ISLED - WORK PACKAGE 3.
REPORT ON THE WORK COMPLETED BY L A B COASTAL

INTRODUCTION

The sedimentation studies done by L A B Coastal under Work Package 3 of the ISLED programme included the following three items. Annual salt marsh accretion rates were determined by the use of erosion/accretion transects at the three Westerschelde sites. Daily sediment deposition rates at these sites were determined directly using filter paper sediment traps. Interactions between the effects of sediment deposition rates and duration of tidal inundation on seedlings of selected salt marsh plants were studied in experimental mesocosms in the greenhouse.

ANNUAL SALT MARSH ACCRETION RATES

Erosion/accretion transects were established in June 1998 at Ritthem (9 transects in 3 rows across the whole marsh), Ellewoutsdijk (10 transects in 4 rows across the west end of the marsh) and Waarde (11 transects in 3 rows across the east end of the marsh). Each transect consisted of two permanent markers 2 m apart and soil surface levels were measured at 100 mm intervals between the markers; this technique had been shown to be an effective way of determining accretion rates (Boorman, *et al*.,1996 & Boorman, *et al*., 1998). The transects were recorded nine times during the following two years.

There were marked differences between the three Westerschelde sites in the mean annual rates of accretion; Ritthem showed the lowest rate at 2.09 mm yr^{-1} and Waarde the highest at 12.15 mm yr^{-1} with Ellewoutsdijk intermediate at 2.58 mm yr^{-1}. The low rate for Ritthem reflects the extent of erosion in parts of this very dynamic site. This is shown in the very variable rates of accretion at Ritthem where there were changes in surface level varying from -22.8 mm to +17.4 mm over 27 months. The results from Ellewoutsdijk were less variable and higher with a mean annual rate of 7.4 mm from individual transect results which varied between 4.2 and 35.5 mm (over 27 months). The mean rate of accretion at Waarde was consistently higher than at Ellewoutsdijk even though the average altitude of the transects was higher at Waarde. The lower mean rate of accretion at Ellewoutsdijk as compared to Waarde can be explained by much lower rates of accretion or even actual erosion in some of the sampling sites within the marsh at Ellewoutsdijk. In contrast the sites at Waarde showed relatively constant rates of accretion right across the marsh.

The rates of accretion varied with the major marsh zones in the three marshes (pioneer marsh at an average level of 1.5 m NAP, middle marsh at 2.6 m NAP and high marsh 2.8 m NAP). The combined data for the pioneer zones showed the lowest average annual rate of accretion (3.47 mm yr^{-1}) but this figure included data from sites where there had been significant erosion and from sites with marked accretion. If the eroding areas were excluded, the mean rate of accretion was similar to the much higher rates observed in other marsh zones (7.05 mm yr^{-1}). The majority of the accretion sites were in the middle marsh zone, reflecting the abundance of middle marsh across the three marshes, and the middle marsh showed the highest rate of accretion (9.02 mm yr^{-1}). Within the middle marsh the sites where *Triglochin maritimum* was the dominant species showed a relatively constant rate of accretion (6.49 mm yr^{-1}). This may reflect the ecological and structural uniformity of stands of this species. The high marsh had a consistently low rate of accretion (4.12 mm yr^{-1}). This reflects the much lower frequency and duration of tidal cover in these areas which limits the total sediment load available for deposition..

DAILY SEDIMENT DEPOSITION RATES

The daily rate of deposition of sediment was measured directly using filter papers pinned to the surface of the mud for the duration of two consecutive tides (Boorman, *et al*.,1996). This type of trap was tested further and the results showed that it gave similar results to other forms of sediment traps currently in use. Measurements on the rates of sediment deposition were done near the seaward edge of the marshes at all three sites in the Westerschelde during September 1998, July 1999, September 1999 and September 2000. The depth of sediment deposited was determined from the weight of sediment deposited per unit area and, after allowing for the frequency of tidal inundation at the level of the papers, an estimate was made of annual rates of accretion. The sites used were situated in middle marsh and pioneer marsh, and had flooding frequencies of between 150 and 350 tides per year (21 - 50 % inundation).

The highest annual rate of sediment accretion was recorded at Ellewoutsdijk (24.0 mm) with the lowest at Ritthem (16.9 mm); Waarde was intermediate (21.6 mm). Waarde showed the least variation in rates of sediment deposition between the four sampling periods (Max. = 26.7 mm - September 1998, Min. = 16.5 mm - July 1999) and Ritthem the greatest variation (Max. = 44.7 mm - July 1999, Min. = 5.5 mm - September 1998). There was considerable variation in the mean rates of deposition of sediment between the four sampling periods varying between a mean of 11.8 in September 1998 and 28.5 in July 1999. These differences were, however, not consistant between the three sites; the highest rate at Ritthem was in July 1999, for Ellewoutsdijk it was September 2000 and for Waarde September 1998). This may be largely explained by geographical differences between the sites and the strength and direction of the wind just before and at the time of the measurements. For example the very high rates of sediment deposition recorded at Ritthem in July 1999 can be explained by the large increase in sediment load caused by wave action from on-shore winds on the outer flats as the tide began to flood.

The turbidity of the water at the seaward edge of the marsh was lowest at Ritthem and increased up the estuary to a maximum at Waarde. At Ellewoutsdijk the turbidity at the marsh edge was up to fifteen times greater than a few metres offshore indicating that the sediment was primarily of local origin. This view was supported by the existence of high rates of cliff erosion in the western half of the marshes.

EFFECTS OF SEDIMENT DEPOSITION RATES AND DURATION OF TIDAL INUNDATION ON SEEDLINGS OF SALT MARSH PLANTS

The effects of high rates of sedimentation on seedlings of key salt marsh plant species when under stress from high rates of inundation were tested in specially constructed tidal mesocosms. Tidal regimes of 2.50, 1.75 and 1.00 hours inundation per tide were used and these corresponded to the lowest levels of pioneer marsh, to the highest pioneer marsh and to the lower edge of the middle marsh respectively. Sediment was added every fourteen days and the quantities added corresponded to annual rates of accretion of 0, 10, 30 and 60 mm yr^{-1}. Seedlings of *Aster tripolium, Salicornia europaea*, *Limonium vulgare* and *Triglochin maritimum* were subjected to tests for periods of approximately two months (Boorman, *et al*., in press).

Plants of *Aster* showed a marked increase in shoot weight with increasing rates of sediment addition. The plants subjected to sediment deposition responded by producing new roots from the buried section of the stem. Increased rates of sediment deposition also resulted in increases in leaf length and width. The number of leaves on Aster remained more or less constant with the older leaves dying and being replaced. Although the high inundation frequency corresponded to the lower limits of *Aster* there was little difference in the response of *Aster* to rates of inundation.

Salicornia plants showed a similar response to *Aster* but without visible effects on the roots. The plants appeared to be benefiting from the improved anchorage as a result of burial even in the sheltered conditions in the mesocosms. Shoot height was measured from the soil surface so the full increase in shoot height was even greater than indicated by the measurements. Increased duration of inundation caused a reduction in both shoot height and root length but an increase in the root weight.

The growth and survival of *Limonium* plants were significantly reduced by sediment addition. The highest rate of sediment addition reduced the percentage survival of plants during the experiment from 90 % to 10 %. This was explained by the repeated loss of leaves by burial and root growth was also greatly inhibited. It was noted that leaves were dying prematurely as a result of burial and the leaves which grew to replace those lost were smaller. Even the sediment rate equivalent to 30 mm yr^{-1} resulted in a reduction in plant survival of more than 30% and a reduction in plant weight of more than 20%.

The growth of *Triglochin* seedlings was largely unaffected by sediment addition, although the leaves grow longer at the higher rates of sediment addition. It should be noted that *Triglochin* plants grew the best when subjected to the lowest duration of inundation. The germination and establishment of *Triglochin*, in terms of the numbers of plants surviving, was favoured by increasing rates of inundation but establishment was unaffected by the rate of sediment addition.

DISCUSSION

While long-term (decadal) sedimentation rates, even in a dynamic area like the Westerschelde, are generally quite low and typically of the order of a few millimetres per year these studies have shown that within these mean rates there is considerable variation with episodes of rapid accretion or major erosion alternating with quiet periods with slow rates of change. The survival of any salt marsh depends on the ability of the vegetation cover to respond to change. In general in a marsh having, for example, a long term accretion rate of 3 mm yr^{-1} and an increase in the rate of sea level rise from 1.5 mm yr^{-1} to 2.5 mm yr^{-1} it might be assumed that the salt marsh would be likely to survive even without any increase in the mean rate of accretion. Any increase in accretion rates might be expected to be beneficial however if there were high rates of accretion the vegetation might not be able to respond. Similarly although in theory marshes can respond to rising sea levels by landward migration this process will only be effective if the salt marsh plants are able to withstand the enhanced rates of accretion that generally follow the erosion of the lower marsh zones and if the changes are sufficiently slow for the necessary changes in the vegetation to occur.

Overall sediment budgets for whole estuaries are clearly very important but the current studies indicate the importance of the recycling of material within individual salt marsh/mud flat systems. It was noted, for example, that high rates of sediment deposition at Ellewoutsdijk seem to be linked to the erosion of material from the cliff face at the seaward edge of the marsh. It was calculated that the material being lost from cliff erosion in the western half of the marsh corresponded closely with the material required to account for the measured annual rate of accretion over a period of three years. It was also estimated that with the great extent of mudflats fronting the marsh only small amounts of material would be need to maintain marsh accretion rates. While these studies showed clearly both the variation in sediment deposition rates and in net accretion rates differences between these two figures showed that there was also significant recycling of sediment within the salt marsh itself. Although the vegetation cover would increase the stability of deposited sediment; water flow while the marsh was covered by the tide and also rain-wash could remobilise this freshly deposited sediment within the marsh system. It has not proved possible to determine the extent of this internal sediment recycling in either space or time. but differences between rates of sediment

deposition and net accretion rates suggest that it is likely to be significant factor in the overall pattern of salt marsh accretion. The erosion of fresh sediment during heavy rain has been directly observed in these marshes.

In addition to accretion resulting from secondary sediment movement, both the measurements of accretion from the accretion/erosion transects and the direct measurements of sediment deposition showed that even quite modest long term rates of accretion could conceal very much higher short-term rates (periods from one tide up to several months). The mesocosm studies indicated that even the more sensitive marsh species were only likely to be affected seriously by sediment deposition corresponding to rates of accretion equivalent to 30 mm yr^{-1}. These are rates approaching an order of magnitude greater than the typical long term accretion rates observed in the field. The mesocosm studies also showed that even as little as two months of enhanced accretion could have fatal results for some marsh plants. Field data indicated that over such periods local sedimentation rates were often as high as annual equivalents of 30-40 mm yr^{-1} and not infrequently as high as 50-60 mm yr^{-1}; rates that are highly likely to have negative consequences for the vegetation, particularly those plant species with a rosette or prostrate growth form in their early stages of growth.

The plant species characteristic of the lower salt marsh, *Aster* and *Salicornia*, were not only tolerant of high frequencies of inundation but they were also the most tolerant of high rates of sediment addition (even benefiting from it) whereas the higher marsh species *Limonium* was intolerant of anything more than moderate rates of accretion. Interestingly, *Triglochin*, which often occurs in the Westerschelde marshes (and elsewhere) in areas where there has been some form of disturbance appeared to be particularly tolerant of high rates of accretion although rather sensitive to the higher inundation frequencies.

There appear to be three crucial problems in assessing the likely effects of changing sedimentation rates on salt marsh vegetation. Firstly consideration must be given to the intolerance of seedlings and small plants of key salt marsh species to high rates of sediment deposition; either in particular places or over relatively short periods of time. Plants can still be affected even when there are only moderate overall annual accretion rates for a particular area. At present it is very difficult to predict the details or even the extent to which sediment can recirculate with the salt marsh system and there are implications here both in regard to the effect of the vegetation on sediment deposition (Boorman, *et al*., 1998) and the effect of sediment deposition on the vegetation. Finally the vegetation may have the theoretical ability to respond to defined changes in sediment and inundation regimes but this will only hold true if the speed of these changes does not exceed the ability of the plants themselves to respond by migration and re-establishment..

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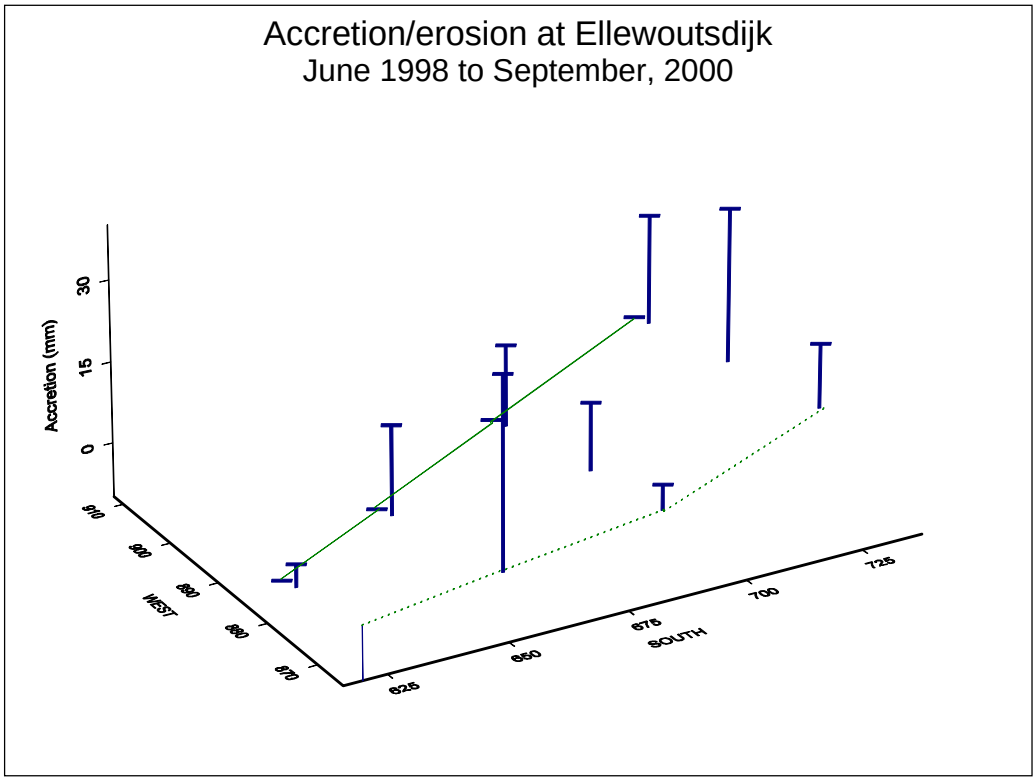
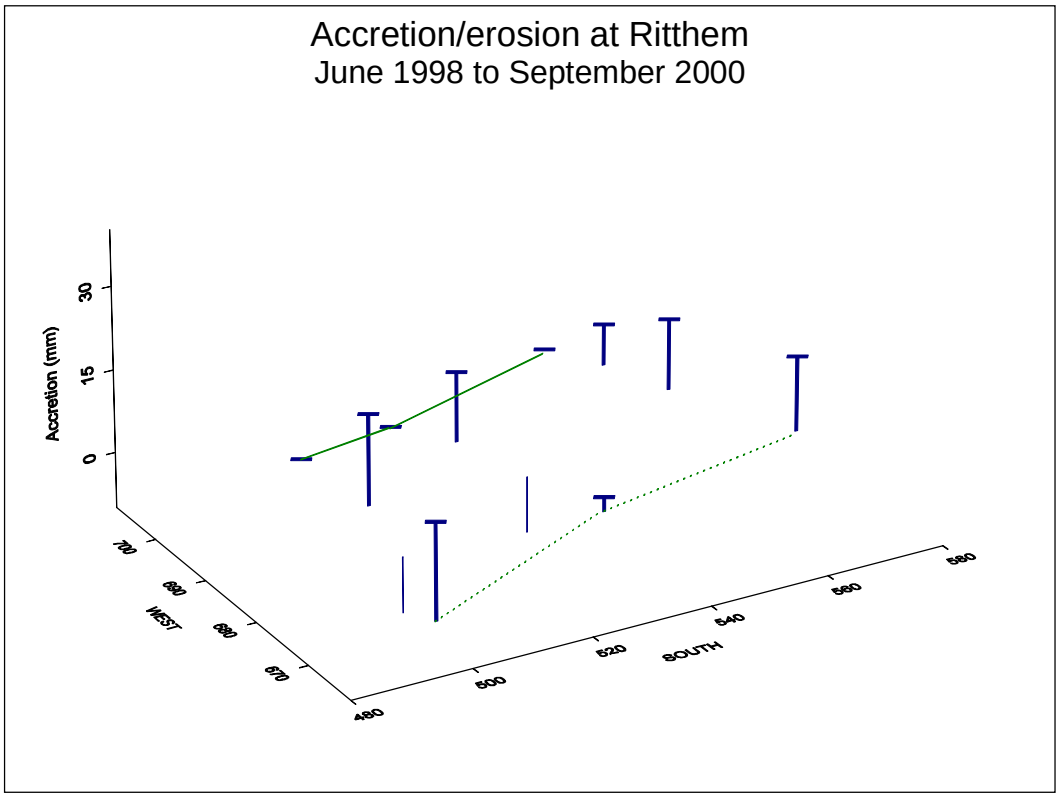
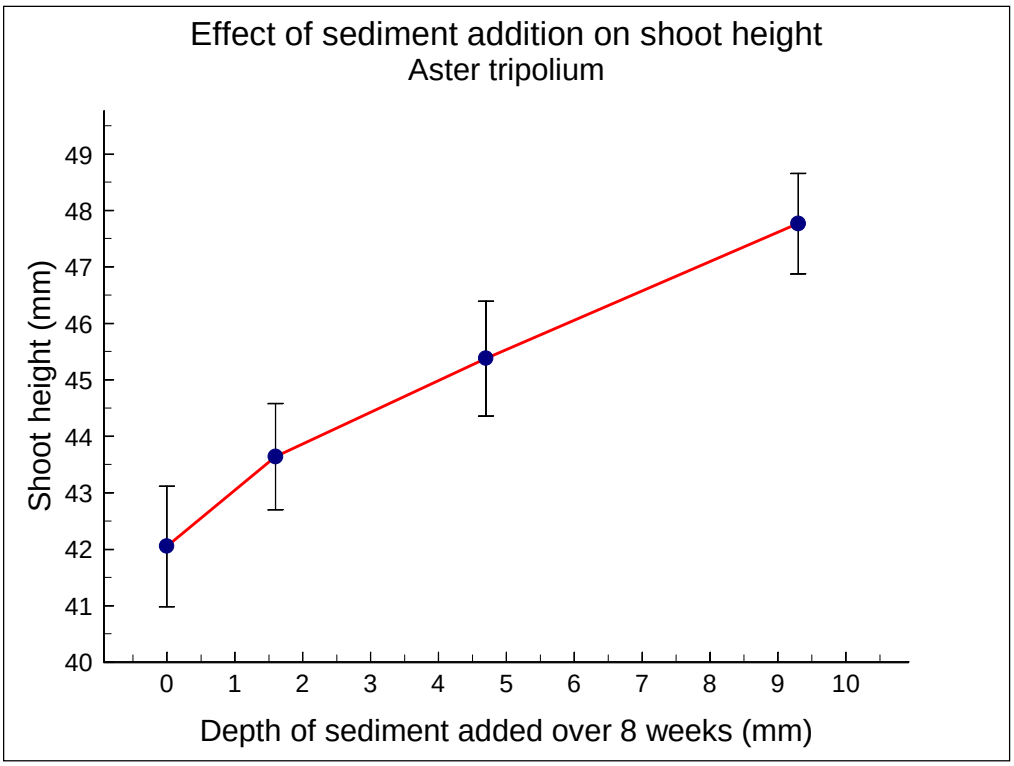
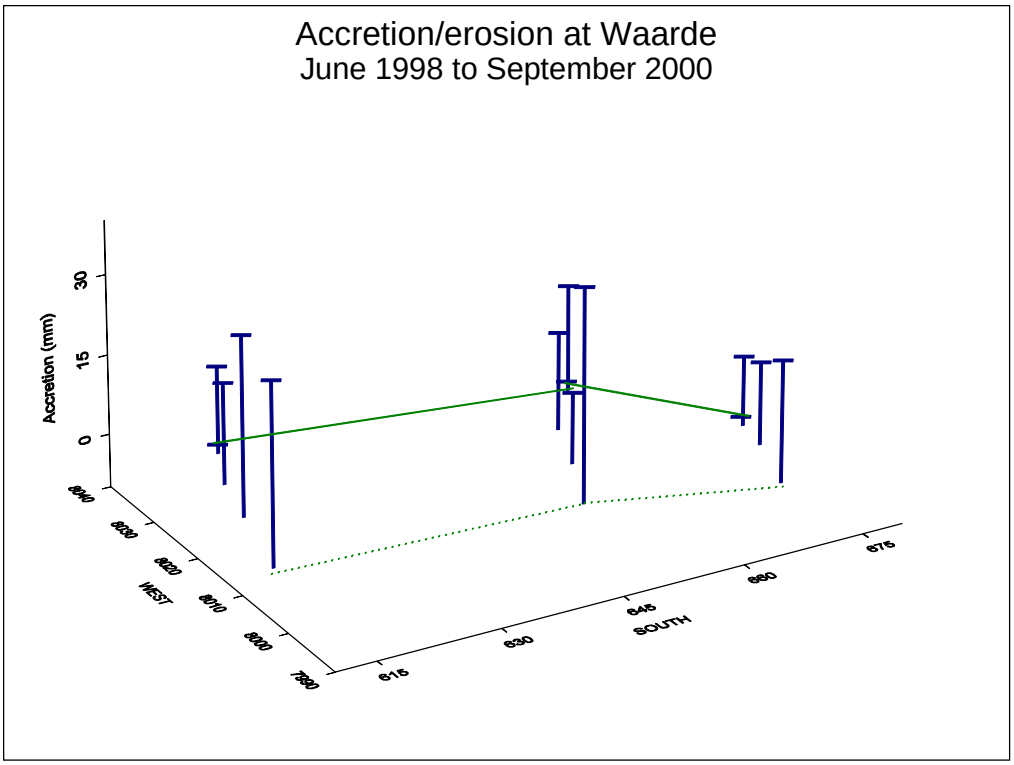
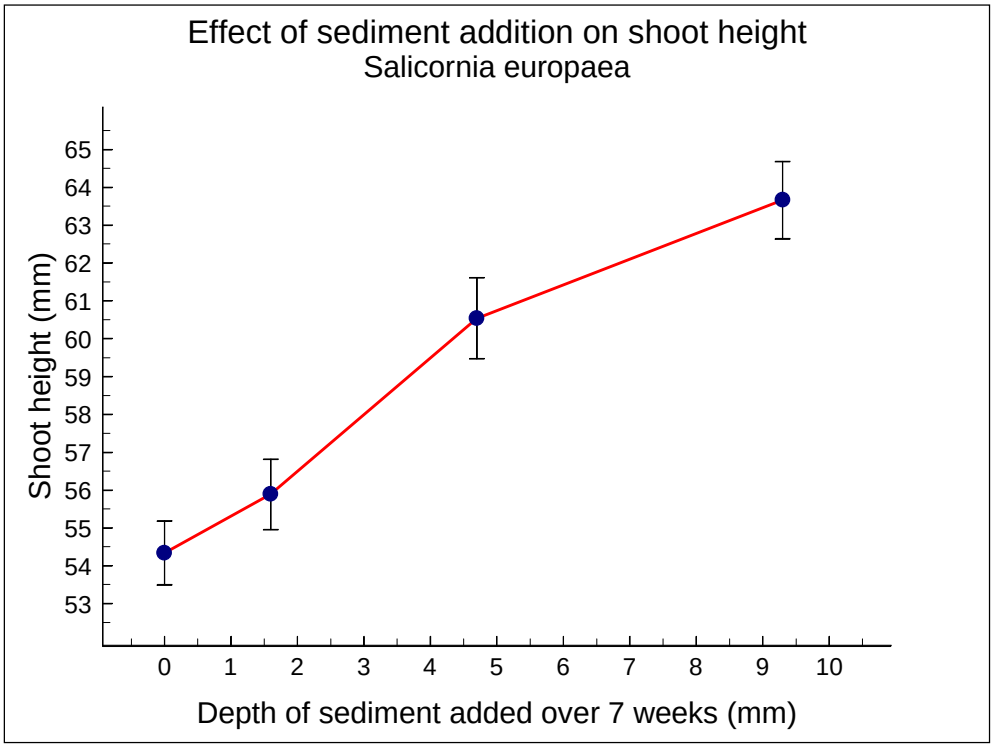

Accretion/erosion at Ellewoutsdijk
June 1998 to September, 2000
Accretion (mm)
30
15
0
WEST
690
680
670
SOUTH
625
650
675
700
725


Accretion/erosion at Ritthem
June 1998 to September 2000
Accretion (mm)
30
15
0
WEST
700
690
680
670
SOUTH
480
500
520
540
560
580


Effect of sediment addition on shoot height
Aster tripolium
Shoot height (mm)
49
48
47
46
45
44
43
42
41
40
0
1
2
3
4
5
6
7
8
9
10
Depth of sediment added over 8 weeks (mm)


Accretion/erosion at Waarde
June 1998 to September 2000
Accretion (mm)
30
15
0
WEST
SOUTH


Effect of sediment addition on shoot height
Salicornia europaea
Shoot height (mm)
65
64
63
62
61
60
59
58
57
56
55
54
53
0
1
2
3
4
5
6
7
8
9
10
Depth of sediment added over 7 weeks (mm)