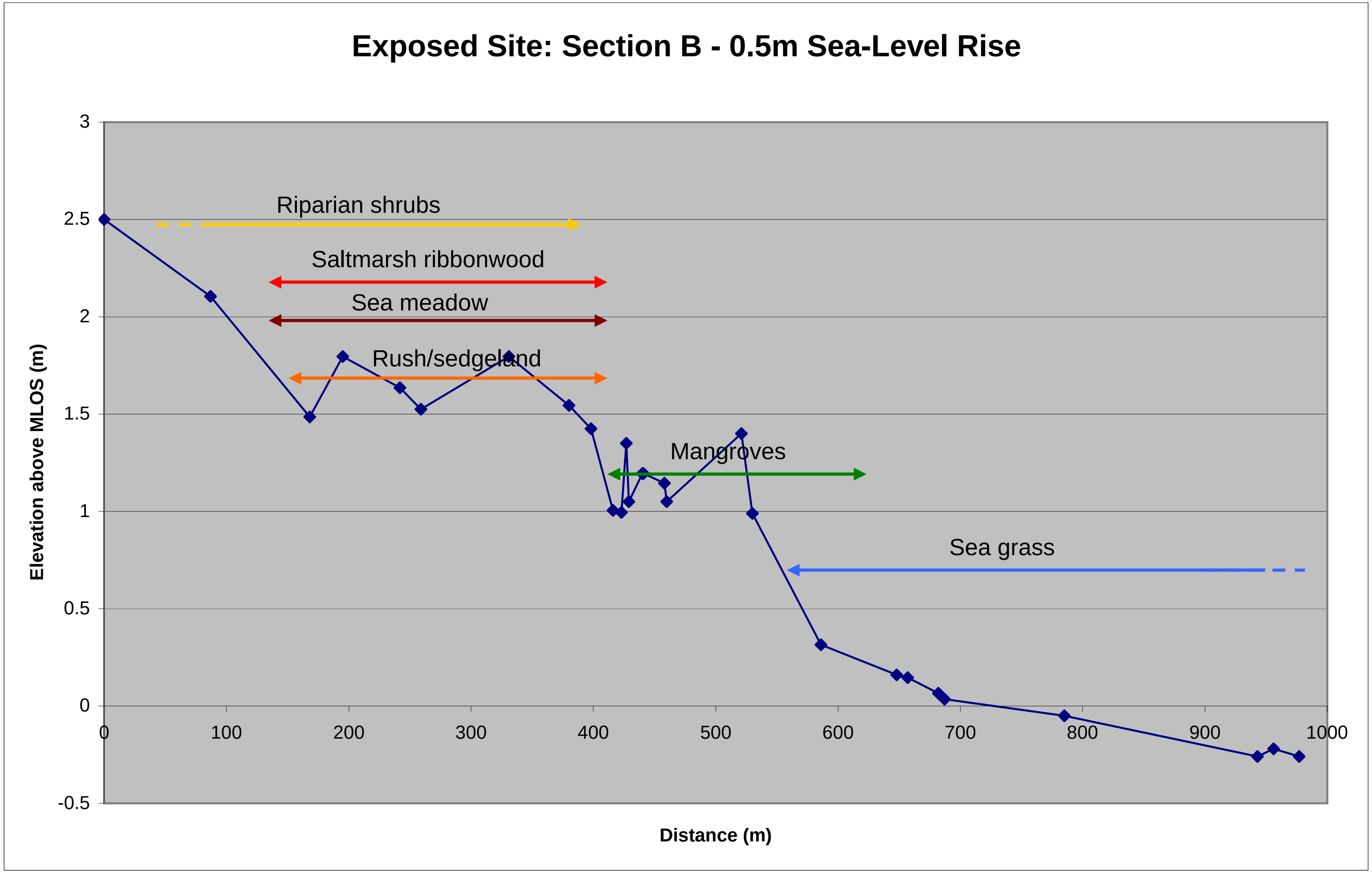


Figure 17: Typical cross-section of Exposed Site (see Figure 3 for location) – 0.5 m sea level rise scenario

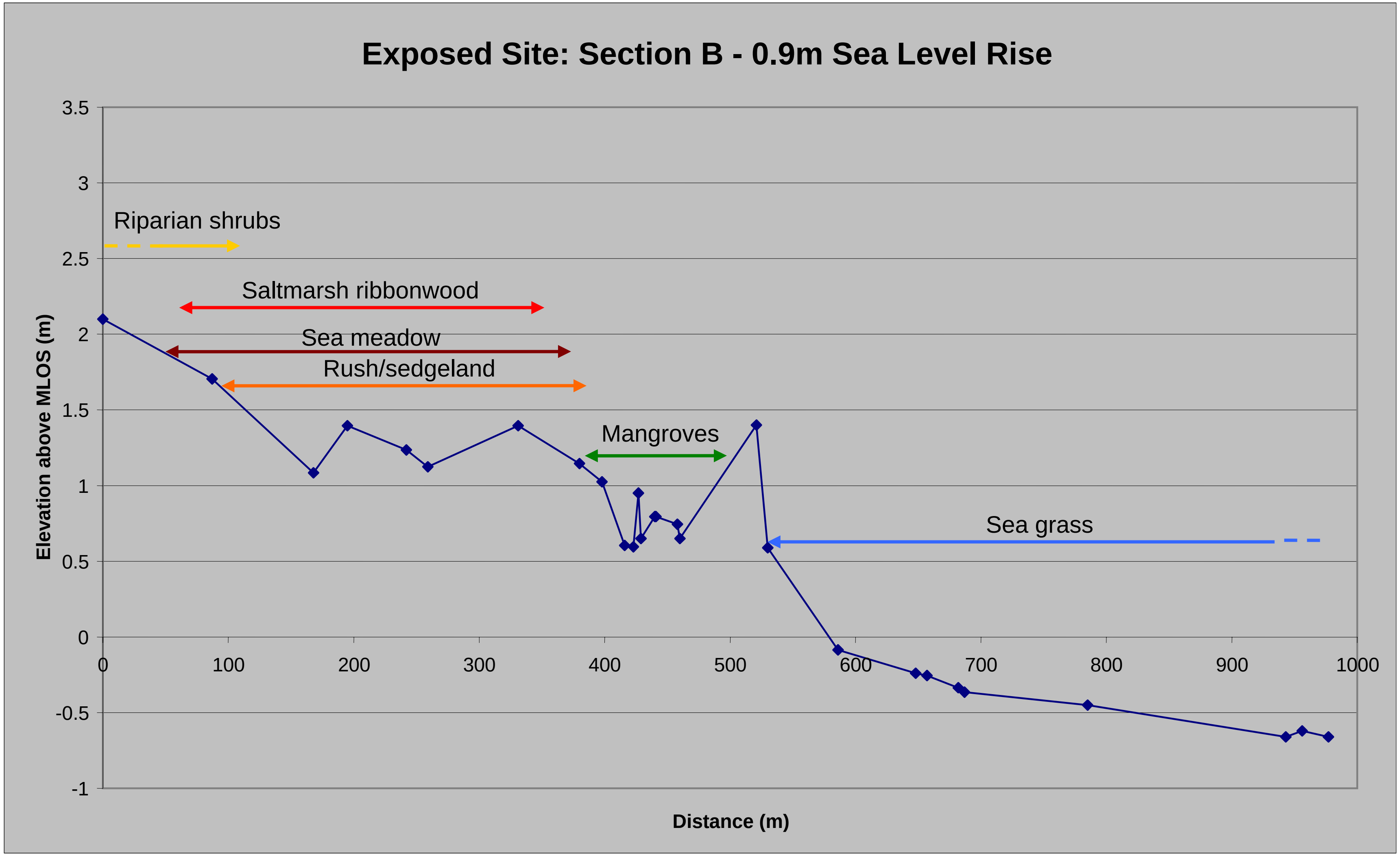


Figure 18: Typical cross-section of Exposed Site (see Figure 3 for location) – 0.9 m sea level rise scenario

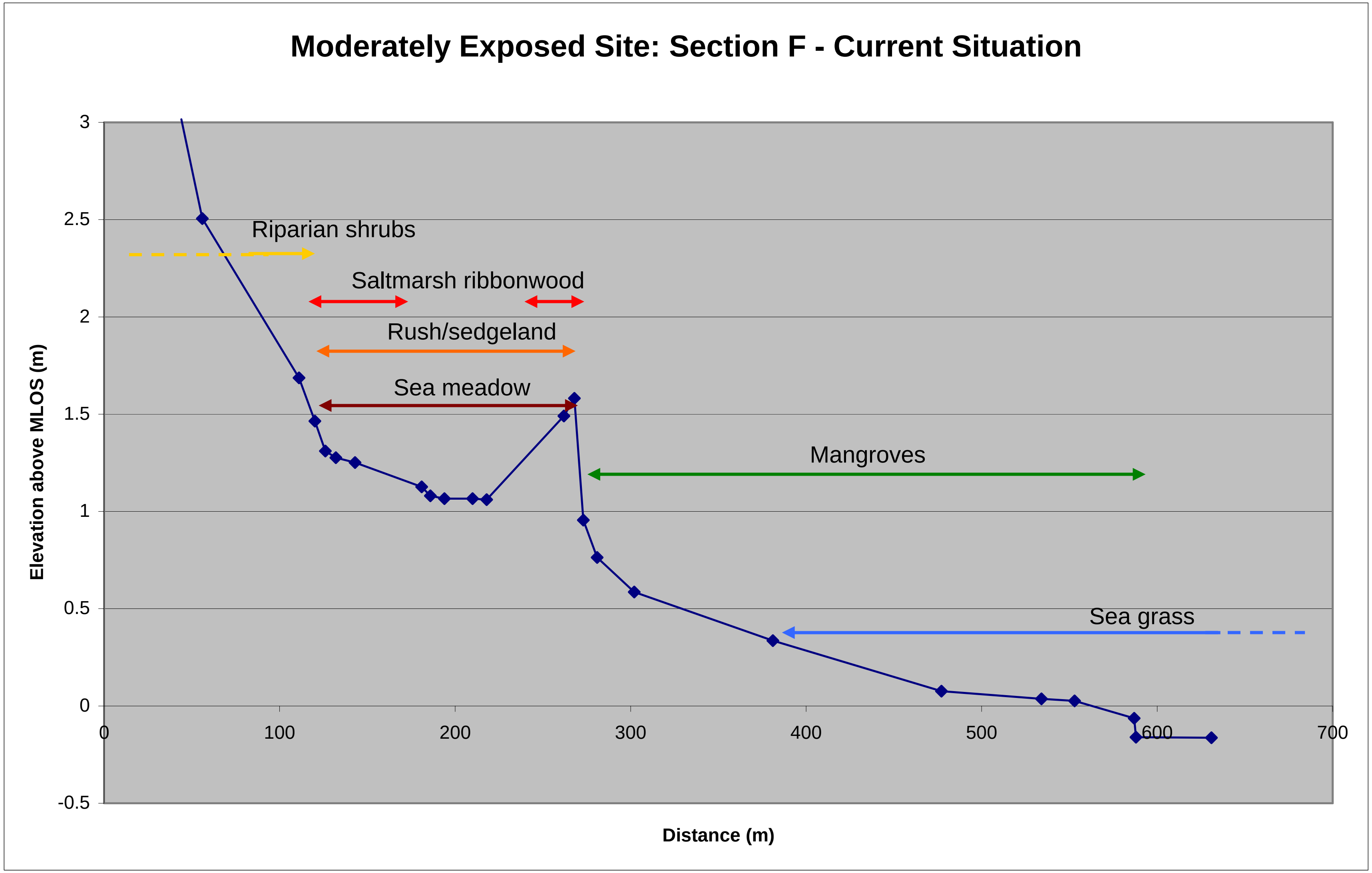


Figure 19: **Typical cross-section of Moderately Exposed Site (see Figure 4 for location) – current situation. Note that the zone range for each vegetation type is shown but this does not always mean that vegetation type is present (e.g. may be open mud within rush**

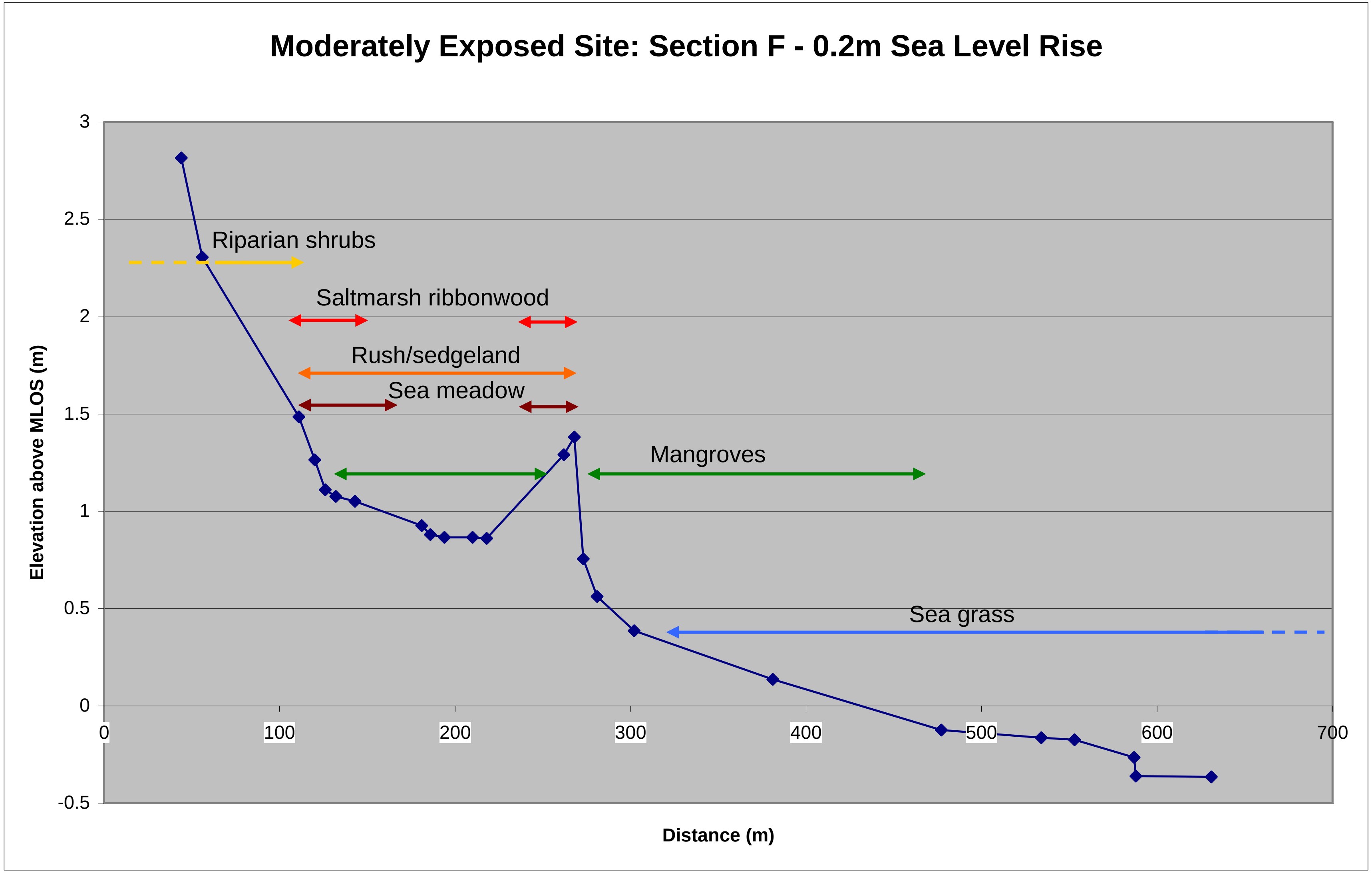


Figure 20: Typical cross-section of Moderately Exposed Site (see Figure 4 for location) – 0.2 m sea-level rise scenario

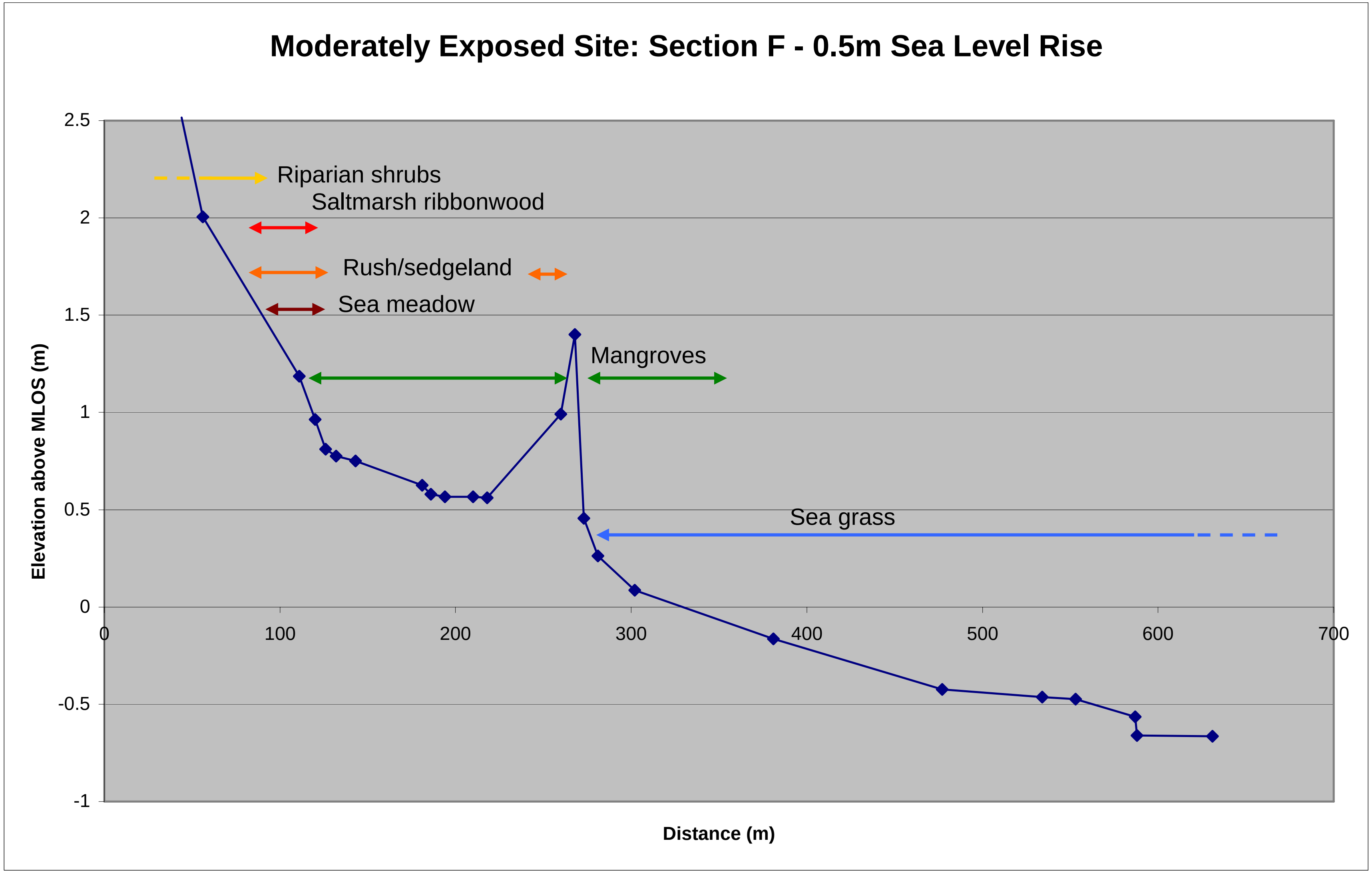


Figure 21: Typical cross-section of Moderately Exposed Site (see Figure 4 for location) – 0.5 m sea-level rise scenario

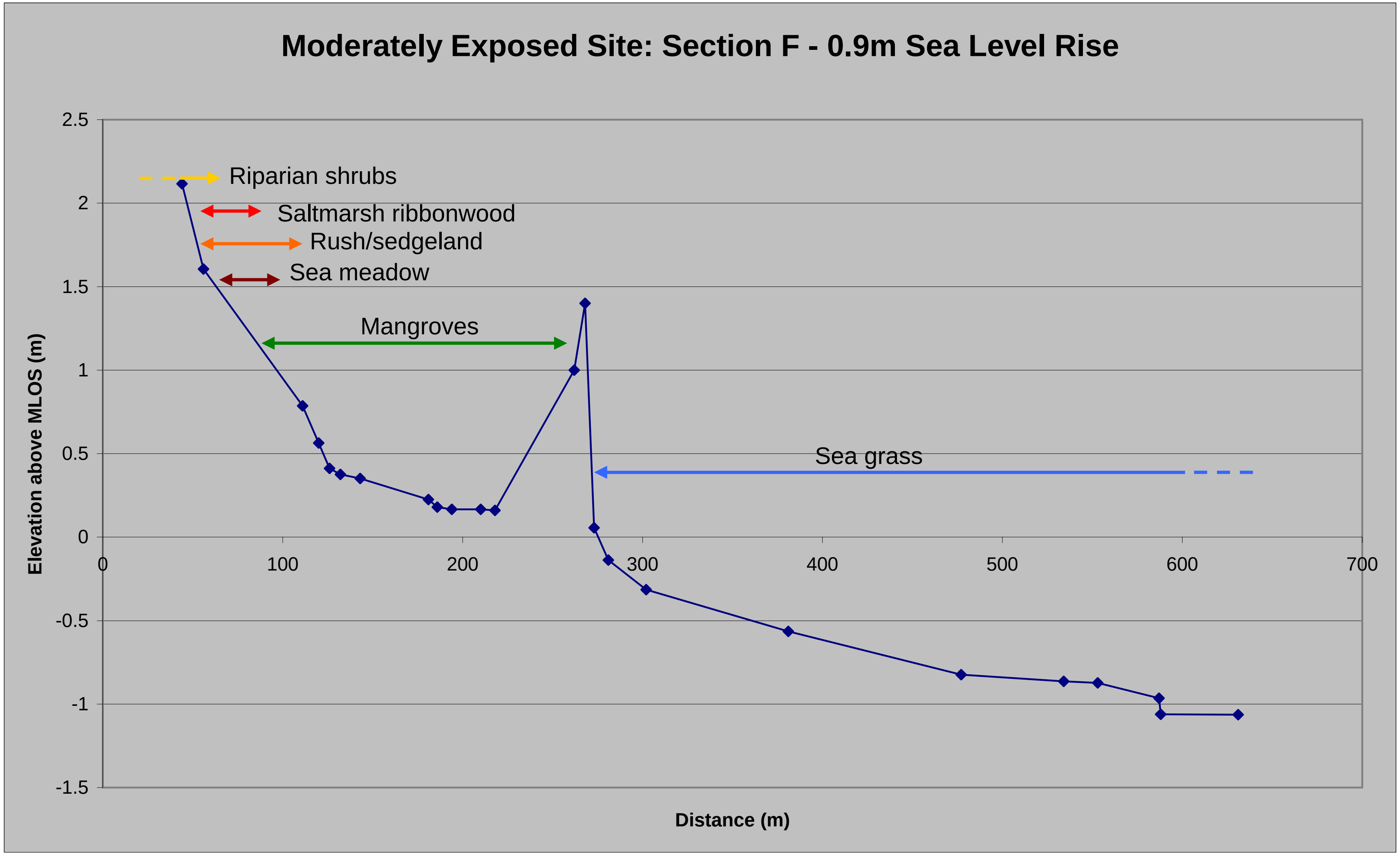


Figure 22: Typical cross-section of Moderately Exposed Site (see Figure 4 for location) – 0.9 m sea-level rise scenario

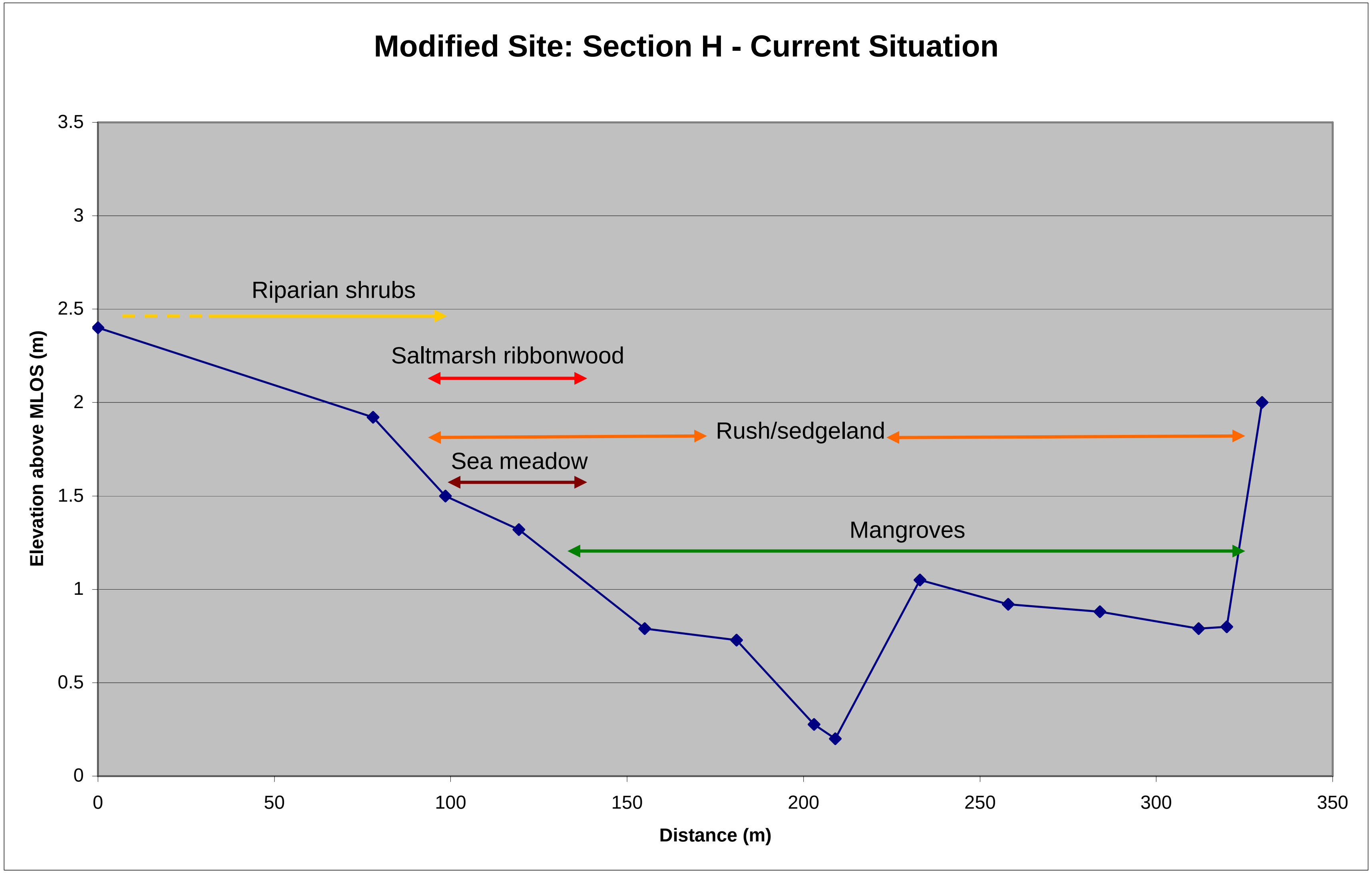


Figure 23: Typical cross-section of Modified Site (see Figure 5 for location) – current situation (assuming flap-gate removed)

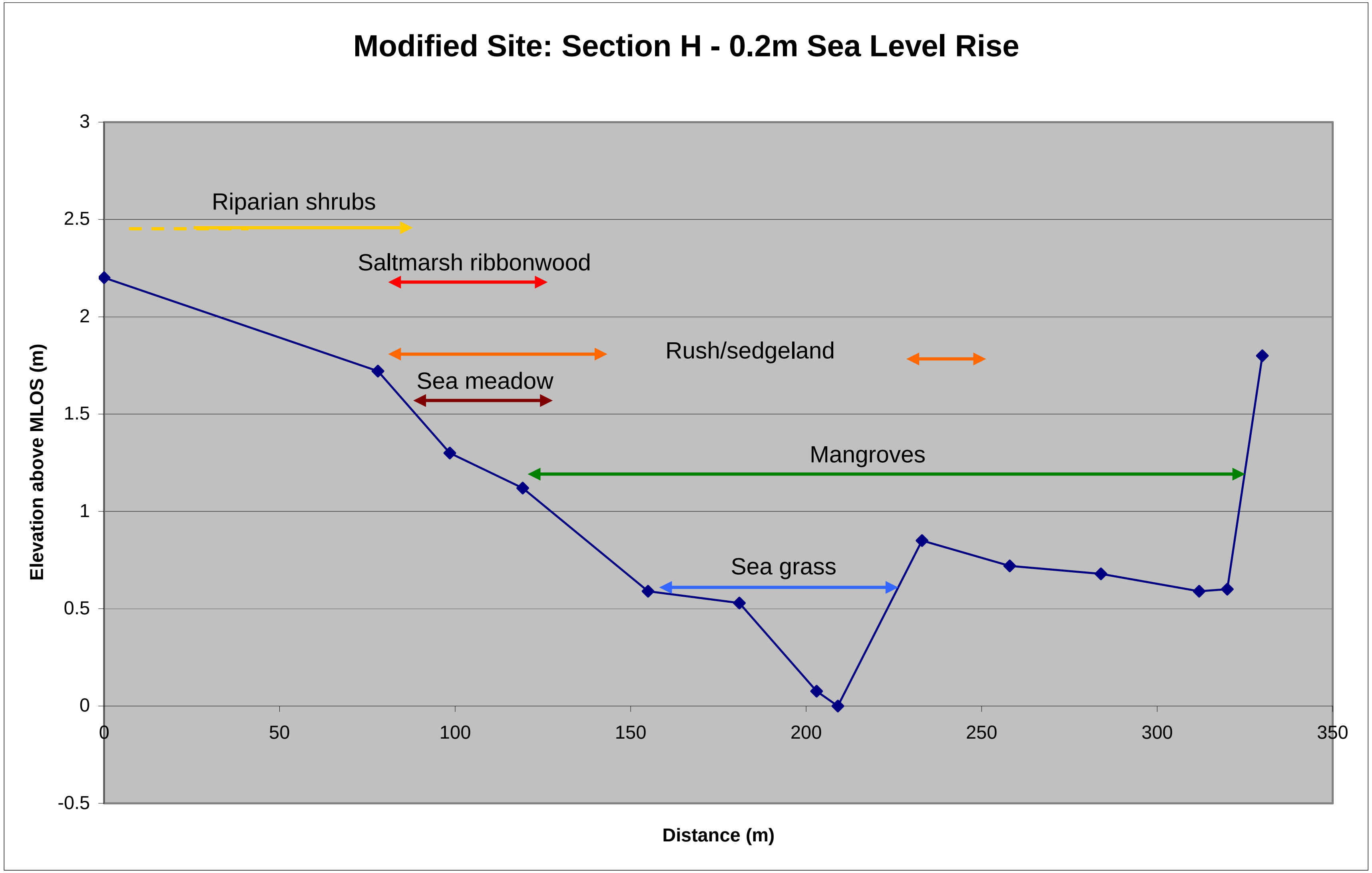


Figure 24: Typical cross-section of Modified Site (see Figure 5 for location) – 0.2 m sea level rise scenario (with flap-gate removed)

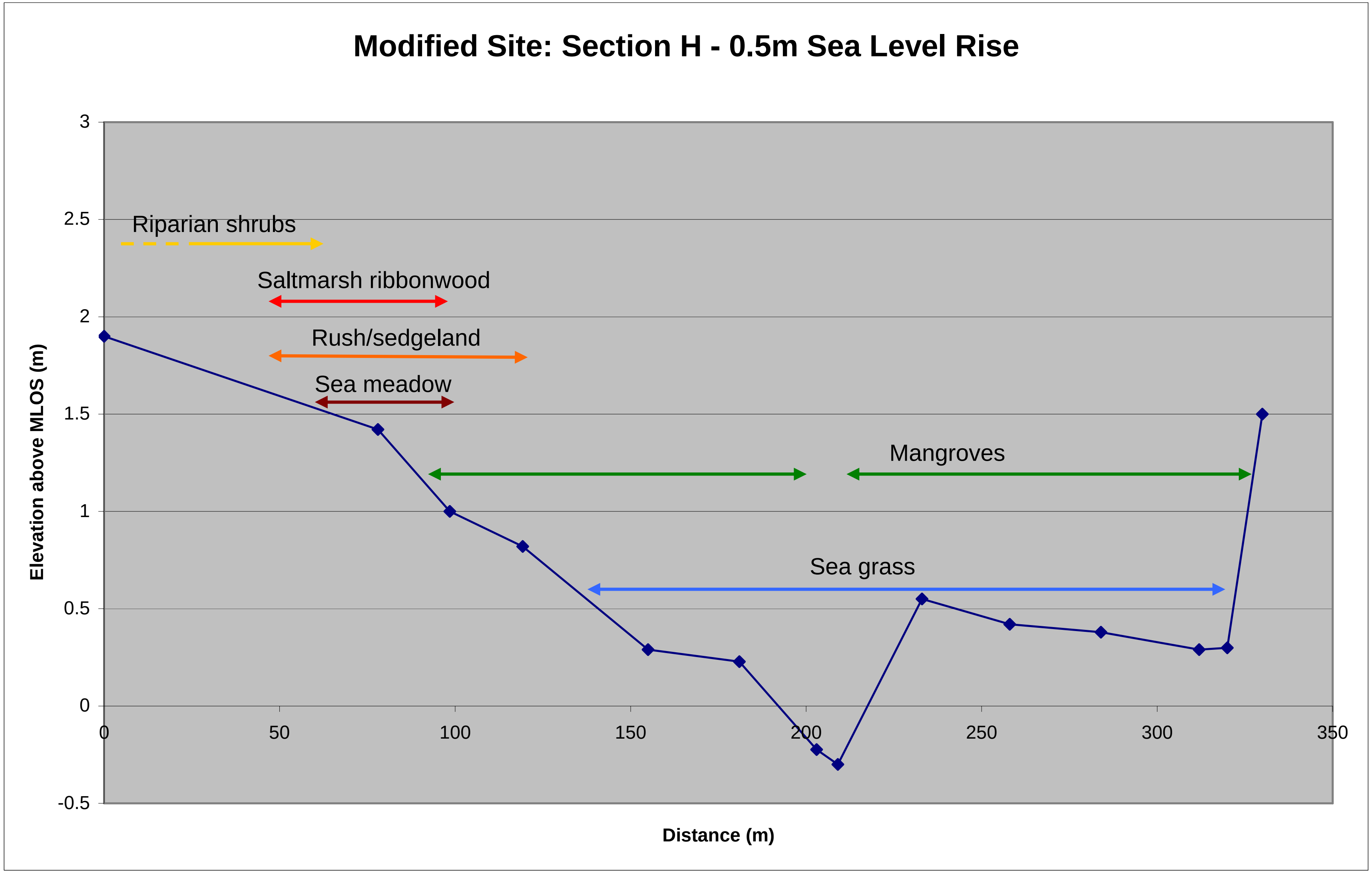


Figure 25: Typical cross-section of Modified Site (see Figure 5 for location) – 0.5 m sea level rise scenario (with flap-gate removed)

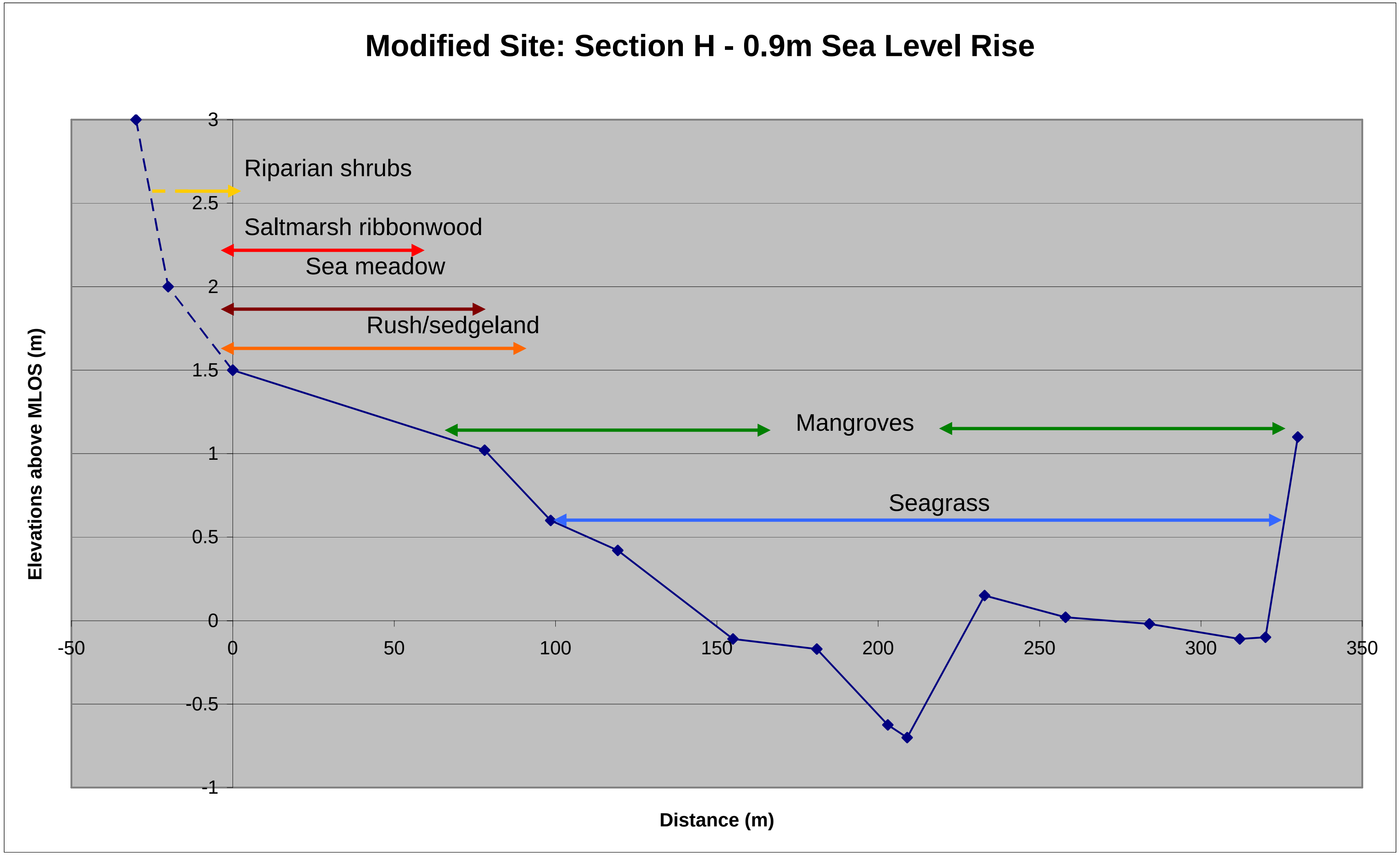


Figure 26: Typical cross-section of Modified Site (see Figure 5 for location) – 0.9 m sea level rise scenario (with flap-gate removed) The approximate landward rising topography is shown with a dashed line.

References

Dahm, J. and Munro, A. 2002: *Coromandel Beaches: Coastal Hazards and Development Setback Recommendations*. Environment Waikato Technical Report 02/06, April 2002. 132p + apps.

IPCC, 1991: *Climate Change 2001 – The Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 881p.

Hume, T.M. and Dahm, J. 1992: *An Investigation of the effects of Polynesian and European Land Use on Sedimentation in Coromandel Estuaries.* DSIR Marine and Freshwater Consultancy Report No. 6104. DSIR, Water Quality Centre, Hamilton, 56p + appendices.

Appendices

Appendix 1: Estuarine vegetation communities

Figure A: Open mud and seagrass boundary – looking south towards Preeces Point.

Figure B: Dense mangrove boundary with open mud – south of Fureys Creek.

Figure C: Rush and sedgeland (sea rush, oioi and marsh clubrush) opposite Strongman Road.

Figure D: Sea rush and glasswort boundary.

Figure E: Saltmarsh ribbonwood and oioi boundary, Fureys Creek

Figure F: A natural manuka wetland edge between Preeces Point and Whangapoua Road. Pampas can also be commonly found around the wetland edge.

Figure G: Red matipo – south of the Waiau River mouth.

Figure H: Coastal tree daisy *Olearia solandri* – south of the Waiau River mouth.

Figure I: Clear boundaries between sea rush, oioi, saltmarsh ribbonwood (and pampas), Isolepis nodosa, and riparian shrubs (manuka and red matipo) – south of the Waiau River mouth.

Figure J: A paddock abutting the Long Bay Road wetland.

Figure K: A kikuyu and tall fescue paddock next to harbour vegetation south of Fureys Creek.

Appendix 2: Benchmarks

Benchmark A

Coordinates: E2731736 N6491346

Location and Description: Road bridge at northern end of causeway. Benchmark is top and southern end of the concrete bridge wall on the seaward side of the bridge.

Elevation: RL 3.18 above MLOS (April 2006)

Benchmark D

Coordinates: E2732937 N6490133

Location and Description: Jacks Pt boat ramp. Top of pole on eastern side of the ramp. Fifth pole seaward from last of the white tipped poles.

Elevation: RL 2.59 above MLOS (April 2006)

Benchmark E

Coordinates: E2733150 N6490200

Location and Description: Jetty adjacent to and behind Strongman Engineering on eastern and true left bank of Fureys Creek. Benchmark is top of the second last pile on the river side and seaward end of the jetty and is cut off below the level of the deck. (The last pile is on the downstream corner and is elevated well above the deck).

Elevation: RL 1.971 above MLOS (April 2006)

Benchmark F

Coordinates: E2733969 N6487355

Location and Description: Post on western side and seaward end of air strip. For the purposes of the survey, we added a concrete pad to lift the laser beam 22.5 cm above the top of post. So the top of the post is 22.5 cm below the benchmark elevation given (i.e. RL 3.108 m).

Elevation: RL 3.333 above MLOS (April 2006)

Benchmark G

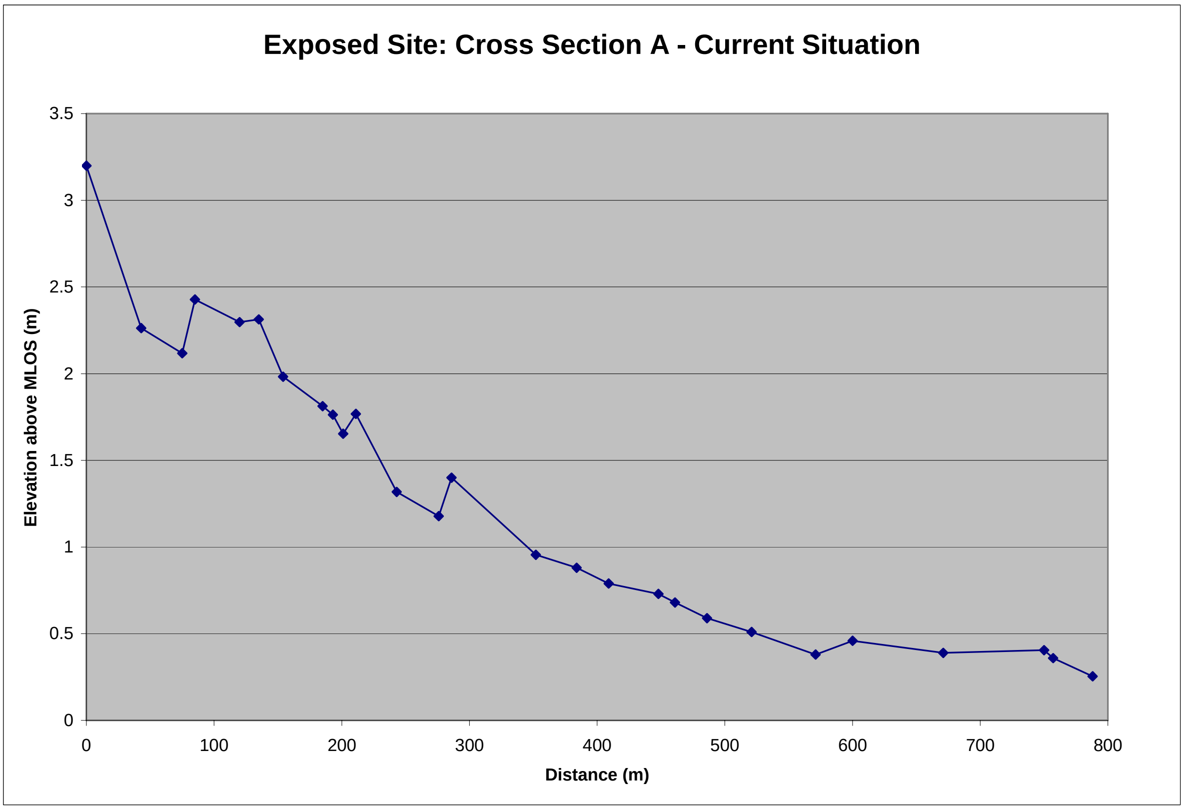
Coordinates: E2733973 N6486776

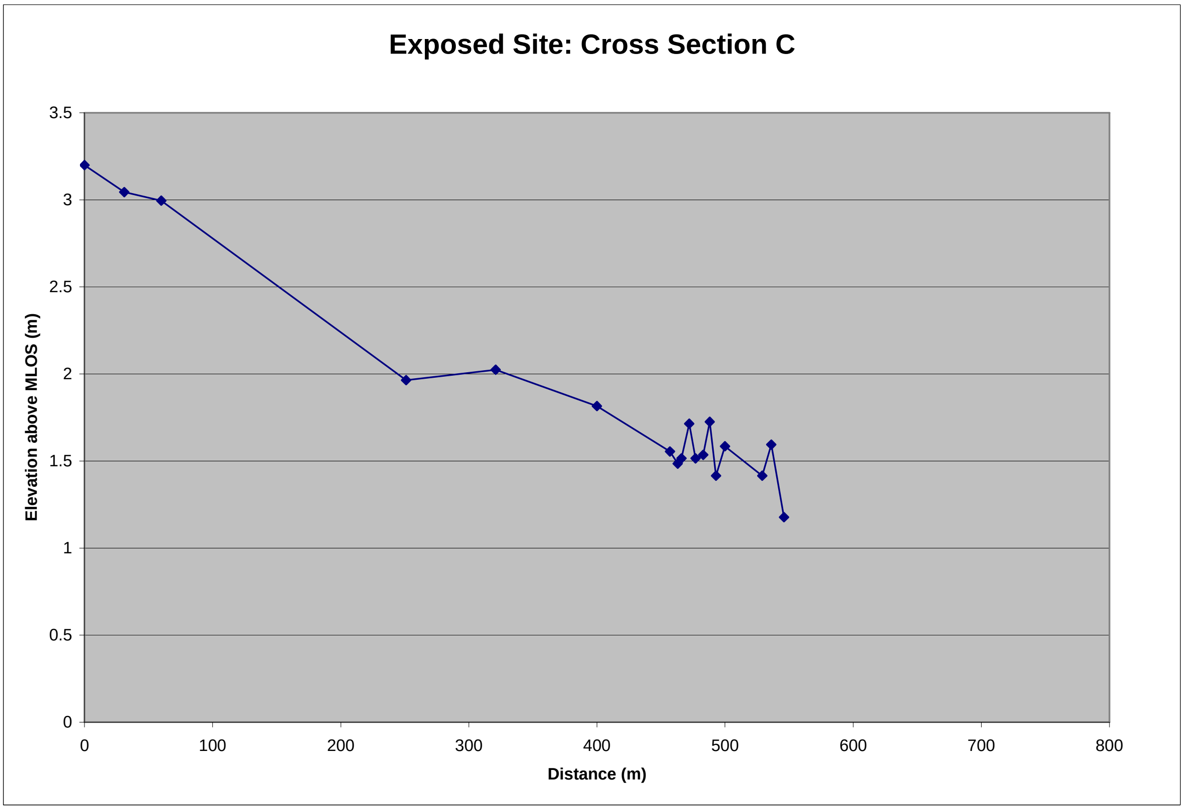
Location and Description: Ground level on immediate eastern side of corner post (i.e. inside paddock)

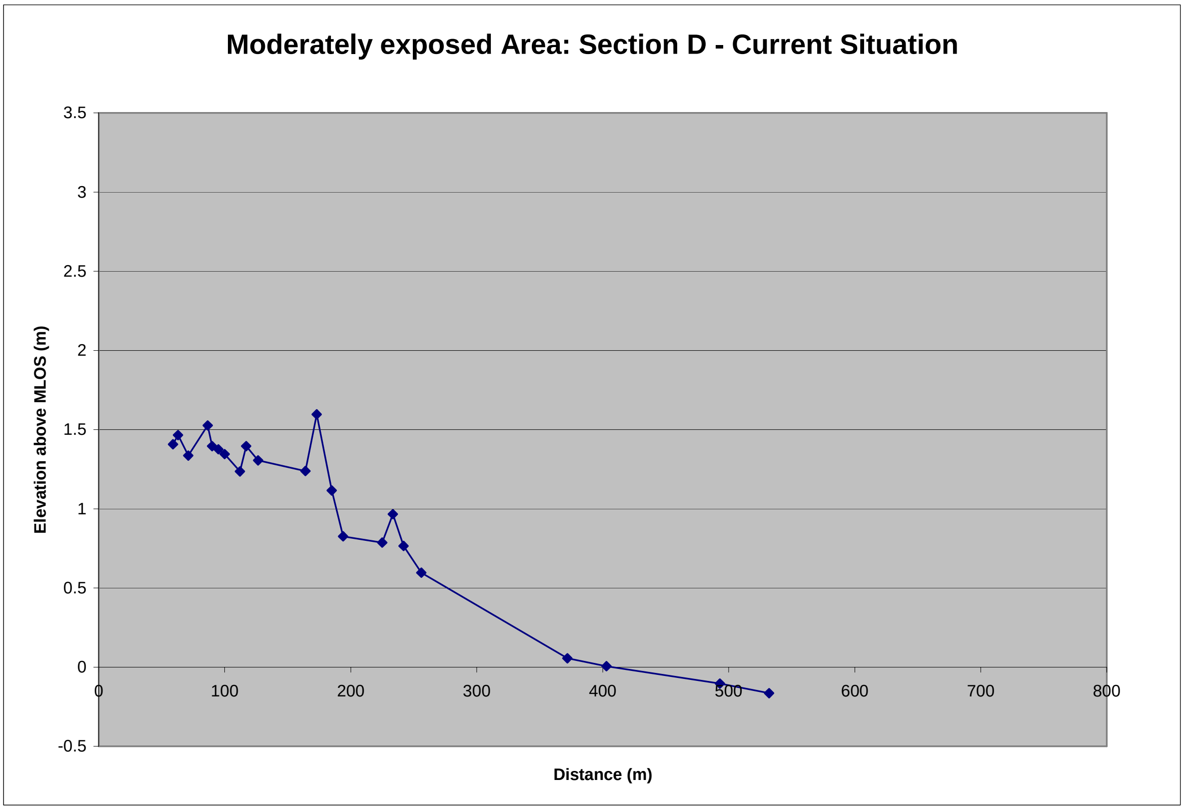
Elevation: RL 1.82 above MLOS (April 2006)

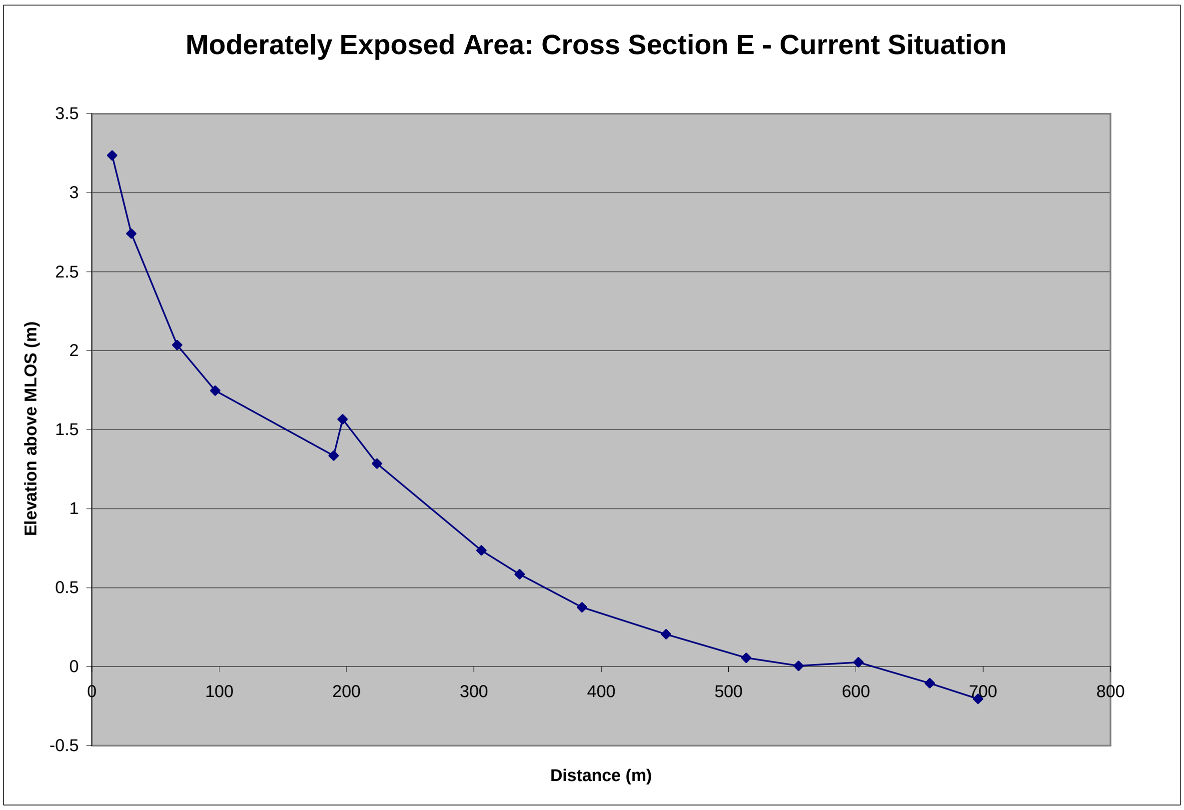
Appendix 3: Additional cross-sections

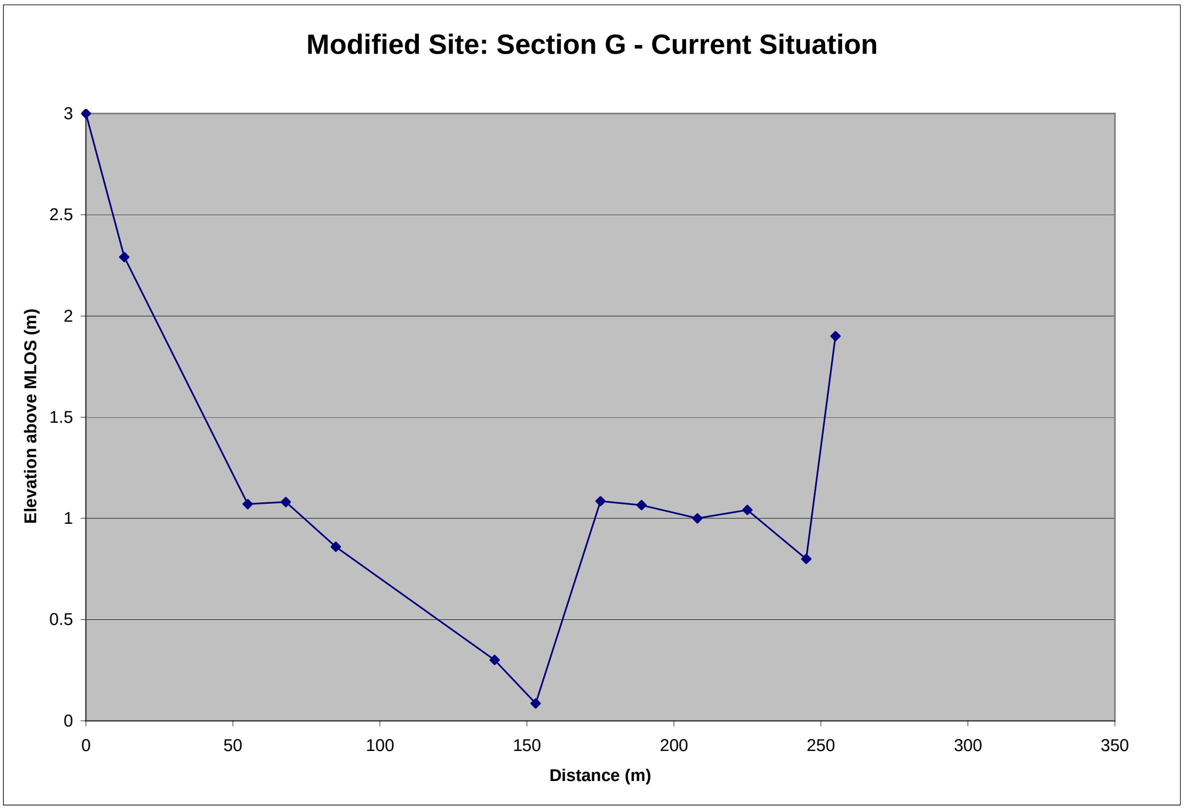
Refer to Figures 3-5 for location of cross sections.

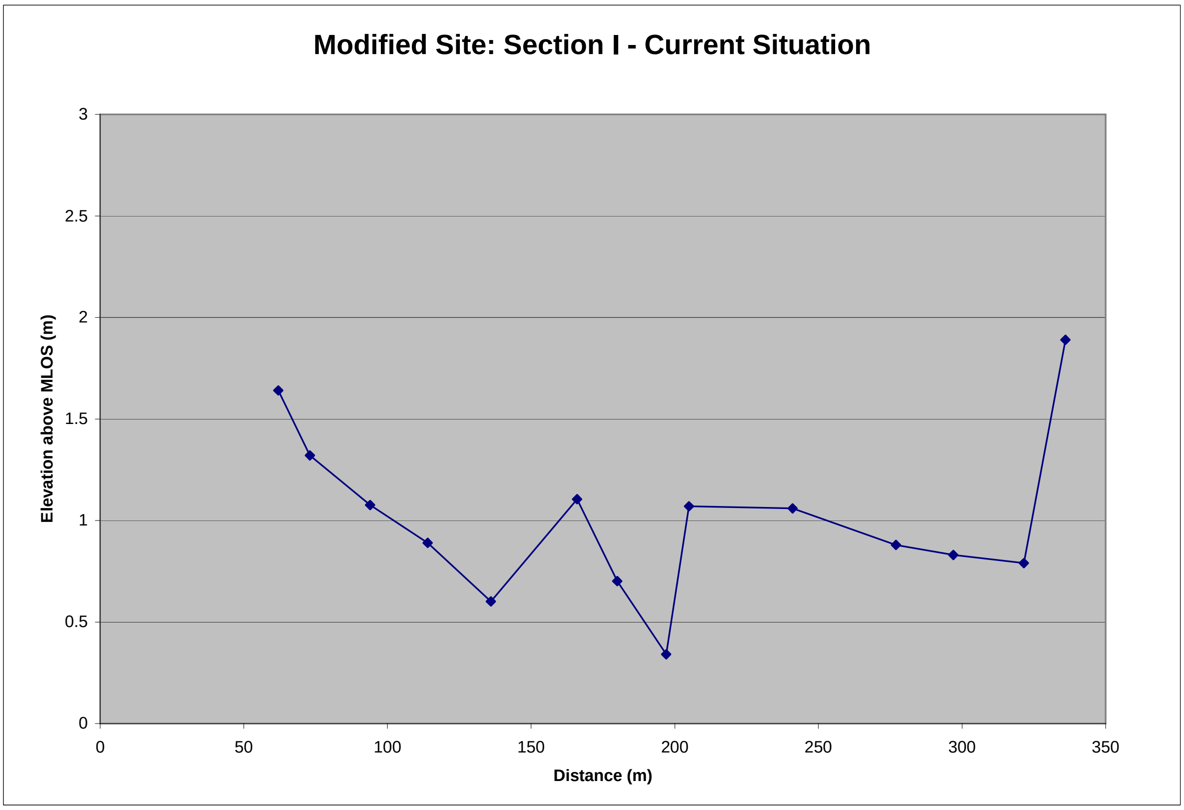


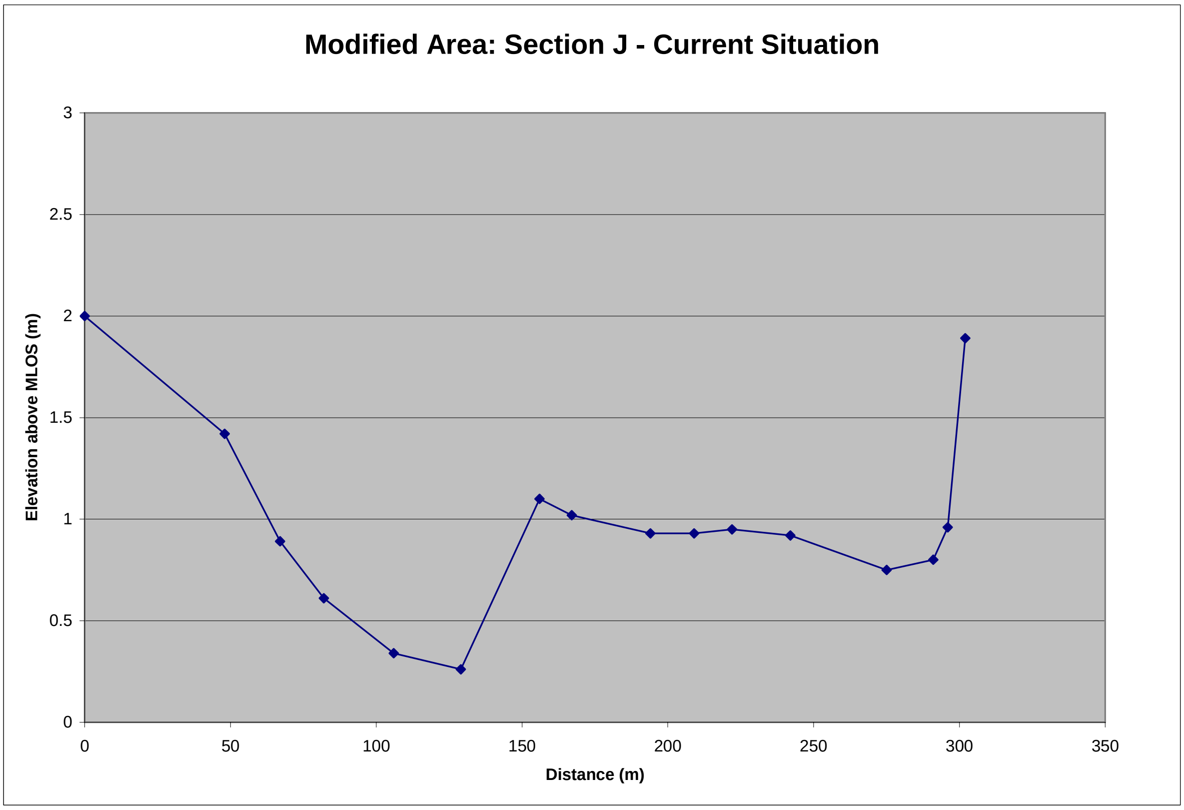


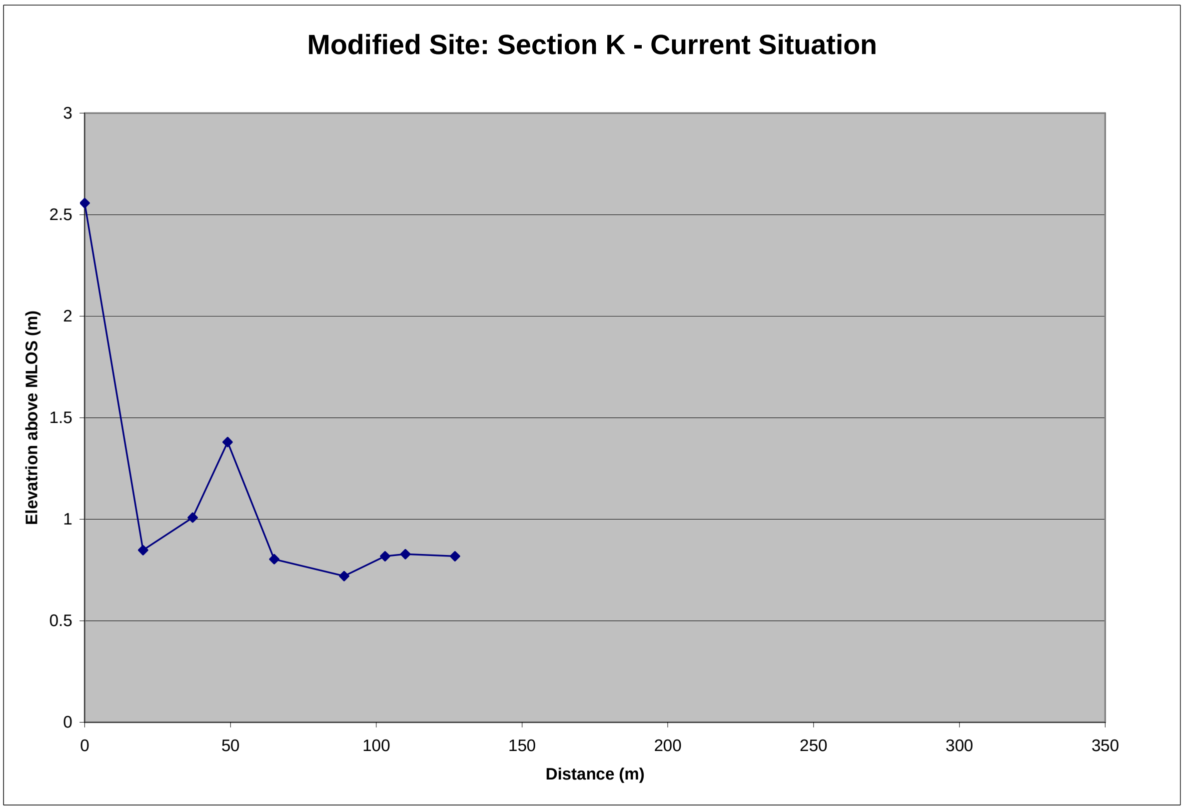

Moderately exposed Area: Section D - Current Situation
Elevation above MLOS (m)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
100
200
300
400
500
600
700
800
Distance (m)


Moderately Exposed Area: Cross Section E - Current Situation
Elevation above MLOS (m)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
100
200
300
400
500
600
700
800
Distance (m)


Modified Site: Section G - Current Situation
Elevation above MLOS (m)
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
Distance (m)


Modified Site: Section I - Current Situation
Elevation above MLOS (m)
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
Distance (m)


Modified Area: Section J - Current Situation
Elevation above MLOS (m)
Distance (m)
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350


Modified Site: Section K - Current Situation
Elevatrion above MLOS (m)
Distance (m)
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350