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Vegetation development in a restored saltmarsh at Blakeney, north Norfolk coast, England

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ABSTRACT

Saltmarshes worldwide are under threat from anthropogenic activities and has been so for the last centuries. In UK, land reclamation for agriculture has been a driving factor for the loss of these habitats. During recent decades, efforts has been made to restore areas to saltmarsh by moving sea defenses landwards and by doing so, allowing tidal inundation to cover previously reclaimed land. In 2005 the tidal River Glaven, located at Blakeney, north Norfolk coast, England, was realigned and as a result, an area previously shielded from the sea became subject to tidal inundation. This study aimed to investigate how the abundance and distribution of vascular plants has developed in the restored area since the restoration. Due to the zonation of plants, which characterize saltmarshes, a sampling methodology based on transects was developed. Both the restored area and an adjacent saltmarsh regarded as pristine was sampled at 10 metre intervals along transects. The result showed a clear zonation of species in the restored area, identified as a low/middle marsh plant community. No zonation was found in the reference saltmarsh, which was characterized by middle marsh communities and located at a higher elevation than the restored area. Fewer saltmarsh species was found in the restored area than in the reference. However, due to the presence of saltmarsh and grassland species, the restored area was found to have higher species diversity than the reference. The species data recorded showed a large skew due to a high amount of zeros. This was explained by the homogenous structure of the saltmarsh vegetation where many sampling squares were dominated by only one or two species. This suggests the need for an updated survey methodology in future surveys where more transects and samples are used. It is further suggested that the sampling effort in terms of transects are put in the restored area since no zonation was observed in the reference saltmarsh. A combination of transect sampling and the sampling strategy used in National Vegetation surveys is suggested.

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The result showed a clear zonation of species in the restored area, identified as a low/middle marsh plant community. No zonation was found in the reference saltmarsh, which was characterized by middle marsh communities and located at a higher elevation than the restored area. Fewer saltmarsh species was found in the restored area than in the reference. However, due to the presence of saltmarsh and grassland species, the restored area was found to have higher species diversity than the reference. The species data recorded showed a large skew due to a high amount of zeros. This was explained by the homogenous structure of the saltmarsh vegetation where many sampling squares were dominated by only one or two species. This suggests the need for an updated survey methodology in future surveys where more transects and samples are used. It is further suggested that the sampling effort in terms of transects are put in the restored area since no zonation was observed in the reference saltmarsh. A combination of transect sampling and the sampling strategy used in National Vegetation surveys is suggested.

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TABLE OF CONTENTS

ABSTRACT i
ACKNOWLEDGEMENTS..... iii
LIST OF FIGURES vi
LIST OF TABLES vii
JOURNAL FRONTPAGE ix
1 INTRODUCTION 1
2 LITERATURE REVIEW 3
2.1 Vegetation and formation of saltmarshes 3
2.2 Soil salinity..... 4
2.3 Plant communities and zonation..... 5
2.3.1 Determining factors..... 5
2.3.2 Characteristic plant species..... 6
2.3.3 Vegetation communities 7
2.4 Saltmarsh restoration..... 8
3 METHODOLOGY 9
3.1 Study area 9
3.2 Data collection 10
3.2.1 Transects..... 11
3.2.2 Data recording and positioning of squares 12
3.3 Analysis 13
3.3.1 Species distribution..... 14
3.3.2 Plant diversity by area 14
3.3.3 Plant diversity by species community..... 15
4 RESULTS..... 19
4.1 Species distribution..... 19
4.2 Plant diversity by area 25
4.3 Plant diversity by species community..... 26
5 DISCUSSION 29
5.1 Species distribution..... 29
5.1.1 Reference saltmarsh..... 29
5.1.2 Restored area 29
5.2 Plant diversity 31
5.2.1 By area 31
5.2.2 By species community..... 32
5.2.3 Diversity indices as a measure of success 32
5.3 Future monitoring..... 33
5.3.1 NVC surveys..... 33
5.3.2 Transects..... 34
5.3.3 Additional data 35
5.4 Conclusion..... 36
6 AKNOWLEDGEMENTS 37
REFERENCES..... 39
APPENDICES 45
Appendix A Maps..... 45
Appendix B List of species..... 46
Appendix C Equations 48

LIST OF FIGURES

Figure 1. The area of study with the restored area in yellow colour and the pristine saltmarsh included as a reference in pink colour............................9
Figure 2. The location of the 165 sampling squares, distributed on the 15 transects (A-O). 12
Figure 3. Position of sampling squares along transects and location of GPS reading. 13
Figure 4. Dendrogram showing result from similarity analysis undertaken on squares present on transect A-H..16
Figure 5. Dendrogram showing result from similarity analysis undertaken on squares present on transect I-N. 17
Figure 6. Distribution of species in the restored area, based on presence/absence data for the 8 transects A-H. The thickness of the bar represents the number of squares (out of 8) in which the species was present. 20
Figure 7. Distribution of species over transect I and J (reference saltmarsh), based on presence/absence data for the 2 transects. The thickness of the bar represents the number of squares (out of 2) in which the species was present. 21
Figure 8. Distribution of species over transect K, L, M and M (reference saltmarsh), based on presence/absence data for the 4 transects. The thickness of the bar represents the number of squares (out of 4) in which the species was present..23
Figure 9. Distribution of species over transect O (reference saltmarsh), based on presence/absence data. 23
Figure 10. Topography (LIDAR) of the study area with positions of sampling transects overlaid. The original LIDAR map was produced by Atkins, with data provided by the Environmental Agency. 24
Figure 11. Whittaker's β-diversity and average number of species per sampling square for all transects in survey (A-O). 26
Figure 12. The location of the 165 sampling squares, distributed on the 15 transects (A-O). The area identified as the saltmarsh community, including both SM10 and developing SM24, is shown in dark green in the restored area. 27

LIST OF TABLES

Table 1. NVC communities identified in the ecological survey, undertaken as part of the EIA[2] (Halcrow 2003) and the post-construction survey undertaken in 2009[1] (Halcrow 2010). 7
Table 2. Grouped transects used to determine species distribution. Refer to Appendix A.1 for a map outlining the different NVC communities in the reference saltmarsh (Halcrow 2003) and Figure 2 for the location of transects. 14
Table 3. Squares grouped for the analysis of plant diversity per species community in the restored area and reference saltmarsh. 15
Table 4. Proportional distribution of species (filtered data) over the restored area (transect A-H) and the reference saltmarsh (transect I-O). The value given is the proportion of squares within each area/sub-area in which the species was recorded. 19
Table 5. Shannon-Weiner diversity H, evenness J, Simpson D diversity and evenness E for the restored area (transect A-H), pristine saltmarsh (I-O), transect pairs I and J, K and L and transect O. D_{max} = total number of species included in analysis. 25
Table 6. Shannon-Weiner diversity H, evenness J, Simpson D diversity and evenness E for the saltmarsh (SM) community and grassland (GM) community in the restored area and middle marsh community in the pristine saltmarsh. D_{max} = total number of species included in analysis. 27

Vegetation development in a restored saltmarsh at Blakeney, north Norfolk coast, England

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ABSTRACT

Aim: To investigate how the vegetation in an area restored to tidal inundation in 2005 has developed in terms of abundance and distribution of vascular plants.

Location: Blakeney, north Norfolk coast, England.

Methods: Plant species abundances were sampled over 100 metre transects at 10 metre intervals in the restored area. An adjacent saltmarsh, regarded as pristine was also sampled as a reference. The results obtained in the restored area were compared with the reference saltmarsh in terms of plant zonation and presence of species.

Results: A clear species zonation was found in the restored area, which was dominated by the low/middle marsh NVC community SM10 but also showed signs of an SM24 community developing. The reference saltmarsh did not show any zonation from the river and consisted mainly of the communities SM14 and SM24. Several middle marsh species were recorded in the reference saltmarsh but not in the restored area (e.g. *Armeria maritima* and *Limonium vulgare*).

Conclusion: The part of the restored area included in this study has developed into a SM10 community with additional communities currently under development. The restored area still lacks several species associated with the middle marsh communities found in the reference saltmarsh.

Keywords: Plant zonation; vegetation communities; biodiversity; transect sampling; ecological restoration; managed realignment.

Nomenclature: Rodwell (2000) for plant communities, Clapham *et al.* (1987) for plant species.

1 INTRODUCTION

Saltmarshes are ecosystems under heavy threat by anthropogenic activities (Barbier *et al.* 2011) and have been for the past centuries, mainly due to marsh reclamation by the construction of embankments (Dijkema 1987; Boorman *et al*. 2002; Pethick 2008) but also due to rising sea levels (Simas *et al*. 2001), eutrophication, invasive species and pollution (Silliman *et al*. 2009). A coastal saltmarsh can be defined as an area periodically inundated with salt water and vegetated with grasses, herbs and low shrubs (Adam 1990). Saltmarsh vegetation is characterised by a distinct zonation due to both physical and biological factors (e.g. Adam 1990; Bockelmann *et al.* 2002; Silvestri *et al*. 2005) and low species diversity (Adam 1990; Allen and Pye 1992; Barbier *et al.* 2011). However, many of the plant species found in saltmarshes are halophytes and not found in other ecosystems. Particularly in the south and southeast of England, saltmarshes host nationally rare plants such as *Suaeda fruticosa* and *Frankenia laevis* (Allen and Pye 1992).

Based on its geomorphology, the saltmarsh at Blakeney, north Norfolk coast, England, is classified as a *Barrier-connected* saltmarsh (Dijkema 1987; Boorman 2003). The marsh has formed south of Blakeney Spit, a shingle ridge that absorbs the wave energy and allow for a net sediment accretion in the marsh. Due to the gradual landward movement of the ridge, the tidal River Glaven that previously had its stretch along the ridge was realigned to its current position in 2005. The river was moved approximately 200 metre landwards and with it, the earth embankment that stretches along the coast and provides sea defense (Halcrow 2003). As a result, 13 ha of improved grassland previously shielded from the sea by the embankment were exposed to tidal inundation.

Prior to the realignment, an environmental impact assessment (EIA) was undertaken on site, including ecological surveys. As part of the vegetation survey, national vegetation communities (NVC) were mapped in the area about to be restored and in the adjacent saltmarsh, regarded as pristine (Halcrow 2003). Two post-construction vegetation surveys were also undertaken in 2007 and 2009 (Halcrow 2007 and 2010). These surveys provided updated information on the development of NVC communities in the restored area but not for the pristine saltmarsh. Even though the extent of NVC communities was mapped, no investigation of plant zonation on the species level was undertaken in any of these surveys.

This study aimed to determine how the vegetation community has developed in the restored area, how plant species are distributed, how it differs from the vegetation communities found in the adjacent saltmarsh, regarded as pristine and how the area is likely to develop in the future.

2 LITERATURE REVIEW

2.1 Vegetation and formation of saltmarshes

Saltmarshes are dynamic ecosystems with physical and biological changes occurring in a range of temporal scales. In the short term, the periodical inundation of saltwater changes the physical properties of the soil, which vegetation and other organisms have to adapt to. In the long term, the balance between accretion of sediments and erosion determine the development and structure of the saltmarsh (Allen and Pye 1992).

Saltmarsh formation is dependent on the accretion of sediments from the incoming tide and additionally in estuarine systems, fluvial sediments (Adam 1990). Saltmarsh vegetation also contributes to the saltmarsh formation by supplying organic matter (Allen and Pye 1992). For a saltmarsh to form, the accretion rate has to exceed the rate of erosion. As a result, saltmarshes are typically formed in the lee of protecting barriers or islands where the wave energy is low (Dijkema 1987). Once deposited, the sediment is stabilised by the saltmarsh vegetation (Boorman 1995). Möller *et al.* (1999) has also shown that saltmarsh vegetation reduce the energy in waves and therefore limits erosion. Vegetation further contributes to the accretion of sediments by lowering velocity of the water, allowing for sediment to precipitate (Stevenson *et al*., 1988). Langlois *et al*. (2003) identified the pioneer saltmarsh plant *Pucinellia maritima* as a key species for trapping sediments. Pioneer saltmarsh plants do not only promote sediment accretion but are also dependent upon it for successful establishment (Boorman *et al.* 2001). Saltmarsh formation is a complex matter affected by many factors. Even so, it is clear that the establishment of vegetation is crucial for the long-term sustainability of a saltmarsh as it both promotes accretion of sediments as well as stabilizes precipitated sediments.

2.2 Soil salinity

Soil salinity is an important parameter to consider when studying plant distribution (e.g. Adam 1990; Allen and Pye 1992; Wang *et al.* 2007) and decomposition rates in saltmarshes (Hemminga *et al*. 1991). As one can expect, areas at lower elevation in a saltmarsh have a higher frequency of seawater inundation than areas at higher elevation (Adam 1990). However, soil salinity does not follow a simple relationship with inundation frequency, important as it is. Additionally, a range of climatic, physical and morphological (e.g. creek formations) factors is required to explain the soil salinity at different elevations (Davy 2000; Wang *et al.* 2007). Evapotranspiration (ET) and temperature has been shown to have a positive correlation with soil salinity (Wang *et al*. 2007) whilst the hydraulic conductivity of the soil has been shown to have a negative correlation (Bertness and Pennings 2000; Wang *et al*. 2007). Precipitation is negatively correlated with soil salinity; however, the correlation is weaker than for ET and temperature (Wang *et al*. 2007).

The highest soil salinity is typically found above mean high water (MHW) where the soil is not regularly flushed (Adam 1990). In southeast Britain, short periods of hyper-saline soil conditions can occur in the high marsh during summer when high ET coincides with neap tides that do not cover the marsh (Boorman 2003). Soil salinity has shown to effect seed germination and root elongation in saltmarsh plants (e.g. Katembe *et al*. 1998; Kahn *et al*. 2006); consequently, salt tolerance is a key factor determining saltmarsh plant distribution.

2.3 Plant communities and zonation

2.3.1 Determining factors

Early studies on saltmarsh vegetation focused mainly on physical properties such as soil salinity, elevation and inundation regime when aiming to explain plant zonation (Mitsch and Gosselink 2008). During the last 25 years, research has also focused on interspecific competition and facilitation (e.g. Ewanchuk and Bertness 2004; Pennings *et al*. 2005; Barbier *et al*. 2011). Typically, saltmarsh vegetation has a lower vertical limit based on physical factors (e.g. soil salinity, inundation regime) while vegetation in the high marsh is limited by interspecific competition (e.g. Gray 1985; Allen and Pye 1992; Pennings *et al*. 2005; Farina 2009). This is obviously a simplified picture of the factors influencing the plant zonation in saltmarshes.

In a study from the Venice lagoon, Silvestri *et al*. (2005) found that neither soil salinity nor tidal regime could explain the distribution of halophytes in the study area. Instead, a strong correlation was found between species distribution and topography/geomorphology. The authors suggested sub-surface flows and root oxygen availability as an explanation to the result. In a similar study in The Netherlands, Bockelmann *et al.* (2002) found that plant zonation had a stronger correlation with inundation frequency than shore height. However, the authors stressed that inundation frequency alone cannot be used to explain plant zonation and many factors needs to be taken into consideration, e.g. wind, spatial heterogeneity in inundation frequency and interspecific competition.

Crain *et al.* (2004) showed the importance of interspecific competition in a study where halophytic species were transplanted to plots with low salinity in the high marsh. The result suggested that halophytic plants grow better on higher elevation with lower salinity levels but are outcompeted by non-halophytic species, naturally occurring in the high marsh, this is consistent with results from earlier studies (e.g. Boorman 1966; Bertness *et al*. 1992). However, species naturally occurring in the high marsh did not grow better in the low marsh, without competition from halophytes. Not surprisingly, Crain *et al.* (2004) also found that the diversity in plants increased with decreasing salinity.

2.3.2 Characteristic plant species

The first zone in a saltmarsh, i.e. where the mudflat ends and the first vascular plants emerge is referred to as the *pioneer zone* and marks the beginning of the saltmarsh. This zone is characterized by the halophytes best adapted to the frequent inundation of seawater. Typical pioneer species in British saltmarshes include *Spartina spp., Salicornia europea agg*., *Aster tripolium, Spergularia spp.* and *Puccinellia maritima* (Oldham and Roberts 1999). Typical low/middle marsh species include *Armeria maritima, Limonium spp., Juncus spp., Artiplex spp.* and *Halimione portulacoides* while species such as *Elymus pycnanthus, Agrostis stolonifera, Suaeda fruticosa* and *Artemisia maritima* are typically found in the upper marsh (Oldham and Roberts 1999).

This is just a general picture of how common British saltmarsh plants are distributed and a certain overlap between the different zones and associated plant species is to expect (Allen and Pye 1992). Additionally, not all zones are represented in every saltmarsh (Boorman 2003). Allen and Pye (1992) suggested Hutchinson's (1957) idea of a fundamental and realised niche to explain the distribution of individual species in saltmarshes. While a species fundamental niche could potentially cover several zones, factors such as interspecific competition and colonisation barriers prevented it to do so (Allen and Pye 1992). This idea agrees with the results obtained by Crain *et al.* (2004) and discussed in section 2.3.1.

2.3.3 Vegetation communities

There are national vegetation communities (NVC) defined by the Join Nature Conservation Council (JNCC), which provide a system for classifying saltmarsh vegetation (Rodwell *et al*. 2000). In total, 28 saltmarsh communities has been defined, see Rodwell *et al*. (2000) for a description of each community. In the NVC survey included in the environmental impact assessment (EIA) (Halcrow 2003), six saltmarsh communities were identified within the area regarded as pristine saltmarsh (Table 1). In the post-construction NVC survey from 2009 (Halcrow 2010), one additional saltmarsh community (SM10) was identified in the part of the restored area included in this study (Table 1). Other areas of SM10, SM24 as well as the pioneer community SM8 were identified in the western part of the restored area (Halcrow 2010), however, not covered by this study due to breeding birds present in this area. Refer to Appendix A.1 for a map outlining the different NVC communities present in the area regarded as pristine saltmarsh (Halcrow 2003).

Table 1. NVC communities identified in the ecological survey, undertaken as part of the EIA[2] (Halcrow 2003) and the post-construction survey undertaken in 2009[1] (Halcrow 2010).

NVC community	Description
SM10[1]	*Puccinellia maritima, Salicornia ssp.* and *Suaeda maritima* low saltmarsh
SM13a[2]	*Puccinellia maritima* saltmarsh Sub-community with *Puccinellia maritima* dominant
SM13c[2]	*Puccinellia maritima* saltmarsh Sub-community with *Limonium vulgare – Armeria maritima*
SM14a[2]	*Halimione portulacoides* saltmarsh Sub-community with *Halimione portulacoides* dominant
SM16e[2]	*Festuca rubra* saltmarsh Sub-community *Leontodon autumnalis*
SM23[2]	*Spergularia marina – Puccinellia distans* saltmarsh
SM24[2]	*Elymus pycnanthus* saltmarsh
MG6b[1, 2]	*Lolium perenne – Cynosurus cristatus* grassland
MG11a[2]	*Festuca rubra – Agrostis stolonifera* grassland Sub-community *Lolium perenne*

2.4 Saltmarsh restoration

Saltmarsh restoration has been occurring for many years in low-laying areas as a result of failing sea defences (Boorman 2002; Wolters *et al*. 2004). Recently, managed de-embankment (or *managed realignment*) projects have been carried out in Europe with the aim of creating/restoring saltmarsh habitats as well as way of improving sea defences (Boorman and Hazelden 1995; DEFRA 2002; Wolters *et al*. 2004; Garbutt and Wolters 2008). The driving factors behind many of the restorations have been European legislation such as the Habitats Directive (Boorman 2002; Pethick 2002; DEFRA 2002) and costs related to the maintenance of sea defences (Boorman 2002; Wolters *et al*. 2004). When aiming to restore previously reclaimed land to saltmarsh it is important to have clear targets set (Thom 2000; Boorman 2002; Zedler and Callaway 2000), e.g. target plant communities or diversity. Without clear targets, determining the success of a restoration is difficult. Zedler and Callaway (2000) suggest that the term *progress,* measureable in degrees, should be used instead of *success* and by doing so, shifting focus away from the categorical *success/failure* and instead focus on the development of a restored ecosystem. In this restoration project, no specific target in terms of species richness/composition has been established, other than to restore the area to a saltmarsh (Meeting on site with Stuart Warrington 24th of May 2011).

In order to determine if a set target has been met, monitoring of the site has to be undertaken. In a study by Wolters *et al.* (2004), looking at 70 restoration projects, only 37 sites were monitored after the restoration. Zedler and Callaway (2000) found in a literature study including 26 restoration projects that most had undertaken monitoring, however, monitoring was short-term and with little repeated sampling. Saltmarsh restoration is a relatively young science (Havens *et al*. 2002) and with many uncertainties regarding the factors determining the restoration success/progress (Zedler and Callaway 2000), it is necessary that sufficient monitoring is undertaken. One can argue that this is true even for projects without a clear ecological target as it provides data useful for future restoration projects and monitoring of current saltmarshes.

3 METHODOLOGY

3.1 Study area

The area of study is located north of the villages Blakeney and Cley on the north Norfolk coast, England (Figure 1). The restored area, now under the influence of tidal inundation is known as Blakeney Eye and constituted, prior to the restoration, the far northern part of Blakeney Freshes. The realigned River Glaven and an earth embankment now separate the study area from the rest of Blakeney Freshes.

Figure 1. The area of study with the restored area in yellow colour and the pristine saltmarsh included as a reference in pink colour.

The old river channel is partially backfilled to the north but remain intact directly to the east and west of the study area. The restored area is separated from the area regarded as pristine saltmarsh, located to the east of the site by the old embankment, now partially demolished (Figure 2). This area of pristine saltmarsh was included in the study as a reference and was chosen because of its close proximity to the restored area and well-documented vegetation communities, (section 2.3.3). Based on measurements in the GIS software ArcGIS, the size of the restored area is 13 ha whilst the reference saltmarsh is 3.5 ha. The study area is owned and managed by The National Trust and is a part of the north Blakeney National Nature Reserve (NNR). The area is also designated under the North Norfolk Coast SSSI, North Norfolk Coast SPA, eSAC (Blakeney Freshes not included) and Ramsar (Halcrow 2003). The area is supporting nationally and internationally important populations of bird species, including *Branta bernicla bernicla, Anser brachyrhynchus* and *Calidris canutus* (Halcrow 2003).

As part of the realignment works, part of the land adjacent to the river were lowered to promote the establishment of saltmarsh vegetation. No efforts was done in terms of introducing species by reseeding or planting, however, the new embankment was reseeded with grass species to stabilize the soil (Meeting on site with Stuart Warrington 24th of May 2011).

3.2 Data collection

A vegetation survey was undertaken between the 13th and 15th of June 2011. On the evening of the 13th June, the site was visited together with David Wood of The National Trust to conclude spatial limitations due to breeding birds on site. The survey was carried out the following two days.

3.2.1 Transects

Because of the expected plant zonation (section 2.3), a survey methodology based on transect sampling is recommended (JNCC 2004). A total of 15 transects, aligned perpendicular to River Glaven were sampled, 8 (designated A to H) in the restored area and 7 (designated I to O) in the reference saltmarsh. Vegetation data were collected with a 0.25 m^2 sampling square with 25 sub-squares, each 10 metre on transects, totalling 11 squares per transect (Figure 2). The length of each transect was 100 metre, which was considered sufficient to cover any plant zonation present. Longer transects would have been difficult in the restored area due to breeding birds and in the pristine saltmarsh due to the limited size of the area.

The first square on each transects was placed next to the river, where the un-vegetated mudflat ended and the first vascular vegetation emerged, i.e. when the pioneer saltmarsh vegetation started. The 8 transects in the restored area were placed with 10 metre intervals down by the river and placed to cover the NVC communities SM10 and MG6b, identified in the post-construction NVC survey undertaken in 2009 (Halcrow 2010). In order to avoid further disturbance to breeding birds during the survey, the angle from the river of transect E and F was altered which resulted in transect F intersecting transect G at about 80 metre from the river (Figure 2). However, without duplication of any sampling squares. The 7 transects located in the pristine saltmarsh were placed to cover all of the NVC vegetation communities identified in the ecological survey undertaken as a part of the EIA. Refer to section 2.3.3 for a description of the NVC communities and Appendix A.1 for a map of the NVC communities (Halcrow 2003). Transect I and J were placed 10 metre apart, perpendicular to the realigned River Glaven in communities identified as SM24 and SM13a/c. Transect K, L, M and N were placed in 40 metre intervals along the old stretch of River Glaven and covered the NVC communities identified as SM13a/c, SM14a and SM24. Transect O was placed to cover an area identified as MG11 (Halcrow 2003).

Figure 2. The location of the 165 sampling squares, distributed on the 15 transects (A-O).

3.2.2 Data recording and positioning of squares

In order to reduce the subjectivity of visually estimating species abundances, each species present in each of the 25 sub-squares was recorded on a presence/absence basis. The abundance of species in the 0.25 m^2 survey square was subsequently calculated by dividing the number of sub-squares in which a certain species was present in with the total number of sub-squares (i.e. 25). As a result, each species received an abundance rating of 0 to 1, independent on the abundances of other species. This method has the obvious drawback of not providing the relative abundance of species as well as classifying one individual present in one sub-square the same way as 10 individuals. However, this method was considered producing more reliable data than visual estimation of the relative species cover. Species nomenclature followed Clapham *et al.* (1987).

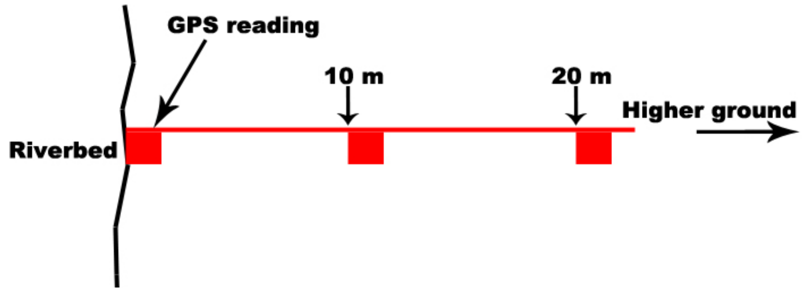

Figure 3. Position of sampling squares along transects and location of GPS reading.

A 50 metre measuring tape and three iron rods were used to lay down the transects, sampling squares were placed with the lower left corner (looking away from the river, up the transect) on the correct distance (Figure 3). The position of each sampling square was registered using a differential GPS unit (Trimble GeoXT). The reading was taken at the upper left corner of the sampling square (Figure 3). Each square was also photographed for later analysis and for possible use in future surveys.

3.3 Analysis

Prior to analysis, the recorded data was filtered from species occurring in less than 5% of the 165 sampling squares (refer to Table B.2, Appendix B.2 for species included in the analysis). This was done in order to reduce the effect of rare species occurring by random in samples. Microsoft Excel 2011 was used for diversity calculations (section 3.3.2 and 3.3.3) and graphing the data (section 3.3.1).

3.3.1 Species distribution

Because of high variability in the recorded data due to a large proportion of zeros, species distribution over transects was graphed on a presence/absence basis rather than the averaged recorded abundances. Various transformations (Box-Cox, Square root, Arcsine on Square root) were tested but did not improve the skew of the data.

Two sets of data were analysed with the Community Analysis Package (CAP) from Pisces Software, one containing data from squares on transect A-H (the restored area) and one containing data from squares on transect I-N (the pristine saltmarsh). A cluster analysis was undertaken on the data with the Bray-Curtis similarity measure. The resulting dendrograms (Figure 4 and 5) were used along side vegetation community data from the previously undertaken NVC surveys (Halcrow 2003 and 2010) to determine the suitability of combining transects. The spatial distribution of transect was also considered. The combined set of transects (Table 2) were thereafter used to graph the distribution of species at each of the 10 metre intervals used in the survey (0 – 100 metre).

Table 2. Grouped transects used to determine species distribution. Refer to Appendix A.1 for a map outlining the different NVC communities in the reference saltmarsh (Halcrow 2003) and Figure 2 for the location of transects.

Combined transects	Location	NVC communities covered
A, B, C, D, E, F, G, H	Restored area	SM10, GM6b
I, J	Reference saltmarsh	SM13a/c, SM24
K, L, M, N	Reference saltmarsh	SM13a/c, SM14a, SM24
O	Reference saltmarsh	MG11, SM24

3.3.2 Plant diversity by area

The Shannon-Wiener (Appendix C, Equation C.1) and Simpson (Equation C.2) diversity indices were calculated for the same set of squares used in the analysis of species distribution (Table 2).

Due to the large skew of the recorded species abundances (section 3.3.1), presence/absence data was used to calculate the indices. That is, the proportion of squares within each area in which a species was recorded (Table 4). Since the calculated proportions represent absolute abundance, the data had to be converted into relative abundance before calculating the indices. This was done by dividing each species abundance with the sum of all abundances, resulting in a sum of 1. Whittaker's β-diversity (Equation C.3) was also calculated which is as a measure of species turnover along transects (Henderson 2003). However, as this index is calculated per transect, the actual recorded abundance data were used.

3.3.3 Plant diversity by species community

In order to compare species communities in terms of plant diversity, the squares rather than transects were grouped. The abundances used in the calculations were derived in the same way as described in previous section, except being based on different sets of squares (Table 3). The aim of this analysis was to compare the saltmarsh vegetation present in the restored area with the one present in the pristine saltmarsh. As a result, transect O was excluded from this analysis because of its location in an area designated as grassland community (Figure A.1, Appendix A) and distance from transect I-N (Figure 2). The dendrograms (Figure 4 and 5) produced from the similarity analysis were used to determine which squares represented a certain species community. Visual inspection of the survey data and photographs were used to interpret the dendrograms. After grouping the squares (Table 3) diversity calculations was carried out as described in section 3.3.2.

Table 3. Squares grouped for the analysis of plant diversity per species community in the restored area and reference saltmarsh.

Area	Species community	Grouped squares
Restored area	Saltmarsh (SM10)	A1-A3, B1-B7, C1-C10, D1-D7, E1-E7, F1-F6, G1-G6, H1-H2
Restored area	Grassland (GM6b)	A4-A11, B8-B11, C11, D8-D11, E8-E11, F7-F11, G7-G11, H3-H11
Pristine saltmarsh	Saltmarsh (SM13a/c)	I2-I7, J4-J6, J10, J11, K7, K11, L7-L10, M6-M9, N8, N11

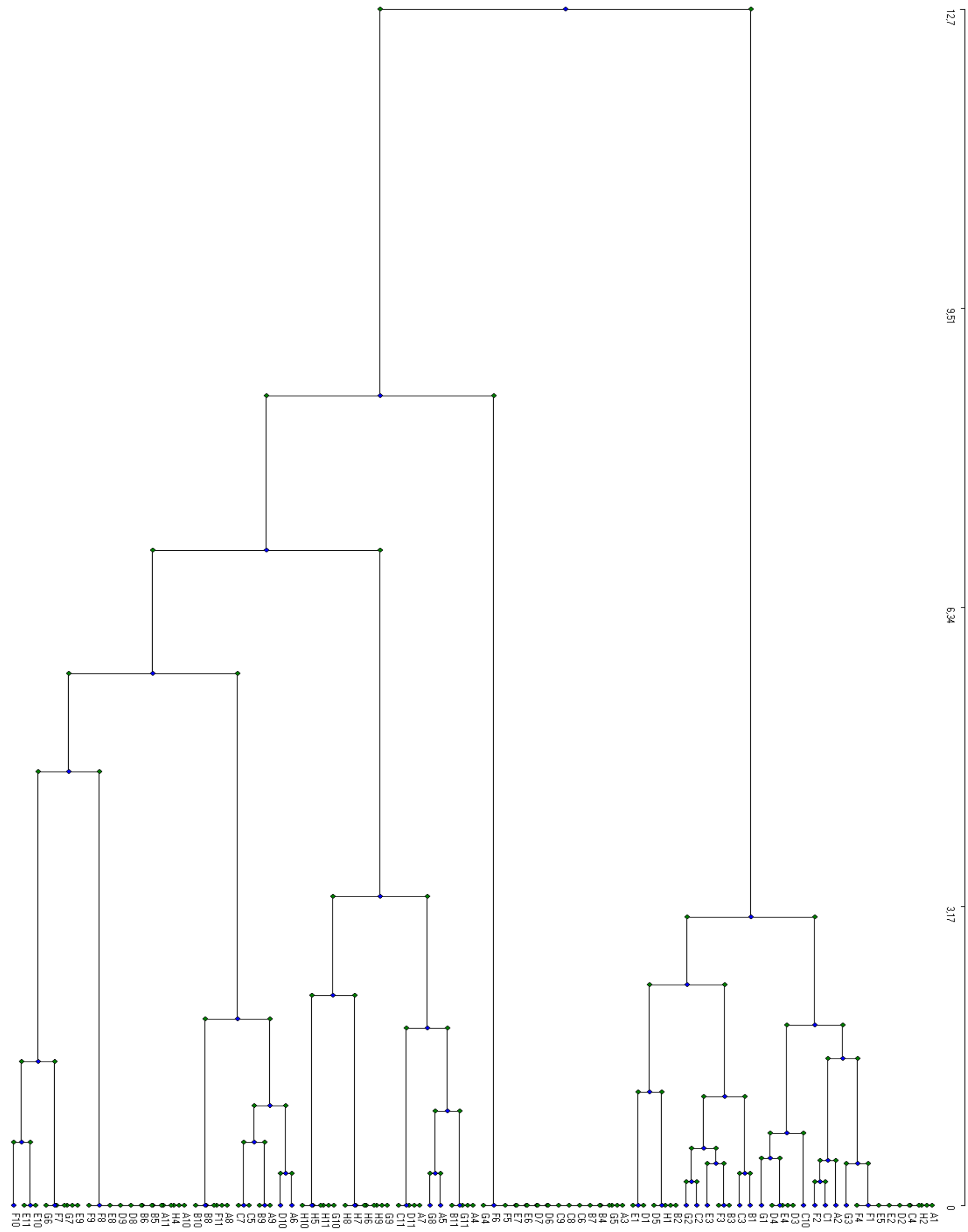

Figure 4. Dendrogram showing result from similarity analysis undertaken on squares present on transect A-H.

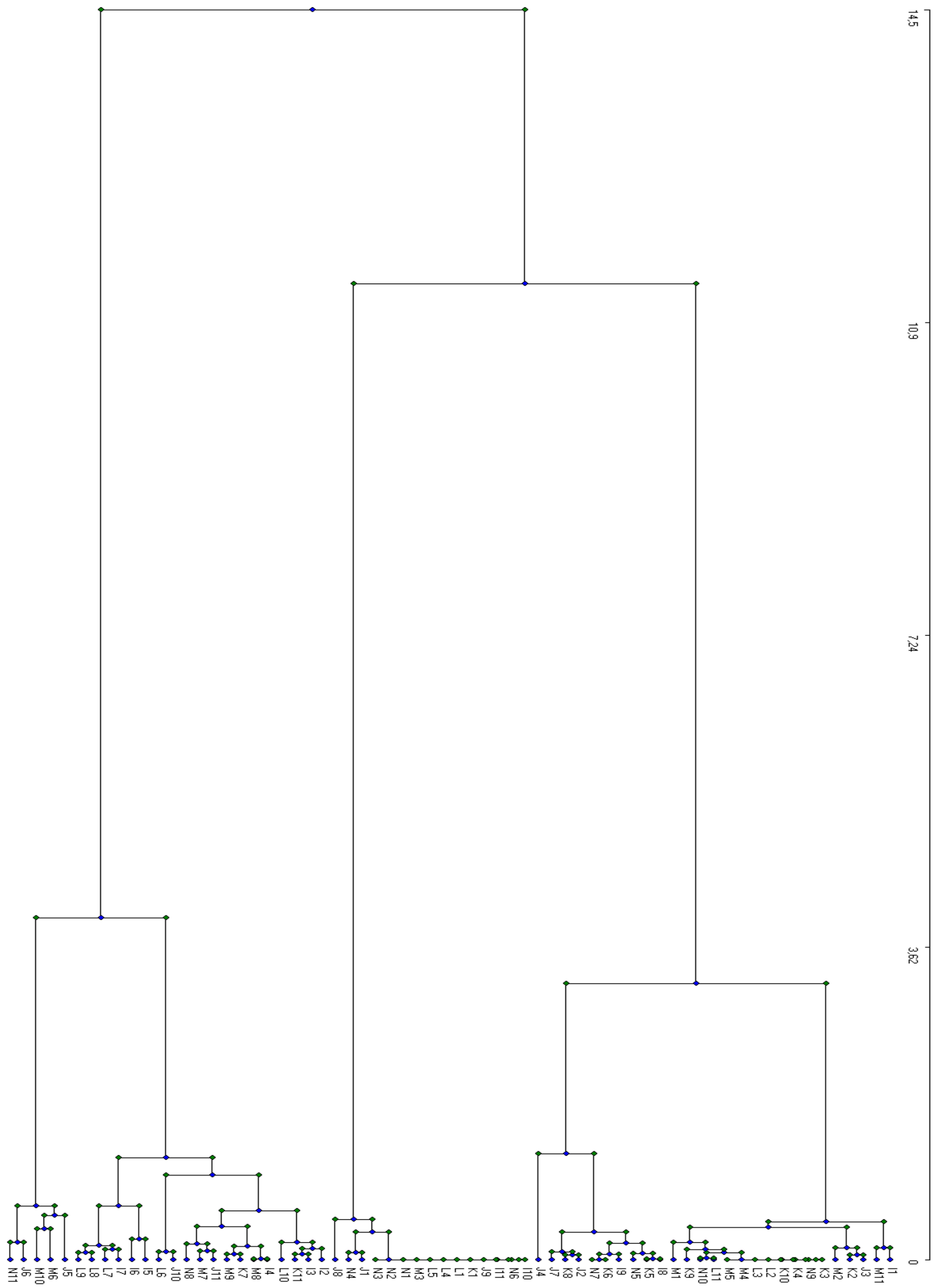

Figure 5. Dendrogram showing result from similarity analysis undertaken on squares present on transect I-N.

4 RESULTS

4.1 Species distribution

As concluded in the earlier NVC surveys (Halcrow 2007, 2010), the low-laying part of the restored area has since the realignment of River Glaven developed into a SM10 saltmarsh community. The proportion of squares in which a species (filtered data) was recorded within the restored area and reference saltmarsh is provided in Table 4.

Table 4. Proportional distribution of species (filtered data) over the restored area (transect A-H) and the reference saltmarsh (transect I-O). The value given is the proportion of squares within each area/sub-area in which the species was recorded.

Species	Restored area	Reference saltmarsh	Transect I and J	Transect K,L,M,N	Transect O
Agrostis capilaris	0.11	-	-	-	-
Armeria maritima	-	0.36	0.27	0.27	-
Aster tripolium	0.22	0.41	0.20	0.20	0.27
Dactylis glomerata	0.14	-	-	-	-
Elymus pycnanthus	0.44	0.50	0.45	0.45	0.73
Festuca rubra	0.08	-	-	-	0.18
Halimione portulacoides	0.41	0.55	0.64	0.64	0.18
Limonium vulgare	-	0.41	0.23	0.23	-
Plantago lanceolata	0.16	-	-	-	-
Puccinellia maritima	0.25	0.23	0.11	0.11	0.27
Salicornia europaea agg.	0.06	0.09	0.11	0.11	-
Spartina anglica	0.09	0.03	0.05	0.05	-

A clear zonation of species was found in the restored area with pioneer/low marsh species being dominant over the first 30 metre on transects (Figure 6). *Halimione portulacoides* and *Elymus pycnanthus* had the widest distribution of the saltmarsh species, resulting in large overlap with the species associated with the grassland community (e.g. *Dactylis glomerata, Plantago lanceolata*). A distinct band of *E. pycnanthus* was observed at 50-80 metre from the river, along the high mark (Halcrow 2010). Although not recorded in the survey, stands of *Limonium vulgare* and *Armeria maritima* were observed within the restored area, directly to the west of the partially demolished embankment, approximately 100 metre to the east of transect H (Figure 13). Refer to Table B.1, Appendix B.1 for a complete list of species recorded in the survey.

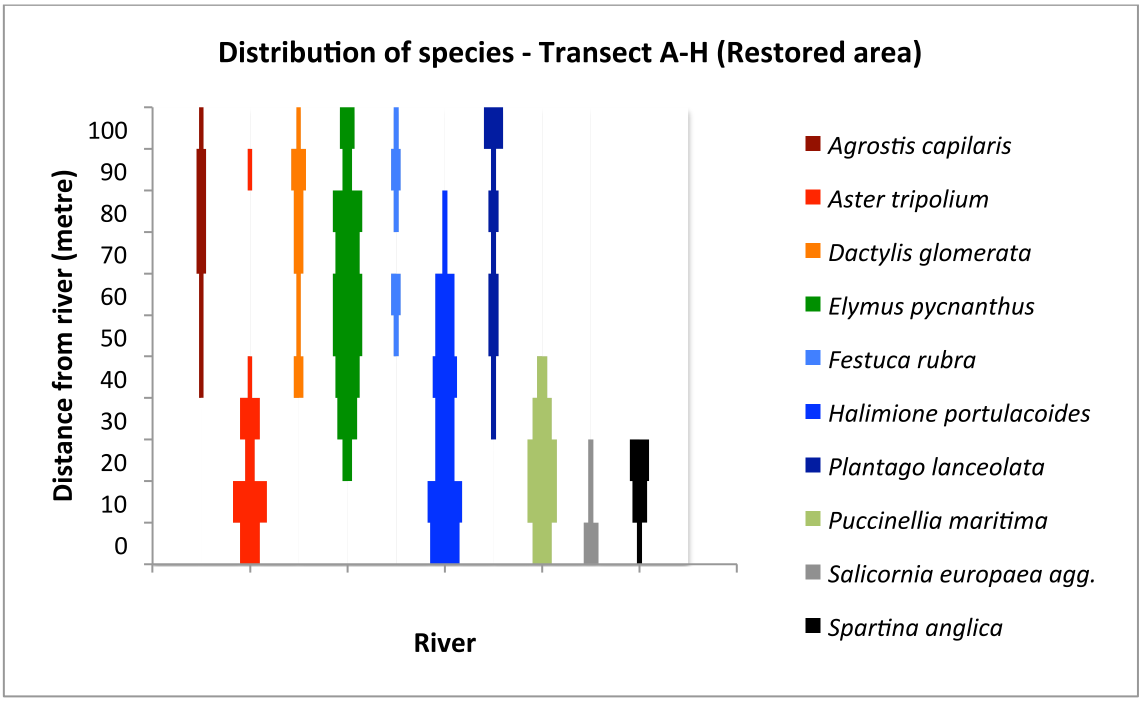

Figure 6. Distribution of species in the restored area, based on presence/absence data for the 8 transects A-H. The thickness of the bar represents the number of squares (out of 8) in which the species was present.

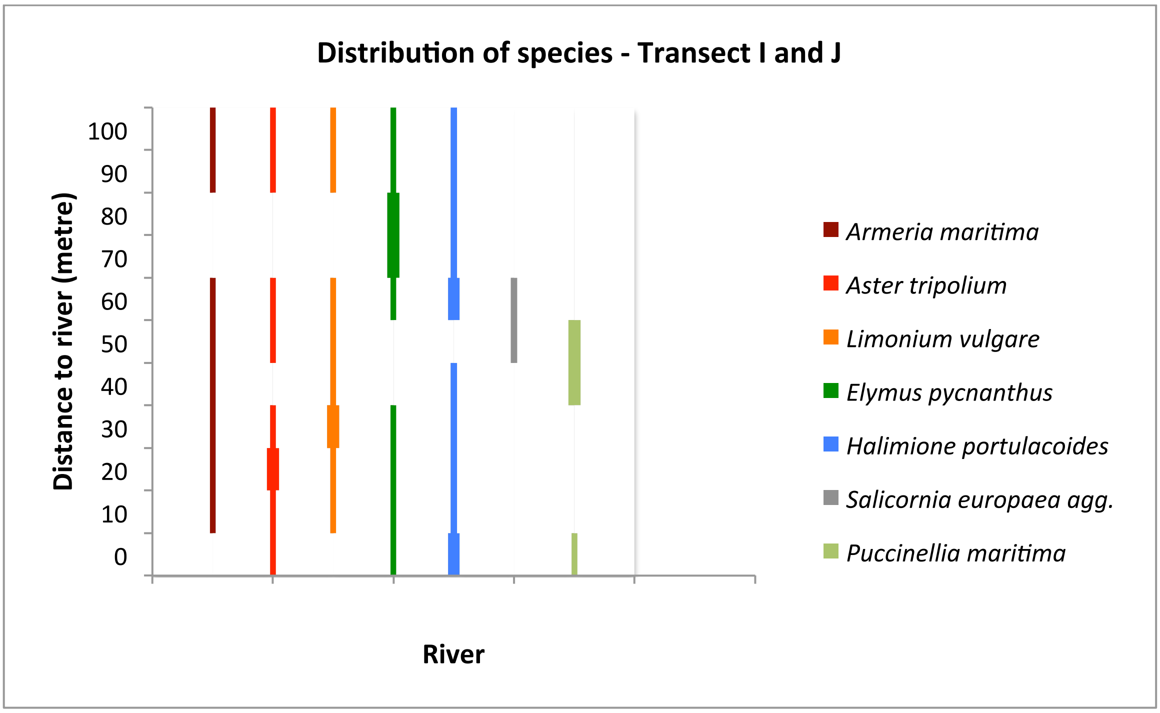

Figure 7. Distribution of species over transect I and J (reference saltmarsh), based on presence/absence data for the 2 transects. The thickness of the bar represents the number of squares (out of 2) in which the species was present.

No clear species zonation from the river was found over transects I and J (Figure 7), covering an area identified as SM13a/c in the NVC survey (Halcrow 2003). This area is predominantly flat (Figure 10), with smaller creeks occurring at 60-80 metres along transects. A large creek (>1 metre wide at the top) was stretching along the east side of transect J. The vegetation along the creek consisted of homogenous stands of *H. portulacoides,* hence this species was frequently recorded on transect J. The dominant species community consisted of typical middle marsh species such as *A. maritima* and *L. vulgare*. However, an area dominated by *E. pycnanthus* was observed at 70-80 metres from the river. A depression dominated with *Puccinellia maritima* was present at 40-50 metres.

The first 40-50 metres of transect K, L, M and N were dominated by homogenous stands of *E. pycnanthus* and *H. portulacoides* (Figure 8), representing the saltmarsh communities SM24 and SM14 respectively (Halcrow 2003). At 50-60 metres from the river, a species community similar to the one covered by transect I and J was observed (Figure 8). This area was characterised by a wide range of species, associated with both pioneer (e.g. *Salicornia europaea agg*.), low (e.g. *Aster tripolium*) and middle (e.g. *Armeria maritima*) marsh communities. Just like the area covered by transects I and J, this area was perceived as being flat, which was confirmed by the LIDAR map (Figure 10). An intricate system of creeks of different sizes was present in this area, where the largest ones were visible on the LIDAR map (Figure 10). No typical saltmarsh plant zonation (section 2.3) from the river was observed in this area. Transect O (Figure 9) was found to be dominated by *E. pycnanthus* (SM24), but with low marsh vegetation present in squares located on the first 30 metres from the old river alignment. Occasional stands of *Festuca rubra* were also recorded on the transect.

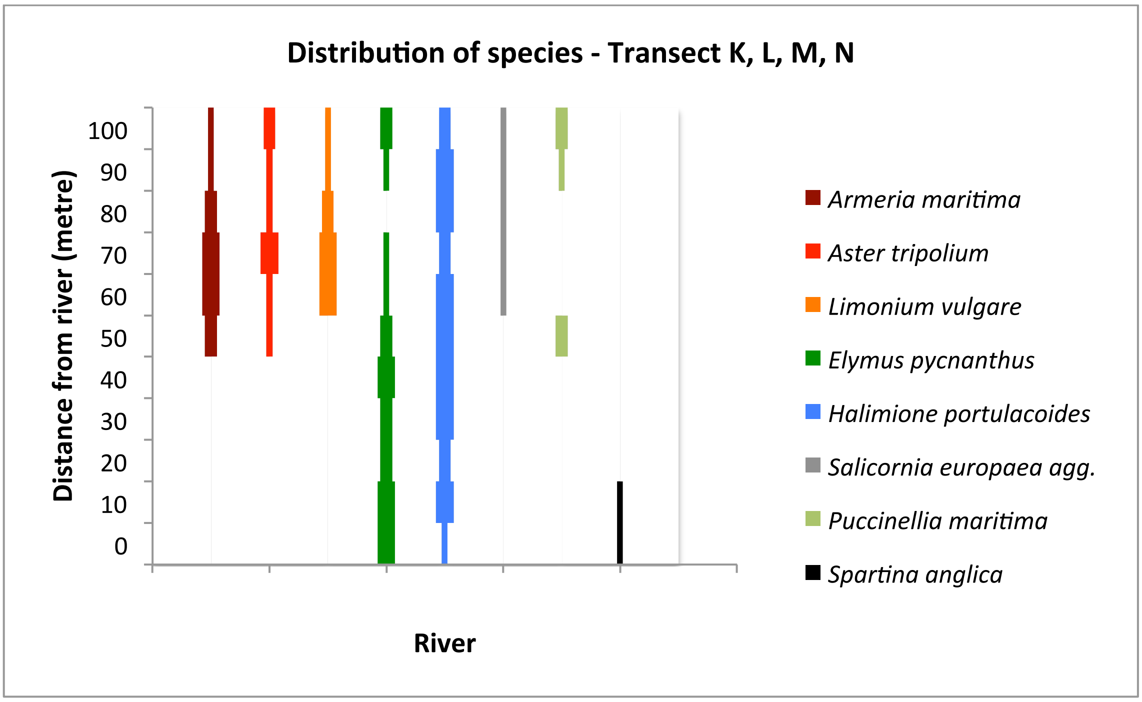

Figure 8. Distribution of species over transect K, L, M and M (reference saltmarsh), based on presence/absence data for the 4 transects. The thickness of the bar represents the number of squares (out of 4) in which the species was present.

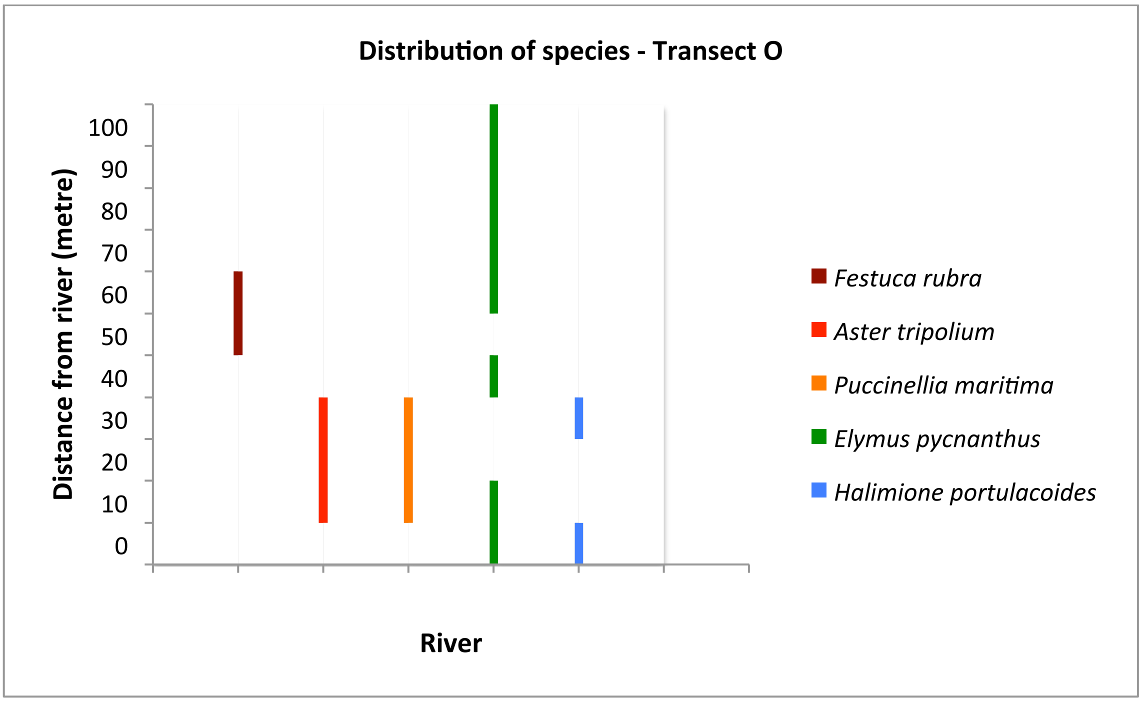

Figure 9. Distribution of species over transect O (reference saltmarsh), based on presence/absence data.

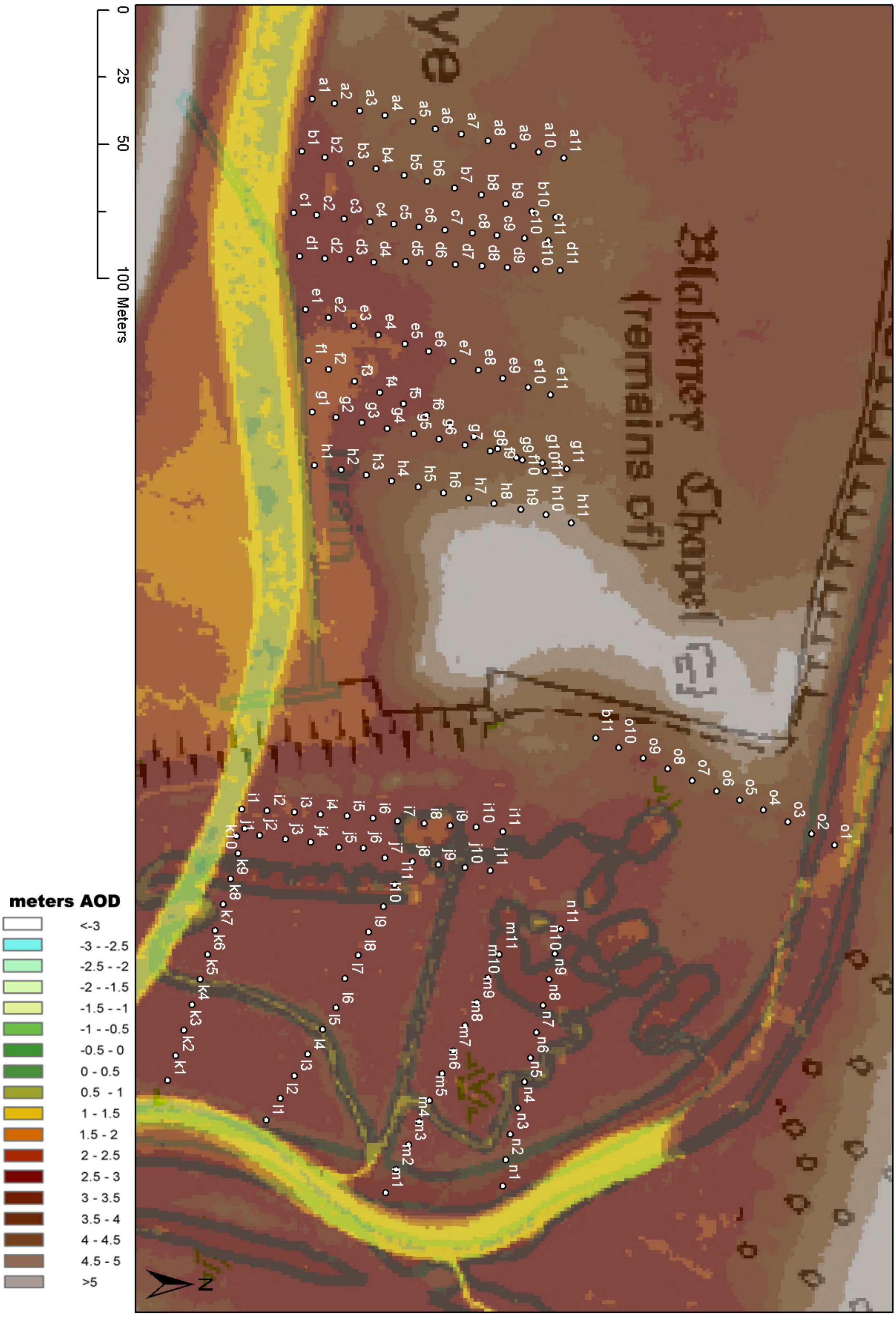

Figure 10. Topography (LIDAR) of the study area with positions of sampling transects overlaid. The original LIDAR map was produced by Atkins, with data provided by the Environmental Agency.

4.2 Plant diversity by area

The results from the diversity calculations based on combined transects are presented in Table 5. The restored area (transect A-H) had the highest Shannon-Wiener and Simpson diversity as well as the highest evenness of the areas included in the analysis. The overall diversity in the pristine saltmarsh was lower than for the restored area. Transect I and J was found to have the highest diversity of the sub-sets of transects, located in the reference saltmarsh. Transect I and J contained one fewer species than K, L, M and N but had a higher evenness in species, both for Shannon-Wiener and Simpson. Transect O was found to have the lowest diversity.

Table 5. Shannon-Weiner diversity H, evenness J, Simpson D diversity and evenness E for the restored area (transect A-H), pristine saltmarsh (I-O), transect pairs I and J, K and L and transect O. D_{max} = total number of species included in analysis.

	Restored area	Pristine saltmarsh	Transect I and J	Transect K,L,M,N	Transect O
D_{max}	10	9	7	8	5
Shannon H	**2.101**	**1.898**	**1.850**	**1.837**	**1.446**
Evenness J	0.913	0.864	0.951	0.883	0.898
Simpson D	**6.977**	**5.777**	**6.031**	**5.298**	**3.600**
Evenness E	0.698	0.642	0.862	0.662	0.720

Transect B, H and O was found to have the highest β-diversity (Figure 11), i.e. the highest turnover rate of species along transects. These transects also had the lowest average number of species recorded per sampling square. Transect I and J was found to have the lowest β-diversity and the highest average number of species recorded per sampling square (Figure 11). In other words, the turnover of species along transect I and J was low compared to the other transects, which indicated a homogenous vegetation structure.

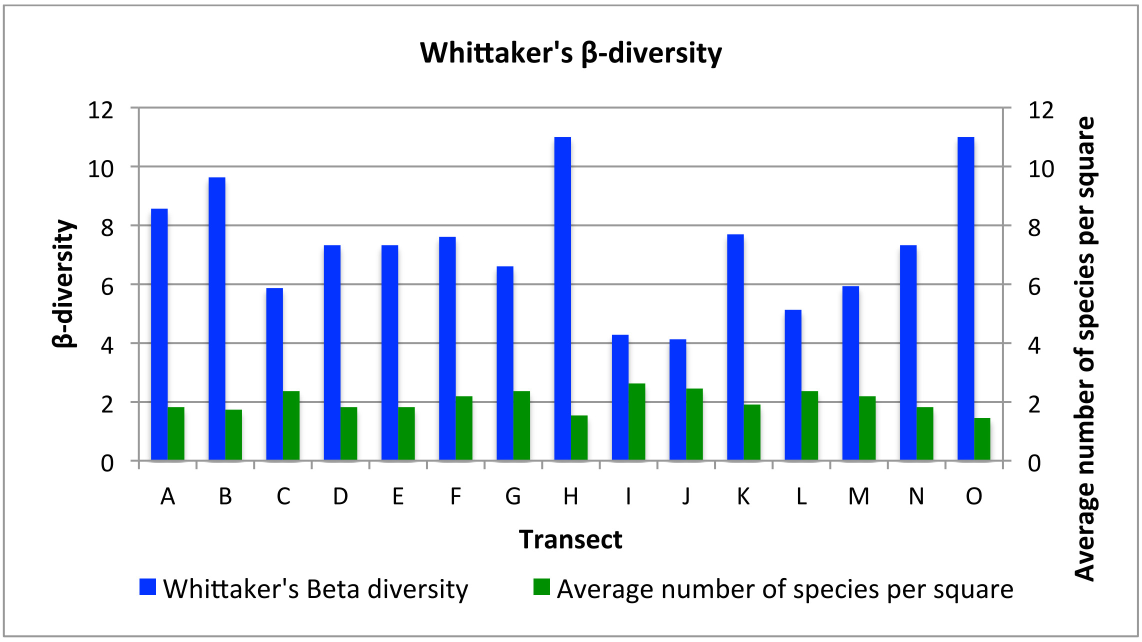

Figure 11. Whittaker's β-diversity and average number of species per sampling square for all transects in survey (A-O).

4.3 Plant diversity by species community

When looking at the species communities rather than areas, the saltmarsh community in the restored area (SM10) was found to have a similar diversity and evenness as the middle marsh community in the reference saltmarsh (SM13a/c)(Table 6). The grassland community present in the restored area was found to have a lower diversity but higher evenness than both of the saltmarsh communities. The area identified as the saltmarsh community SM10 in the restored area is shown in Figure 12. Because of the overlap of *H. portulacoides* and *E. pycnanthus* with the low marsh community, these species has been considered a part of the SM10 community. Due of the spread in spatial distribution of squares identified as covering the vegetation community SM13a/c (Table 3), this community has not been delineated on the map (Figure 12).

Table 6. Shannon-Weiner diversity H, evenness J, Simpson D diversity and evenness E for the saltmarsh (SM) community and grassland (GM) community in the restored area and middle marsh community in the pristine saltmarsh. D_{max} = total number of species included in analysis.

	Restored area SM10	Restored area GM6b	Pristine saltmarsh SM13a/c
D_{max}	7	6	7
Shannon H	**1.692**	**1.596**	**1.782**
Evenness J	0.869	0.891	0.916
Simpson D	**4.748**	**4.501**	**5.400**
Evenness E	0.678	0.750	0.771

Figure 12. The location of the 165 sampling squares, distributed on the 15 transects (A-O). The area identified as the saltmarsh community, including both SM10 and developing SM24, is shown in dark green in the restored area.

5 DISCUSSION

5.1 Species distribution

5.1.1 Reference saltmarsh

The most striking difference between the restored area and the reference saltmarsh was the topography. While the restored area showed a gradual increase in elevation with distance from the river, the reference saltmarsh was predominantly flat with an elevation range of 2.5 to 3 metre (Figure 10). Moreover, the reference saltmarsh also exhibited a well-developed system of creeks, which has been shown to improve drainage of the soil and also the rate of colonization in saltmarshes (Eertman *et al*. 2002). As a result, the saltmarsh was characterized by middle marsh communities (SM13a/c, SM14a, SM24) and lacked a typical plant zonation. Even though the saltmarsh is not suitable as a reference in terms of plant zonation, it provides information on the vegetation communities that are likely to develop in the restored area, given enough time.

5.1.2 Restored area

What was striking when undertaking the species survey was the homogeneity of the saltmarsh vegetation. This was particularly true for *Halimione portulacoides*, which typically occurred in dense stands, however, with a distribution not obviously bound to any particular elevation. This species was frequently occurring both in the restored area and in the reference saltmarsh. *Elymus pycnanthus* was found to have a similar distribution in the two areas, although more frequently occurring at higher elevation.

Results obtained from the restored area agreed well with what earlier studies has shown (Halcrow 2007 and 2010), both in terms of species composition and distribution. The vegetation exhibited a clear zonation from the river up towards higher elevations. The band of *E. pycnanthus* located 60-80 metres from the river is likely to develop into a SM24 community, currently present in the reference saltmarsh at the same elevation.

Elevation has been shown to be a primary factor determining the establishment of species in restored saltmarshes (Wolters *et al*. 2005). In this case, the elevation of the land was lowered to promote the establishment of saltmarsh vegetation, which has proven to be successful, or, if the recommendation by Zedler and Callaway (2000) is to be followed: has progressed towards a distinct SM10 community. This community is not present in the reference saltmarsh included in this study and can therefore be considered to have increased the diversity in saltmarsh communities on a local scale.

As concluded in section 2.3, many uncertainties remain regarding saltmarsh development on restored land (Havens *et al*. 2002). Even though middle marsh vegetation have started to colonize the restored area, it is difficult to estimate if and when a middle marsh community, with similar characteristics of the SM13 community present in the reference saltmarsh will develop. The data available from other restoration projects suggest that it can take many years before a restored saltmarsh exhibits similar characteristics to those of a natural one (Garbutt *et al.* 2006). Looking at de-embankments in Essex, Garbutt et al. (2008) found that even after 100 years, species communities still differed between restored and natural saltmarshes. Even though not used in this restoration project, artificial creation of creeks has been used in other projects to promote colonisation (Wolters *et al.* 2005) and is worth considering in future projects where high species richness is an expressed target. As concluded in the survey report from 2010 (Halcrow), the grassland community has since the cessation of grazing shifted from a *Lolium perenne* dominated grassland to one dominated by *Dactylis glomerata*, *Agrostis capilaris* and *Holcus lanatus*. This species composition was also shown in this survey, with the exception of *H. lanatus,* which occurred less frequently in samples. Based on the current species composition, it would be more suitable to classify the grassland community as MG5 (Rodwell *et al.* 2000) rather than MG6b, which is the current classification (Halcrow 2010). However, this is based on the data acquired from this study, which only covered the southern part of the area classified as MG6b.

5.2 Plant diversity

5.2.1 By area

The restored area was found to have higher plant diversity than the reference area, which can be explained by the fact that the area consisted of both a saltmarsh community as well as grassland community. Even though more saltmarsh species were recorded in the reference saltmarsh, only two (*A. maritima* and *L. vulgare*) were included in the analysis due to the filtering undertaken on the data. The MG11a grassland community sampled on transect O (reference saltmarsh) did not yield the same variety of species as the grassland community in the restored area (MG6b). Instead, *E. pycnanthus* (SM24) was the dominating species here, suggesting a need for an updated NVC survey of this area.

It is questionable whether sampling over transects, which is recommended for plant zonation surveys (JNCC 2004), is an optimal method for diversity studies of this kind. As shown in this study, saltmarsh species such as *Plantago maritima, Glaux maritima* and *Artemisia maritima*, which were locally abundant in the reference saltmarsh, were not included in the diversity analysis (Table B.2, Appendix B.2) since these species, by chance occurred in the area between sampling squares. To mitigate this problem, more sampling squares are needed within each area (Henderson 2003).

Whittaker's β-diversity was highest for the periphery transects A, B and H in the restored area as the steepest rise in elevation (Figure 10) and hence most rapid change in species communities was present here (Figure 11). Unlike Shannon-Wiener and Simpson indices, which provide information on the α-diversity, the β-diversity provides information on the rate of change in species composition over environmental gradients. Since the β-diversity has been developed for analyzing this type of data, it is arguably more suitable to use on the data acquired in this study. However, to fully assess the biodiversity of a saltmarsh, it is desirable that both types of indices are used.

5.2.2 By species community

The low marsh community (SM10) present in the restored area and the middle marsh community (SM13a/c) present in the reference saltmarsh were found to have similar α-diversity. The primary reason being that the same number of species (7) was included in the calculations for both areas and the fact that both areas had similar species composition. While *L. vulgare* and *A. maritima* only occurred in the SM13 community, *E. pycnanthus* was included in the SM10 community since this species was recorded in the same squares as low marsh species and thus included in the SM10 group of squares. The same goes for *H. portulacoides*, which had a wide distribution over the area, occurring in squares classified as covering both saltmarsh and grassland communities.

5.2.3 Diversity indices as a measure of success

While high species diversity is generally sought for (Millennium Ecosystem Assessment 2005), it is not necessarily the best indicator for a successful saltmarsh restoration as these ecosystems are naturally poor in plant species (e.g. Adam 1990). This is not to say that biodiversity indices should not be used at all, if a SM10 community had been present in the reference saltmarsh as well, it would have been of interest to compare the diversity indices of the two communities.

This, of course, relates to the target set for the restoration. In this case, where there is no explicit ecological target in terms of species composition other than restoring the area to “saltmarsh”, the approach of comparing communities in terms of species composition is arguably more feasible. That is, looking at what types of species are present and how they are spatially distributed (as discussed in section 5.1). Wolters *et al*. (2005) suggested the concept of species pools (reviewed by Zobel *et al*. 1998) as a way to determine the success of a restoration. The authors suggested that target species should be identified from a regional species pool; the success of the restoration should subsequently be determined by comparing the diversity of the restored saltmarsh with that of the target pool. However, the authors also pointed out that the presence of a particular species does not provide information whether a particular community has established and that data of plant species abundances are needed. De Jong (2004) argued that both diversity in species and zones should be considered when evaluating the status of a saltmarsh.

5.3 Future monitoring

5.3.1 NVC surveys

As discussed in section 2.3, sufficient monitoring of restored saltmarshes is not always undertaken. In this restoration project however, NVC surveys have been conducted in the restored area (Halcrow 2007 and 2010). These surveys provide information on the species communities present and how they are developing. However, it would be a good idea to also include the reference saltmarsh in these post-constructions surveys to determine if and in that case, how these communities are changing. This would be of particularly interesting since NVC survey data is available from the post-construction survey of the reference saltmarsh (Halcrow 2003).

Additionally, it is strongly recommended that future NVC surveys utilise high-precision GPS to record the position of sampling squares as well as the borders between vegetation communities where possible. The location and distribution of vegetation communities in the two post-construction surveys are presented on hand-drawn maps (Halcrow 2007 and 2010), which render it difficult to analyse change with computer based GIS tools.

5.3.2 Transects

Even though the NVC surveys provide general information of plant zonation, as certain species are associated with certain communities, they do not provide information on the species level. It would be desirable to continue monitoring over transects in the restored area to determine if and how the distribution of individual species changes, both as a result of natural succession but also due to the relative rise in sea level (Environment Agency 2007). Since no plant zonation due to elevation was found in the reference saltmarsh, it is suggested that no transect sampling is carried out here. Instead, the transect sampling in the restored area should be extended to include a greater part of the area with more transects and thus more sampling squares. As seen in this study, even though many small (0.25 m^2) squares per transect provide a high resolution in the data, it also increases the risk of many zeros in the data set (Henderson 2003), which result in a high skew. Increasing the amount of small squares (0.25 m^2) is considered more feasible than using fewer large ones (Henderson 2003).

Finally, in order to monitor the colonization rate of saltmarsh species (e.g. *L. vulgare* and *A. maritima*) from the reference saltmarsh, additional transects should be sampled between transect H and the old embankment (Figure 12). By doing so, data from sampling squares could be analysed parallel to the realigned river in addition to the perpendicular plant zonation analysis. It has been suggested that surveys should be carried out every six years (JNCC 2004). However, in this case where an area has been restored quite recently, it is arguably feasible to undertake monitoring more frequently to detect any changes occurring as saltmarsh vegetation is establishing.

Even though there are general guidelines available for surveying saltmarsh vegetation (JNCC 2004), the methods of evaluating the status of a saltmarsh is still under development (Best *et al.* 2007). To fully assess the development of a saltmarsh, physical factors such as erosion and accretion has to be monitored in addition to vegetation structure and distribution (JNCC 2004).

5.3.3 Additional data

It is recommended that spatially referenced LIDAR data is acquired for the site. This data can be used to undertake more detailed analyses of the correlation between distribution of species and elevation in the restored saltmarsh. Edaphic factors, in particular soil salinity would also be of interest to collect as an explanatory variable for plant zonation (Wolters *et al*. 2005). Soil carbon is another factor of interest as it has been shown to differ between restored and natural saltmarshes as a result of the topsoil being removed to lower the elevation (Havens *et al.* 2002, Craft *et al.* 2003). This is, of course dependent on the time and resources available for the survey.

5.4 Conclusion

In the absence of explicit ecological targets, which is the case in this restoration project, determining if the project is successful or not is difficult. Instead, it can be concluded that the part of the restored area covered in this study has progressed towards a SM10 community with other communities currently developing (SM24). As shown in this study, transect sampling is a suitable method to detect zonation in the distribution of species. However, in future surveys, more transects per area and therefore more samples per area are needed to reduce the amount of zeros in the data set. This will allow for statistical analyses to be undertaken on the data, which is needed to conclude any changes occurring in plant zonation.

6 AKNOWLEDGEMENTS

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REFERENCES

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

Allen, J.R.L. and Pye, K. 1992. *Saltmarshes: Morphodynamics, conservation and engineering significance*. Cambridge University Press, UK.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* 81(2): 169–193.

Bertness, M.D., Gough, L., Shumway, S.W. 1992. Salt tolerances and the distribution of fugitive salt marsh plants. *Ecology* 73: 1842–1851.

Best, M., Massey, A., Prior, A. 2007. Developing a saltmarsh classification tool for the European water framework directive. *Marine Pollution Bulletin* 55: 205–214.

Bertness, M.D., Pennings, S.C. 2000. Spatial variation in process and pattern in salt marsh plant communities in eastern North America, in: Weinstein, M.P., Kreeger, D.A. (Eds.), *Concepts and controversies in tidal marsh ecology*. Kluwer Academic Publishers, Norwell, USA.

Bockelmann, A.C., Bakker, J.P., Neuhaus, R., Lage, J. 2002. The relation between vegetation zonation, elevation and inundation frequency in a Wadden Sea salt marsh. *Aquatic Botany* 73: 211–221.

Boorman, L.A. 1966. *Experimental studies in the Genus Limonium*. DPhil thesis, University of Oxford.

Boorman, L.A. 1995. Sea level rise and the future of the British coast. *Coastal Zone Topics: Process, Ecology and Management* 1: 10–13.

Boorman, L.A. and Hazelden, J. 1995. Saltmarsh creation and management for coastal defence, in: Healy, M.G. and Doody, J.P. (Eds.), *Directions in European coastal management*. Samara Publishing Limited, Cardigan, UK.

Boorman, L.A., Hazelden, J., Boorman, M. 2002. *Littoral 2002: The Changing Coast.* Volume 2. 22–26 September 2002, Faculty of Engineering, Porto, Portugal. Eurocast, Portugal. 35-45.

Boorman, L.A. 2003. Saltmarsh Review: An overview of coastal saltmarshes, their dynamic and sensitivity characteristics for conservation and management. *JNCC Report* 334.

Clapham, A.R., Tutin, T.G., Moore, D.M. 1987. *Flora of the British Isles*. Third Edition. Cambridge University Press, UK.

Craft, C., Megonigal, P., Broome, S., Stevenson, J., Freese, R., Cornell, J., Zheng, L., Sacco, J. 2003. The Pace of ecosystem development of constructed *Spartina alterniflora* marshes. *Ecological Applications* 13(5): 1417–1432.

Crain, C.M., Silliman, B.R., Bertness, S.L., Bertness, M.D. 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. *Ecology* 85(9): 2539–2549.

Davy, A.J. 2000. Development and structure of salt marshes: community patterns in time and space, in: Weinstein, M.P., Kreeger, D.A. (Eds.), Concepts and Controversies in Tidal Marsh Ecology. Kluwer Academic Publishers, Norwell, USA.

DEFRA. 2002. Managed realignment review. *Project Report,* August 2002.

De Jong, D.J. 2004. Water Framework Directive: determination of the reference condition and potential-ref/potential-ges and formulation of indices for plants in the coastal waters CW_NEA3 (K1), CW-NEA4 (K2), CW- NEA1 (K3), transitional waters, TW-NEA11 (o2) and large saline lakes, NEA26 (M23), in the Netherlands. *Working document RIKZ/OS/2004.832.x*.

Dijkema, K.S. 1987. Changes in salt-marsh area in the Netherlands Wadden Sea after 1600, in: Huiskes, A.H.L., Blom, C.W.P.M., Rozema, J. (Eds.), *Vegetation Between Land and Sea*. Dr. Junk Publishers, Dordrecht, 42–49.

Eertman, R.H.M., Kornman, B.A., Stikvoort, E., Verbeek, H. 2002. Restoration of the Sieperda tidal marsh in the Scheldt estuary, The Netherlands. *Restoration Ecology*,10:438–449.

Environment Agency. 2007. *Saltmarsh management manual*. R&D Technical Report SC030220.

Ewanchuk, P.J. and Bertness, M.D. 2004. Structure and organization of a northern New England salt marsh plant community. *Journal of Ecology* 92**:** 72–85.

Farina, J.M., Silliman, B.R., Bertness, M.D. 2009. Can conservation biologists rely on established community structure rules to manage novel systems? ... Not in salt marshes. *Ecological Applications* 19(2): 413–422.

Garbutt, A. and Wolters, M. 2008. The natural regeneration of salt marsh on formerly reclaimed land. *Applied Vegetation Science* 11(3): 335-344.

Garbutt, R.A., Reading, C.J., Wolters, M., Gray, A.J. and Rothery, P. 2006. Monitoring the development of intertidal habitats on former agricultural land after the managed realignment of coastal defences at Tollesbury, Essex, UK. *Marine Pollution Buletin,* 53: 155-164.

Gray, A.J. 1985. Adaption in perennial coastal plants – with particular reference to heritable variation in *Puccinellia maritima* and *Ammophila arenaria*. *Vegetatio* 61: 179-188.

Halcrow. 2003. Blakeney Freshes Environmental Statement. Environment Agency Anglian Region. Draft for comment, June 2003.

Halcrow. 2007. *Post-construction vegetation surveys 2007. River Glaven diversion. NVC and scarce plant monitoring*. December 2007.

Halcrow. 2009. *Post-construction vegetation monitoring 2009. River Glaven diversion. NVC survey*. January 2010.

Havens, K.J., Varnell, M.L., Watts, B.D. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. *Ecological Engineering* 18: 305-315.

Hemminga, M.A., Leeuw, J., Munek, W., Koutstaal, B.P. 1991. Decomposition in estuarine salt marshes: the effect of soil salinity and soil water content. *Vegetatio* 94: 25-33.

Henderson, P.A. 2003. *Practical Methods In Ecology*. Blackwell Publishing, Malden, USA.

Hutchinson, G.E. 1957. Concluding remarks. *Cold spring harbour symposium in quantitative biology*, 22: 415-427.

JNCC. 2004. *Common standards monitoring guidance for saltmarsh habitats*. Join Nature Conservation Committee. August 2004.

Kahn, M.A., Ahmed, M.Z., Hameed, A. 2006. Effect of sea salt and L-ascorbic acid on the seed germination of halophytes. *Journal of Arid Environments* 67: 535–540.

Katembe, W.J., Ungar, I.A., Mitchell, J.P. 1998. Effect of salinity on germination and seedling growth of two *Atriplex* species (Chenopodiaceae). *Annals of Botany* 82(2): 167-175.

Langlois, E., Bonis, A., Bouzille, J.B. 2003. Sediment plant dynamics in the salt marsh pioneer zone: *Puccinellia maritima* as a key species? *Estuarine, Coastal and Shelf Science* 56: 239–249.

Millennium Ecosystem Assessment. 2005. *Ecosystems and human well-being synthesis*. Island Press 137.

Mitsch, W.J. and Gosselink, J.G. 2008. *Wetlands*. VanNostrand Reinhold, New York.

Möller, I., Spencer, T., French, J.R., Leggett, D.J., Dixon, M. 1999. Wave transformation over saltmarshes: A field and numerical modeling study from North Norfolk, England. *Estuarine, Coastal and Shelf Science* 49: 411–426.

Oldham, J. and Roberts, C. 1999. *Saltmarsh plants of Britain*. FSC Publications, Shrewsbury, UK.

Pennings, S.C., Grant, M.B., Bertness, M.D. 2005. Plant zonation in low-latitude salt marshes: disentangling the roles of flooding, salinity and competition. *Journal of Ecology* 93: 159–167.

Pethick, J. 2002. Estuarine and tidal wetland restoration in the United Kingdom: policy versus practice. *Restoration Ecology* 10: 431–437.

Rodwell, J.S., Dring, J.C., Averis, A.B.G., Proctor, M.C.F., Malloch, A.J.C., Schaminée, J.N.J., Dargie, T.C.D. 2000. Review of coverage of the National Vegetation Classification. *JNCC Report* 302.

Silliman, B.R., Grosholz, T., Bertness, M.D. 2009. Salt marshes under global siege, in: Silliman, B.R., Grosholz, T., Bertness, M.D. (Eds.) *Human impacts on salt marshes: a global perspective*. University of California Press, Berkeley, California, 103-114.

Silvestri, S., Defina, A., Marani, M. 2005. Tidal regime, salinity and salt marsh plant zonation. *Estuarine, Coastal and Shelf Science* 62: 119–130.

Simas, T., Nunes, J.P., Ferreira, J.G. 2001. Effects of global climate change on coastal salt marshes. *Ecological Modelling* 139: 1–15.

Stevenson, J.C., Ward, L.G., Kearney, M.S. 1988. Sediment transport and trapping in marsh systems: implications of tidal flow studies. *Marine Geology* 80: 37–59.

Thom, R.M. 2000. Adaptive management of coastal ecosystem restoration projects. *Ecological Engineering* 15: 365-372.

Wang, H., Hsieh, Y.P., Harwell, M.A., Huang, W. 2007. Modeling soil salinity distribution along topographic gradients in tidal salt marshes in Atlantic and Gulf coastal regions. *Ecological Modelling* 201: 429–439.

Zedler, J.B. and Callaway, J.C. 2000. Evaluating the progress of engineered tidal wetlands. *Ecological Engineering* 15: 211–225.

Zobel, M., van der Maarel, E., Dupre´, C. 1998. Species pool: the concept, its determination and significance for community restoration. *Applied Vegetation Science* 1: 55–66.

APPENDICES

Appendix A Maps

A.1 NVC Communitites

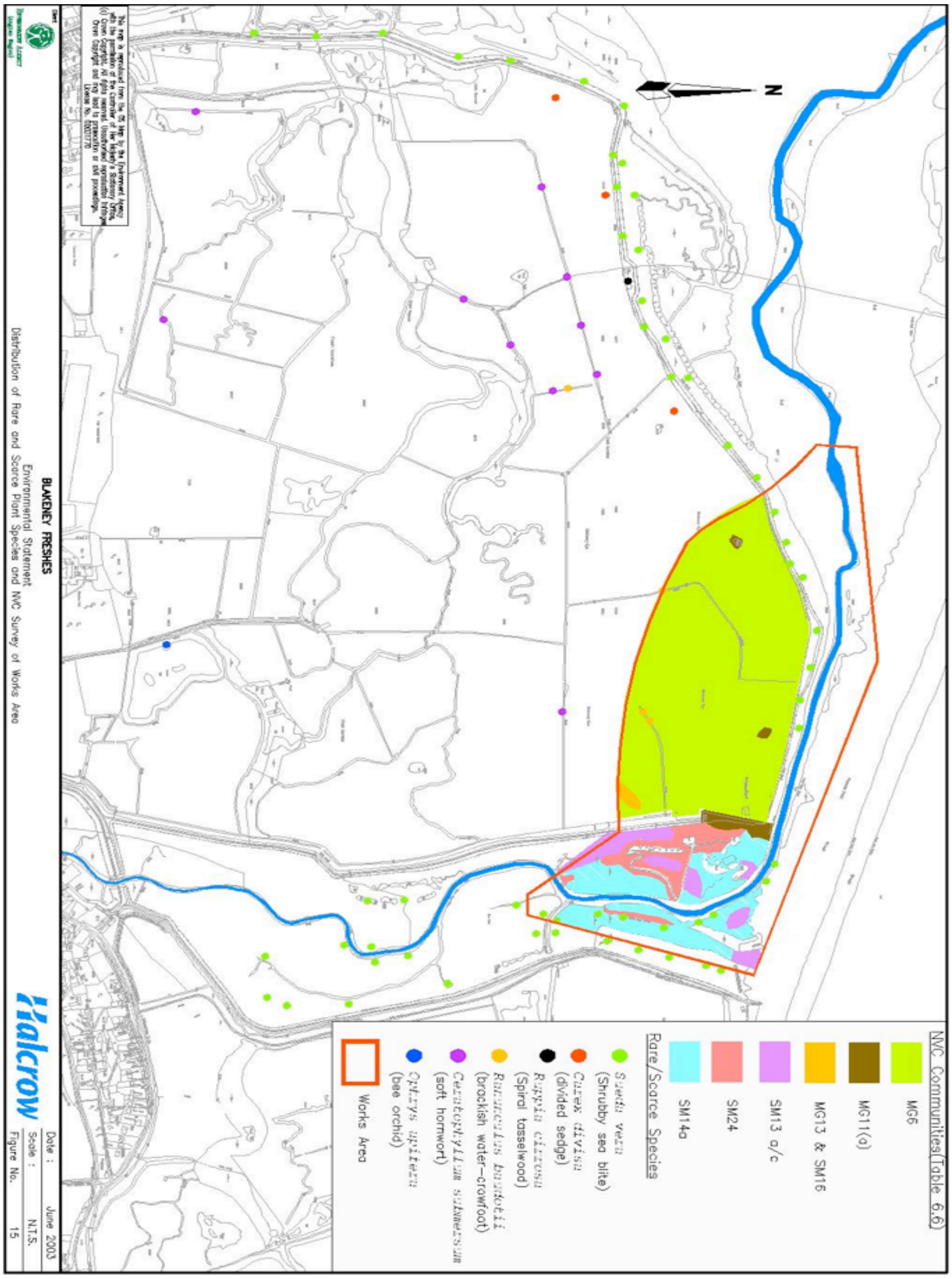

Figure A.1. NVC communities recorded in the ecological survey, undertaken as part of the EIA for the realignment of River Glaven (Halcrow 2003).

Appendix B List of species

B.1 Recorded species

Table B.1. Species recorded in the restored area ("Restored") and in the reference saltmarsh ("Reference"). Species nomenclature follows Clapham *et al.* (1987).

Species	Common name	Area
Achillea millefolium	Yarrow	Restored
Agrostis capilaris	Common Bent-grass	Restored
Agrostis stolonifera	Fiorin	Restored
Anthriscus sylvestris	Cow parsley	Restored
Armeria maritima	Thrift	Reference
Artemisia maritima	Sea wormwood	Reference
Aster tripolium	Sea aster	Restored / Reference
Atriplex prostrata (hastata)	Hastate Orache	Reference
Bromus hordeaceus	Lop-grass	Restored
Cirsium arvense	Creeping Thistle	Restored
Dactylis glomerata	Cock's-foot	Restored
Elymus pycnanthus	Sea couch grass	Restored / Reference
Festuca rubra	Red fescue	Restored / Reference
Glaux maritima	Sea milkwort	Reference
Halimione portulacoides	Sea purslane	Restored / Reference
Holcus lanatus	Yorkshire Fog	Restored
Leontodon autumnalis	Autumnal Hawkbit	Restored
Limonium vulgare	Sea Lavender	Reference
Plantago lanceolata	Ribwort Plantain	Restored
Plantago maritima	Sea plantain	Reference
Potentilla anserina	Silverweed	Restored
Puccinellia maritima	Common Saltmarsh-grass	Restored / Reference
Salicornia europaea agg.	Glasswort	Restored / Reference
Spartina anglica	Common Cord-grass	Restored / Reference
Suaeda vera (fruticosa)	Shrubby seablite	Restored / Reference
Trifolium repens	White Clover	Restored

B.2 Species included in analysis

Table B.2. Species occurring in at least 5% of survey squares and included in analysis of species distribution and diversity calculations. Species nomenclature follows Clapham *et al.* (1987).

Species	Common name
Agrostis capilaris	Common Bent-grass
Armeria maritima	Thrift
Aster tripolium	Sea Aster
Dactylis glomerata	Cock's-foot
Elymus pycnanthus	Sea Coach-grass
Festuca rubra	Red Fescue
Halimione portulacoides	Sea Purslane
Limonium vulgare	Sea Lavender
Plantago lanceolata	Ribwort Plantain
Puccinellia maritima	Common Saltmarsh-grass
Salicornia europaea agg.	Glasswort
Spartina anglica	Common Cord-grass

Appendix C Equations

Equation C.1. Shannon-Wiener H.

$$Shannon - Wiener\ (H) = \sum_{i=1}^{S_{obs}} p_i log_e p_i$$

where p_i is the proportion of individuals of species i (Henderson 2003).

Equation C.2. Simpson D.

$$Simpson\ (D) = \frac{1}{\sum_i^{S_{obs}} \left(\frac{N_i}{N_T}\right)^2}$$

where N_i is the number of individuals of species i and N_T the total number of individuals in the sample (Henderson 2003).

Equation C.3. Whittaker's β_w.

$$Whittaker's\ (\beta_w) = \frac{S}{\alpha - 1}$$

where S is the total number of species and α the average number of species in each sample (Henderson 2003).