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UNIVERSITY of GLASGOW

Department of Geography and Geomatics

Saltmarsh Sedimentation: Processes & Patterns

Heather McFerran

Thesis submitted to the Faculty of Physical Sciences for the degree of MSc (research)

May 2005

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Map Pocket: Map 1 (Figure 3.2.1.1)

Declaration

Except where specific reference is made to other sources, the work presented in this thesis is the original work of the author. It has not been submitted, in part or in whole, for any other degree.

Heather McFerran

Abstract

When considering the importance of saltmarsh dynamics it is important to understand the processes of saltmarsh sedimentation. Many authors have researched the importance of sedimentation on a saltmarsh via direct settling, but very few have analysed the role of vegetation and the implications it may have for sedimentation. Much opposition exists between researchers in establishing whether vegetation truly plays a role within the sedimentation dynamics on a saltmarsh. This thesis will investigate the importance of vegetation in relation to surface sedimentation on a saltmarsh and assess what temporal and spatial patterns exist.

Orchardton Marsh on the Solway Firth, Southwest Scotland, is unusual due to its colonisation by *Spartina,* which is normally confined to areas in Southern England. Three methods were employed to assess the role of sedimentation in relation to (i) direct settling and (ii) on-vegetation settling. Fieldwork was undertaken on a monthly basis over the period of 1 year.

The results demonstrate that vegetation within the saltmarsh system has a significant role in both temporal and spatial aspects. On-vegetation deposition was highest in the mature marsh. It was also found that the highest sedimentation amounts were recorded at creek edges. Thus, deposition of sediment is influenced greatly by vegetative and direct settling. Overall, long-term erosion is occurring on parts of Orchardton saltmarsh.

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Chapter 1

1.1 Introduction

The way in which saltmarshes accrete has attracted scientific attention for many years (Pethick, 1984, Cahoon & Reed 1995 and Harvey 2000) with studies mainly focusing on the rate of vertical accretion as a function of tidal inundation period (the hydro-period), marsh altitude, sediment supply and vegetation type (Chapman 1976, Pethick 1984, Hansom & May 2003). However, it appears that only limited attention has been given to the role of vegetation in sediment trapping/flocculation (Stumpf 1983, Grey 1992, Bieniowski 1999 and Harvey 2000). The work reported here aims to clarify the relationship between accumulation of sediment on vegetation relative to direct settling of sediment on the saltmarsh surface. From this overall aim the following can be identified that form the basis of specific objectives:

- What is the role of vegetation in relation to surface sedimentation on a saltmarsh?
- What spatial variations exist in the pattern of sediment trapped by vegetation and on the surface of vegetation with respect to other forms of surface sedimentation?
- What temporal variations exist in vegetation performance as sediment trappers?
- Can the future sedimentation patterns on this saltmarsh be predicted?

1.2 Definition of Salt Marshes and Their Formation

Saltmarshes can be defined as:

"areas of alluvial or peat deposits, colonised by herbaceous and small shrubby terrestrial vascular plants, almost permanently wet and frequently inundated with saline waters." Adam (1990)

1.3 Scottish Saltmarshes

Saltmarshes (See Figure 1.3.1) can be found distributed around the coasts of Scotland especially along moderate and low energy shorelines. They tend to develop in sheltered areas where physical factors such as wave exposure, slope of the land and tidal range are suitable. According to May and Hansom (2003), Scottish saltmarshes make up 15% of the total British saltmarsh area. Whilst saltmarshes in England and Wales are generally regarded as being muddier and dominated by *Zosteretum, Spartinetum, Asteretum, Saliconietum, Halimoionetum and Juncetum,* Scottish saltmarshes mainly consist of sandy sediment and are generally colonised by *Puccinellia maritima* (Hansom & May 2003). *Puccinellia maritima* is generally found on the middle/upper saltmarshes in East and West of Scotland. Sandy sediments lie at a higher point in the tidal range than muddy sediments; therefore *Puccinellia maritima* is common on most Scottish saltmarshes even at the seaward edge where it is eroding. It is generally true to state that *Spartina spp.* is common in England and Wales but not in Scotland. However, colonisation by *Spartina spp* has occurred in the Solway Firth. (Harvey 2000, Hansom 2003).

Map 4.2: Distribution of saltmarsh in the Solway (source: Burd 1989)

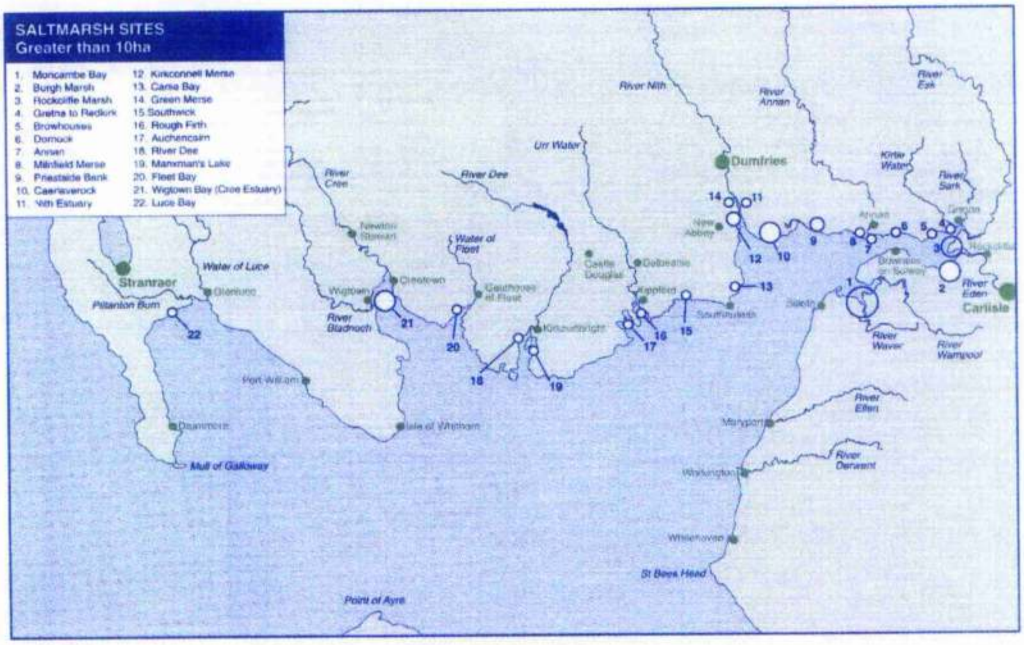


Figure 1.3.1 Source: Solway Firth Review, Solway Firth Partnership June 1996

The Solway Firth hosts the largest area of saltmarsh in Great Britain (Solway Firth Review, 1996). The saltmarsh ecosystem has an essential role within coastal processes, as well as being a salt tolerant environment and supporting many diverse species of plants. Saltmarshes act as breeding and feeding ground for wildfowl and are used as grazing for domestic sheep and cattle. In addition, the ability of the saltmarsh to reduce wave energy in the macro tidal regime of the Scottish coast provides a potential function in coastal protection that is both natural and successful. With the above in mind, it is of little surprise to find many of the Solway saltmarshes are of national conservation interest and are protected by SSSI and SPA status. (Hansom,2003).

In spite of the widespread interest in the Solway and generally, some aspects of saltmarsh development and sedimentation remain poorly defined. For example, the relative roles of sedimentation directly onto the saltmarsh surface, the role of vegetation enhancing surface sedimentation and the amount of sediment actually deposited onto vegetation surfaces have not yet been fully explored. According to Chapman (1976), the primary growth stage of a salt marsh is extremely irregular. Sediment deposition varies with tide and deposition in one tidal cycle can be removed in the next. Tidal currents are generally responsible for the distribution of seeds over the primary marsh area although waves have an effect on whether the germination of the seeds is successful. Germination depends on several factors i.e. competition, availability of space and resubmergence of the marsh area. As noted by Ranwell, (1972), a saltmarsh is only established when germinating seeds are completely free from tidal influence. Dijkema (In Beukema Et al.1990) argues that saltmarsh formation is optimal on coasts with low energy and adequate sediment supplies. Suitable surface elevation, tidal amplitude and drainage are also required as this ensures the oxygenation of the soil, which stimulates plant growth. Dijkema (1990) notes, that if these conditions are met then further development will result, eventually leading to an area inhabited by halophytic plants as illustrated by Figure 1.3.2

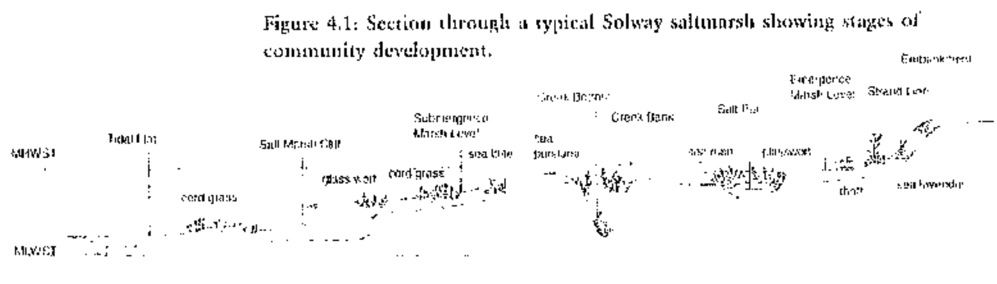


Figure 1.3.2 Source: Solway Firth Review, Solway Firth Partnership June 1996.

It is apparent from the research so far conducted that many authors more or less agree on definitions of saltmarshes and their general mode of formation, but several contentious issues surround saltmarshes and their detailed development. One such issue, the role of vegetation in relation to the overall sedimentation rates is dealt with below.

Chapter 2: Context

2.1 Salt Marshes and Topography

According to Harvey (2000), the overall pattern of accretion on saltmarshes relates to the relationship between the rate of sedimentation, the frequency of tidal inundation and the elevation of the marsh. With increasing sedimentation the marsh surface rises and leads to a decrease in hydroperiod as the tidal waters may no longer reach all parts of the marsh. French (1993) argues that with the above in mind, elevation is the principal control on long-term sedimentation. Whilst salt marshes are generally considered to be relatively flat, Dijkema et al (1990) suggest "conditions for salt marsh formation are best on a gently sloping shoreline with little wave energy and sufficient sediment supply". Figure 1.3.2 illustrates a typical Solway Firth saltmarsh.

In the primary stages of marsh development, small changes across the marsh surface can define the future development of the system. Trenhaile (1997) states that during development salt marsh tidal flats attain an elevation that encourages colonisation by perennial halophytic plants. Whilst tidal flats become stabilised with vegetation, small creeks form through the interior of the salt marsh system. Once these sinuous channels are formed, they are enlarged by the scouring action of the water as it runs off after each tidal cycle. (Chapman, 1976). Trenhaile (1997) furthers this discussion by noting that the younger marsh area (the upper middle inter tidal zone) is submerged about 360 times each year. The more mature area of the salt marsh consists of the uppermost area of the inter-tidal zone and can experience hardly any flooding for the majority of the year. Allen and Pye (1992) note that inundation may only occur during high water spring tides, thus allowing time for the muddy substrates to drain and solidify. If the saltmarsh surface is dry for long periods of time, some areas of the mature marsh may become isolated and blocked by water movement. This can lead to the development of saltpans (Chapman, 1976). During the summer, water in the saltpan evaporates leading to salinisation which further retards plant growth.

Salt marshes are generally agreed to support a limited number of species that have limited potential to grow elsewhere. (Chapman 1976 and Harvey 2000). Furthermore, Dijkema et al (1990) state that the vegetation found on salt marshes illustrates a zonal pattern, which can be directly related to the tidal inundation frequency Chapman (1976), Dijkema et al (1990) suggest that the germination of seeds noted in the pioneer and mud zones is retarded by seedlings being washed away before germination. However at the middle and higher levels of the intertidal zone (Dijkema *et al*, 1990, lower and middle marsh in Figure 2.1.1) seeds become trapped in vegetation, and "pioneer plants and further sedimentation will do the rest, creating an environment which promotes a closed cover of perennial halophytic plants" Dijkema *et al* (1990).

2.2 Salt Marshes and Sedimentation

According to Trenhaile (1997) the "vegetated marsh surface constitutes a very efficient sediment sink…" but Reed and Cahoon (1992) state that, "marsh sediments consist of both organic and inorganic material, but the processes of marsh accretion are poorly understood". Most studies agree that the factors controlling the delivery of sediment to the salt marsh are: creek morphodynamics, estuarine sediment type, riverine inputs and climatic conditions, including flooding and winter storms, (Reed, 1997 and French, 1993). However at this point there appears to be debate about the relative importance of each controlling factor. While French (1993) emphasises the importance of elevation, Cahoon et al (1996) tend to emphasis climatic conditions, particularly episodic winter floods. In spite of these differences in emphasis, there is agreement that the settling lag theory of Postma (1961) offers a unifying theory of saltmarsh sedimentation process. The theory of settling lag was proposed to explain increasing amounts of sediment being brought onshore by the tide. Postma (1961) argued that sediment would be deposited when the tide attained the maximum of the 'critical deposition velocity'. As indicated by Figure 2.1.3 sediment is moved onshore and some of the deposited sediment is not re-entrained. Pethick (1984) notes that sediment grains take "…two steps forward, one backwards,"

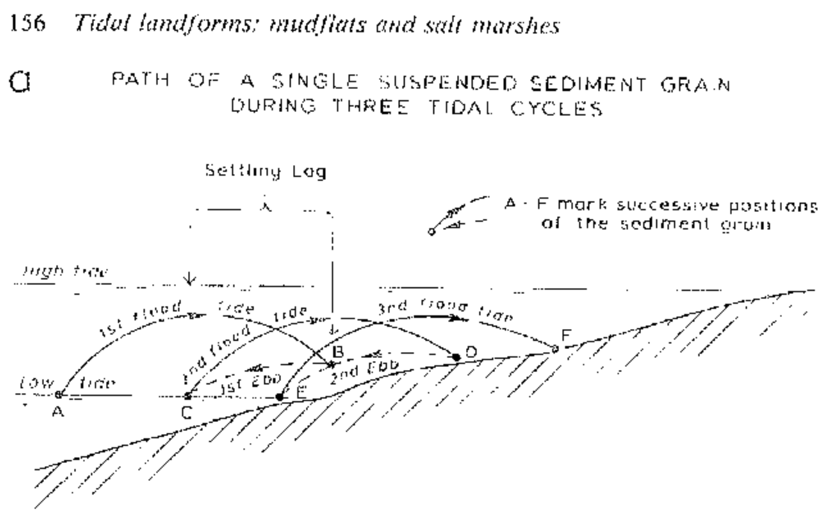


Figure 2.1.3. Sediment paths on a tidal cycle (Source: J Pethick. 1984)

According to Stumpf (1983), during tidal inundation the intricate creek system is flooded and eventually over banks. During this process the suspended sediment load is carried inland and deposited, although much sediment is deposited at the creek edge. Postma's theory supports the formation of levees and assists in our understanding of low sedimentation rates on the more mature marsh surface, as in order for the sediment to be carried further onto the marsh, there must be sufficient energy within the tidal inundation to support the particles in the water column. Obviously grain size is fundamental in this theory and Postma (1967) furthers this discussion with the idea of "scour lag". The latter process occurs due to the corresponding relationship between the velocity required to entrain a sediment particle and the velocity at which it is dropped. Therefore, to move larger particles of sediment into the salt marsh intertidal zone, higher tidal velocities are required. As indicated by Figure 2.1.4 further explanation of this process has been found in the form of the Hjulstrom Curve when the relationship between velocity and deposition of various calibres of sediment can be observed. However, small clay particles require as high velocity as coarse material to facilitate movement due to their cohesive nature. Thus sediment deposition is affected by both tidal inundation (velocity) and sediment type.

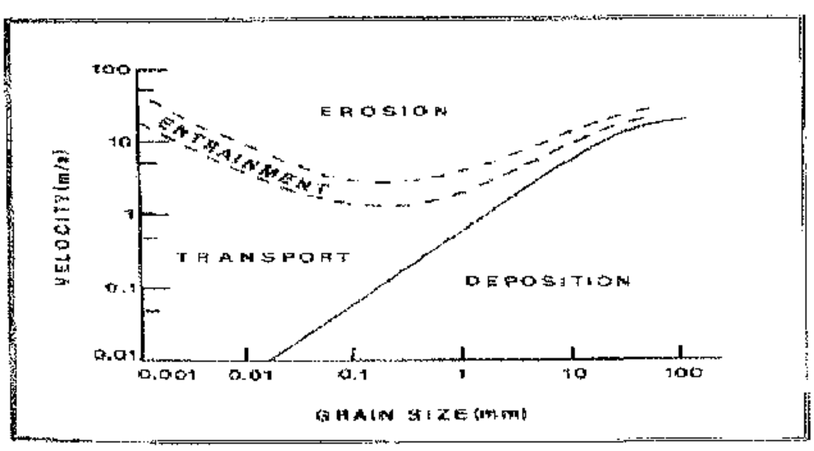
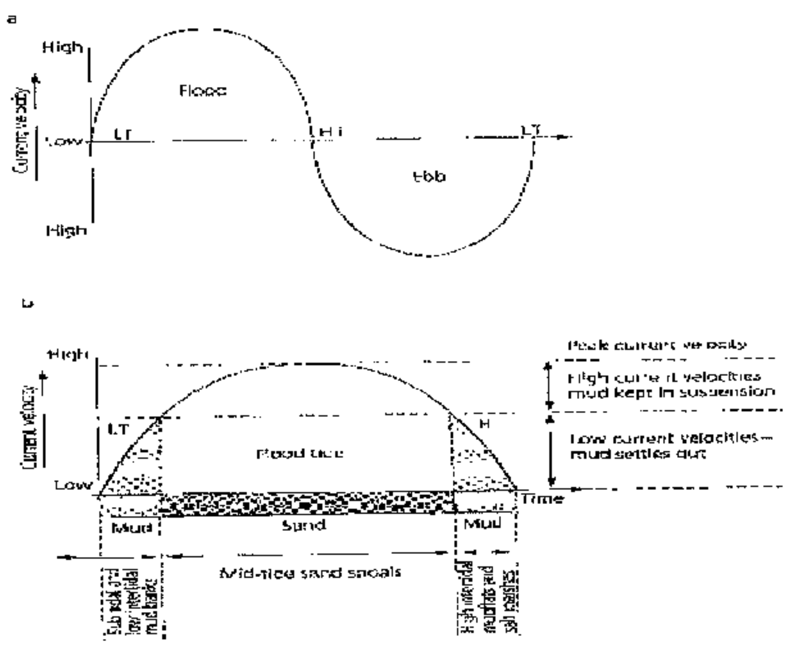


Figure 2.1.4 The Hjulstrom Curve, indicating relationships between entrainment and deposition of sediment. Source: Knighton, (1998).

According to French 1997, sediment is deposited when it becomes too heavy for the water column to support it. French 1997 explains that flood and ebb tide velocities vary over the tidal cycle. As indicated by Figure 2.1.5 when the tide has fully inundated the saltmarsh, and begins to turn, the current velocity should be close to zero, however the settling of particles is impaired by other processes such as flocculation (the mixing of fresh water and salt water to form an electrolytic imbalance leading to some particles sticking together) actually leads to the mudflats and saltmarshes that are typical to such areas. At lower elevations (in the primary marsh area) and mid tide velocities, the higher water force on ebb and flood [1]serve to sweep mud's clear of channels and produce mud tides and shoals elsewhere.



[1] At this point the tidal inundation velocity and energy will be high, this is the beginning of contact with land and hence more resistance to the velocity of the waves.

Figure 2.1.5. The relationship between velocity and sediment entrainment

Various aspects of sedimentation influence marsh accretion processes and some of these processes have been summarised by Letzsch & Frey (1980):

- Net deposition rates are generally low;
- Deposition rates increase with tidal range;
- Deposition in low marsh habitats exceeds that of high marsh habitats;
- Rates of deposition or erosion vary seasonally and annually;
- Sediment accumulations may be enhanced by subsidence of the substrate or eustatic rises in sea level;
- Rates of deposition decrease with increased marsh maturity or with increased marsh stability.

Various researchers (Pizzuto, 1987 and French & Spencer, 1993) also argue that sediment accumulation rates are higher at the creek edges than anywhere else in the marsh. They indicate the velocity of the tidal waters to be the essential factor in this theory as it is reduced when tidal waters overbank. Many channels and creeks are created during the flood and ebb tides which are considered essential in transporting sediment in and out of the saltmarsh environment. French (1993), Stoddart *et al.*, (1989) and Letzsch & Frey (1980) all initiate that the rate of sedimentation is fundamental to the proximity of the various creeks on a saltmarsh. However, this theory is challenged by Pethick (1984), who argues that tidal inundation of the saltmarsh surface occurs mainly via the overflow from the seaward edge rather than the overbanking of the creek system.

While the afore-mentioned discussion refers to sediment deposition by tidal inundation, it is also essential to consider the implications of marsh development through vegetation. Vegetation establishment is largely dependent on hydroperiod, mainly the submergence and emergence of the saltmarsh. The amount of sun-light that reaches the vegetation is also essential in determining the growth periods achieved by vegetation. Most researchers (Harvey, 2000, Ranwell, 1972) accept that colonisation of mud flats by particular saltmarsh species occurs at the Mean High Water Neap. The species that are normally identified are *Puccinelia maritima, Salicornia* and *Spartina* spp which can generally flourish in this environment. The colonisation of a mudflat can be difficult and generally requires a two to three week time period where salinity is reduced (Zedler and Beare, 1986). The colonisation also requires a sheltered environment and a substrate which can support established plants. According to Harvey (2000) after the colonisation has begun, sediment accumulation can be enhanced by the presence of vegetation in several ways. Firstly, vegetation can reduce the velocity of waves as they overwash the mudflats. This can reduce transportation competence and deposition of sediment. Investigations by Frey & Basan (1978) indicated a decline in wave height by 71% due to the presence of vegetation. Other investigations by Christiansen and Miller (1983) noted that the presence of vegetation tended to still incoming water and thus allowed sediment suspended in the water column to settle. Evans (1965) in Harvey (2000) notes that plants also protect the surface of the saltmarsh from degradation by reworking and binding the sediments with decaying plant mass, which could then lead to further growth and stabilisation of the saltmarsh. Normally, sediment accumulation will increase the height of the saltmarsh and the original plant species will be replaced by other species (via competition as salinity and hydroperiod falls) and in some cases zoning may be apparent. According to Hayden *et al* (1995) the species that survive will be defined by tidal inundation and the salinity of the water. Stumpf (1983) studied the importance of biological factors with relation to sediment trapping ability. He argued that vegetation acted as a 'baffle' so that as the floodwaters inundated the marsh, the vegetation would attenuate wave activity and reduce tidal currents enough to allow sediment to settle. Harvey and Allan (1998) supported this idea and furthered the discussion by noting three factors which promote it:

- vegetation dissipates flood tide energy;
- vegetation helps bind sediment particles together and;
- vegetation encourages the deposition of sediment at the plant base and on foliage.

By binding the sediments to the plant roots, Trenhaile (1997) argued that vegetation promotes accumulation of ' clayey, cohesive sediments'. While Pethick (1984) noted "...it would be unlikely that much deposition could take place were it not for vegetation cover." Pethick (1984) states that as well as the providing the 'baffle effect', vegetation stems collect sediment, which on drying falls to the marsh surface and leads to higher deposition rates. While Harvey (2000) argues that vegetation plays a very important role within the sedimentation pattern of Orchardton marsh in the Solway, Ranwell (1964a) suggests that in general higher sedimentary rates can be attributed to migration of newly deposited sediment from the primary saltmarsh to the developed high marsh. This process, occurring from August to October, appears to coincide with the rising tides prior to the autumnal equinox. Bieniowski (1999) and Harvey (2000) also note that the role of vegetation in saltmarshes is understudied but of great importance. However no comparisons are available for sediment collected at the surface and vegetation collected from plants. This is also the case for many studies, including Letzsch and Frey (1980), Stumpf (1983), Pethick (1984), A. J Gray, (1992) and French and Spencer (1993). Harvey (2000) does note that accretion predominates where there are higher percentages of organics, silts or clays. In the Solway Harvey (2000) found that the fine sediments and organic material exhibited a cohesive quality which ensured that if accretion occurred less sediment was re-entrained following the initial deposition. Summerfield (1991) supports this argument by stating that once sediment has been deposited it doesn't tend to be re-entrained. Harvey (2000) noted that the mudflats and landward marsh areas in the Solway experienced the highest accretion rates. This provides an area of debate as most literature: Gray 1992, Pethick 1981, Letzch & Frey 1980, argue that accretion rates should be decreasing with the marsh maturity. As a result, this important aspect of vegetation interaction with sediment processes is targeted in this research project.

2.3 Salt Marsh and Climate

According to Cahoon and Reed (1995),

"…winter storms (i.e. cold fronts) and summer tropical cyclones (i.e. hurricanes) are important mechanisms for mobilising sediments in these marshes not receiving new riverine sediments."

This suggests that climatic effects can be felt differently by marshes with no riverine input as opposed to marshes with riverine input. Cahoon and Reed (1995) argue that marshes with no riverine influence are more dependent upon episodic sediment deposition and note, "…inorganic sediment can only be deposited when it is mobilised by storm related turbulence…" In their study of a Louisiana salt marsh, they found that

"accretion was greater during a period which included a greater number of long and deep flooding events, implying the importance of storms in increasing the supply of suspended sediment." (Cahoon & Reed, 1995)

Reed and Cahoon (1992) noted that sites that were subject to high frequency and long duration flooding (in storm weather) were more likely to suffer plant deterioration, which could ultimately lower the surface of the marsh. They argued that the longer, deeper flooding would only increase sediment accumulation if plant growth were vigorous, thus supporting Stumpfs (1983) argument that plant growth may be a more important factor in the control of sedimentation. Cahoon et al (1996).

A study on the Tijuana estuary in Southern California, Cahoon et al (1996) noted that after episodic storm events, large amounts of sediment would enter into the drainage basin and lead to catastrophic changes in the basin morphology. Zedler (1988) stated that sediment deposition was clearly visible after storm episodes, clearly changing the elevation and build-up of salt marsh area. Furthermore, studies by French and Spencer (1993a) reported that a storm event had deposited 0.7-09mm of mud on the upper saltmarsh of the Hut marsh in England, concluding that a high proportion of sediment deposition on upper marsh areas can be attributed to periodic storm events. French and Spencer (1993) also noted that enhanced sedimentation during high spring tides and storm weather would be essential in the maintenance of the higher parts of the saltmarsh. This was due to the higher energy storms allowing coarser sediment greater access to the high marsh areas, (those areas not normally accessed during normal tidal inundation). However, a comprehensive review of sediment trapping and transport by Stevenson *et al* (1988) disagrees with the generalisation that most sediment is deposited during episodic conditions. Stevenson *et al* (1988) state "…storm activity does not inevitably lead to import of materials". Although sediment is imported to salt marshes during storm events, it is also exported through ebb tidal energy and flash floods. Heavy winter storms can erode desiccated upland soils and increase the availability of particles mobilised from river basins. According to Cahoon *et al* (1996), in the storm years 1980,1983 and 1993, an enormous sediment load > 5 million tons was generated during and after storm episodes (Cahoon *et al* (1996) did not specify the number of storms or the specific area where sediment was measured). Not all of this sediment can be classified as input to the salt marsh as some may have been eroded from the marsh itself. Higher tidal velocity and turbulence also mean that suspended sediment amounts can vary widely. Scouring of the marsh surface may be more severe and areas not normally flooded could be inundated with tidal waters. Much of the floodwater will drain over the marsh edge or through the many tidal creeks and be flushed from the marsh creek system to another nearby coastal area. Depending on the severity of the storm, this can vary from medium sediment load to debris and litter build up. This theory is furthered by Nyman *et al* (1995) who argues that a storm, within a low-pressure centre can lead to sedimentation and erosion of a saltmarsh. Whether sedimentation or erosion occurs depends on whether the wind is blowing on-shore (increasing water levels) or off-shore (lowering water levels) Furthermore, stormy weather can lead to the uprooting of vegetation, leaving the saltmarsh bare in some places and thus is a destabilising influence. In the final analysis, storm events in tidal marshes probably serve as much to increase sediment exports as they do to promote imports.

2.4 Salt Marshes and Sea Level Rise

Cahoon and Reed (1995), state that

"...survival of coastal marsh during periods of sea level rise depends on the marsh remaining at an intertidal elevation suitable for growth of marsh vegetation."

As a result, the equilibrium between sea level rise and accretion or, subsidence and erosion must be maintained. Stumpf (1983) supports this idea and states during a slow rise in sea level, marsh surface accretes at a rate determined by sea level variation, with level of marsh surface relative to main sea level determined by sediment supply and frequency of tidal flooding. As sea levels rise, salt marshes experience a change in the hydro period. Generally, increase in hydro period will increase marsh flooding and perhaps the area flooded (e.g. mature marsh). As a result of the increasing tidal levels, more sediment may be deposited on the marsh and if this supply is sufficient, the marsh may elevate in pace with sea level rise. However, increased sediment deposition does depend on the supply of sediment. Reed (1988) discusses the erosion of sediments from marsh edges of the Dengie Peninsula in England. The Dengie peninsula lies to the east of Celmsford, Essex, bounded by the North Sea to the East, The River Crouch to the South and the River Blackwater to the North. (Map of location in Reed, 1988). As sediments are eroded from the marsh edge (due to wave action associated with a higher sea level), the sediments are carried into the intertidal area and deposited, thus, maintaining the elevation of the marsh. However, if the marsh edge continues to be eroded, the marsh itself (although building in elevation) will decrease in size. If marsh elevation continues to rise, tidal waters will no longer inundate the marsh with the former frequency. Houghton (1994) estimates global sea

level rise at 1- 2.5 mm a^{-1}, however, in the Solway Firth, Firth *et al* (2000), pinpoint isostatic uplift in the Solway Firth to be 0.4-0.56 mm a^{-1} meaning that erosion of the marsh edges will proceed in the future, with accretion occurring in surrounding areas. In May and Hansom (2003), studies of Caerlaverock saltmarsh indicated the west side to be experiencing high levels of erosion, this erosion was indicated by the vertically stepped terraces formed alongside the seaward edge accompanied by damaged vegetation. The east side of this marsh shows the opposite with sediment deposition occurring and accretion of sediment extending to other nearby saltmarshes (Priestside Merse). According to Hansom *et al* (2000), that sea level rise may result in the erosion of saltmarshes. In those areas where sedimentation rate is exceeded by sea level rise; deterioration will occur as a result of declining vegetation. Also, we may also see changes that can be attributed to climate change, mainly; the frequency of storm related incidences will increase. (Allen 1992). If a marsh depends on sediment accretion via storm related incidences then it follows that these marshes will increase in their sediment intake. If, however, the marsh does not gain sediment from storm activity but rather from daily inundation, then erosion may be likely and some marshes may decrease in size. Overall, Reed (1995) states "…understanding and predicting the response of coastal marshes to relative sea level rise requires the consideration of both physical and biotic components of the marsh system." Therefore, we need to consider why some authors believe sea level rise drives the accretion of salt marshes, whilst others argue elevation alone is the sole contributor to salt marsh accretion (French, 1993). Reed (1995), concludes, "…this review has shown that the sedimentologic and vegetative responses to sea level rise are complex, and these control the net vertical accretion
of the marsh surface."

2.5 Management of Saltmarshes

"A combination of development and fixed coastal defences are fragmenting and squeezing out naturally mobile coastal habitats and their associated wildlife"

Poor management and uncontrolled and ill-advised development are destroying marshes. According to Woodhouse (1979) various wetland areas have been declining in size, Woodhouse (1979) notes that wetland areas have been viewed in the past as value-less and could be more effectively utilised by agriculture, commercial, industrial and recreational means. This common stereotypical view has coincided with 25% of all salt marshes being damaged, eroded or swamped; "salt marsh habitats are being lost at a rate of 1000 hectares (2,500 acres) a year". The use of saltmarshes for grazing and agriculture is probably the oldest form of exploitation. However, without proper management, the implications of these land uses will tend to modify or destroy the natural habitat and saltmarsh environment. As with all land use there is generally a conflict on how best to use the land in question and different perspectives lead to emphasis on various aspects of a saltmarsh. For example, the ecologist may wish to conserve the plants, while the agriculturalist may want to use the plants as grazing fodder. With such diverse land uses, conservation is a complex issue.

Over the last decade, it has become apparent that wetland areas may represent a valuable resource. As coastal marshes occur naturally in the intertidal zone of moderate to low energy shorelines, they stabilise and protect the area they surround. As a result the presence of mud flats and saltmarshes provides a control on the wave energy reaching the upper saltmarsh surface, acting as a buffer against storm surges.

Furthermore, salt marshes play an essential role as a productive habitat for many species. Chapman (1976) states that the detritus from salt marsh vegetation decays on the mud and in the creeks, forming the basis of an extensive food chain.

Doody (in Allen and Pye, 1992) notes that many attempts are being made to protect the valuable resources of saltmarshes, however, it remains that the long-term problems need to be addressed in a global context. Doody (in Allen and Pye, 1992) states that "…so long as their inherent value is recognised both for wildlife and as part of a functioning ecosystem, then decisions can be made which should ensure their better future."

Due to the value of the Solway Firth in an environmental sense, integrated and sustainable management practices have been introduced to maintain the biodiversity of the area. The vision of the Solway Firth Strategy (1998) is

" To secure an environmentally sustainable future for the Solway Firth Area which allows the economy to prosper while respecting the distinctive character, natural features, wildlife and habitats of the Firth". Solway Firth Strategy, (1998).

Working jointly, Scottish Natural Heritage and English Nature have responded to the need for a combined management of the Solway due to its important location (the national boundary) and its numerous conservation directives already in place.

Whilst conservative directives have been put into place, the saltmarshes of the Solway Firth have also become more important in respect of an ability to assist management in tide-dominated coastlines. French (1998) argues that the presence of a saltmarsh can reduce the overall costs of sea defence due to their natural ability in dissipating wave energy. Table 2.1 indicates the relationship between the width of the saltmarsh, and the height and cost of a sea wall. From this, the presence of a saltmarsh greatly reduces the height of a sea wall required and thus the cost to government.

Width of marsh (m)	**Required height of sea wall (m)**	**Cost (m^{-1})**
80	**3.0**	**£400**
60	**4.0**	**£500**
30	**5.0**	**£800**
6	**6.0**	**£1,500**
0	**12.0**	**£5,000**

Table 2.1 Saltmarsh width and the required height and cost of the sea wall, Source: French (1998).

Thus, the wider the saltmarsh, the better defence against flooding. This can be attributed to the wave energy being attenuated by the saltmarsh, with the various types of vegetation acting as a buffer.

2.6 Summary

Chapman (1976), Stumpf (1983), Pethick (1984), Bieniowski (1999) and Harvey (2000), all claim that vegetation plays an essential role on a saltmarsh, but they do not fully establish the relative importance of the mechanisms whereby vegetation may affect saltmarsh sedimentation. The following chapters aim to

- Clarify the role of vegetation in relation to on-surface sedimentation

- Analyse whether spatial patterns exist in the pattern of sediment trapped by vegetation and on the surface of vegetation with reference to other forms of surface sedimentation
- Examine if temporal variations exist in vegetation performance as sediment trappers.
- Assess the future sedimentation patterns on this saltmarsh

Chapter 3: Methodology

3.1 Location

Much of the recent literature that focuses on salt marshes and their processes has been completed on American and English marshes. For example, the Louisiana marshes (Cahoon & Reed, 1995,1996) and The Wash and the Norfolk Marshes (Pye, 1992, and Pethick,1984). However, the nature and processes on many other British salt marshes have been relatively understudied and thus require attention. For example, most Scottish saltmarshes are relatively sandy in nature rather than muddy like English saltmarshes (Hansom 2003) and because of these general assumptions concerning sedimentation processes, elevation and vegetation effects may not be universally applicable for such coarse substrates. Against this backdrop, Orchardton marsh, near Auchincairn in the Solway Firth. (See Figure 3.1) was chosen as the site for the project for the following reasons:

1. Orchardton Merse consists of a well-developed mudflat, primary, middle and high marsh areas apparently subject to rapid sedimentation rates (Harvey 2000). The marsh is generally undisturbed and ungrazed by domestic animals.
2. Previous research by Harvey (2000) and Bieniowski (1999) had identified outstanding questions related to vegetation performance in sediment trapping vis a vis direct settling.
3. The data sets of Harvey (2000) and Bieniowski (1999) were available to provide both context and extend the sampling time frame
4. Orchardton Merse is a *Spartina* dominated marsh, yet it is located at the northernmost limit for *Spartina* in the United Kingdom.

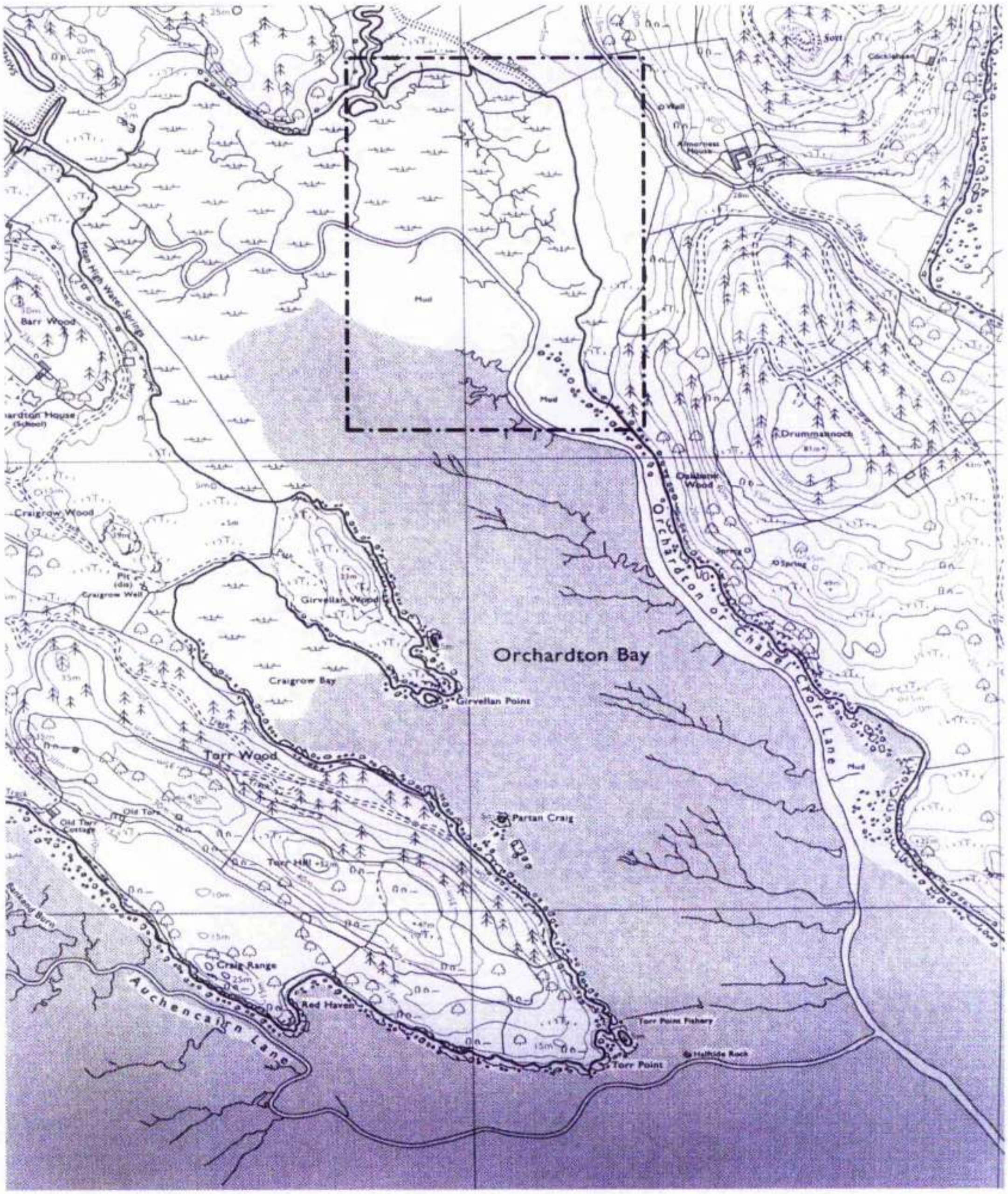


Figure 3.1

Location of Orchardton Marsh study area (source: OS Map NX 85SW)

3.2 Sampling Techniques

This chapter will outline the techniques used and a consideration of problems and constraints. The aims of the project were:

- What is the role of vegetation in relation to surface sedimentation on a saltmarsh?
- What spatial variations exist in the pattern of sediment trapped by vegetation and on the surface of vegetation?
- What variations exist in vegetation performance as sediment trappers?
- Can the future sedimentation patterns on this saltmarsh be predicted?

Therefore the factors that need to be established are:

1. The amount of direct settling on the saltmarsh surface of sediment in space and time.
2. The amount of sediment settling on vegetation in space and time

Field Techniques

3.2.1 Direct Settling Sampling

3.2.1.1 Plates:

In order to measure the depth of sediment accumulation over time in the primary marsh zone of the salt marsh, it was decided that aluminium plates already in place on the salt marsh would be re-used. These plates, 3mm thick, were inserted into the salt marsh, and left there by Harvey (2000) to provide a time series record. Each plate measured 20cm squared and contained 64 regularly spaced, drilled holes. This facilitated vertical movement of water through the plates, avoided water logging and ensured root development was not disrupted. The plates were located throughout the salt marsh (see Figure 3.2.1.1). It was decided that these plates would be reused, to avoid disruption of the current vegetation and sedimentation on the marsh. In the previous study the plates had been inserted into the ground and left to allow the surface to settle. Thus, as the present study was completed over a time period of one year, it was felt that reusing the plates would avoid ground disturbance issue and retrieve more data than inserting new ones (Figure 3.2.1.1. is located in back cover pocket).

The original (Harvey, 2000) placement procedure was as follows: each plate was placed in a hole 1.5 times its size and 30cm deep. The plates were then tapped into place. Plate depth was measured, with depths being collected from the four corners of the plate and then averaged. The hole was then re-filled with the sediment and any vegetation that had been removed. No further measurements were taken on the salt marsh for several months to allow the plates to settle and adjust in their new environment. After a settling time had passed the plates were relocated with the aid of a metal rod and measurements taken at the four corners of the plates (Harvey 2000). The rod itself had to have a circular diameter wider than that of the holes on the aluminium plate. This allowed the rod to locate the plates with ease. After each set of monthly measurements had been taken, the four results were averaged to give one overall sedimentation rate (with an error margin of 1 mm). It is important to note at this point that although every effort was made to find all of the buried plates, Harvey (2000) reported erosion of the marsh in some locations and a loss of several plates. This may be attributed to the disruption caused by loosening the sediment initially, but some more plates were lost due to bank erosion and creek migration. This problem was still visible on the marsh 8 years later. Data recorded for this study followed the same logging procedure as Harvey (2000) in order to allow comparisons at a later stage.

3.2.1.2 Disks:

In order to measure sedimentation directly onto the surface of the salt marsh and at a finer scale than that possible with buried plates, a system was devised to allow collection of sediment with minimal disturbance to the environment whilst attaining highly accurate results. The area chosen was selected to capture primary, middle and high marsh accretion areas, dense vegetation cover and to overlap with the area used by Harvey (2000). The area on Orchardton salt marsh measured 150m in length and 50m at it's widest. Inside the rectangular transect, 22 sedimentation disks were placed at points throughout the salt marsh. Each disk was placed in the same position during fieldwork excursions. Marking these locations with yellow bamboo canes ensured ease of relocation and accuracy. Bamboo canes were chosen as markers since the average diameter of each cane matched that of the vegetation on the salt marsh, emulating nature and minimising disruption to water and sediment movement. Traditionally, researchers have used petri dishes with filter paper attached (French & Spencer, 1993). This method was deemed undesirable, since petri dishes disrupt the water flow and encourage the water to pool and stagnate and so the sediment is trapped in an unnatural, ponded, fashion. Petri dishes also collect other sediment above the surface level, and so lead to further inaccuracies in surface sediment collection. What was required was a collection system that was flush with the saltmarsh surface, could accept sediment as the flow passed over (rather than ponding) and was easily replaced with minimum disruption to the sediment surface. The disk system used here consisted of a computer compact disc (CD), 1 plastic rim, 1 brass weight and three clips to hold the unit together, as illustrated by Figure 3.2.1.2.1a and b.

Figure 3.2.1.2.1a Disc placed at study location and inundated by high tide, this location coincided with a survey station denoted by the square peg.

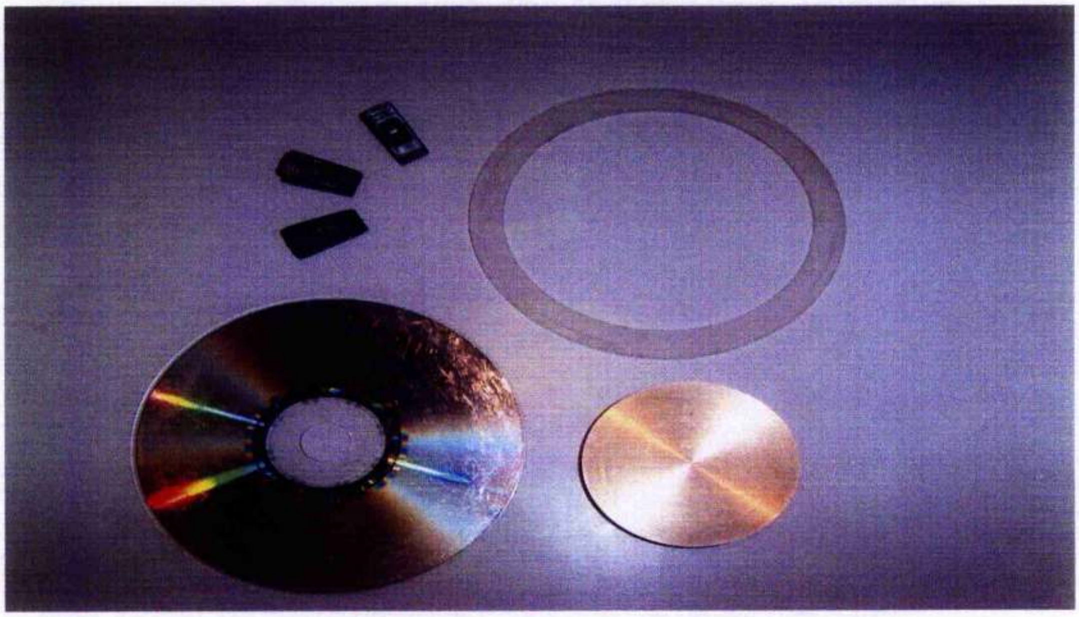


Figure 3.2.1.2.1 b. The different components used to make the disc.

The brass weight was attached to the underside of the CD to fix the measuring device to the marsh surface by gravity. Several tests were run in the laboratory to establish weight required to maintain disk position. On top of the CD, a filter paper 0.1 cm thick was placed and kept in place by a plastic rim to ensure that the filter paper remained in place during the experiment. To the paper, rim and CD, 3 clips were used, only just touching the plastic rim and the under side of the CD. The result was a filter paper flush with the saltmarsh surface.

All 22 disks were positioned on the marsh before inundation. Sampling occurred on a monthly basis. The location of each disk on the marsh was chosen to be representative of each of the marsh zones and the study area separated into three main zones as follows.

The first zone, (the primary marsh) was located at the seaward edge of the saltmarsh and consisted of a mud/sand flat to seaward with a progression towards primary saltmarsh growth landward. Small patches of *Salicornia europaea* (Glasswort) occurred in this area, a species commonly found in UK muddy saltmarshes. There were also small stands of *Spartina townsendii* (Townsends Cordgrass), which was initially introduced to assist in the reclamation of mudflats. The boundaries of the mud-flat consist of a major creek system which surrounds the mud flat extent at this location, with a slightly smaller but extremely complex, creek system intersecting the eastern section of the mud flat. This complex creek system also represents a boundary between the first transect primary marsh and the second zone (middle marsh), as illustrated by Figure 3.2.2.2.

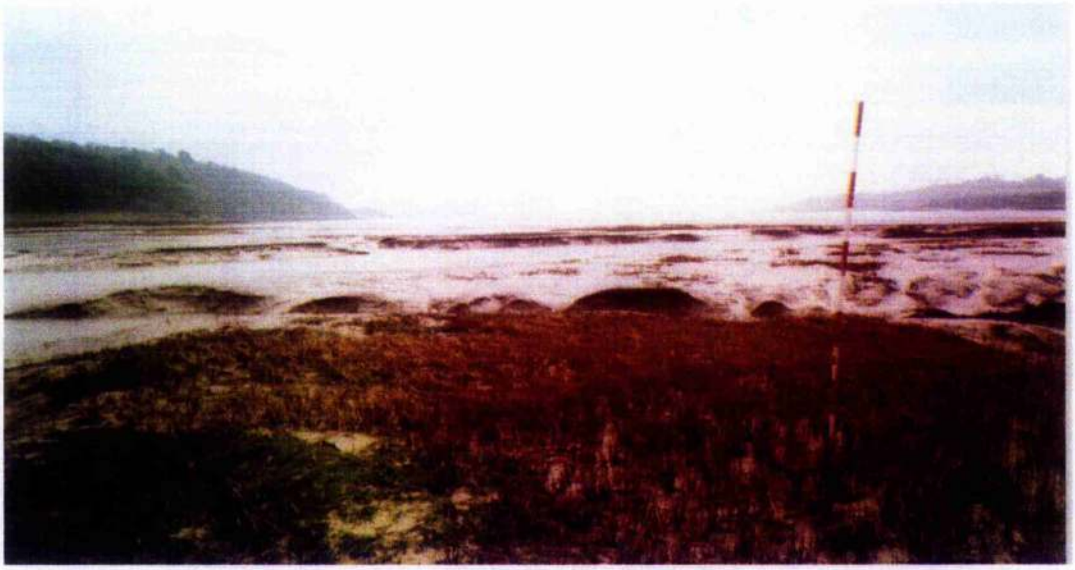


Figure 3.2.2.2 The primary marsh study area, Orchardton saltmarsh, Auchincairn. View looks South over the primary marsh and mudflat edge with creek separating the primary and the middle zones.

Eight disks were placed on the primary marsh. Previous research by Harvey (2000) indicated that this area experienced rapid sedimentation and so it was felt appropriate to locate more disks in this area. Harvey (2000) also noted that some aluminium plates were lost in this area, perhaps due to the high energy environment, thus, extra disks may compensate for any plate losses. Of the eight disks placed upon the primary marsh, four were placed along the smaller creek edge; while two were placed towards the large creek edge and a further two were placed centrally. The aim was that the distribution of the disks would replicate sedimentation rates and variability over the mudflat/saltmarsh interface. See Figure 3.2.2.2.

The second zone stretched from the edge of the primary marsh out to the middle marsh, a distance of 30m and was vegetated mainly by *Spartina townsendii*. Inside zone 2; the saltmarsh was relatively muddy, with very few intersecting creeks and poor drainage. Between the primary marsh and zone 2 there was an increase in elevation of 0.1m.The main features in this study area were hummocks of mud. The surface was uneven with vegetated areas beside hummocks appearing much muddier with vegetation lying often in stagnant pools. In total, 8 disks were positioned along this zone.

The third zone consisted of a more diverse and mature high saltmarsh. Zone 3, measured 30m, was slightly higher than zone 2 (approximately 5 cm) and appeared less muddy and better drained. The dominant plant species in this area was *Spartina townsendii* but throughout the area many different plants were also identified. Since zone 3 was only inundated at high spring tides only 6 disks placed onto the surface, since it was expected that a reduced amount of sedimentation would occur at this elevation.

3.2.2 Position Fixing and Survey.

GPS (Leica) was used to accurately determine positions of discs, plates, surface elevations of the marsh and topographic features. Using this system, 3 surveys were carried out on the saltmarsh throughout the two-year research time-period, as illustrated by Figure 3.2.3.1.Surveys were completed in order to locate position and elevation of sampling points and allow their mapping. The accuracy of these maps also allowed a comparison between the elevation in year 1 and 2 and offered an independent check on sediment amounts at each site.

Figure 3.2.3.1 Kinematic Survey of the middle marsh at high tide

The first GPS survey was a Rapid Static Survey (RSS). After observing a number of known points in the local system, RSS allows new points to be measured which can be converted into the local system. Once set points had been established, the next surveys were Kinematic using two receivers: a reference receiver placed on a point with known co-ordinates, and a rover whose co-ordinates are calculated relative to the reference. The surveys are carried out to a vertical accuracy of +/- 1mm and so are capable of detecting very small amounts of elevation change on the saltmarsh. During each survey, the disk locations were measured using the above technique which, when processed, gave the height of the marsh (above sea level) at that date. 3 surveys were carried out throughout the two years and the processed data used to illustrate any increase or decrease in height of the saltmarsh.

3.2.3 Vegetation Trapping Sampling

As well as sampling sediment directly from the saltmarsh surface, it was essential to sample the sedimentation rates on the vegetation surfaces. This was completed using 2 methods, coverage assessment and vegetation cropping.

3.2.3.1 Vegetation Coverage

The extent of the vegetation cover and various plant species may affect sediment-trapping rates. Coverage assessment was completed before any samples of vegetation were removed from the marsh. At each site a $1m^2$ quadrat was placed randomly within 1m to minimise disruption to the vegetation and the surface of the marsh at each peg (the quadrat wasn't always placed at the exact spot as previous sampling but within 1m to minimise disruption to the vegetation and the surface of the marsh). The vegetation coverage was assessed using the Domin Scale, and included the listing and identification of all species present on the sample site, (within the sample $1m^2$ quadrat) and an evaluation of vegetation according to vegetation strata. As illustrated by Figure 3.2.1.1 the Domin Scale provides an ocular estimation of vegetation present in an area chosen.

Plant cover	Domin scale
Cover about 100%	10
Cover over 75%	9
Cover 50% - 75%	8
Cover 33% - 50%	7
Cover 25% - 33%	6
Abundant, cover about 20%	5
Abundant, cover about 5%	4
Scattered, cover small	3
Very scattered, cover small	2
Scarce, cover small	1
Isolated, cover very small	+

Figure 3.2.2.1 The Domin scale for recording plant abundance.

3.2.3.2 Vegetation Cropping:

15 sites were selected for quadrat analysis from the vegetated areas throughout the three zones, 5 sites allocated to each zones, and these were matched and located adjacent to the plate and disk network. At each site, a 1m^2 quadrat was used for vegetation cover assessment before 25 samples of vegetation (with sedimentation attached to foliage) were taken and bagged. The sediment-covered vegetation was removed by carefully plucking one sample (a stem from each section in the quadrat) the samples were then bagged, sealed and returned to the laboratory to be processed.

3.2.4 Suspended Sediment Delivery

Although much of this research project concentrated on sediment collection from the saltmarsh vegetation and surface, it was also decided that the sediment concentration in the water delivered by creeks to the saltmarsh surface would be useful to identity the provenance of sediment and so, an automatic water sampler (ISCO) was used to gather the data.

The ISCO was placed at the seaward edge of the primary saltmarsh, at a location where the tide first came into contact with the vegetated saltmarsh area, as illustrated by Figure 3.2.4.1.

Figure 3.2.4.1 Hose connected to ISCO, collecting tidal water every 5 minutes.

The ISCO was programmed to extract water every 5 minutes and collected 24 litres in total across 1 tide (2.5 hours). Whilst the ISCO collected water, a record of time was also collected to allow an in depth comparison of sediment concentration in the tidal waters.

To ensure the ISCO remained dry at all times, it was placed on a small boat, which was anchored via eyelets to four poles, and, as an extra precaution, a further anchor was attached to the ground with stakes. This is clearly illustrated by Figure 3.2.4.2 and Figure 3.2.4.3 As the tide rose, the boat floated up along its guiding poles.

Figure 3.2.4.2 Setting up the ISCO, Orchardton Merse, Auchincairn

3.2.4.3 ISCO ready to sample, anchored via sliding eyelets to four poles.

Once the tide had receded, the boat returned to the surface with its sampled water and the ISCO was transported back to the laboratory and the samples processed.

3.2.5 Tidal Inundation Logging

Tidal inundation on Orchardton Merse is clearly of importance to sediment delivery to various elevations of the marsh. Using a data logger and pressure transducer tidal depths of inundation were established. Before the equipment was placed on the marsh the pressure transducer required laboratory calibration. Once completed, the data logger was programmed to operate on one channel only and record depth information every 5 minutes. The logger was transported to the marsh and used to record data for the entire study period. As illustrated by Figure 3.2.5.1

Figure 3.2.5.1 Tidal inundation approaching the Data Logger. Site location at the primary-middle saltmarsh boundary during high tide.

The equipment was mounted on a 3m pole, which was placed on the marsh at the primary-middle saltmarsh boundary. The pole could be lowered whenever the logger was full. Four guy ropes then anchored the pole and data logger.

Laboratory Techniques

3.3.1 Quadrat Analysis

Vegetation sampled from the saltmarsh was brought to the laboratory in sealed plastic sample bags. For analysis, each sample was immersed in deionised water (no detergent was added) and shaken vigorously to release the sediment from the vegetation. The turbid water was poured into a pre-weighed foil dish and then evaporated to leave only sediment. The samples were then re-weighed and sediment weight calculated. As a precaution to ensure all sediment was washed from the plants, the plant samples were then 'ashed' at a very high temperature and checked for any sediment residue. This was verified by weighing the samples before and after the ashing. Any sediment residue was then added to the evaporated sample.

3.3.2 Coulter Counter

Although this research project concentrated on comparisons between the weights of sediment from subaerial, surface and vegetation sources, it was decided that particle size distribution should be analysed, in order to identify any trends. In order to establish size distribution, a Coulter Counter LS230 was used. The Coulter Counter LS230 measures various particle sizes by means of an optical laser. As stated by Mc Cave et al (1976)

> "Laser-diffraction-size analysis is based on the principle that particles of a given size diffract light through a given angle, the angle increasing with decreasing size."

Samples from both the surface of the saltmarsh and from the vegetation were collected and analysed by the Coulter Counter. Surface sedimentation samples were scraped from the 15 study sites, used for vegetation analysis. Each sample was bagged and processed in the laboratory. After the vegetation analysis was complete, sediment samples washed and evaporated from the vegetation were extracted and sized using the Coulter Counter.

3.3.3 Water Sampler

The samples that were collected with the ISCO were transported to the laboratory and then processed. Each sample was strained with the use of a vacuum pump, pre-weighed filter paper and a beaker. Once the entire contents had been strained, the filter paper and sediment was left to dry in a pre-heated cabinet. Once each sample was dry, the samples were re-weighed and sediment weight was then calculated.

3.4 Errors in Data Collection

As with all research projects, alterations to the initial designs had to be made as problems became apparent.

3.4.1. Problems associated with sediment collection accuracy:

Plates: As noted previously, 3 mm thick aluminium plates which were already buried in the saltmarsh were used in this research project. Although plate positions were noted, it was extremely difficult to locate some of the plates, even with the use of a metal detector. The plates had been buried in the marsh for nearly eight years so it is possible that they had become buried too deep to allow measurement or/and had been washed into creeks and therefore lost, or more unlikely the plates may have disintegrated as noted by Burd (1996).

Disks: Whilst the disks were the chosen method to measure surface sediment rates, there was still a small error during the collection of sediment. Occasionally, the filter paper, which was attached to the disk, was lost and this was attributed to strong tides. This leads to a potential number of gaps in results and the inability to compare entire data sets. Another problem associated with the strong tidal waters was the complete loss of a disk. Initially, a disk was placed in a set position on the primary saltmarsh. However, after each tidal inundation, the disk was lost, meaning no measurement was received. The same process occurred at the second attempt and it was decided that no more disks would be placed at this site and an adjacent site would be used.

GPS: As with all systems, there are limitations when surveying with GPS. Firstly, the GPS antenna must have an unobstructed view of at least 4 satellites. Depending on the position of satellites, if only 2 are visible then accuracy will decrease as fewer measurements can be received. This error is technically known as: Dilution of Precision, as it is "a measure of the strength of satellite geometry and is related to the spacing and position of satellites in the sky". 21 This research project maintained minimal errors by always obtaining a good GDOP when surveying was in progress.

Vegetation Sampling: Although every care was taken with sampling methods, the analysis of coverage assessment may not be cited as 100% accurate. As stated by Hatton et al, 1988,

> "Ocular estimation of plant cover is a fundamental and widely employed method for the evaluation of plant dominance, succession and treatment response in vegetation studies." 22

However, the ability of each researcher to assess and estimate vegetation cover will differ in the field. With this in mind, research was carried out under very strict guidelines using quadrats to maintain a level of consistency and with only one observer throughout.

3.4.2. Equipment Limitations

As well as the afore mentioned problems and constraints, other issues, mainly equipment limitations should be discussed. It was decided at the beginning of the research project that a data logger be placed on the saltmarsh to record tidal behaviour. However, after several months, it became apparent that the data logger needed to be replaced due to a malfunction. During the process of the research project, several downloads of information were received from the data logger, but the information received was inaccurate. Results from the data logger indicated water presence when the tide was not present. The frequency of these recordings made it very difficult to distinguish between 'real' recordings and other recordings. Therefore, it was decided that information from the data logger would not be used. Instead, tidal information prepared by the Institute of Coastal Oceanography and Tides, at nearby Heston Islet was used for the research area.

Chapter 4 Results

4.1 Introduction

This chapter sets out the results obtained in the project: Firstly, sedimentation using sub surface erosion plates is reported across the entire saltmarsh, followed by sedimentation using sedimentation discs and sedimentation on vegetation surfaces (also across the entire saltmarsh). This is followed by a comparison of the results obtained via each method in each area of the marsh, and finally, the results report the main sediment patterns and differences in trends between the primary, middle and high marsh areas.

4.1.1 Primary Marsh Setting

Figure 4.1.1 Primary marsh, Orchardton Saltmarsh, July 2003. Looking North West towards an eroding marsh edge.

Figure 4.1.1 shows the primary marsh in Orchardton salt marsh to be characterised by a scattering of algae and an individual cluster of *Spartina Townsendii* developing along the upper mudflat, with increasing plant densities from the front of the marsh towards its boundary with the middle marsh. During the summer months, the primary marsh is substantially colonised by *Spartina townsendii* which covers 90% of the marsh surface. For the rest of the year as the *Spartina* dies back, the marsh surface tends to be very muddy. The limits for this study are marked by a substantial creek located at the seaward edge of the primary marsh, and winds around the study area with mud flats on the seaward side.

4.1.2 Sedimentation on the primary marsh using sub surface erosion plates

Sedimentation patterns on the marsh surface were obtained through the use of buried aluminium plates. The depth from the surface of each plate was measured monthly by the insertion of a measuring rod and any changes were recorded. In the primary marsh area (See Figure 4.1.1) two aluminium plates inserted by Harvey (2000) were used in this analysis. The two plates chosen were the only plates of Harvey (2000) that could be located in the primary saltmarsh area. The following maps and graphs give a detailed account of the results at each site.

As illustrated by Figure 4.1.2, plate sediment depths were measured at locations 5 and 6. For the month of March, sediment depth at plate 5 was measured at 1.275cm, whilst at plate 6 sediment depth was measured at 7.275cm.

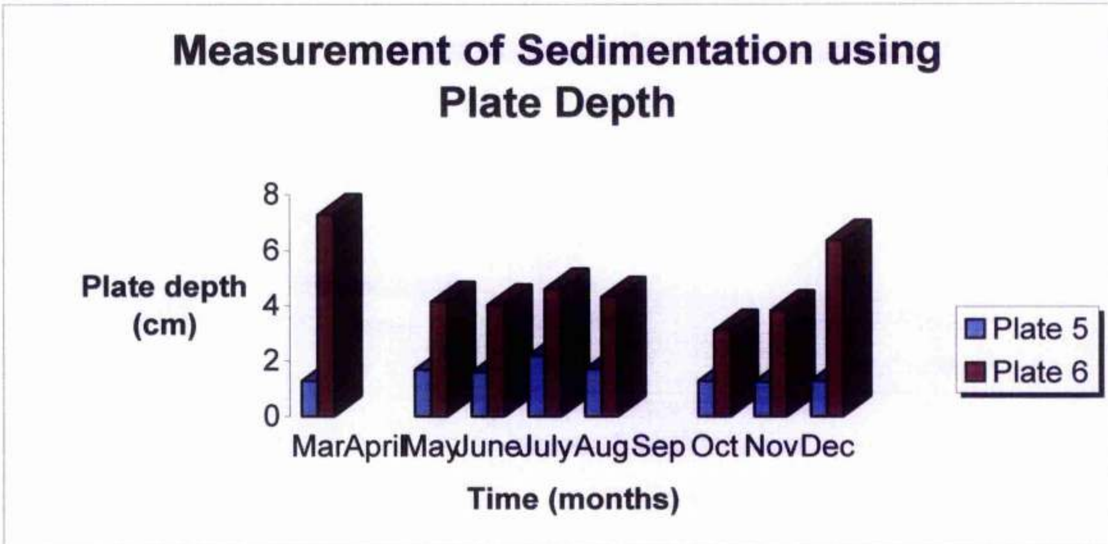


Figure 4.1.2 Measurement of sedimentation using plate depths in the primary marsh.

In May 2003, plate 5 measured 1.675cm below the surface whilst plate 6 noted an amount of 4.125cm. Plate 6 actually notes a small decrease in depth in comparison with March, this small decrease in sediment depth continues with plate 5 noting a measurement of 1.575cm and plate 6 noting 4.025cm. This pattern of surface erosion is halted in July as noted by Figure 4.1.2 where plate 5 accretes by a small amount, 2.175cm, with plate 6 also accreting to depth of 4.6cm. Thereafter all plates note a decrease in sediment depth, apart from plate 6 in November and December. As illustrated by Figure 4.1.2 during August plate 5 noted an amount 1.7cm and plate 6 of 4.3cm. In October, there is a further decrease with plate 5 noting a measurement of 1.275 cm and plate 6 of 3.1cm. This pattern continues in November where plate 5 notes an amount of 1.237cm and plate 6 of 3.8cm.This decreasing pattern of sediment accumulation comes to a halt in December as plate 5 notes an amount of 1.275cm and plate 6 of 6.35cm. Overall, Plate 6 appears to be buried deeper in winter and shallower in summer, suggesting removal of sediment in this area during summer months. Plate 5 shows limited variation throughout the year with perhaps a slight increase in sediment depth in summer.

4.1.3 Middle Marsh

Figure 4.1.3 Middle marsh, Orchardton Marsh, 2003. Looking North West over a creek system during low tide.

Looking North West over the creek system and emerged cliffs indicating some slumps, the middle marsh area is largely vegetated with *Spartina Townsendii*, with a slight increase in elevation landwards and an extensive system of creeks. It exhibits a mature and stable saltmarsh environment.

4.1.4 Sedimentation on the middle marsh using sub surface erosion plates

In the middle marsh study area, two buried aluminium plates were used to measure the amount of surface sedimentation. Both plates (plates 14 and 18) are indicated on Map 1. Plates 14 and 18 were chosen, to represent different areas within the middle marsh study area. Each plate measurement was collected on a monthly basis; the sediment accumulation for each month is shown in Figure 4.1.4

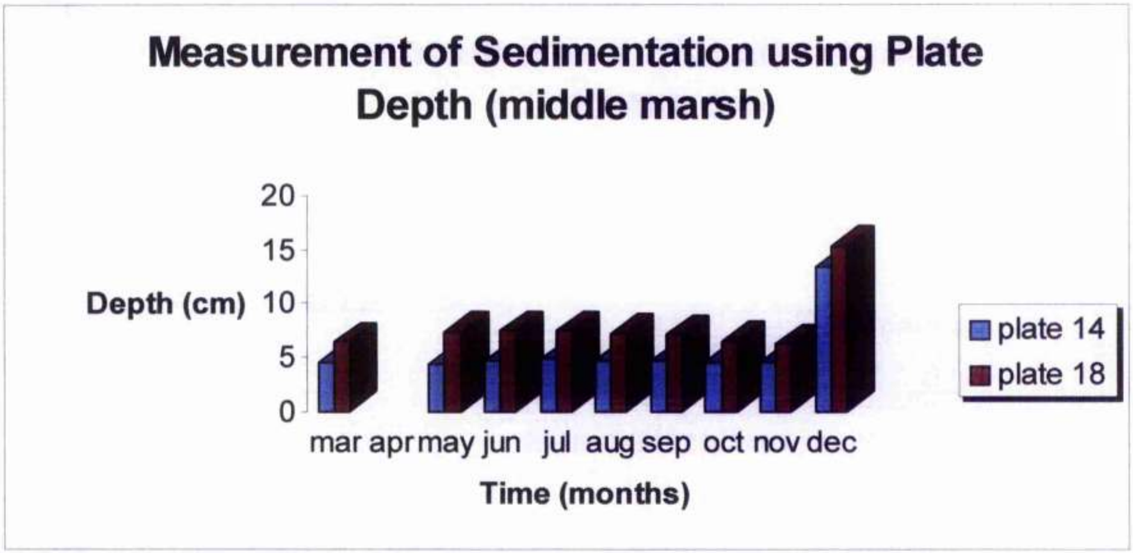


Figure 4.1.4 Measurement of sedimentation using plate depths in the middle marsh area.

Both plates are located near the creek edge and display very similar results for each month. The starting depths in March for plate 14 and plate 18 are recorded at 4.75cm and 6.8cm. From the months March to November, both plates indicate only slight change in depth, with Plate 18 indicating higher results overall. No results were recorded for April, as tidal levels did not overbank onto the marsh at this point. Whilst sediment depth appears consistent for both erosion plates throughout the year, Figure 4.1.4 indicates a large increase in sediment deposition during December which affected both erosion plates.

From these results slightly higher sediment accumulation was recorded in Plate 18 (and Plate 14 to a lesser extent) during June and July with limited sediment erosion in October and November. This slow decline in depth at plate 18 in the autumn months is reversed dramatically in December for both plates, where rapid accretion occurs at both plates, plate 14 measuring a depth of 12.5cm and plate 18 measuring a depth of 15cm. It is possible that the change in sediment reflects a definite seasonal pattern and the implications of this will be investigated in the interpretation of the results. (Chapter 6).

4.1.5 High Marsh

As illustrated by Figure 4.1.5, the high marsh at Orchardton Merse consists of an intricate, but deeply incised, creek system and well-established vegetation cover characterised by *Puccinellia maritima* and various grasses. The various creeks that meander across the saltmarsh area lead to salt pans and large shrubby areas to the landward edge. It is rarely inundated with tidal waters and therefore is much drier and less muddy than the other areas within the study. Plant cover in this area of the saltmarsh always measured at 100% and consists of many varieties, notably, *Salicornia*, *Puccinellia maritima* and in the summer *Aster tripolium.*

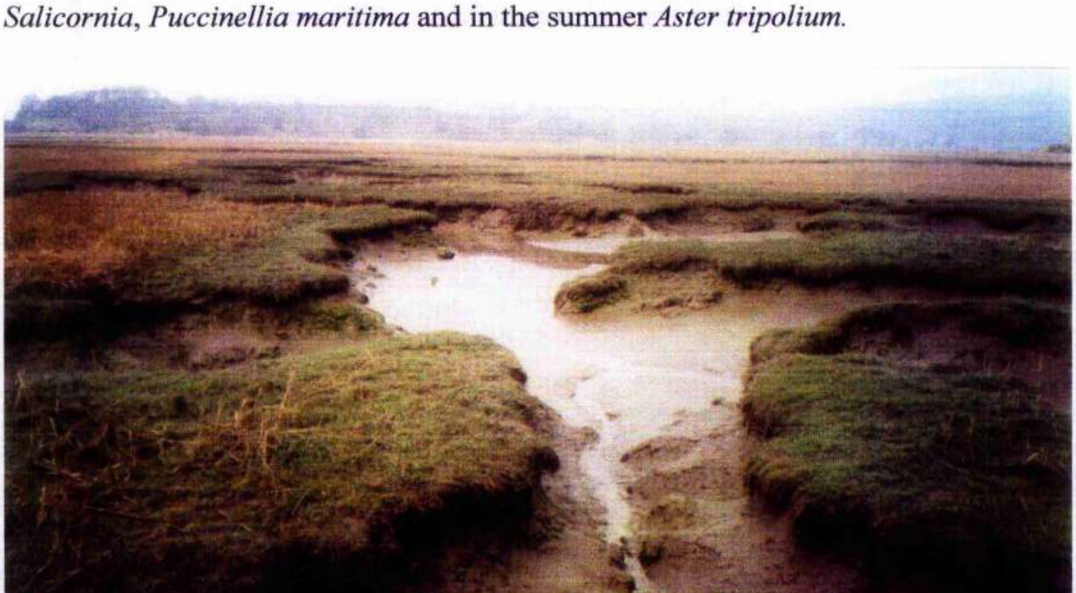


Figure 4.1.5 High marsh, Orchardton Merse, 2003, looking North West towards the landward edge.

4.1.6 Sedimentation on the high marsh using sub surface erosion plates.

The location of buried plate number 21 is shown on Map 1. As with all other aluminium plates this plate was originally buried to a known depth and was the only re-locatable plate in the high marsh from Harvey (2000). The plate was originally located near a creek and so was fairly easy to relocate. However, in 2003 half of plate 21 was exposed and visible at the creek edge. Thus, results collected from this plate were based on two measurements and averaged, rather than four and represent conditions very close to the creek edge. Again each plate measurement was collected on a monthly basis and the results for the monthly depths are given below. (Figure 4.1.6.). The first depth measured during the study was recorded in March, this was noted as 6.5cm. A slight accumulation of sediment is noted during the summer months, with the autumn months indicating a slight decrease in sediment and then some surface erosion. In December, sediment accumulation produces a rapid depth increase, probably on account of the collection day coinciding with a period of storm wave activity.

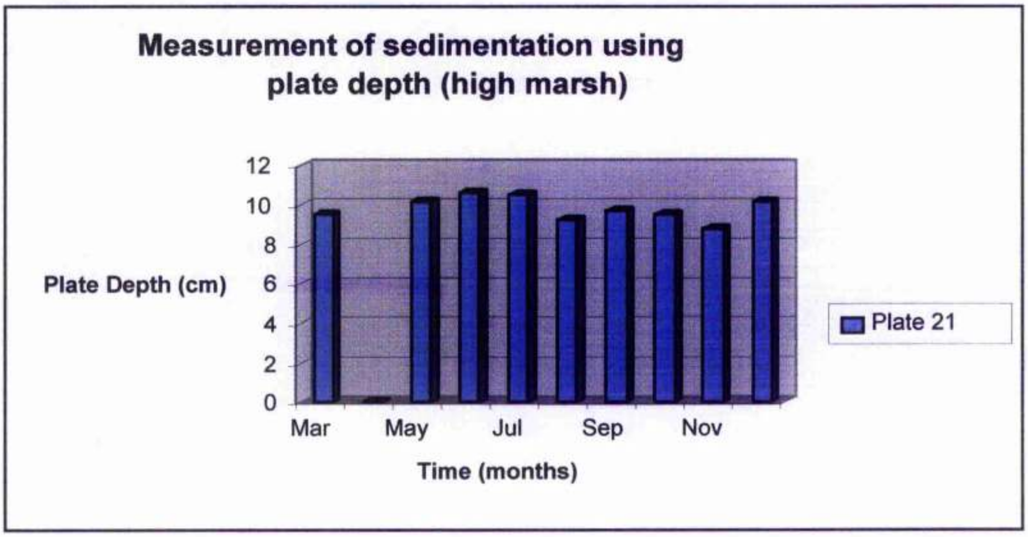


Figure 4.1.6 Sediment Accumulation at plate 21, high marsh.

4.2.1 Surface sedimentation on the primary marsh using sedimentation discs

As an alternative method of establishing surface sedimentation, 22 discs placed on the saltmarsh surface were measured at the same time as the erosion plates. In the primary marsh, 8 discs were placed to allow a consistent measure of surface sedimentation rates as illustrated by Map1. Each month the discs were replaced below HWST and collected at LWST. Sediment accumulation on each disc was then measured in the laboratory. Figure 4.2.1 shows the amount of sediment collected.

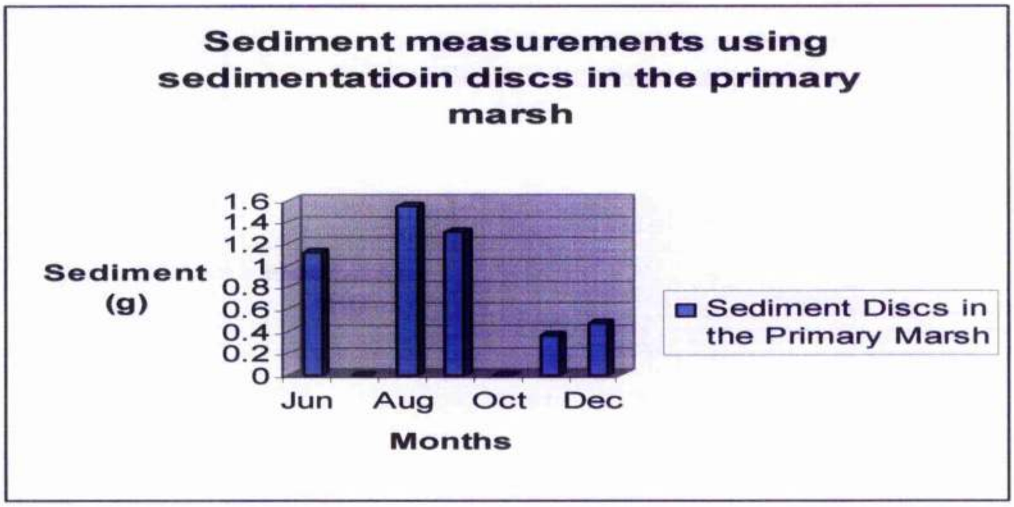


Figure 4.2.1. Sediment measurements using sedimentation discs in the primary marsh

During the month of June, sediment accumulation was relatively high in the primary marsh area, with the most sediment being collected at disc 4. During the month of July, discs were laid down to collect sediment but unfortunately, the Spring tide did not overbank and thus no sediment was collected. In August, data collection from discs was successful and sediment was collected from the primary marsh area that indicated a decrease in rate of sediment deposition. Also, during June, high rates of sediment deposition were recorded in the centre of the marsh, whilst in August, the highest sediment rates were found at disc 2 and disc 8, both located close to the creek edge. During September this pattern continued.

Whilst August had an average sediment accumulation of 1.546g, the average sediment accumulation in September was 1.311g. In November, this decrease in sediment accumulation became even more pronounced with sediment accumulation highest at disc 2 and disc 8, with an average amount of 0.36g at each disc. In December, the highest amount of sediment was deposited at disc 4 and the average sediment deposited at each disc is noted at 0.463g.

When comparing sediment change using data from August- September and November- December, see Figure 4.2.2, sediment collected by discs in Summer/Autumn months illustrates a high ratio of sediment collection, while sediment collected by discs during the winter months indicates lower amounts throughout the primary marsh. The biggest winter change being indicated at discs 4 and 8 (See Figure 4.2.2). Otherwise the winter amounts are low but fairly consistent at most discs.

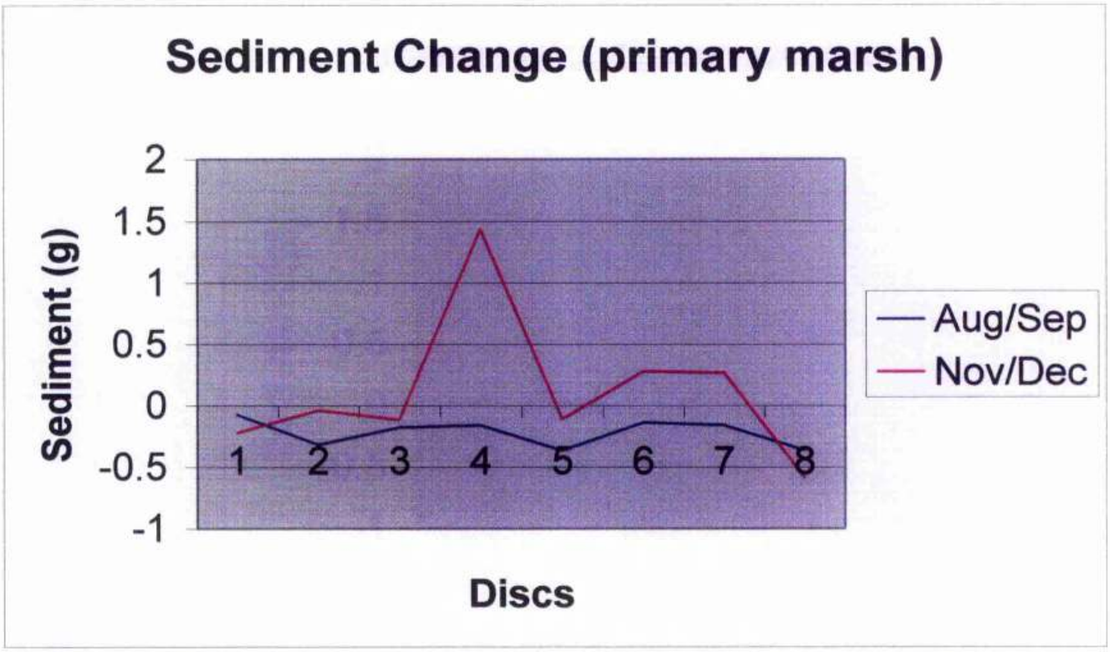


Figure 4.2.2 Patterns of sediment change in the primary marsh. Comparison of changing sediment deposition between August and September and November and December. Negative values indicate a drop in sediment accumulation and a tendency to erosion.

4.2.2 Surface sedimentation in the middle marsh using sedimentation discs

In the middle marsh study area, 8 discs were used to measure the sedimentation accumulation. Map 1 indicates the disc locations.

Each month the discs were placed into position before Spring tide and then collected when the tide receded. Figure 4.2.2.1 shows the amount of sediment collected for each disc.

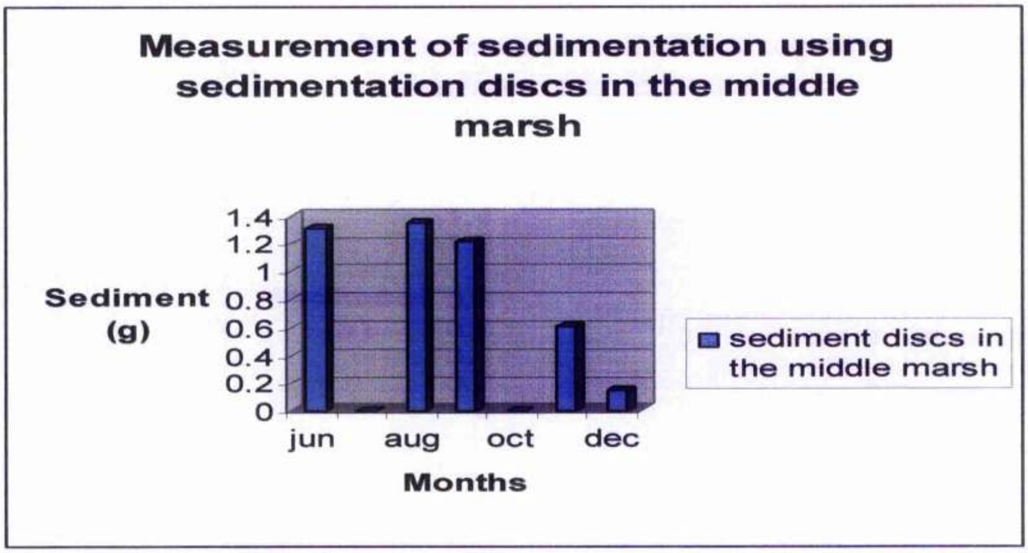


Figure 4.2.2.1 Measurement of sedimentation using sedimentation discs in the middle marsh.

From these results it appears that sediment collection rates were higher in the summer months of June to August, whilst there is a marked decrease from September onwards for most discs. The exception is Disc 13, located close to a creek located at the boundary between the primary marsh and the middle marsh which indicates ongoing sedimentation into November. Other noticeable summer peaks, were noted at discs 9,10 and 12. As illustrated by Map 1, the locations of Discs 9,10 and 12 are again at the boundary between primary marsh and middle marsh, Discs 9 and 10 were placed at the very edge of a creek that is part of a high-energy complicated creek system. Disc 12 was located slightly further inland.

When comparing sediment change using data from August- September and November- December, sediment collected by discs in the middle marsh indicates the largest change (a tendency towards erosion) occurs during winter months as illustrated by Figure 4.2.2.2 (see below). Although Disc 13 accumulated a high amount of sediment during November, no sediment was recorded during December, suggesting net erosion overall for adjacent surfaces. Thus, if we consider results from Figure 4.2.1 and Figure 4.2.2.1 there is a definite trend with the highest annual sedimentation being recorded at discs 9 and 10 (creek edge) and more specifically a reduction in sediment accumulation in the winter months, especially in December, when only 4 discs produced sediment records.

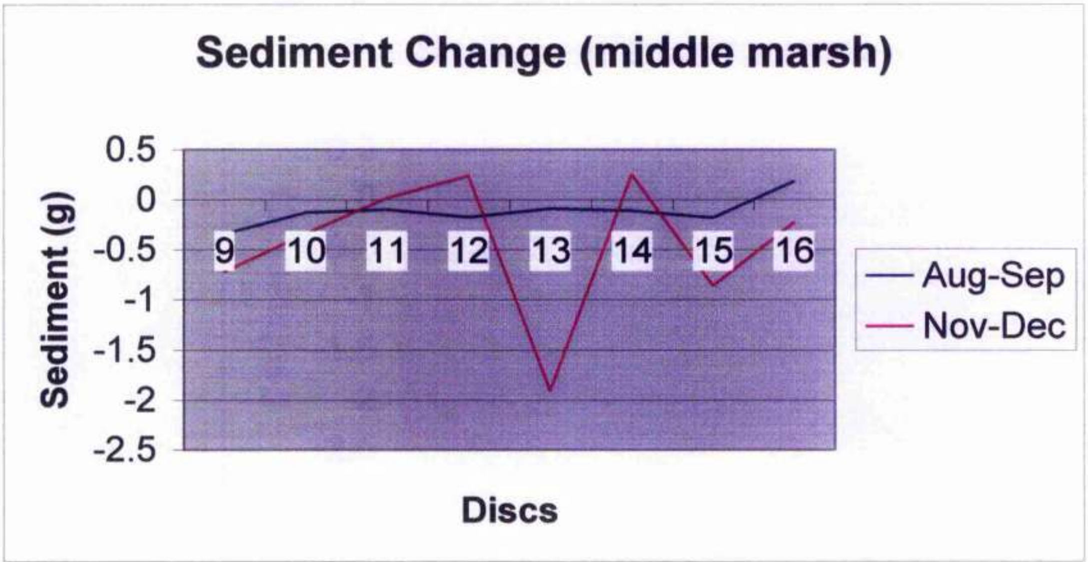


Figure 4.2.2.2 Patterns of sediment change in the middle marsh. Comparison of changing sediment deposition between August and September and November and December. Negative values indicate a drop in sediment accumulation and a tendency to erosion.

4.2.3 Sedimentation on the high marsh using sedimentation discs

In the high marsh area 6 discs were placed to measure sedimentation these locations are exhibited on Map 1.

Again, the discs were placed into position each month before HWST and then collected at LWST. Table 1 and Figure 4.2.3 show the sediment accumulation for each visit.

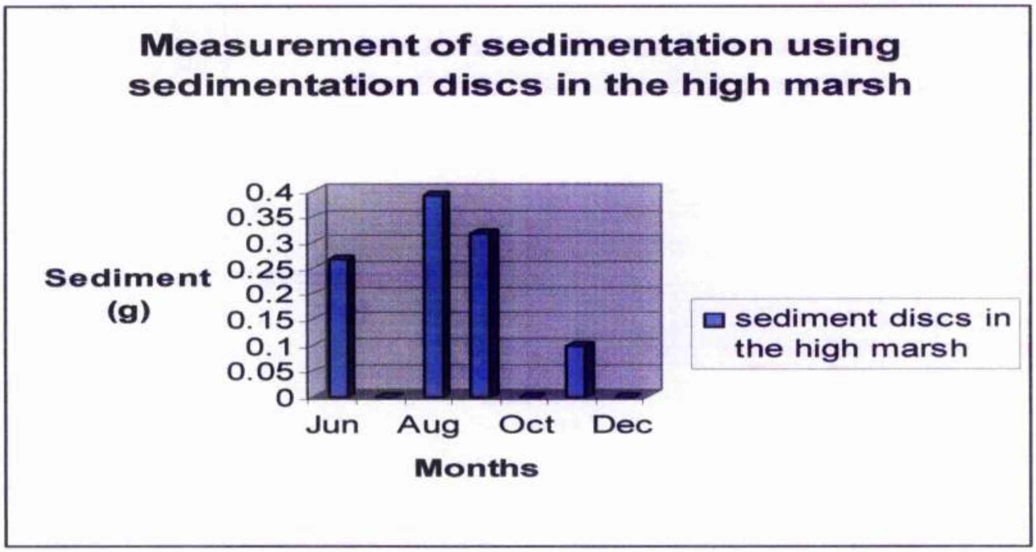


Figure 4.2.3 Measurement of sediment using sedimentation discs on the high marsh.

Through summer and autumn months, discs 17,18 and 19 produced small amounts of sediment. However discs 20,21 and 22 only recorded sediment deposition during June when the tide covered the site. It was also noted that during each visit, discs 18 and 19 displayed the highest sediment recordings in this study area. During the month of December, the tidal inundation did not cover these discs.

4.3.1 Sedimentation on primary marsh using vegetation surfaces.

Alongside the study of plates and discs, the role of vegetation was also examined. Like the other methods used, the vegetation analysis allowed comparisons to be made between both study sites and data gathering methods. In the primary marsh area 5 sites were used for vegetation analysis. The analysis of each site involved a visual assessment of vegetation cover, cropping of vegetation, and establishing the amount of sediment accumulated onto these vegetation surfaces.

It can also be noted that visual assessment of plant cover on the primary marsh during summer months has been rated as 7 at Layer 1 and 0 at all other layers (see Figure 3.2.2.1 for breakdown of the Domin Scale). Each number has a meaning relating to the density of plant cover and 7 denotes a high coverage of vegetation (70%). Each assessed area was also split into 3 layers, with the first layer being the ground level, the second layer being 5cm above the ground and the third layer between 6 and 10cm off the ground. Using the Domin Scale this implies that the primary marsh area experienced 70% of vegetation cover during the summer months reducing to 60% in September. However, it is also important to note the type of plant cover, as this may influence sediment collection. The majority of vegetation on the primary marsh at Orchardton saltmarsh was *Glasswort* with only small patches of *Spartina townsendii*. Figure 4.3.1 1 shows the sediment accumulation on the vegetated surfaces at sites 1 to 5 on the primary marsh.

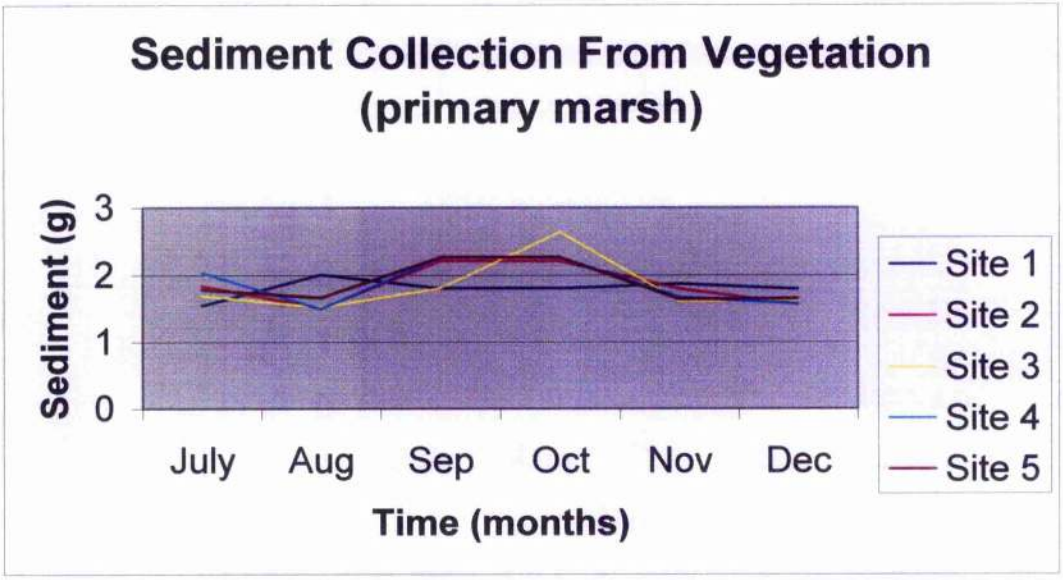


Figure 4.3.1.1. Sediment Collected from vegetation in the primary marsh, 2003.

The sediment accumulation on the primary marsh vegetation at each site remains low from the months July to September; there is a slight peak at most sites during September and October and then a general decrease in November and December. From the visual assessment of plant cover, peaks occurred in July and August (Figure 4.3.1.2) followed by a decrease in percentage coverage, with October, November and December reporting low vegetation cover as plants begin to die back.

	July	August	September	October	November	December
Primary Marsh						
1	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=4 Layer 2=0 Layer 3=0	Layer 1=1 Layer 2=0 Layer 3=0	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]
2	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=4 Layer 2=0 Layer 3=0	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]
3	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=4 Layer 2=0 Layer 3=0	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]
4	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=4 Layer 2=0 Layer 3=0	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]
5	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=7 Layer 2=0 Layer 3=0	Layer 1=4 Layer 2=0 Layer 3=0	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]	Layer 1=[illegible] Layer 2=[illegible] Layer 3=[illegible]

Figure 4.3.1.2 Visual Assessment of plant cover results, 2003

Colour Key: Green – Low cover, Blue - Medium cover & Yellow – High cover

4.3.2 Sedimentation on the middle marsh, vegetation surfaces

As illustrated by Map 1, 5 sites were located in the middle marsh, to examine the potential contribution of vegetation in enhancing the rates of sedimentation on the marsh.

Vegetation sites 6 to 10 were measured on a monthly basis between July and December with the results of sediment collected shown below in Figure 4.3.2.1 Generally, more sediment was collected on the vegetation surface in the summer months, particularly site 8, with a decline during the winter months at all sites. Both sites 7 and 8are located on slightly higher ground with a denser network of vegetation surrounding the sample sites.

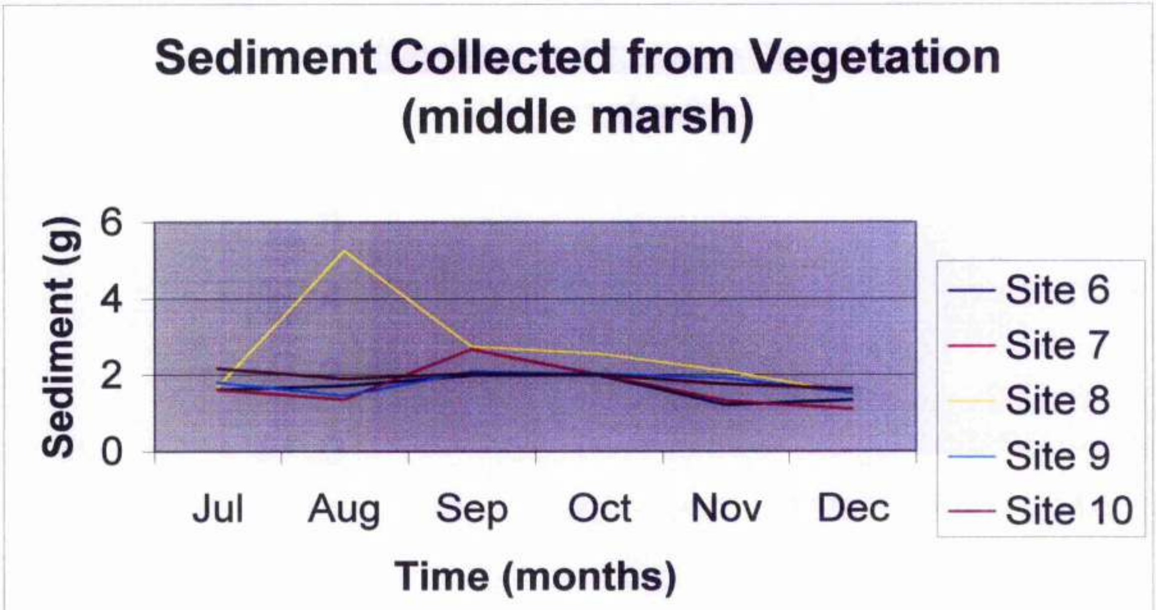


Figure 4.3.2.1 sediment collected from the vegetation sites in middle marsh.

As shown by the figure 4.3.2.1, more sediment was collected during the summer growth months. From the results of the visual assessment of plant cover see (Figure 4.3.2.2), there appears to be a definite relationship between increasing sediment collection and increased plant density. While the results for July, August and September indicate relatively consistent amounts of vegetation. The months of November and December indicate lower sediment accumulation and a reduction of plant cover.

Middle Marsh	July	August	September	October	November	December
6	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
7	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
8	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
9	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
10	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]

Figure 4.3.2.2 Visual Assessment of plant cover, middle marsh, 2003.

Colour Key: [redacted], Blue - Medium cover & Yellow – High cover

4.3.3 Sedimentation on the high marsh on vegetation surfaces

5 sites were located in the high marsh. (Map 1) Sites 11 – 15 were analysed on a monthly basis with the results exhibited below in Figure 4.3.3.1

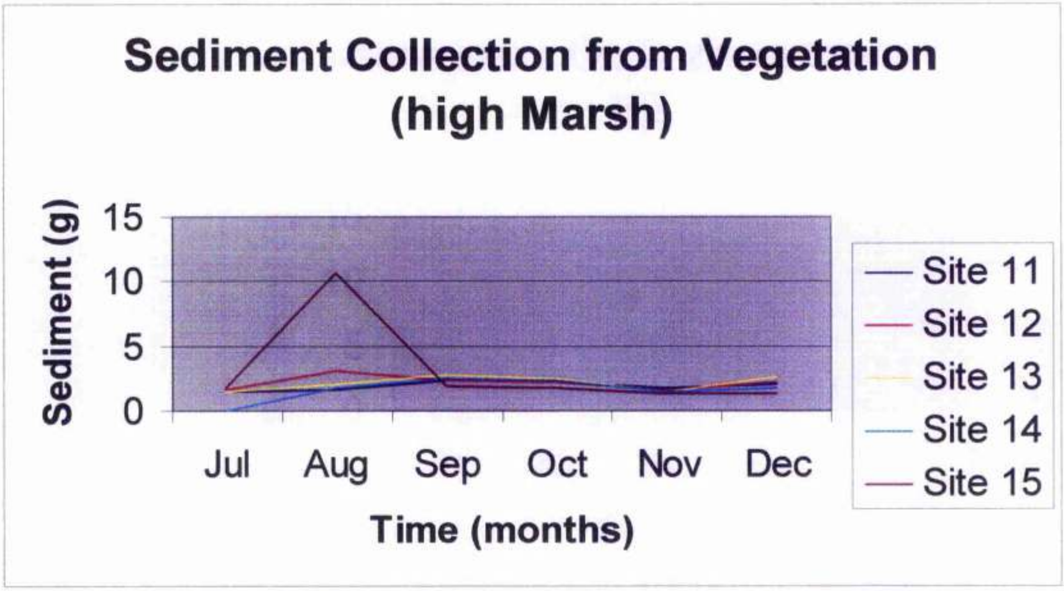


Figure 4.3.3.1 Sediment Collection from disc location in the high marsh, 2003.

It is clear from the above diagrams that sedimentation rates remained low but fairly consistent throughout the study. Sediment accumulation rates appeared slightly higher during the months of August and September especially at site 12 (near the creek), which recorded sediment accumulation on vegetation of over 10g. It is also of importance to note that in spite of plant die-back in the winter months, the high marsh always maintained a high coverage (75%) on the ground layer as well as a second layer of 25%. Figure 4.3.3.2 demonstrates the visual assessment of plant cover for this area which shows three layers of vegetation in the summer and two layers in the winter months.

High Marsh	July	August	September	October	November	December
11	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=4 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=4 [illegible]	Layer 1=4 Layer 2=4 Layer 3=[illegible]	Layer 1=4 Layer 2=4 Layer 3=[illegible]
12	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=4 Layer 2=4 Layer 3=[illegible]	Layer 1=4 Layer 2=4 Layer 3=[illegible]	Layer 1=4 Layer 2=4 Layer 3=[illegible]
13	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]	Layer 1=4 Layer 2=4 Layer 3=[illegible]
14	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]
15	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=9 Layer 2=7 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]	Layer 1=7 Layer 2=4 Layer 3=[illegible]

Figure 4.3.3.2 visual assessment of plant cover in the high marsh.

Colour Key: Green – Low cover, Blue - Medium cover & Yellow – High cover

4.4 Spatial variation in sedimentation over the primary, middle and high marsh.

4.4.1 Primary marsh: sub surface erosion plates, sedimentation discs and vegetation sedimentation. The location of erosion plates (plates 5 and 6), sedimentation discs (discs 1-8) and vegetation study sites (1-5) are shown on Map 1. When comparing these results using Table 4.4.1 it appears that plate 6 indicates the highest net accretion compared to anywhere else in the primary marsh study area. Plate 6 is closest to the creek edge in this study. It is also of great interest to note that sedimentation discs indicate a net erosion of sediment in summer throughout most of (not discs 4,6 & 7) the primary study area. Table 4.4.1 also indicates net accretion during winter months in most discs and erosion plates. This seasonal trend will be discussed later in the interpretation of the results. Sediment gathered and measured from the vegetation in the primary marsh appears to remain consistent throughout the year with a slightly higher summer value. As indicated by Table 4.4.1, when comparing erosion plates and study sites both areas indicate an increase in August with decreases following. However, erosion plates have a more obvious pattern. In July, the average depth for plate 6 is 4.6cm. In November this depth has decreased to

3.80cm. This small decrease is consistent with the vegetation analysis and may be related to seasonal die-back in foliage and therefore a reduction in surface area available for potential sedimentation.

When comparing sedimentation discs and sediment accumulated from vegetation trapping in the primary marsh, it appears that much of the sediment is indeed accumulated through trapping on vegetation surfaces. Whilst both sedimentation discs and vegetation trapping indicated a marked decrease from June to December, the decrease in sedimentation is more marked in the sedimentation discs and therefore on the surface of the marsh. Vegetation trapping results appear to collect very similar and consistent amounts. Thus in the primary marsh area, vegetation trapping appears to play a much more important role than surface sedimentation. However, it is important to note in this section of the primary marsh, vegetation coverage is limited and non-existent in some areas at some times. Thus not all areas of the primary marsh were accumulating sediment at these rates.

4.4.2 Middle marsh: sub surface erosion plates, sedimentation discs and vegetation sedimentation.

The location of erosion plates (plates 14 and 18), sedimentation discs (discs 9 to 16) and vegetation study sites are shown in Map 1. Erosion plate 14 shared similar sedimentation trends with discs 10 and 11. All 3 measuring devices were located beside a complicated creek network between the primary and middle marsh. During the summer months discs and plates indicated a positive relationship with regards to sediment collection. Moving into the winter months both plates and discs illustrate a decrease in sediment collection as illustrated by Table 4.4.1.

On the other side of the study area, at the location of erosion plate 18 and discs 13 and 14, a slightly different pattern is indicated. Whilst sediment accumulation at plate 18 is substantially higher than that of plate 14, plate 18 does not share a similar relationship with the surrounding discs. During months of peak sediment collection at disc 13, plate 18 displays a decreasing sediment amount. Also, when disc 13 shows a decreasing result for sediment collection, plate 18 displays a positive sediment accumulation (e.g. December results). These differences may be explained by the different location of plates and discs. As shown on Map 1, discs 13 and 14 are clearly situated at creek edges whilst plate 18 is more centrally located, thus making a comparison between measuring devices at these sites problematic.

During the months of July, August and September, sedimentation via vegetation trapping appears variable in comparison to the sediment accumulated at erosion plate sites but is often higher in the summer months when foliage is at a maximum. As indicated on Figure 4.2.1.1, vegetation trapping experiences less variation during winter. Unlike vegetation trapping, erosion plates experience more change during the winter months, as the surfaces are less vegetated therefore their potential to collect sediment in this fashion is limited. Sediment accumulation for vegetation trapping continues to note results while erosion plates record lower values of sediment.

During the summer months of June through to September results comparing sediment discs and vegetation trapping results are found to be higher in both measuring devices. In the month of June, 4 discs presented sedimentation accumulation over 1.0g, whilst in November only 1 disc recorded sedimentation accumulation over 1.og. However, while surface-measuring devices noted a marked decrease in sedimentation during the

Sediment accumulation using various techniques, Orchardton saltmarsh,2003											Change in sediment accumulation between various time periods			
	March	April	May	June	July	August	September	October	November	December	Jun-aug	aug-sep	sep-Nov	nov-dec
Sub Erosion Plates (depth in cm)														
5	1.275		1.675	1.575	2.175	1.7	1.65	1.275	1.2375	1.275	-0.125	-0.05	0.4125	0.0375
6	7.275		4.125	4.025	4.6	4.3	3.6	3.1	3.8	6.35	-0.275	-0.7	-0.2	2.55
14	4.5		4.325	4.55	4.75	4.625	4.6	4.5	4.45	13.4	-0.075	-0.025	0.15	8.95
18	6.3		7.25	7.4	7.4	7.1	7	6.4	6.15	15.3	0.3	-0.1	0.85	9.15
21	9.525		10.125	10.575	10.5	9.825	9.725	9.5	8.75	10.1175	-0.075	-0.1	0.975	1.3675
Sediment Discs In grams/disc														
1				0.6472	0	1.2159	1.1356	0	0.4632	0.2386	-.5687	-0.0803	0.6724	-0.2246
2				0.4562	0	1.8199	1.5003	0	0.3073	0.2626	-1.3637	-0.3196	1.193	-0.0447
3				1.5452	0	1.3365	1.1565	0	0.4144	0.2936	0.2087	-0.18	.7421	-0.1208
4				2.5579	0	1.4915	1.3298	0	0.3015	1.7316	1.0664	-0.1617	1.0283	1.4301
5				1.0428	0	1.515	1.1498	0	0.4622	0.3106	-.4722	-0.3652	0.6876	-0.1166
6				0.9042	0	1.5741	1.3211	0	0	0.2706	-.6699	-0.1416	1.3211	0.2706
7				0.5027	0	1.5948	1.4325	0	0	0.2586	-1.0921	-0.1623	1.4325	0.2586
8				1.2938	0	1.828	1.465	0	0.9314	0.3456	-.5342	-0.363	0.5336	-0.5858
9				3.0412	0	1.5924	1.255	0	0.7196	0	1.4488	-0.3374	0.5354	-0.7196
10				2.475	0	1.2603	1.1332	0	0.6926	0.3546	1.2147	-0.1271	0.4406	-0.338
11				0.9255	0	1.1046	1.009	0	0.2836	0.3026	-.1791	-0.0956	0.7254	0.0119
12				2.3556	0	1.2847	1.1113	0	0	0.2406	1.0709	-0.1734	1.1113	0.240-6
13				0.4725	0	1.1217	1.0359	0	1.9063	0	-.6492	-0.0858	-0.8704	-1.9063
14				0.2828	0	1.1102	1.002	0	0	0.2516	-.8274	-0.1082	1.002	0.2516
15				0.2184	0	1.214	1.0365	0	0.8615	0	-.9956	-0.1781	0.175	-0.8615
16				0.3788	0	1.1096	1.2958	0	0.2276	0	-.7308	0.1862	1.0682	-0.2276
17				0.3376	0	0.994	0.8523	0	0.1874	0	-.6564	-0.1417	0.6649	-0.1874
18				0.5027	0	1.3831	1.1	0	0.4396	0	-.8804	-0.2831	0.6604	-0.4396
19				0.1572	0	0.9505	0.7994	0	0.1512	0	-.7933	-0.1511	0.6482	-0.1512
20				0.5787	0	0	0	0	0	0	.5787	0	0	0
21				0.2039	0	0	0	0	0	0	.2039	0	0	0
22				0.1592	0	0	0	0	0	0	.1592	0	0	0
Vegetation In grams.														
1					1.5385	1.998	1.795	1.795	1.865	1.785	0.4595	-0.203	-0.07	-0.08
2					1.826	1.498	2.195	2.195	1.785	1.555	-0.328	0.697	0.41	-0.23
3					1.685	1.516	1.8	2.635	1.605	1.625	-0.169	0.284	0.195	0.02
4					2.03	1.4903	2.255	2.255	1.665	1.565	-0.5397	0.7647	0.59	-0.1
5					1.777	1.657	2.255	2.255	1.635	1.645	-0.12	0.598	0.62	0.01
6					1.609	1.7136	1.985	1.985	1.217	1.345	0.1046	0.2714	0.768	0.128
7					1.609	1.36	2.675	2.003	1.315	1.115	-0.249	1.315	1.36	-0.2
8					1.6755	5.2557	2.755	2.565	2.105	1.515	3.5802	-2.5007	0.65	-0.59
9					1.798	1.4544	2.085	2.023	1.915	1.525	-0.3436	0.6306	0.17	-0.39
10					2.165	1.9005	2.035	2.001	1.755	1.625	-0.2645	0.1345	0.28	-0.13
11					1.4805	1.5568	2.385	2.21	1.715	1.975	0.0736	0.8282	0.67	0.26
12					1.5647	3.0256	2.285	2.185	1.595	2.125	1.4609	-0.7406	0.69	0.53
13					1.5192	1.998	2.725	2.525	1.425	2.555	0.4788	0.727	1.3	1.13
14					0	1.7476	2.505	2.305	1.455	1.675	1.7476	0.7574	1.05	0.22
15					1.7805	10.6846	1.835	1.815	1.345	1.365	8.9041	-8.8496	0.49	0.02

Table 1 Sediment collection using sub erosion plates, surface discs and vegetation analysis (highlighted in yellow), Orchardton Saltmarsh, 2003. The number 0 represents no over banking during inundation by tidal waters.

Key for colour coding

Area of marsh	Colour Code
Primary Marsh	Blue
Middle Marsh	Green
High Marsh	Red

winter months, vegetation-trapping shows only a slight decrease, or little change at all vegetation study areas.

4.4.3 High marsh: sub surface erosion plates, sedimentation discs and vegetation sedimentation

The locations of erosion plate (plate 21), sedimentation discs (discs 17-22) and vegetation study sites are shown on Map 1.(Figure 3.2.1.1)

Disc 19 is closest to plate 21 and will therefore be used in this analysis. As indicated by Table 1 unlike the other results, the plates and discs do not appear to share similarities in sedimentation rates. Table 1 indicates sediment accumulation for the study area and also a monthly comparison of sediment accumulation. All of the sedimentation discs in this study area indicate sedimentation occurring but the negative results of the monthly comparisons note that the sediment amounts are decreasing. Plate 21 mostly indicates erosion throughout the year with a small indication of accretion in December. This is not the case for disc 19, which indicates much larger variations. Both measuring devices show a decrease in sedimentation over the year.

From Table 1, while sediment accrued from vegetation trapping, plate 21 indicates erosion in the summer and accretion in the winter. Both measuring devices (vegetation trapping and sedimentation discs) indicate an increase during December. As shown by Table 1, the results for vegetation analysis at site 14 can also be compared to plate 21. Vegetation study site 14 experiences an increase in sediment accumulation from July to September then exhibits a decrease in November and

December. Apart from the month of December, where both measuring devices indicate a decrease, plate 21 reflects the opposite of the vegetation results. When comparing sedimentation discs and the vegetation study sites results, it is clear from Map 1 that discs 17, 18, 19 and 20 correspond with vegetation study sites 11, 12, 13 and 15. Table 1 shows the results. At each study site a distinct pattern can be noticeable, this is then followed by a decrease and then, sediment accumulation begins increasing again. The discs illustrate a peak in sediment collection during August and then a decrease is also noted. Study sites 11-15 also indicate small changes in vegetation coverage, (as noted in Table 1)

However, throughout the year on the high marsh, layers 1 and 2 of vegetation cover (see Figure 4.3.3.2) remains, with most change occurring in layer 3. When comparing vegetation cover and disc sedimentation results, a distinct similar pattern emerges: both the primary and middle saltmarsh results indicate a decrease in sediment accumulation during the winter months. However, while this pattern indicates temporal implications the high marsh differs. The quantity of sediment collected from discs in the high marsh area was much lower than the sediment collected from the high marsh via vegetation analysis. These results imply that the presence of vegetation may be more significant for marsh growth than sediment brought in by tidal inundation and deposited directly onto the marsh surface.

4.5 Spatial variation in sedimentation across the entire Orchardton saltmarsh

This section sets out to report the results of comparisons of all of the results from each of the primary, middle and high marsh study areas. That is, it compares the patterns over each of these areas by using all of the results obtained from the various techniques employed in an attempt to highlight variation in relative efficiencies.

4.5.1 Patterns of Sedimentation over the marsh indicated by sub surface erosion plates

The locations of erosion plates for the primary, middle and high saltmarsh are shown by Map 1. Plates 5 and 6 measured the primary marsh, plates 14 and 18 measured the middle marsh and plate 21 measured the high marsh. It is clear from Figure 4.5.1.1, that plates 14 and 18 collected more sediment than plates 5 and 6. The middle marsh has collected approximately 66% of sediment (onto the erosion plates) from March to December, with Plate 18 recording the largest amount of sediment totalling 84% of all sediment deposited on the erosion plates in the middle marsh area. As noted by Figure 4.5.1.1 erosion plate 21 has recorded a significantly higher amount of sediment from March to December than erosion plates 5, 6, 14 and 18.However, as plate 21 was the only plate to be examined in this section the results should be viewed with caution. Out of the five erosion plates, plate 5 accrued the least sediment, with only 8% of total sediment (of all plates) deposited on this plate.

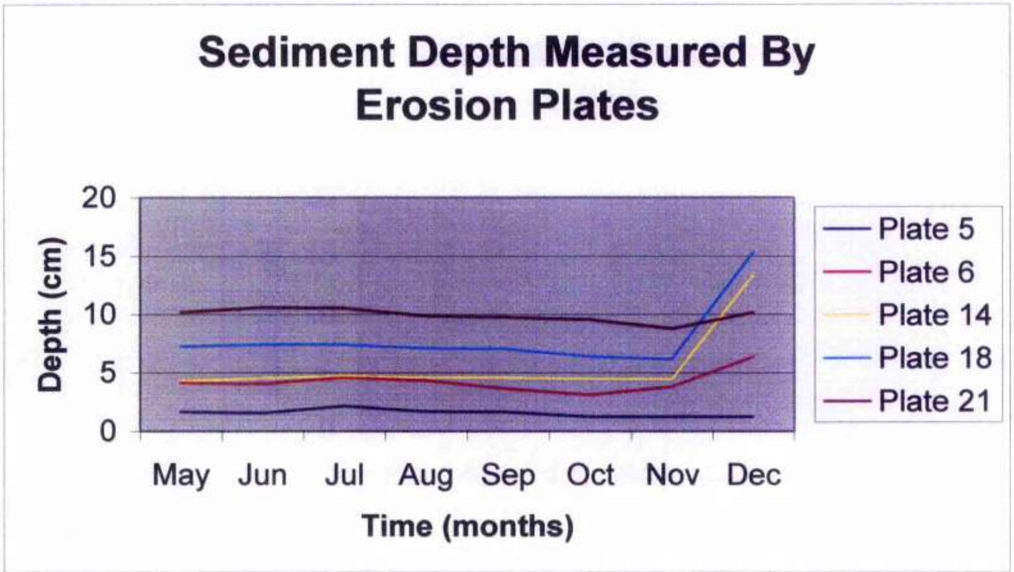


Figure 4.5.1.1 indicates sediment depth measured by sub surface erosion plates.

Examining each plate more closely, in the primary marsh, plate 6 results show in general higher sedimentation than plate 5. Similarly, plate 18 also illustrates higher sedimentation than plate 14b. Both plates 18 and 6 are located directly at creek edges. Whilst plates 5 and 14b both collect slightly less sediment and are also further from the creek edge. Plate 21 is located directly at a creek edge within the high marsh and collects the highest quantities of sediment during the study. Noting the monthly change between sediment depths each month furthers this analysis. Most change occurs in the winter months. Plates 14 and 18 indicate a large change between October and November, whilst Plate 5 remains consistent and Plate 6 reports a small but definite change during the winter months. Plate 21 does not record a significant monthly change in sediment depth, rather it measures consistent depths. The three plates that indicate change all show a net accretion of sediment during the winter months. In the long term, plate 21 indicates a net accretion whilst erosion plate 5 points towards net erosion. Thus, the main patterns that were observed in this comparison were:

- Plate depths deepen in the middle of the marsh
- The winter months of October, November & December indicate a higher rate of accretion in most areas (including the primary marsh).
- Plates close to the creek edges show higher accretion rates than those away from the creek edge.

4.5.2 Pattern of Sedimentation over the marsh indicated by sedimentation discs.

Map 1 (Figure 3.2.1.1) indicates sedimentation disc locations. The primary marsh consists of 8 discs (1-8), as does the middle marsh (discs 9-16). The high marsh consists of 6 discs (17 - 22). In order to compare the disc results for each area studied, sediment accumulation for each month measured was totalled. These results were then converted into graph format. As indicated by Figure 4.5.2.1, sediment accumulation varied throughout the study area.

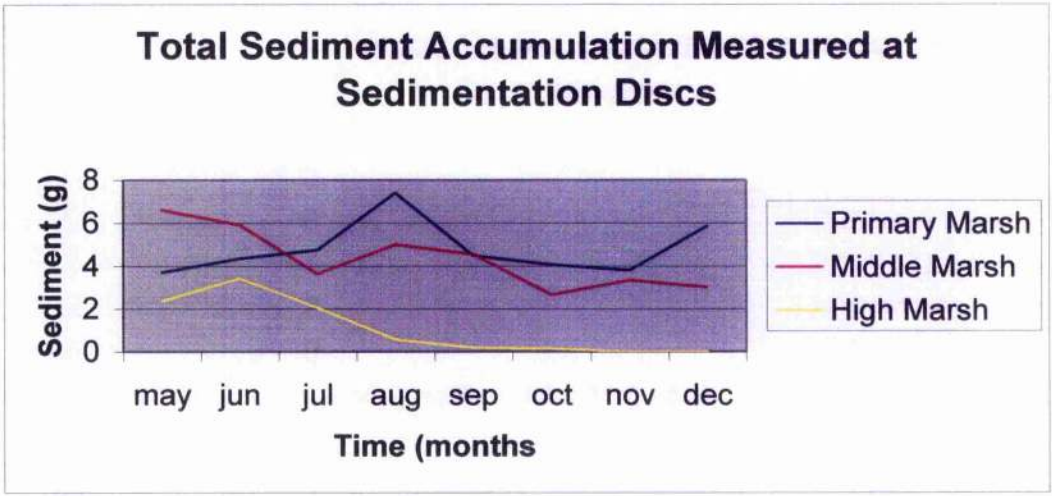


Figure 4.5.2.1: Total sediment accumulation measured by the sedimentation discs, Orchardton saltmarsh.

Figure 4.5.2.1 also indicates higher sediment accumulation at creek edges. This is indicated by high sedimentation at discs 4 and 8 for the primary marsh and discs 1, discs 9 and 10 in the middle marsh The high marsh did not record any peaks at creek edges, instead, it peaked approximately 2 meters from the creek edge. Furthermore, as illustrated by Figure 4.5.2.1, the primary marsh collected slightly more sediment throughout the study than the middle and high marsh.

On closer inspection, sediment accumulation in the high marsh area was much lower than that of the primary marsh, with discs 20, 21 and 22 only recording sediment in the month of June (see Table 1). Also, whilst the primary marsh indicates high sedimentation at creek edges, the high marsh does not reflect this pattern. Highest sedimentation in the high marsh was noted at disc 18, which is located in the centre of the marsh, not the creek edge, (see Map1, Figure 3.2.1.1).

Thus, patterns that are evident from analysis of sedimentation in the primary, middle and high marsh areas are:

- The primary marsh collects more sediment than the middle and high marsh.
- The middle marsh collects more sediment than the high marsh.
- The highest sediment amounts were recorded at creek edges.

4.5.3 Patterns of sedimentation in the saltmarsh indicated by vegetation sampling.

In order to compare patterns of vegetation cover over the saltmarsh, vegetation study site were chosen and these are indicated in Figure 4.5.3.1. In total, 15 sites were used, 5 in each saltmarsh study section. The vegetation cover was assessed using a method called the Domin Scale (see Figure 3.2.2.1, chapter 3 for further explanation). The results of the vegetation trapping study are shown by Figure 4.5.3.2.

Using Figure 4.5.3.2, 3 layers for each study site have been given a number and a colour. The number represents the Domin Scale and the colour is an indication of the level of plant cover, i.e. is it low, medium or high cover. The colour green indicates high cover of vegetation, blue indicates a medium cover of vegetation and yellow indicates a minimum cover of vegetation. From this several patterns emerge.

Firstly, in all the study sites during the summer months, a high level of plant cover occurs over the entire marsh (with three layers of vegetation on the high marsh and two layers on the middle and primary marsh), which gradually decreases during Autumn and then notably declines in the winter months (with the exception of the high marsh). Results from sediment accumulated at these study sites are in keeping with this plant cover pattern (see Figure 4.5.3.3). Total sediment collected in the primary marsh from July to December is very similar to the sediment accumulation in the middle marsh during the same timescale. The middle marsh vegetation study sites only exceed the primary marsh vegetation study sites in sediment accumulation by 1%. The high marsh vegetation study sites indicate much denser plant cover throughout the year and a higher sediment accumulation throughout the year. The high marsh vegetation cover decreases slightly during the winter months, changing from 3 layers in the spring, summer and

	July	August	September	October	November	December
Primary Marsh						
1	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
2	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
3	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
4	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
5	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]

Middle Marsh	July	August	September	October	November	December
6	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
7	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
8	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
9	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
10	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]

High Marsh	July	August	September	October	November	December
11	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]
12	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=4 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]
13	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 Layer 3=+	Layer 1=9 Layer 2=7 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]
14	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]
15	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]

Table 4.5.3.2 Plant Cover Data Measured Using Domin Scale

Colour Key: [redacted], Blue - Medium cover & Yellow – High cover autumn months to 2 layers of vegetation during the winter months. Sediment trapping is greater here in winter when compared to the primary and the middle marsh. The high marsh indicated more diversity of cover with high plant abundance in the winter months as well as the summer months.

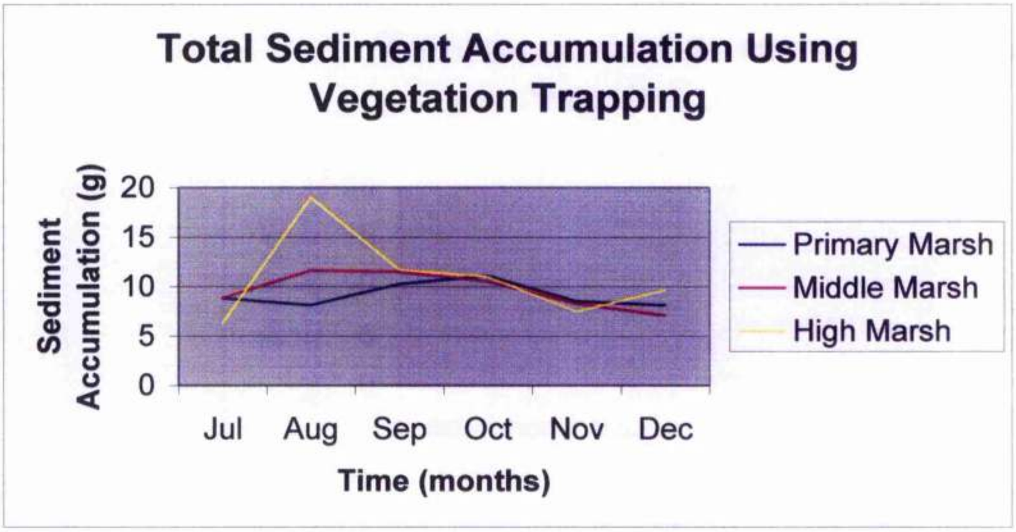


Figure 4.5.3.3 Sediment accumulation using vegetation trapping (July to December)

Thus the main spatial patterns that can be derived from the results are:

- There is generally more vegetation cover in the spring and summer and more layers in the middle and high marsh at this time, however, whilst winter vegetation cover is maintained on the high marsh it is very limited on the primary and middle marsh.
- The middle marsh has higher sedimentation rates than the primary marsh; however, the high marsh outperforms the primary and the middle marsh overall, especially in summer and to a certain extent in winter.
- More sediment is accumulated throughout the marsh when the plant coverage is high. Sediment accumulation decreases as plant cover declines.

4.6 Long Term Evaluation

4.6.1 Comparison of Sub-Surface Erosion Plate Depth 2003 with Erosion Plate Depth 1995'96 and '97.

In terms of contextualising the sedimentation on Orchardton Marsh, a longer-term perspective would be useful. Sub-surface sedimentation plate results from 2003 were compared with those of Harvey, 2000. Figure 4.6.1.1 illustrates the time series sediment accumulation over the period September 1995, June 1996 and August 1997 and March 2003.

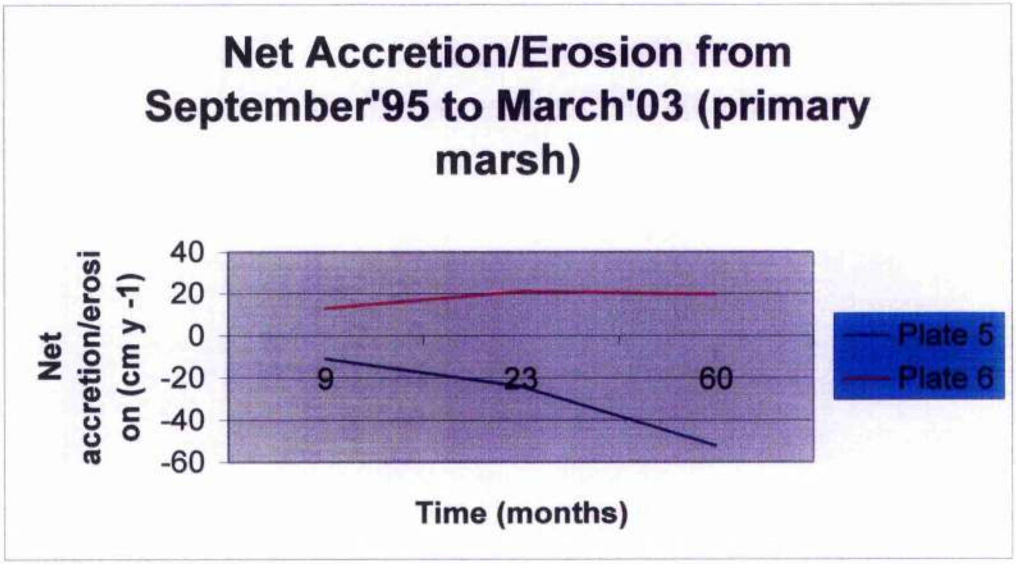


Figure 4.6.1.1 Time Series Comparison of sediment accumulation at plate locations 5 and 6. Net accretion/erosion measured cm y^{-1}.

Plate 5 illustrates a steady loss of sediment over the plate location (i.e. erosion), from September 1995 to March 2003, while Plate 6 illustrates a rapid accretion over the first period followed by a lesser rate.

In the middle marsh, plate's 14b and 18 were measured in 2003 to allow a comparison between plates measurements collected in September 1995, June 1996 and August

1997. As illustrated by Figure 4.6.1.2 plate 14 b indicated net erosion after 9 months. However by August 1997 this had changed and net accretion rate was measured at 0.7 cm y-1. This study site is no longer indicating a net accretion, but rather net erosion. It also evident from Figure 4.6.1.2 that plate 18 also illustrates consistent net erosion from September 1995 to March 2003.

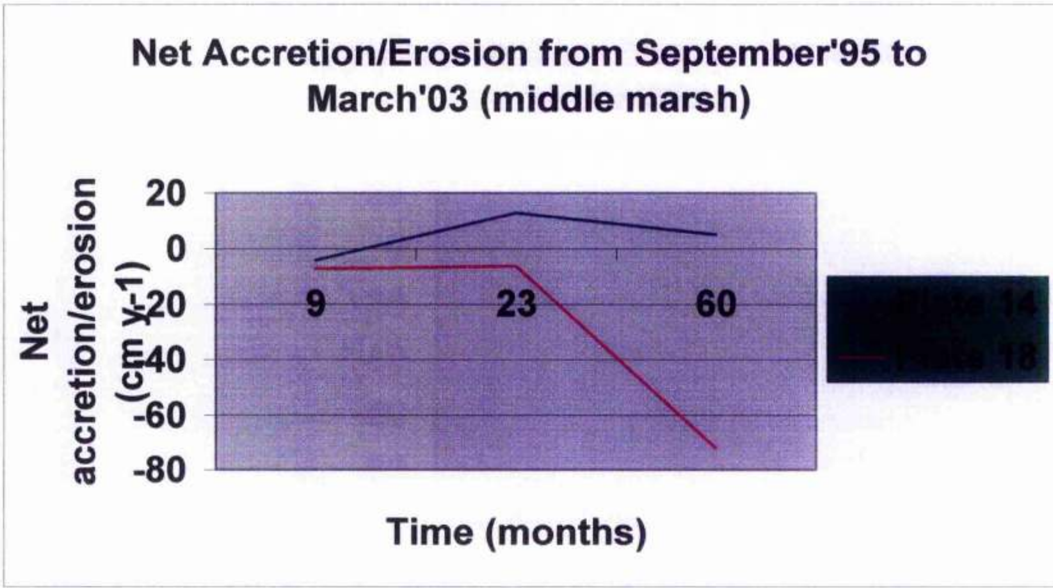


Figure 4.6.1.2 Net accretion/erosion from September 1995 to March 2003 in the middle marsh.

On the high marsh for the third study area in the research project, the plate chosen from the high marsh was plate 21. As shown by Figure 4.6.1.5, plate 21 also indicates a consisted net reduction of sediment over the plate in the long term and indicates long term erosion of this site. Further recordings for this plate are now unattainable since the plate cannot now be located. It has likely been eroded out of the creek bank and lost.

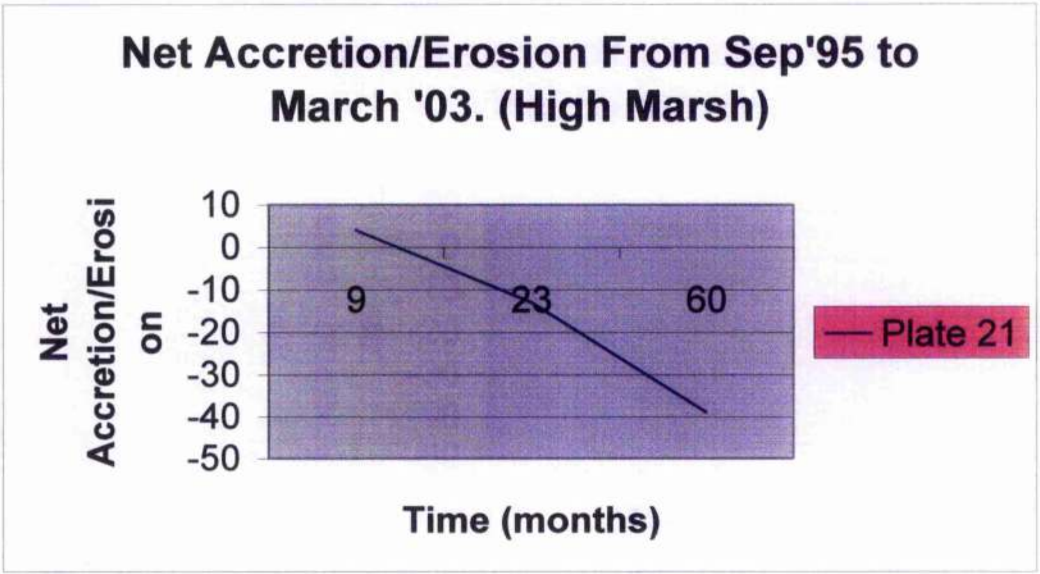


Figure 4.6.1.5 Net accretion/erosion from September 1995 to March 2003 in the high marsh.

From this analysis of longer term trends, it appears that while long term erosion occurs on the high marsh, the situation on the primary and middle marsh is more variable and depends on location and proximity to creeks whose margin accrete more rapidly. It appears that the lower marsh is experiencing erosion at the southeast creek edge and the middle marsh has experienced some accretion at the north east, beside the creek edge.

4.7 Summary of Trends

Overall,

- Plate depths deepen in the middle of the marsh
- The winter months of October, November & December indicate a higher rate of accretion in most areas (including the primary marsh).
- Plates close to the creek edges show higher accretion rates than those away from the creek edge.
- The primary marsh collects more sediment than the middle and high marsh.
- The middle marsh collects more sediment than the high marsh.
- The highest sediment amounts were recorded at creek edges.
- Long term erosion is occurring on the high marsh.

Chapter 5: Interpretation

5.1 Interpretation

The importance of sedimentation upon saltmarshes and the underlying processes that affect it has been the subject of several studies both in the Solway (Hansom, 2003) and elsewhere in the UK, Adam (1990), Allen & Pye (1992) and French & Spencer (1993). The aim of this research project was to examine saltmarsh sedimentation patterns and processes in order to address the following objectives:

- What is the role of vegetation sedimentation versus surface sedimentation on a saltmarsh?
- Can the patterns of sediment trapped by vegetation be identified?
- Can the patterns of sediment trapped on the surface be identified?
- Are there seasonal effects on vegetation performance?

Whilst considering the above objectives, the results of this research project indicated a series of trends, which are discussed individually as follows.

5.2 Spatial sediment accumulation patterns across the saltmarsh

During the research project several methods were employed to assess sedimentation on the saltmarsh. From the results it became apparent that some areas of the study area were highly influenced by sedimentation while other areas showed minor (if any) change.

5.2.1 Sediment collection on the saltmarsh surface by erosion plates

The first method used to study the implications of direct settling of sedimentation at Orchardton was the use of a surrogate marker horizon. The marker horizons consisted of aluminium plates buried in the marsh. Several erosion plates were located and measurements collected on a monthly basis. Although the depth measurements cannot be strictly and quantitatively compared alongside the weights of the other methods used, the varying patterns of accretion, erosion, time and space can be. Table 5.2.1 shows the annual measurements of the erosion plates. Data highlighted in bold indicates the highest values for each month.

Erosion Plates Depth	July	August	September	October	November	December	Maximum change
5	2.175	1.7	1.7	1.275	1.2375	1.275	7.19
6	4.6	4.3	4.3	3.1	3.8	6.35	1.95
Total							9.14
14	4.75	4.625	4.625	4.5	4.45	**13.4**	8.75
18	*7.4*	*7.1*	*7.1*	*6.4*	*6.15*	***15.3***	*7.9*
Total							*16.65*
21	***10.5***	***9.825***	***9.825***	***9.5***	***8.75***	***10.117***	*0.4*
Total							*0.4*

Primary Marsh
Middle marsh
High marsh

Table 5.2.1 Depth measured to erosion plates from July to December. All depths in cm. Those erosion plates in bold indicate a high reading. Those erosion plates in italics are located beside a creek edge.

The highest sedimentation results were indicated on those erosion plates at creek edges. For example, plate 21, located in the high marsh and directly beside a creek is a good example supporting this point. French and Spencer (1993) and Postma's theory of settling lag (Stumpf, 1983) support this interpretation elsewhere. According to Stumpf (1983) and Allen (1992b) sediment rates show a decline as distance from the creek edge increases. This is further demonstrated by Plate 18, which is also located beside a creek edge and indicates relatively high sedimentation rates in those months when plate depth increases (December). While most literature argues that the highest sedimentation rates generally occur at the seaward edge of a saltmarsh and this sedimentation rate should then decrease as height increases and the saltmarsh matures, Adam (1990) and Beukema (1990). Harvey (2000) does not concur and found that the sedimentation patterns at Orchardton saltmarsh were high in the mudflat areas (seaward edge) as well as locations further inland. As shown by Table 5.2.1, this study has found some erosion plates located in the more mature area of the saltmarsh have higher sedimentation than some lower areas. The primary marsh area indicates limited accretion with the greatest depth being measured in November and December (plate 6). The results produced in this study from erosion plates tend to agree with other research findings, i.e. that sedimentation generally reduces away from the creeks but that accumulation at the primary marsh was lower than the middle marsh. Findings by Pethick (1984) and Stumpf (1983) support this opinion by stating that suspended sediment load will reduce as waves pass over the creek edge and move towards the middle of the marsh. This reduction can occur via entrapment, which is associated with a reduction in wave energy, this can induce direct settling at creek edges and lead to the formation of levees and eventually an elevated marsh surface. However, it is also clear from Table 5.1.1 that all areas of the marsh at Orchardton underwent a loss of sediment from the surface over the summer months.

5.2.2 Sediment collection on the saltmarsh surface by discs

Direct settling of sedimentation on the saltmarsh surface was examined with the use of discs, a sediment trap designed to optimise results with minimum interference (Allen and Duffy 1998; French and Spencer 1993; Pestrong 1972). From the results of this study, direct settling appeared to play an important role in sediment accretion. Disc results indicate high sedimentation rates where tidal inundations occur. Disc results from the high marsh area that were not inundated by the tide recorded no sediment at each collection. As indicated by Table 5.2.2 the annual sediment collection total indicates the primary marsh as the highest trapper of sediment with the middle marsh following closely behind. From Table 5.2.2 patterns can also be established using sediment accumulation data. Data highlighted in bold in Table 5.2.2 indicates high sediment accumulation for the disc. (sediment accumulation over 1.5g was recorded as high) Significantly, most of the disc sites with a high rate of sediment accumulation are located beside creeks which correspond to other research findings in this field. Stumpf (1983) states that during tidal inundation the intricate creek system is filled and eventually over banks. During this process particles that are being carried with the tide are preferentially deposited at or near the creek edge. Only three discs out of 22 (that were not directly beside a creek) showed high sediment accumulation amounts. This pattern of high sedimentation alongside creeks agrees with French and Spencer (1993), who show that in Norfolk, more sediment will be deposited at the creek edges rather than the interior of the marsh.

French and Spencer (1993) also note in their 5-year study, that 8mm/yr was recorded at the front of the marsh in comparison with only 1mm/yr at the back of the marsh. They attributed these results to the spatial location of creeks. Support for results in this study are further enhanced by Postma's model of settling lag (Stumpf 1983). Postma indicates that the formation of levees alongside creeks can be attributed to sediment, mainly course particles, being deposited at the creek edge, with the majority of sedimentation occurring in the primary and middle marsh. Furthermore, as stated by Adam (1990), the rate of sedimentation in the mature areas of a saltmarsh decreases because of fewer flooding tides and also the deposition of sediment in the lower levels. Randerson (1979) also argued in agreement with this theory and noted that coarser sediment would settle out first supporting Steers (1948) argument for the formation of creek levees. As indicated by Table 5.2.2, the high marsh sediment values at Orchardton were significantly lower than the primary and middle marsh. Discs in this area were not inundated frequently with tidal waters and so such locations recorded less tidal duration and less opportunity for sedimentation. Thus the results presented in this study support the arguments presented by French and Spencer (1993) and Postma (Stumpf 1983) that more sediment is recorded at the creek edges of a saltmarsh.

Discs	June	July	August	September	October	November	December	**Annual Sediment Collection**
1	0.6472	0	1.2159	1.1356	0	0.4632	0.2386	3.7005
2	*0.4562*	*0*	***1.8199***	***1.5003***	*0*	*0.3073*	*0.2626*	*4.3463*
3	***1.5452***	*0*	*1.3365*	*1.1565*	*0*	*0.4144*	*0.2936*	*4.7462*
4	**2.5579**	*0*	*1.4915*	*1.3298*	*0*	*0.3015*	***1.7316***	*7.4123*
5	1.0428	0	1.515	1.1498	0	0.4622	0.3106	4.4804
6	0.9042	0	1.5741	1.3211	0	0	0.2706	4.07
7	0.5027	0	1.5948	1.4325	0	0	0.2586	3.7886
8	*1.2938*	*0*	***1.828***	*1.465*	*0*	*0.9314*	*0.3456*	*5.8638*
Total Sediment collection								38.4081
9	***3.0412***	*0*	***1.5924***	***1.255***	*0*	*0.7196*	*0*	*6.6082*
10	***2.475***	*0*	*1.2603*	*1.1332*	*0*	*0.6926*	*0.3546*	*5.9157*
11	0.9255	0	1.1046	1.009	0	0.2836	0.3026	3.6253
12	**2.3556**	0	1.2847	1.1113	0	0	0.2406	4.9922
13	*0.4725*	*0*	*1.1217*	*1.0359*	*0*	***1.9063***	*0*	*4.5364*
14	0.2828	0	1.1102	1.002	0	0	0.2516	2.6466
15	0.2184	0	1.214	1.0365	0	0.8615	0	3.3564
16	*0.3788*	*0*	*1.1096*	*1.2958*	*0*	*0.2276*	*0*	*3.0118*
Total Sediment collection								34.6926
17	*0.3376*	*0*	*0.994*	*0.8523*	*0*	*0.1874*	*0*	*2.3713*
18	*0.5027*	*0*	*1.3831*	*1.1*	*0*	*0.4396*	*0*	*3.4254*
19	*0.1572*	*0*	*0.9505*	*0.7994*	*0*	*0.1512*	*0*	*2.0583*
20	0.5787	0	0	0	0	0	0	0.5787
21	0.2039	0	0	0	0	0	0	0.2039
22	0.1592	0	0	0	0	0	0	0.1592
Total Sediment collection								8.7968

Primary Marsh
Middle marsh
High marsh

Table 5.2.2 Sedimentation in gms, on the saltmarsh collected from Discs from June to December 2003. Those sedimentation discs in bold indicate a high reading. Those sedimentation discs in italics are located beside a creek edge.

5.2.3 Sediment collection by On-Vegetation Deposition

The third method used to assess sedimentation across the study area was to harvest sediment that had accumulated on vegetative surfaces. Whilst French and Spencer (1993) argue sediment is predominantly attributed to spatial positioning of intricate creek systems and tidal inundation frequency, they suggested that vegetation has a secondary influence on saltmarsh sedimentation. Pethick (1984) and Stumpf (1983) both argue that vegetation plays a much larger role. Pethick (1984) states "it would be unlikely that much sedimentation could take place were it not for the vegetation cover." As indicated by Table 5.2.3, sediment harvested from vegetation surfaces at Orchardton saltmarsh show that vegetation represents an important source of sediment. Again, while the data is not quantitatively comparable with the other measurements collected during the study period, we can qualititatively compare the resulting patterns that are distinguishable in the data. This is because

- Erosion plates record depths and are dependent on the limited burial depth. Changes in depths indicate accretion and erosion in the plate area.
- Sediment discs record the amount of sediment accumulation on the disc area. Changes in monthly amounts reflect accretion but not erosion at the disc site. However, erosion is uncommon, the amount 0 is mostly due to the lack of overbanking tides.
- On-vegetation amounts show the amount of sediment trapped on the shoots of the vegetation within a 1x1 quadrat and over the vertical length which represents the interception of sediment up to 30cm above the surface of the marsh.

Unlike, the sedimentation discs and erosion plates, the vegetation data showed a different response. Whilst sedimentation discs indicated low sediment accumulation on the high marsh surface, the vegetation results indicate that sediment accumulation on vegetation is higher in this area. French and Spencer (1993) suggest that less than 5% of sediment was attributed to vegetation trapping during their study, results from vegetation trapping techniques on Orchardton saltmarsh indicate on-vegetation collection is more important. While the methods are not directly comparable, vegetation study sites located within the saltmarsh recorded high on-vegetation sedimentation throughout the study period. In the primary marsh area, the total sediment accumulation recorded for the study sites 1 to 5 was 55.1808g, the middle marsh recorded 60.6497g of sediment accumulation through entrapment and the high marsh reported 65.3625g. Thus, unlike the erosion plates and the sedimentation discs, the amount of sediment collected from the vegetation study sites increases inland. This again contradicts the view that most sediment is deposited at the seaward edge of the saltmarsh. Another important difference between the vegetation study sites and the other sediment collection processes is that no correlation apparently exists between the sediment collections at the creek edge. Previously, as argued by Pethick (1984) and Postma's (1961) theory on settling lag, the majority of sediment should be deposited at a creek edge. However, the on-vegetation results in this study do not.

Vegetation Study sites	July	August	September	October	November	December	Total Accumulation
1	*1.5385*	*1.998*	*1.795*	*1.795*	*1.865*	*1.785*	*10.7765*
2	1.826	1.498	2.195	2.195	1.785	1.555	11.054
3	1.685	1.516	1.8	**2.635**	1.605	1.625	10.866
4	**2.03**	1.4903	2.255	2.255	1.665	1.565	11.2603
5	*1.777*	*1.657*	*2.255*	*2.255*	*1.635*	*1.645*	*11.224*
Total sediment collection							55.1808
6	*1.609*	*1.7136*	*1.985*	*1.985*	*1.217*	*1.345*	*9.8546*
7	1.609	1.36	2.675	2.003	1.315	1.115	10.077
8	1.6755	5.2557	**2.755**	2.565	**2.105**	1.515	18.4362
9	1.798	1.4544	2.085	2.023	1.915	1.525	10.8004
10	*2.165*	*1.9005*	*2.035*	*2.001*	*1.755*	*1.625*	*11.4815*
Total sediment collection							60.6497
11	*1.4805*	*1.5568*	*2.385*	*2.21*	*1.715*	*1.975*	*11.3223*
12	1.5647	3.0256	2.285	2.185	1.595	2.125	12.7803
13	1.5192	1.998	2.725	2.525	1.425	**2.555**	12.7472
14	0	1.7476	2.505	2.305	1.455	1.675	9.6876
15	*1.7805*	***10.6846***	*1.835*	*1.815*	*1.345*	*1.365*	*18.8251*
Total sediment collection							65.3625

Primary Marsh
Middle Marsh
High Marsh

Table 5.2.3 Sedimentation accumulation at Vegetation Study Sites in gms. Those sedimentation discs in bold indicate a high reading. Those sedimentation discs in italics are located beside a creek edge.

As shown by Table 5.2.3, sediment collection was as high in the study sites located away from creek edges as those sites located beside creek edges. For example, study sites 1 and 5, 6 and 10, and 11 and 15 were all located beside creeks on the saltmarsh. As illustrated by Table 5.2.3, the total accumulation of sediment at study site 1 was 10.7765g and study site 5 recorded 11.224g. The other sites located in between these sites did not differ greatly over the study time: study site 3 recorded 10.866g of sediment, only slightly lower than study site 1. Study site 6 recorded 9.8546g of sediment throughout the study, while study site 10 noted 11.4815g. Those sites in between did not differ greatly and furthered the opinion that creeks might not be so influential as a controlling influence on on-vegetation sediment accumulation. The study sites in the mature area of the marsh reinforced this opinion by showing similar patterns and results. Study site 11 recorded 11.3223g of sediment and study site 15, 18.8251g. Thus results indicate that the views of Randerson (1979), Stumpf (1983) and Pethick (1984) and Harvey (2000) when they state that vegetation maintains a very important role on a saltmarsh. Results from a more limited study on Orchardton saltmarsh (Bieniowski, 1999) also concluded that vegetation had a significant role in saltmarsh sedimentation and provided a weak correlation between vegetation and sedimentation rates. Bieniowski (1999) identified that direct settling rates were lower at sites with less vegetation when compared to those sites that did maintain a vegetative cover where rates were higher. Bieniowski (1999) also found that if the tidal current was not dissipated suspended sediment was carried further up the marsh and intercepted by denser vegetation. However, there is a lack of research into the absolute and relative importance of on-vegetation sedimentation. A clear and concise model is required to allow comparison between the three dimensional data from vegetation with that of sediment trapping. Overall, patterns of on-vegetative sedimentation indicate a degree of variation across the saltmarsh and support the general pattern identified by French and Spencer (1993) and Stumpf (1983). However, sediment patterns accrued from on-vegetation sedimentation indicate, as Pethick (1983), Chapman (1983), Stumpf (1983), Bieniowski (1999) and Harvey (2000) all concur, that vegetation plays a larger role than that which is currently acknowledged.

5.3 Spatial and temporal sediment accumulation patterns: vegetation

Whilst Stumpf (1983), Pethick (1984) and French and Spencer (1993) all point to decreasing sedimentation rates as the marsh increases in elevation, results from this study indicate a more complicated pattern. Both plates and disc results certainly indicated a decrease in surface sedimentation rates with increasing elevation and marsh maturity; but on-vegetation-trapping results did not. This study indicates an increase in on vegetation sedimentation from the primary marsh to the high marsh. (Table 5.3.1)

Total sediment measured across Orchardton saltmarsh. 2003.			
Area of marsh	Erosion plates (cm)	Sedimentation discs (g)	Vegetation collection (g)
Primary marsh	9.14	38.4081	55.1808
Middle marsh	16.65	34.6926	60.6497
High marsh	0.4	8.7968	65.3625

Table 5.3.1 Total sediment measurements for each area of the marsh

While vegetation analysis clearly indicates an increase in sediment collection from the primary marsh to the high marsh, sedimentation discs show the opposite. There is a clear decrease in sediment accumulation from primary to high marsh and erosion plates also show the lowest change in the high marsh. Although tidal waters did not always inundate the high marsh it still collected sediment throughout the vegetation study. Therefore consideration must be given to other important factors within this study.

Vegetation density was largely ignored by French and Spencer (1994) and Stumpf (1983), although this study indicates that it may provide a more important role than previously thought. During the study period, the primary marsh and middle marsh maintained a sparse *Spartina* cover, except at layers 1 in summer, when cover was high. However, the high marsh maintained a diverse and well-established vegetation cover that was more or less maintained all year round, whilst vegetation cover in the primary and middle marsh tended to be much more influenced by seasons (Table 5.3.2). For each vegetation study site a record was given to measure the density of the vegetation each month. Each site was separated into three layers (as explained in Chapter 3) and a value allocated using the Domin Scale. As illustrated by Table 5.3.2, during the traditional summer months level 1 on the saltmarsh has a dense cover of vegetation throughout the three study areas. During the winter months whilst there is a decline in vegetation density throughout the study areas, this decline is more marked in the primary and middle marsh areas. The high marsh maintains a relatively dense cover throughout. Thus, when we consider the sediment accumulation results from each vegetation study site and the vegetation density results from the same study sites, certain patterns can be distinguished:

	July	August	September	October	November	December
Primary Marsh						
1	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
2	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
3	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
4	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
5	Layer 1=7 [redacted]	Layer 1=7 [redacted]	Layer 1=4 [redacted]	[redacted]	[redacted]	[redacted]
Middle Marsh						
6	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
7	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
8	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
9	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
10	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=7 [redacted]	[redacted]	[redacted]	[redacted]
High Marsh						
11	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=4 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]
12	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=4 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]
13	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=4 Layer 2=4 [redacted]
14	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]
15	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=9 Layer 2=7 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]	Layer 1=7 Layer 2=4 [redacted]

Table 5.3.2 Vegetation Cover throughout the study area.

Colour Key: [redacted], Blue - Medium cover & Yellow – High cover

Overall, the most densely vegetated areas appear to have collected the most sediment. For example, study site 15 (high marsh) collected 10.6846g of sediment during the August analysis. This site also had an extremely dense vegetation network with the first two layers of vegetation noted as high cover and the third layer recording a low vegetative cover. In comparison with results from the August analysis in the primary and middle marsh, the vegetation study sites recorded lower amounts of sediment and vegetation coverage. That is, study site 10 collected 1.9005g of sediment and recorded a more varied vegetation density consisting of 2 layers one high and one medium and study site 5 collected 4.657g of sediment and recorded only one layer of vegetation. This pattern was evident throughout the study.

Secondly, the results indicate a seasonal pattern throughout the different study areas on the saltmarsh. The most obvious pattern being sediment accumulation decreases as vegetation density declined. Chapman (1976), Pethick (1984) and Pye (1990) all attribute this seasonal pattern to partly changing vegetation processes and the vegetations ability to act as a buffer during tidal inundation. The results from this study concur and clearly show sediment accumulation to be higher during the summer and lower in winter. It is also important to note that while sediment processes indicated a decline during winter months, this was more noticeable on the primary marsh. From the results, the high marsh indicated a higher vegetation cover with different species throughout the winter months as opposed to the primary months. Some of this increase can be attributed to plant die back, which feeds both plant matter and on-vegetation sedimentation back onto the mature and more densely vegetated (even in winter) high marsh.

It should also be stated that vegetation could increase sediment deposition through the process of flocculation as a result of the release of salt compounds from the plant stems. The process of reducing the surface charges on the particles causes the various particles to come together and fall out of the water column. The denser particle will settle on the surface and is less likely to be re entrained due to its larger nature.

Overall, the results from the vegetation analysis support Stumpf's discussion. In his studies of *Spartina* on the Holland Glade Marsh, Delaware, USA, Stumpf found that sediment collected from plants accounted for 50% of the suspended sediment lost during a spring tide. Stumpf (1983) argued that vegetation presence was highly influential as opposed to direct settling. Furthermore, Stumpf (1983) argued that when the saltmarsh is inundated by the tide, the various plants would act as a 'baffle' and reduce the velocity of the tide. As the velocity is reduced, sediment is deposited, as less energy is present. As per Postma's theory of settling lag (1961), most deposition will occur at the creek edges where levees will then form. At Orchardton saltmarsh this phenomena was also present with the marsh topography being slightly higher at creek edges. When tidal inundation did occur, both discs and vegetation recorded higher sedimentation rates at creek edges.

5.4 Long-term accumulation

Results indicate the saltmarsh is not accumulating sediment in the long-term. Whilst the results presented were gathered over a one-year period, context is provided by previous research by Harvey (2000) covering the period 1996 to 2000. The combined erosion plate data provide an eight-year time span and provide some indication of long-term trends at Orchardton saltmarsh.

Harvey (2000) suggested that her data showed the study area was not a growing saltmarsh, rather a degrading one and pointed to the plant *Spartina* as a major factor in this degraded state. Harvey (2000) notes:

"The *Spartina* does not provide the marsh with a complete vegetation cover, leaving the sediment vulnerable to re-entrainment by successive tides."

From visual analysis, the Orchardton saltmarsh is regarded as having an incomplete vegetation cover (in the primary and middle marsh) and the area was always very wet and never drained entirely. So while Harvey (2000) notes that sediment was vulnerable and likely to be re-entrained, currently this is still the case. Chapman (1975) argues that a waterlogged surface will enhance entrainment and any germination thus supporting the current results. Further measurements recorded from 5 of the original buried plates note that there is very little growth in the elevation of the saltmarsh surface. Plates 5, 18 and 21 all indicated net erosion. Only plate 6 and 14 indicated low rates of accretion. Those plates found illustrating a loss in sediment were all located on the western side of the saltmarsh, as was Plate 6. Plate 14 was located on the eastern side of the saltmarsh. It seems that with the exception of plate 6, the eastern part of the saltmarsh is eroding and the western part of the saltmarsh is slightly accreting.

Although the results of this study indicate that Orchardton marsh has experienced a decline in the primary and middle marsh areas and growth throughout the high marsh area, it is not necessarily the case that the saltmarsh will continually degrade and eventually disappear. Measurements that indicate an increase point to areas of growth and in the case of plate 6; it is a steady and consistent growth. This may indicate that sediment within the saltmarsh is being redistributed, not necessarily lost from it. The idea is favoured by results from water sampling. (Results: Chapter 4). Hardly any sediment was brought to the saltmarsh via the tide. Unfortunately, this experiment was only conducted once on a calm, sunny day with no waves. Therefore, more experiments would be required to fully support this idea.

Chapter 6: Conclusion

The aim of this research project was to clarify the role of vegetation and its relationship to sedimentation on a saltmarsh. The relative importance of vegetation in sedimentation is unclear and various different theories exist in the current literature, as discussed in the literature review.

Overall, patterns that were evident in this research project are as follows:

- Erosion plate depths deepen in the middle of the marsh
- The winter months of October, November & December indicate a higher rate of accretion in most areas (including the primary marsh).
- Erosion plates close to the creek edges show higher accretion rates than those away from the creek edge.
- When using sedimentation disc results the primary marsh collects more sediment than the middle and high marsh.
- When using sedimentation disc results the middle marsh collects more sediment than the high marsh.
- The highest sediment amounts were recorded at creek edges.
- On-vegetation deposition was highest in the high marsh
- Deposition of sediment is influenced greatly by vegetative and direct settling.
- Long-term erosion is occurring on parts of Orchardton saltmarsh.

While Harvey (2000) concludes that Orchardton saltmarsh is degrading, this research project does not concur. Certainly, as illustrated by some areas on the marsh, there is a notable decline, but as shown by this study the saltmarsh still continues to gain sediment into those areas, which were indicated to be in decline.

More importantly, the rise and fall of sediment accretion rates change throughout the year. Thus, the research points towards temporal influences, mainly, the changing seasons. On the whole, the primary and middle marsh areas collected more sediment during summer and autumn months. This gain in sediment also coincides with increasing plant cover in the area discussed. During the winter, net sediment accretion rates declined, as did vegetation coverage. However, the high marsh with its diverse vegetation coverage accrued sediment all year round. Although high marsh plant cover decreased in winter, sedimentation rates remained consistent, thus indicating that the primary and middle marsh are feeding and maintaining the high marsh.

While French and Spencer (1993) argued that most sedimentation on a saltmarsh came from direct settling, and that vegetation did not play an important role; this research does not agree. Studies on direct settling and vegetation trapping resulted with more sediment being collected from vegetation than directly on the marsh. Thus, discussions from Stump (1983) who indicated that vegetation was the primary mode of sediment collection are more appropriate for this study. Furthermore, as noted by Chapman (1975), vegetation is essential in saltmarshes for many reasons; namely, its ability to bind the sediment together. Therefore, in conclusion, while direct settling is important for saltmarshes, Orchardton saltmarsh appears to rely on the role of vegetation for its stability and growth.

Recommendations

Whilst every effort to methodically examine Orchardton saltmarsh was made, further studies should be continued to allow further insight into the interior marsh processes. This study has established the importance of vegetation in relation to sediment accumulation. It would be more accurate with a detailed assessment of plant species and plant growth. Although this research assessed vegetation coverage, more detail of species type and growth patterns is required

Another recommendation that would further our knowledge of Orchardton saltmarsh is implementing monthly water sampling. A major constraint during this study was the inability to pinpoint sediment location, where the sediment originated. A water sampler was deployed during research, but the results only reflected conditions at that time. Had samples been retrieved on a monthly basis, research could also have investigated any spatial and temporal trends.

Bibliography

Adam P.1978. Geographical Variation in British saltmarsh vegetation. Journal of Ecology, 66, pp339-366

Adam, P. 1981. The vegetation of British Saltmarshes. New Phytologist, 88, pp143-196.

Adam, P. 1990. Saltmarsh Ecology. Cambridge University Press. Cambridge.

Allen, J. 1989. Evolution of salt marsh cliffs in muddy and sandy systems: a qualitative comparison of British west coast estuaries. Earth Surface Processes and Landforms, 14, pp85-92.

Allen J. 1992. Tidally influenced marshes in the Severn estuary, south-west Britain. In saltmarshes: Morphodynamics, Conservation and Engineering Significance. Eds. Allen J and Pye K. Cambridge University Press. Cambridge. pp123-147.

Allen, J and Pye, K. 1992. Coastal Saltmarshes: their nature and significance. In saltmarshes: Morphodynamics, Conservation and Engineering Significance. Eds. Allen J and Pye K. Cambridge University Press. Cambridge. pp1-18.

Allen J and Duffy M. 1998. Temporal and spatial depositional patterns in the Severn estuary, Southwestern Britain. Intertidal studies at Spring-Neap and seasonal scales, 1991-1993. Marine Geology, 146, pp147-171

Beeftink W. 1977. The coastal saltmarshes of western and northern Europe: An ecological and phtosociological approach. In Wet Coastal Ecosystems. Ed Chapman, V. Elsevier Scientific Publishing Company. Pp109-155.

Beukema J. J. *et al* 1990. Expected effects of climatic change on marine coastal ecosystems. Kluwar Academic Press.

Bieniowski, I. 1999. Saltmarsh Accretion in the Solway Firth- The Role of Vegetation. Unpublished undergraduate dissertation, Department of Geography and Topographic Science, University of Glasgow.

Blake, B. 1955. The Solway Firth. Robert Hale Limited,

Cahoon, D *et al.* 1996. Marsh vertical accretion in a southern California estuary, USA. Estuarine, Coastal and Shelf Science, 43, pp19-32.

Chapman, V. 1974. Saltmarshes and Salt deserts of the world. Second Supplemented Reprint edition. Verlag Von J. Cramer, Lehre

Chapman V. 1976. Coastal Vegetation, 2nd Edition.

Chapman, V. 1977. Introduction. Wet Coastal Ecosystems. Ed: Chapman V, Elsevier Scientific Publishing Company, pp1-29

Finlayson, M and Moser M. 1991. Wetlands. Published by Facts on File

French J. 1993. Numerical Simulation of vertical marsh growth and adjustment to accelerated sea level rise, North Norfolk, UK. Earth Surface Processes and Landforms, 18, pp63-81.

French, J and Spencer, T. 1993. Dynamics of sedimentation in a tide dominated backbarrier saltmarsh, Norfolk, UK. Marine Geology, 110, pp315-331.

Gleason M and Zieman J. 1981. Influence of tidal inundation on internal oxygen supply of *Spartina alterniflora* and *Spartina* patens. Estuarine, Coastal and Shelf Science. 13, pp47-57.

Good J *et al* 1999 Protecting estuaries and coastal wetlands through state coastal zone management programs. Coastal Management. 27, pp139-186.

Goodall (Ed). 1977. Wet Coastal Ecosystems. Ecosystems of the World 1.

Hansom. J.D. 1988. Coasts. Cambridge University Press. Cambridge.

Hansom, J.D. 1999. The Coastal Geomorphology of Scotland: understanding sediment budgets for effective coastal management. In Baxter, J., Duncan, K., Atkins, S. and Lees, G. (Eds). Scotlands Living Coastline. The Stationary Office. Pp34-44.

Hansom, J.D. ***et al*** 2000. Sea level changes and sustainable management of the coast: the potential for managed realignment in the Forth estuary. In Gordon J. (Ed). Earth Science and the Natural Heritage of Scotland. The Stationary Office.

Hansom, J.D. and May V. 2003. Coastal Geomorphology of Great Britain. Geological Review Series; 28.

Harrison E and Bloom A. 1977. Sedimentation Rates on tidal saltmarshes in Connecticut. Journal of Sedimentary Petrology, 47, pp1484-1490.

Harvey M. 2000. Geomorphological Controls on the Sedimentation Patterns of, and Distribution of Anthropogenic Radionuclides in, Coastal saltmarshes, Southwest Scotland. Thesis. Department of Geography and Geomatics, University of Glasgow

Harvey, M. and Allan R. 1998. The Solway Firth Saltmarshes. Scottish Geographical Magazine, 114, pp42-45.

Haslett S ***et al.*** 2001. Vertical saltmarsh accretion and it's relationship to sea level in the Severn estuary, UK. Estuarine, Coastal and Shelf Science, 52,

Hemminga M. ***et al*** 1994. Bedload and nearbed detritus transport in a tidal saltmarsh creek. Estuarine, Coastal and Shelf Science.pp55-62.

Kastler J and Wiberg P. 1996. Sedimentation and boundary changes of Virginia saltmarshes. Estuarine, Coastal and Shelf Science. 42, pp683-700.

Letzsch, W and Frey R. 1980. Deposition and erosion in a Holocene saltmarsh, Sapelo Island, Georgia, Journal of Sedimentary Petrology, 50, pp529-542.

Milan C ***et al*** 1995 Assessment of the 137Cs method for estimating sediement accumulation rates: Louisiana Saltmarsh. Journal of Coastal Research. 11, pp296-307.

Nyman J. *et al* 1995. Roles and Patterns of hurricane sedimentation in an estuarine marsh landscape. Estuarine, Coastal and Shelf Science. 40, pp665-679.

Pethick, J. 1981. Longterm accretion rates on tidal saltmarshes. Journal of Sedimentary Petrology, 51, pp571-577.

Pethick, J. 1984. An Introduction to Coastal Geomorphology. Edward Arnold, London.

Pethick, J. 1992. Saltmarsh Geomorphology. In saltmarshes: Morphodynamics, Conservation and Engineering Significance. Eds. Allen J and Pye K. Cambridge University Press. Cambridge. pp41-62.

Pye, K. 1995. Controls on long-term saltmarsh and accretion in the wash, Eastern England. Journal of Coastal Research, 11, pp337-356.

Randerson, P. 1979. A Simulation model of saltmarsh development and plant ecology. In Estuarine and Coastal Land Reclamation and Water Storage. (Eds) Knights, B and Philips, A. Estuarine and Brackish water Sciences Association. pp48-67.

Ranwell, D. 1964. Spartina marshes in S.England.II. Rate and seasonal pattern of sediment accretion. Journal of Ecology.52, pp79-94.

Reed, D. 1987. Temporal sampling and discharge asymmetry in saltmarsh creeks. Estuarine, Coastal and Shelf Science, 25, pp459-466.

Reed, D. 1995. The response of coastal marshes to sea level rise: survival or submergence? Earth Surface Processes and Landforms, 20, pp39-48.

Reed, D. 1989. Patterns of sediment deposition in subsiding coastal saltmarsh: the role of winter storms. Estuaries, 12, pp222-227

Reed D and Cahoon D. 1992. The relationship between marsh surface topography, hydroperiod and growth of *Spartina alterniflora* in a deteriorating Louisiana salt marsh. Journal of Coastal Research. 8. pp77-87.

Reed, D and Cahoon, D. 1995. The relationship between marsh surface topography, hydroperiod and soil accretion in a deteriorating Louisiana salt marsh. Journal of Coastal Research, 11, pp357-369

Stevenson J *et al.* Sediment transport and trappings in marsh systems: implications of tidal flux studies. Marine Geology, 80, pp 37-59.

Stumpf, R. 1983. The process of sedimentation on the surface of a saltmarsh. Estuarine, Coastal and Shelf Science. 17, pp495-508.

Summerfield, M. 1991. Global Geomorphology. Longman Scientific and Technical. New York. P202.

Suk, N. *et al* 1998. Feasibility of using a turbiditmeter to quantify suspended solids concentration in a tidal saltmarsh creek. Estuarine, Coastal and Shelf Science. 46, pp383-391.

Trenhaile A. 1997. Coastal Dynamics and Landforms.

Wheeler A *et al* 1999. Saltmarsh deposition and it's relationship to coastal forcing over the last century on the North-west coast of Ireland. Geoligie en Mijnbouw, 77, pp295-310.

Woodhouse, W. 1979. Building saltmarshes along the coasts of the continental United States. Special Report Number 4. May.

Zedler J. 1995. Saltmarsh Restoration: Lessons from California. In Rehabilitating Damaged Ecosystems, Editor, J Cairns.

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Map 1

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