Hydroseral succession: Butterby Marsh, Durham

T.N.R Redman

HYDROSERAL SUCCESSION:

BUTTERBY MARSH, DURHAM

by

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Air Photos: Alan Campbell and B.K.S. Surveys Ltd., Ballycairn Rd., Coleraine, Co. Londonderry, N. Ireland.

Fig. 4. 10: (Distribution of *Scirpus sylvaticus* and *Impatiens glandulifera* in County Durham). Rev. G. G. Graham.

Figs. 6.2,6.3,6.4: (Three plans of the River Wear at Butterby) Captain G. M. Salvin.

Figs. 6.5,6.6,6.7: (O.S. 1 : 2 500 Maps of Butterby Marsh 1857, 1897, 1919). The Durham County Archivist and the Ordnance Survey.

Fig. 6.8: (O.S. 1 : 2 500 1960). The Controller of Her Majesty's Stationery Office, (Crown Copyright reserved).

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Declaration

This thesis is the result of my own work. Data from other authors which are referred to in the thesis are acknowledged at the appropriate point in the text.

Statement of Copyright

To Jonathan and Sonia

and my parents

ABSTRACT

Butterby Marsh is a partially vegetated old meander loop of the River Wear located about two miles from Durham City. The main current of the river was diverted away from the loop in 1811 by a new channel cut across its neck. Within the next 46 years, embankments were built which isolated the loop from the river. It is now a system of ponds, marsh and marsh forest extending over an area about 1400 m. (over ¾ mile) in length, with a width of between 30 m. and 80m.

A unique opportunity for tracing the development of the hydrosere is afforded by the maps of the marsh vegetation published by Dr. B. M. Griffiths D.Sc. F.L.S. in the Journal of Ecology, 1932. Part of the Marsh (an area of approximately 500 x 50 m.) was remapped in the summer of 1982. The western area of the loop was selected for study as it is thought to be less disturbed. The distribution of the plant communities is analysed by habitat (water depth, water chemistry, substrate type, shade) and competition is examined in certain pure stands using light monitoring equipment.

The rate of sedimentary infill in the Marsh is investigated. The depth of the organic deposit beneath different plant communities is examined and sediments are analysed for their record of succession by qualitative examination of plant macrofossils. In addition, a stratigraphic profile is produced for a cross section of the old channel at one location to examine the form of the sediments. One core of 2.5 m. depth is selected for physical and chemical analysis in an attempt to separate fluvial sediments from Marsh sediments, thereby assigning an approximate date to the deposits. The project is primarily concerned with tracing the development of the Marsh as a habitat for plants.

The results of the vegetational study show that there have been great advances in the boundaries of Phragmites communis Trin. since 1929 in the western area of Marsh, with associated reduction of other species. The area of Marsh forest has not greatly changed, although Impatiens glandulifera Royle has spread across its herb layer in the drier parts. No great extensions of the vegetation into areas that were open water in 1929 were recorded.

It is suggested that there has been only a small accumulation of sediment (<75 cm.) since the embankments were built over 120 years ago. This is largely organic in its composition. Below it lies up to 2 m. of unconsolidated sediment, mostly grey silt. The mining detritus content and metal enrichment, (e.g. high levels of lead) seem to indicate that the silt was deposited by the river. Thick layers of sand (up to 20 cm.) above the grey silt on the point bar of a meander curve suggest that the silt originated before the cessation of flow conditions within the channel. It may have accumulated after 1811 when the main current of the river was redirected away from the loop, or be the product of a much longer period of accumulation extending back earlier than this.

With the present slow rate of infill, negligible flow, and a fairly similar substrate, it is suggested that competition amongst the plant communities may be an important factor in determining the future direction of vegetational shifts. The importance of site history for the development of the vegetation (especially the initial depths of the channel) is stressed.

CHAPTER 1 INTRODUCTION

1.1 THE STUDY AREA

Butterby Marsh is an old river channel of the River Wear. It is located about two miles south of Durham City (GR 2738 - 2739), but is relatively inaccessible due to the winding course of the river which almost encircles it. It is part of the private land of the Croxdale Hall estate.

The Marsh has formed in a meander loop from which the river was diverted by the landowners in 1811 (Griffiths, 1932). This involved cutting a new channel across the neck of the loop. Final communication with the river ceased sometime before 1857 when a series of large embankments were built. The operation shortened the course of the river by nearly one mile and was undertaken to stop the constant shifting of the river's course (which affected property boundaries) and to counteract serious flooding of the farm land at Low Butterby.

The old channel subsequently became infilled and is now a series of ponds, marshes and marsh forests. Hydroseral succession was initiated by the diversion of the river, which may have caused a fall of the water level in the old channel and reduced flow conditions. The only present sources of water supply are direct rainfall and surface drainage from Croxdale Woods and the surrounding fields. It is not known whether the river has ever crossed the embankments, but this has certainly not happened in recent times.

1.2 PREVIOUS WORK

A number of papers were published by Dr. B. M. Griffiths D.Sc. of the Department of Botany, University of Durham, who worked at Butterby Marsh during the 1920's and 1930's. To the writer's knowledge no publications have been made since then.

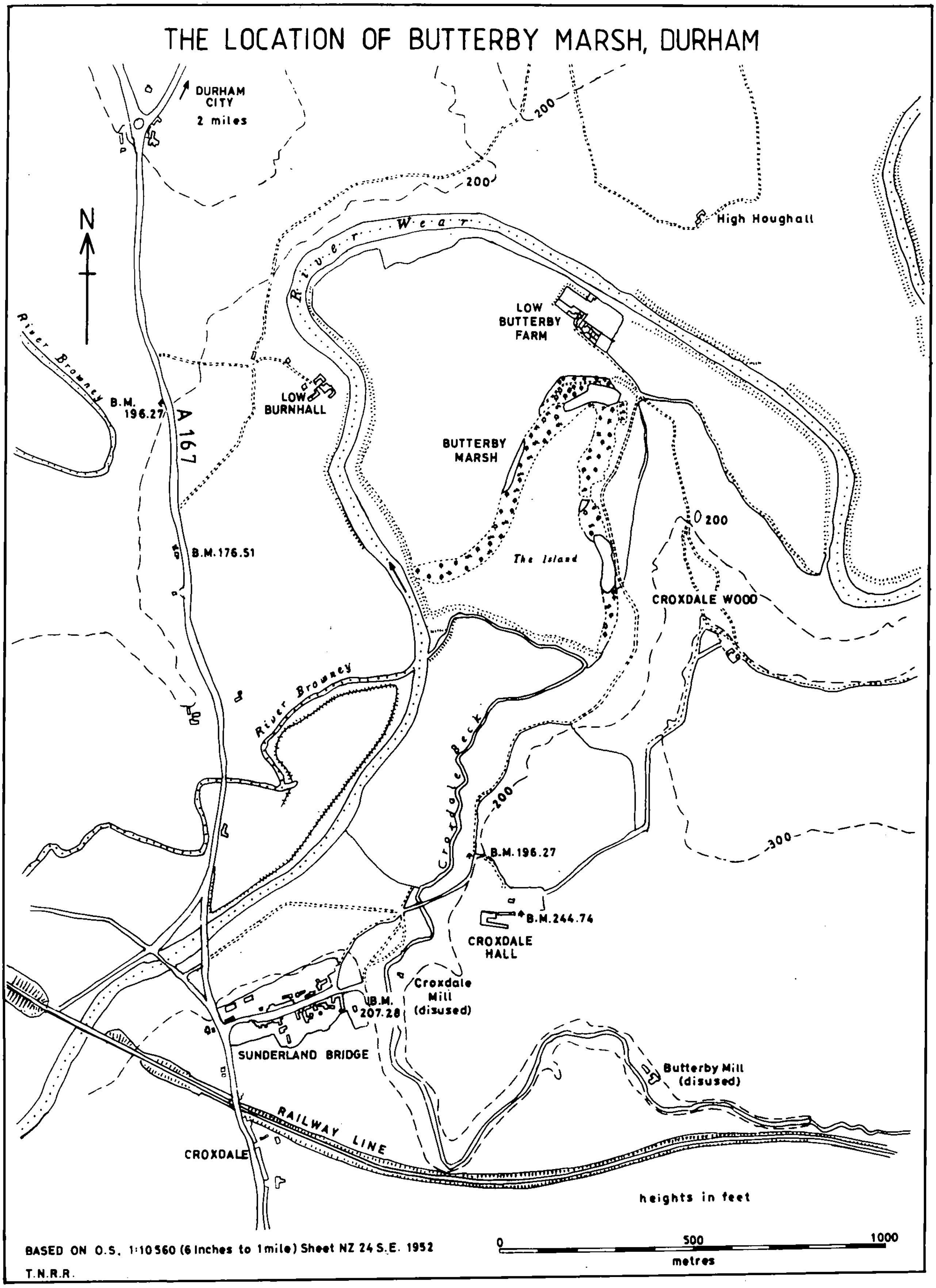
THE LOCATION OF BUTTERBY MARSH, DURHAM
DURHAM CITY
2 miles
N
200
200
High Houghall
River Wear
LOW BUTTERBY FARM
River Browney
B.M. 196.27
A 167
LOW BURNHALL
BUTTERBY MARSH
200
B.M. 176.51
The Island
CROXDALE WOOD
River Browney
Croxdale Beck
200
B.M. 196.27
300
B.M. 244.74
CROXDALE HALL
Croxdale Mill (disused)
B.M. 207.28
SUNDERLAND BRIDGE
Butterby Mill (disused)
RAILWAY LINE
CROXDALE
heights in feet
BASED ON O.S. 1:10 560 (6 Inches to 1 mile) Sheet NZ 24 S.E. 1952
T.N.R.R.
0
500
1000
metres

Fig. 1.1

Dr. Griffiths was a limnologist and much of his work at Butterby relates to the limnology of the "Long Pool". However, his first publication about the site was entitled "The Ecology of Butterby Marsh Durham"(Journal of Ecology, 1932). This presented the results of a vegetational survey made in the summers of 1929 and 1930 and included a number of plant distribution maps and also some photographs.

Dr. Griffith's study of Butterby Marsh in 1929 records the distribution of the vegetation at a particular stage in the hydrosere. It provides a baseline or datum mark from which subsequent changes can be recorded. His survey, undertaken fifty years ago, provides a unique opportunity for comparative work. Fifty years is, in theory, ample time for significant change to have taken place (Wade, 1982). The remapping of the Marsh vegetation is, in a sense, an experiment over time.

Similar studies on the development of the vegetation in hydroseres have been undertaken elsewhere. Godwin (1936, 1974), in studies of the ecology of Wicken Fen, traced the development of fen carr. Pearsall (1918) had studied the aquatic and marsh vegetation of Esthwaite Water. Pigott and Wilson (1978) resurveyed the North Fen at Esthwaite in 1967 - 1969. Wade (1982) has remapped Pearsall's Lake District sites since then. His aim was to determine whether any significant changes had occurred in the vegetation of these Lakes.

1.3 AIMS OF THE STUDY

The aims of the study are as follows:

(i) to remap the plant communities over part of the Marsh

(ii) to examine the reasons for the present distribution of plant communities and the species richness at different parts of the study site by examining habitat features

(iii) to trace the development of the Marsh vegetation and to try to predict the likely direction of future change.

The following hypotheses are erected and will be examined in the light of the results obtained:

(i) that the marsh vegetation will have changed during the last fifty years reflecting and producing habitat changes.

(ii) that in some parts of the marsh change has proceeded more rapidly than in others

(iii) that the sediments will record these changes.

The study falls into two main sections. The first involves the mapping of the vegetation and the analysis and characterization of habitats. This includes the collection of floristic data, water analysis, an examination of competitive exclusion under certain pure stands in a light and temperature experiment, and the ageing of marsh forest.

The second part of the study involves a detailed analysis of the sediments. The relation of the sediment surface to the water level in the Marsh is critical for the distribution of the plant communities. Substrate and water depth are two habitat features which the plant communities respond to, but which they can, in turn, modify.

The study of the sediments has four main aims:

(i) to see if different communities are growing on different substrates

(ii) to examine overall organic matter deposition under different plant communities and to see how effective they have been in raising the level of the sediment

(iii) to see what evidence the sediments contain of succession between plant communities

(iv) to find out the depth of unconsolidated sediment in the old river channel and to distinguish, if possible, a marker horizon between river and lake- or marsh-deposits in order to trace the amount of build up of sediment during the last 170 years.

1.4 LIMITATIONS OF THE STUDY

Any conclusions that are drawn about changes during the last fifty years obviously are limited by the accuracy and the shortcomings of both the 1929 and the present survey. As far as possible efforts have been made to ensure the comparability of mapping. Old copies of the O.S. 1 : 2500 and 6 inch maps have been used as a basis.

The study confines itself to the macrophytic vegetation. Comparative limnology and detailed studies of micro organisms are not attempted. Pollen analysis would be a very interesting technique to employ in the analysis of the sediments but this was considered beyond the scope of the present study due to time availability. Such studies are discussed in the section on suggestions for further work in the concluding chapter.

Only a small portion of the Marsh (approximately 500 x 50 m.) was studied in detail, again due to the restrictions of time. The work can be extended and could be an ongoing project. This is discussed in the concluding chapters.

1.5 THEORY AND DEFINITIONS

For the purpose of clarity the theory of hydroseral succession is now briefly outlined. It seems helpful at the outset to define the meaning of terms as understood by the present writer and as used in the text.

Succession is - the process whereby a series of communities replace each other at a given spatial location in a predictable sequence with the passage of time during which external environmental conditions remain stable.

A sere (or a succession) is - the sequence of plant communities which succeed each other during succession in a given environment.

A hydrosere is - a sere which begins in open, abiotic freshwater in a lake or pond.

A primary sere is - a sere which begins from an abiotic but naturally produced starting point and proceeds without interruption or perturbation to its hypothetical endpoint, the "climax community", which is determined by the regional climatic zone.

A secondary sere is - a sere which begins in an already existing plant community as a result of disturbance and/or environmental change. Although the river would have had a lot less vegetation than the "ox-bow lake" that was produced with its diversion, the case of Butterby Marsh falls into the category of a secondary sere.

Around a water body there is a zonation of plant communities due to differential tolerances of waterlogging (resulting in anaerobiosis of the roots) and flooding (resulting in anaerobiosis of the shoots). Decreasing water level is one type of environmental gradient. At one point in space a sequence of plant communities will establish themselves with the course of time, as the water depth is reduced by sediment accumulation.

The depth of water in a lake or pond will be influenced by the change in the sediment surface as a result of the products of organic decay, and minerogenic input (which will be present in any lake or pond with an inflow). Succession is driven by the accumulation of auto- and allogenic (transported) material. Once the river was diverted it would be expected that allogenic mineral input would be much smaller. The change in the ratios of one type of sediment to the other (organic : minerogenic) might be an indication of the event in the sediments.

CHAPTER 2 METHODS : THE VEGETATION AND THE HABITAT

2.1 CHOICE OF STUDY SITE

The western side of the old meander loop in which the Marsh lies was selected for study for the following reasons:

(i) It lies between two arable fields and there is therefore no disturbance of the plant communities by cattle. On the eastern side of the Marsh which is adjacent to pasture the sediments are poached and the vegetation is grazed and broken up by the trampling of cattle. This may also result in nitrogen/phosphorous changes and does not satisfy the condition that "external environmental conditions remain stable" for the "natural" development of a hydrosere. Changes in the Marsh vegetation since 1929 along the eastern and northern banks of the Long Pool, the Typha Marsh, the East Salix Marsh, the Iris Marsh, the Boathouse Pool and the Middle Pasture and Woodside Marsh are probably due to changed external environmental conditions to a certain extent.[I]

(ii) The western side of the Marsh is more remote, being far from any footpaths. It is bounded by the river embankments which are not walked and is in the midst of private land. It is therefore more isolated from disturbance by man.

(iii) The west side of the Marsh has less tree cover. During the summer months the Marsh is a breeding area for mosquitoes which are very abundant especially under the trees. These make working conditions considerably difficult. Also, vegetation

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I Names of marsh areas after Griffiths (1932).

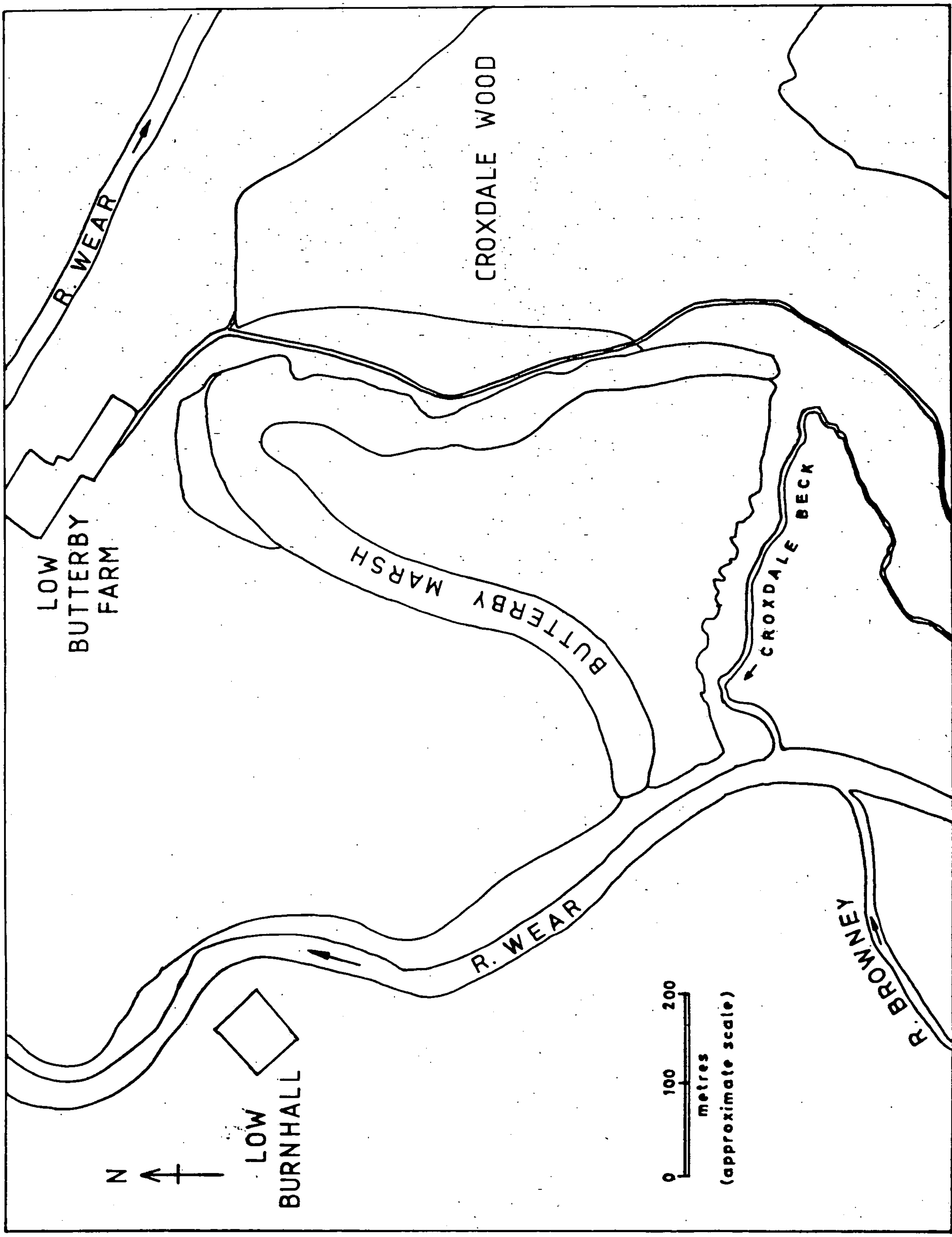

Plate I : <u>AIR PHOTO BKS U05 3740. 1971 1.27 p.m. 2 150 ft. (detail).</u>
Showing the situation of Butterby Marsh.
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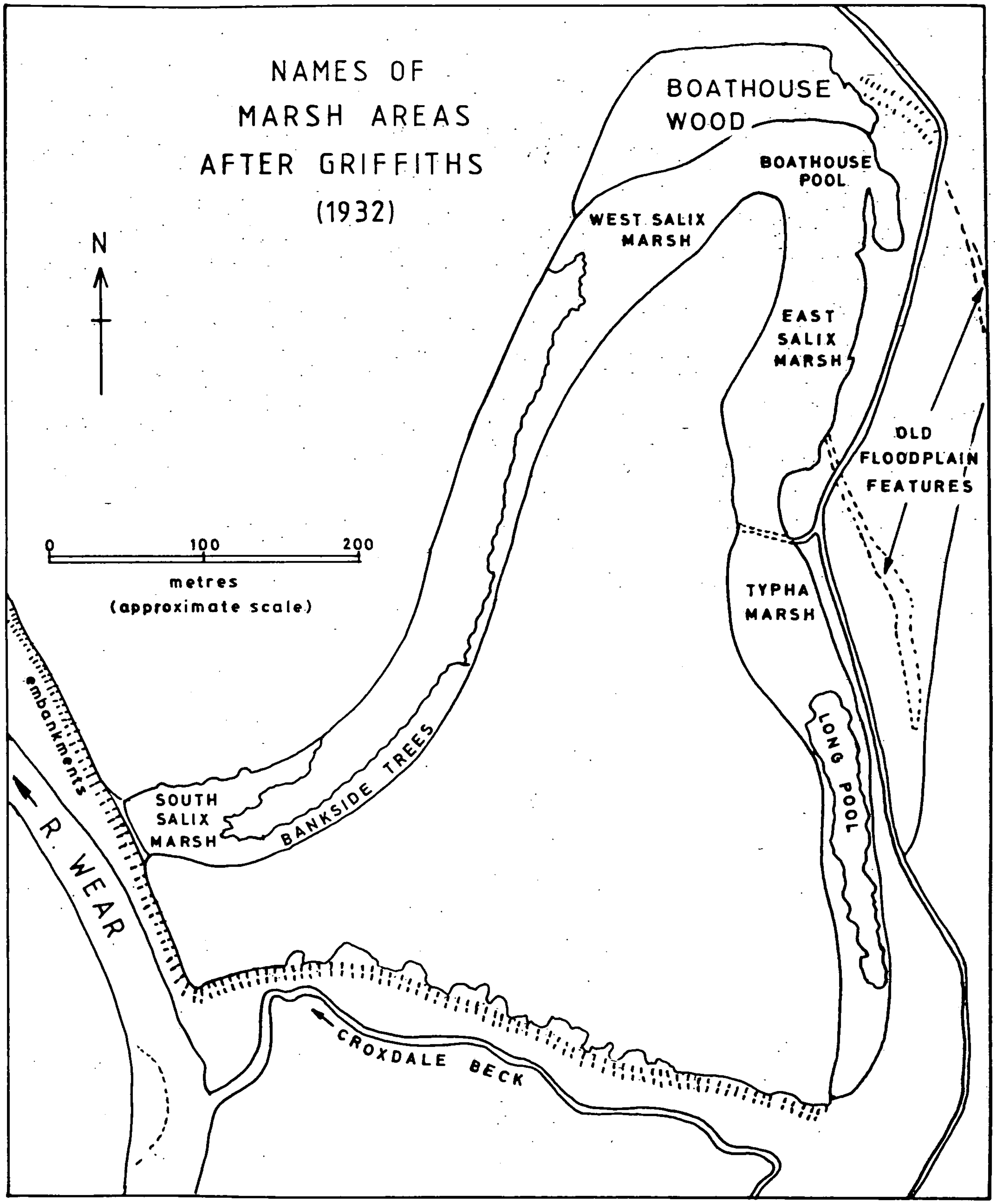

Plate 2 : AIR PHOTO BKS U05 3740. 1971 1.27 p.m. 2 150 ft. (detail).

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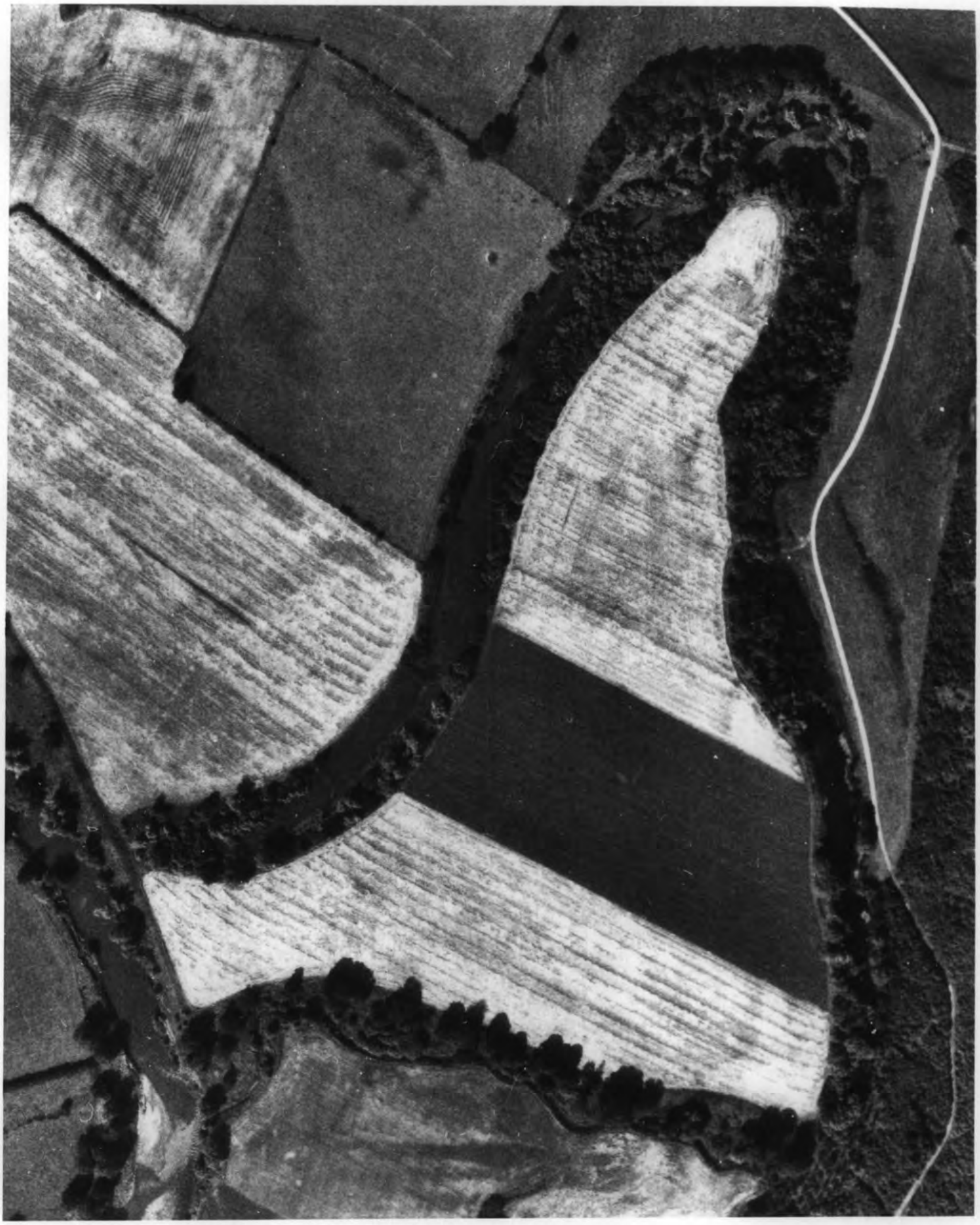

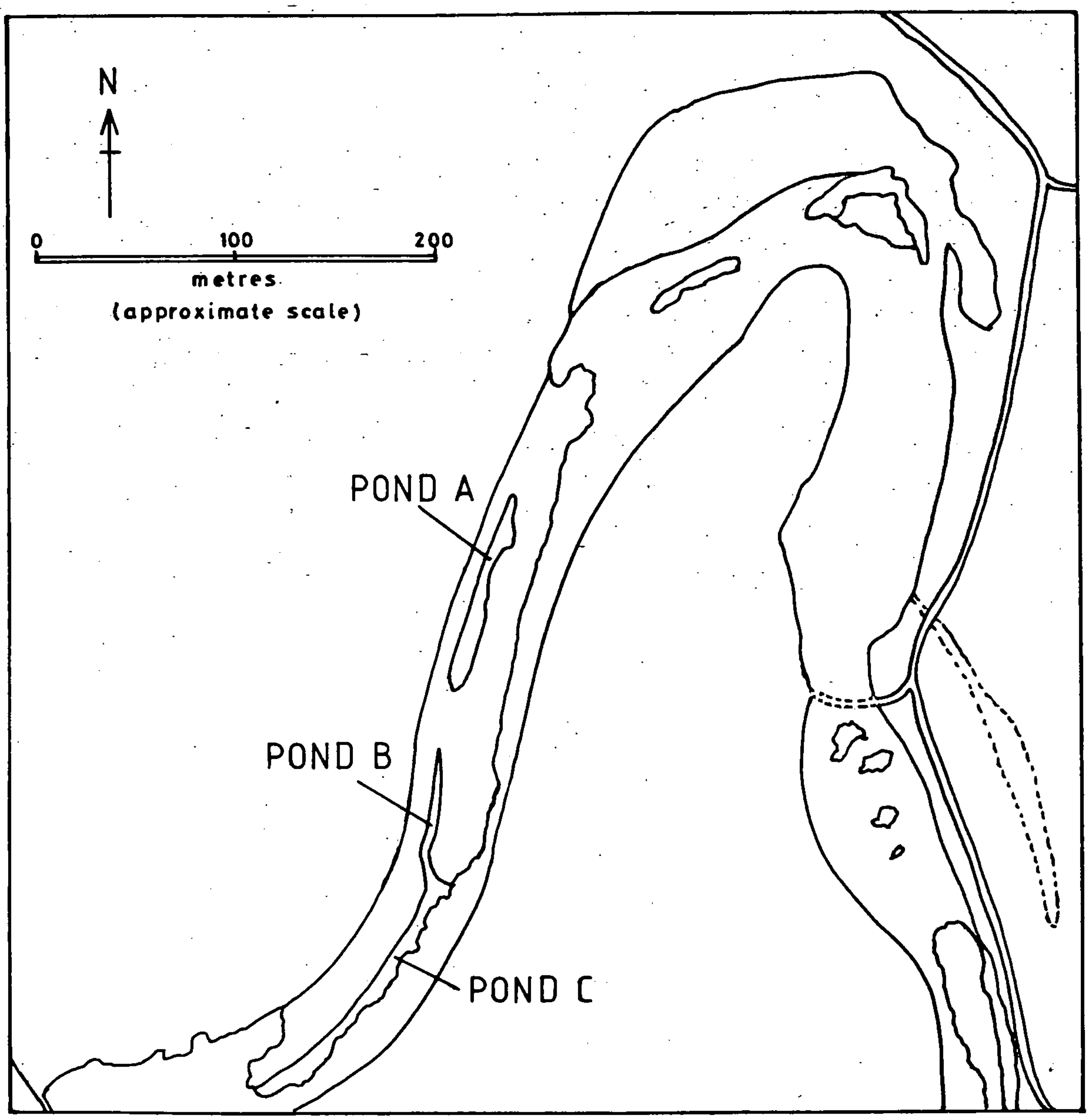

Plate 3 : AIR PHOTO BKS U05 374I. I97I I.27 p.m. 2 I50 ft. (detail)

Showing ponds due to reflection of light from water surface.
Ponds named are those included within the study site.
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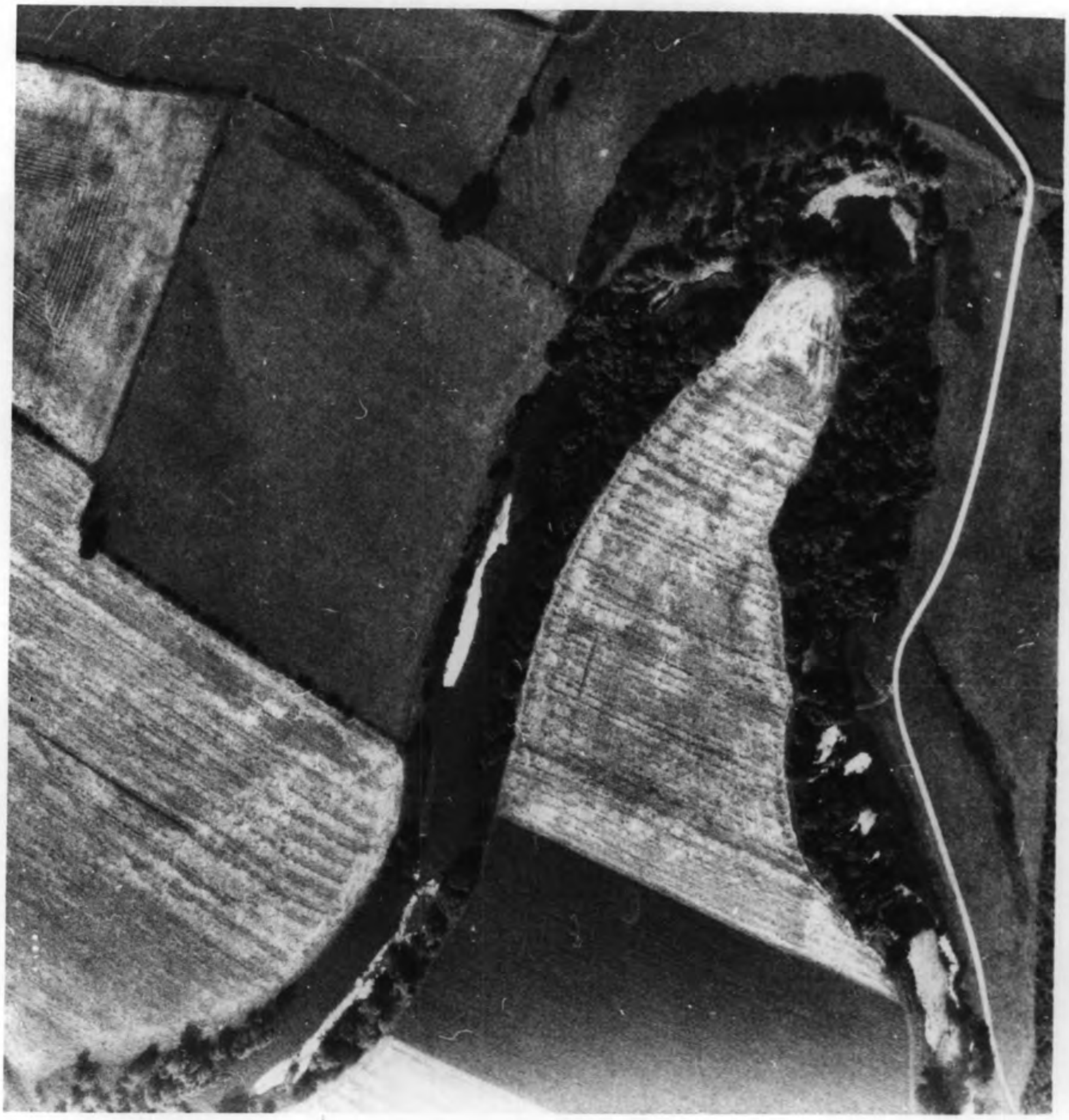

under the Marsh forest is very mixed and variable and difficult to map.

The study site included three "open" areas or ponds, relatively free from tree cover apart from that on the banks, and one Marsh forest. The area was artificially divided for convenience into "Pond A", "Pond B", "Pond C", and the South Salix Marsh. In the open areas the plant communities are easily characterised and can be accurately mapped and sampled.

2.2 FIELD MAPPING

The base map used was the 1960 O.S. 1 : 2500 map. To accurately fix the position of plant community boundaries and to position transects accurately a grid was devised. From the base of the embankment the western side of the study area was measured out at 20m. intervals and markers (wooden pegs or string and labels) were placed by the field edge. The same procedure was followed on the eastern side of the Marsh. The position of one point on one bankside could be compared with a conspicuous landmark on the opposite bankside and fixed accurately using a Silva compas and binoculars. Elderberry bushes and hawthorn bushes proved to be good landmarks from opposite banksides due to their white flowers.

Tree cover was plotted with the help of 1971 Air Photos of the site and checked in the field.

2.3 COLLECTION OF FLORISTIC DATA

A reconnaisance was first made of most of the Marsh including the eastern half and the Boathouse Wood bank margin, and a species list was compiled. The full species list of those plants identified in 1982 at Butterby Marsh appears in the Appendix.[1]

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1. Dr. B. Huntley, Miss K. Pratt and the Rev. G. Graham gave considerable help with the identifications.

Rather than positioning Relevés (or "quadrats") randomly amongst stands or communities it was decided to record their location accurately and to sample at regular intervals.

On the west bank of the west side of the Marsh bankside transects were taken using the 20m. interval markers for reference points. Two x two metre quadrats were placed at the field edge, halfway down the bankside and at the waters edge.

Communities below seasonal h.w.m. were examined with the aid of Westgate Rivermaster Waders and an Avon Redstart inflatable dinghy. [1]

In the South Salix Marsh the transects were taken right through from field edge to field edge. A line was laid out using string and a Silva compas. Quadrats were placed and floristic data collected at four metre intervals along each line. Community boundaries were marked on a sketch map as the regular intervals meant that "pure" stands were not always sampled.

For each quadrat the following data were recorded:

1. The height of the vegetation and an estimate of the total percentage cover. If the vegetation was stratified into distinct layers the height and cover values were recorded for each layer separately.

2. Relevant features of the community e.g. age structure, regeneration etc. were recorded and also a brief verbal characterization of the community.

3. All vascular plants were listed including those adjacent to the quadrat. When field determination was impossible and the identity of a species was in doubt then a specimen was collected, labelled and

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1. This was kindly loaned by the Zooology Department.

returned to the laboratory for determination.

The species composition of bryophytes was not recorded in detail for each quadrat. A list of those identified from the study site appears in the Appendix. Species identification of lichens and fungi was not undertaken.

4. A cover abundance estimate was assigned to each listed species using the Domin scale as follows:

+ present in the stand adjacent to the quadrat but absent within the quadrat.

1	$< 4\%$ cover	- rare, one or a few individuals.
2	$< 4\%$ cover	- scattered individuals.
3	$< 4\%$ cover	- frequent.
4	$4 \leqslant$ cover $\leqslant 10\%$	
5	$10 <$ cover $\leqslant 25\%$	
6	$25 <$ cover $\leqslant 33\%$	
7	$33 <$ cover $\leqslant 50\%$	
8	$50 <$ cover $\leqslant 75\%$	
9	$75 <$ cover $\leqslant 90\%$	
10	$90 <$ cover $\leqslant 100\%$	

5. The sociability of each species was recorded using the Braun-Blanquet Scale of Sociability as follows =

1 - growing once in a place, singly.

2 - growing in groups or tufted.

3 - growing in troups, small patches or cushions.

4 - growing in small colonies, extensive patches or forming carpets.

5 - growing in great crowds or pure populations.

6. Brief notes were made on the vitality and performance of the taxa e.g. flowering, fruiting, in bud, seedlings, moribund.

2.4 ANALYSIS OF FLORISTIC DATA

140 Relevés (quadrats) were collected from the study site. The position of each was recorded. The four geographical areas from which the data were collected were used as a framework in which to analyse the data. These were:

1. West side of Pond A. Floristic data from 3 quadrats were collected along each of 8 bankside transect lines which ran from field edge to below h.w.m. (24 quadrats in total).

2. West side of Ponds B and C. Floristic data from 4 quadrats were collected along each of 5 bankside transect lines, (20 total).

3. East side of Pond C. Floristic data from 4 quadrats were collected along each of 7 bankside transect lines (28 total).

4. South Salix Marsh. Floristic data from between 12 and 8 quadrats were collected along each of 7 transect lines (68 total).

2.4.1. Raw data tables

The Domin cover-abundance values for each species in each quadrat were used in the construction of raw data tables. Tables for each of the above four areas are presented in the appendix.

1. Data from Pond A west bankside

One quadrat was positioned on the bankside, one at the waters edge and one 1 m. beyond h.w.m. on each transect line. These were tabulated, keeping the three altitudinal groups separate, with herb layer species listed on the vertical axis and quadrats along the top (horizontal) axis. The herb layer species were divided a priori into two grouns: "bankside" species and "Fen + Aquatic species". In each of the three vertical column groups (bankside, waters edge and 1 m. beyond h.w.m.) the sum of the Domin values (ΣD) and the number of occurrences, (Frequency or 'F') is listed for each species.

2. Bankside Transect data from Ponds B and C West side

This was the second batch of data collected. Beyond h.w.m. the main plant species recorded were Phragmites communis and Lemna minor. It was decided to collect data from four quadrats along each transect line to record the zonation of vegetation from the field edge to the Phragmites marsh. One was positioned at the field edge, one on the middle bankside, one at the waters edge and one 1 m. beyond h.w.m.

The Domin cover abundance values for each species in each quadrat were tabulated as before, but as there were so few Fen and Aquatic species this did not warrant an apriori division into two groups of species on the vertical axis. Thus all species are listed in alphabetical order. As before, the Domin values for each species are summed at the end of each of the four columns (Field edge, middle bankside, water edge and below h.w.m.) and the number of quadrats that it occurs in is listed.

3. Seven transects, each running from field edge to 1 m. beyond h.w.m., were placed at 20 m. intervals along the East

bankside of Pond C. Four quadrats were placed on each transect line. The only species that occurred in the quadrat placed 1 m. beyond h.w.m. were Nuphar lutea, Lemna minor and Phragmites communis.[1] All these transects were under, or adjacent to, dense shade of the fringing bankside trees, mostly S. fragilis but also with S. alba, Acer pseudoplatanus and Sambucus nigra.

4. In the South Salix marsh 68 quadrats were collected along 7 transect lines, which stretched from the field edge on the west side of the marsh to the field edge on the east. Quadrats were placed regularly at 4 m. intervals except where there were large areas of standing water or extensive pure stands of Phragmites. Spacing was also adjusted along the Eastern bankside which usually measured 8 - 9 metres wide. $2m^2$ was sampled for each quadrat rather than 2 x 2 m. due to the close spacing. One m^2 was sampled on the immediate west of the transect line that was laid out with string and one on the immediate east. Thus the area was sampled on a regular grid basis.

Separate tables for each transect line were formulated in a similar way to the previous tables and F and ΣD values were listed for the cover abundance of each species along the transect line.

All 68 quadrats were then tabulated together on a master table of Domin values, but were kept in their transect group (the order of collection). Thus a raw data matrix of Domin values for each quadrat placed in the South Salix Marsh was drawn up. F and ΣD values were calculated for each species to summarize it's importance from the samples taken in that area of marsh.

Only this table is presented in the appendix due to the repetitive species lists in the previous 7 tables of data from each transect line.

[1] Some Carex acutiformis occurred in the extreme north east of Pond C.

2.4.2. Summary of data

From these tables graphs were constructed using the F and ΣD values as co-ordinates.

For the data from Pond A, the two measures for each species were used to plot its position on each of three graphs, one for the bankside, one for the waters edge and one for the quadrats placed 1 m. beyond h.w.m. Four graphs were constructed for the data from the 2nd area (Field edge quadrats, bankside, waters edge and 1 m. beyond h.w.m.) and four for the data from the 3rd area. A similar procedure was followed using one graph for each transect line in the South Salix Marsh, and then one graph was constructed for F and ΣD values for each species over the total 68 quadrats using the master table for the South Salix Marsh.

This analysis was one obvious and simple method of summarizing the floristic data for the area. It placed emphasis on the distribution pattern (clumped or scattered) and cover abundance of each species rather than the character of each quadrat. It gives a measure of the relative importance (in terms of cover-abundance) of each species within each of the four areas. These areas were all different enough to warrant apriori separation. The first was a bankside with low growing herb species and mixed aquatic communities, and a relatively small amount of tree cover. The second was a more overgrown bankside with Phragmites as the dominant species beyond h.w.m. The third was an area of bankside with dense shade and mostly Nuphar lutea beyond h.w.m. The fourth was a wide expanse of marsh forest right across the old channel.

"F" represents the relative abundance of each species in terms of frequency of occurrence in quadrats and ΣD is a measure of its total cover from the samples of vegetation for that area. If a species is high with respect to the F measure but low on the ΣD measure it would indicate a scatter of the species throughout the area. An example is <u>Lemna minor</u> in the South Salix Marsh 80 m. transect line. If a species is high on the ΣD axis but low on the F axis it would indicate a clumped distribution.

The scatter of points on each graph (each representing a species) can then be visually divided into groups to show relative importance. Most graphs, due to the scales chosen (approximately equal lengths along each axis) show a scatter approximating to a straight line. High total cover (ΣD) within the sample seems to be correlated with a high frequency of occurrence for that species. Clumped distributions are overshadowed due to the cluster of points at the lower end of each axis. For example <u>Scirpus sylvaticus</u>, occurring only in 1 quadrat on transect line 80 from the South Salix Marsh but with a Domin value of 6 ($25\% < \text{cover} \leq 33\%$) is an interesting fen species but is lost within a group of points representing species of "minor importance" in terms of cover abundance.

A species cannot reach a value >10 on the ΣD axis if only occurring in one quadrat. The x axis, in drawing it to the same length as the y axis, was divided into ten times the number of units as the y axis.

For the South Salix Marsh the data from the quadrats nearest each field edge (East and West) on each transect line could have been omitted from the F and ΣD values. This would have suppressed the importance of common bankside species such as <u>Urtica dioica</u> on the graphs and given more attention to the "Fen-Carr" area of the marsh forest and its species. However, this would only have reduced the number of quadrats from 68 to 54 (-14) and it was decided to leave this data in the batch as Urtica and, more especially, Impatiens glandulifera were important species further into the marsh forest. This can be seen from the tabulated data where the middle quadrats along each transect line often still retain a high Domin value for such species. Aegopodium podagraria and Arrhenatherum elatius have high positions on the graphs due to their high frequency and abundance on the field edges, but rarely occurred within the marsh forest.

Another alternative to using F and ΣD values as co-ordinates would have been to convert each to a % cover within the total cover, i.e.

$$\frac{\Sigma D \text{ values for a species}}{\text{Total } \Sigma D \text{ values for all species}} \times 100$$

and

$$\frac{F \text{ for a species}}{\text{No. of quadrats}} \times 100$$

or

$$\frac{\Sigma D \text{ for a species}}{\text{Total } \Sigma D \text{ for the total area sampled (e.g. 68 x } 2m^2 \text{ quadrats in S. Salix Marsh).}}$$

This did not seem promising as an aid to the interpretation of the data and was therefore not pursued.

A further stage of analysis would be the classical phytosociological procedure of grouping relevés (quadrats) into abstract vegetational units (noda) based on similarity of floristic composition (similar Domin values for the component species). The aim is to maximise between group (noda) differences and maximize within group similarity. The method involves organising the quadrats by two way tabular re-arrangement into groups. For these noda, constancy values can then be calculated for each species (the proportion of the quadrats it occurs in within that nodum).

Computer programs have been developed [1] for this purpose as classical or manual rearrangement of the table is highly prone to error. This analysis would be useful to objectively organize quadrats with similar floristic composition into groups, as a basis for defining mapping units.

For the purpose of the present study the apriori grouping of the quadrats into bankside, waters edge and 1 m. beyond h.w.m. batches was deemed sufficient. The distribution maps are based on the visually dominant species for each vegetation type. The mapping units could be more objectively defined using computer methods to formulate noda within the tables of Domin values from quadrats but this is a further stage of phyto-sociological analysis that was not reached in this project.

Usually a stratified-random sampling strategy is followed in phytosociology so that quadrats are placed within characteristic stands of vegetation. Because a regular sampling strategy was followed in this project, due to the emphasis on changes in the exact locational position over the last 50 years of the vegetational communities, mixed rather than distinctive stands were often sampled along the grid laid out as quadrats were often placed in boundary zones. In the South Salix Marsh the

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[1] e.g. Huntley B. et al. (1981) "PHYTOPAK" - A suite of computer programs designed for the handling and analysis of phyto-sociological data. Vegetatio 45 89 - 95.

vegetation is very variable and mixed and therefore the division into noda would be very difficult by hand for the tabulated data. The aquatic and fen communities are, in contrast to those of the Marsh forest, more easily characterized as they often form almost pure stands. It was sufficient, therefore, to use the raw data tables as guides and, in the case of these communities, definition of "noda" was unnecessary.

2.5 WATER ANALYSIS

In order to further characterize the habitat of the plants at the marsh, the water of the ponds was analysed using the following methods.

The pH and the specific conductivity of the water were recorded. The instruments used were a pH meter (Pye Unicam model 293) and an Electrolytic Conductivity measuring set (Kent Electronic instruments Ltd. model MC-1 Mark V). These were carried in the field with sufficient distilled water to wash the pH electrode and the conductivity measuring cell thoroughly between each reading.

Six water samples for chemical analysis were collected in acid washed snap-top vials in the late afternoon of 20.8.82 and returned to the laboratory. Three drops of HNO_3 were then pipetted into each and the vials were stored at 4^oC until they were analysed by Atomic Absorption Spectroscopy for the cations Na, K, Mg and Ca.

2.6 METHODS: TREE BORING TO AGE MARSH FOREST

A wood increment borer, made by AND MATTSON, MORA, SWEDEN was used. This was greased with Castrol L.M. grease before each boring was taken. The borer extracts a 43 cm. section. One boring was deemed sufficient; although other workers have used three at different angles which intersect at the centre of the tree. The section extracted was examined in the field or, if necessary, returned to the laboratory in 'Deeko' tall plastic straws, shaved and examined under a dissecting microscope to count the annual rings. The hole in the tree will, in the case of conifers, usually quickly fill with resin and be sealed. However, in the case of the deciduous trees at Butterby, this was not thought to be sufficient. Either the original section (if the age was able to be determined immediately) or a suitable sized young twig stripped of its bark was pushed into the hole. The hole was then sealed using ARBREX 805 produced by Pan Britannic Industries (P.B.I.) Chemicals Ltd. This is a fungicidal paint used to treat tree wounds and contains Bitumen and oxine copper, and was supplied by the University Botanic Gardens.

2.7 METHODS: LIGHT AND TEMPERATURE EXPERIMENT

EQUIPMENT

Three light and temperature integration units were used. Each consisted of a black plastic box, measuring 21 x 18 x 12 cm. which contained a temperature integrator and a light integrator which gave a measure in counts on two modified Casio calculator display units. The integration carries on in the memory of the calculator. They can only be activated and read by pressing a sunken microswitch on the calculator. The integrator plus calculator requires a current of about 260 uA at 9 V.D.C. An Ever Ready PP9 will have a life of about 10 to 15 weeks at this current drain. To these boxes are connected the temperature sensor and a Photosynthetically Active Radiation (P.A.R.) sensor on cables.

FIELD

These units were placed at inaccessible parts of the Marsh, marked on the reference map. This was achieved with the aid of the inflatable boat. To protect the units from submergence they were placed on stands 1 m. tall with a platform or table 23x23cm. The sensors, on cables approximately 180cm. long, were both taped to a bamboo pole 210 cm. long which was driven into the sediment at the location required for monitoring. The more conspicuous integration unit on its platform could thus be concealed amongst the vegetation when a measurement was required in "open" conditions.

The boxes were then sealed using black insulating tape. They had previously been clearly labelled on the outside explaining what they were, who they belonged to, and that the present worker had the permission of the owner to work at the site. The boxes were wrapped with clear polythene bags which were again sealed with insulating tape to render them waterproof.

The units were placed at the Marsh on p.m. 22.6.82 and retrieved on p.m. 25.8.82, a total time of 64 days or 1536 hours.

Laboratory

The calibration of the count numbers obtained from the field against known quantities of light and temperature was determined on their return to the laboratory. This was done using the following standard procedure.

The temperature sensors were calibrated using a fridge, freezer unit and a water bath with thermoregulator unit and built in pump. Two accurate mercury/glass thermometers were placed in the rack to which the temperature sensors were clipped. A time interval of 17 minutes, measured precisely by an interval timer, was used and the counts on each machine were recorded. Five runs were made, one with the sensors inside the fridge, one in the freezer unit, and three in the water bath. The following temperatures were used: + 40°C, + 30°C, + 21.5°C, -3°C and - 10°C.

Linear regression was used to fit a line for counts/hr. against the different temperatures. The observed field reading in counts was converted to counts/hr. and then converted to a reading in degrees centigrade by subtracting the intercept of the regression line (b) and dividing by the slope (a) in the formula $y = ax + b$.

The calibration of the P.A.R. integrators was achieved in a similar manner, but in this case one of the units had been calibrated against known light quantities by a previous worker and therefore the other two units could be calibrated against it.

Five different irradiance levels were used, (one in the dark, one at a high level of irradiance and three in between) using a normal tungsten bulb lamp at intervals of 17 minutes.

Seventeen minute intervals were used in the following way. The first unit was activated, followed by the second one minute later and the third a minute after that. The timer was then set for fifteen minutes. After this time the first unit was stopped followed one minute later by the second and a minute later by the third. Thus each ran for seventeen minutes.

The measurements are expressed in $\mu E\ m^{-2}\ s^{-1}$ (micro Einsteins per square metre per second). In the past and on this occasion it has been found that the calibration of counts/hr. against $\mu E\ m^{-2}\ s^{-1}$ is an exceptionally good fit with a linear regression.

It must be emphasised that the figures obtained from the conversion of counts/hr. in the field to $\mu E\ m^{-2}\ s^{-1}$ are integrals - they include hours of darkness. Thus the absolute figures have little meaning, but relative values are very important for the light experiment. It would be possible to estimate hours of darkness from meteorological records and hence correct the figures to daylight hours.

The absolute figures are, however, more meaningful for the temperature experiment.

CHAPTER 3 METHODS : ANALYSIS OF THE MARSH SEDIMENTS

3.1 EQUIPMENT FOR DATA COLLECTION

The equipment used in the field was:

(i) reconnaissance sampler

(ii) wing or "bucket" augers for sand and clay

(iii) Livingstone square rod piston corer

(iv) Russian type peat borer.

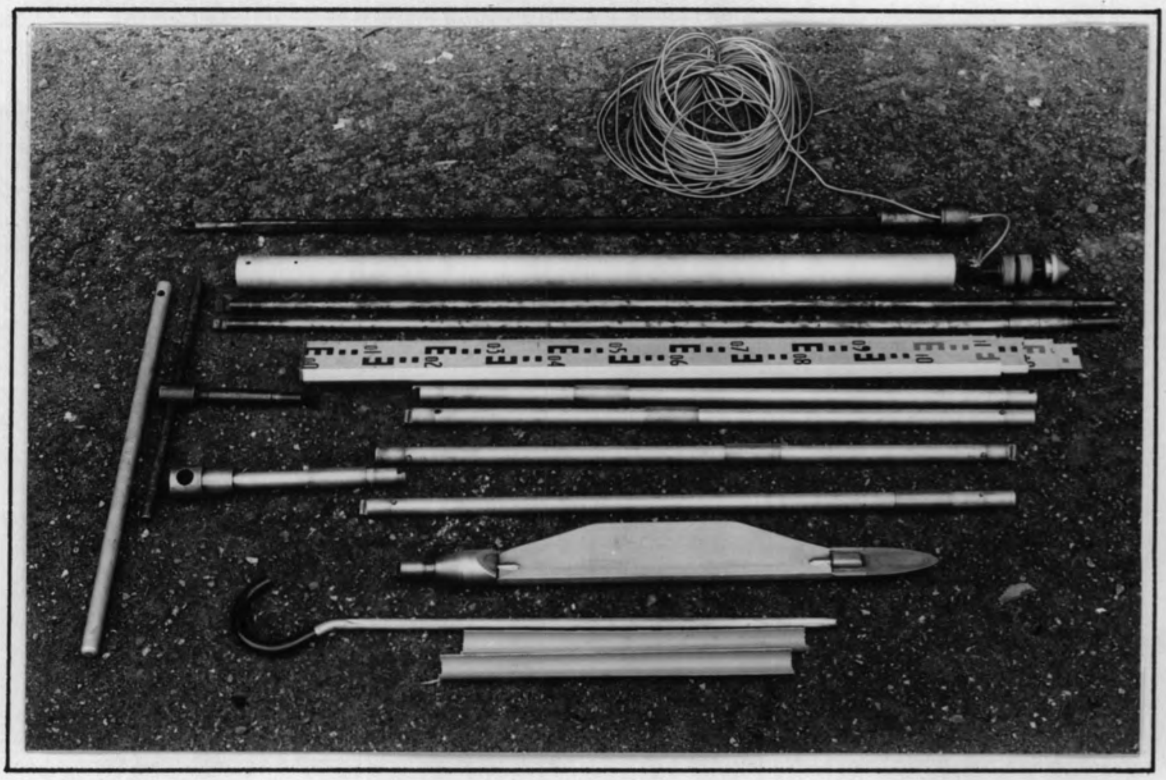
Also used was a Watts Quickset Level and extendable metal staff.

This equipment and its use is described in Birks and Birks (1981), Livingstone (1955a), Tooley (1981), West (1977), Wright (1967) and Wright (1980).

3.2 EQUIPMENT PERFORMANCE IN THE FIELD

The reconnaissance sampler was found useful for estimating soil depth when collecting quadrat data. However, it has no extension rods and cannot sample at depth. It takes only a narrow sample which is insufficient to warrant return to the laboratory. The stratigraphic layers are not easily visible unless the sample is scraped, and it will not successfully sample very wet sediment.

The wing or "bucket" augers were marked off at 20 cm. intervals, the length of the head, so that sampling could be made at consecutive intervals. These work on a scoop principle and hence will churn the sediment up and destroy any fine stratigraphic layers. Their main use was thought to be to try to pull up the sediment that lay below what was sampled by the Livingstone or the Russian corer. However, only two extension rods were available and this did not reach the depth required in many instances.



Phot. I : Equipment used for sampling the Marsh sediments

Top : Livingstone square-rod piston sampler.
Middle : Russian type peat sampler with extension rods. The split p.v.c. tubing used to return the sample to the laboratory is shown at bottom of photograph.
Bottom : Reconnaissance sampler for estimating soil depth.

The Livingstone square rod piston corer was designed for soft lake sediments and it was initially expected to be the most useful device for sampling the very wet sediments at the study site. It displaces only the wall thickness of the aluminium cylinder and takes an 100 cm. core. Extension rods can be attached.

Some disadvantages found in using it are listed below:

(i) It is difficult to use by one worker, mainly due to the problem of accurately and efficiently anchoring the piston wire in position.

(ii) The cylinder in many instances would not penetrate the root mat of reedswamp. The cylinder is not heavy (unlike the point of the Russian type peat borer) and was difficult to push through dense root and rhizome systems.

(iii) It compressed the fine unconsolidated detritus so that no accurate measure of how deep the deposit was could be taken. It also compressed the roots that were caught up in the sample. The chamber filled with water when semi liquid deposits at the top of the sediment surface were part of the sample taken.

The Livingstone corer only worked successfully where there were no dense root mats and where the sample site was easily accessible. It was found to be unwieldy and difficult to use from the boat. In reedbeds, where there is some depth of water, anchoring the piston wire in position was a particular problem even with two workers, due to the soft substrate. On firmer sediment the wire can be wrapped around the handle of a sand or clay auger pushed in adjacent to the Livingstone. But in the case of a waterlogged reedbed such an auger will not be supported. An attempt was made to provide a firm surface on which to rest a supporting rod by laying down a wooden board (used to carry the Livingstone corer) on top of the reedswamp root mat. This was fairly successful but the operation was too impractical to be repeated many times.

The Russian type peat borer consistently proved to be the most useful sampling device.

3.3. SAMPLING PROCEDURE WITH THE RUSSIAN CORER

The method used was first to find the total depth of the unconsolidated sediment. In some instances the material at the base of the deposit could be felt to be stones or boulders. At other points it may have been a sand layer. The depth sampled usually represented the force that could be put on the corer by one worker. The maximum depth was often greater than that which could be reached by the sand or clay augers. With a longer auger and more help it would, on many occasions, no doubt have been possible to sample to greater depths.

The heavy point of the Russian peat borer penetrated the root mats very effectively. Four extension rods meant that it could sample to greater depths than the other devices, which was also made possible by its design.

The basal sediment was then sampled. The position on the top extension rod in relation to the water surface (or the sediment surface if the core was not taken under water) was marked with a Pentel marker pen. The corer was then extracted, returned to the bankside where the chamber was opened and the stratigraphy of the components of the sample described. The design of the device is such that the material sampled is not compressed at all, and is merely grasped by rotating the 50 cm. cylinder against its plate or flange. When the chamber was opened the very fine laminations in the sediment were revealed on the open plate. Detail was lost when the sample was transferred to the split p.v.c. tubing and therefore the layers were recorded immediately in the field. A tape measure was used to record the exact position of each sand, dark silt, light silt or organic peat layer.

After this had been completed a piece of split p.v.c. tubing 50 cm. long was placed on to the sample and its depth (top and bottom), location and date was clearly printed with the marker pen on to the tubing. It was then wrapped in cling-film and elastic bands.

The next sample was taken after the corer had been thoroughly washed in pond water. The device was pushed into an adjacent spot (not the same hole) approximately 15 cm. away until the sediment or water surface was level to a new mark placed on the extension rod 50 cm. below the last one. Hence the layer sampled lay exactly 50 cm. above the previous sample.[1.]

As with the Livingstone corer the Russian type peat borer will not hold in its chamber the semi-liquid gyttja at the top of the sediment under a water body. However, the depth of this layer can be determined by inference from the water depth and the depth of the last firm sediment sampled.

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1. The usual method is to work from the top downwards pushing the peat corer into two alternate holes adjacent to each other. However, in this case it was decided to work from the basal sediment upwards as the top sediment (when under water) is very soft and will not sample easily.

3.4. CHOICE OF SITES TO CORE

The best mud cores would come from the middle of the pond, but this would be an allochthonous fine detritus gyttja rather than an autochthonous "turfa" in which succession might be revealed.[1]

It was decided to firstly work in marginal communities to see whether succession was revealed in the sediments at individual sites. In areas that from map evidence had changed since 1929 (for example from sedge to reedswamp or from reedswamp to carr), it was expected that the sediments would show a change from one type of deposit to another. (For example from an allochthonous fine detritus gyttja to a sedge or reed peat and then to a wood peat).

The sediments under different plant communities were sampled to see the total depth of unconsolidated sediment in the old river channel and to see how effective the different communities had been in raising the sediment surface. It was also hoped to discover whether the different communities were growing on different substrates.

After this sampling had been done it was decided that plant communities might have differential opportunity for raising the sediment surface depending on where they were growing in relation to the cross profile of the old river channel. Some grew on previous "slip off slopes", others on floating mats further towards the pond edge and others had built up a deposit close to the outside of meander bends. There were, therefore, different conditions affecting infill rate, and differential susceptibility to erosion and transport of detritus produced.

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[1] Terms are defined in the glossary.

Therefore, a transect line was laid out across one point of the old river channel to produce a stratigraphic profile which:

(i) was accurately levelled in order to altitudinally correlate the stratigraphic layers. (A bench mark was too far away to easily find absolute height).

(ii) Could follow stratigraphic layers and persistant horizons across the old river channel to see whether they thinned or thickened, rose or fell, under different plant communities and water depths.

Bore holes were placed at 5 m. intervals along this transect line after bamboo marker poles had been laid out to mark the points that had been levelled.

The transect line was positioned in a place which spanned several habitat types and plant communities. Additional information was gathered along this line on the plant community present, the pH and conductivity of the water and the pH of the sediment surface or soil, to record change along the environmental gradient of increasing water depth, and decreasing tree cover and soil accumulation.

3.5 SEDIMENT ANALYSIS - LABORATORY

The stratigraphic layers were, in the case of the nine cores taken along the transect line, recorded immediately in the field as the fine laminations were not as clear once the core had been placed into the p.v.c. tubing. In the laboratory the following examinations were made:

3.5.1 DESCRIPTION OF THE COMPONENTS OF EACH LAYER

The sediment samples that were returned to the laboratory were all described in a standardised and orderly manner using the scheme proposed by Troels-Smith (1955) for the characterization of unconsolidated sediments. This scheme is described in the Appendix. The cores were unwrapped and the surface cleaned with a knife, and the components of each layer described, especially trying to distinguish between rooted plant material and detritus. Munsell soil colour charts were also used to try to standardize the colour description.

3.5.2 MACROFOSSIL ANALYSIS

The core was cut centrally and one part of each gross layer was then wet sieved through 2 mm. and 425 µm mesh B.S. Test sieves. A crude grain size distribution could thus be determined but the main purpose was to seperate plant remains from inorganic sediments. The contents were transferred from the coarse and the finer mesh sieves to two petri dishes. These were then scanned under a dissecting microscope. Any material that could be identified was recorded. The main objective was to distinguish between rooted material and allochthonous detritus in the aim of distinguishing riverine deposits from marsh (post river diversion) deposits.

3.5.3 PHYSICAL/CHEMICAL ANALYSIS

One core from the stratigraphic profile was selected for more detailed analysis to trace the stages of infill of the river channel and in particular to try to distinguish river sediment from sediment that had accumulated during the 170 years since the river was diverted when the channel had become a lake and then a pond. The previous analysis had revealed a pattern much more complex than a simple switch over from minerogenic river sediment to biogenic lake or pond sediment. Layers alternated and a marker horizon for the last 170 years could not easily be distinguished. The following analytical techniques were employed to try to distinguish this boundary in order to see what the effect of diverting the river (the initiation of the hydrosere) had had on the build up of sediment and at what rate this had proceeded given that the time scale from the initiation of the hydrosere is known.

Results showed that in the bottom layers of each core (at a depth of 1.5 - 2.5 m.) there were grey silts with very fine laminations of yellow silt and sand layers. Above this were grey silts with fewer laminations. At a depth of approximately 30 - 50 cm. in each core was a thick (10 - 30 cm.) sand layer above and below which were black gyttjas. At the top was gyttja, reed peat, wood peat or soil depending on the location.

The core selected was that which had the greatest depth of sediment. This was the core take adjacent to staff site H on the levelled transect line.

Five analytical techniques were employed:

(i) particle size distribution
(ii) loss-on-ignition as estimate of organic matter content
(iii) pH
(iv) mineral constituent analysis
(v) chemical analysis for metal content as a proxy dating method.

The aim of each technique and the methods used are given below.

3.5.3.1 Particle size analysis

Various standard field tests had been employed to estimate the proportions of sand, silt and clay in each layer. Clay can be rolled in the hand into the shape of a sausage and turned into a ring without cracking. It will also stick the finger and thumb together. Silt can be felt between the teeth. Sand sized particles can be seen with the naked eye.

Particles were also scanned under a microscope at various powers of magnification and measured using a calibrated graticule.

However, it was desirable to determine objectively the particle size distribution of the characteristic layers of the sediments that formed persistent horizons both altitudinally and latitudinally across the transect boreholes. Thus a 'sand' 'silt' or 'clay' could be defined quantitatively and following a standardized scheme so that comparisons could be made with other work on sediments.

Particle size distribution is an analytical technique commonly used in soil science but is lengthy and therefore only three stratigraphic layers were chosen for analysis. These were:

(i) the grey silty-sand from 30 - 50 cm.

(ii) the top sand layer (65 - 80 cm.) and

(iii) a grey silt layer (115 - 130 cm.) from core 'SSH'.

At least 10 gm. of material is needed and therefore it was not feasible to attempt analysis of the particle size distribution of a single yellow silt layer.

Method

The method used was the pipette method, Test 7 (c) outlined in section 2.7.3 of the British Standards Institutions Methods of Testing soils for Civil Engineering Purposes (1967, 61 - 72, British Standard 1377).

This method covers the quantitative determination of the particle size distribution in a soil or sediment from the coarse sand size down. The test is not applicable if <10% of the material passes the no. 200 (75 microns) B.S. Test Sieve. The method involves pre-treatment and dispersion of sediment, sieving of sand fraction, and sedimentation and pipetting of silt and clay fractions.

3.5.3.2. <u>Organic Matter Content</u>

Loss of weight on ignition at 275° - 800° is often used as an approximation of the organic matter content of soil. There are several variations as to the temperature and time used. However, at temperatures of 800°C water of crystallization is driven off and certain minerals are also combustible. Thus this method of organic matter determination is not very accurate. Ball (1964) recommends a combination of a lower temperature and longer time as this has less serious effect on any combustible minerals or water of crystallization present in the sample. In this experiment 275°C was used over a time of 16 hours.[1]

<u>Method</u>

Approximately 1 g. of sediment from twelve sample depths on core SSH were placed in dry pre-weighed (A) and numbered vitreosil crucibles and oven dried at 105°C for 24 h. They were then removed from the oven and cooled in a dessicator. Crucibles and sediment were removed individually for weighing (B) and then placed in a muffle furnace at 275°C for 16 h. They were then removed when cool, put into the dessicator and taken out individually for weighing (C).

A = crucible weight

B = crucible wt. + sample wt. after drying at 105°C

C = crucible wt. + sample wt. after ignition at 275°C

I Ball (I964) reccomends 375°C. 275°C was unfortunately used in the present study due to an error in a laboratory handbook. The original referance was traced after the experiment had been completed.

Sample dry wt. = B - A = DW

Sample wt. after ignition at 275 ^{o}C = C - A = IW

% loss-on-ignition at 275 ^{o}C = $\frac{(DW - IW)}{DW}$ x 100 = OL

OL provides an estimate of organic content.

3.5.3.3 pH Analysis

Material from the same twelve sampling depths in core SSH were analysed for their pH reaction. The aim was to characterize the type of environment and substrate to which the plant communities had to respond at different times during the stages of infill, and to relate the pH to organic matter content.

Method

A pre-weighed petri-dish was filled with 5 g. (wet weight) of sediment which was accurately weighed out. The sediment samples had been removed from the p.v.c. tubing using a spatula washed in distilled water each time. This was then placed in a graduated beaker and 15 mls. of distilled water was added. This was then stirred for two minutes to achieve a paste consistency with a glass rod washed in distilled water. The pH electrode was then placed in the beaker and, using a gentle stirring movement, the reaction was recorded after two minutes.

3.5.3.4 Mineral Analysis

It was desirable to accurately determine the mineral constituents of the different layers of sediment, so as to define a "yellow silt", "a grey silt" and a "sand". This would be an aid to determining the source of the sediment - whether long distance or from bankwash. The main aim was again to distinguish a river deposit from a lake or marsh deposit in order to date the stages of infill in the marsh.

Method

About 300 mg. of sediment was taken from four different characteristic layers and air dried. This was then ground down to a fine powder in an agate pestel and mortar. A small portion was then mounted with acetone on a slide and analysed using iron-filtered cobalt k - alpha radiation on a Philips P.W. 1320 2KW x-ray generator diffractometer assembly (XRD) with a 35 kv. 20 milliamp. setting. This machine produces a print out chart on which peaks occur at different angles of bombardment with x-rays. Individual minerals will produce characteristic peak diffraction patterns due to their individual crystalline structure.[1.]

Samples for analysis were scraped over 3 mm. depths from the basal sand layer of core SSH (251 - 254 cm.) a grey silt layer (244 - 247 cm.) a yellow silt layer (241 - 244 cm.) and the top sand layer (69 - 72 cm.). These were analysed to define a "grey silt" and a "yellow silt". The two sand layers were selected to see whether the top sand layer which appeared to seal the minerogenic deposits underneath it was different in its mineral constituents from the basal sand because it was uncertain whether this top sand was a river deposit.

A distinctive and datable marker horizon in the sediment was hypothesised to be the occurrence of calcium fluorite, a gangue mineral from the mining industry which was dumped into the Wear in quantity until it began to be sold to the aluminium industry. The dumping ceased around 1882 (G.A.L. Johnson, Sir K.C. Dunham pers. comm.). Fluorspar had been

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1. The mineral constituents of the sediment samples were analysed with the kind assistance of Mr. R. G. Hardy of the Geology Department. J.C.P.D.S. (Jt. Comm. on Powder Diffraction Standards) Files were used.

mined in quantity in Weardale (Dunham 1948 : 90, 94, 97).

Fluorite did form part of the mineral constituents in all four layers analysed by XRD analysis, and a quartz - fluorite ratio was calculated for each layer (quartz being the dominant mineral present). To try to produce a depth profile for fluorite, material left in the twelve crucibles from which 100 mg. had been removed for chemical analysis of metals were run at "peak height" for quartz and fluorite on the XRD to produce similar quartz - fluorite ratios.

Hand picked particles > 210 μm from the upper sand layer were also analysed on the XRD to determine their mineral constituents as were particles isolated from microscope analysis which had a distinctive and unusual appearance. They were also analysed using a hand lens and microscope.

3.5.3.5 Chemical analysis for metals

^{210}Pb has been analysed by Oldfield et al. (1979) to date ombrotrophic peat deposits. This was unfortunately not feasible in the present study. It would have been very appropriate as the technique was designed for lake and marine sediments (Eakins and Morrison 1977).

However, the study of metal levels in the sediments and the production of a depth profile of metal accumulation was another possibility as a proxy dating method.

Muller et al. (1977) analysed lead and other heavy metals (measured in ppm) from sediments in Lake Constance. They showed that metal enrichment increased after 1900 which corresponded with the general increase in European coal consumption. Coals were assumed to be the main source of heavy metal enrichment.

A marker horizon for 1900 was already available in the Lake Constance sediments. In 1900 the Rhine was shifted to a new artificial bed and since that time it has begun to build up its present delta. The 1900 event can be traced over large areas in the eastern part of the Lake bottom by a sudden change in textural properties of the sediment within a sediment core.

Muller produced depth profiles for Pb, Zu and Cd in ppm as well as for Polycyclic Aromatic Hydrocarbons. The levels of both types of pollutants rose steadily after the 1900 event in the sediment. A similar trend was found in other metals (K, Li, Fe, Hg, Cu, Cr, Co, Ni).

Metal enrichment due to atmospheric pollution seemed in theory a useful technique to try to determine the approximate date of the sediments at Butterby Marsh. Each fine layer in the sediment represented a former bed of the Marsh and would accumulate metals from atmospheric pollution. If levels rose steadily from a certain point within the profile this could be correlated with an increase in atmospheric pollution and an approximate date could be assigned to the sediment.

However, a major complication was the fact that the Marsh lies in an old river channel of the Wear. River sediment was likely to contain a lot of background lead from Weardale. The depth profile of metals that Muller found might therefore be seen in reverse. High metal enrichment might be seen in river sediment, with a decrease after the river water was diverted. The fall might even be followed by a rise as atmospheric pollution increased in the late C19 and there was increased traffic on the nearby Newcastle - Darlington Road (A 167) in the C20.

The technique seemed to offer a possibility for tracing the 1811 event (the River diversion) in the Butterby Marsh sediments. Thus river deposits might be separated from those deposits that had built up since the initiation of the hydrosere. The rate of organic matter accumulation during the past 170 years since the Marsh was formed might then be determined.

Method

The method used was that outlined by Burrows (1980).

Determination of the metal composition of solid materials required that the sediment be brought into solution. A small portion (c. 200 mgs.) of the twelve sediment samples that had been dried for the loss on ignition experiment were taken after 24h. drying and ground in a pestle and mortar. They were then redried at 105^{o}C for 44 h.

They were then cooled in a dessicator, taken out individually and 100 mg. of dried sieved sediment was weighed out in the following way. Filter paper was weighed, 100 mgs. of sediment was weighed out to an accuracy of .0001 g. and this was then dropped into numbered glass boiling tubes. The filter paper was reweighed so that the actual weight of the sediment that had entered each boiling tube was known.

All glasswear used was acid washed by submergence in 4% volume for volume nitric acid. It was then rinsed six times with distilled water and three times with de-ionised water and dried in an oven.

5 ml. of concentrated nitric acid was then pipetted into each boiling tube. The samples were boiled in a fume cupboard for 1 h. The resulting solution was cooled to 20^{o}C. Digest solutions were then made up to the required volume with de-ionised water.

The digest was then poured into a centrifuge tube. The digestion vessel was rinsed out with de-ionised water and the washings poured into the same centrifuge tube. The samples were then centrifuged at 3500 r.p.m. for 5 mins. The supernatant was decanted into a 50 ml. volumetric flask and made up to volume with de-ionised water.

The digest solution was finally poured into snap top vials and stored at $4^{\circ}C$ until analysis by atomic absorption spoctroscopy.[1]

Values obtained from this were given in ppm for the digest solution. They were converted to ppm in the sediment by using the following formula:

$$\frac{\text{Concentration in digest solution } (\mu g l^{-1}) \times \text{dilution } (50 \text{ ml.})}{\text{exact dry wt. (mg.)}} \times 1000$$

$$= \text{ppm } (\mu g\ g^{-1}) \text{ in the sediment.}$$

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1. Analysis by Atomic Absorption Spectroscopy was made possible by the assistance of Dr. M. J. Tooley of the Geography Dept. Atomic Absorption Spectroscopy is a facility jointly owned by the Chemistry, Geography and Botany departments.

CHAPTER FOUR RESULTS : THE VEGETATION AND THE HABITAT

4.1 FIELD MAPPING

Maps of Pond A, Pond B and Pond C showing the boundaries of the distinctive plant communities appear on the following pages. The outline and significant features of the South Salix Marsh are also shown.

The description of each area that Griffiths gave is given below, together with the map he drew of the marsh vegetation.[1]

4.1.1 Pond A.

This area was described by Griffiths as "the Great Rumex Marsh".

> "The West Salix Marsh passes into a great expanse of Rumex hydrolapathum and Equisetum limosum,[2] mixed with Typha latifolia. The region is 800 ft. long and 190 ft. wide and is one of the largest regions of the Marsh. Towards the southern bank there are three groups of Carex paludosa[3] upon which are small forests of Salix cinerea. On the north side there are three narrow pools containing Potamogeton natans. Pure Equisetum limosum surrounds each pool. At the south end, the community is terminated by a society of Phragmites." (Griffiths 1932, 121).

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[1] The map was published in three sections. These have been joined together to give a representation of the vegetation of the whole marsh.

[2] E. limosum L. = E. fluviatile L.

[3] C. paludosa Good = C. acutiformis Ehrh.

Fig. 4.1: Griffiths' Map of the Vegetation of Butterby Marsh in 1929

The map has been reconstructed from the three seperate maps of the herbaceous vegetation published in the Journal of Ecology (1932).

Symbols explained on an additional key are : Y Iris, and + Deschampsia caespitosa . P indicates an isolated part of the East Pasture.

The names given by Griffiths to the different areas of the Marsh have been retained in the present study (e.g. the 'Long Pool', the 'East Salix Marsh'). However the 'Great Rumex Marsh' is now referred to as the area surrounding 'Pond A' and the 'Phragmites Marsh' as the area surrounding 'Pond B' and 'Pond C'.

Maps of the dendrophytic vegetation of the East- and West Salix Marsh (similar to the inset at left of 'Long Pool'), and three cross-sections through different communities were also presented in the 1932 paper.

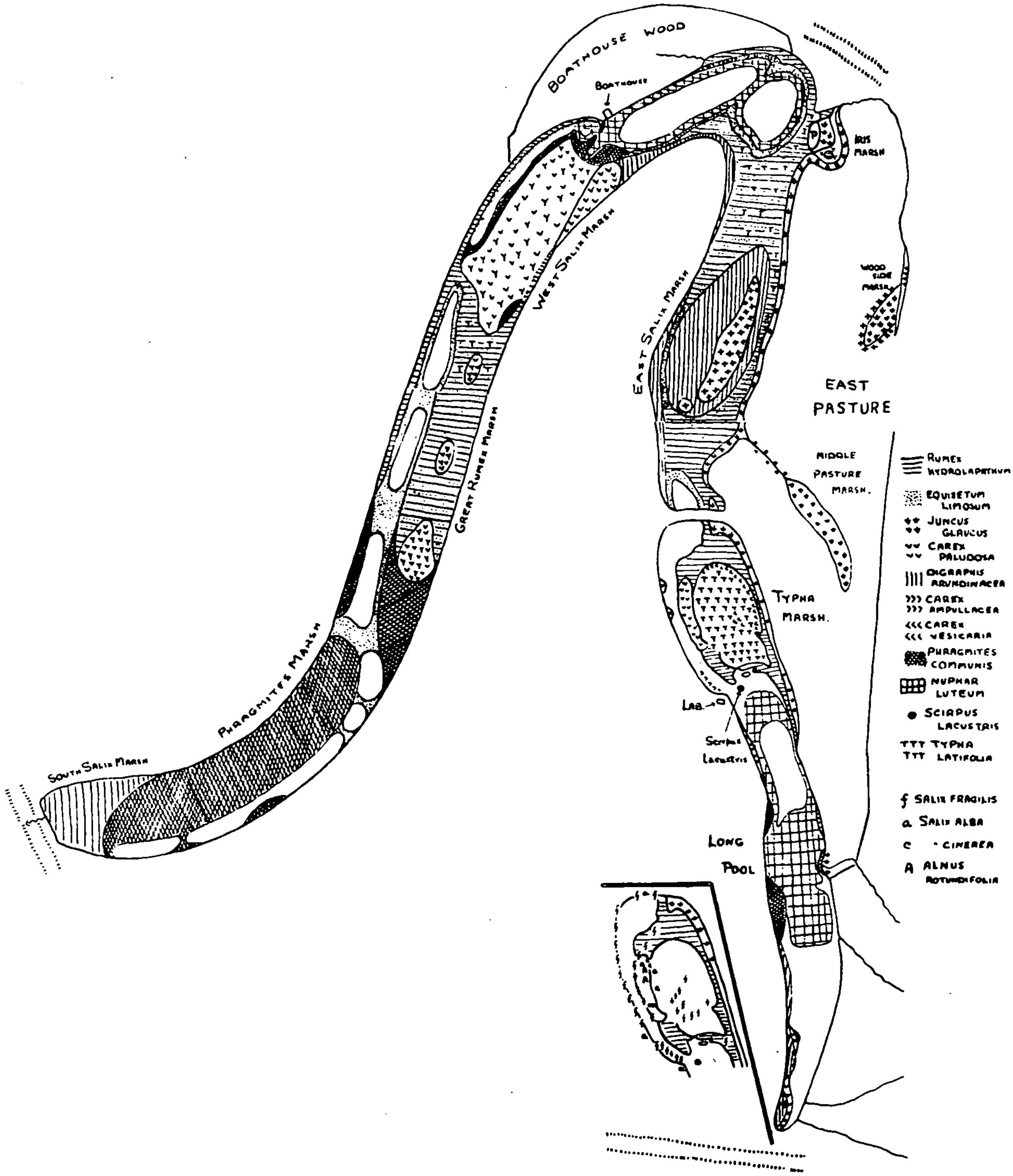

Boathouse Wood
Boathouse
Iris Marsh
Wood Side Marsh
East Salix Marsh
West Salix Marsh
Great Rumex Marsh
Phragmites Marsh
South Salix Marsh
East Pasture
Middle Pasture Marsh
Typha Marsh
Lab.
Scirpus Lacustris
Long Pool
Rumex hydrolapathum
Equisetum limosum
Juncus glaucus
Carex paludosa
Digraphis arundinacea
Carex ampullacea
Carex vesicaria
Phragmites communis
Nuphar luteum
Scirpus lacustris
Typha latifolia
f Salix fragilis
a Salix alba
c " cinerea
A Alnus rotundifolia

Fig.4.1

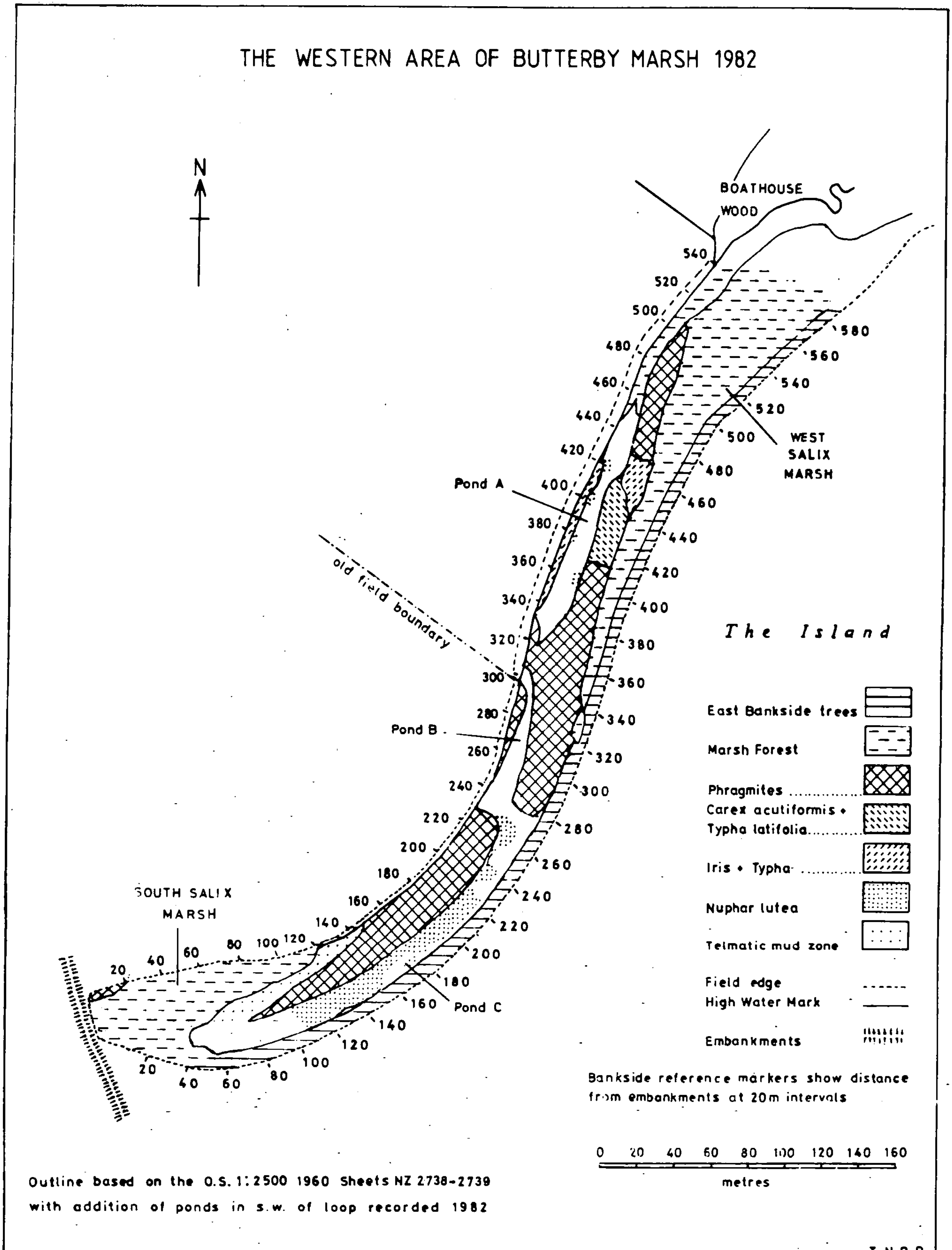

THE WESTERN AREA OF BUTTERBY MARSH 1982
N
BOATHOUSE
WOOD
WEST
SALIX
MARSH
Pond A
old field boundary
Pond B
Pond C
SOUTH SALIX
MARSH
The Island
East Bankside trees
Marsh Forest
Phragmites
Carex acutiformis + Typha latifolia
Iris + Typha
Nuphar lutea
Telmatic mud zone
Field edge
High Water Mark
Embankments
Bankside reference markers show distance from embankments at 20m intervals
0 20 40 60 80 100 120 140 160
metres
Outline based on the O.S. 1:2500 1960 Sheets NZ 2738-2739
with addition of ponds in s.w. of loop recorded 1982
T.N.R.R.

Fig. 4.2

The mapping revealed major changes in the boundaries of the plant communities around Pond A. It is assumed that the present mapping is directly comparable with that of Griffiths. He unfortunately did not show the hedge boundary at the south west of Pond A. This runs across the adjacent field on the O.S. maps available in the 1920's, which is a convenient landmark. However, the shape of the ponds shown on his map and their relative positions in terms of the length of the whole section of the western marsh enables comparison of the two mapping surveys.

According to the present mapping the Phragmites which terminates the Great Rumex Marsh at its southern end has advanced northwards by at least 60 m. It has replaced the southern 'island' of Carex acutiformis and Iris.

It seems unlikely that the whole of this "island" was covered by a "small forest" of Salix cinerea as the Phragmites has completely replaced it. Salix cinerea bushes (also S. pentandra, S. viminalis and S. cinerea x S. viminalis) do grow beyond h.w.m. at this point but are on the eastern water's edge, between the 320 m. and 360 m. W. bankside markers. They are encircled by Phragmites and no understory of Carex or Iris grows beneath them.

In 1929 Pond A was divided from Pond B by a wedge of E. fluviatile. This has also been replaced by the Phragmites in its advance northwards. The Phragmites completely fills the old channel at this point.

The Phragmites at the northern edge of Pond A has also spread and forms a more extensive stand than that recorded in 1929. The northern boundary of the "Great Rumex Marsh" was shown as the understory of *Iris* and *Carex acutiformis* of the West Salix Marsh. A thin wedge of *Phragmites* was shown along the channel to the west of the West Salix Marsh and a small stand on its south eastern margin. These societies appear to have spread southwards so that a stand of almost pure *Phragmites* now extends to the edge of the open water on the north east of Pond A. This represents an advance of the boundary by about 30 m.

At the southern and northern boundaries of what remains of "The Great Rumex Marsh" there are transition zones of approximately 10 m, where the *Phragmites* thins out and decreases in height. However, next to the pond's edge it ends in an abrupt and dense 'sheer wall'. At the north east of Pond-A some *Carex acutiformis* skirts it. Here the sharp boundary between the dense reedbed and the open water may be due to a change in substrate or critical water depth, related to the deeper channel which connects Pond A with the Boathouse Pool.

From the eastern bankside between the 360 m. and the 500 m. markers, the fringing bankside trees extend into the Marsh and join with the *Salix cinerea* forests recorded by Griffiths. The *S. cinerea* bushes seem to have spread along the side to join the northern two "islands" of *C. acutiformis* recorded by Griffiths, but do not seem to have extended their range into the Marsh.

What remains of the "Great Rumex Marsh" is a small area about 35 m. in length and 15 - 20 m. in width (c. 105 by 60 ft.), compared to the 800 by 190 ft. expanse that Griffiths recorded. (190 ft. represented the total width of the old channel since the whole area of Pond A was dominated by *Rumex* and *Equisetum*). It is bounded on the north and south by dense stands of

Phragmites, on the east by Salix cinerea bushes with an understory of Iris and on the west by the water of Pond A. It can be divided into two visually separate areas. The northern one is composed of Iris with some Carex acutiformis. Typha latifolia grows amongst it in abundance and is more conspicuous in late July and August as its leaves rise above the Iris. A few clumps of Rumex hydrolapathum grow amongst it. The vegetation on the eastern side of Pond A was difficult to sample thoroughly due to the "impassibility of the marshy ground" from the east bankside (Griffiths 1932 p.119), but the boat was used to sample vegetation on its western edge. Using binoculars from the high ground on the west bankside, it can be seen that Rumex hydrolapathum is very scarce in this area. The southern community consists of almost pure Carex acutiformis. Some Typha latifolia grows amongst it and there is some Iris beneath the Salix cinerea bushes growing on its eastern margin.

The vegetation of the western margin of pond A was sampled intensively in the collection of transect data. It mainly consists of Iris and Typha latifolia. Rumex hydrolapathum and Equisetum fluviatile do occur but are rare. Pond A was formerly divided in two by a band of Equisetum fluviatile about 5 m. wide (presumably a summer outline) and each of these pools were surrounded by Equisetum. This is also shown on the photograph (No. 4) of the Great Rumex Marsh in Griffith's paper. Very little Equisetum fluviatile now occurs around Pond A. The outline of the pond is narrower at this point but there is now open water with a small patch of Nuphar lutea in place of the E. fluviatile.

At three points on the eastern margin of the pond there are floating mats of mixed communities similar to those on the waters edge of the western bankside. These include such species as Epilobium palustre, Epilobium parviflorum, Epilobium adenocaulon, Epilobium hirsutum, Lycopus europaeus, Scutellaria galericulata, Galium palustre, Cardamine amara, Cardamine pratensis and a few individuals of Equisetum fluviatile. One such mixed stand is at the extreme north of Pond A on a floating mat of Iris, the second is at the junction of the Carex acutiformis and the Iris community on the east side of the pond and the third is adjacent to the Phragmites at the southern most part of the pond.

The pond was not dredged for submergent macrophytes. However, in using the inflatable boat to sample the vegetation and the sediments on its eastern margin, no specimens of Potamogeton natans were recorded. Some Alisma plantago-aquatica occurs on the western edge of the pond and Nuphar lutea occurs in a few locations.

In summary, there have been major advances of Phragmites since 1929 around Pond A. It has annexed large areas which were formerly occupied by Equisetum fluviatile, Rumex hydrolapathum, Carex acutiformis and Iris. The first two of these are now scarce in the vicinity of Pond A. Typha appears to be more abundant than in 1929, especially on the west of the pond, and mixes with the Iris. The pond has not noticeably contracted in shape which suggests little decrease in mean water depth. The depth of the pond is, at most points, approximately 1 m. The maximum depth recorded was 2 m. Phragmites has replaced the previous vegetation but has not extended its limits into the deeper water areas. This is probably accounted for by the sudden increase in depth of water which represents the deeper part of the old river channel. Until the depth is decreased by sedimentary infill the open water areas are unlikely to be

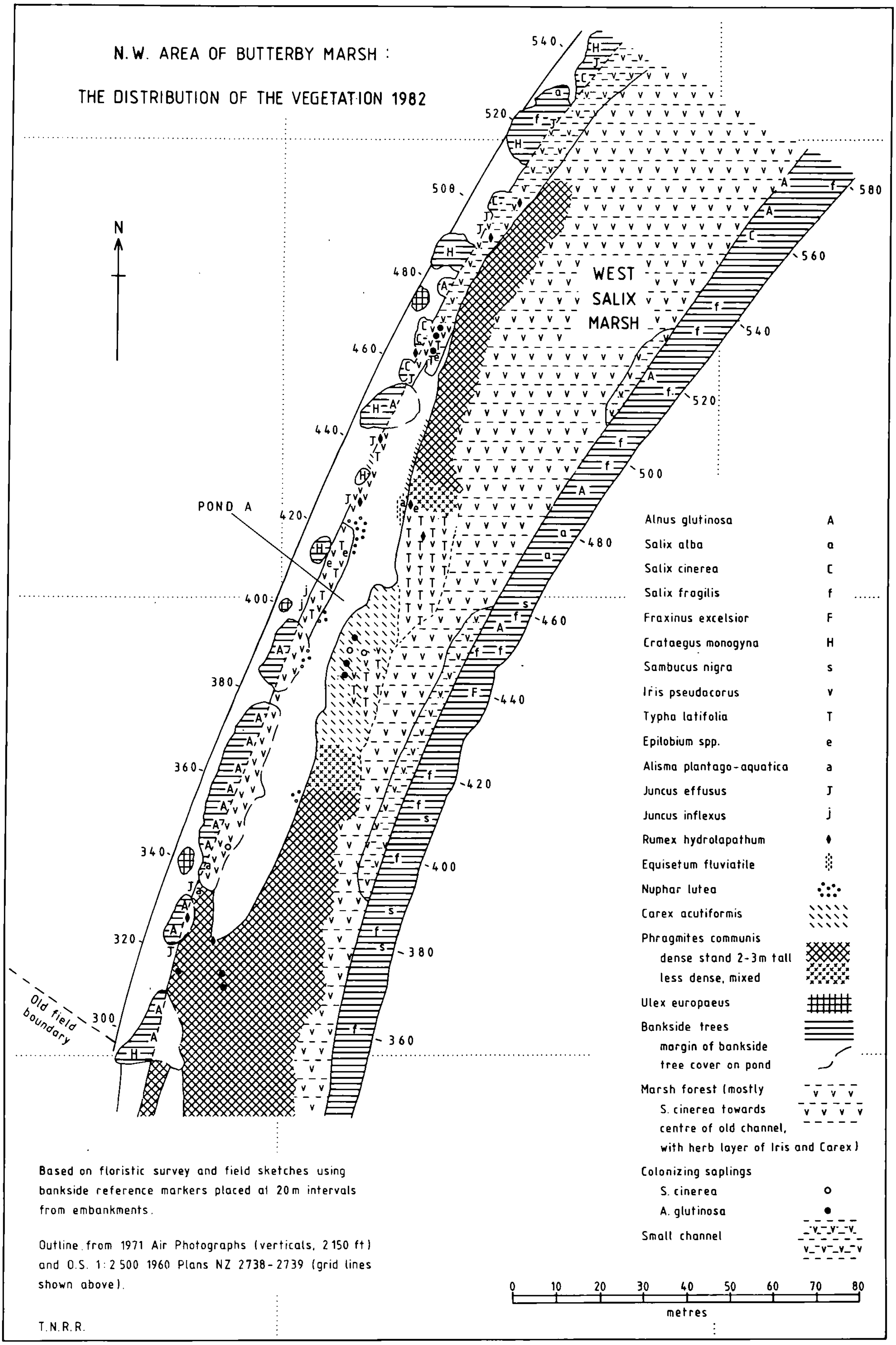

N.W. AREA OF BUTTERBY MARSH :
THE DISTRIBUTION OF THE VEGETATION 1982
N
POND A
WEST SALIX MARSH
Old field boundary
Alnus glutinosa A
Salix alba a
Salix cinerea C
Salix fragilis f
Fraxinus excelsior F
Crataegus monogyna H
Sambucus nigra s
Iris pseudacorus v
Typha latifolia T
Epilobium spp. e
Alisma plantago-aquatica a
Juncus effusus J
Juncus inflexus j
Rumex hydrolapathum
Equisetum fluviatile
Nuphar lutea
Carex acutiformis
Phragmites communis
dense stand 2-3m tall
less dense, mixed
Ulex europaeus
Bankside trees
margin of bankside tree cover on pond
Marsh forest (mostly S. cinerea towards centre of old channel, with herb layer of Iris and Carex)
Colonizing saplings
S. cinerea
A. glutinosa
Small channel
Based on floristic survey and field sketches using bankside reference markers placed at 20m intervals from embankments.
Outline from 1971 Air Photographs (verticals, 2150 ft) and O.S. 1:2500 1960 Plans NZ 2738-2739 (grid lines shown above).
T.N.R.R.
0 10 20 30 40 50 60 70 80
metres

Fig.4.3

colonized by the marsh vegetation, unless it extends as floating mats. Such mats require dense root and rhizome systems and are often bound together by bryophytes. Sedges, being less exclusive to other plants such as mosses than Phragmites, might ultimately be more capable of spreading across the open water as floating mats than the reed.

4.1.2 Pond B

Pond B and Pond C are described by Griffiths as "the Phragmites Marsh".

> "At the south end of the marsh, the line of the deeper part of the old channel of the river moves over to the south side. The south end of the channel is almost filled with a society of Phragmites. The narrow channel pool which is left open on the south side is filled with Nuphar. There is another smaller society of Phragmites on the north bank opposite the end of the Great Rumex Marsh, and a third society on the south bank. Equisetum limosum is invading the channel pools and cutting them into sections." (Griffiths 1932 p.124).

Pond B is defined as the pool to the south of the point where Phragmites now completely fills the old channel. It connects with Pond C but at this point the deeper water switches over to the eastern side. This junction is almost impassable by boat as the channel is almost blocked by fallen branches of Salix fragilis and Populus x. canadensis.

Pond B is smaller than Pond A (approximately 45 m. long and with a maximum width of 10 m.). It is almost completely bounded by Phragmites, which grows vigorously and forms an abrupt wall at the waters edge, approximately 2.8 m. high (from the sediment surface) and almost enclosing the pond. The depth of water at different points varied between 1.5 m. and 60 cm. in late June 1982. This depth seemed to exclude the Phragmites from extending across the pond.

Very little Lemna occurs amongst the Phragmites or on the water surface. Nuphar does not occur on this pond. The only mixed community is near to the junction with Pond C on a floating raft of vegetation that has developed at the edge of the Phragmites on the fallen branches of the fringing trees. A small specimen of Sorbus aucuparia has colonized amongst the Phragmites and beneath it is a little Ribes nigrum. Mosses grow on the fallen twigs and branches. At the base of the Phragmites the following species have established themselves: Epilobium palustre, Stellaria nemorum, Cardamine pratensis, Solanum dulcamara, Angelica sylvestris, Lycopus europaeus, Urtica dioica and a little Rorippa nasturtium-aquaticum.

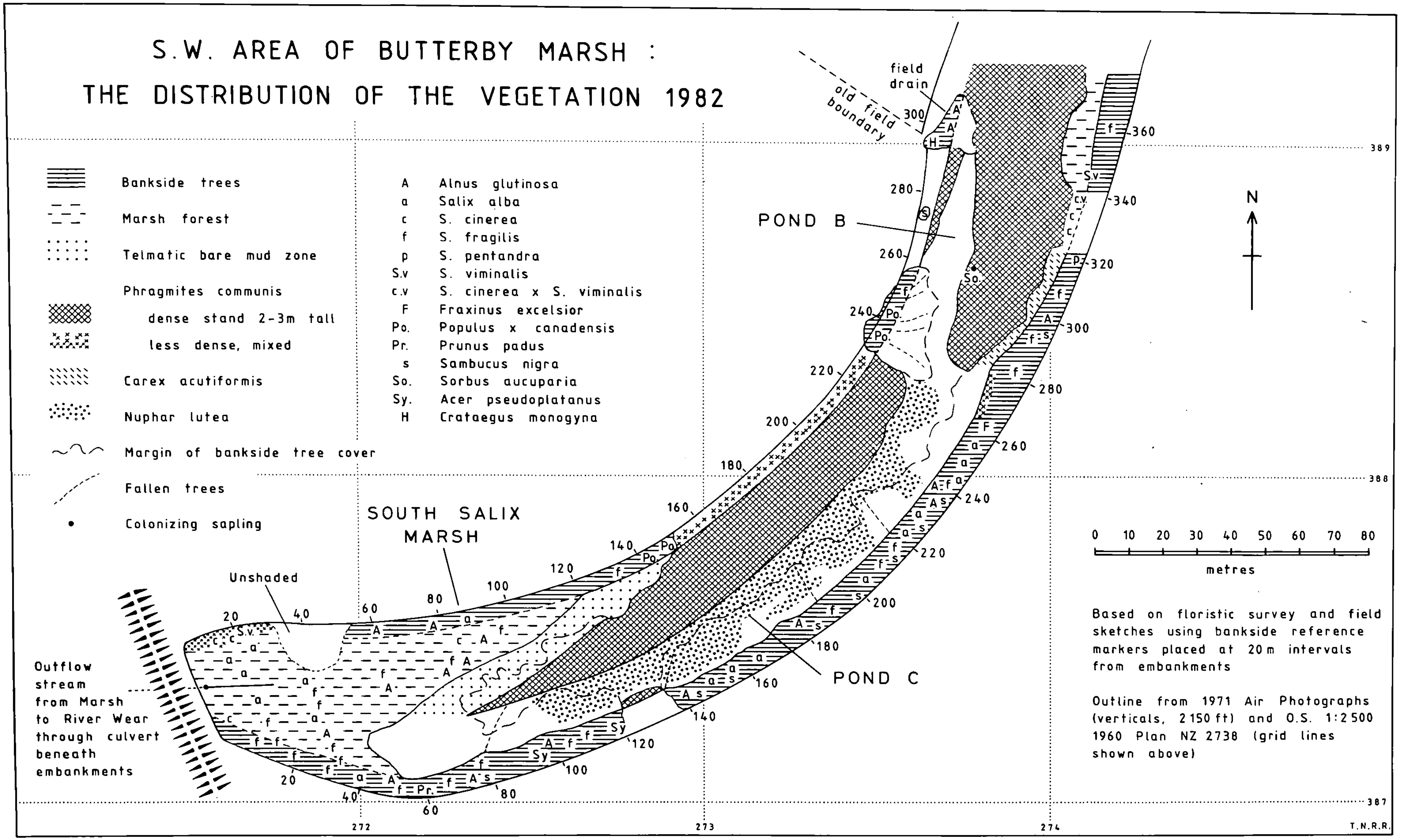
The main change since 1932 is the loss of Equisetum fluviatile. The Phragmites has narrowed the outline of the pond towards its northern end where it has filled the whole channel. It has not advanced at the southern end of the pond, presumably due to a greater water depth, and also possibly due to the shading effect of the large Populus and S. fragilis trees at this point. A field drain has been built beneath the alders near the 300 m. marker on the west side and this may possibly have led to an inflow of water bringing fine sediment with it and raising the surface of the sediment at the north end of Pond B, thus allowing the spread of Phragmites at this point. No Phragmites grows beneath any of the fringing trees, which suggests it may be intolerant of shade.

4.1.3 Pond C

Along the western bank of this area there is a wide expanse of *Phragmites* as shown on Griffith's map. It has built out to a width of 22 m. beyond the h.w.m. of the western bank-side. The western bankside is devoid of tree cover and the *Phragmites* grows right up to the field edge, although here it grows only to the same level as that in the channel, suggesting that it depends on shelter, or strength through density, to protect it from the wind blowing across the wide open field to the west.

To the east of the *Phragmites* the narrow channel is almost completely filled with *Nuphar lutea*, but no *Equisetum fluviatile* occurs. At the north of Pond C there are a few open pools free from *Nuphar* which reach a depth greater than 2 m. The eastern bankside is heavily shaded by the fringing salices and the southern end of the channel is almost blocked at some points by fallen trees. *Phragmites* only grows on the south eastern bankside at one point which corresponds to the stand marked on Griffith's map. Nowhere does the *Phragmites* actually cross the channel. Griffiths showed a narrow band across the channel at the south east of Pond C. A fallen *Salix fragilis* lies at that position now and it is possible that, when it was covered with foliage, it caused the disappearance of the narrow band of *Phragmites*. The water depths, reflecting the deepest part of the old river channel and following the outside of the curving meander bend, together with the shading effect of the fringing trees, seem to determine the location of the *Phragmites*.

Fig. 4.4



S.W. AREA OF BUTTERBY MARSH :
THE DISTRIBUTION OF THE VEGETATION 1982
Bankside trees
Marsh forest
Telmatic bare mud zone
Phragmites communis
dense stand 2-3m tall
less dense, mixed
Carex acutiformis
Nuphar lutea
Margin of bankside tree cover
Fallen trees
Colonizing sapling
A Alnus glutinosa
a Salix alba
c S. cinerea
f S. fragilis
p S. pentandra
S.v S. viminalis
c.v S. cinerea x S. viminalis
F Fraxinus excelsior
Po. Populus x canadensis
Pr. Prunus padus
s Sambucus nigra
So. Sorbus aucuparia
Sy. Acer pseudoplatanus
H Crataegus monogyna
POND B
POND C
SOUTH SALIX MARSH
Unshaded
field drain
old field boundary
Outflow stream from Marsh to River Wear through culvert beneath embankments
N
0 10 20 30 40 50 60 70 80
metres
Based on floristic survey and field sketches using bankside reference markers placed at 20 m intervals from embankments
Outline from 1971 Air Photographs (verticals, 2 150 ft) and O.S. 1:2 500 1960 Plan NZ 2738 (grid lines shown above)
389
388
387
272
273
274
T.N.R.R.

4.1.4 THE SOUTH SALIX MARSH

The account given by Griffiths of the South Salix Marsh is brief:

> "The end of Butterby Marsh is occupied by a society of Digraphis,[1] which is covered with a forest of Salix fragilis. In some places there is a mixture of Digraphis and Phragmites. Carex distans occurs under the trees, together with a few tufts of Carex paniculata. A little Iris and Carex ampullacea [2] are found at the junction of the Digraphis and Phragmites." (Griffiths 1932 121).

The floristic composition of this small marsh forest was intensively sampled and recorded on a grid basis. The herb layer communities are difficult to map as they are very variable and mixed.

The area of water is quite different to that shown on Griffith's maps. His outline of the South Salix Marsh probably represents the tree cover and the understory is shown as Phalaris. However, there is a large, wide (20 m.) terminal area of open water that is fringed by young Alnus glutinosa and Salix cinerea bushes. Fallen Salix fragilis branches and trunks lie around this and from them new stems grow up. Further south there is a small overflow channel connecting to a drain which leads under the embankment to the present river. It is a reddish-orange colour, presumably with iron precipitates.

Fringing this water at the southern part of the South

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[1] Digraphis arundinacea = Phalaris arundinacea L.

[2] Carex ampullacea Good = Carex rostrata Stokes.

Salix Marsh are many square metres of *Carex acutiformis*. A little *Carex vesicaria* mixes with this but the two are difficult to separate without detailed examination. *Carex vesicaria* was only previously recorded for the "Typha Marsh". (Griffiths 1932 p.113). There are still many scattered tussocks of *Carex paniculata*. On fallen logs and near to open mud areas much *Carex remota* occurs. *Carex rostrata* and *Carex distans* were not recorded in 1982.

Scirpus sylvaticus grows with the *Carex* near h.w.m at one location on the n.w. side of the marsh, between 60 and 90 m. from the embankment. *Lycopus europaeus* and *Juncus effusus* are also common near to the maximum h.w.m.[1] *Iris* still grows in a few isolated clumps, rising above the *Carex*.

Further from maximum h.w.m., beyond the *Carex acutiformis* (towards and up to the field edge), grow large masses of *Impatiens glandulifera*. This plant was not recorded at Butterby by Griffiths. It grows in the same zone as *Phalaris arundinacea* and would seem to have replaced it in many locations. In early summer the more open areas at the south west of this marsh forest are covered by *Cardamine amara*, *Stellaria nemorum* and some *Silene dioica* but this is replaced by *Impatiens* in the seasonal progression of dominance.

The distribution of *Phragmites* seems to be determined by the tree cover. At the south end of the "Phragmites Marsh" the junction with the South Salix Marsh consists on the western side of open expanses of mud. These areas seem to exclude the *Phragmites* due to the shading effect of the fringing trees. The water depth in winter may be responsible for preventing

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[1] h.w.m. = the mean water level in winter, characterized by mud and *Lemna minor*.

L.w.m. = mean water level in summer, progressively less until around the end of August.

other species from colonizing. Only Equisetum palustre and Lemna minor occur on the mud surface although Epilobium spp. and various mosses grow on fallen branches. No Carex acutiformis has advanced into this zone. It is possible that the area was covered by Phragmites which has recently been excluded by the growth of the fringing willows. The comparison of the outline of the tree cover in this area on Griffith's maps with that on the present maps allows room for this interpretation.

In the south west area Phragmites grows in a few isolated patches. One is a small pool a few metres in diameter near to the overflow channel but free from tree cover. Equisetum palustre and Lemna minor occur with it and the zonation is then to Lycopus europaeus Phalaris arundinacea, Juncus effusus and Impatiens glandulifera in that order.

The main changes since 1929 in the South Salix Marsh can be summarized as follows. Impatiens glandulifera, a species not recorded by Griffiths, would seem to be replacing Phalaris arundinacea to a great extent. Many species have been added to the previous list for the area, notably Scirpus sylvaticus, Carex vesicaria, Carex remota and Lycopus europaeus, together with Cardamine amara and Stellaria nemorum from the more open "fen" areas. (They may have been there in 1929, but were simply not recorded). Carex distans and Carex rostrata were not recorded in the present survey of the South Salix Marsh.[1]

The boundary of the marsh forest may have advanced as the fringing trees grew in height, but regeneration of trees and increasing density of tree cover is more apparent further away from these deeper water areas. The area of Phragmites may have declined since 1929 with the extension of the influence of

[1] It is possible that Carex remota was mistaken for Carex distans in the 1929 survey.

marsh forest but the comparability of Griffith's mapping at this point with that of the present survey is uncertain.

4.2 FLORISTIC COMPOSITION OF THE MARSH AREAS

The graphs summarizing the data collected from quadrats along transect lines are shown below. Raw data tables appear in the appendix. The importance of a species in terms of its cover abundance at each of the areas studied is rated according to its frequency of occurrence within quadrats (F) and the sum of its Domin cover scale values from the samples from that area (ΣD).

4.2.1 Pond A. West Bankside Transects

Thirty-nine "bankside" species were recorded from the western side of Pond A within the herb layer, and nineteen "fen and aquatic" species.

The species with the highest F and ΣD values on the bankside included the grasses Poa trivialis, Dactylis glomerata and Arrhenatherum elatius, together with Achillea millefolium, Conopodium majus, Epilobium augustifolium, Galium aparine, Galium verum, Impatiens glandulifera and Rumex acetosa. Less important species included Lotus corniculata, Betonica officinalis, Vicia cracca, Campanula rotundifolia, Galium cruciata, Centaurea nigra and Carex hirta, amongst many others. This low herb layer has a great species richness at this point. Ulex europaeus occurs but has been killed by frost in the last, very severe winter.[1] There are some bankside trees and shrubs but

[1] (1981 - 82)

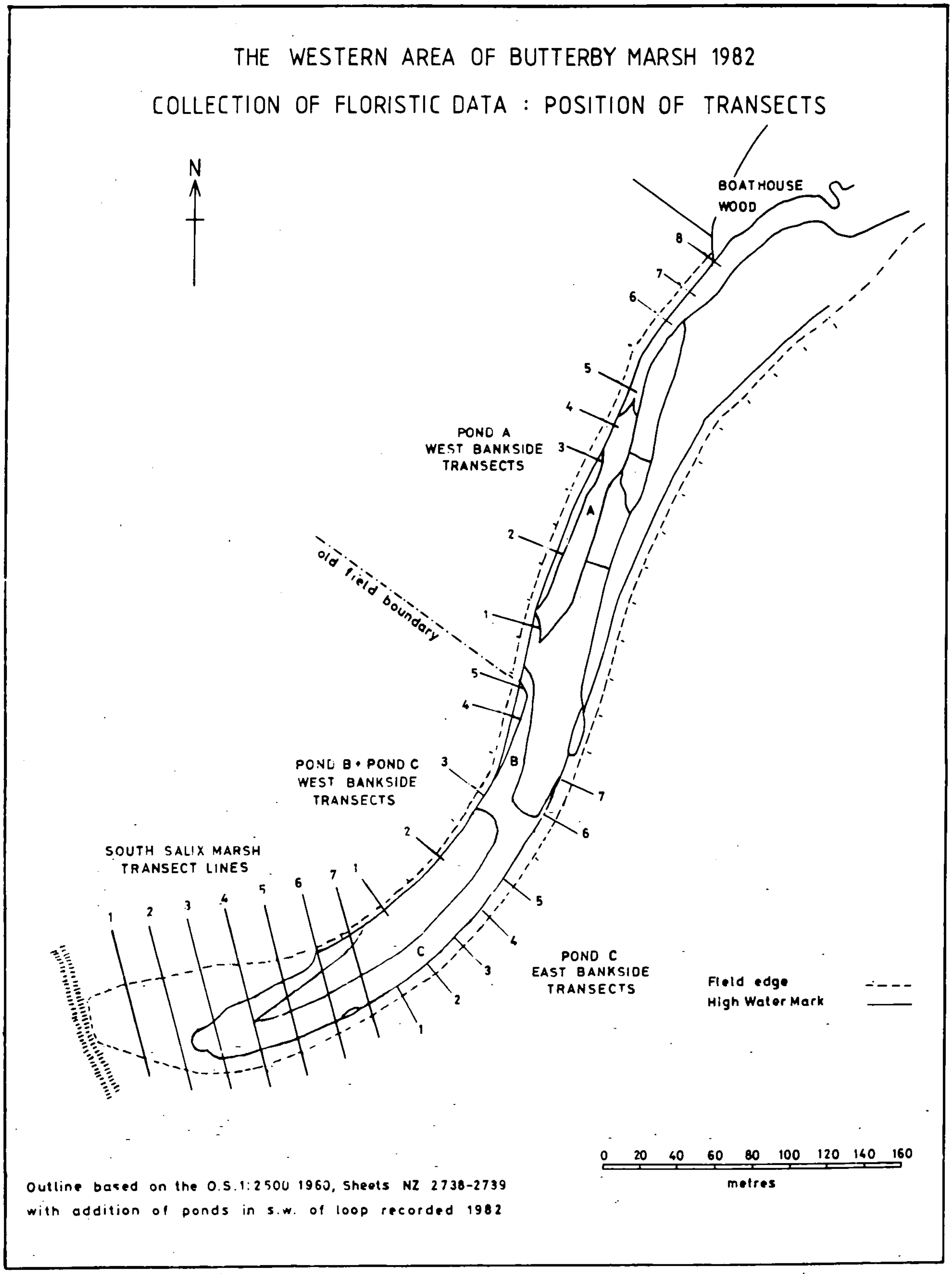

THE WESTERN AREA OF BUTTERBY MARSH 1982
COLLECTION OF FLORISTIC DATA : POSITION OF TRANSECTS
N
BOATHOUSE WOOD
POND A WEST BANKSIDE TRANSECTS
old field boundary
A
B
C
POND B + POND C WEST BANKSIDE TRANSECTS
SOUTH SALIX MARSH TRANSECT LINES
POND C EAST BANKSIDE TRANSECTS
Field edge
High Water Mark
0 20 40 60 80 100 120 140 160
metres
Outline based on the O.S.1:2500 1960, Sheets NZ 2738-2739
with addition of ponds in s.w. of loop recorded 1982

Fig. 4.5

Fig. 4.6.1

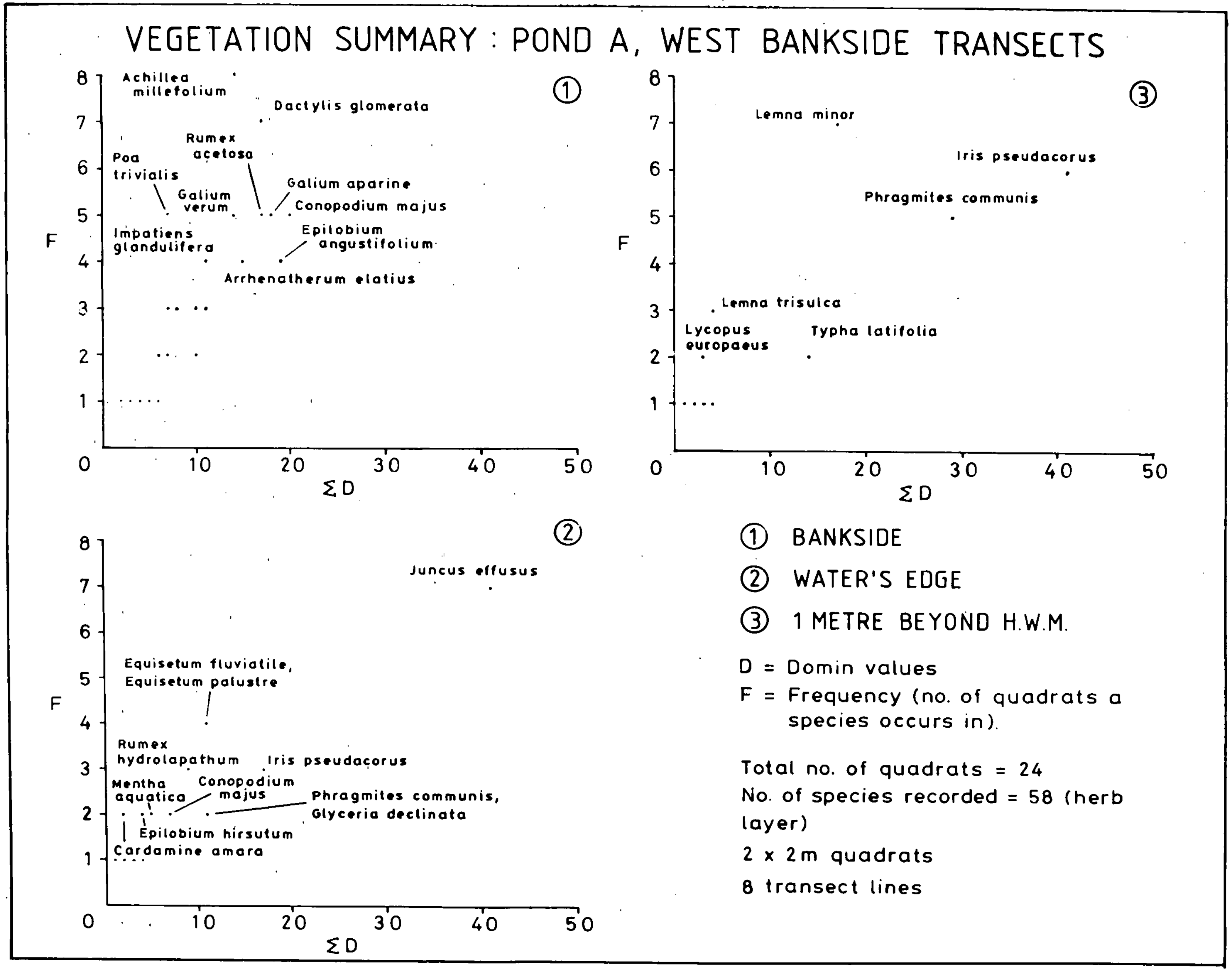

VEGETATION SUMMARY : POND A, WEST BANKSIDE TRANSECTS
①
Achillea millefolium
Dactylis glomerata
Rumex acetosa
Poa trivialis
Galium verum
Galium aparine
Conopodium majus
Epilobium angustifolium
Impatiens glandulifera
Arrhenatherum elatius
F
ΣD
②
Juncus effusus
Equisetum fluviatile, Equisetum palustre
Rumex hydrolapathum
Iris pseudacorus
Mentha aquatica
Conopodium majus
Phragmites communis, Glyceria declinata
Epilobium hirsutum
Cardamine amara
③
Lemna minor
Iris pseudacorus
Phragmites communis
Lemna trisulca
Lycopus europaeus
Typha latifolia
① BANKSIDE
② WATER'S EDGE
③ 1 METRE BEYOND H.W.M.
D = Domin values
F = Frequency (no. of quadrats a species occurs in).
Total no. of quadrats = 24
No. of species recorded = 58 (herb layer)
2 x 2m quadrats
8 transect lines

Fig. 4.6.2

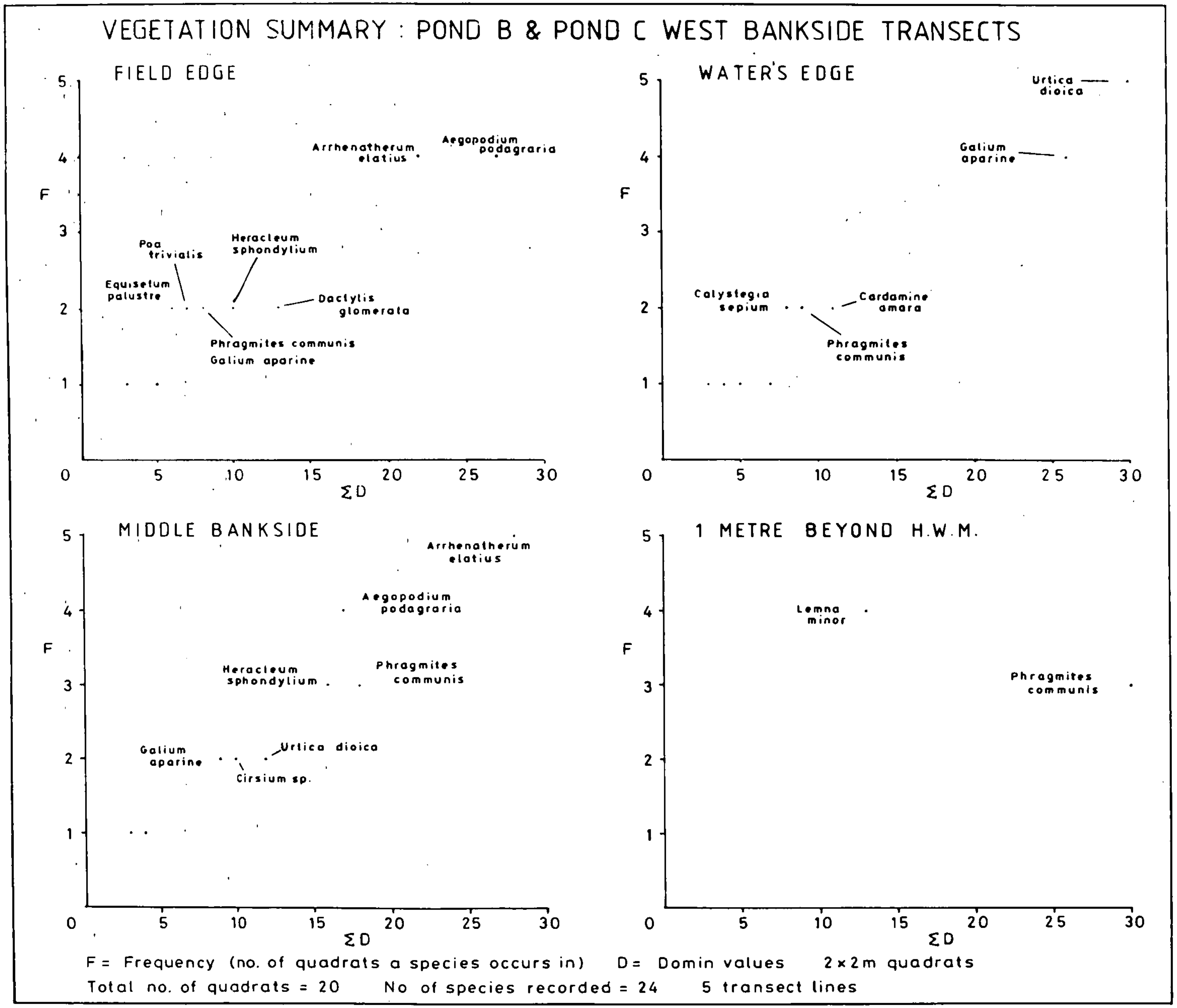

VEGETATION SUMMARY : POND B & POND C WEST BANKSIDE TRANSECTS
FIELD EDGE
Arrhenatherum elatius
Aegopodium podagraria
Poa trivialis
Heracleum sphondylium
Equisetum palustre
Dactylis glomerata
Phragmites communis
Galium aparine
WATER'S EDGE
Urtica dioica
Galium aparine
Calystegia sepium
Cardamine amara
Phragmites communis
MIDDLE BANKSIDE
Arrhenatherum elatius
Aegopodium podagraria
Heracleum sphondylium
Phragmites communis
Galium aparine
Urtica dioica
Cirsium sp.
1 METRE BEYOND H.W.M.
Lemna minor
Phragmites communis
F
ΣD
F = Frequency (no. of quadrats a species occurs in) D = Domin values 2 x 2m quadrats
Total no. of quadrats = 20 No of species recorded = 24 5 transect lines

Fig. 4.6.3

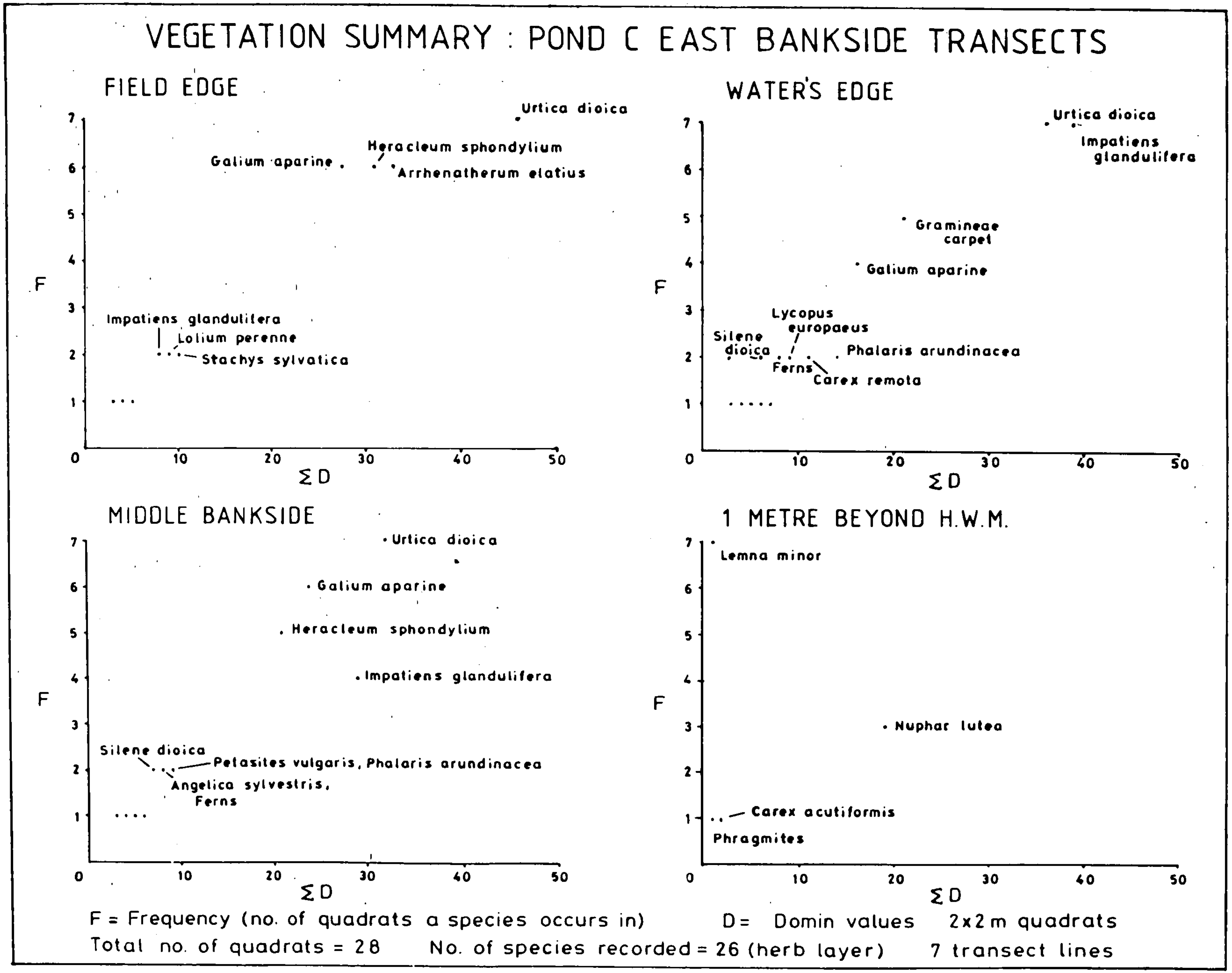
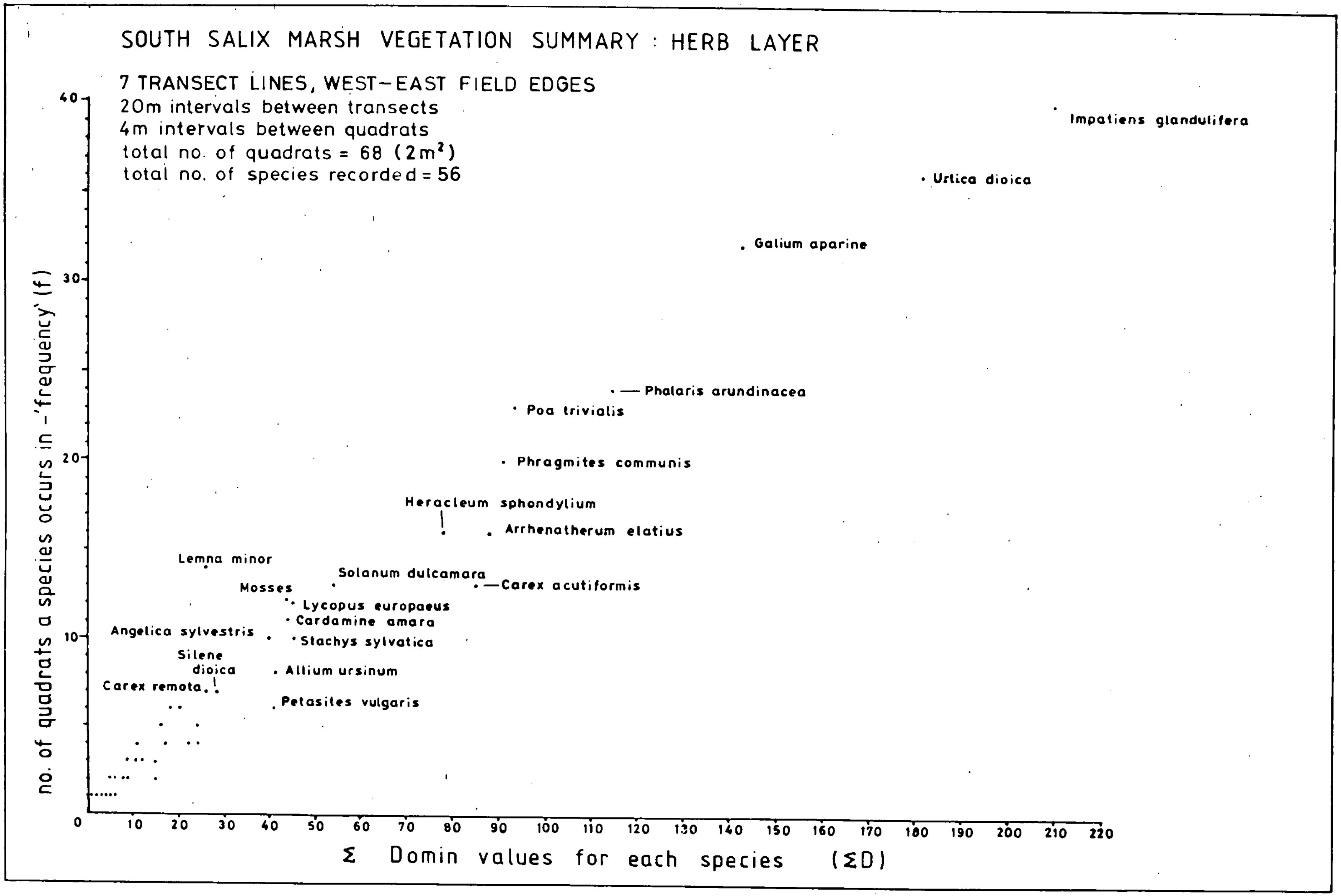

VEGETATION SUMMARY : POND C EAST BANKSIDE TRANSECTS
FIELD EDGE
Urtica dioica
Heracleum sphondylium
Galium aparine
Arrhenatherum elatius
Impatiens glandulifera
Lolium perenne
Stachys sylvatica
WATER'S EDGE
Urtica dioica
Impatiens glandulifera
Gramineae carpet
Galium aparine
Lycopus europaeus
Silene dioica
Phalaris arundinacea
Ferns
Carex remota
MIDDLE BANKSIDE
Urtica dioica
Galium aparine
Heracleum sphondylium
Impatiens glandulifera
Silene dioica
Petasites vulgaris, Phalaris arundinacea
Angelica sylvestris, Ferns
1 METRE BEYOND H.W.M.
Lemna minor
Nuphar lutea
Carex acutiformis
Phragmites
F
ΣD
F = Frequency (no. of quadrats a species occurs in)
D = Domin values
2x2 m quadrats
Total no. of quadrats = 28
No. of species recorded = 26 (herb layer)
7 transect lines

Fig. 4.6.4


SOUTH SALIX MARSH VEGETATION SUMMARY : HERB LAYER
7 TRANSECT LINES, WEST-EAST FIELD EDGES
20m intervals between transects
4m intervals between quadrats
total no. of quadrats = 68 (2m²)
total no. of species recorded = 56
Impatiens glandulifera
Urtica dioica
Galium aparine
Phalaris arundinacea
Poa trivialis
Phragmites communis
Heracleum sphondylium
Arrhenatherum elatius
Lemna minor
Solanum dulcamara
Carex acutiformis
Mosses
Lycopus europaeus
Cardamine amara
Angelica sylvestris
Stachys sylvatica
Silene dioica
Allium ursinum
Carex remota
Petasites vulgaris
no. of quadrats a species occurs in - 'frequency' (f)
Σ Domin values for each species (ΣD)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220

these are mostly Salix fragilis and Salix cinerea at the north end, and at the south-west Alnus glutinosa and Crataegus monogyna. The bankside is moist and relatively undisturbed by cattle or man.

At the waters edge there is a mix of "bankside" and fen species. Rumex hydrolapathum occurred in three of the eight transects at the waters edge. Equisetum fluviatile, Equisetum palustre, Iris pseudacorus, Phragmites communis, Agrostis stolonifera, Scutellaria galericulata and Glyceria declinata are also species present at this location.

The most important species occurring beyond h.w.m. from the samples were Iris, Phragmites, Lemna minor and Typha latifolia. Other species were Mentha aquatica, Lycopus europaeus, Lemna trisulca, Alisma plantago-aquatica, Equisetum fluviatile, Equisetum palustre, Carex acutiformis and Nuphar lutea.

4.2.2 Pond B and Pond C West Bankside Transects

The bankside at this stretch becomes more overgrown and narrower, rising up from the field edge. The fringing tree and shrub layer species include Alnus glutinosa, Salix fragilis, Populus x canadensis and Sambucus nigra but the bankside is generally free from shade.

Twenty four herb layer species were recorded from this area. Only Phragmites and Lemna occurred 1 m. beyond h.w.m. At the edge of the Phragmites a few seedlings of Cardamine amara occur, and also some Calystegia sepium. Galium aparine and Urtica dioica are important species next to the waters edge, while Phragmites continues to grow right up to the field edge. On the middle bankside and at the field edge Aegopodium podagraria Arrhenatherum elatius and Heracleum sphondylium have the greatest cover-abundance values. Impatiens glandulifera became a more important species on this bankside later in the season but was not recorded in early May in significant quantities.

4.2.3 Pond C East Bankside Transects

Twenty-six herb layer species were recorded from seven bankside transects. This bankside is densely shaded by Salix fragilis and Salix alba. Towards the southern stretch Alnus glutinosa is also important. Fraxinus excelsior occurs near to the 260 m. marker. Sambucus nigra is a common shrub adjacent to the field edge.

The most important species in their cover abundance from the samples on the field edge and middle bankside were Arrhenatherum elatius, Urtica dioica, Galium aparine, Heracleum sphondylium and Impatiens glandulifera. Lolium perenne, Stachys sylvatica, Petasites vulgaris, Angelica sylvestris and Silene dioica also occurred.

Other species that became more important near to the waters edge were Lycopus europaeus, Phalaris arundinacea, Carex remota, various ferns and mosses and a low carpet of grass species. Impatiens glandulifera increased its frequency and cover abundance in the quadrats collected from the waters edge.

Beyond h.w.m. the only species recorded were Nuphar lutea, Lemna minor and, at the north end of Pond C, Phragmites communis, **and some Carex acutiformis**.

4.2.4 South Salix Marsh Transects

From the 68 quadrats sampled along 7 transect lines, 56 species were recorded. When the ΣD and F values were plotted for each species on a graph representing the total sample, the most important species were Impatiens glandulifera, Urtica dioica and Galium aparine, in that order. The fourth most important species within the sample in its cover abundance was

Phalaris arundinacea.

The next species with high ΣD and F values were, in order of their importance, *Poa trivialis*, *Phragmites communis*, *Heracleum sphondylium*, *Arrhenatherum elatius* and *Carex acutiformis*.

The third group of species in order of importance on the graph consists of mosses, *Lemna minor*, *Solanum dulcamara*, *Lycopus europaeus*, *Cardamine amara*, *Angelica sylvestris*, *Stachys sylvatica*, *Allium ursinum*, *Petasites vulgaris*, *Silene dioica* and *Carex remota*.

Species which occurred very infrequently along the transect lines (in less than 10% of the quadrats) and which had a low total Domin value within the sample (< 25) included the fen and aquatic species *Alisma plantago-aquatica*, *Carex paniculata*, *Carex remota*, *Carex vesicaria*, *Epilobium palustre*, *Filipendula ulmaria*, *Galium palustre*, *Juncus effusus*, *Lemna minor*, *Myosotis scorpioides*, *Nuphar lutea*, *Scirpus sylvaticus* and *Valeriana officinalis*.

Many of the species with high F and ΣD values are those that are common and abundant at the field edges, for example, *Urtica dioica* and *Galium aparine*. *Impatiens*, however, is a common species in the central area of marsh forest.

The zonation of the vegetation along four of the seven transect lines is now briefly described. The raw data appears in the appendix.

Transect line 1, W - E, 20 m. from embankment.

This is the southernmost area of the South Salix Marsh and is more open in terms of tree cover than that further to the north.

Impatiens glandulifera occurred in ten quadrats and had the highest total of Domin values. *Phragmites* occurs in an isolated clump next to the western field-edge, with the common field-edge species *Urtica dioica*, *Galium aparine* and *Poa trivialis*. *Phalaris arundinacea* is an important species towards the centre of the marsh but has less cover-abundance than *Impatiens*. *Cardamine amara*, *Carex acutiformis* and *Solanum dulcamara* are other species with a high cover-abundance in the central area. Along the base of the steeper and more shaded eastern bankside *Allium ursinum*, *Silene dioica* and *Equisetum palustre* grow, with *Arrhenatherum elatius*, *Urtica dioica* and *Petasites vulgaris* closer to the field edge.

Transect line 2, W - E, 40 m. from embankment.

Impatiens glandulifera and *Phalaris arundinacea* are dominant species in the first five quadrats on the western side (0 - 21 m.). *Carex acutiformis* then grows almost exclusively before it is replaced by *Stachys sylvatica*, *Urtica*, *Impatiens*, *Petasites* and *Arrhenatherum elatius* on the eastern bankside. Some *Valeriana officinalis*, *Filipendula ulmaria*, *Solanum dulcamara*, *Epilobium palustre*, *Angelica sylvestris* and *Lycopus europaeus* grows with the *Carex* at the waters edge at the base of the eastern bankside. To the south *Myosotis scorpioides* grows amongst the fallen branches of *Salix fragilis* and stands of *Impatiens*.

Transect line 3, W - E, 60 m. from embankment.

Aegopodium podagraria, *Arrhenatherum elatius*, *Cirsium* sp., *Galium aparine*, *Impatiens*, *Lathyrus pratensis*, *Poa trivialis*, *Tripleurospermum maritimum*, *Urtica* and *Vicia cracca* grow close to the field edge. Within the next five metres *Impatiens*, Phalaris and Phragmites become dominants. A mixed fen vegetation grows in the central area of marsh forest. This consists of Angelica sylvestris, Cardamine amara, Carex paniculata, Carex remota, Filipendula ulmaria, Juncus effusus, Lycopus europaeus and Solanun dulcamara, with some Phalaris and Impatiens. There is then a transition to the terminal open water pool with Carex acutiformis (and a little Epilobium palustre) growing around its edge in a dense mass. Some Alisma plantago-aquatica is present by the waters edge. The narrow eastern bankside is densely shaded and at its base consists of Allium ursinum, Myrrhis odorata, Phalaris arundinacea and mosses. The field edge vegetation is composed of Arrhenatherum elatius, Heracleum sphondylium, Poa trivialis, Stachys sylvatica and Urtica dioica.

Transect line 4, W - E, 80 m. from embankment.

The typical field edge vegetation comprising Arrhenatherum elatius, Poa trivialis, Dactylis glomerata, Galium aparine, Tripleurospermum maritimum and Cirsium sp. is replaced by Impatiens glandulifera, Angelica sylvestris, Phalaris and Cardamine amara after the first six metres. Phalaris, Juncus effusus, Solanum dulcamara, Silene dioica and Stellaria nemorum mix with Impatiens glandulifera in the fourth quadrat (15 - 16 m.) Scirpus sylvaticus was the dominant species in the next quadrat (19 - 20 m.) with associated fen species such as Lycopus europaeus, Solanum dulcamara, Galium palustre, Carex remota, Carex vesicaria and Cardamine amara. Impatiens and Galium aparine are still present. Iris rises above the Scirpus sylvaticus in isolated clumps further to the north with tufts of Carex paniculata. Holcus mollis, Cirsium palustre and Circaea lutetiana are also present adjacent to the transect line. At 20 m. in from the field edge Phalaris and Lycopus are the only herb

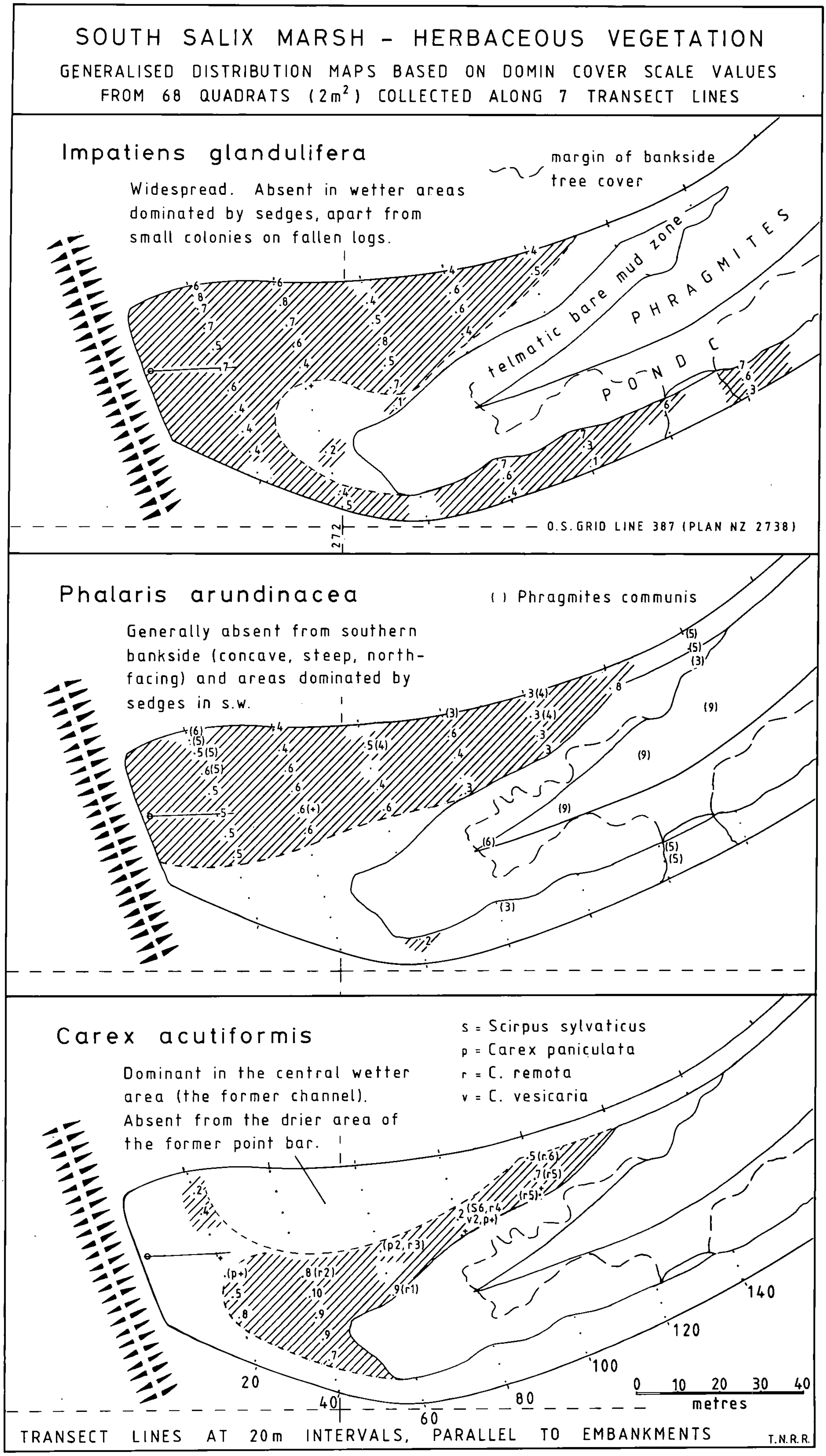

SOUTH SALIX MARSH - HERBACEOUS VEGETATION
GENERALISED DISTRIBUTION MAPS BASED ON DOMIN COVER SCALE VALUES
FROM 68 QUADRATS (2m²) COLLECTED ALONG 7 TRANSECT LINES
Impatiens glandulifera
Widespread. Absent in wetter areas dominated by sedges, apart from small colonies on fallen logs.
margin of bankside tree cover
telmatic bare mud zone
PHRAGMITES
POND C
O.S. GRID LINE 387 (PLAN NZ 2738)
272
Phalaris arundinacea
( ) Phragmites communis
Generally absent from southern bankside (concave, steep, north-facing) and areas dominated by sedges in s.w.
Carex acutiformis
s = Scirpus sylvaticus
p = Carex paniculata
r = C. remota
v = C. vesicaria
Dominant in the central wetter area (the former channel). Absent from the drier area of the former point bar.
20
40
60
80
100
120
140
0 10 20 30 40
metres
TRANSECT LINES AT 20m INTERVALS, PARALLEL TO EMBANKMENTS
T.N.R.R.

Fig.4.7

layer species, with mosses and Hieracium perpropinquum on the fallen branches. Immediately following this is a shallow open water zone that dries out in late summer to form an expanse of bare mud. Beyond the tree cover is the southernmost part of the Phragmites on Pond C. There is more open water next to the eastern bank with fallen willows blocking the channel. The eastern bankside has the floristic composition typical of this shaded, steep slope with Impatiens, Urtica, Stachys and Galium aparine and common grass species such as Poa trivialis.

The zonation and stratification of the vegetation is, as Griffiths points out (1932 p.121), difficult to fix accurately. Where the plants have similar vertical ranges with respect to h.w.m. there is much overlapping between fen species. This is the case in the South Salix Marsh, resulting in communities with great variability. For example, Phragmites grows at the field edge and in small pools where there is less tree cover but is then absent until the central unshaded open water to the north east of this marsh forest, while Impatiens grows in abundance next to the field edge and beneath the shade of the marsh forest in great masses. However, a general zonation can be seen from field edge plants to those tolerant of shade and moisture, then to mixed communities of fen species and finally to the sedge swamp (where there is tree cover around the deeper water) or reedswamp (in the more open areas) of the telmatic zone and beyond l.w.m.

4.3 WATER ANALYSIS

The marsh is still a neutral water habitat as in 1929. The water sampled had a specific conductivity of between 400 and 650 micro mhos/cm. Both pH and conductivity readings are

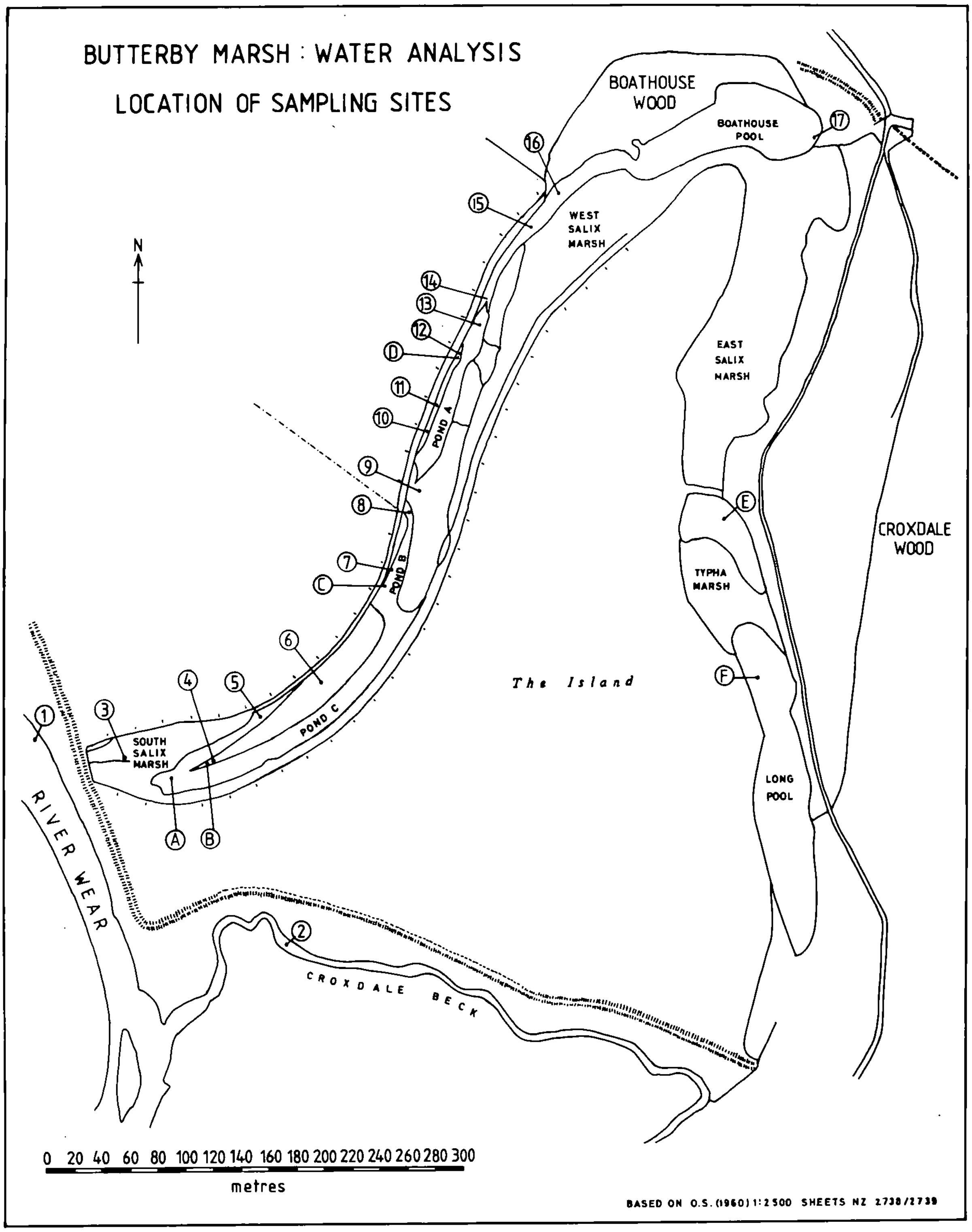

BUTTERBY MARSH : WATER ANALYSIS
LOCATION OF SAMPLING SITES
BOATHOUSE WOOD
BOATHOUSE POOL
WEST SALIX MARSH
EAST SALIX MARSH
TYPHA MARSH
CROXDALE WOOD
The Island
LONG POOL
SOUTH SALIX MARSH
POND A
POND B
POND C
RIVER WEAR
CROXDALE BECK
N
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
metres
BASED ON O.S. (1960) 1:2500 SHEETS NZ 2738/2739

Fig.4.8

TABLE 4.1 WATER ANALYSIS 1929 (SUMMARISED FROM GRIFFITHS 1932)

Site Description	pH
CROXDALE WOOD, OUTFLOW INTO LONG POOL	8.5
LONG POOL BOATHOUSE WOOD, WOODSIDE MARSH POOL, POND A DEEPER PART	7.0 - 7.5
OUTFLOW CHANNEL (POND C)	7.0 - 7.5
TYPHA MARSH, IRIS MARSH, SMALLER SHALLOWER POOLS	6.5 - 7.0
EAST SALIX MARSH. S.end (S. cinerea) W. side (pure E. limosum)	6.5

The seasonal fall in water level was: 1927, 1928 2 ft; 1929 2ft. 9 ins; 1930 9 ins.

TABLE 4.2 WATER ANALYSIS (1) pH and Conductivity of Selected Sites

Site No.	SITE DESCRIPTION	DATE	TEMPERATURE OF SAMPLE (°c)	pH	SPECIFIC CONDUCTIVITY MICRO MHOS/CM.
1	River Wear	27.5.82	15°	8.1	1012.
1	River Wear	31.5.82	15°	8.2	1230.
2	Croxdale Beck	31.5.82	15°	8.4	2500.
3	N. end Orange outflow stream South Salix Marsh	27.5.82	15°	7.2	425.
4	80 m. from embankment W. side. <u>Phragmites</u>. Marsh	27.5.82	15°	6.9	370.
5	120 m. W. side Stagnant pool near field edge. <u>Populus</u> cover	27.5.82	14°	7.3	379.
6	180 m. W. side <u>Phragmites</u> Marsh (Pond C)	27.5.82	16°	7.3	441.
7	260 m. W. side Pond B. <u>Populus</u> cover	27.5.82	15°	7.4	595.
8	300 m. W. side <u>Alnus cover</u> open water	27.5.82	15°	7.8	437.
9	320 m. W. side <u>Phragmites</u> Marsh Pond B/C <u>J.effusus</u>, <u>R. hydrola pathum</u>, <u>A.plantago-aquatica</u>	31.5.82	26°	7.5	600.
10	360 m. W. side <u>Iris</u>. <u>Alnus</u> cover. Pond A.	31.5.82	28°	7.5	610.
11	380 m. W. side <u>J.effusus</u> zone edge. Pond A.	31.5.82	28°	7.5	630.
12	420 m. W. side <u>Iris</u> - <u>Typha</u> mix. Pond A.	27.5.82	15°	7.7	455.
13	440 m. W. side Open water. Pond A.	31.5.82	20°	7.3	517.
14	460 m. W. side <u>Iris</u>.	31.5.82	15°	7.1	507.
15	520 m. W. side <u>Phragmites</u> - <u>Iris</u>. <u>S.cinerea</u> cover.	31.5.82	23°	7.5	562.
16	540 m. W. end of Boathouse Pool. <u>C.riparia</u>. <u>Iris</u>	31.5.82	21°	7.3	530.
17	E. end Boathouse Pool. Pure <u>Equisetum fluviatile</u>	31.5.82	15°	7.5	630.

TABLE 4.3 WATER ANALYSIS (2) [PPM]

Site No.	Site Description	Date	Na	K	Mg	Ca
A	60m. from embankment. South end of Pond C W. side (South Salix Marsh)	19.8.82	13.54	2.4	16.0	50.2
B	80m. from embankment. South end of Pond C W. side (South Salix Marsh)	19.8.82	14.07	1.3	17.4	50.9
C	240m. from embankment. Pond B. *Populus* cover W. side	19.8.82	14.39	2.6	17.9	57.9
D	420m. from embankment. Pond A. *Alnus* cover W. side	19.8.82	14.23	0.8	18.1	63.0
E	Typha Marsh. Stagnant pool	19.8.82	28.05	10.0	95.0	343.0
F	Long Pool. Open water	19.8.82	14.88	5.2	22.7	51.8

SEASONAL FALL IN WATER LEVEL > 50 cm.

very different to the values obtained on the same days in the field from the water of Croxdale Beck and the River Wear, which flow adjacent to the marsh but are separated by the embankments. The River Wear water was more alkaline than that in the marsh and had a specific conductivity approximately twice its value. Croxdale Beck had a higher pH than the R. Wear and also a higher specific conductivity. The results show that the marsh has a much lower concentration of mineral ions than the habitat usually experienced by river plants along the Wear. The diversion of the river water from this old channel meant a replacement of polluted water by water from local run off, relatively unpolluted.

There is little variability between the water that was sampled for pH and conductivity under different plant communities and at different locations in the marsh.

The chemical analysis for the cations Na, K, Mg and Ca in the water again showed little variation within the marsh, apart from a much higher value for all four cations in water from a stagnant pool in the Typha Marsh. This is probably due to a concentration of mineral salts due to the evaporation of water. This may be an important habitat factor for the aquatic and fen species at the marsh.

Pigott and Wilson (1978) suggested that the vegetation at Esthwaite Water was changing in response to increased input of Nitrogen and Phosphorous. N/P variations might be found between the cattle poached eastern part of Butterby Marsh and the western side which lies between two arable fields. Run-off from the fields may bring in enrichment of minerals from fertilizer sources. The present figures provide a basis for monitoring future change.

TABLE 4.4 CONCENTRATIONS OF SELECTED CATIONS IN WATER SAMPLES FROM RIVER WEAR

(Courtesy of J. D. Wehr, Botany Dept. Durham)

	Na	K	Mg	Ca
Examples:				
May 1981	87.8	9.6	31.2	78.
August 1981	154.	-	44.	108
1980-81 Min.	43.9	-	15.1	46.8
1980-81 Max.	203.	-	44.	108.

Concentrations in mg l^{-1} (ppm) for waters filtered through 0.2 μm Nuclepore filter. Over 1980-81 concentrations varied greatly, as is typical. K is not analysed yearly.

Figures for Na, K, Mg and Ca are generally higher in the samples from the River Wear compared to the samples from the open water of the ponds (the stagnant pool had a very high concentration of Ca and Mg). The samples of pondwater were not filtered and figures are for "total waters". Further comparative work would be interesting as it would seem the water chemistry of the ponds in the marsh is very different to that of the adjacent River Wear and Croxdale Beck. Water samples should ideally be collected from all three sites at the same time as concentrations vary greatly over very short time periods. The aquatic and fen plant communities of the marsh would seem to experience a less "polluted" habitat than those growing beside the modern river and its tributaries.

The seasonal fluctuation in water depth is large. A marker placed in the form of a bamboo cane near the 140 m. marker, west bankside, 10 m. from the field edge, recorded a fall of at least 50 cm. The area completely dried out. Future monitoring of water levels would have to be made at a deeper point in the pond system.

4.4 AGE OF MARSH FOREST TREES

The purpose of the tree boring study was to age the marsh forest trees and the bankside trees to determine the dates at which the marsh began to develop swamp carr vegetation and to see if any of the original riverbank trees were still present.

The alders at the west side of Pond A were found to be between 27 and 40 years old. However, the stems are growing up from thick basal trunks and it is likely that they have been cut in the past, perhaps a number of times. The bankside trees were not marked on the 1929 maps and a photograph of the "Great Rumex Marsh" from the western bankside of Pond A does not show the presence of alder or hawthorn trees. A comparable photograph today would be obscured by the presence of the trees. However, trees in similar locations are marked on the first edition Ordnance Survey map (1857) which does suggest that the original riverbank trees have been cut and regrown perhaps several times. Hawthorn trees were not bored because the wood is very hard.

A large _Salix fragilis_ located 100 m. from the embankments along the eastern edge of the _Phragmites_ marsh was found to be 109 years old. The size of this tree is untypical as those growing by the waters edge have often collapsed, and block the deepest part of the old channel which forms Pond C.

Young stems grow up from them, producing cover which may shade out the _Phragmites_.

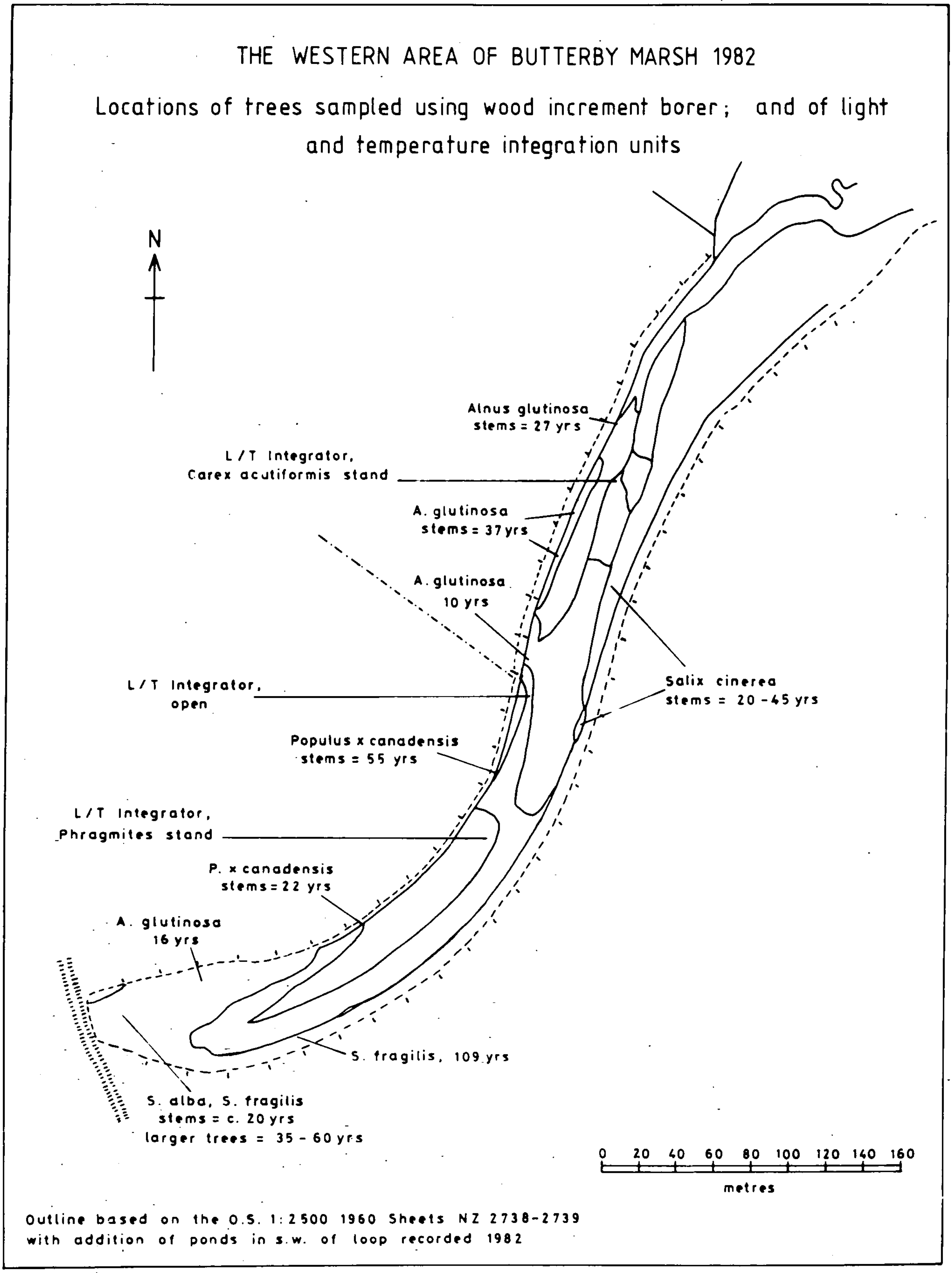

THE WESTERN AREA OF BUTTERBY MARSH 1982
Locations of trees sampled using wood increment borer; and of light and temperature integration units
N
Alnus glutinosa stems = 27 yrs
L/T Integrator, Carex acutiformis stand
A. glutinosa stems = 37 yrs
A. glutinosa 10 yrs
L/T Integrator, open
Salix cinerea stems = 20 - 45 yrs
Populus x canadensis stems = 55 yrs
L/T Integrator, Phragmites stand
P. x canadensis stems = 22 yrs
A. glutinosa 16 yrs
S. fragilis, 109 yrs
S. alba, S. fragilis stems = c. 20 yrs larger trees = 35 - 60 yrs
0 20 40 60 80 100 120 140 160
metres
Outline based on the O.S. 1:2500 1960 Sheets NZ 2738-2739 with addition of ponds in s.w. of loop recorded 1982

Fig. 4.9

The Populus x canadensis stems on the west side of Ponds B and C are, respectively, 55 and 22 years old. Their large basal trunks that have collapsed into the water indicate a much longer presence. Many of the original bankside trees seem to have collapsed, especially the willows. The South Salix Marsh is an area with many old, fallen willows from which new stems grow.

In the South Salix Marsh many young Salix alba and Salix fragilis stems are present, sometimes as separate trees not growing from old trunks. These are aged about 20 years. The larger Salix trees are aged between 35 and 60 years. The very large willows with wide basal trunks have collapsed. It is difficult to determine their age because the inner wood is soft and decayed which prevents the tree borer from gripping it. Sampling only showed that such trees were a minimum of thirty years old.

The young Alnus glutinosa trees colonising below h.w.m. on Ponds B and C amongst the Phragmites were inaccessible. Similar sized alders at the bankside were bored and found to be between 10 and 15 years old. The Salix cinerea bushes that are colonising on the eastern side of Ponds A and B consist of many young stems but older, thicker bases. Those stems sampled ranged from between twenty and forty-five years old. The Salix cinerea bushes, from map evidence, do not seem to have noticeably extended their geographical range since 1929 on the eastern side of Ponds A and B.

It was not possible to distinguish an "advancing front" of young colonizers anywhere at the study site. The extension of the range of marsh forest has not proceeded as rapidly as the extension of reedswamp at the study site.

4.5 RESULTS : LIGHT AND TEMPERATURE EXPERIMENT

LOCATION	P.A.R. ($\mu E\ m^{-2} s^{-1}$)	T (^{o}C)
Open (Pond B)	142.0	-
Carex acutiformis stand (Pond A)	38.50	13.78*
Phragmites stand (Pond C)	9.51	15.49

* Difficulty in reading result

\- Equipment malfunction

The figures quantify the amount of shade produced by the sedge stand and the reed stand. The stand of *Carex acutiformis* reduced the amount of photosynthetically active radiation (P.A.R.) reaching the basal litter layer to 27% of its level in the open. The *Phragmites* stand reduced the amount of P.A.R. to only 6.6% of its level in the open.

The labels that were placed on the black boxes were written on paper cut from a large green-brown envelope and covered with plastic adhesive film. Those on the different boxes all faded to different degrees, that from the open monitor most and that from the *Phragmites* least. This gives further evidence for the shading effect of the two types of vegetation.

It is clear that the *Phragmites* casts a dense shade which few species can tolerate. The great number of stems/m^2 is probably more important than leaves/stem in producing this effect. The dense root and rhizome system may also reduce the ability of other species to grow amongst it.

Mixed communities occur where light can penetrate laterally or where the reed or sedge stands grow less vigorously. Such situations occur at the junction with open water or with high water mark and the bankside. Mixed communities are found where tree branches have fallen into the *Phragmites* at the pond water edge as on Pond B. In this case a floating raft or mat has built out and a specimen of *Sorbus aucuparia* has established itself. There is an understory of *Ribes nigrum*, *Epilobium palustre* and *Lycopus europaeus*, with seedlings of *Cardamine* and bryophytes on the twigs and fallen branches of *Salix fragilis* and *Populus*. Further into the *Phragmites* no other plants or seedlings occur.

Calystegia sepium, *Galium palustre* and seedlings of *Angelica sylvestris* and *Cardamine* are sometimes found growing amongst the *Phragmites* within one metre of the bankside edge.

The temperature reading from the sedge community was problematic in its retrieval and must be viewed with some caution. However, if it is accurate, the overall mean temperature under the *Phragmites* was higher than that under the sedge community. This could be accounted for by greater radiative loss at night and greater windchill because of greater exposure. The sedge community only grows to between one third and one half the height of the *Phragmites*. The closed canopy of the *Phragmites* may result in a more constant temperature and light environment.

It might have been expected that the greater insolation available to the more exposed temperature sensor in the sedge community would have produced a higher mean temperature. The effect of the water in modifying temperature extremes must be emphasised. Both temperature sensors were approximately 50 cm. above mean water level.

Unfortunately, no figure for mean temperature was recorded from the open due to equipment malfunction. Had the reading been available it might be expected that it would be less than the two recorded readings if the change from a sheltered to an exposed environment results in lower mean temperatures, as the trend in the above figures suggests. This would presumably be due to windchill, and greater radiative loss at night.

Water temperatures from samples of surface water collected in beakers and analysed immediately in the field for pH and specific conductivity were, in late May, approximately 15°C in the early morning, but rose to 28°C at noon. The air temperature at ground level was as high as 40°C at noon.

Overall, the temperature experiment was less successful than the light experiment due to equipment malfunction. However, the light experiment was the main focus of interest, and results were successfully obtained.

4.6 DISCUSSION

The western area of Marsh that was selected for study does not have many of the aquatic and fen species recorded in the preliminary survey of the Marsh.[1] For example, *Caltha palustris*, *Oenanthe aquatica*, *Scirpus lacustris*, *Ranunculus hederaceus* and *Adoxa moschatellina* are absent from the western Marsh and others such as *Mentha aquatica* occur only infrequently. Many additional species recorded by Griffiths at Butterby occurred in the eastern marsh area which was not intensively studied in 1982 and this may explain their absence from the

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[1] (made in the present study).

present species list. The vegetation of the eastern marsh has been grazed and trampled by cattle in many places, although one "natural" change noted was the spread of Scirpus lacustris at the north end of the Long Pool.

The western area of the Marsh comprising the study site is now dominated by Phragmites, which has spread dramatically since 1932 across the more open areas, and forms monodominant stands. It would correspond to a C - strategist (competitor species) in Grime's (1979) terminology since it has become quickly established and grows at great densities, casting a shade that few other species can tolerate. Haslam has noted that normal succession is barely noticeable in dense stands (Haslam 1965, 1972 : 591) although it may be suppressed by shading from marginal trees as they increase in height.

Rumex hydrolapathum was described as the "dominant herbaceous plant of the Marsh" in 1932 by Griffiths. It formed, with Equisetum fluviatile, one of the largest Marsh communities. Both have now greatly diminished in their cover-abundance at the study site. Their reduction can be partly attributed to the advance of the Phragmites, although other factors may be responsible for the loss of Equisetum from the edges of the ponds in areas that are still open water rather than reedswamp. Equisetum fluviatile still occurs in abundant pure stands in the East Salix Marsh.

There has been no significant contraction in the shape of the ponds, which represent the deepest part of the river's course on the outside of meander bends. These areas of open water may not be colonised by the Marsh vegetation for a long time, although there seems little reason why the Phragmites should not continue to spread along the shallow sides of the old river channel. It completely fills the channel where it replaced Equisetum fluviatile, but has not extended the vegetational limits. As certain interesting species such as Rumex hydrolapathum (for which Butterby Marsh is one of the few suitable localities in County Durham)[1] are disappearing and this part of the Marsh is being diminished in its species richness, there may be a case for controlling the spread of Phragmites.

Less change has occurred in the distribution of the Marsh forest. The area of carr has not significantly been extended although isolated young tree species occur within the central area of Marsh at a few locations.

Many additions were made to the list of species in the South Salix Marsh. Some may have simply been unrecorded in the study published in 1932. Scirpus sylvaticus was only previously recorded for the eastern area of Marsh. It is widespread throughout the British Isles but has a scattered distribution and Butterby Ponds is one of these favourable sites.

A major change to the herb layer vegetation of the South Salix Marsh has been the spread of Impatiens glandulifera[2] which has replaced the dominance of the small reed Phalaris arundinacea. Its arrival at Butterby seems to post date the 1932 study.

Impatiens glandulifera is not mentioned in the Flora of Northumberland and Durham (Baker and Tate 1868). The Flora of North Yorkshire (Baker 1906) only records Impatiens Noli-me-Tangere, "an occasional straggler from garden cultivation", but this would not be confused with I. glandulifera due to its yellow flowers. Kent's "Historical Flora of Middlesex" places its first record for the London area as 1855 (Phytologist N.S.

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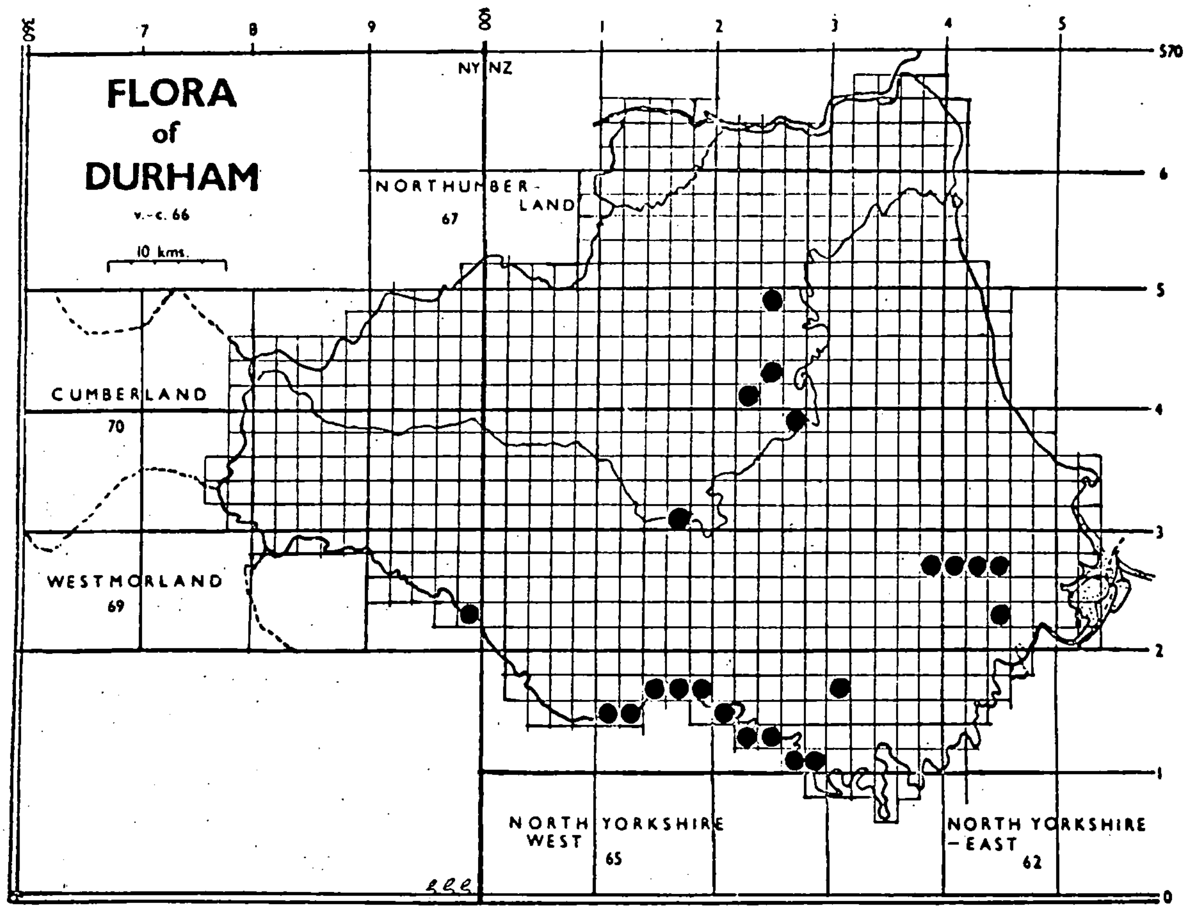
[1] Rev. G. G. Graham pers. comm.

[2] Introduced species. A native of the Himalayas.

Distribution of Scirpus sylvaticus L. and Impatiens glandulifera Royle in County Durham (courtesy of G.G. Graham).

Scirpus sylvaticus



Impatiens glandulifera

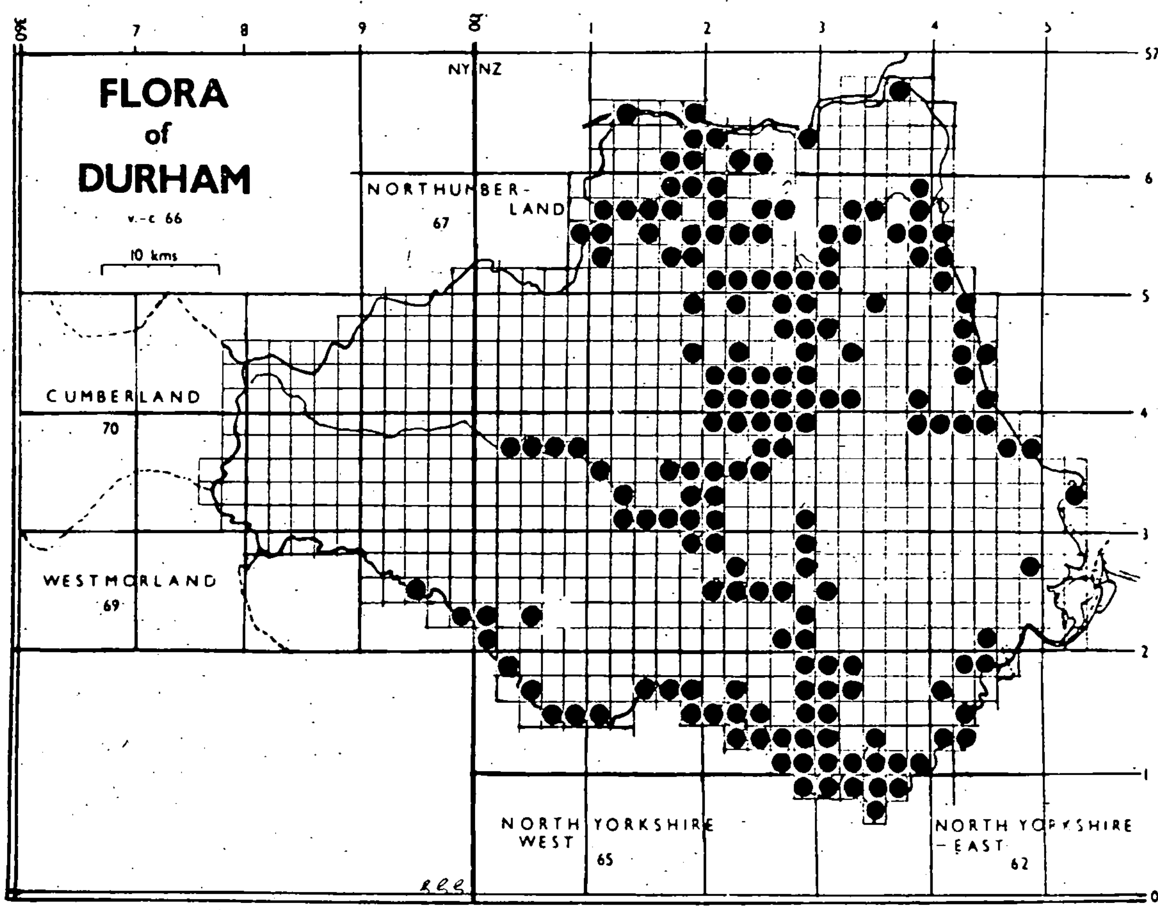


Fig. 4.10

1 166). It was subsequently mentioned in the Journal of Botany in 1900 (38 pp 50, 87 - 88, 278, 445) and 1901 (p.184). The account in volume 38 included a record from Durham City by C. B. Clarke, who had noted the species there about 1892. "There was a grove of this close to the Prebend's Bridge, high enough to bury the cows."[1]

Impatiens glandulifera is now abundant on the banks of the Wear. Its major spread took place at least 25 years ago.[2] Its distribution in County Durham is mainly concentrated along the banks of rivers, streams and ponds and on damp waste ground. It may continue to spread at Butterby Marsh in the mixed fen communities replacing other species such as Phalaris arundinacea, due to its rapid growth, great height (> 2m.) and the greater amount of cover per plant.

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[1] I am grateful to the Rev. G. G. Graham for guiding me to the literature. The original volumes of these journals are held at the British Museum.

[2] Mr. J. Crosby, Mr. J. Richardson, Dr. B. Huntley, pers. comm.

CHAPTER 5 RESULTS : THE MARSH SEDIMENTS

5.1 PREVIOUS WORK

5.2 RESULTS OF SAMPLING THE SEDIMENT BENEATH DIFFERENT PLANT COMMUNITIES

5.3 INTERPRETATIONS

1. Different substrates.
2. Depth of unconsolidated sediment.
3. Amount of Organic Matter accumulation beneath different plant communities.
4. Succession.

5.4 RESULTS OF CROSS-CHANNEL STRATIGRAPHIC PROFILE

1. Levelling.
2. The pH and the vegetation along the transect line.
3. Description of stratigraphy of transect line cores.
4. Macrofossil content of transect line cores.

5.5 PHYSICAL/CHEMICAL ANALYSIS OF ONE CORE

1. Particle size.
2. Organic Matter content.
3. pH reaction.
4. Mineral Analysis - Results:- Grey Silt, Yellow Silt, Basal sand, Upper sand.
   Discussion : Siderite, Fluorite.
5. Metal content.

5.6 INTERPRETATIONS OF THE STRATIGRAPHY : THE ORIGIN OF THE SEDIMENTS

1. Hypothesis 1.
2. Hypothesis 2.
3. Alternative hypotheses.
4. Further Work.

5.7 SUMMARY

CHAPTER 5 RESULTS: THE MARSH SEDIMENTS

5.1 Previous Work

Griffiths gives an account of the sediments at Butterby Marsh (1932 : 109, 126).

> "The surface layers of the soil of the river plain through which the channel of the Marsh runs, are composed of sandy clay silts almost entirely devoid of pebbles. Sections through the deposits of the river plain are to be seen in the south arm of the loop where the Croxdale Beck has cut a deep channel down through the beds. The sections show 5 - 6 ft. of sands and clay silts above.
>
> The vegetation of the Marsh, however, does not grow directly on the clay silt but on a layer of autochthonous organic detritus which varies from 9 in. to as much as 2 ft. in thickness. The upper layer of the detritus contains more or less recognizable fragments of the vegetation from amongst which the sample of detritus was taken, but the lower layers consist of minute amorphous particles, dark brown, grey or black in colour forming a black mud.
>
> Among the _Rumex_ plants at the south end of the East Salix Marsh (see also p.126) and at the south end of the Typha Marsh, the detritus is about 9 in. thick; among the _Nuphar_ plants in the Long Pool the thickness is about a foot; in the middle of the _Typha_ society in the Typha Marsh the mud is from 1 ft. 6 in. to 2 ft. thick.
>
> By means of a mud sampler of special design, it was found that the black mud layer of the Typha Marsh overlay a stratum of grey clay 3 ft. thick, passing down into

yellow silty clay 1 ft. 6 in. thick. Below this lay pebble beds that the mud sampler was unable to penetrate.

The layer of grey clay contained abundant fragments of the rhizomes, roots and shoots of Equisetum limosum (E. fluviatile) but they were absent from the yellow clay silt. As Equisetum does not occur in the present surface layer black mud, the grey clay stratum probably represents a former surface of the Marsh which was covered with Equisetum (see p.126).

The succession of sediments underneath the Typha Marsh is not the same as that of the river plain through which the channel of the Marsh runs. The sediments which fill the channel of the Marsh, namely clay and clay silt, have probably been deposited from the water of the river when the rate of flow of the current was diminished on entering the long and almost level reach of the old loop."

P.126 "........ The vegetation is making a new substratum out of autogenous products of decay, and the floor of the Marsh is being raised and the relative position of the level of H.W.M. is being changed. The accummulation is most marked in the Rumex-Equisetum community, where the bulky rhizomes of Rumex tend to grow on top of one another.

A hole was dug in the south end of the Rumex-Equisetum Community of the E. Salix Marsh in the summer of 1929 when the water level was abnormally low, and the following stratification of deposits was found:

(a) Stratum about an inch thick, consisting of living rhizomes of Rumex covered with, and embedded in, dense masses of Mnium and Hypnum.

(b) Stratum from 3 - 5 in. thick, consisting of three successive layers of old rhizomes of Rumex, embedded in finely divided black detritus. The old rhizomes were black, hard and semi carbonised.

(c) Stratum 7 - 9 in. thick, consisting of dark coloured finely divided detritus, densely penetrated by living and dead rhizomes of Equisetum limosum.

(d) Basal stratum of clay silts.

The stratification indicates that at this particular spot there has been an accumulation of autochthonous detritus to the extent of about 1 ft. during the period of 100 years which has elapsed since the Marsh was formed. The invasion of the Rumex-Equisetum community by Salix fragilis (pp. 115, 116) is probably a result of the increase in the height of the surface by autogenous accumulation."

Following Griffith's account of the Marsh sediments it was decided to re-examine the sediment under different plant communities. The aim (as outlined in the introduction) was to investigate substrate type, succession between plant communities as revealed by the macrofossils, depth of unconsolidated sediment, and the amount of organic matter that had accumulated under the different plant communities.

The sites sampled were not at the same locations as those examined previously. The aim was to trace the development of the Marsh at the site selected for study (the western area). It would be difficult to assess the amount of organic matter that had accumulated during the last 50 years due to local variability and the problems of locating the exact position previously sampled. However, if a marker horizon could be found within the stratigraphic layers that could be demonstrated to be a riverine deposit, this would enable the rate of infill over the last 170 years to be determined, and also the amount of differential infill under different plant communities due to litter accumulation and slope wash.

5.2 Results of Sampling the Sediment beneath different Plant Communities

Eight sites were investigated, the locations of which are marked on the reference map. The detailed descriptions of each core, and the scheme used (that proposed by Troels-Smith, 1955) are given in the Appendix. A brief verbal description of the stratigraphy is given below.

In addition to these eight sites others were selected for investigation, but results could not be obtained due to compaction of sediment. These were the terminal Phragmites at the S.W. field edge of the South Salix Marsh, the outflow stream in the South Salix Marsh, and the small 'Woodside' and 'Middle Pasture' marshes. The latter two were thought to be river features in the flood plain and it was hoped to be able to compare the stratigraphy with that of the main marsh system, but this was not possible. Another site, investigated with the clay auger, was the Phragmites on the west side of Pond C. Grey silt was found beneath the immediate root mat.

When the Livingstone corer was used it was not easily possible to sample to great depths[1] and therefore an approximation of the total depth of the deposit was not determined.

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1 See methods section.

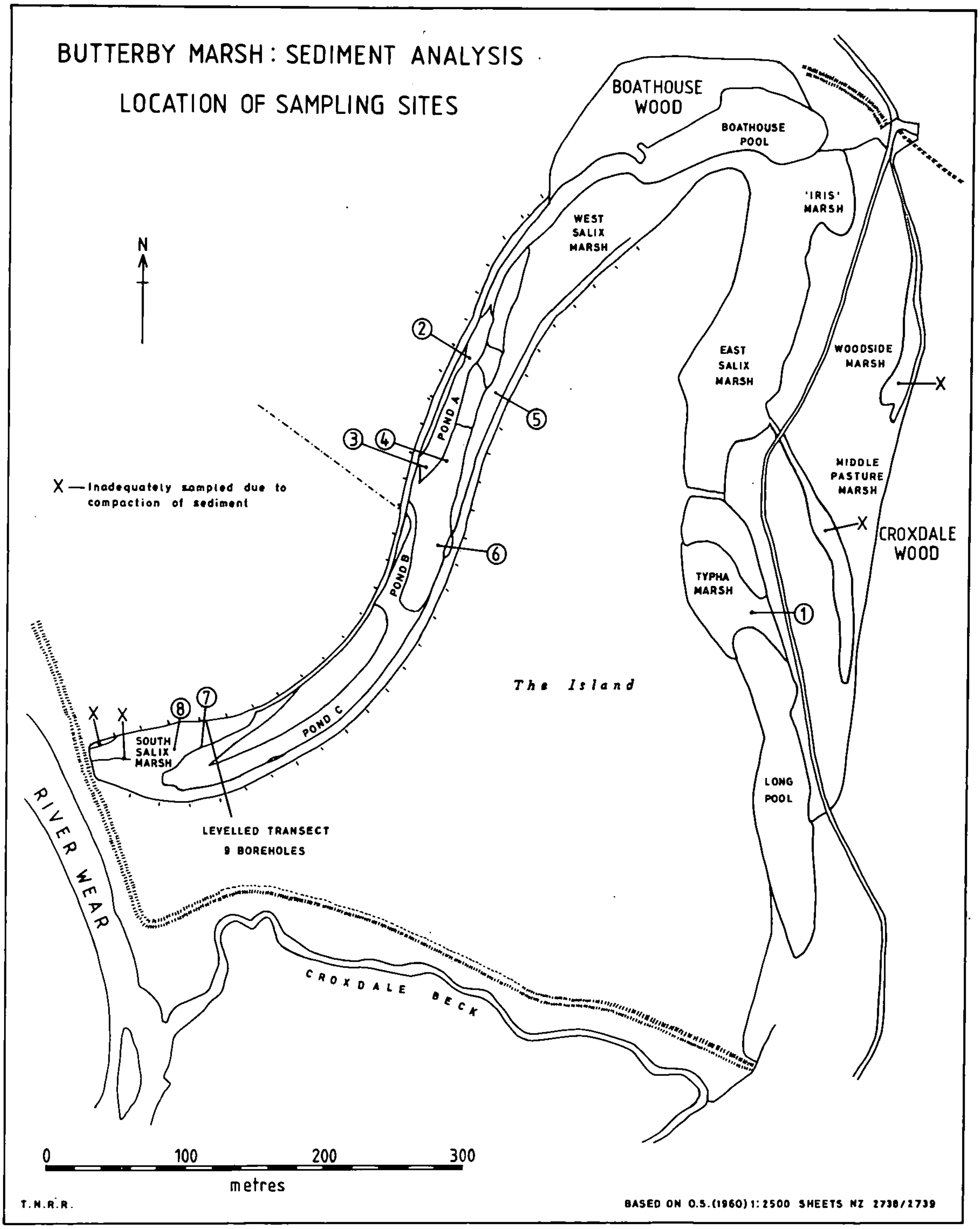
BUTTERBY MARSH: SEDIMENT ANALYSIS
LOCATION OF SAMPLING SITES
N
X — Inadequately sampled due to compaction of sediment
BOATHOUSE WOOD
BOATHOUSE POOL
'IRIS' MARSH
WEST SALIX MARSH
EAST SALIX MARSH
WOODSIDE MARSH
MIDDLE PASTURE MARSH
CROXDALE WOOD
TYPHA MARSH
POND A
POND B
POND C
The Island
SOUTH SALIX MARSH
LEVELLED TRANSECT
9 BOREHOLES
LONG POOL
RIVER WEAR
CROXDALE BECK
0 100 200 300
metres
T.H.R.R.
BASED ON O.S.(1960) 1:2500 SHEETS NZ 2738/2739

Fig.5.1

5.2.1 Description of Each Core

Core 1 "Typha Marsh" (Livingstone) Water depth 30 cm.

The top layer (0 - 14 cm.) of sediment was composed of a black-brown, coarse-detritus gyttja and the living stems and roots of *Carex* sp. and *Typha* latifolia. From 14 - 55 cm. depth the deposit consisted of a dark grey silt which was well laminated with light bands. The silt was lighter grey towards the base. This lower layer, mainly inorganic, contained many fine black roots that were impregnated in the silt. The stems and the nodal septa of *Equisetum* occurred with these fine black roots. The roots were of a different nature to the more fibrous and longer roots nearer to the surface of the core. Assessment of whether the stems of *Equisetum* were detritus or turfa was difficult but the latter interpretation seems more probable.

Core 2 Pond A. (Livingstone) Water depth 50 cm. *Nuphar lutea*.

The top 35 cm. of sediment consisted of a semi-liquid, black, fine-detritus gyttja. The next layer, from 35 - 49 cm., had a greater proportion of silt and was less saturated with water. The remains of *Equisetum* were present in it. Beneath this was another black, fine-detritus gyttja, extending from 49 - 62 cm. These uppermost layers contained a slight presence of fine black root fibres. The lowest layer, from 62 - 90 cm., consisted of grey silt and was well laminated with fine light and dark bands.

Core 3 Pond A, Southern end (Livingstone) Water depth 1 m. (Open water)

The top 48 cm. of sediment consisted of a semi-liquid, black, fine-detritus, gyttja. From 48 - 55 cm. grey silt was the main component and this was less saturated. From 55 - 66 cm.

another fine-detritus gyttja was present, which was more saturated than the grey silt above it. Below this, from 69 - 95 cm. was a grey silt that was well laminated with a slight presence of black fine detritus.

Core 4 Pond A, S.E. Corner (Russian). *Phragmites* bed.
Water depth 20 cm.

The Livingstone corer would not penetrate the dense root mat, and the Russian type sampler was used. The top 55 cm. of sediment consisted of a semi-liquid brown gyttja of detritus with roots, that could not be sampled. (Its depth was determined by inference, working upwards from the basal sediment). The next layer, from 55 - 63 cm., consisted of slightly humified and unhumified root systems that were very fibrous and black. The layer from 63 - 73 cm. consisted of a fibrous black root-mat set in silt. Between 73 and 100 cm. the dark grey silt was impregnated with small fine, black, less fibrous roots. The layers from 100 cm. - 130 cm. consisted of dark grey silt. Black layers of fine detritus occurred between 107 - 115 cm. and 130 - 133 cm. Below 133 cm. the stratigraphy consisted of well laminated grey silt. There was a slight presence of fine black detritus within this section. Narrow (3 mm. wide) light yellow bands occurred intermittently. A few black, flattened tubular stem sheaths, 1 - 2 cm. wide, 3 - 4 cm. long and finely striated, were hand picked from between 100 and 200 cm.[1] The Russian type sampler could not be pushed below 200 cm. from the top of the sediment.

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[1] Later identified as *Scirpus lacustris* (*Schoenoplectus* l.) See 5.3.4.

Core 5 Pond A, E. Bankside (Russian). Water depth 30 cm.[1] Iris and Carex acutiformis community, 20 cm. beyond h.w.m.

The depth of sediment sampled was 94 cm., below which the Russian type corer could not be pushed. The top 20 cm. consisted of semi-liquid coarse-detritus gyttja and the living roots of Iris and Carex. From 20 - 50 cm. grey silt with slightly humified, very fibrous, rooted material was found, and some detritus (leaves of Carex, and black, wide, flattened, tubular sheaths, finely striated). The basal layer, from 50 - 94 cm., consisted of grey silt with some clay and a slight presence of fine black roots of Equisetum. Some coarse detritus such as Carex leaf fragments were also found.

Core 6 Pond A/B transition. E. Bankside. (Russian) Water depth 20 cm. 10 m. beyond h.w.m. Phragmites bed.

The top 75 cm. consisted of unhumified rooted material and coarse-detritus gyttja with some silt. That at the top was semi-liquid. After 75 cm. a continuous dark grey silt layer was found which extended to 140 cm., and towards its base this was well laminated. Within it was a small proportion of rooted material and coarse detritus. Flattened black tubular sheaths, wide and finely striated (similar to those mentioned above) occurred at two locations within the 75 - 100 cm. section. The layer below 140 cm. was unpenetrable.

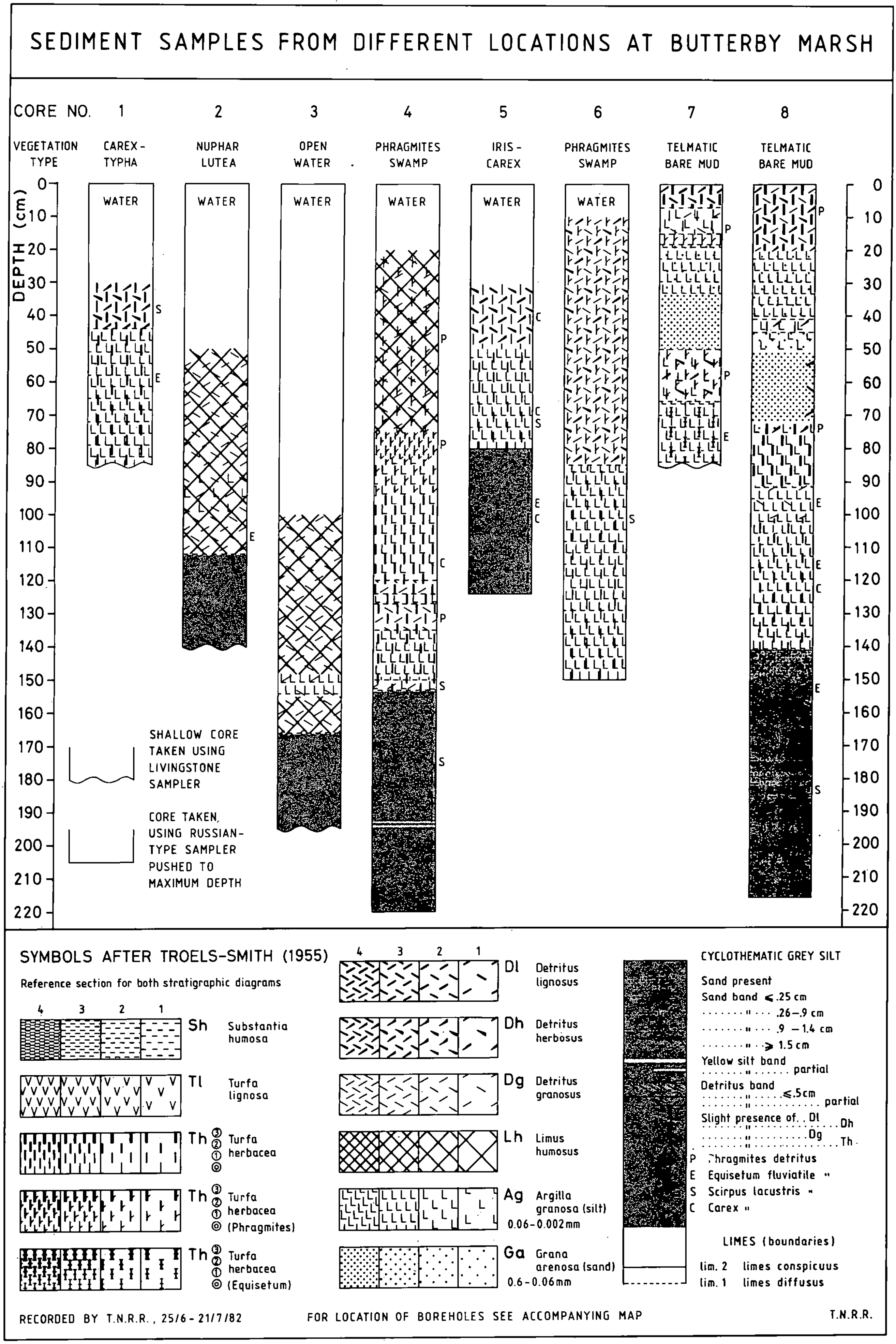
Core 7 South Salix Marsh. 70 m. from Embankment, West Bankside, 30 m. from field edge. (Livingstone). Bare mud surface with Carex acutiformis, C. vesicaria on margins, C. remota on fallen trunk nearby.

The depth sampled was 85 cm., but as the Livingstone was used, sampling to a greater depth was not attempted.

The top 7 cm. consisted of dark coarse-detritus peaty mud with fragments of wood twigs and Phragmites. From 7 - 15 cm. the layer was comprised of silt with unhumified rooted material and fine detritus. From 15 - 18 cm. there was a black coarse-detritus gyttja and slightly humified rooted material. From 18 - 33 cm. there was a silty sand layer, well laminated, with detritus in black bands. From 33 - 50 cm. a thick sand layer occurred, with no visible plant remains. Between 50 and 66 cm. there was a silt layer with the abundant unhumified light brown roots, stem nodes and leaves of Phragmites with black coarse detritus. From 66 - 85 cm. there was dark grey silt with a few laminations of lighter bands and a slight presence of sand. In this were the very abundant remains of the stems (with nodal septa well preserved) of Equisetum fluviatile.

Core 8. South Salix Marsh. 60 m. from Embankment, 20 m. from W. field edge. (Russian). Bare mud surface with Lemna minor, Lycopus europaeus and Carex remota on fringes. Depth sampled: 216 cm.

The first 20 cm. was composed of dark-brown coarse-detritus mud, and wood and Phragmites peat. From 20 - 41 cm. there was a sandy silt with some unhumified rooted material. Between 41 and 45 cm. there was a silt with more rooted material and coarse detritus. From 45 - 51 cm. there was silty sand with particles of coal present. From 51 - 72 cm. a thick sand layer occurred with only a very slight presence of plant remains. Between 72 and 76 cm. there was a sandy silt with the abundant unhumified light brown and pale green stem nodes, leaves, and roots of Phragmites. From 76 - 91 cm. more Phragmites peat occurred, mixed with silt. From 91 - 101 cm. there was a grey silt with some coarse detritus and the abundant nodal septa of Equisetum. From 101 - 141 cm. the grey silt was well laminated, and a small component consisted of fine black roots and the detritus of Equisetum fluviatile. Between 191 and 216 cm. there was more grey silt with some clay. It was well laminated, with recurrent thin sand bands and light yellowish silts. In this there was very little detritus and no rooted material. The sampler could not be pushed below a depth of 216 cm.



SEDIMENT SAMPLES FROM DIFFERENT LOCATIONS AT BUTTERBY MARSH
CORE NO. 1 2 3 4 5 6 7 8
VEGETATION TYPE
CAREX-TYPHA
NUPHAR LUTEA
OPEN WATER
PHRAGMITES SWAMP
IRIS-CAREX
PHRAGMITES SWAMP
TELMATIC BARE MUD
TELMATIC BARE MUD
DEPTH (cm)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220
WATER
SHALLOW CORE TAKEN USING LIVINGSTONE SAMPLER
CORE TAKEN USING RUSSIAN-TYPE SAMPLER PUSHED TO MAXIMUM DEPTH
SYMBOLS AFTER TROELS-SMITH (1955)
Reference section for both stratigraphic diagrams
4 3 2 1
Sh Substantia humosa
Tl Turfa lignosa
Th ③ ② ① ◎ Turfa herbacea
Th ③ ② ① ◎ Turfa herbacea (Phragmites)
Th ③ ② ① ◎ Turfa herbacea (Equisetum)
Dl Detritus lignosus
Dh Detritus herbosus
Dg Detritus granosus
Lh Limus humosus
Ag Argilla granosa (silt) 0.06-0.002mm
Ga Grana arenosa (sand) 0.6-0.06mm
CYCLOTHEMATIC GREY SILT
Sand present
Sand band ≤.25 cm
" .26-.9 cm
" .9 - 1.4 cm
" ≥ 1.5 cm
Yellow silt band
" partial
Detritus band ≤.5cm
" partial
Slight presence of.. Dl
" Dh
" Dg
" Th
P Phragmites detritus
E Equisetum fluviatile "
S Scirpus lacustris "
C Carex "
LIMES (boundaries)
lim. 2 limes conspicuus
lim. 1 limes diffusus
RECORDED BY T.N.R.R., 25/6-21/7/82
FOR LOCATION OF BOREHOLES SEE ACCOMPANYING MAP
T.N.R.R.

Fig.5.2

5.3 INTERPRETATIONS

5.3.1 Different substrates

In all cases the sediment upon which the present plant community is growing is a black gyttja above grey silt into which roots penetrate. It was not possible to show a correlation between plant community type and type of substrate. Water depth seemed to be a more significant factor influencing the type of plant community.

In some locations a thick sand layer occurred beneath this gyttja and silt (cores 7 and 8). Roots were absent from it although they occurred above and beneath it. The sand layer might influence the conditions of growth of the Phragmites above it (e.g. acidity of the soil) but the remains of the same plant beneath it would suggest that the sand does not determine the reed's distribution. Elsewhere Phragmites grows on grey silt without a sand layer.

The literature indicates that Phragmites can be found on a variety of substrates and that it also tolerates a wide range of levels of organic content of sediment or soil, and of pH values (Haslam 1972, 588).

Silt is more nutrient-rich than sand, and clay streams are often eutrophic (Haslam 1978; 120). Haslam (1978; 36) arranged species into groups with similar responses to substrate types. "Where several substrate types occur in one site, each species present is recorded as though it occurred in each substrate type. This shows correctly that habitats of particular particle sizes can support particular species, but it also wrongly implies that each species present grows on each substrate type, which may not be the case, e.g. a particular species may only grow on the silt banks in a gravel stream."

The species that Haslam most closely correlates with fen-peat or organic alluvium include large, deep rooted emergent plants and non-rooted submerged ones, (also correlated with negligible flow), such as Carex acutiformis and Phragmites. Those species best correlated with fen peat that also occur frequently in other soil types include Lemna minor and Potamogeton natans. Those best correlated with soil and mud are Nuphar lutea and species of Potamogeton. However Nuphar lutea and other species often occur on a wider range of soils than those in which they grow well.

Species that Haslam most closely associates with medium grained substrates include Rorippa nasturtium-aquaticum agg., Schoenoplectus lacustris (Scirpus l.), Sparganium spp. and Ranunculus spp. Mosses are most closely associated with coarse substrates (Haslam 1978; 35 - 39).

Many factors will determine the distribution of plants at the Marsh:- water depth and shade would seem to be more closely correlated with different plant communities than substrate, as the substrate is fairly similar within the samples examined.

5.3.2 Depth of unconsolidated sediment

This was not examined when cores were taken using the Livingstone sampler. The Russian type sampler was a more successful tool for this purpose. Depths to which it was possible to sample ranged from 140 - 216 cm. and depended on the strength of the worker(s) and the position of the site with respect to the cross profile of the river channel. It might have been possible to sample to greater depths in some cases using a clay or sand auger with a great number of extension rods and more labour. The impenetrable layer may have been a thick sand layer, river gravel, boulders or bedrock.

At the greater depths sampled, the grey silt became very well laminated. Each fine lamination probably represents a former surface of the top sediment in the channel.

The different types encountered (sand, yellow silt, dark grey silt) presumably represented different environmental conditions such as flow type and sediment source (e.g. long distance or local bankwash).

Interpretation of a marker horizon that represented the event of diverting the flowing river water was not easy, as organic gyttjas alternated with inorganic layers which could have been the products of local input. This problem was examined further in laboratory analyses of the layers within one core selected from those taken along the stratigraphic profile, and is discussed more fully in later sections.

5.3.3 Amount of Organic Matter accumulation beneath different plant communities

The depth of the upper organic layer varies in different cores, but this does not represent a simple relationship to different organic production or litter accumulation rates beneath the different plant communities presently at the site. Many problems of interpretation can be outlined.

The depth of the uppermost black gyttja upon which the present plant community is growing will be influenced by autogenous products of decay and also the washover of fine and coarse detritus from the banksides, and the transportation of fine detritus during high water levels.

The position of a site in relation to mean water level and the cross profile of the river channel will influence the depth of the black organic gyttja. For example, that in the centre of the pond will be the product of slumping of material from the shallower pond margins and will therefore often be thicker. Infill may, therefore, proceed more quickly here so that the ponds may not contract in shape for many years even though infill is going on. Compaction levels will however vary and a greater depth will not necessarily mean greater volume of organic sediment. For example, many of the plant communities around the margins of Pond A extend over the greater water depths as floating rafts of root mats. Underneath these, products of decay will rain down on to the sediment surface and raise it as they accumulate. This organic detritus may be less compact than a telmatic deposit due to being permanently saturated.

As outlined in the previous section, the interpretation of the dates represented within the sediment (the relation to a river or marsh deposit) is crucial to assessing the amount of organic matter accumulation under different communities as organic layers are overlain by inorganic layers. Just as the depth of the top organic layer immediately beneath the present plant community is partly composed of transported material, a lower organic layer may also represent transported detritus in some cases. In other cases these lower layers are partly comprised of rooted material that has accumulated in situ. It may be the product of a different plant community to that growing in the upper organic layer (succession). This may indicate the washing away of the previous plant community or destruction by inorganic sediment deposition above it. But in the single top organic layer it is difficult to separate the remains of different types of plant community due to the semi-liquid condition of this layer at most sites.

The position of the first rooted material is not always clear as some of this may be detritus consisting of root fibres deposited in the grey silt after being transported. Neither is the presence of rooted material a simple guide to the date of deposition of the layer in which they occur, due to the penetration of fine roots from above.

There are some problems of classification of this upper organic layer. The term gyttja (mud) implies transported material in contrast to a peat or turfa that accumulates in situ in telmatic or terrestrial situations. The distinction between a turfa that accumulates beneath a telmatic sedge or reed community and a gyttja of detritus that accumulates beneath an emergent, submergent, or floating-leaved macrophyte community beyond the low water mark is difficult. The latter three communities, unless they occur as floating root mats, will have rooted material (turfa) growing in the sediment, but the products of decay will be transported to the sediment surface and may therefore be classed as detritus.

Many factors influence the depth of the uppermost organic layer and its base is often difficult to determine due to a gradual transition to silt. A simple change over from organic marsh deposits to inorganic riverine deposits was not found. Modern river sediment may have at its surface shingle, sand, silt or black organic mud depending on flow conditions and other factors.

Bearing in mind these problems of interpretation, the depth of the top organic layer and the other organic layers from the samples taken may be summarised as follows.

Cores 1 and 5 have shallow, compacted turfa and detritus beneath sedge communities. They come from marginal communities at the lowest point in the telmatic zone.

Cores 2 and 3 are from deep water sites. They have a greater depth (35 cm. and 48 cm. respectively) of uncompacted fine detritus. Below this other fine-detritus gyttjas occur intermittently within the silt.

Cores 4 and 6 are from Phragmites beds in deep water and telmatic localities. There is a deep layer of fibrous turfa (63 cm. and 75 cm. respectively). Beneath this are fibrous roots set in silt and then fine black roots and some detritus. This may represent a community that Phragmites has replaced.

Cores 7 and 8 are from bare mud patches in the South Salix Marsh. Coarse detritus mud overlies the remains of a Phragmites turfa that is shallow and compacted. At its base this is mixed with sandy silt. At greater depths (33 and 51 cm. respectively) there is a thick (c.20 cm.) sand layer without plant remains. Below this is more Phragmites turfa, in silt, (to 66 and 81 cm. respectively) and then the abundant detritus of Equisetum and fine black roots set in silt extending in Core 8 to a depth of 141 cm. Below this (141 - 216) there is the slight presence of detritus.

Organic infill can, therefore, be shown to be greater in some locations nearer the centre of the old channel but is less compacted and partly due to slumping of material from the banksides. Phragmites beds have greater depths of organic detritus beneath them, but some is probably from the community Phragmites replaced. (Cores 4 and 6).

5.3.4 Succession

In certain localities the comparison of the present mapping with that published in 1932 indicates succession. The examination of plant macrofossils within a core should allow these developments to be traced over a longer time scale.

Macrofossils were hand picked from the dissected cores in the examination of the sediment from these eight sites. The sediments of the 9 cores from the stratigraphic profile were separated by wet sieving (see methods), the results of which are outlined here.

The presence of seeds, fruits and other detritus must be viewed with caution as they are easily transported within a water body, especially if there is flow along the channel (in a river system) or washover from banksides.

The presence of different types of root, rhizome and stem systems is a more accurate guide to succession. However, rooted material is extremely difficult to identify. That encountered ranged from thick and very strong fibrous brown and black material to very fine soft smaller black roots. When large, abundant, identifiable detritus was encountered with this, it gave a guide to the plant community that existed in the locality. The problem of roots penetrating to basal silts from above has already been mentioned.

A description of some of the macrofossils that were identified is given below, with an interpretation of the evidence. Evidence was assessed on a qualitative basis.

Unhumified Phragmites stem nodes and leaves, often light brown and green, together with a characteristic strong, light-brown, root system, were identified from above and below the sand layer in cores 7 and 8 from the South Salix Marsh. Above the upper Phragmites turfa, a coarse detritus mud with woody fragments occurs.

This evidence may be interpreted as follows. A *Phragmites* reedbed previously existed in the area that is now the marsh forest, perhaps connecting the *Phragmites* on Pond C with the terminal *Phragmites* stand at the N.W. field edge of the South Salix Marsh. At some time in the past it was replaced by a deposit of sand that accumulated to a depth of 20 cm. Whether this was a river deposit is investigated further in the next section. Above the sand more silt accumulated and later *Phragmites* again established itself. This was in turn replaced by the herb layer characteristic of the marsh forest as tree cover became established at a later stage in the hydrosere, which shaded out the tall monocotyledon.

In many cores small discs were found that resembled stem nodes of grasses. These were later identified as the nodal septa of *Equisetum fluviatile* when comparisons were made with modern specimens. On one fossil specimen the fringing "teeth" were found. These parts seem to be differentially preserved. They were extremely abundant beneath the *Phragmites* turfa in core number 7 and as they were associated with fine black rooted material it may be assumed that they grew at that location, within the grey silt. This agrees with Griffith's hypothesis that the marsh floor (or river bed) was at some time in the past more extensively covered with *Equisetum fluviatile*. This may, therefore, represent a stage in the hydrosere earlier than the *Phragmites* that preceded the carr at the location of the South Salix Marsh. Whether the *Equisetum* grew at a time when the river was flowing through the channel is difficult to assess.

Other remains that could be seen without the aid of a microscope were wide (1 - 2 cm.) flattened tubular sheaths that were black and finely striated. The smaller examples may have been species of *Juncus*. The larger examples were identified[1] as *Schoenoplectus lacustris*.[2] Some were thought to be part of the below ground rooting systems due to their greater size when compared with modern above ground specimens.

The modern specimens and the fossil specimens were examined together under a microscope, and it seems highly probable that the identification is correct. The width of the flattened tubes is too great for *Equisetum* and the fine striations are of a different nature. The presence of stomata could be used to determine whether they were above or below ground parts, but this was not examined in detail.

Such large black tubular sheaths occurred beneath the *Phragmites* around Pond A (cores 4 and 6) and also in core 5 which was from a sedge community nearby. They occurred in the same silt that contained fine blackened roots. If they do represent a deposit accumulated *in situ* it might indicate that *Schoenoplectus* preceded the *Phragmites* at this location. However, they may represent detritus that could have been transported from long distances if the grey silt is a river deposit.

The core taken on the S.E. side of Pond A (core 4) amongst the *Phragmites* is in an area previously occupied by *Rumex hydrolapathum* and *Equisetum fluviatile* according to the 1929 Survey. Such tubular sheaths were found in the basal layers. The uppermost organic layers beneath the dense root and rhizome system of the *Phragmites* were saturated to the extent that they

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1 With the assistance of Dr. A. GreatRex.

2 *Schoenoplectus lacustris* = *Scirpus lacustris*.

could not be adequately sampled. A layer which should represent the Rumex-Equisetum community could not be determined, although fine black roots were found in the basal grey silts.

Smaller macrofossils were separated from the sediment samples by wet sieving, and isolated from fibrous miscellaneous detritus under a microscope, when analysing the 9 cores taken along the transect line (see next section). Those that could be identified[1] included seeds of Rumex sp., Atriplex sp., Ranunculus sp., Carex sp., Sambucus nigra and Caryophyllaceae sp. In addition, buds of Salix spp. were identified and, in the basal silts, there occurred the fruitstones of Potamogeton natans, Daphnia egg cases and moss leaves (including a specimen of Sphagnum). Unidentifiable miscellaneous detritus always represented the greatest proportion of any sample examined.

These smaller macrofossils were not able to be used to demonstrate succession in the time available. Detailed microscopy on one core of the seeds and fruits in conjunction with the type of rooting systems encountered might enable the plant community that was present at the time of deposition to be more precisely determined. This might be able to be done on a quantitative basis. When dissecting a core with fine "roots" in grey silt it was sometimes difficult to determine whether the remains were roots growing in situ or miscellaneous fibrous detritus. If washed through a sieve the macrofossils were then randomly arranged giving an impression of detritus, whereas in the dissection of a core they gave the impression of a turfa.

Unless gross macrofossils occurred in abundance, such

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1 I am grateful for the help of Dr. A. GreatRex with this task.

as the *Equisetum* and *Phragmites* remains in cores 7 and 8, a deduction was not made concerning succession. Gross macrofossils and stratigraphy were used in the interpretation of the evidence that the sediments contained of succession. Smaller macrofossils occurring amongst miscellaneous detritus often gave conflicting pictures. For example, the *Sphagnum* leaf suggests long distance transport i.e. a river deposit, as *Sphagnum* does not grow at the site at present but occurs in abundance in Weardale, while *Daphnia* egg cases and the fruit stones of *Potamogeton natans* suggest that the sediment was deposited in slow or still water. It must be cautioned that, in a fluvial system, small detritus generated in other types of environment, such as still backwaters, will be washed into the drainage basin from the catchment and transported perhaps over long distances.

Small white twisted particles ($> 425\,\mu m$) were also isolated under a microscope. These were identified by Dr. A. GreatRex as shavings from the split p.v.c. tubing that the cores taken using the Russian sampler were transported to the laboratory in. Other researchers working on macrofossils have previously identified such particles as calcareous material until the origin was demonstrated.

5.4 RESULTS OF CROSS-CHANNEL STRATIGRAPHIC PROFILE

The locations of the previous boreholes were scattered in relation to the cross profile of the old river channel. Additional information on the form of the sediments within the channel was gained from a cross-channel stratigraphic profile produced at one location with a consistent series of bore-holes. This aimed at following stratigraphic layers across the channel to see whether they were persistent horizons, and at accurately correlating these with regard to altitude and distance.[1]

The transect line spanned several types of plant community and a pond. It was located between the two field-edge markers at 84m. from the embankment in the South Salix Marsh on a line running N - S parallel to the embankment at 350^{o} magnetic north.

5.4.1 Levelling

The levelled cross-channel profile showed that the south-eastern field, closest to the deepest part of the surface of the old channel which contained the pond, was 1.6m. higher than the north western field. This corresponds to the characteristic cross profile of a curve on a meander bend, with a "river cliff" nearest the deep water of the channel where there would have been maximum flow velocity and scour. The outside of the curve has a concave bank. On the inside of the curve there is a convex "slip-off-slope" or "point bar" profile, on to which the river in flood would have deposited its load and spilled out on to the fields.

The field named "the island", on the eastern side, is

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[1] The aims have been outlined in the methods section.

a slightly higher area at the point of the transect line.[1] However, a brief levelling exercise between the 329m. E. bankside marker and the 290m. W. bankside marker on a line 113° magnetic north showed that at this point "the island" was 0.189m. below the altitude of the western field. At this section the river is flowing in a fairly straight line. The fields might not have received as much floodwater as the inside of the meander curve at the point of what is now the "South Salix Marsh".

5.4.2 The pH and the Vegetation along the Transect line.

Field measurements of the pH of the sediment or soil subsurface (6 cm. below the surface) were made along the transect line. The method used was that outlined in Section 2.5. Soil was not weighed in the field, but approximately similar volumes were used for each sample tested for its pH reaction.

Table 5.I

DATE	LOCATION (m N of B.M.)	pH	Conductivity	Dominant herb layer species
19.8.82	Pond	7.2	430 μ mhos/cm.	-
"	35 (Borehole 6)	5.6		*Phragmites*
"	40 (Borehole 7)	5.2		(Bare mud)
"	45 (Borehole 8)	6.0		*Lycopus europaeus*
"	50 (Borehole 9)	5.4		*Scirpus sylvaticus*
"	55	6.5		*Impatiens glandulifera*
"	60	5.0		*Impatiens glandulifera*
"	70	5.7		Barley (Field).

[1] There is a possibility that the earth that was used to construct the embankments may have been in part taken from the field near to the South Salix Marsh, which might have influenced the field-level on its northern side.

The soil/sediment samples all gave a pH reaction of < 6.6, including the sample taken from the field, while the pond water had a neutral pH. This acidity may be due to leaching, related to the underlying sand layer (see next section). The soil of the field is also sandy.

The main tree species along the transect line are saplings of *Alnus glutinosa* and *Salix fragilis* in the telmatic zone. *Salix cinerea*, *Salix fragilis*, *Salix alba* and *Alnus glutinosa* are present up to the field edge.

The herb-layer vegetation is similar to that described in section 4.2 for the South Salix Marsh 80m. transect line. *Phragmites* is dominant at Borehole 6. Borehole 7 is located in a bare mud zone where the shading effect of the trees would seem to exclude the *Phragmites*.

Borehole 8 is located at h.w.m. where mosses, *Lycopus europaeus* and *Carex remota* are dominant in the herb layer. *Carex paniculata*, *Carex vesicaria*, *Carex acutiformis*, *Filipendula ulmaria*, *Juncus effusus*, *Solanum dulcamara*, grasses and ferns also grow in this zone nearby.

Borehole 9 has a very mixed vegetation growing around it, consisting of *Scirpus sylvaticus*, *Galium palustre*, *Impatiens glandulifera*, *Lycopus europaeus* and *Heracleum sphondylium*.

At 55m. N of basemark, *Impatiens* is dominant in the herb layer. *Phalaris*, *Urtica*, *Iris*, *Carex paniculata*, *Filipendula ulmaria*, *Circaea lutetiana* and *Cirsium palustre* also grow nearby. *Impatiens*, *Aegopodium podagraria*, *Urtica* and grasses are dominant in the herb layer of the northern field edge.

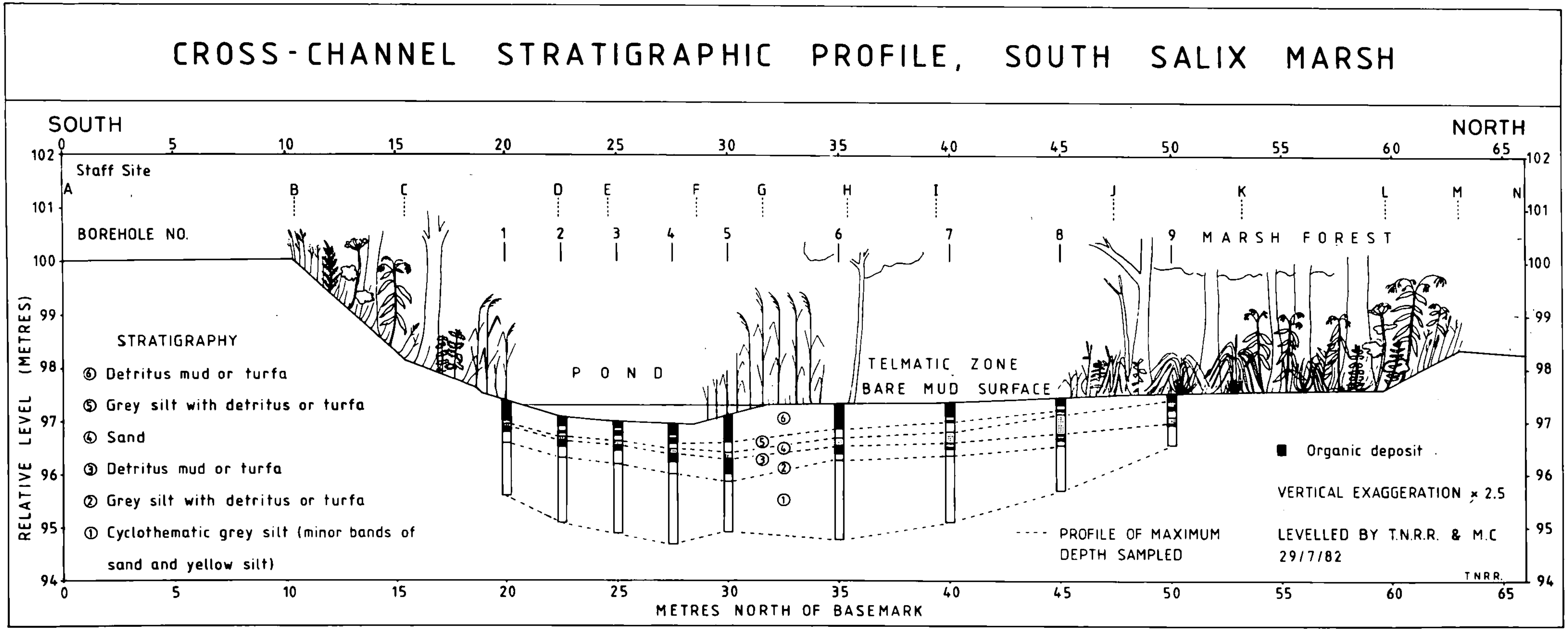
CROSS-CHANNEL STRATIGRAPHIC PROFILE, SOUTH SALIX MARSH
SOUTH
NORTH
Staff Site
A
B
C
D
E
F
G
H
I
J
K
L
M
N
BOREHOLE NO.
1
2
3
4
5
6
7
8
9
MARSH FOREST
POND
TELMATIC ZONE
BARE MUD SURFACE
STRATIGRAPHY
⑥ Detritus mud or turfa
⑤ Grey silt with detritus or turfa
④ Sand
③ Detritus mud or turfa
② Grey silt with detritus or turfa
① Cyclothematic grey silt (minor bands of sand and yellow silt)
Organic deposit
VERTICAL EXAGGERATION × 2.5
---- PROFILE OF MAXIMUM DEPTH SAMPLED
LEVELLED BY T.N.R.R. & M.C
29/7/82
T.N.R.R.
RELATIVE LEVEL (METRES)
102
101
100
99
98
97
96
95
94
0
5
10
15
20
25
30
35
40
45
50
55
60
65
METRES NORTH OF BASEMARK

Fig.5.3

5.4.3 Description of Stratigraphy of Transect Line Cores

Boreholes were sunk regularly at intervals of 5m. along the transect line. Boreholes 2 and 4 were intermediates, sunk beneath the pond, where the sampling interval was decreased to 2.5m. This aimed at altitudinally correlating the stratigraphic layers more precisely beneath the deepest part of the old river channel. Nine boreholes were made in total.

A tenth borehole was attempted between staff site K and staff site L, at 60m. north of Basemark. This was near the field edge on the inside of the meander curve (on the "slip off slope" or "point bar".) The sediment was too compacted for the Russian sampler to be pushed to depths greater than 40 cm. A soil pit was dug, which revealed a sand layer between 24 and 28 cm. depth, and another from 32 cm. - 1m. At 1m. there was a grey silt and clay with roots present in it. The hole rapidly filled with groundwater which suggested that the water table had been reached.

The Russian sampler could not be pushed further than the sand horizon when it was not placed in the soil pit. This might suggest that the profile of maximum depth produced from the nine cores could represent a basal impenetrable sand layer rather than bedrock. Only at one borehole (no. 3) could a hard rock-like basal layer be felt with the sampler.

From the 9 cores successfully obtained, six gross stratigraphic layers that occurred persistently can be defined. Layers were numbered 1, 2, 3 etc. beginning at the base. The layers show a curved rather than an horizontal arrangement in respect of altitude, so that they form a concave pattern similar to the profile of maximum sampling depth. The layers reach greatest altitudinal depth beneath the present pond, although core no. 6, from the telmatic zone, had the greatest depth of sediment that was sampled (254 cm.).

Layer 1 consisted of basal grey silts that were well laminated with fine bands of light grey - yellow silt, and fine bands of sand. The structure can be described as "cyclothematic".[1] Some detritus occurred in this layer, and in some cores there was a slight presence of rooted material.

Layer 2 is a continuum from Layer 1, but consisted of grey silt that had fewer laminations in it. In general there were fewer sand bands. The layer was estimated to consist of up to two parts organic matter. Fine black roots and plant detritus were more abundant than in layer 1.

Layer 3 consisted of a black mud, with an element of turfa or rooted material. In some cores there were the abundant remains of Phragmites stems within this layer.

Layer 4 consisted of almost pure medium-grained quartz sand. This layer gradually thickened towards the "slip-off slope" or "point-bar". At the extreme N.W. of the transect line (Core 9) this layer was difficult to reconcile with the other cores as there were two major thicknesses of quartz sand and numerous minor layers which interspersed black organic and grey silt layers.

Layer 5 consisted of alternating sandy-silt bands and detritus. In some cores roots entered this layer from above, but in general did not penetrate through the sand layer (Layer 4).

Layer 6 consisted of a fine-detritus black mud, saturated with water, from the cores beneath the pond. Beneath

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[1] "At times a deposit may consist of a number of minor layers within which, from bottom to top, the proportion of component layers alternates e.g. sand - sandy clay - clay, or lake marl - lake marl containing gyttja - gyttja etc. Such minor layers are called cyclothems and the structure is called cyclothematic". (Troels-Smith 1955).

this was a layer of brown mud. In the cores from the telmatic zone Layer 6 again consisted of brown mud, saturated with water. There was an element of rooted material in both these areas. In the cores at h.w.m. and beyond (8 and 9) Layer 6 consisted of wood- and fen-peat.

PLATE 4

SEDIMENT SAMPLES FROM TRANSECT LINE BOREHOLES

Description of sample follows numbers shown on tape measure (cm.). 0 = top, 50 = bottom of sample. "Stratum" refers to the gross layers within the transect line cores. SS in Photograph label refers to adjacent staff site. Small detritus was identified by laboratory microscope analysis.

TOP : Borehole 2. Sample 4 0-49 cm. beneath sediment surface, (Water depth 17 cm.)
STRATUM 6 : 0-12 Fine black organic mud. 12-17 dark brown mud with woody fragments and some roots of *Phragmites*. *Daphnia* egg cases.
STRATUM 5 : 17-28 Silt with some sand, *Phragmites* stems, roots and twigs. 28-31 Brown roots and twig fragments 75% 31-41 Grey silt with some clay.
STRATUM 4 : 41-47 Yellow quartz sand.
STRATUM 3 : 47-50 Black organic mud.

MIDDLE : Borehole 2 Sample 3. 49-99 cm. depth.
STRATUM 3 (cont.) 0-8 75% organic.
STRATUM 2. 8-25 Grey silt with 50% organic remains, detritus and roots. Fragments of *Phragmites* and *Equisetum* nodal septa.
STRATUM 1 : 25-50 Silt with light bands and slight presence of fine black roots. Leaf fragment of *Phragmites*.

BOTTOM : Borehole 2 Sample 1. 149-199 cm. depth.
STRATUM 1 (cont.) Cyclothematic grey silt. Minor layers of sand and yellow silt. Some plant detritus including *Equisetum* nodal septa, wood fragments and a *Phragmites* stem node and leaf. No roots. Coal particles > 425 μm.


SSD4 82-32
7/8/82


SSD3 7/8/82
132-82


232 - 182
SSD.
POINT TO WATER SURF
7·8·82

PLATE 5

SEDIMENT SAMPLES FROM TRANSECT LINE BOREHOLES

Description of sample follows numbers shown on tape measure (cm.). 0 = top, 50 = bottom of sample.

TOP : Borehole 7. Sample 3 69-119 cm. depth.
STRATUM 4 : 0-7 Sand, with *Phragmites* stem.
STRATUM 3 : 7-17.5 Black mud and dark grey silt, in minor layers with *Phragmites* stems and miscellaneous detritus including: *Sphagnum* leaf, *Daphnia* egg cases, *Ranunculus* seed and *Rumex* seed.
STRATUM 2 : 17.5-30. Grey silt with up to 50% plant remains including *Phragmites* stem node and roots.
STRATUM 1 : 30-50. Cyclothematic grey silt with slight presence of plant remains.

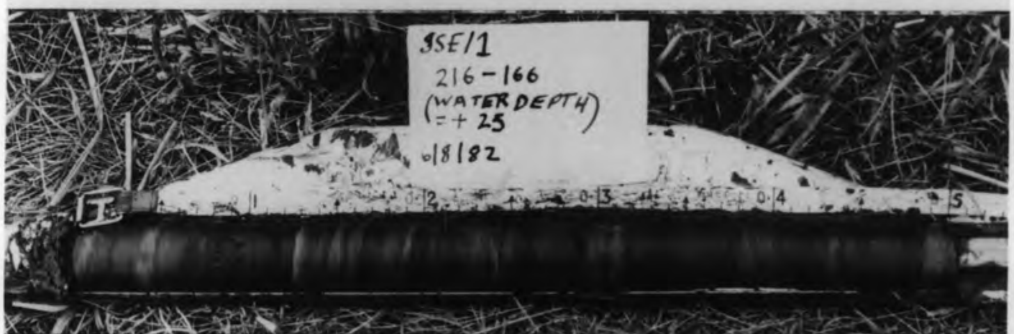
UPPER MIDDLE : Borehole 7. Sample 1 169-219 cm.
STRATUM 1 (cont.) Cyclothematic grey silt with some black detritus bands. Miscellaneous detritus. No remains identified.

LOWER MIDDLE : Borehole 3. Sample 1 159-209 cm.
STRATUM 1 : Cyclothematic grey silt. Plant remains almost absent. 1 *Equisetum* node, and wood fragment. Coal particles.

BOTTOM : Borehole 4. Sample 1 176-226 cm.
STRATUM 1 : Cyclothematic grey silt. Wood fragment. Mica, coal and metalliferous slag particles > 425 μm.


70-120
SSI/3
4/8/82


1
220 - 170 cm


SSE/1
216-166
(WATER DEPTH)
= + 25
6/8/82


217 - 167 cm
SSF/E
[250cm below Water
Surface (w-depth 33cm)
5.8.82.

PLATE 6

Description of sample follows numbers shown on tape measure in cms., 0 = top, 50 = bottom.

<u>TOP</u> : <u>Borehole 9</u>. <u>Sample 2</u> (at bottom of Photo.) <u>Depth 0-50 cm</u>.

0 - 15 cm.	Brown wood peat with well preserved roots and twigs.
15 - 24.5 cm.	Yellow quartz sand with twig fragments, roots absent.
24.5 - 38	Silty sand with humus substance and roots.
38 - 44.5	Grey silt with humus substance and roots.
44.5 - 50	Quartz sand with some plant detritus (sedge leaf).

<u>Sample 1</u> (top of Photo.) <u>47-97 cm. depth</u>. (3 cm. overlap in depth).

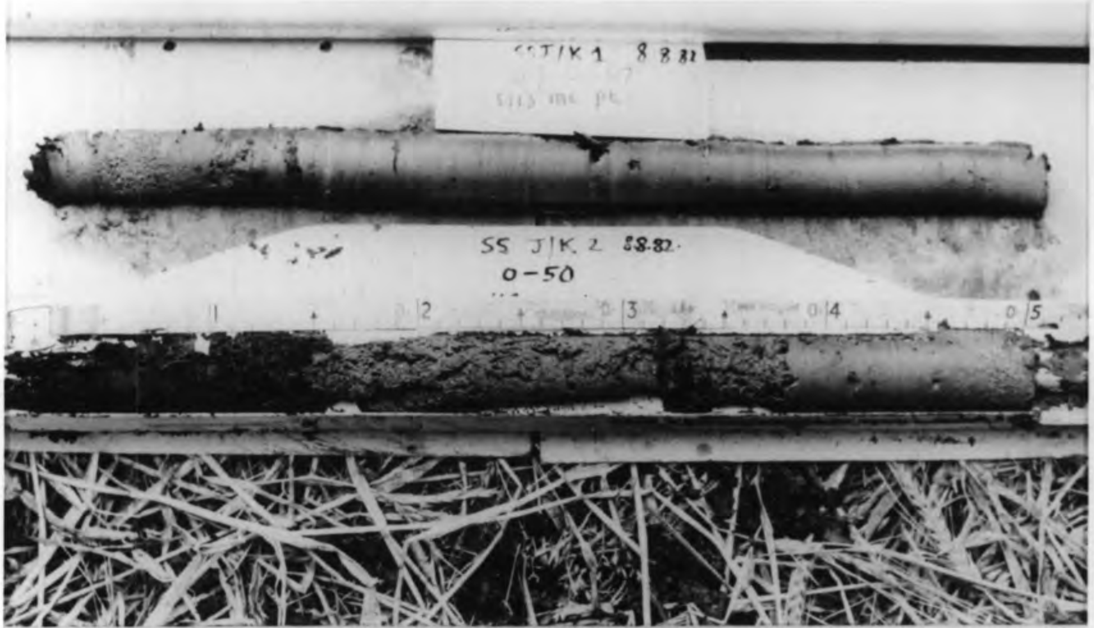
0 - 2.5	Silty sand. 2.5 - 6 Yellow quartz sand.
6 - 9	Yellow sand + silt.
9 - 14	Grey silt with fibrous plant remains and some clay.
14 - 14.5	Light band. 14.5 - 50. Uniform grey silt layer with dark partial streaks of humus substance and abundant well preserved fine detritus and roots. <u>Phragmites</u> leaf at 25-30.

<u>MIDDLE</u> : <u>Borehole 6</u>. <u>Sample 1</u> <u>204 - 254 cm. depth</u>.

<u>STRATUM 1</u> : Cyclothematic grey silt. Some fine detritus and two <u>Equisetum</u> nodes.

<u>BOTTOM</u> : <u>Borehole 6</u>. <u>Sample 4</u> <u>54 - 104 cm. depth</u>.

<u>STRATUM 5</u> :	0 - 10	Grey silt with some sand and roots.
<u>STRATUM 4</u> :	10 - 25	Sand layer, very few visible plant remains. <u>Phragmites</u> leaf.
<u>STRATUM 3</u> :	25 - 37	Black organic mud, <u>Phragmites</u> stem node. Sand band at 28 - 29.
<u>STRATUM 2</u> :	37 - 50	Grey silt with 50% black fine roots.


SS J/K 2 8.8.82
0-50

5.4.4 Macrofossil content of Transect Line Cores

Much of the organic material isolated by wet sieving and examined with a dissecting microscope represented unidentifiable miscellaneous detritus from the basal two layers. An element of fine rooted material was sometimes present. Some coarse and fine detritus that could be identified were:

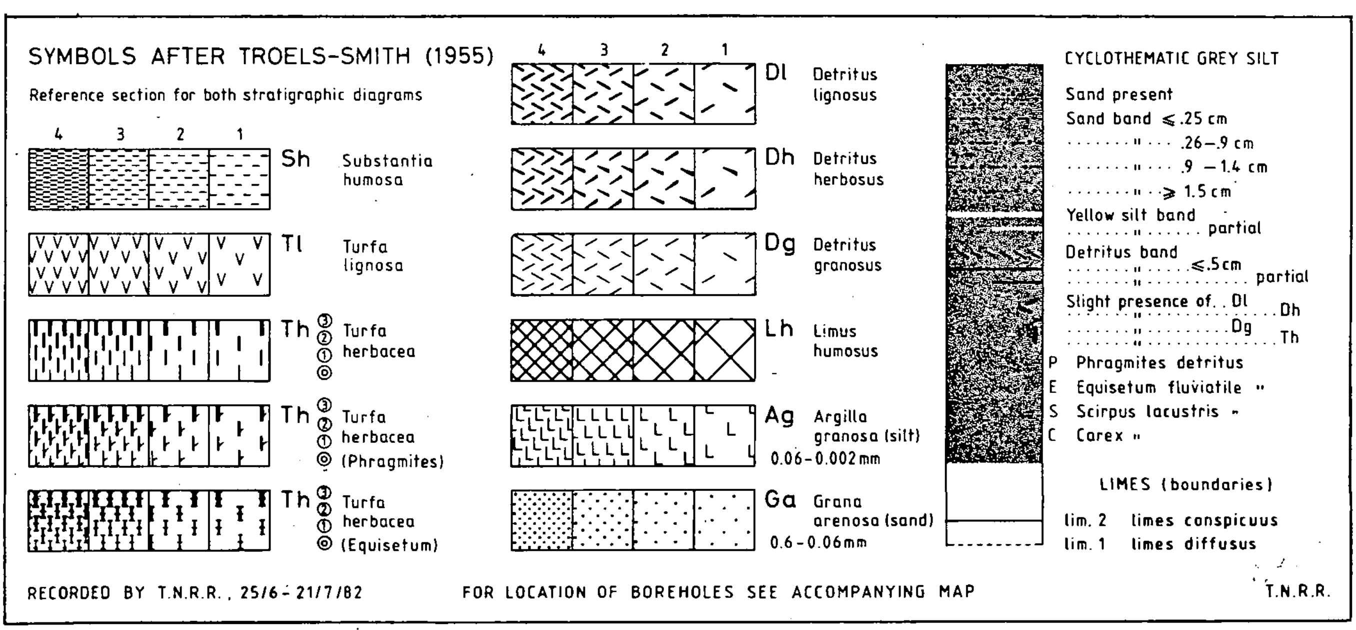
Core 1	Equisetum nodes, beetle elytra, twigs, Phragmites leaf, roots.
Core 2	Phragmites leaf. Equisetum nodal septa. Potamogeton - natans fruitstones. Atriplex seed. Roots.
Core 3	Equisetum stem node. Phragmites stem node. Daphnia egg cases. Carex leaf. Potamogeton natans fruitstone. Salix bud. Sambucus nigra seed. Twig fragments. Coal particles. Roots.
Core 4	Phragmites remains. Equisetum nodal septa. Daphnia egg cases. Fruitstone of Potamogeton natans. Roots.
Core 5	(Miscellaneous detritus). Wood fragments. Coal particles.
Core 6	Equisetum nodal septa. Phragmites stem node. Roots.
Core 7	Sphagnum leaf. Daphnia egg case. Ranunculus seed. Rumex seed. Phragmites stem node. Some roots.
Core 8	Twigs. Phragmites stems, and some roots.
Core 9	Fine rooted material. Phragmites leaf.

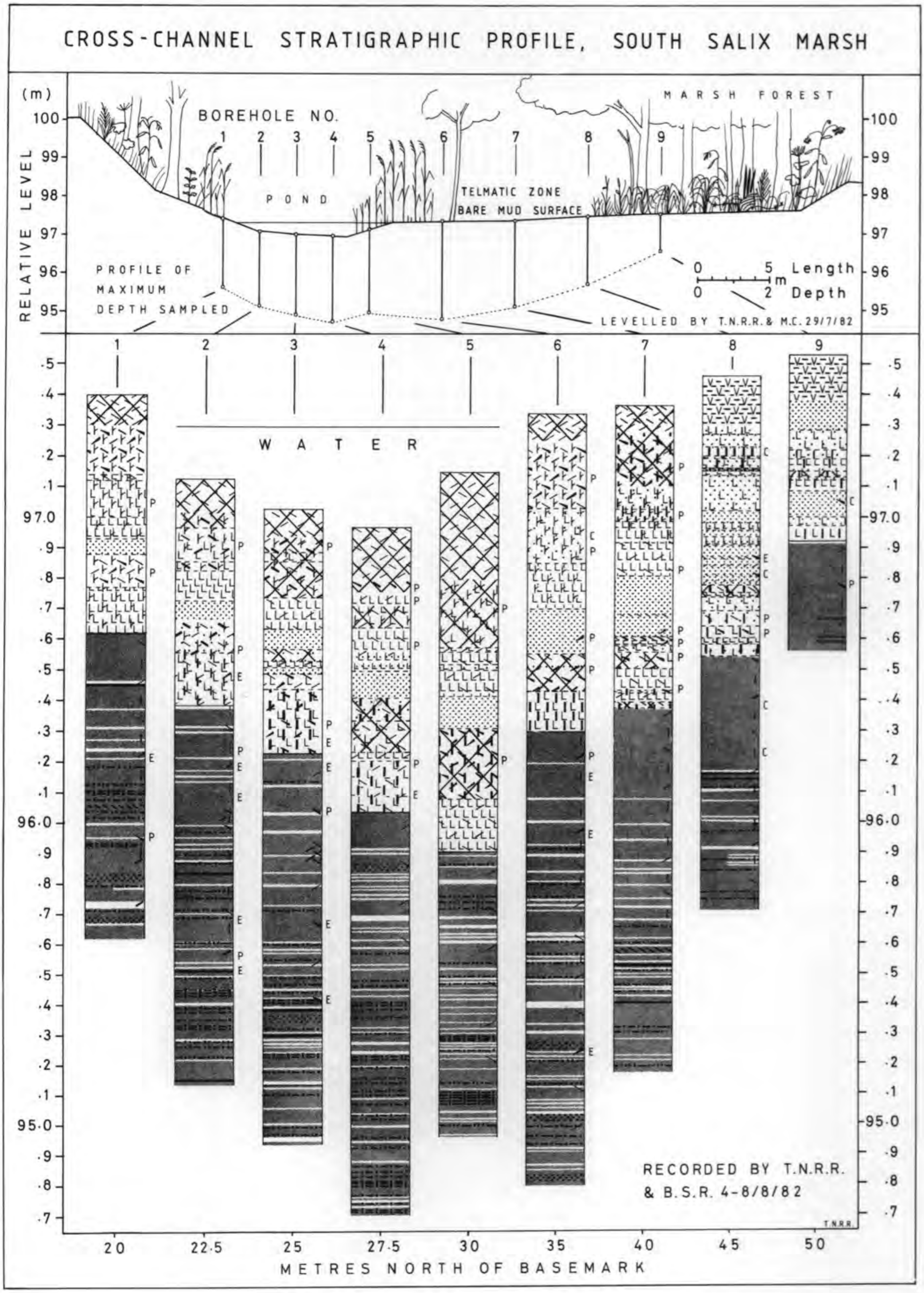
Potamogeton natans grows in lakes, ponds, rivers, ditches. It especially grows on a highly organic substratum, and usually in water less than 1m. deep. (Clapham, Tutin, Warburg 1958, p. 1193). It was recorded in abundance in 1932 from Pond A, but none was found in 1982. Atriplex is a weed of agricultural land. None was recorded from the banksides in 1982.

Layer 3 consisted of a black mud with some grey silt and abundant plant remains beneath the sand horizon. The plant remains were highly humified, but some detritus that could be identified were stems of Phragmites and fine rooted material. From Cores 8 and 9 this stratum was difficult to define as it consisted of minor layers in which the components of silt, sand and detritus alternated.

Layer 4, (the sand layer), had very few plant remains in it. The rooted material from above did not penetrate it in most cores.

Face p. 115


SYMBOLS AFTER TROELS-SMITH (1955)
Reference section for both stratigraphic diagrams
4 3 2 1
Sh Substantia humosa
Tl Turfa lignosa
Th Turfa herbacea
Th Turfa herbacea (Phragmites)
Th Turfa herbacea (Equisetum)
Dl Detritus lignosus
Dh Detritus herbosus
Dg Detritus granosus
Lh Limus humosus
Ag Argilla granosa (silt) 0.06-0.002 mm
Ga Grana arenosa (sand) 0.6-0.06mm
CYCLOTHEMATIC GREY SILT
Sand present
Sand band ≤ .25 cm
" .26-.9 cm
" .9 - 1.4 cm
" ≥ 1.5 cm
Yellow silt band
" partial
Detritus band ≤ .5cm
" partial
Slight presence of.. Dl
Dh
Dg
Th
P Phragmites detritus
E Equisetum fluviatile "
S Scirpus lacustris "
C Carex "
LIMES (boundaries)
lim. 2 limes conspicuus
lim. 1 limes diffusus
RECORDED BY T.N.R.R., 25/6-21/7/82
FOR LOCATION OF BOREHOLES SEE ACCOMPANYING MAP
T.N.R.R.



CROSS-CHANNEL STRATIGRAPHIC PROFILE, SOUTH SALIX MARSH
(m)
RELATIVE LEVEL
BOREHOLE NO.
POND
TELMATIC ZONE
BARE MUD SURFACE
MARSH FOREST
PROFILE OF MAXIMUM DEPTH SAMPLED
0 5 Length
0 2 Depth
m
LEVELLED BY T.N.R.R. & M.C. 29/7/82
WATER
RECORDED BY T.N.R.R. & B.S.R. 4-8/8/82
T.N.R.R.
20
22.5
25
27.5
30
35
40
45
50
METRES NORTH OF BASEMARK

Fig.5.4

Layer 5 partly consisted of a *Phragmites* peat, with woody fragments and miscellaneous detritus. In core 8 *Juncus* and *Equisetum* detritus also occurred.

Layer 6 had well preserved living roots within it but much of the detritus was highly humified. Wood and twig fragments were present in this layer from the cores from the telmatic zone.

Detritus that is unconnected to a rooted layer within the deposit must be viewed with caution as it may have been transported over long distances within a fluvial system. However, very fine black rootlets occur within the basal layers, and beneath the sand layer there is a black mud with abundant plant detritus. The basal layers are indicative of a lake or pond, but the sand layer is suggestive of flow conditions in the channel. It thickens towards the inside of the meander bend and is a persistent horizon. *Phragmites* usually grows in shallow, still water (Haslam, 1972). Its occurrence beneath the sand layer raises questions about the date of origin of the sand. It could be the product of floodwater from the river after the Marsh was formed, but the embankments appear to be effective barriers to such occurrences.

To try to determine whether the sediment was deposited by the river, five physical/chemical analyses were made of the sediment from Core 6, which contained the greatest depth sampled. The aims of each technique have been outlined in the methods section.

5.5 PHYSICAL/CHEMICAL ANALYSIS OF ONE CORE

One transect line core (core 6) was selected for detailed analysis to aid interpretation of the stratigraphy.

5.5.1 Particle Size Analysis

Microscope analysis of sediment using a calibrated graticule showed that the dark-grey and yellow-grey layers were composed of silt and clay size particles. Particles of the grey silt ranged from .001 - .012 mm. Particles of the yellow silt ranged from .001 - .047 mm. Particles of the sand horizon (layer 4) ranged from .02 - .5 mm.

A particle size analysis was made of three layers. Approximately 10g. of material is required from each sample point. The yellow-grey silt was not analysed due to insufficient material from any one sample point. Results are summarized in the following table.

The dark grey silt beneath the sand layer had only a small percentage of clay sized particles. Had the percentage for clay been greater, it might have suggested very still water conditions.

The sand layer is dominated by medium sized sand particles. This layer had very little clay (4%) or silt (9%) and is highly sorted. This would support the hypothesis of a high energy environment of strong flow conditions within the channel. Had the sand been reworked and deposited by bankwash or by flooding across the fields from the modern river into the Marsh, it would be less likely to have such a consistent grain size. If it had been artificially deposited by man it might form a fan shape rather than this persistent horizon. It gently tapers towards the area of maximum scour under the deepest part of the channel but is thicker on the point bar.

TABLE 5.2 : PARTICLE SIZE ANALYSIS OF SEDIMENT FROM THREE LAYERS OF TRANSECT CORE 6

CORE 'SSH' (NO. 6)			FINE SIEVING				SEDIMENTATION				
Sample	Depth	Air Dried Wt. of Sample	% Material Retained on Sieves								Σ %
			No. 7 2 mm. > 2.4 mm.	No. 25 600 μm 2.4 - 0.6 mm.	No. 72 210 μm 0.6 - 0.21 mm.	No. 200 75 μm 0.21 - 0.075 mm.	0.06 - 0.02 mm	0.02 - 0.006 mm	0.006 - 0.002 mm	< 0.002mm	
			% Fine Gravel	% Coarse Sand	% Medium Sand	% Fine Sand	% Coarse Silt	% Medium Silt	% Fine Silt	% Clay	
1	46-49 cm.	11.0157 g	-	0.76	4.11	55.119	25.802	6.861	2.449	4.899	100
2	69-72 cm.	11.0357 g	-	5.056	54.40	26.59	6.287	1.919	1.432	4.316	100
3	105-108 cm.	11.0252 g	-	-	1.52	6.95	29.530	34.661	13.183	14.156	100

Sample 1 = "Sandy Loam" U.S.D.A. Scale, "Silty Loam" International Scale.
Sample 2 = "Sand" U.S.D.A. Scale, "Loamy Sand" International Scale.
Sample 3 = "Silt Loam" U.S.D.A. Scale, "Silt" International Scale.

PARTICLE SIZE ANALYSIS OF SEDIMENT

B.S. 1377 (1967) Test 7 (c) Pipette Method

The sample from 46 - 49 cm. depth does show a more mixed distribution of grain sizes, but is dominated by sand.

5.5.2 Organic-Matter Content

The percentage loss of weight on ignition, that provides an estimate of organic-matter content, peaked in the sample from the black mud beneath the sand layer, and in the black mud at 24 - 27 cm. depth. It generally increased up the core as expected, although it is uncertain why the inorganic sand layer should occur above a point where the organic matter content of the sediment is already beginning to increase.

It was initially hypothesised that the dark-grey silt had a greater element of organic "limus" or "detritus" than the yellow-grey silts, which gave it its darker colour. The differential amounts of organic matter were, it was thought, perhaps related to seasonal conditions of organic activity within the water body. This hypothesis was not substantiated by the present experiment. The yellow-grey silt unexpectedly lost more weight on ignition (6%) than the grey-silts (2 - 4%).

The basal layers that were sampled from 254 - 90 cm. depth are mostly inorganic. Minor peaks might have occurred at all yellow-grey silts had the sampling interval been smaller.[1]

5.5.3 pH Reaction

The pH of samples decreased as organic-matter content increased towards the top of the core. This may result from humic acids produced by decomposition.

The smallest pH value came from the black mud beneath the sand layer (pH 4.7). The upper layers of mud above the sand are less acidic, perhaps due to being less decomposed. The surface pH at Staff Site H (core 6) was 5.7 i.e. less acidic than

[1] % wt. loss on ignition was also recorded for four samples from transect core 9 (see Appendix 11, p.274). The sample from the upper sand layer lost 2.2%, samples from two silty sand layers lost 2.6%, and a sample from the lower grey silt lost 3.2% .

at 24 - 27 cm. beneath the surface. This may result from less decomposed organic material. Nowhere along the transect line samples did the soil subsurface give a pH reaction of <5.0.

The grey silts, almost inorganic, are close to a neutral pH. This is similar to the present water body today, while the river is more alkaline. However, it is the present water that saturates them, and their pH value does not necessarily indicate that the sediments are not of fluvial origin.

5.5.4 Mineral Analysis

Four layers were selected for mineral analysis to try to determine the origins of the Butterby Marsh sediments.

1. Grey Silt layer

The grey silt layer from 220 - 223 cm., that is the characteristic component of the bulk of the unconsolidated sediment at this and other locations, had the following mineral constituents:

The main mineral was quartz (SiO_2). Fluorite (CaF_2) was also present in large amounts. The sediment contained clay minerals - illite (mica) and kaolinite (an aluminium silicate) are present in quite appreciable quantities.

2. Yellow Silt layer (241 - 244 cm. depth).

The main mineral was quartz. This sample, however, contained large amounts of Siderite ($Fe\ CO_3$) an iron carbonate, as well as illite, Kaolinite and fluorite. Feldspar was also present (it is difficult to determine whether it is a plagioclase or a potash feldspar). There was more quartz and less fluorite in this sample than sample 1.

3. Basal Sand layer (251 - 254 cm. depth).

The main mineral present was again quartz. Also present were kaolinite and fluorite.

4. <u>Upper Sand</u> (69 - 72 cm. depth).

The main mineral was quartz with minor kaolinite and fluorite.

Dark coloured particles separated from a sample of particles >425 μm from this layer were analysed. The X-ray pattern showed a typical trace of an amorphous material. This was determined to be particles of coal, which was confirmed by hand lens study. (Coal is not crystalline and is therefore not picked up on the X-ray trace). Also present were small quantities of Kaolinite, chamosite and quartz. Fragments were also present which exhibited a clinker or slag like appearance. Some particles were metalliferous and could be seen to have gas vesicles (bubbles) when examined under a microscope. Other particles were thought to be iron carbite, a product of smelting that has a shiny appearance. A fluorescent green-blue particle was also isolated.

<u>Discussion of results of mineral analysis</u>

All samples were dominated by quartz (C.60 - 80% of each sample). It is difficult to determine the origin of the quartz as it is widespread in the region (see Dunham 1948 p.90).

The grey silt is also composed of illite which would originate from muds and clays from weathered shale or bedrock. Illite is produced by the decomposition of feldspars and the degradation of mica (Reineck and Singh 1980 p.151). The presence of illite is likely to be responsible for imparting its dark shaley colouration.[1] Kaolinite also forms from the destruction of feldspars and is associated with the coal measures in the shales.

<u>Siderite</u>

The sample of the yellow-grey sediment contained a large amount of siderite, an iron carbonate. These yellowish

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[1] R.G. Hardy pers. comm.

bands consist of silt and clay-sized particles that sometimes form concretions greater than 425 μm. Mica is often present with them. They are crushable in the hand or in a pestle and mortar. Some of these concretions had grooves in them where organic detritus may have been present. Oxidation of iron may be responsible for their colouration. In many cases the split p.v.c. tubing, in which the samples were returned to the laboratory to await analysis, were stained a rust-coloured reddish brown over large parts of their internal section.

Siderite has a dissociation temperature of 580°C when CO_2 is given off. The sample gave a chemical reaction with 10% HCL (gas bubbles were produced) which indicated that it contained carbonates. This might account for the greater percentage loss of weight on ignition than the grey silt although a lower temperature than 580°C was used (275°C).

The occurrence of bands of siderite may have significance for interpreting the time of origin of the sediments i.e. whether the large depths of silt beneath the sand horizon that were sampled (c.1.5m.) were deposited before 1811 when there was major flow in the channel, after 1811 in the reduced flow conditions of the long backwater that was temporarily created, or in the conditions of autogenous accumulation within a lake and then a marsh environment once flow had been stopped (after the embankments were built). Various possibilities are outlined below, together with information that was gathered on the formation of siderite, but in the present study no firm conclusions were drawn about the exact cause or genesis of these fine yellow bands that occur within the grey silts.

There are a variety of types of siderite. Clay ironstone is an impure iron carbonate occurring as beds and nodules in coal measures, clays and shales. It is usually fine grained and sometimes concretionary. Formerly these clay ironstones constituted valuable ores of iron and have been worked in County Durham. (Mason and Berry 1968 p.339, Read 1974 p.522).

Some siderite deposits are formed in modern environments by direct precipitation in lakes, as in some bog iron ore deposits. Sedimentary siderites are common in the locality of coalfields (Read 1974 p.222). The conditions governing the precipitation of siderite are outlined by Berner (1971 p.199) as follows:-

> "Since siderite is a carbonate, it is soluble under acidic conditions and does not form in mineral free swamps or bogs. However, many lake sediments and some bogs are not acidic because of buffering by fine grained silicate minerals and/or a high carbonate alkalinity. Thus siderite could form in a clayey bog or lake sediment, low in dissolved sulphate and high in organic matter .... There is indirect evidence for the formation of siderite in the anaerobic muds of freshwater ponds."

Reineck and Singh (1980 p.151) note that primary siderite can be formed only in lakes with low Eh values and that it is known from many lacustrine deposits. Sedimentary siderite can only be precipitated if the Ca:Fe ratio is less than 20 (Leader 1982 p.158).

Sedimentary siderite readily alters to limonite ($Fe_2 O_3 \cdot 3H_2O$) which is composed of hydrous ferric oxides, mainly geothite ($Fe_2 O_3 H_2O$) with absorbed water, clay minerals and other impurities ...

> "Limonite sometimes occurs in dull earthy conditions and in concretions which are yellow or brownish yellow. One variety is Bog Iron Ore, a loose porous earthy form which is found in swampy and low lying ground, often impregnating and enveloping fragments of wood, leaves etc. The bog iron ores are formed on the floors of some lakes, as in Sweden, where a layer of 7 inches in thickness accumulated in 26 years; the deposition of iron compounds from the stream waters flowing into the lake may be caused by minute organisms such as bacteria." (Read 1974 p.520).

Limonite may thus have been a stage in the origin of the yellow silt bands. It is not crystalline (Read 1974 p.520) and may therefore not have been identified in the XRD analysis. It results from the alteration of other iron minerals.

Besides these types of occurrence of iron oxides on the floors of lakes and marshes, they are specifically noted to form thin bands in clayey deltaic deposits, suggesting that such patterns are produced by changing sources and rates of sediment supply ....

..."Siderite also occurs as thin bands and horizons of concretions in argillaceous deposits especially in deltaic facies. It is not uncommon to find siderite bands contorted and fractured by slumping. Siderite clasts are also found in intraformational conglomerations. These facts suggest that siderite forms diagenetically during early burial while the sediments are still uncompacted. Its formation is favoured by alkaline reducing conditions (Fig. 42)." (Selley 1982 p.149).

The siderite bands in the grey silts of Butterby Marsh could have originated from transported (detrital) material laid down under differing flow conditions at the surface of the sediments, in the conditions of either the river or the backwater, so that the sand bands represent slightly increased flow conditions. They may however have been precipitated at the surface of the sediment in a still-water lacustrine situation, with the intermittent sand bands resulting from seasonal turbidity currents. A third possibility is that they have formed <u>within</u> the silt, rather than at the surface of the sediments, perhaps at times of low water levels or "drawdowns"[1]. Thus their formation could post date the deposition of the sediment.

The iron content of the silts could have been transported to the site from several sources. One might be the weathering of siderite deposits within the shale and coal measures. Another might be the working of iron ore deposits in the catchment area of the Wear. A third might be bog-iron-ore formed under

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[1] Shifts in the water table.

acidic conditions in Weardale, seasonally eroded, and washed in and deposited by the river in the slack water conditions at Butterby.

The occurrence of siderite from precipitation in lakes and its formation within silt in swamps and ponds is consistent with the other evidence (such as Daphnia egg cases, Potamogeton natans fruitstones, beetle elytra and rooted plant material) for a slow water depositional environment at the time of the formation of the c.1.5m. depths of silt.

The yellow silt bands of siderite may be related to times of low water level. They may be related to the post - 1811 seasonally lowered water levels (drawdowns) within the Marsh so that soil forming processes are occurring.[2] Again an important question is - were they deposited at the surface of the sediment so that each represents a former surface of the floor of the Marsh covered by shallow water; or were the bands formed within the silts at times of large drawdowns, when iron present at intermittent points in the silt formed these concretions and laminations (perhaps due to illuviation)? The first option would suggest a gradual accumulation of the silts since the Marsh was formed, as there would not have been great decreases in water level when the river was flowing through the channel prior to 1811 (although this particular area may have been shallow water even at that time). The second suggests that the siderite bands may have formed due to Marsh conditions (drawdowns) acting on sediment previously deposited in the post 1811 or pre-embankment period, when there was probably a more abundant supply of sediment to the Butterby loop. Reineck and Singh (1980 p.297) note that the sediments of flood basins undergo soil formation and that in some of the reducing soils siderite nodules are formed. It is the

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[2] Dr. G. A. L. Johnson (pers. comm.)

reduced form of iron (Ferrous oxides, Fe^{++}) that is found in waterlogged soils (Brady 1974 p.264). Selley (1982) suggested that siderite forms during "early burial", but the length of time involved is not indicated.

Thus sediments in the modern River Wear may consist of grey silts of similar (fluvial) origin but might not show this cyclothematic pattern, as they have not been subjected to the same conditions as those that fill the channel of the Marsh. An obvious follow up to this problem would be to take a core through the sediments in the channel of the modern River Wear on a slow stretch comparable to the loop of Butterby prior to 1811. If the core showed the presence of similar fine bands of siderite then this would suggest that the sediments which fill the channel were deposited in the period prior to 1811. However, it could be argued that if such a sample did not show the development of such a cyclothematic pattern in the silts, it does not necessarily indicate that the silts within the old channel date to the period after the Marsh was formed. As previously mentioned, the siderite bands could have formed due to drawdowns occurring within the Marsh, allowing soil forming processes to act on the grey silts previously deposited during the conditions of the river or the backwater.

It would be interesting to determine the conditions that governed the formation of these fine bands of siderite in the lower grey silts. They may well be of significance in tracing the origin of the sediments that fill the Marsh. Further study of the grain structure of the siderite has been suggested (i.e. angular/rounded/broken).[1]

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[1] Prof. J.R.L. Allen, Dr. M. Tucker (pers. comm.)

Fluorite

Calcium fluorite, a gangue mineral from the mining industry, was dumped into the River Wear in quantity until about 1882 so that the river bed in the dales was reported by locals to have been white with this deposit. It was suggested that the presence of this mineral within the sediment might indicate that the deposit was of fluvial origin.[1]

Fluorite was present in quantity in the samples analysed. The ratio of fluorite to quartz peak heights on the X-ray trace was calculated. All the samples were dominated by quartz, but by examining the ratio of the peak heights at appropriate X-ray wave lengths on the trace for each sample, an approximation of the relative amount of fluorite in each sample can be determined. The ratio of the peaks for $CaF_2 : SiO_2$ would have to be of a value of approximately 7 for there to be as much fluorite as there was quartz.

The basal sand had a peak height ratio at

$$\frac{1.932\ \text{Å}\ CaF_2}{1.981\ \text{Å}\ SiO_2} \quad \text{of} \quad \frac{33}{28} = 1.18^{*}$$

At the same peaks, the height ratio of $CaF_2 : SiO_2$ was $\frac{39}{45}$ (0.87) for the dark grey silt, $\frac{47}{65}$ (0.72) for the lighter, yellow, silt and $\frac{11}{37}$ (0.3) for the upper sand.

The amount of fluorite was therefore fairly consistent in the three basal samples from below 220 cm. depth, but was reduced in the upper sand layer (69 - 72 cm. depth). However, this smaller value for the sample from the thick upper sand horizon may be related to a lighter weight or lower specific gravity of fluorite to quartz so that it was "flushed out" if the

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[1] Dr. G.A.L. Johnson (pers. comm.)

* Å = Ångstrom unit(s). A length unit of 10^{-10}m (0.1 nm).

sand was deposited rapidly by a flood. Concentrations of metals are also reduced in this upper sand, but rise again above it (see next section).

Material from the same twelve sample depths analysed for organic matter content, pH reaction and metal content was also analysed for fluorite. Oven dried sediment that had been ground down and passed through a 210 µm nylon mesh sieve (in preparation for metal analysis) was analysed by XRD and ratios at the same peak heights were used to produce a depth profile for relative amounts of fluorite.

Results from this analysis showed that fluorite remained in fairly similar quantities at all sampling depths. It was greatest in the grey silt between 220 and 223 cm. and least in the yellow silt at 193 - 196 cm. It was still present in the mineral constituents of the uppermost black-brown mud layer (24 - 27 cm. depth).

Two samples in this batch overlapped with the previous samples analysed for their total mineral constituents. The figures are higher for fluorite in the < 210 µm fraction. This might be accounted for by the greater hardness of quartz which could make it less resistant to being ground down and passing the 210 µm nylon mesh sieve, thus increasing the relative amount of fluorite.

No trend in fluorite content of the sieved samples was revealed over the 12 sample depths. The very top sediment was not analysed. This might have revealed reduced amounts of fluorite. However in the black muds it must be noted that the organic content is increased thereby reducing the absolute amounts of the minerals present.

If the high fluorite content of the sediment is related to mining detritus, then it would suggest that the bulk of the deposit is of fluvial origin prior to the isolation of the loop from the river, and would place the base of the deposit at least in historical times.

Coal, clinker, slag and metalliferous material (products of smelting) were identified from the upper sand layer in hand picked particles $>425\,\mu m$. Presumably, small particles would be "flushed out" while heavier, larger, particles were being deposited in this horizon which is dominated by medium grain size sand particles.

During the analysis for fluorite the samples from the organic mud layers beneath and above the sand horizon were also analysed for their total mineral constituents. No great difference between these and the sample of grey silt was noted, although of course the absolute amount of inorganic sediment in these layers was less. Results are summarized on the following table.

5.5.5 Metal Content

Metal concentration in the sediments of Lake Constance has been demonstrated by Muller et.al. (1977) to increase in upper deposits dated to the C20. This is attributed to the burning of fossil fuels (coal ash contains high concentrations of Pb, Cd, Zn, Cu, and Hg) and industrial processes such as cement production that lead to atmospheric pollution; and to local or point sources such as industrial waste, domestic sewage and agricultural run off. While dating by ^{210}Pb (see Oldfield et. al. 1977) was not feasible in the present study, analysis of the metal concentration in the sediment offered a possibility for an approximation of the date of the deposits at Butterby (see methods section).

TABLE 5.3 PHYSICAL/CHEMICAL ANALYSIS OF ONE SEDIMENT CORE : DEPTH RELATIONSHIP OF SELECTED FEATURES

Depth	Colour Description	Particle Size International Scale			Type of Plant Remains	% Organic [Loss on Ignition at 275°16h.]	pH	Mineral Constituents X.R.D.	Fluorite/Quartz Peak Ratio	Fluorite/Quartz Peak Ratio <210 µm fraction	METAL COMPOSITION ($\mu g\ g^{-1}$) OF SEDIMENTS (<210 µm fraction) DIGESTION AND ATOMIC ABSORPTION SPECTROSCOPY							
		% Sand	% Silt	% Clay							Pb	Cd	Zn	Fe	K	Cu	Co	Ni
24-27	Brown Mud				Phragmites peat $Th^{o}2$ Det 2	27%	5.4	Quartz, Illite Kaolinite Fluorite	-	1.14	1 656.6	13.5	783.1	13 403.6	5 155.6	80.3	26.6	426.7
46-49	Dark Grey Silt	59	35	4	Phragmites roots $Th^{o}2$	6%	5.9	-	-	1.17	3 736.1	13.5	996.9	37 562.9	3 172.2	85.5	37.2	468.2
69-72	Yellow Sand	86	9	4	None	3%	6.1	Quartz, minor Kaolinite and Fluorite coal, clinker, slag	0.3	1.06	785.0	10.5	455.0	34 750.0	1 900.0	5.0	31.5	365.0
85-88	Black Fine Detritus Mud				Phragmites Stems and roots Th^{2}+ Det 2	13%	4.7	Quartz, Kaolinite Fluorite, Illite	-	1.25	2 427.1	9.5	678.3	59 497.4	4 266.3	70.3	42.2	482.4
105-108	Dark Grey Silt	8	77	14	Th^{1} + Det +	4%	5.5	-	-	1.17	4 109.6	13.5	1 066.3	54 275.6	5 623.7	90.5	42.6	508.1
124-127	Grey Silt				Th^{1} + Det +	3%	6.2	-	-	1.41	3 333.3	11.6	987.8	67 375.8	4 848.0	65.8	37.4	516.7
147-150	Grey Silt				Det +	2%	6.8	-	-	1.15	4 630.9	12.6	1 268.9	60 768.4	5 793.7	70.7	37.4	455.0
177-180	Grey Silt				Det +	2%	6.6	-	-	1.83	2 912.4	14.5	1 086.5	50 100.6	5 256.5	45.2	42.2	442.6
193-195	Yellow Silt				None	6%	6.6	-	-	0.91	3 021.2	12.6	2 211.5	105 516.1	3 507.0	20.2	58.7	521.2
204-207	Grey Silt				Det +	2%	6.7	-	-	1.33	5 528.1	14.3	1 456.0	59 526.1	5 256.5	45.2	42.2	442.6
220-223	Grey Silt				Det +	2%	7.0	Quartz, more clay minerals Illite, Fluorite, Kaolinite	0.87	2.11	5 946.0	12.6	1 325.9	54 352.2	5 946.3	45.5	37.4	480.7
241-244	Yellow Silt				None	-	-	Quartz, Siderite, Illite, Kaolinite, Fluorite, Feldspar	0.72	-	-	-	-	-	-	-	-	-
244-247	Grey Silt				Det +	2%	6.8	-	-	1.51	2 765.0	12.5	1 420.0	63 000.0	5 005.0	35.0	47.5	460.0
251-254	Sand				None	-		Quartz, Fluorite Kaolinite	1.18	-	-	-	-	-	-	-	-	-

Muller used 14 sample points over 40 cm. to produce depth profiles for 11 metals and 18 Polycyclic Aromatic Hydrocarbons. In the present study, 12 sampling depths were used over 254 cm. The depth profiles produced are therefore less detailed. Results were obtained for Pb, Cd, Zn, Fe, K, Ca, Co and Ni.

Lead can be seen to be present in large quantities (up to 6,000 ppm) at all sample points. The quantities are equivalent to levels in some mine discharge streams.[1,2.] The concentration of Pb falls to < 1,000 ppm in the upper sand layer, but rises again above this. This could be accounted for by a) a rapid accumulation rate of the sand, perhaps due to deposition by a flood, and/or b) the inability for sand to retain metals and chemicals due to its grain structure. Metals and chemicals might be more easily retained in sediment by adherence to clay particles and fine silt particles. Sand rapidly drains due to its greater porosity, and the metals and chemicals might be leached out. Grain size factors may not have been eliminated by grinding and sieving of sediment prior to analysis. The concentration of all metals decreases within the sand horizon at 69 - 72 cm. depth.

Another "unusual horizon" is the yellow silt layer. At this point Pb, Cd, K and Cu decrease, while Zn, Ni, Fe, and Co increase. The concentration of Fe at this point represented the highest concentration of any metal from any sample : 105 516.1 ppm. This is in agreement with the mineral analysis which showed the presence of iron carbonate in large quantities.

The other samples were all taken from grey silt layers, apart from the sample of the black mud at 24 - 27 cm. and 85 - 88

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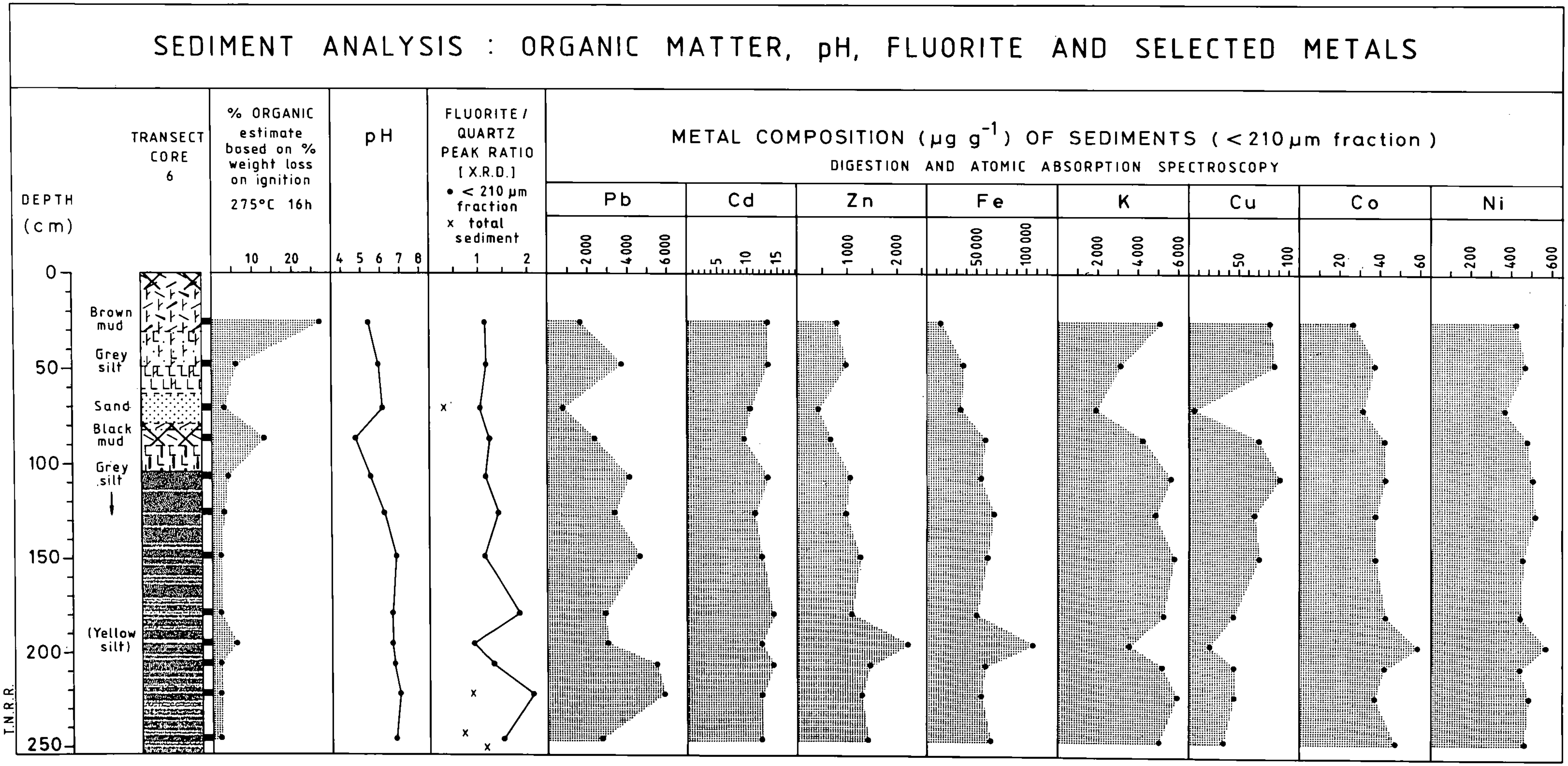
[1] I.G. Burrows (pers. comm.) [2] Denny (1981) found that lead levels in sediments from Ullswater ranged from 17.0 - 41 000 $\mu g\ g^{-1}$ dry wt. attributable to mining input.



SEDIMENT ANALYSIS : ORGANIC MATTER, pH, FLUORITE AND SELECTED METALS
DEPTH
(cm)
TRANSECT CORE 6
% ORGANIC estimate based on % weight loss on ignition 275°C 16h
pH
FLUORITE / QUARTZ PEAK RATIO [X.R.D.]
• < 210 μm fraction
x total sediment
METAL COMPOSITION (μg g-1) OF SEDIMENTS (< 210 μm fraction)
DIGESTION AND ATOMIC ABSORPTION SPECTROSCOPY
Pb
Cd
Zn
Fe
K
Cu
Co
Ni
Brown mud
Grey silt
Sand
Black mud
Grey silt
(Yellow silt)
T.N.R.R.

Fig. 5.5

cm. If the sand and yellow silt layers are discounted, certain trends can be noted in the depth profiles.

Pb decreases from 5 900 ppm at 220 - 223 cm. to 1 656 ppm at 24 - 27 cm., although the pattern fluctuates greatly. The concentration of Pb decreases in the black mud beneath the sand layer, but rises again above the sand layer. The level in the top sample may be reduced due to leaching (the core was located in the telmatic zone near to l.w.m.). It is unfortunate that a sample was not prepared for analysis from the surface of the sediment. Had a smaller sampling interval been used and the very top sediment been analysed, an increase might be found due to modern atmospheric pollution.

However, the quantities of lead in the Butterby sediments are an order of magnitude higher than the highest lead levels in Lake Constance found by Muller (87 ppm). Therefore it seems unlikely that the metal enrichment of the lower sediment is due to atmospheric pollution. It would seem more probable that it results from metal enriched load that was deposited at Butterby by the river prior to isolation of the loop. Lead concentration in sediments in the present River Wear may be much smaller due to a decrease in input from mine discharge streams and other sources.

Fe also decreases towards the top of the depth profile. (Yellow bands of iron carbonates are absent from the upper sediment). Leaching may be partly responsible for this. Co also decreases towards the upper layers, as does Zn. Ni and Cd is not reduced in the upper sediment. K rises in the upper sediment, from a decreased concentration in the layers beneath and above the sand horizon. Cu shows a gradually increasing trend, rising to a value of 85 ppm in the upper sediment. The range of Cu and Co values are the only comparable figures to those found by Muller. If Cu was not a product of mining in Weardale, then gradual enrichment towards the upper sediment might be attributable to atmospheric pollution.

The large quantities of Pb, Cd, Zn, Ni and Fe in the Butterby sediments are probably attributable to the enrichment of river water by these pollutants from point sources. Since the embankments were built, it is thought that no river water or water from Croxdale Beck has entered the pond system. If so, this would place the bulk of the deposit of unconsolidated sediment as originating prior to 1857.

Lead mining reached its peak in the Northern Pennine Orefield between the end of the Napoleonic Wars and 1880, although mining can be traced back to the period following the Norman Conquest (Dunham 1948 p.4, Raistrick 1935, 1948).[1] The mining of iron ore began in Weardale many centuries ago but was of little importance until 1842.[2] These local sources of emittents in the drainage area of the Wear are suggested as the origin of the metals that enrich the sediment at Butterby. The presence of coal particles, slag, clinker and metalliferous material was also demonstrated by mineral analysis. Prior to embankment and isolation, the loop at Butterby would have three main sources of pollutants: the River Wear, Croxdale Beck and the River Browney.

The high concentrations of these pollutants in the sediments at Butterby may not affect the present plant communities due to leaching out of the rooting zone. However, the fact that some of the concentrations are not greatly reduced in the upper sediment could indicate that metals are being recycled from the lower sediment. There could be some mobility of metals in soluble form up and down the profile. This could affect the aquatic ecosystem (see Denny 1981). The concentration at depths

I For a recent review of the history of mining in the Northern Pennines, see Dunham (1982). In this account lead mining is traced back to Roman times, and it is suggested that the industry reached its peak during the 18th and first half of the 19th centuries; only the richest lead mines persisted into the 20th century. 2 (Dunham 1948 p.5).

could represent toxic quantities.

The present water in the Marsh was not analysed for its metal content, although this information would be desirable (as would present values for the River Wear). The specific conductivity and pH values for the River Wear, Croxdale Beck and Butterby Ponds obtained in the present study suggest that there is no connection between the two former areas and the latter. It would seem that the water of the loop was isolated from long distance sources of pollution when the embankments were built, and that metal and mineral enriched water was replaced by water from local run off on the slopes of Croxdale Woods and the surrounding fields. The water quality at Butterby that the plant communities experienced may therefore have changed considerably after 1857.

The outflow stream in the South Salix Marsh may be enriched with iron as it has a reddish-orange colour. Samples were collected for pH and specific conductivity measurements, but a future study of the metal concentrations in this stream would be interesting. (Whether this represents modern formation of bog-iron-ore is uncertain).

One other metal that might be used to date the sediments could be an aluminium horizon. Aluminium in the form of "silver paper" was dropped in quantity by aircraft during the 1939-45 period in relation to strategic usage of radar. Such aluminium horizons can be traced in peat layers in the Pennines.[1]

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[1] Dr. G.A.L. Johnson (pers. comm.)

5.6 INTERPRETATIONS OF THE STRATIGRAPHY : THE ORIGIN OF THE SEDIMENTS

Although the evidence of plant macrofossils suggests that the silts were deposited under slow water conditions, results from mineral and metal analysis suggest that they originated from the River Wear. Deposition may have occurred when the loop still had a connection with the river, before closure.

The time scale that is represented in the stratigraphy is difficult to assess. It is possible that there are many more stratigraphic layers of sediment beneath that which was sampled. The time scale of documented events concerning the history of Butterby Marsh is outlined on p.277. The two most significant events concerning the initiation of the hydrosere were 1) the diversion of the main current of the river by cutting the new waterway across the neck of the loop in 1811, and 2) embankments were built sometime before 1857, which finally cut off the loop from the flow of the river and redirected Croxdale Beck away from the loop.

Griffiths (1932) placed the embankments as being built within the twenty years following 1811. He suggested that they were built after 1820 when Low Butterby was added to the Croxdale Estate. Surtees' description (given in next chapter) in 1840 suggests there was still flow in the loop at this late date. The First Edition Ordnance Survey map (1 : 2500) shows the embankments in place in 1857.[1]

According to Griffiths (1932 p.105) ....

> "The cutting of the new channel in 1811 would probably not greatly alter the character of the old channel, because at

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[1] During the envisaged time interval between 1811 and their construction, the point of access to the field named "the island" may have been a bridge, or the small embankment between the north of the present Typha Marsh and the East Salix Marsh. This formerly had a culvert beneath it (Griffiths 1932).

first there would be no difference in water level and the water would flow through both channels. A much greater change would occur when the embankments were made after 1820, when the current through the loop was stopped and the channel of the loop became a long backwater. The greatest change would be caused by the erosion of the bed of the river by the quickening of the current which the shortening of the course would bring about, and the consequent fall in the water level of the backwater in the loop. At the present day the surface of the river is nearly 6 ft. below the level of the outlet of the culvert which drains the Marsh. The southern arm of the loop is completely drained, and the Croxdale Beck has cut a deep channel down into the old bed. The drainage of the rest of the loop was only partial, owing to the great irregularities of the bed, and it is this portion which is the Butterby Marsh of today."

In the light of the evidence collected in the present study, two hypotheses that could explain the stratigraphy of the sediments in the Marsh are now outlined. Both assume that the sediment beneath and including the sand layer in the transect line cores date to the period before the embankments were built. After this event, flow in the channel and sediment supply from long distance transport probably ceased. The major inflows and the outflow to the loop were presumably blocked as a further preventive measure to flooding of the farmland at Low Butterby. Alternative hypotheses are outlined in a later section (section 5.6.3).

5.6.1 <u>Hypothesis 1</u>

Griffiths seems to suggest that the grey silts were a product of natural river deposition prior to diversion, due to the long and level stretch of the old loop -

"The succession of sediments underneath the Typha Marsh is not the same as that of the river plain through which the channel of the Marsh runs. The sediments which fill the channel of the Marsh, namely clay and clay silt, have probably been deposited from the water of the river when the rate of flow of the current was diminished on entering the long and almost level reach of the old loop." (Griffiths 1932 p.109).

On page 126, Griffiths only interprets the black mud on top of the grey silt as having accumulated "during the period of 100 years which has elapsed since the Marsh was formed."

He suggested that the abundant fragments of the rhizomes, roots and shoots of Equisetum fluviatile in the grey clay represented a former surface of the floor of the Marsh covered with Equisetum. (This was perhaps the old river bed on to which the fringing herbs later spread when the water level in the loop fell). Griffiths noted that the Equisetum remains were absent from the "yellow clay silt".

If the upper layers of the grey silt were the former bed of the River Wear prior to 1811, it would have to have been very shallow in places. The original water level was suggested by Griffiths to have been 2 - 3 ft. higher than at present. However, since the banksides are at places only "a few inches" above present h.w.m. (Griffiths 1932 p.108) this may not necessarily have been the case. For example, the river at the point of the transect line would be very shallow according to this reconstruction, as at its deepest the top of the grey silt is only 2.2 m. below the N.W. field edge of the South Salix Marsh. If the sand represents a deposit prior to 1811 then the river could have been only a maximum of 2 m. deep at this point unless it was in flood or if levees were in place on its N.W. side[1]. Shallow fording points are however present at some locations on the Wear, e.g. one is marked on old maps near to Low Butterby Farm.

The plant detritus that is present in the basal silts could have been washed in from the catchment or from lagoonal backwaters on the floodplain. This includes the seeds and fruits of species such as Potamogeton natans, Ranunculus and Rumex,

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[1] Artificial levees were built extensively on the eastern part of the loop, as can be seen on John Bell's map of 1805 (see next section).

larger plant detritus (Equisetum nodal septa, Phragmites leaves) and other macrofossils (Daphnia egg cases, beetle elytra). Such remains are present in small quantities in the basal yellow/grey silts. The fact that such light organic detritus has been incorporated into the sediment could indicate very slow water conditions.

The black mud that occurs beneath the sand horizon could (according to this hypothesis) be accounted for by rapid deposition of the sand above an organic layer that was not usually incorporated into the sediment. However, since rooted material is abundant in this organic layer, it suggests that river plants (perhaps submergent aquatics) were growing in the grey silt prior to deposition of the sand. The sand could be attributed to a major flood, which destroyed river plant communities growing at this shallow point in the channel. As there are successive layers of sand on the highest area sampled on the point bar, this may indicate several flooding episodes, or a migration in the spatial patterning of the pool and riffle system.

There is documentary evidence which could allow for this reconstruction of events. Records exist for a major flood in 1771 which destroyed many mills on the River Wear, for example the Abbey mill at Durham and that at Witton-le-Wear (Anon 1849, Kirby 1968). Such a flood could have been responsible for depositing the sand layer at this point.

Other documentary evidence which could support this first hypothesis is the presence of a gravel (or sand) -bank shown on the inside of the curve at the point of the South Salix Marsh on a map by John Bell (1805). This could be the sand horizon that was encountered in the present study.

If Bell's map is compared with the map made by Pickering in 1802, it can be seen that the river has been redirected from flowing around the west side of the present "East Salix Marsh" to a position on its east side. There was much human interference with the river immediately upstream of the South Salix Marsh. This could account for the unusual pattern in the sediments, which suggest that slow water capable of depositing fine organic detritus and allowing the growth of river plant communities (such as Equisetum and Phragmites) was replaced by faster flow conditions. With a greater velocity, sand particles could be picked up and deposited on the shallower convex bank of the inside of the South Salix Marsh curve, in quantities that destroyed the plant communities growing there. "Gravel beds" can be seen to be widespread immediately upstream on Bell's and Pickering's maps. Sand is noted beyond the point of entry of Croxdale Beck to the loop on Pickering's map. Presumably these areas are the immediate source of the sand.

If the sand layer dates to 1771, or to the period prior to 1805, then the basal silts may be much older. The high metal concentrations and fluorite levels might however suggest a more recent origin, as mining activities reached a peak in the middle of the C19 (although mining has a very long history in Weardale). It would seem that the depositional environment at Butterby was a sediment trap for industrial and mining waste entering the loop from the River Wear, Croxdale Beck and the River Browney.

It has not been determined what conditions of flow allowed the formation of siderite bands within the grey silts. Each sand band that is interspersed with them may be the result of a temporary increase in flow conditions. This problem of interpretation has already been discussed.

Descriptive accounts of the character of the river at

Butterby, which are quoted by Griffiths, would allow for the above reconstruction. Surtees (1840) mentioned that the river plain at Butterby was always liable to serious floods. Griffiths (1932 p.105) suggests that although the River Wear is fairly rapid over most of its course, at Butterby it was very slow. He quotes Hutchinson's account (c.1787):

> "on the more distant side of the estate (of Low Butterby) the river flows deep and slow, forming a canal a mile in length, where the adjacent lands make a considerable plain."

There are still deep pools in the old loop. (e.g. The Long Pool, the Boathouse Pool) but many other sections are shallow. If the above hypothesis accounts for the pattern of events recorded by the sediments, then the river would have to have been very shallow at the point of the South Salix Marsh, allowing the growth of river plants. It may also have been very slow (apart from flood events), allowing the deposition of plant detritus. These conditions could be responsible for the organic mud layer beneath the sand horizon at this point. An account by Surtees (see following chapter) suggests that the river at Butterby was already partly overgrown by vegetation before 1840 and this could also apply to the period prior to 1811.

There is a possibility that the grey silts were deposited before 1811, but that the black mud beneath the sand layer results from marsh conditions. The sand layer could have been deposited by flooding into the marsh at a later date, perhaps the late C19 or early C20 so that after this marsh deposits again began to accumulate.

5.6.2 Hypothesis 2

This suggests that the former bed of the River Wear before 1811 is represented by the maximum depth to which the sampler could be pushed. The hypothesis focuses attention on the suggested time-lag between the opening of the new channel and the construction of the embankments. If there was a period of up to 46 years (1811 - 1857) before final communication with the river ceased and flow stopped, this could explain the pattern of events recorded in the sediments.

When the new waterway was dug across the neck of the loop, water would still flow through it (as Griffiths says) but its velocity would be decreased. Water that was already reported to be unusually "slow" would probably have become slacker. Any erosion of the bed would probably have ceased. Rapid silting up may have occurred, especially at times of flooding when overbank flows would carry material across the flood-plain from the new course of the river to be deposited in the backwater. There would still have been a source of bedload, as well as suspended load from flooding from the new course of the Wear. An abundant sediment supply to the loop may have come from the digging of the new channel. Once the embankments had been completed, flooding from the river into the pond system would probably be prevented and sediment supply greatly reduced.

The loop may therefore have become a depositional sedimentary environment in the long backwater that was formed after 1811, which could have greatly altered its character. This hypothesis seems to be a different idea to that envisaged by Griffiths.

River plants such as Phragmites, Equisetum fluviatile, and Potamogeton natans might increase in abundance and become established in the situation of reduced flow conditions. Their growth would also be favoured by a build up of sediment reducing the water depth. Daphnia might also be likely to respond to the slow water by increasing in abundance. Surtees' description in 1840 of the partially vegetated loop (see next chapter) may have only been appropriate for the period after 1811, in the decaying channel. The date of this description could also suggest that there was still some flow within the old channel at least two decades after the new channel had been dug. If so, this would mean that the embankments were not yet in place at the time Surtees made his observation.

The sand horizon capping the deposit of black mud and grey silt could be attributed to a flooding incident in the period shortly before the embankments were built. It could also relate to human interference with flow conditions upstream of the South Salix Marsh. It could, perhaps, have resulted from the construction process of the embankments, or from erosion of them before stabilization by vegetation. But if flooding incidents still took place after the backwater was created (after 1811) a response to this might have been to build the embankments across the inflow and outflow of the loop and cut off communication with the river in order to prevent flooding to the surrounding fields.

Once the embankments were completed, no bedload would be available to the old channel, and suspension load would only be available if river water breached the embankments or passed around them at some point to cross the flood plain and re-enter the pond system.

If "hypothesis 2" is correct, the gravel (or sand?) at the inside of the curve at the South Salix Marsh shown on Bell's map (1805) could be the basal impenetrable stratum. This could reach the subsurface close to the N.W. field edge of the transect line. This deep cross-profile would seem to be more characteristic of the River Wear at this point before 1811 when there was major flow during at least part of the year within the channel, with erosion of the bed. Scour would prevent an accumulation of silt. Sediment would accumulate only on the point bar, and this would probably be gravel or sand. "In fluvial sediments, shear velocities greater than about 20 cm./sec. rapidly remove all sand, leaving only coarser materials, and a minimum shear velocity of about 1.4 cm./sec. is required to move sand at all " (Reineck and Singh 1980 p.11). The transect line was placed at the outflow from the very long (c.1 mile) and very level meander loop, but even so it might be expected that there would be enough erosion in the active part of the channel at this location to prevent an accumulation of silt and black mud.

This hypothesis could be supported by the two old maps (1802 and 1805) which specifically refer to "gravel beds" (rather than sand) at many locations. The widespread gravel beds shown on Bell's map could indicate that the bed of the channel before 1811 was gravelly rather than silty. If the deposit shown on the inside of the curve of the South Salix Marsh on Bell's map [1] was in fact gravel and not just sand, this would lend weight to hypothesis 2. The same symbols are used as those for "gravel beds". While it is possible that the sand horizon noted on the transect line cores thickens to become gravel on the extreme north of the line, a soil pit that was dug close to this point revealed sand rather than gravel.

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[1] Also shown on the Low Butterby Farm Estate plan c.1805.

Both maps would suggest that the river had a gravelly bed originally. This may now be buried deep below the grey silts. Griffiths (1932 p.109) noted that below the yellow silty clay "lay pebble beds that the mud sampler was unable to penetrate." According to "hypothesis 1" this would be either an ancient bed of the river or an ancient surface of the floodplain across which the river later moved. The present hypothesis suggests it was the bed of the river before the digging of the new channel. This would mean that Croxdale Beck, on being redirected, cut down into the silts deposited in the backwater after 1811. Sections there show sands and clay silts above passing down into coarse sand and pebble beds below. (Griffiths 1932 p.109).

The high metal levels in the sediment might also be explained more readily by the second hypothesis. The period 1811 - 1857 was part of a time of great mining activity in the Wear catchment. Although the flow of the River Wear would have been diminished after 1811, the water of Croxdale Beck would probably still have flowed around the loop before the embankments were built, as it entered it beyond the cut across the neck. The position of the entrance of the River Browney might also have directed some of the flow around the loop. An 1874 reference to Croxdale Beck states that it was "as red as any mining river in Great Britain, depositing an orange coloured mud which heightens the bright red water passing over it" (Kirby 1968 p.180 - 181)[1].

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[1] This description would also fit the overflow stream from the present South Salix Marsh (which drains into a culvert beneath the embankments) which is also composed of reddish orange mud. It is possible that during exceptionally high river levels, water passes up through this culvert into the Marsh. The relative levels of the culvert and the river were not checked in 1982 accurately. In 1929 Griffiths estimated that the surface of the water in the river was 6 ft. below the level of the drainage culvert from the Marsh. Since records began in 1957 for the Sunderland Bride gauging station river levels have been higher than 2 m. on 25 occasions. This could affect the pondwater and explain the orange coloured mud in the drainage stream from the South Salix Marsh. However, it is unlikely that large quantities of sediment could come from such a source. This would also apply to the field-drain at the N.W. of Pond B.

Later, Griffiths (1932 p.108) noted that "no water enters the Marsh from the river or from Croxdale Beck, both of which are much polluted with coal washings, pit water, coke oven effluent and sewage."

In this long backwater into which there was an inflow with polluted water and load, iron enriched sediment may have been laid down at certain times of high input of iron to the system, perhaps from mine discharges or smelting. Selley's (1982) account of the formation of siderite bands within the clays of deltas, where there are alternations in the rate and source of sediment supply, could be an analogy of the situation in the backwater after 1811. The siderite bands could have originated in these conditions rather than when there was the major flow in the channel.

The laminations or cyclothems may be more suggestive of the backwater than the situation prior to 1811, even though the river at Butterby was already noted as a very slow stretch. As in the previous hypothesis, the fine bands of sand interspersed with the yellow silts could be accounted for by slightly increased flow in the channel.

In Haslam's (1978) analysis of the distribution of river plants she notes that:

> "the particle sizes and the stability of the substrate are largely controlled by flow. For example, faster flows have coarse substrates and streams with widely fluctuating flows have a wide range of scours and deposition during a season, and so have unstable substrates. Thus although flow exercises an overall control, the plants may be responding to the flow, the substrate, or both."

Records of floods occurring in the Butterby loop shortly before the building of the embankments could allow for this second hypothesis. Such floods could have caused the deposition of the sand above the grey silts of the slow backwater, which destroyed the plant communities that had already become established in the channel. The flood of 1771 has already been noted. Other floods reported from the Wear Valley include those of 1773, 1791, 1822, 1825, 1839 and 1841 (Anon 1849, see notes p.276). The sand horizon above silt deposits could be attributable to the floods after 1811 but before the building of the embankments.

This hypothesis agrees with Griffiths' suggestion that only the black mud (largely organic) above the grey silts has accumulated "since the Marsh was formed" but attributes the grey silts to deposition during the period between 1811 and the construction of the embankments. Deposition is attributed to the conditions in the decaying channel of the loop after the new channel became a through waterway.

5.6.3 Alternative Hypotheses

"Hypothesis 2" would require that about 2 m. of sediment built up in the relatively short time-period of less than 40 years (perhaps only 10 years if Griffiths' suggestion about the date of the embankments is correct). If this is unrealistic, then "hypothesis 1" may be correct; or the assumption that the sand horizon was formed before the embankments were built may be wrong. It is possible that it was formed in the late C19 or early C20, so that the infill of the channel represents a much longer period of accumulation that began after the main current of the river was diverted away from the loop. This alternative is discussed below.

If the maximum depth to which the sediment sampler could be pushed does represent the former bed of the river immediately prior to 1811, the possibility that the build up of the grey silt layers partly resulted from deposition of load carried by floodwaters after 1857 cannot be discounted. Water from the new course of the River Wear may have re-entered the pond system and washed in material. If so, this material could be enriched with mining detritus and metals. The laminations in the silts could be lacustrine, dating to the period after the embankments were built, with the minor sand bands being related to seasonal turbidity currents or faster floodwater carrying sand as suspended load. The load of a river in flood is deposited on the flood plain, and the pond system could accumulate transported material rapidly, due to its lower altitude. Sediment will also have reached the ponds as a result of run-off from the surrounding arable fields, and wind-blown material from the arable fields may have contributed to the accumulation.

A flood in the late C19 or early C20 could have deposited the sand horizon above the black mud and grey silt. Unfortunately, no reference work that collected together information on floods of the Wear could be found since the publication of 1849. Information is probably scattered through local history sources. This would seem to be an obvious gap that should be filled. Rainfall data from the Durham Observatory dates to the 1830's which could be used to trace "wet periods". River level records for the Sunderland Bridge gauging station kept by the Northumbrian Water Authority begin in 1957.

If the sand layer(s) above the grey silts was deposited by the river after the embankments were built it would probably have been transported as suspension load rather than as bedload. Once cut-off is complete, no bedload is available.[1] (Reineck and Singh 1980 p.294). Allen (1965 p.155) states that after closure, further filling in a cut-off meander is limited to deposition of fines introduced by overbank flows.

Sundborg and Hjulström type curves (see Allen 1965 pp. 108 - 109, and Reineck and Singh 1980 p.10, p.11) show that sand grains greater than .22 mm. can be transported by suspension load only at flow velocities greater than 30 cm./sec. For particles of .6 mm. (5% of the grains in the sand layer are larger than this), transportation as suspended load requires a flow velocity of about 130 cm./sec. Figures from the Sunderland Bridge gauging station dating from 1957 record peak flows in "cumecs".[2] They show discharges as great as 415.27 cumecs when the river was a record 3.423 m. above station zero (5/11/1967).[3] The river has risen 2 m. above station zero 26 times in the period 1/10/57 - 4/1/82. Discharges of this magnitude may be great enough to transport sand on to the flood plain. The field to the

---

1 There is a field drain (?) at the north end of Pond B but this would be unlikely to yield such a quantity of sand.

2 1 cumec = 1 m^3 $sec.^{-1}$

3 equivalent to a flow velocity > 300 cm. $sec.^{-1}$

north of the South Salix Marsh has a sandy soil, which could support this idea.

The embankments are at this point at least 4 m. above the present river and would prevent water breaching them, but flood water could pass around them at some point. In the past, the river level in the new channel may have been higher, before erosion of the bed (a suggestion made by Griffiths). If so, flooding over the embankments may have been possible in the time period shortly after their construction. Floodwater could also rise up through the drainage culvert from the South Salix Marsh. The South Salix Marsh is close to the present river and at a low point on the flood plain. Sand transported by floodwater would enter the Marsh on the lower field edge and could, therefore, form a layer that was thicker on that side; although if it had been transported as far as this it would probably fill up the lowest point of the old channel in the deeper water. There would be no strong channel flow North - South to erode it in this area (which would also leave the black mud beneath it intact).

However, a number of factors suggest that the sand horizon was deposited before the embankments were built. Allen (1965 p.108) stated that "for quartz particles, a diameter of approximately 0.2 mm. divides sediment that is carried and laid down mostly by bedload from sediment transported and deposited chiefly from suspension." The sand layer, which is dominated by quartz, has the following particle size distribution : 26% fine sand (0.21 - 0.075 mm.), 54% medium sand (0.6 - 0.21 mm.) and 5% coarse sand (2.4 - 0.6 mm.) This could indicate that it was carried to the site as bedload rather than as overbank flow from the new course of the river, so that it dates to a time before closure of the old loop. Allen (1965 p.125) noted that channel-fill deposits do not easily fall into the categories of "lateral accretion" deposits (bedload) or vertical accretion deposits (suspended load from overbank flow). They are transitional between the two. They consist partly, and sometimes wholly, of bedload material; but this can only be deposited before closure.

The sand horizon is thin beneath the deepest part of the old channel, while there are successive layers on the point bar. This would suggest flow within the channel. It is highly sorted and contains very little organic debris. Its accumulation seems to have destroyed a *Phragmites* bed. Destruction could have been caused by strong flow within the channel, or the rapid accumulation of the sand above the reeds.

If strong flow within the channel from North to South did transport the sand, it is curious that the black mud beneath it was not eroded, especially in the deeper part of the channel. It is possible that the sand was deposited shortly before the large embankments were built, or during their construction, (prior to their stabilization by vegetation), so that its accumulation results from floodwater entering the backwater from the nearby new course of the river in a direction south to north. It might therefore result from the action of the river in its new channel building a levee of coarse material deposited during flooding. Previous floods may have transported the suspended load of grey silt further across the floodplain to fill the old channel, while during a major flood at a later stage coarser material was deposited nearer to the new course of the river, across the outflow of the loop.

Allen (1965, diagram p.156, p.157) shows that deposits within "neck cut offs" are composed of silts and clays for most of their length, but at the points of closure at the inflow and outflow there are sand plugs. The evidence from Butterby would seem to show a slightly different situation as, at least at the sampling location, the sand does not extend to great depths. But it does occur at the end of the loop and may therefore result from transported bed load that had begun to plug the outflow prior to man-made closure of the loop, in a similar manner to Allen's example. "Interstratification of major fine and coarse grade units in the channel fills of neck cut-offs is usually restricted to the upstream ends of the channel fills where most of the bedload material is to be found." (Allen 1965 p.157). The stratigraphic transect cores were taken at such a location.

A major question must be: how effective have the embankments been at preventing floodwater entering the old loop? If they have been effective barriers, the sand layer would date to the period before their completion. This would assign a minimum date of c.1850 to the sand layer. The date of deposition of the grey silts beneath it could either be accounted for by "hypothesis 1" or "hypothesis 2". However, the river level may have fallen in the new channel beyond the embankments due to erosion of the bed, as Griffiths suggests. Therefore floodwaters may have been able to breach or pass the embankments more easily in the past. The sand may have been deposited above the black mud (formed in marsh conditions) by a flood shortly after the embankments were built, when the level of the river in the new channel may have been higher.

Another possible origin of the cyclothematic grey silts is that the river moved across its own flood-plain deposits so that the grey silts represent a very ancient former surface of the flood plain. Griffiths (1932 p.109) noted that ....

> "sections through the deposits of the river plain are to be seen in the south arm of the loop where the Croxdale Beck has cut a deep channel down through the beds .... the

succession of sediments underneath the Typha Marsh is not the same as that of the river plain through which the channel of the Marsh runs."

However, ancient flood plain deposits may be different from more recent deposits. Reineck and Singh (1981 p.297) describe flood basin deposits in the following way ....

"Sediments of a flood basin contain the finest grains of all the alluvial sediments. Flood basin sediments are finer than the corresponding natural levee, crevasse splay and point-bar deposits, and generally they are fine silt and clay (Fig. 426). There may be a slight upward fining in each flood basin sequence of silt-clayey sediments. Flood basin deposits seldom show horizontal bedding with textural differences. Mostly uniform finely laminated mud is present, interrupted by some sandy or silty intercalations. Sometimes small channels with sandy-silty sediments may be present. Soil horizons with disturbed bedding are abundant. Organic debris and mottled structures are other important features. Locally, pockets of freshwater mollusc shells and bones of vertebrates may be present. Because of repeated exposure, flood basin deposits are subject to dessication. Mud cracks and other surface features are widespread. Locally, windblown sand deposits may be present.

Some parts of this description do seem to fit the lower sediments in the channel. They may therefore be an ancient surface of the floodplain across which the river later moved; or be the deposits of floodwater that passed around (or across?) the embankments and washed material across the fields into the Marsh - two very different ideas. The latter option seems more possible due to the metal enrichment of the silts. Although flood basin deposits accumulate slowly, the old channel could rapidly fill due to its lower altitude. Clay plugs in old channels, the result of suspension load carried by floodwater after closure, are known in the Mississippi River flood basin to be up to 40 m. thick (Reineck and Singh 1980 p.293).

However, because of the sand above the grey silts in the South Salix Marsh, the deposits which fill the old meander loop are suggested to have originated before the embankments were completed. It seems possible that they result from conditions in the old channel in the period between 1811 and the completion of the embankments. Suspended load and bedload could have contributed to the accumulation, and coarser material could be transported from the new course of the river to locations near the inflow and outflow of the loop during flood events.

5.6.4 Further Work

An obvious follow up to this problem would be to take a deep core from a modern stretch of the River Wear, comparable to the situation at the Butterby loop before 1811, in order to see if the sediment resembled that which fills the old channel. Comparative studies of sediments from the present river could aid interpretation of the stratigraphy. The conditions governing the formation of the fine bands of siderite within the silt would also need further investigation - it would be interesting to see whether they occur within sediment beneath the present river.

Data on peak flows of the present river since 1957 is available for the Sunderland Bridge gauging station immediately upstream of the Butterby loop. The figures could possibly be used to reconstruct the flow regime of the river in the Butterby loop and correlate this with the cyclothems in the sedimentary layers. However, it is likely that the flow regime of the Wear, and its input of sediment load, has altered during the last few centuries due to changed patterns of human interference. Water would have been used in the past for pit washings and flushings.

It might be possible to experimentally model the conditions during the time period under consideration. This could suggest whether the situation after 1811, when there was still an inflow to the backwater with an input of polluted load, could have resulted in a fairly rapid accumulation of silt.

Perhaps the best way to test these different ideas and to accurately assess the time period under consideration would be to date material in the sediments using ^{210}Pb (Eakins and Morrison 1977, Oldfield et al. 1979). It is thought to be a relatively short time period under consideration and ^{14}C may be less appropriate.

Further work may reveal new evidence that will enable conclusions to be made with greater certainty about the dates of deposition of the various sedimentary layers in the Marsh. It must be stressed that the hypotheses advanced by the present writer concerning the origin of the sediments are merely ideas based on the data gathered in the present study. Interpretation of what the evidence means is, without the employment of accurate dating techniques, speculative. The site's history as a depositional sedimentary environment seems to be complex; although the short time scale involved since the diversion of the river may be an advantage for the interpretation of the evidence. The summary of ideas is not intended to be a conclusion to the problem.

Butterby Marsh seems to be an interesting site which could prove to yield valuable information about the processes of alluvial, lacustrine and marsh sedimentation, and the role of this in the vegetational development of such sites. There seem to have been major changes in the mean water depths, the water quality, the source of sediment supply and its characteristics, and the relative stability of the habitat during the last 180 years. This has produced corresponding changes in the ecology of the site. What must originally have been an unstable habitat for plants (and animals) has been replaced by a large area of marsh favourable to the luxuriant growth of certain species.

5.7 SUMMARY

Analysis of one sediment core of 2.5 m. depth showed that it contained high concentrations of metals and other mining detritus, such as fluorite, over much of its depth profile. Similar detritus (e.g. coal particles) was found in other cores examined.

A sand horizon capping the grey silts on the point bar of a meander curve near to the old outflow from the loop would suggest strong flow conditions within the channel at the time it was deposited. Plant remains and rooted material indicative of slow water conditions occurred beneath this.

From the evidence gathered in the present study, the following suggestions are made. It would seem that the grey silts that fill the old channel originate from the River Wear. They probably were deposited before closure of the loop. The sand layer that occurs above them on a meander curve near to the point of closure does not seem to have formed due to an overbank flow from the new course of the river after the embankments were built. This suggests a marker horizon for the phase of strictly marsh sedimentation above it.

A lower marker horizon may be the basal impenetrable stratum, which is suggested to be the former river bed before 1811. The silts that fill the channel may have accumulated due to the reduction of flow when a new channel was dug across the neck of the loop. This might account for:

(i) the shallow depth of the surface of the sands and silts in many places,

(ii) the plant detritus and rooted material in the grey silts, and the black organic mud beneath the sand layer at the South Salix Marsh;

(iii) the high level of mineral and metal enrichment (the period 1811 - 1857 was part of a time of high mine output); and

(iv) the laminations of siderite, which often forms under "deltaic", lacustrine and low water level situations.

The channel of the loop at Butterby may therefore have only been a depositional environment and a sediment trap since 1811, so that the river prior to the excavation of the new channel had a deeper bed with a range of scour and deposition cycles. Channel fill deposits usually result from aggradation in an abandoned or decaying channel (see Allen, 1965, p.127).

Old maps of the loop, drawn shortly before 1811, suggest that the river at that time had a gravel bed. Major floods of the River Wear are reported in the time between the opening of the new channel and 1857, (the first available documentary evidence of the presence of the embankments). These could have contributed to the accumulation and deposited the sand layer above the grey silts on the curve of the present South Salix Marsh.

An alternative hypothesis is that the grey silts were deposited by the river on entering the long and almost level reach of the old loop. This suggests that the unconsolidated sediment which fills the old channel represents a much longer period of accumulation, with "natural" deposition of silt occurring before 1811. This seems to be the explanation suggested by Griffiths (1932) for the origin of the grey silts that fill the channel.

There is a possibility that the bed of the river prior to 1811 <u>is</u> represented by the impenetrable basal layer, but that the build up of silts represent a gradual increase over the last 170 years even though the embankments were in place. However, flooding past the embankments into the old channel from the present river would be unlikely to renew flow conditions to an extent that could form such a thick horizon of medium grain sand on the point bar of the South Salix Marsh. There may have been no communication between the pond system and the River Wear or Croxdale Beck since the embankments were built. Griffiths (1932) noted that no water entered the ponds from these two sources. Water analysis made in the present study would also suggest that this observation is correct. The fields surrounding the ponds have been seen under water in the past but this is attributed to poor drainage rather than river flood water.[1] But originally the water level of the river in the new channel may have been (on average) higher than at present, before deepening by erosion of the bed. If so, flooding past the embankments could more easily have occurred.

Both hypotheses concerning the origin of the bulk of the unconsolidated sediment assume that the sand layer was laid down by flow in the channel before the completion of the embankments. This would ascribe a minimum age to the grey silts of c.120 years (1857 - 1982). If this assumption is correct, then the amount of infill (or "autogenous accumulation") that has taken place in the old channel since the Marsh was formed has been small - less than 75 cm. This seems to be the conclusion also reached by Griffiths (1932). This small amount of autogenous accumulation is perhaps attributable to the reduced supply of inorganic sediment, due to the isolation of the pond system from the bedload and suspended load carried by the River Wear and Croxdale Beck.

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[1] Mr. J. Hannaby, Low Butterby Farm.

It would seem that river plants had already begun to produce organic sediment in the shallow water of the South Salix Marsh prior to the last major input of inorganic sediment, as a black mud with plant remains underlies the sand. The plant communities that later became established in the old channel would seem to have produced only a small amount of organic sediment since the Marsh was formed. The upper layers of organic accumulation are only 56 cm. at Core 6 and 15 cm. at Core 1 along the transect line. At other points in the pond system the organic black mud at the surface varies from 35 cm. from the deeper water of Pond A (Core 2) to 75 cm. beneath a Phragmites bed (Core 6). Organic detritus does not appear to accumulate rapidly.

Hydroseral succession, as driven by sediment accumulation, is unlikely to proceed at a fast rate at Butterby Marsh if the above suggestions are correct and a similar trend continues. However, large changes in the floristic composition of the Marsh areas can take place in time periods of 50 years or less, as demonstrated in the present study. These may be attributable to biotic factors affecting the fen and aquatic plant communities, rather than to increases in the thickness of the sediment. Such factors may be differential tolerance to the instability of a habitat in which there are large fluctuations in water level seasonally, and competition amongst the plant communities.

However, the accumulation rate of sediment in the Marsh, and its effect on the mean water depth, is important in analysing hydroseral succession in the context of long term change. The nature of the sediment (its texture, nutrient status, toxicity etc.) and the water chemistry are probably both important habitat factors for the plants at the Marsh.

CHAPTER 6 : DISCUSSION

6.1 THE DEVELOPMENT OF THE MARSH VEGETATION

1. The period 1811 - 1929.
2. The period 1929 - 1982.
3. Comparison of the O.S. 1 : 2500 map surveys of 1857, 1897, 1919 and 1960.

6.2 THE FUTURE DEVELOPMENT OF THE MARSH

6.3 COMPARISON WITH OTHER HYDROSERES

6.4 FURTHER WORK

CHAPTER 6 : DISCUSSION

6.1 THE DEVELOPMENT OF THE MARSH VEGETATION

Griffiths gives an account of the development of the Marsh at Butterby. (1932 p.125-126).

> "The fall in the water level of the original channel of the Marsh was probably due to the erosion of the bed of the river in the new channel which was cut across the neck of the loop. The river was shortened by nearly a mile, and the resulting acceleration of the current brought about a vertical erosion of the bed for a considerable distance both up and down the course of the river. If the fall of the water level in the loop has been some 2 or 3 ft., then the highest parts of the present floor of the Marsh, namely the East and West Salix Marshes, must have been from 1 ft. 6 in. to 2 ft. 6 in. under water. This depth of water would permit the growth of Phragmites, Scirpus lacustris and Equisetum limosum (and possibly Typha in stagnant places), but would exclude Rumex, Sparganium, Iris and the plants of the higher zone. It would also exclude all the Marsh-forest trees. The present flora of the Typha Marsh, and the East, West and South Salix Marshes would be replaced by Phragmites, Sc. lacustris and Equisetum, the last probably being the most abundant. The Great Rumex Marsh would be open water, and the Long Pool and Boathouse Pool would be longer, broader and deeper. This reconstruction agrees with Surtees' description (see p.105) and is also confirmed by the presence of fragments of Equisetum in the deposit of grey clay under the present Typha Marsh.
>
> On these grounds it is probable that the societies of Phragmites represent original vegetation which is now in process of retrogression, but the Rumex-Equisetum community and the Marsh forests are secondary and have arisen by the colonisation of the channel from the littoral region (including the marshes of the East Pasture) as the water level fell. The colonisation phase is now over and the present phase is one of autogenous development of the habitat. The vegetation is making a new substratum out of autogenous products of decay, and the floor of the marsh is being raised and the relative position of the level of the h.w.m. is being changed. The accumulation is most marked in the Rumex-Equisetum community, where the bulky rhizomes of Rumex tend to grow on top of one another. A hole was dug in the south end of the Rumex-Equisetum community of the East Salix Marsh in the summer of 1929, when the water level was abnormally low, and the following stratification of deposits was found:

(a) Stratum about an inch thick, consisting of living rhizomes of Rumex covered with, and embedded in, dense masses of Mnium and Hypnum.

(b) Stratum from 3 to 5 in. thick, consisting of three successive layers of old rhizomes of Rumex, embedded in finely divided black detritus. The old rhizomes were black, hard and semi-carbonised.

(c) Stratum 7 to 9 in. thick, consisting of dark coloured finely divided detritus, densely penetrated by living and dead rhizomes of Equisetum limosum.

(d) Basal stratum of clay silts.

The stratification indicates that at this particular spot there has been an accumulation of autochthonous detritus to the extent of about 1 ft. during the period of 100 years which has elapsed since the Marsh was formed. The invasion of the Rumex-Equisetum community by Salix fragilis (pp. 115, 116) is probably a result of the increase in the height of the surface by autogenous accumulation."

The present study has attempted to trace the overall development of the Marsh since the diversion of the river in 1811, with particular attention to the western side. It was intended to trace changes in the vegetation since the 1929 survey by remapping the plant communities and collecting floristic data. The Marsh history as recorded in the sediments was also investigated in order to trace vegetational succession over a longer time scale and quantify the rate of infill. This would give a basis for the prediction of the future development of the Marsh.

The results of the two parts of the present study have already been summarised and briefly discussed. Here they are discussed together in a more general framework, in order to describe the stages of the hydrosere.

6.1.1 The period 1811 - 1929

Surtees (1840)[1] gave a description of the river at Butterby.

> "The Manor House stands on a level fertile haugh in the depth of the valley, at the foot of a wooded range of hills, and rendered nearly a semi-isle by the circling sweep of the Wear. On the north the river falls swiftly over a rocky channel, under shelving banks fringed with native wood. The southern reach of the Wear assumes a rather unusual character, flowing for near a mile, dark, deep and slow, in sullen sedgy majesty, through pools haunted by heron.
>
> The common daffodil, (Narcissus pseudo narcissus) flowers plentifully at Low Butterby in moist meadows near the Wear. The globe flower (Trollius Europaeus) is also plentiful on the river banks. The giant throatwort (Campanula latifolia) is frequent in the woods and hedges."

Surtees' description suggests that the reach of the Wear at Low Butterby was already partly vegetated by sedges in 1840, and overhung by the fringing trees. It is uncertain whether this description would have applied to the Wear at Butterby prior to 1811. After 1811, the flow may have diminished due to the cut across the neck of the loop which could have allowed the spread of sedges and reeds. Surtees describes the river as containing deep pools. These would presumably be the present Boathouse Pool and the Long Pool. However, other points may have been shallow if the reconstruction suggesting that the grey silts were the former bed of the Wear prior to 1811 is correct.

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[1] Surtees' volume has been republished in 1972 and additional information to that given by Griffiths is quoted here. The extract comes from the section of "City and Suburbs of Durham, St. Oswalds" pp. 110-113. I would like to thank Mr. J. Richardson for allowing me to consult copies of the 1972 edition in his care.

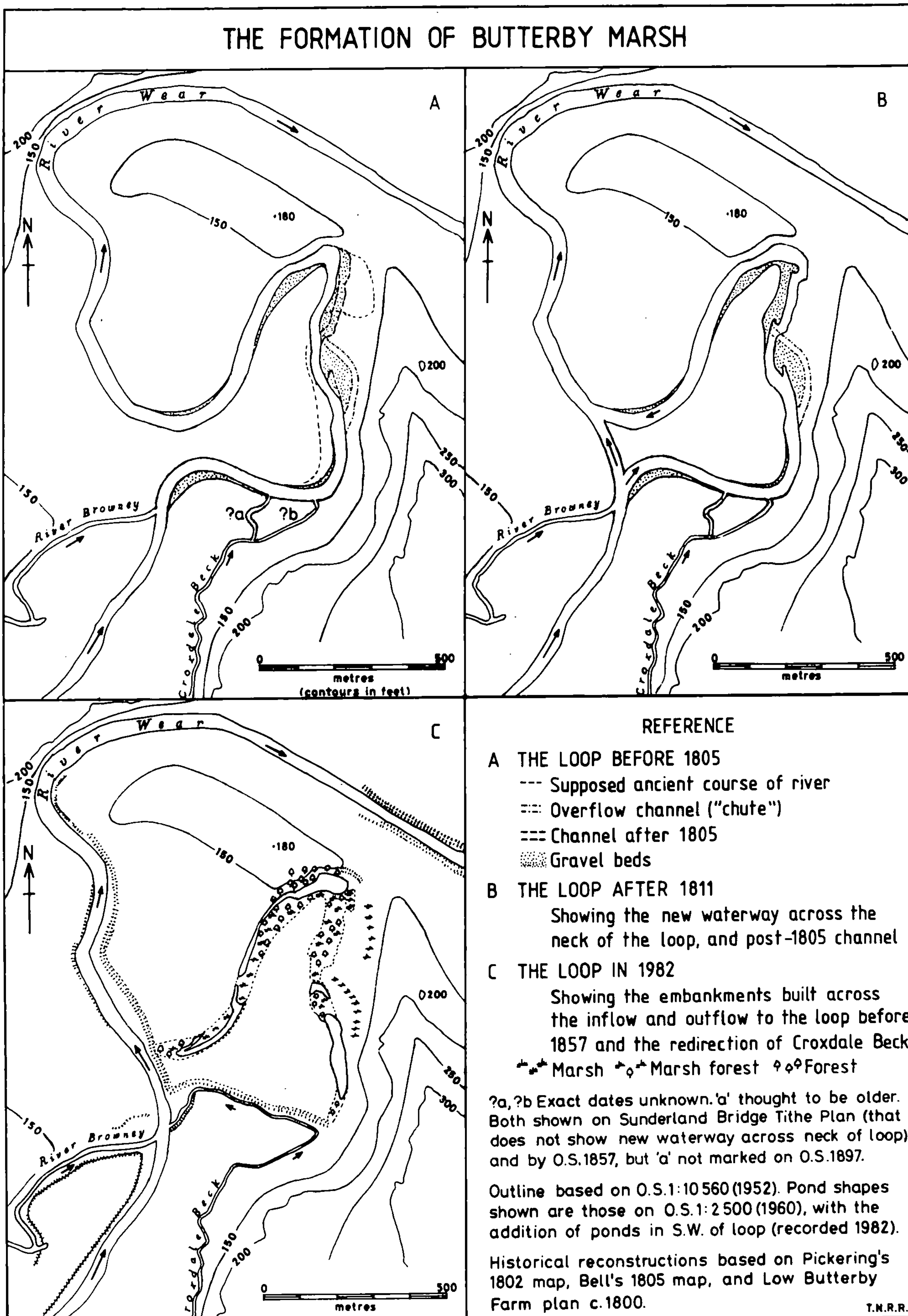
THE FORMATION OF BUTTERBY MARSH
A
B
C
River Wear
River Browney
Croxdale Beck
N
?a
?b
150
180
200
250
300
0
500
metres
(contours in feet)
REFERENCE
A THE LOOP BEFORE 1805
--- Supposed ancient course of river
Overflow channel ("chute")
Channel after 1805
Gravel beds
B THE LOOP AFTER 1811
Showing the new waterway across the neck of the loop, and post-1805 channel
C THE LOOP IN 1982
Showing the embankments built across the inflow and outflow to the loop before 1857 and the redirection of Croxdale Beck.
Marsh Marsh forest Forest
?a, ?b Exact dates unknown. 'a' thought to be older. Both shown on Sunderland Bridge Tithe Plan (that does not show new waterway across neck of loop), and by O.S.1857, but 'a' not marked on O.S.1897.
Outline based on O.S.1:10 560 (1952). Pond shapes shown are those on O.S.1:2 500 (1960), with the addition of ponds in S.W. of loop (recorded 1982).
Historical reconstructions based on Pickering's 1802 map, Bell's 1805 map, and Low Butterby Farm plan c.1800.
T.N.R.R.

Fig.6.1

Maps of the river at Low Butterby were produced by Pickering (1802) and Bell (1805) in relation to disputes about property boundaries due to the continued shifting of the river's course on the low level flood plain. Both maps show the position of large deposits of sand and gravel beds, and the many different positions that the Wear had occupied at different times. On the eastern part of the Marsh there was much human interference with the course of the Wear. Shifting of the river's course meant a loss of property to one or other of the estates on different sides of the river. Many jetties and erections were built. Between 1802 and 1805 the maps suggest that the river's course was diverted from the west to the east side of the present "East Salix Marsh".

The maps have implications for explaining the present distribution of plants at the Marsh. They show the influence that the initial depths and location of the old river channel has had on the vegetation that has developed at Low Butterby.

Old river features on the flood plain are still occupied by small marshes. The 1805 map shows "(6) the supposed line or channel of a branch of the river formed by a flood, where the water continued to run for some time but which it in time abandoned and in which there remains dubs of water." This may have been the disastrous flood of 1771 which has already been mentioned, and the jetties may have been constructed in response to this. This is the location of what Griffiths termed the Middle Pasture Marsh, presently overgrown with _Juncus inflexus_. A "supposed ancient course of the river" flowing beneath "Croxdale Low Slidings (8)" now contains the small area named the "Woodside Marsh" by Griffiths (1932).

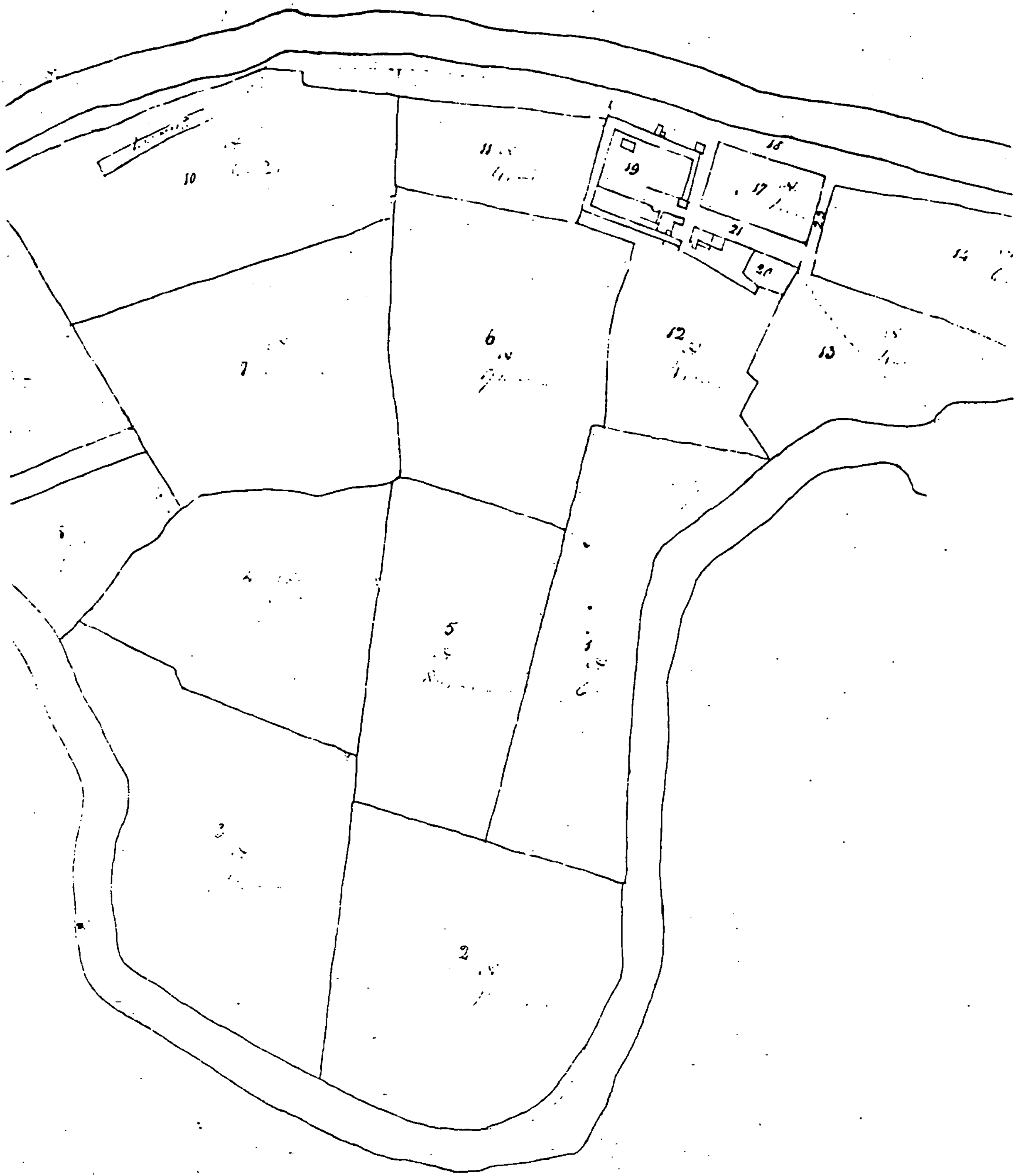

Fig 6.2 Low Butterby Farm Plan (c.1800).

Source : Durham County Records Office. D / Sa. / P.5
Fig.s 6.2, 6.3, and 6.4 reproduced with kind permission of Captain G.M. Salvin.

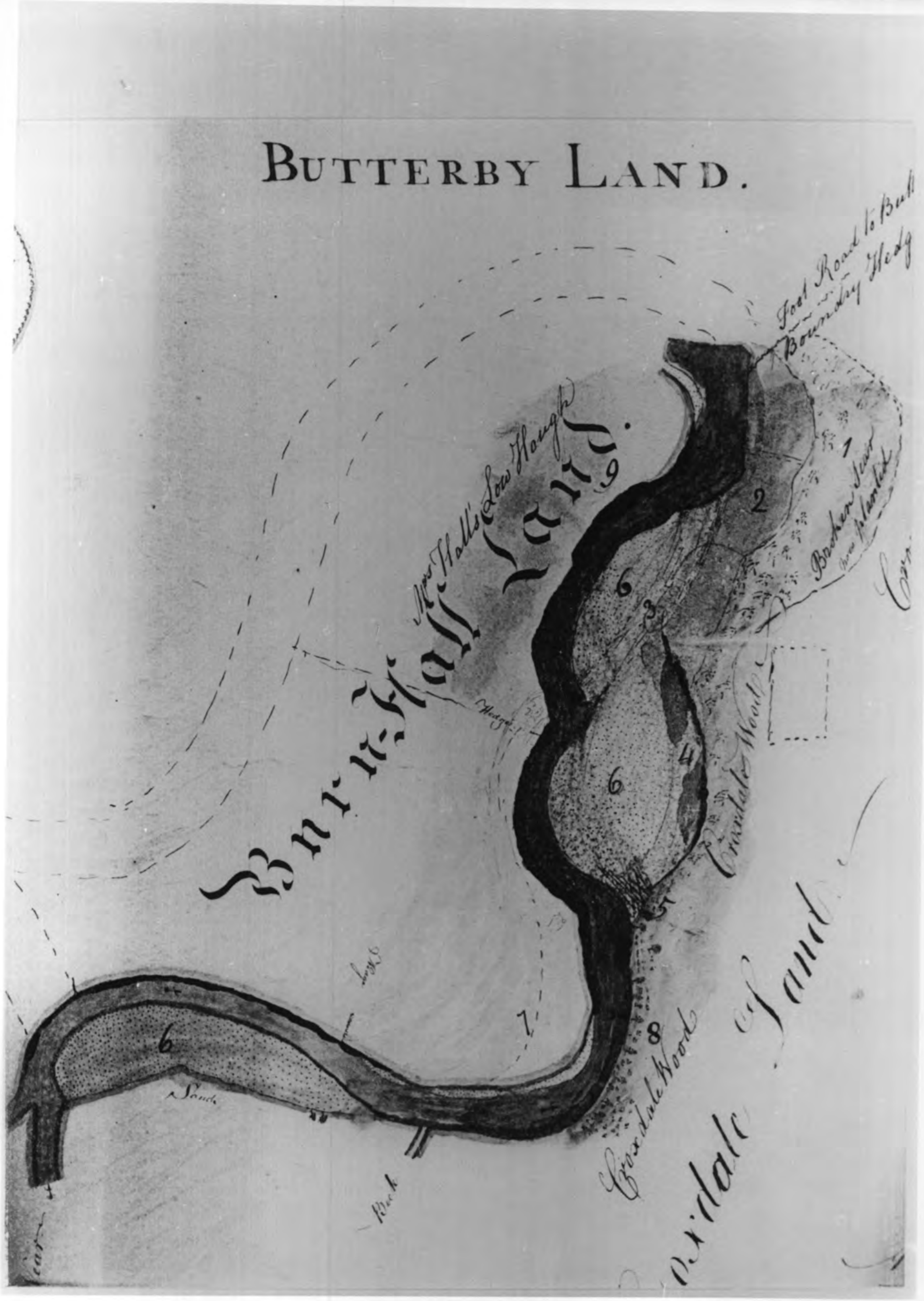

Fig.6.3 <u>River between Croxdale and Burn Hall estates by J. Pickering 1802 D/Sa/P43</u>

<u>Legend</u> 1. The Low Slidings. 2. A Bat now in Potatoes. 3. A branch of the river now dry in summer. 4. A channel formed by a sudden flood now standing in holes full of water called Dubs. 5. First Fundering or jetty the point of dispute. 6. Gravel beds. 7. An old course of the River where Mrs. Hall has gained ground. 8. The Deeps under Croxdale Wood where Mr. Salvin has lost ground. 9. Mrs. Halls Low Haugh where she has lost ground.

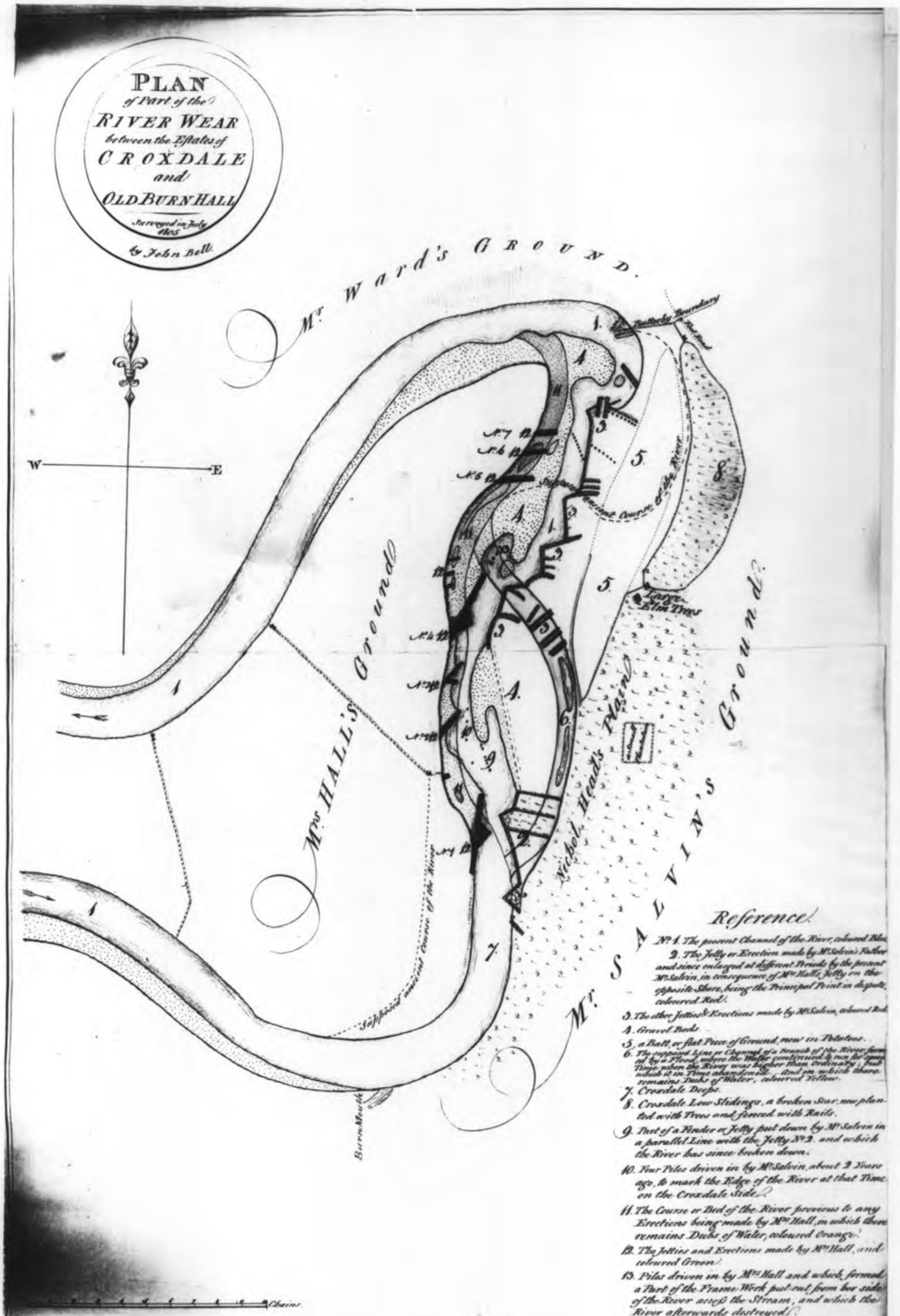
PLAN
of Part of the
RIVER WEAR
between the Estates of
CROXDALE
and
OLD BURN HALL
Surveyed in July 1805
by John Bell.
Mr. Ward's Ground.
Mrs. HALL'S Ground
Mr. SALVIN'S Ground
Nicol. Head's Plain
Large Elm Trees
Supposed ancient Course of the River
W
E
Burn Mouth
Chains
Reference
No. 1. The present Channel of the River, coloured Blue.
2. The Jetty or Erection made by Mr. Salvin's Father and since enlarged at different Periods by the present Mr. Salvin, in consequence of Mrs. Hall's Jetty on the opposite Shore, being the Principal Point in dispute, coloured Red.
3. The other Jetties & Erections made by Mr. Salvin, coloured Red.
4. Gravel Beds.
5. a Ball, or flat Piece of Ground, now in Potatoes.
6. The supposed Line or Channel of a Branch of the River formed by a Flood, where the Water continued to run for some Time when the River was higher than Ordinary; but which it in Time abandoned. And on which there remains Dubs of Water, coloured Yellow.
7. Croxdale Deeps.
8. Croxdale Low Slidings, a broken Scar, now planted with Trees and fenced with Rails.
9. Part of a Fender or Jetty put down by Mr. Salvin in a parallel Line with the Jetty No. 2. and which the River has since broken down.
10. Four Piles driven in by Mr. Salvin about 2 Years ago, to mark the Edge of the River at that Time on the Croxdale Side.
11. The Course or Bed of the River previous to any Erections being made by Mrs. Hall, in which there remains Dubs of Water, coloured Orange.
12. The Jetties and Erections made by Mrs. Hall, and coloured Green.
13. Piles driven in by Mrs. Hall and which formed a Part of the Frame Work put out from her side of the River across the Stream, and which the River afterwards destroyed.

Fig.6.4

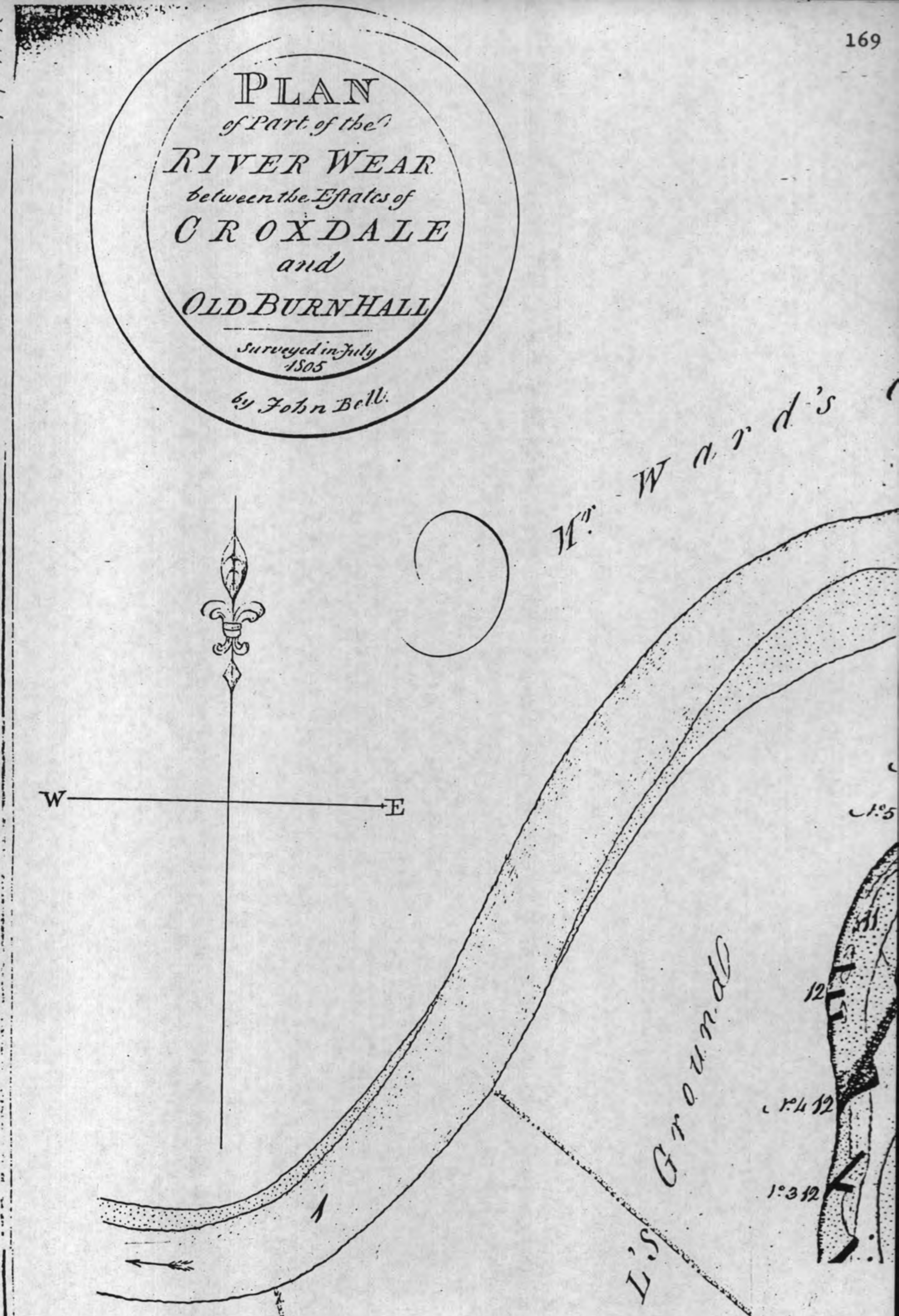

Fig 6.4.I. The Study Site in 1805 (detail from John Bell's map).

Note the 'point bar' deposits ('gravel beds') at the location of the present West- and South Salix Marshes, where there has been extensive development of marsh forest. (Original plan 46 x 66 cm.).

It is interesting to note that the shallow water areas and exposed gravel beds shown on the maps underlie what is now the "East Salix" and "West Salix" Marshes where there has been extensive development of fen Carr. The O.S. map of 1857 shows this carr in an early stage of development. The sand and gravel substrate may have influenced the type of soil that has developed. The deeper channel around the east side of the East Salix Marsh is filled with a floating raft of Iris beneath a cover of Salix fragilis. At the south of the East Salix Marsh, where the 1802 channel and the 1805 channel parted, there is still standing water filled with pure Equisetum fluviatile.

The shape of the meander curve at the point of the present 'South Salix Marsh' is shown on the Butterby Farm estate plan (c. 1800) and on John Bell's map (1805). A point-bar or slip-off-slope of 'gravel beds' is shown on both maps on the inside of the curve. This may be the deposit that was noted in cores 7 and 8, and the cores of the N.W. of the transect line that was placed at this point. It could, however, represent a basal layer of sand or gravel which the corer could not penetrate. If so, then this sand could be related to the flood in 1771, and the sand horizon found capping the grey silts to a flood in the 1820's or 1830's. This reconstruction (hypothesis 2 in section 5.5), would attribute the grey silts at this point to deposition in the slow backwater created after 1811.

The gravel shown on the 1805 map could be attributable also to the diversion of the river around the west of the "East Salix Marsh" in 1802 - 1805 when there would have been increased erosion of the gravel bed on the western side. The human interference with flow patterns immediately upstream could account for the variable nature of the deposits with depth along the transect line, in which substrates characteristic of low velocity flow are replaced by substrates of coarser textural properties. The pattern might also suggest changing sources of sediment supply. The plant detritus in the grey silt might be attributable to such activities when the current was redirected across former gravel beds on which vegetation may have developed (i.e. the present East Salix Marsh).

Along the western arm of the loop, the deeper water channel still for the most part consists of ponds. These follow the line of previous maximum velocity and scour on the outside of the meandering curve, which switches sides at the junction of Ponds "B" and "C". The deeper water channel at the point of the South Salix Marsh is still an open pool with a steep "river cliff" or concave bank up to the field edge, while the convex, shallower, slip-off slope has developed a marsh forest similar to that on other former slip-off slopes at the West and East Salix Marshes. This marsh forest has an acid soil, perhaps attributable to the rapid drainage and leaching through the sand layer. The soil of the field adjacent to the N.W. of the South Salix Marsh, part of the former river's flood plain, is also sandy and has a pH reaction of <6.

Griffiths suggests that there was a fall in the water level in the original channel of the marsh due to the erosion of the bed of the river in its new course. Its flow velocity would have increased due to the shortened course. He estimated that the surface of the river is nearly 6 ft. below the level of the outlet of the culvert which drains the marsh, (1932 p.107) and that there was a fall in the water level of the loop by 2 or 3 ft. This reconstruction suggests that "the highest parts of the floor of the marsh, namely the East and West Salix Marshes, must have been from 1 ft. 6 in. to 2 ft. 6 in. under water." However, since the gravel beds are shown as exposed areas on the 1802 and 1805 maps, reconstruction of the pre-1811 situation does not necessitate a water level much higher than the present level in the marsh. The shallow areas that Griffiths accounts for by suggesting that the water level was previously higher could also be accounted for by a reconstruction suggesting that the former bed of the river is represented by pebble beds and sand beneath the grey silts. The latter may have accumulated in the period between 1811 and the construction of the embankments (perhaps some 30-40 years later). However, these two ideas do not necessarily conflict, so that water level may indeed have fallen and the sediment may also have only accumulated after 1811.

Between the documentary evidence of the old maps of the loop prior to the digging of the new channel, and Surtees' description of the area in 1840, the backwater may have increased in its vegetative cover. The early stages of the hydrosere between 1811 and Griffith's survey in 1929 can only be speculative. However, the sedimentary record does provide some evidence on which to base an account of the development of the vegetation.

The succession of plant communities in the South Salix Marsh is recorded in the sediments. Equisetum remains are abundant in the grey silt in cores 7 and 8, and in the cores along the transect line. In the latter, fruitstones of Potamogeton natans were also found, along with fine black roots. Plant detritus is also present in minor quantities in the basal yellow/grey silts. This might have been incorporated into the sediment after 1811 when average flow conditions would have been reduced.

Above the Equisetum remains at this point, there is a black mud with rooted remains of Phragmites (cores 7 and 8, and cores of the transect line). The question of the date of the deposition of the sand horizon above this Phragmites, which may have destroyed it has been much discussed in earlier sections. Very few plant remains occur within the sand and the roots from Phragmites peat further above it do not penetrate it. It is suggested that a flood or floods washed away the Phragmites reedbed that had established itself on the inside of the meander curve. Such areas in a river system are unstable habitats for plants and animals.[1]

After the sand was deposited a Phragmites bed again established itself if the interpretations of the stratigraphic evidence are correct. However, the reduction (after 1811) or cessation (sometime prior to 1857) of the flow in the old channel, and perhaps also the fall in the water level, allowed the spread of the fringing bankside trees across the sandy point bar, which shaded out the Phragmites.

Beneath the trees a mixed fen vegetation of sedges and sedge relatives and the smaller reed Phalaris arundinacea could however grow. Phragmites persisted only in areas uncovered by trees, such as in the deeper water closer to the maximum depth of the old channel (Pond C). An isolated relict of this formerly more extensive area of reed might be the stand of Phragmites at the N.W. of the South Salix Marsh by the field edge. Beneath the trees, sedges and mixed fen communities developed a shallow compacted soil above the remains of the Phragmites. In places bare mud areas, from which Phragmites had been excluded, developed in the telmatic zone. The reason why these have not been colonized by sedges is uncertain.

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[1] Whittaker (1979) examined the dynamics of Chrysomelid beetles feeding on docks growing in such a hazardous natural habitat (a shingle bar).

Griffiths suggested that "the societies of *Phragmites* represent original vegetation which is now in process of retrogression, but the *Rumex-Equisetum* community and the Marsh forests are secondary and have arisen by the colonization of the channel from the littoral region (including the Marshes of the East Pasture) as the water level fell." The present study of the sedimentary record of the South Salix Marsh would agree with Griffiths' suggestion that *Equisetum* was the most abundant plant of the early stages of the hydrosere (1932 p.126) and that *Phragmites* also represents original vegetation, perhaps growing at the site in shallower water even prior to 1811.

However, while *Phragmites* was replaced in the shallow water areas by the trees that could establish themselves there, in the former areas of medium water depth it has spread across the *Rumex-Equisetum* community in the last 50 years. Therefore it cannot in this sense be said to be "in process of retrogression", although *Rumex hydrolapathum* and *Equisetum fluviatile* may be in such a process.

Macrofossil evidence from cores no. 4, 5 and 6 around Pond A suggest that *Scirpus lacustris* may have been present at an early stage in the development of the vegetation, perhaps due to its tolerance of deep water. The survey of 1932 shows this area to be covered with *Rumex* and *Equisetum*. The upper layers of plant detritus are saturated with water around the east side of Pond A, and macrofossil evidence for the former abundance of *Rumex* was not found.

6.1.2 The Period 1929 - 1982

In the region of Pond A and Pond B *Phragmites* has advanced into the "Great Rumex Marsh" and annexed large areas.

It may also have been partly responsible for the loss of the Equisetum that fringed the pools, divided Pond A from Pond B, and cut Pond A into two separate pools. This may be less attributable to a decrease in water level by autogenous accumulation than to the rhizomatous spread of the tall monocotyledon in gregarious masses which shade out other smaller plants. Its competitive ability may be largely due to its density and height (typical heights are 2.8m). The tallest specimen recorded was 3.2m. in early winter. Large areas of the Western Marsh now consist of monodominant stands of dense Phragmites.

The area of the "Great Rumex Marsh", much diminished in size, has largely been replaced by two new communities. One is composed of Iris and the other of Carex acutiformis both mixed with Typha latifolia.

Haslam (1978) suggested that Phragmites is a slow growing perennial requiring stable conditions. However, its deeper rooting system may make it more tolerant of the fluctuating water levels in the Marsh than Rumex or Equisetum. It is often present on field edges at the Marsh. A severe drought may have given the Phragmites advantage over the Rumex and Equisetum.[1] In these open areas Equisetum fluviatile has greatly diminished in its extent since 1929. It does, however, grow in pure stands in the East Salix Marsh filling the area of the old channel shown on Pickering's 1802 map (on the western side). The shade of the trees may in some way account for its persistance in this area, while it has been lost in the western area of Marsh. Drought may have partly been the cause of the reduction in its cover abundance in the latter area and may also have affected Potamogeton natans which was not recorded from Pond A in 1982, although it was said to fill the pond in 1929.

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[1] Some Rumex hydrolapathum plants around Pond A were noted to be severely damaged by grazing herbivores (perhaps a chrysomelid beetle - see Whittaker, J.B. 1979 J.Animal Ecol. 48 973-986). This may also have weakened its dominance in this area.

The area of carr has not advanced to any noticeable extent since the mapping survey of 1929. However, regeneration within the area may have proceeded as there are abundant saplings of Alnus glutinosa and species of willow in the South Salix Marsh. Many of the older trees have collapsed and from them new stems rise up.

The herb layer cover in the South Salix Marsh has also changed since 1929. Impatiens glandulifera is dominant in terms of cover abundance in late summer. This plant would appear to have arrived at Butterby since 1929. Phalaris arundinacea, formerly noted as the dominant herb layer vegetation in this area, is still present, but is less abundant than Impatiens. Other species such as Cardamine amara, Stellaria nemorum and Silene dioica, previously unrecorded for the South Salix Marsh, were also a very abundant and conspicuous component of the herb layer vegetation in the early summer of 1982.

The eastern area of Marsh was not studied in detail but observations suggested that Scirpus lacustris has spread since 1929 at the north end of the Long Pool. This area is trampled, poached and grazed by cattle in the summer months. Burning of stubble scorched the small stand of Phragmites on the west of the Long Pool in 1982. Interference with the "natural" development of the vegetation would appear more obvious on this side of the Marsh.

6.1.3 Comparison of the O.S. 1 : 2500 Map surveys of 1857, 1897, 1919 and 1960.

While these maps do not show the vegetation in great detail, the outlines of ponds are recorded. On the 1857 First Edition O.S. map, the shrubs and trees in the South Salix Marsh and West Salix Marsh are shown in an early stage of development. On the original copy of this map held in the County Records Office, the water has been shaded with dashes of blue pencil. The Long Pool is continuous with the Typha Marsh, and areas of the East Salix Marsh (its East Side) are still open water. The western arm of the loop is not shaded as containing swamp vegetation. Careful use seems to have been made of shrub, swamp and tree symbols. The east bankside of the western arm of the loop is shown as shrubs and small trees. A few large trees are shown beside the west of Pond A. The size of the various numbered parcels of land is not given.

On the 1897 map, four ponds are shown:- the Long Pool, the N.W. of the Typha Marsh, the Boathouse Pool, and the pond called "Pond A" in the present study. Acreages are given for each parcel of land on the map. Tree symbols are here used only for the Boathouse Wood, while the whole marsh apart from the ponds is covered with scattered symbols of shrubs and marsh. The woods beside the east of the Long Pool have disappeared. The extreme N.W. corner of the South Salix Marsh, which was shown as being covered by shrubs in 1857, has been reclaimed for arable land. A boathouse is shown on "the Boathouse Pool" for the first time.

On the 1919 map even fewer shrub symbols are used, and the whole area between the field edges (apart from the ponds) is shaded with scattered symbols of marsh and shrubs. Tree symbols are used only for the Boathouse Wood. The outlines of the ponds have not changed, but the acreages of the parcels into which they fall seems to have been revised. For example, the Long Pool in 1897 was a combination of Parcels 25 and 275 as in

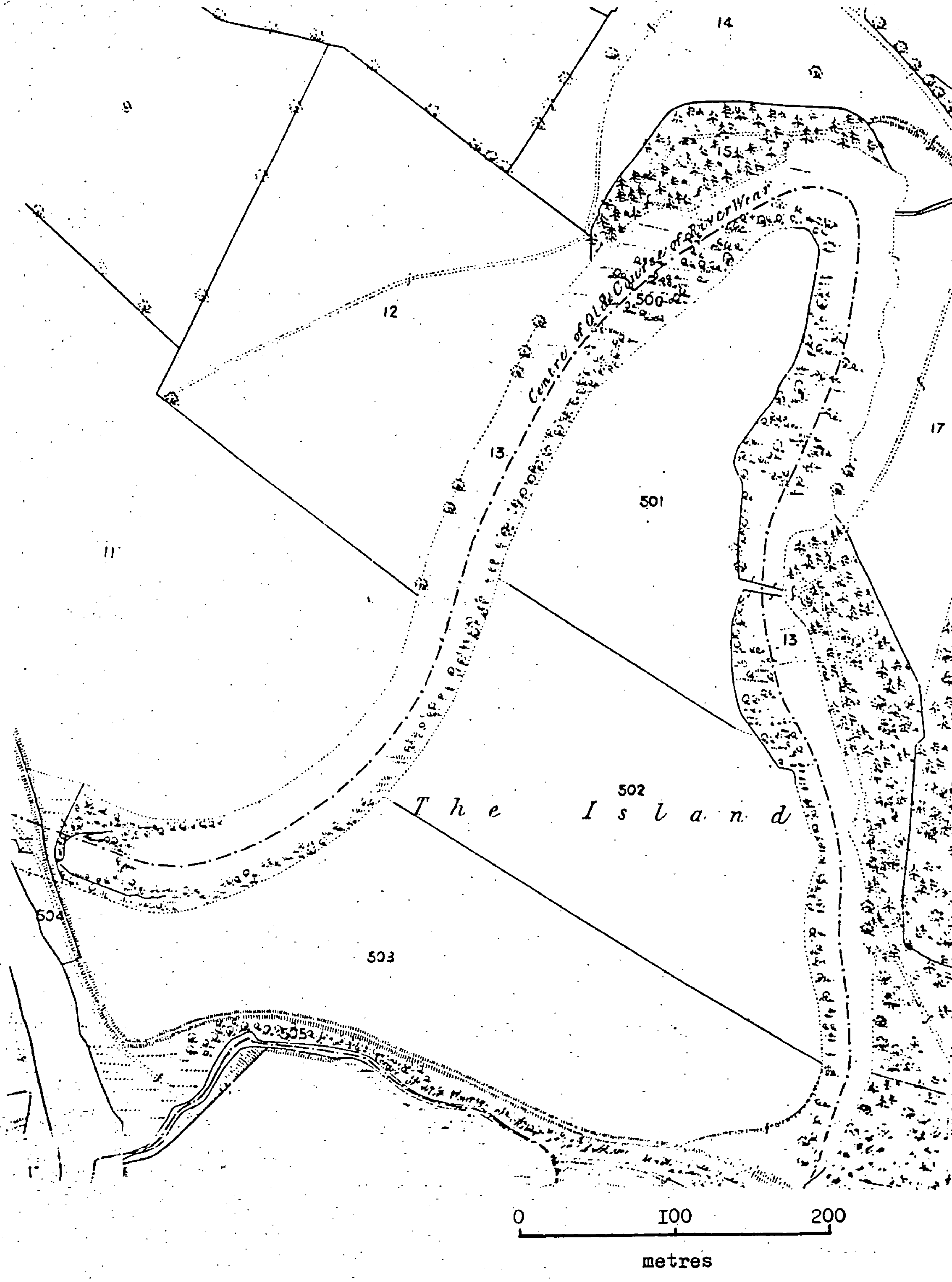

Fig. 6.5 : Ordnance Survey 1857 (First Edition) 1: 2 500 Map.

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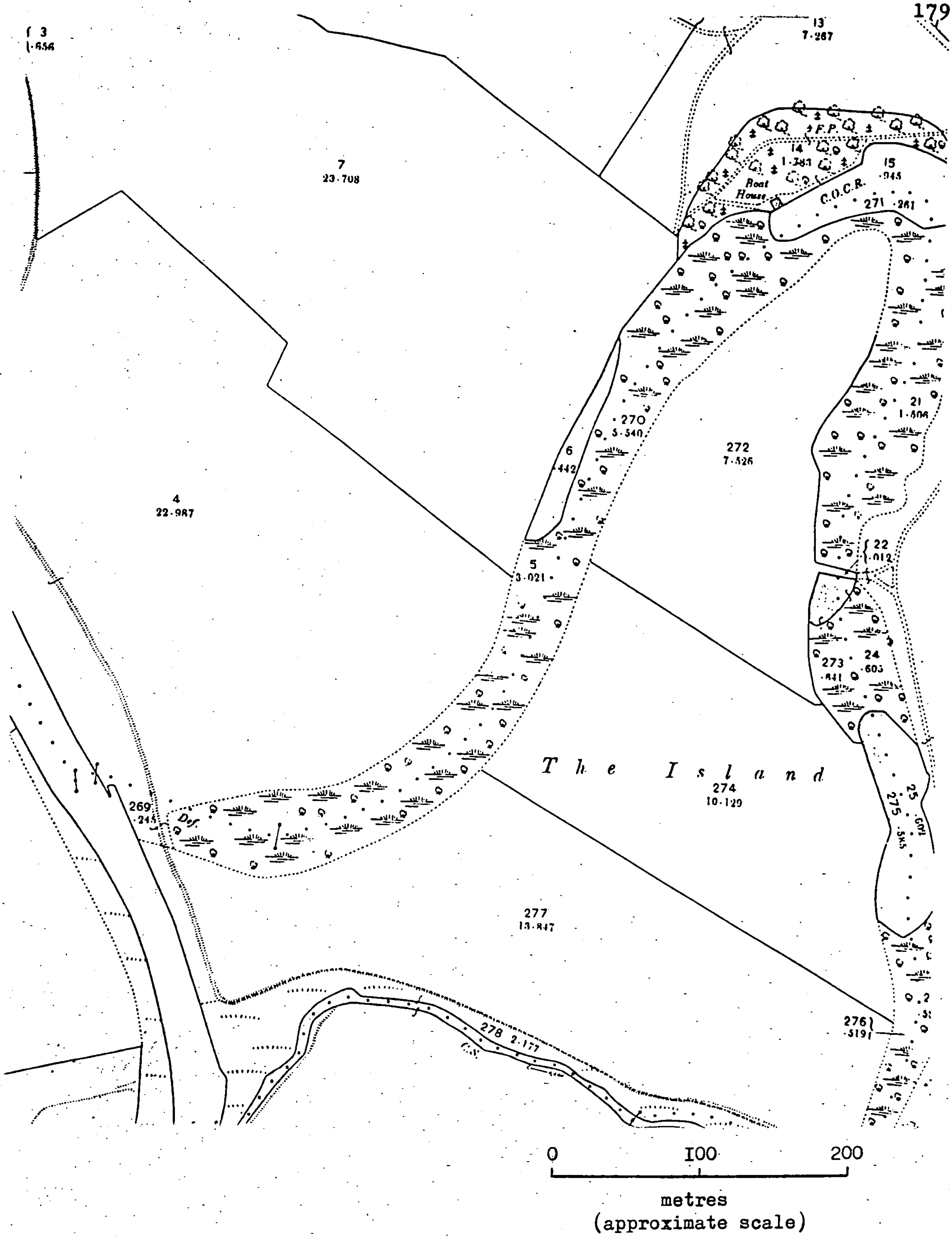

Fig. 6.6 : Ordnance Survey 1897 (Second Edition) 1: 2 500 Map.

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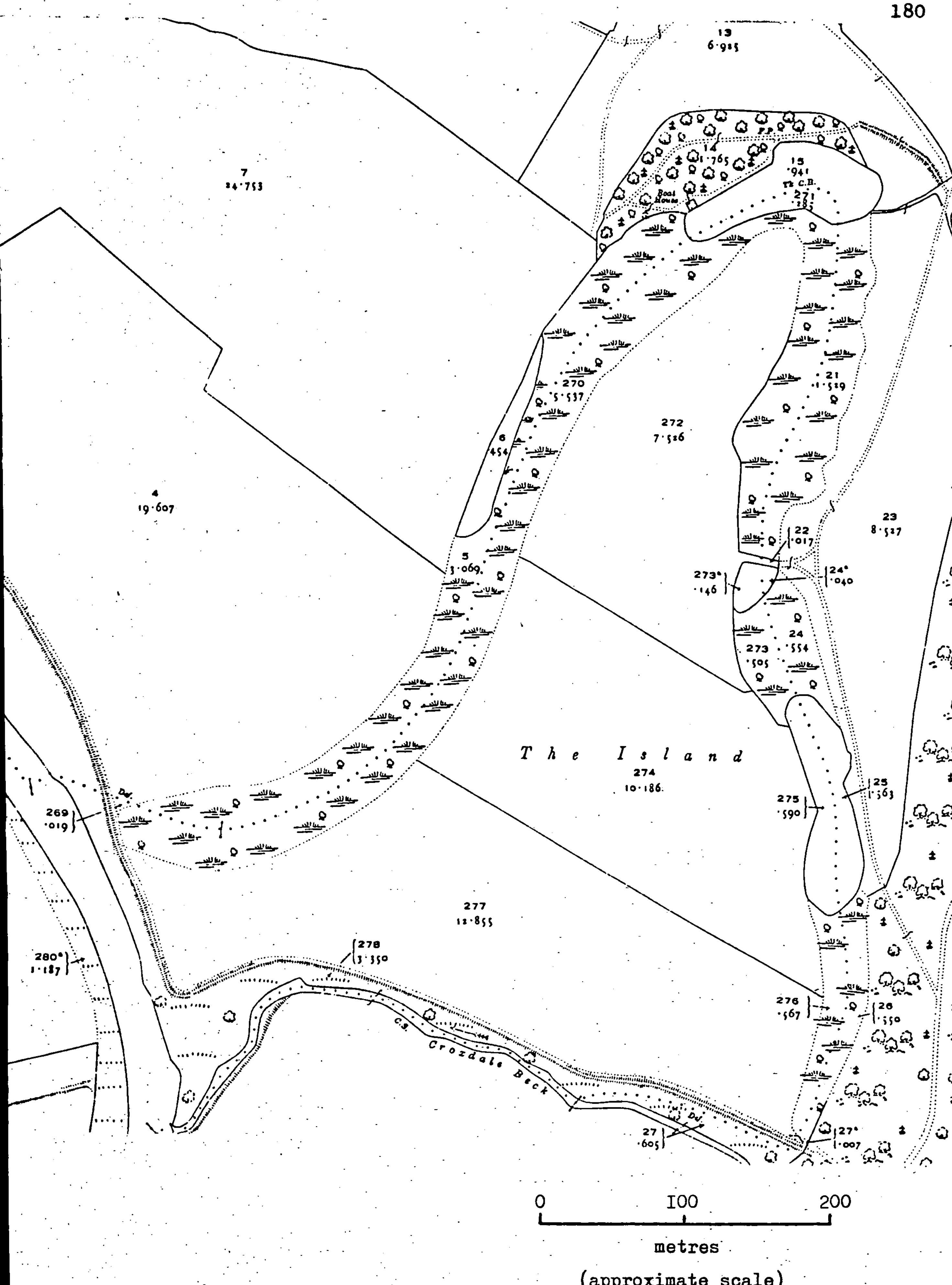

Fig. 6.7 : Ordnance Survey 1919 (Third Edition) 1: 2 500 Map.

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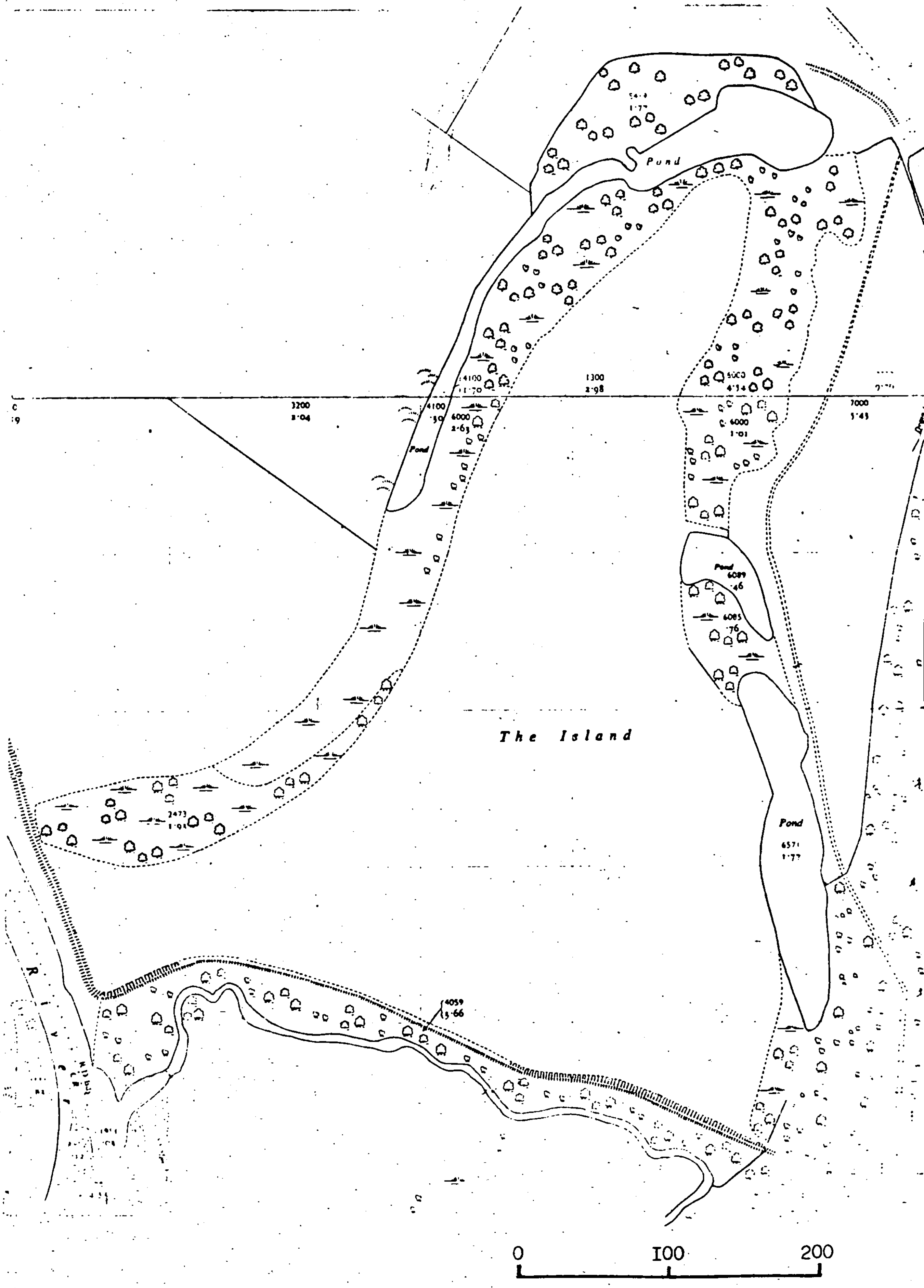

Fig. 6.8 : Ordnance Survey 1960 1: 2 500 Map.

Bottom half from Sheet NZ 2738, top half from Sheet NZ 2739. Reproduced with the permission of the Controller of Her Majesty's Stationary Office, Crown copyright Reserved. (Reduction).

1919, due to the Parish boundary which followed the centre of the old course of the River Wear. Its area in 1897 totalled 1.187 acres while in 1919 this figure had been revised to 1.153. Similar alterations were made for the other parcels shown.

On the 1960 map the old parcels have been regrouped and their acreages revised. The open water of the Long Pool has been enlarged so that it extends further south by a distance of about 80m. Whether this represents a real change is difficult to assess. The southern end of the Long Pool is not easily accessible and is out of view from the track. It may possibly have been overlooked or misrecorded in earlier surveys. The size of the pond at the north end of the Typha Marsh has also been enlarged. A channel has been added between the Boathouse Pool and Pond A, and the boathouse has disappeared. The acreage of Pond A has again been revised. Large tree symbols are used for the East-, West- and South-Salix Marshes. There has also been the addition of a pecked line to group the southern part of the western arm of the loop into one parcel. This may have been made on the basis of tree cover.

In the present survey of the western part of the marsh, many details have been added, especially to the outline of the various bodies of water. For example, Ponds B and C have been added. These are large areas of deep water which were omitted on the 1960 map and the 1919 and 1897 maps. Griffiths recorded them in his Survey of 1929, but the outline in 1982 has been revised. It is uncertain whether this represents a real change in all instances. Griffiths seems to have used the O.S. outline of the marsh, but his map of the herb layer vegetation for the western arm of the loop fills the area between the pecked lines on the O.S. map. These lines on the original 1857 map can clearly be seen to represent the field edge, not h.w.m., as the eastern bankside trees are included within them. The area of the old channel that he shades in as vegetation below h.w.m. is very wide, which may represent an error in working from the outline of the marsh on the O.S. 1 : 2500 map of 1919, which had omitted the E. bankside trees and shaded the whole area between the pecked lines with marsh symbols.

The channel which is shown on the 1960 O.S. map connecting the Boathouse Pool and Pond A still exists but is overgrown in most places by Phragmites, Iris, and willows and is not easily visible.

Large time periods are involved between these various surveys. There will probably have been many inconsistencies in the degree of accuracy employed in surveying the marsh, and the outline of the original survey has been used in later maps without distinguishing clearly between the field edge and h.w.m. (a distance of 8 - 10m. in the western arm of the loop). This confuses the analysis of the changing distribution of the various "vegetational units" and pond shapes. For example, only on the 1857 map were the east-bankside trees of the western arm of the loop shown accurately. The pecked outline which represents the field edge includes them in the 1857 map. The 1897 and 1919 maps have retained this outline but omit the trees, shading the whole channel with symbols of marsh and shrubs. This is probably how the width of the area of marsh vegetation came to be exaggerated for this part of the loop on Griffiths' maps.

There are large fluctuations in water level seasonally and probably large differences in annual mean water level, which could account for the changing outlines of some of the ponds on the O.S. maps. For example the area of water at the north end of the Typha Marsh had been enlarged on the 1960 map. However in 1982 it largely dried out during the summer and therefore regained the former outline shown on the 1919 map.

Apart from these annual and seasonal fluctuations, the ponds have not noticeably contracted in shape since the survey of 1897 and do not seem to be drying up. The water level will rise and fall according to the amount of rain that falls within their small local catchment area. The deeper pools will probably remain open water for a very long time if their natural development is allowed to continue.

6.2 THE FUTURE DEVELOPMENT OF THE MARSH

Phragmites has annexed large areas of the western area of marsh since 1932, and it may continue to spread. There may be a case for controlling this development, as areas of mixed vegetation are replaced by monodominant stands.

The taller plants would seem to spread by shading out smaller plants. Haslam has analysed competition amongst river plants (1978. 170)

> "The overall controlling factors in the distribution of river plants are flow and substrate, and competition is, in consequence much less important in river communities than in typical land communities. The effect can be due to the mere presence of one species making the habitat less suitable for another species. It is also possible for tall plants to kill short ones by shading them, or for emergents to smother submergents by the silt they accumulate. So if both can grow well in any one place, it is the taller which survive. Tall emergents shade short ones, emergents shade submerged ones and submergents high in the water shade those below. Compensating for this, both flow and human interference remove mostly the taller plants, so the end result is that the overall pattern remains stable although the detailed arrangement in any one place may vary."

Haslam also analysed the development of plant patterns at the edge of the channel and within the channel.

> "At the edge of the channel river plants, if present, may be tall emerged monocotyledons or fringing herbs. Rarely, other large broad leaved plants may occur, (e.g. Alisma plantago-aquatica, most frequent in somewhat small clay streams, and Rumex hydrolapathum, most frequent in canals), or small grasses may be prominent (as opposed to present but inconspicuous). When both tall and short plants can grow at the edge, the tall will shade and kill the short. However, the habitat preferences of the tall monocotyledons and the fringing herbs, while overlapping, do differ. The tall monocotyledons (except sometimes Phalaris arundinacea) require or prefer a soft substrate in which their deep roots and large rhizomes can anchor and, being slow growing perennials, need habitats which are stable, preferably for some years. They are also, being tall and deep rooted, less likely to be harmed by fluctuating water levels and are thus more able to colonize steep slopes. The fringing herbs, in contrast, can invade temporary habitats, and can root in both fine and coarse substrates (though they can anchor more firmly in coarse ones). Within the channel the basic habitat preferences of the tall monocotyledons and fringing herbs are the same as those described above for the channel edges. Tall monocotyledons are characteristic of shallow water and deep soft soils, with little scour but some drying. They are therefore usually at the sides, but occasionally grow right across the channel. They are commonest in clay streams."

The suggestion that the fringing herbs can more easily invade temporary habitats might account for the widespread remains of Equisetum fluviatile in the basal silts (found by Griffiths and in the present study) which suggests a former abundance of this plant. It may represent an initial stage in the hydrosere, prior to the spread of the Phragmites.

At one point (the division of Pond A from Pond B) Phragmites has replaced a large "wedge" of Equisetum fluviatile and forms a large monodominant stand from field edge to field edge. Within this, tree saplings are unlikely to be able to establish themselves in any great quantity. Haslam (1972) noted that normal succession is hardly noticeable within dense, pure stands of *Phragmites*. Where trees penetrate from the banksides they may replace the *Phragmites* and allow a mixed fen vegetation of *Iris* and *Carex* to grow beneath them.

The spread of *Phragmites* has, however, been more noticeable along the shallower sides of the old channel. It has replaced former mats of sedge, *Rumex* and *Equisetum*, but has not extended the vegetated area across the ponds.

The initial depths of the old channel largely determine the present distribution of aquatic and fen vegetation. The deeper pools are unlikely to be rapidly taken over by *Phragmites*. Sediment accumulation within them would seem to be proceeding at a slow rate. The shape of the ponds has not noticeably contracted since 1929 but they may be filling up with material slumping from the sides into the centre, so that their contraction in plan does not proceed as fast as the raising of the sediment surface. Organic input may now be the largest component of the sediment supply due to the blocking off of the former major inflow channels.

Communities of *Carex* and *Iris pseudacorus* with *Typha latifolia* might ultimately be more capable of spreading across these open water areas due to their ability to form floating mats bound together with bryophytes. *Phragmites* tends to exclude bryophytes and this may make it less capable of forming such floating root mats.

Haslam (1978) listed the main factors affecting the plant patterns in river channels as "physical, chemical and biotic." Physical factors include flow and substrate texture. Chemical factors include nutrients in the silt. Biotic factors include shading by larger plants and grazing by animals.

"It is easier to list the causes of such patterning than it is to classify plant behaviour, and some phenomena, for example the pattern of fringing herbs, are due to more than one cause. A final limiting factor on vegetation patterns is that any one site will only support a specified number of species and only some of these will be capable of luxuriant growth " (Haslam 1978).

The water chemistry of the habitat may have greatly changed when the ponds were isolated from Croxdale Beck and the River Wear. The latter two areas have more alkaline water and a much higher specific conductivity, suggesting that there is little connection at present between the ponds and these more "polluted" areas.

The sediments of the marsh, which it is suggested mostly originated from the river and Croxdale Beck prior to 1857, are enriched with metals and minerals. Leaching of these materials from the rooting zone of the present plant communities may reduce any toxic effects they could have. Relocation of the metal enriched sediments in Ullswater (which result from former mining activity) has been analysed by Denny (1981).[1] Denny's limnological study showed that submerged water plants and periphytic algae provide a means of entrance of lead into the food web from lake sediments. Heavy metals were not locked up or permanently buried in the sediment, as plants and animals and turbulence within the lake encouraged the cycling of metals. Metal concentrations in the water of the Ponds at Butterby, and in the plants, could be analysed to test this. (This might provide a means of testing the longevity of the presence of lead and other metals in the aquatic ecosystem, since no water or sediment from long distance transport has probably entered this

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[1] in <u>Heavy Metals in Northern England : Environmental and Biological Aspects</u> ed Say, P.J. and Whitton, B.A.

part of the marsh for about the last 130 years). However, from the water analysis made in the present study, it would seem that the fen and aquatic plants at Butterby probably experience a "less polluted" habitat than where they grow beside the Wear and its tributaries.

There are large fluctuations in water level in the marsh but here the plants are not restricted in their development by flow conditions as are most river plants, so that the relative importance of biotic factors such as competition may be increased.

The water analysis made in the present study may provide some basis for monitoring future changes in water quality. Griffiths made detailed studies of the limnology of the Long Pool, which may offer scope for comparative or historical studies of the changing limnology, and of changes in the phyto and zoo plankton - some of which may be indicators of water quality.

Nitrate and phosphate levels in the water were not recorded in the present study, but may be an important parameter for monitoring future change. Pigott and Wilson suggested that the vegetation at Esthwaite Water might be changing in response to increased input of phosphate and nitrate. At Butterby such input might come from run off from the fields which receive fertilizer. Differences between the western arm of the loop lying between two arable fields, and the eastern area that is heavily trampled, poached and grazed in the summer months, might be detected in such analysis.

6.3 COMPARISON WITH OTHER HYDROSERES

Hydroseral succession is a hypothetical model. The model ideally requires that (a) the sequence of vegetational shifts be predictable, and (b) external environmental conditions remain stable for a sufficient length of time to allow the sequence to take place. For many hydroseres the time scale is unknown or variable, i.e. changes take place irregularly both spatially and temporally. External environmental conditions do not often remain stable over long periods of time. For example a change in the level of the water table might result in reversion of the stages in the succession model. Hence the predictions made about the future direction of change are often not realised.

Primary hydroseres might occur in former glacial lakes or "kettle holes." The time scale of the early stages of the sere are difficult to assess, although the changes are recorded in the sediments. Over long periods of time the condition of external environmental conditions remaining stable may not be applicable, due to climatic shifts. More recent "secondary" seres, often triggered by man's actions, may not experience major changes of climate in the short term but may be susceptible to other chance events such as interference by man, grazing attacks by insects, or fires.

The predicted end point of hydroseres is the establishment of the climax community of mixed, oak dominated, deciduous woodland. There may be a high rate of decomposition at the surface due to the aerobic conditions which allow fungi and bacteria to become established. With drying of the surface there may be a cessation of the upward growth of peat, and this autogenic process that has driven the succession may end.

Evidence may be collected to test this model, and to try to establish the time scale involved. Long term monitoring at a single site may witness the model in action.

Results from two other case studies of hydroseral succession are now briefly discussed.

Wicken Fen

Results were published by Godwin et al. in 1973 of successive studies made of hydroseral succession at Wicken Fen, Cambridgeshire. A small ($740m^2$) triangular plot of the Nature Reserve had been set aside since 1923 for study of bush colonization and fen carr formation in the mixed-sedge fen (Cladio-Molinietum) community previously cut as a crop.

In 1923 great attention was given to mapping the outline of every bush more than 1 m. tall and 50 cm. crown diameter. Results showed a mixed sedge fen into which shrubs were invading. By 1934 the size of individual bushes had greatly increased, especially the main clump of Rhamnus cathart-icus L.

Three phases were noted in the development of fen carr: (i) the colonization of mixed sedge by seedling establishment, and the development of these seedling bushes to form carr; (ii) the internal processes of development within established masses of carr of different types; (iii) the lateral extension of established masses of carr over mixed sedge. After 1934 the studies were only concerned with the latter two developments.

By 1972 the fusion of the crowns of Rhamnus catharticus had proceeded to a great extent, overwhelming previous Salix cinerea cover. Rhamnus frangula[1] had also consolidated into

[1]In the paper the authors thought it convenient to adhere to the older taxonomic names employed in the earlier studies. Thus Rhamnus frangula L. is Frangula alnus Mill.

a nearly complete cover of carr. The mixed-sedge dominants and Salix repens L. had vanished, which was attributed to this competition. Viburnum opulus L. that was vigorously expanding until 1934 had almost disappeared by 1972 which was attributed to attack by a chrysomelid beetle. In 1951 fire swept the Fen but did not greatly affect the study site. Stools of Rhamnus frangula carr survived easily in the wet peat and produced new shoots, but a minor effect was the increased abundance of the grass Calamagrostis canescens. (Weber) Roth. Three 30 ft. squares were mapped 4 - 5 times between 1923 and 1972 and the floristic changes in these sub plots were recorded in great detail.

Godwin used this study as a basis for more generalized conclusions on recent acceleration of bush and tree invasion over the whole of Wicken Fen. There has been some development of birchwood on dried peat surfaces on higher parts of the fen. These surfaces are becoming leached and acidified and acidicolous bryophytes have been recorded in the more recent studies. There has also been the development of alder fen carr. Both changes are termed by Godwin "reversionary", as he considers that the Wicken Fen successions seem to be reverting to older more familiar fen successions.

These changes may be a response to recovery from long and intensive peat cutting and crop-taking and perhaps also a response to a changed hydrologic regime. The alkaline fen peat recorded in the early studies may now be in a process of transition to acidic raised bog peat involving a brief phase of wood peat. Past layers of acidic peat were probably dug off for fuel and trees and shrubs were removed. This brought the fen surfaces again within reach of flooding by calcareous water from the uplands. Winter flooding has not taken place in the last 20 years, and trees are now recolonizing. Rhamnus frangula may be an earlier stage in this recolonization than alders and birches due to its persistance locally and its capabilities of easy dispersal and rapid spread.

Soil acidification and carr formation follow the pattern of natural primary successions, but they have been sudden and widespread, perhaps due to the changes in water relations of the fen. Lowering of water level is likely to be responsible for major changes in the fen communities. "As is common, the past and present influence of man has been underestimated." (Godwin 1972 p.123).

Godwin therefore placed the bush and tree colonization processes into three categories:-

(a) secondary successions on alkaline fen peat following cessation of crop cutting, involving the development of Rhamnus frangula and R. catharticus carr at the expense of Cladio-Molinietum vegetation. The reserve triangle that was remapped involves this type of succession. No soil acidification was however noted for it.

(b) Secondary successions on alkaline fen peat accelerated by drying of the Fen involving spread of Betula spp., Alnus glutinosa, Populus tremula L. and Fraxinus excelsior.

(c) Secondary successions on peat becoming acidic at the surface (probably associated with increased dryness), involving development to rather dry birch wood, loss of many fen species, and invasion by acidicolous species, especially mosses and ferns.

How does this hydrosere relate to that at Butterby? Both have been classed as "secondary successions", involving the influence of man on water relations which has produced sudden vegetational shifts. The Wicken Fen studies illustrate the fragility of the model hydrosere with respect to changing external conditions. For example reversionary changes followed changed hydrology, and the chrysomelid beetle attack greatly reduced the abundance of Viburnum opulus (which it was thought, in the early studies, would have great potential in the establishment of fen carr).

Some notes made on the autecology of individual undergrowth plants at Wicken Fen are similar to observations made at Butterby. For example Phragmites communis, once widespread through the reserve triangle is now restricted to the flank next to Drainer's Dyke where it is less shaded: it only rarely persists in the most recently closed Rhamnus frangula carr. This pattern is similar to the events suggested from investigations of the sediments in the South Salix Marsh, where establishment of carr on the point-bar has replaced an area that was twice formerly occupied by Phragmites.

There is also a tendency towards soil acidification at Butterby. This was not investigated in the 1932 study, but it may also have been prevalent then. Water pH has not changed in the last 50 years. It is doubtful whether the peat formation at Butterby could ever become an acid raised bog, but there may be increases in acidicolous species and birches may become established in the marsh forest alongside the alders already there. No species of acidicolous bryophytes have been recorded yet at Butterby however.

The Wicken Fen reserve site has been monitored for 50 years, and one major transition was observed: that from mixed sedge fen to the invasion by shrubs and the eventual establishment of closed mature carr. But at Butterby, carr does not seem to have spread in the past 50 years, and water levels have not noticeably decreased (if they had then carr might have spread). Sapling colonization amongst the Phragmites is only apparent in a few individual cases; lateral extension of carr may be more important.

The extension of reedswamp at the expense of the fringing herbs such as Rumex hydrolapathum might be seen as a reversionary change, as Griffiths suggested that Phragmites was an earlier stage in the sere than Rumex and Equisetum.

The comparison between the two sites would seem to emphasize the vulnerability of "natural development" to external environmental changes. Should fire sweep the reedswamp at Butterby this could allow tree species to become established amongst the Phragmites. Fire from burning of stubble was noticed to scorch the Phragmites on the west bank of the Long Pool in 1982. The comparison would also seem to stress the influence of man, and the importance of site history to the development of both hydroseres.

Esthwaite Water

Pigott and Wilson (1978) have also traced the development of hydroseral succession of part of the fen at the north end of Esthwaite Water. As with the case of Butterby Marsh and Wicken Fen, old maps of the vegetation were available. The area was first mapped by W. H. Pearsall in 1914-16, and again by Pearsall in 1929. In this 15 year interval the reedswamp at the northern end had extended its boundary into the lake by an average distance of 30m. being replaced on its northern side by Molinia caerulea (L.) Moench. Tansley (1949) pointed out that the two maps demonstrated the process of succession over a relatively short time interval.

Pigott and Wilson resurveyed the vegetation of North Fen at Esthwaite in 1967 - 9. With additional historical records in the form of O.S. maps (dating to 1848), they calculated that the boundary of the shoreline formed by reedswamp has moved southwards by 47m. at the mouth of the inflow stream of Black Beck, and 28m. in the middle of the basin since 1848. "Comparing all the surveys, it is clear that the rate of movement has varied from one period to another by an order of magnitude (0.2 - 3.0 m/a)." Change since 1929 would seem not to have proceeded as rapidly as in the period 1914 - 1929.

The inflow stream was emphasized by Pearsall (1918) to be important in determining both the rate of succession in North Fen, and the marked distinction between the successional sequence of vegetation on the heavily silted western part of the fen often flooded by Black Beck, and that on the predominantly organic deposits in its eastern part. The shore has gradually moved southwards as deposits have accumulated and so have the vegetation associations "which confirms their successional relation" (Pigott and Wilson, 1978: 334).

<u>Schoenoplectus lacustris</u> forms an outer fringe to the <u>Phragmites</u> suggesting that it can root in deeper water and that it is an earlier stage in the hydrosere. This is also suggested by macrofossil evidence from the western side of Pond A at Butterby. <u>Typha latifolia</u> has spread since 1914 at Esthwaite so that it now grows amongst the reedswamp in patches. <u>Typha latifolia</u> has also spread at Butterby, around the margins of Pond A.

The three species above form one vegetational association that was defined. Others were:- an association of <u>Carex rostrata</u> and <u>Phragmites</u>; an association of <u>Carex elata</u> All. ; one of <u>Molinia caerulea</u> and <u>Succissa pratensis</u> Moench.

and one of Phalaris arundinacea and Filipendula ulmaria.

One of the greatest changes that was recorded from the southern part of North Fen since 1929 has been the increase in the density of trees and shrubs and their spread southward on the area of alluvium. "By 1967-9 woodland of Alnus glutinosa and Salix cinerea, with a field layer characteristic of deep shade, occupied an area which in 1929 was fen dominated by Carex elata and in 1914-16 was reedswamp, though probably with Carex rostrata present." Closed carr woodland has extended southward by a distance of 25 m. (an average rate of 0.6 m/a) and also to the S.W. by as much as 45 m. since 1929. Betula pubescens and Fraxinus excelsior have filled the gaps in the canopy since 1950. In the older pre-1929 woodland the larger Salix cinerea bushes have sunk into the peat.

Although there has been no great extension of marsh forest at Butterby during the past 50 years there are some similarities with that at Esthwaite. In the South Salix Marsh many of the older willows (mainly S. fragilis and S. alba) have collapsed and sunk into the water and peat, or lie as fallen logs on the soil surface. The understory of the closed carr at Esthwaite is also similar to that at Butterby with a "mixture of Phalaris arundinacea, Carex nigra (L.) Reichard and Filipendula ulmaria, with Dryopteris dilatata plentiful in the more shaded parts and large tussocks of Carex paniculata in the wetter parts."

Elsewhere at North Fen the shift of the boundaries of vegetational associations has not been as great. Little change has been noted for the northern part of the fen. Vegetational stability on the eastern side is partly attributed to the previous mowing of the grass. There has been only a small extension of the wooded western half of the northern part of the fen since 1914 - 16. In the older part of this wood Quercus petraea saplings are becoming established, which may indicate the beginning of the final phase of the sere with a transition to the "climax community". No Quercus was recorded from the South Salix Marsh forest. This may suggest there could be a further stage of the hydrosere at some future date.

As at Butterby, the pattern of succession and vegetational shifts has not proceeded at a regular rate at all parts of the fen -

> "it is clear that succession has not consisted simply of the gradual advance of the reedbed into the lake followed by an orderly southward migration of successive zones, all moving at more or less the same rate. On the contrary, as one species or association has moved south, another has been stationary, so that zones have at various times contracted or expanded and species have sometimes been separated and at others mixed." (Pigott and Wilson 1978 : 348)

The spread of certain species at Esthwaite (such as Typha latifolia, Salix purpurea and Salix fragilis) may be related to increased mineral nutrients in fresh supplies of alluvium, rather than physical properties of this substrate. It is probable that more phosphate is reaching the reedbed than in the past. Since Butterby Marsh has no major inflow streams it is likely that there are no large supplies of fresh alluvium. However there are field drains (as at the western side of Pond B) and some small drainage channels from Croxdale Woods into the Long Pool, which might be sources of additional mineral nutrients. This could be further investigated.

Comparative studies of aquatic macrophytic vegetation have been made at other Lake District sites which were originally mapped by Pearsall. Wade (1982) reported on the re-mapping of six of Pearsall's sites. Vegetation was re-mapped along transects by a combination of the observations of divers and samples collected by using a weed grapnel operated from a dinghy.

Wade points out the shortcomings of comparisons of the map surveys.

> "Pearsall worked solely from a boat and was not able to give an impression of density of stands. Also there is no record of the distribution of the aquatic vegetation at these sites for the last fifty years or more."

Results showed that at all but one site the extent of the vegetation was significantly less than in Pearsall's time, especially that of weed beds.

> "The species most notably affected was Nitella opaca agg. Others were Naias flexilis (Willd.) Rostk, & Schmidt in Esthwaite Water and Potamogeton praelongus Wulf in Windermere. These reductions were associated with a general decrease in the maximum depth to which the vegetation was found in 1981. Further investigations would be needed to explore the relevance of such factors as an increase in turbidity of lake water which is indicated by the secchi disc readings. Some species had a much wider distribution in 1981 than in 1914 - 1929 e.g. Potamogeton obtusifolius Mert & Koch, in Esthwaite Water sites and Elodea canadensis Michx at all sites. Despite these spatial changes, the species composition of the sites surveyed was very similar to that described in the 1914 - 29 surveys ..... The project has drawn attention to the almost complete lack of any research into the aquatic macrophytic vegetation of the Lake District lakes and the disturbing decrease in the extent of weed beds. Further studies are needed to explore other lakes mapped by Pearsall and to investigate the reasons for these declines."

Grapnels and diving equipment were not used to investigate the submerged and floating leaved macrophytes at Butterby in 1982. However, from observations using a dinghy, there would seem to have been a disappearance of Potamogeton natans from "Pond A". Nuphar lutea may have increased in abundance on Pond C and Equisetum fluviatile has disappeared from that area, but no maps showing the vegetation within this channel were given in the 1932 paper. There is clearly scope for further study of the aquatic vegetation at Butterby, although the maps of 50 years ago show mostly the distributions of emergent macrophytes. There is ample scope for comparative historical limnology, however.

Comparison of Butterby Marsh with these other hydroseres would seem to emphasize the importance of site history. The results of long term studies in numerous sites would suggest that the development of each is unique in detail, but certain broad generalizations can be made and that the hypothetical hydrosere is a reasonably realistic model.

Other studies of hydroseral succession have used very detailed hypothetical models. Van der Valk (1981) produced a qualitative model of succession in freshwater wetlands which he viewed as a "Gleasonian approach".

> "For Gleason, any change in the relative abundance of species in the plant cover of an area or in its floristic composition with time was a successional change. Because environmental conditions at a site almost invariably change from year to year, because there are continuous interactions among the species, and/or because new species may reach the site from surrounding areas, all vegetation is, for him, protean by nature. It is constantly in the process of adapting to a unique, new set of biological and physical conditions. The rate at which this vegetation change occurs is sometimes very rapid (e.g. after a major disturbance), but may be, at other times, very slow and almost imperceptible."

Van der Valk outlined four factors which could produce changes in the floristic composition of wetland vegetation. These were (1) the destruction of all or some of the existing vegetation by pathogens, herbivores, or man; (2) changes in the physical or chemical conditions of the habitat (e.g. a change in water or nutrient levels) that favour the growth of some species over others; (3) interactions among the plants (competition, allelopathy), or (4) the invasion and establishment of new species.

Van der Valk's model is based on the life history features of the species involved. Wetland species can be classified according to three life history traits: life span, propagule longevity, and propagule establishment requirements. From these, twelve wetland life history types are recognised. For each the future state (presence only in the form of propagules in the seed bank, presence as adult plants,or complete absence) of each species type in a wetland can be predicted if environmental conditions change, such as a lowered water table. Studies of the wetland's seed bank (see also Moore 1980) allow experimental analysis of the potential responses of the vegetation to environmental change.

With a knowledge of the wetland's seedbank and the life history traits of its species the model can be applied to a particular site, to predict the likely changes in vegetation if a "drawdown" occurs. Van der Valk shows how his model can be applied to examples of studies of the wetland seedbanks of lakes in Africa and in Iowa.

As he points out, the model could be further refined. In its present form it only predicts which species will be present, not their abundance. It also ignores interactions among the plants (competition, allelopathy) that may affect the presence, absence, abundance and location of individual species. With further refinement the model may achieve greater utility for prediction. It could be used to predict the outcome of potential management practises in wetlands.

Studies of the soil seed banks would certainly be an interesting exercise at Butterby Marsh. Such "drawdowns" may be responsible for the elimination of certain species and the spread of others from large quantities of seed present in the substrate that may only be capable of germination and growth at this lowered water level. There was probably a great reduction of water level in the droughts of 1975 and 1976. Van der Valk indicates that his model should be applicable to any type of freshwater wetland and that very little work is needed to assign each species present to its appropriate life history type.

6.4 FURTHER WORK

Butterby Marsh is an area of considerable ecological interest. Future monitoring of change in the vegetation may prove to be rewarding in the analysis of hydroseral succession.

Further work that is directly related to the themes of the present study and that would be undertaken if possible would be:-

(A) The Vegetation and the habitat

(1) Re-mapping the Eastern Marsh, the Boathouse Pool area, the West Salix Marsh.

(2) Sampling for submergent macrophytes.

(3) Litter accumulation experiments in the appropriate season under different communities, to examine variable amounts of organic sediment production.

(4) More detailed floristic studies, of the bryophytes especially.

(5) Analysis of phosphate and nitrate content of selected ponds.

(6) Analysis of possible recycling of the metal enriched sediments by the present vegetation.

(7) Study of the chemistry of the "orange" outflow stream.

(B) The Sediments

(1) Levelling:- between the South Salix Marsh and the Long Pool to determine past and present differences in gradient

of water levels; - to the present River Wear from the South Salix Marsh to determine relative water levels; - to a bench mark to determine absolute heights.

(2) Boring beneath modern River Wear sediments and flood plain sediments, to compare these with the sediments in the marsh.

(3) Pollen analysis of sediment cores.

(4) Dating of sediment cores using ^{210}Pb or ^{14}C to test the hypotheses that have been put forward concerning the origin of the sediments.

(5) Pushing a sediment sampler (possibly one of a more appropriate design, such as an auger with a great number of extension rods) to the very bottom of the unconsolidated sediment, to sample and find the position of bedrock and/or pebble beds. In the cores recovered a greater depth of sampling might have been possible with more labour.

(6) Further research into the information that can be obtained about the origin of the sediments from minerals present in them, such as siderite.

Other ecological studies that could be conducted at Butterby Marsh might be:-

(1) Comparative limnology, analysing change between 1929 and 1982.

(2) Animal - Plant Interactions. There is a large variety of insect life at the Ponds. Mosquitoes are abundant from June till late August. A Prunus padus bush, near the 60m. E bankside marker of the South Salix Marsh, was covered with downy webs that were thought to be a

result of infestation by sawfly larvae. The tree was largely defoliated later in the summer. Purple aphids and green aphids were abundant on the Phragmites - (see Haslam 1972 p.604-605 for a list of animal feeders and parasites). Salices often had many red galls on their leaves.

(3) Study of the animal life. Fish, frogs, toads, water snails and Daphnia live in the ponds. Small frogs and toads were abundant in late July and early August. Previously, Pond C had been noted to have many large tadpoles. Damselfies were very abundant in June - July. There is a wide variety of bird life. A juvenile gull was often seen in very early summer (May - June), circling the vicinity of Pond C. Up to eighteen grey heron were seen taking off from the Ponds on one occasion. An estimated one hundred duck have taken off from the ponds on being disturbed. Two greylag geese were also seen at the ponds on one occasion in late July.

Weasels were seen in the South Salix Marsh and deer broke cover close to the present worker on three separate occasions. Mr. S. Redhead (pers. comm.) when assisting Dr. Griffiths in the 1930's, saw an otter by the Long Pool.

The ponds are largely isolated from human interference due to the inaccessible locality and the private land. They are unspoilt, untouched and are not exploited in any way apart from some fishing on the Long Pool. The site is a very pleasant area, reflected in its place name, which is probably a corruption of "Beautrove" (Surtees 1840).

CHAPTER 7. CONCLUSIONS

Results from the present study of the western area of Butterby Marsh may be summarized as follows:-

(1) There have been striking changes in the distribution of certain plant species since 1929. *Phragmites communis* has annexed large areas around Pond A and forms very dense mono-dominant stands. An estimate of the area involved is an extension of cover across at least 800 $m.^2$ These areas were formerly occupied by communities of *Carex acutiformis* with *Iris pseudacorus*, and *Rumex hydrolapathum* with *Equisetum fluviatile*. The latter two species have greatly diminished at the study site. No contraction of pond shape was noted and the vegetated area may not have been extended.

An experimental analysis of light reaching the water surface over a period of 60 days in midsummer showed that *Phragmites* reduced the value in the open to 6%, and *Carex acutiformis* to 27%. Shading by the tall reed may be partly responsible for its ability to out-compete other species.

(2) The area of marsh forest has not been greatly extended since the 1929 survey, although colonization by individual saplings was noted in a few locations. Many new undergrowth species have been recorded for the South Salix Marsh, perhaps due to more detailed study in this area. One new species recorded was *Impatiens glandulifera*. From a sample of 68 quadrats collected along seven transect lines this species had the greatest cover abundance. The understory was mapped in 1929 as being dominated by *Phalaris arundinacea*, which is still present in substantial quantities. The arrival and spread of *Impatiens* may represent a major change since 1929.

(3) Water analysis did not reveal any change in the pH of the ponds since 1929. Comparison of pH and specific conductivity with water from Croxdale Beck and the River Wear suggests that, as in 1929, there is no connection between these two areas. The pond system in the old loop would appear to be an isolated area supplied by water from a small local catchment. The water has a neutral pH and a low specific conductivity in comparison with the more alkaline river water. This may suggest that it is a less "polluted" habitat for the plants than the nearby river and its tributaries. Figures for Na, Ca, Mg, and K are given for selected sites at the ponds. With the large fall in water level over the summer it would appear that there is a concentration of these chemicals in small pools of stagnant water which may influence the plants.

(4) Studies of the marsh sediments showed that the bulk of the unconsolidated sediment at all sample sites was grey silt. There was some variation in the depth of black organic mud beneath different plant communities (nowhere more than 75 cm.) This may be due as much to (i) the position of each site in relation to the cross-profile of the old channel, as to (ii) differential litter accumulation and organic production since the Marsh was formed. The maximum depth of the unconsolidated sediment sampled was also probably related to the first factor. Some qualitative evidence suggesting succession was gained from examination of plant macrofossils. Schoenoplectus lacustris may have preceeded the Rumex and Equisetum around Pond A, which has now been largely replaced by Phragmites, Carex acutiformis, Iris pseudacorus and Typha latifolia. Abundant remains of Equisetum were found in the basal layers of many cores, which would seem to indicate that it was more widespread in the early vegetation of

the hydrosere. The fringing herbs may have spread quickly across the old channel, while Phragmites expanded its range later from small colonies of original vegetation present at an early date.

(5) The production of a stratigraphic profile across the old river channel raised many questions regarding the origin of the sediments and the time period represented by them. A marker horizon dividing river sediment from marsh sediment was not easy to assess. Layers of organic and inorganic sediment alternated.

Macrofossil evidence from the stratigraphy suggests that on the former point-bar of the South Salix Marsh, Equisetum fluviatile was replaced by a Phragmites community. This was later destroyed by the accumulation of a thick layer of sand. Phragmites again established itself but was replaced by the marsh forest as fringing trees spread on to the point bar. The soil that has developed above the sand at this location has a pH ranging between 5 and 6.5 along the transect line.

(6) Analysis of one core of 2.5 m. depth (the deepest recovered), showed that the sediment contained large concentrations of metals and fluorite over most of 12 sample points. This could be attributable to detritus from mining. Coal, clinker, slag and metalliferous particles $>425\ \mu m$ were also present. The basal silts were cyclothematic, containing many fine yellow-grey layers partly composed of siderite (an iron carbonate) interspersed with fine sand bands. Organic matter content gradually increased up the core, and high organic content seemed to be correlated with a low pH.

(7) The precise dating of the stages of infill of the old channel is difficult, as there seem to be many factors to consider

concerning the relationship between the old loop and the river in its new channel at different times. There seem to have been a complex number of different stages in the relative isolation of the loop from the river.

However, two suggestions arising from the discussion seem fairly probable:-

(i) that the grey silts (and the sands where they occur above them), were deposited by river water.

This could have occurred by overbank flow from the new course of the river into the dammed loop, or by deposition before closure. Deposition probably occurred before the completion of the embankments, which stopped flow in the loop and which may have isolated it from river floodwater.

(ii) that there has been only a small accumulation of organic sediment (less than 75 cm. depth) since the Marsh was formed.

It is probable that only this top black-brown mud is a product of autogenous accumulation within the Marsh (although rooted plant material penetrates the grey silts from above).

While the determination of the time of origin of the grey silt layers is of interest, this last point is a more important consideration in analysing the present changing ecology of the plants at the Marsh.

(8) The importance of site history is emphasized for the interpretation of the present distribution of plant communities within the Marsh.

The initial depths of the channel appear to have determined the pattern of vegetational development to a great extent. The deepest area of the channel follows the outside of the curves within the western arm of the loop, where there would have been maximum flow velocity and scour. This is still in many places open water. There has been no noticeable contraction in pond shape since 1929, although depth may have decreased. Shifts in the boundaries of vegetational communities have been most noticeable along the shallower sides of the old channel.

Historical evidence in the form of old maps shows the positions of gravel beds when the loop contained the river. These previous shallow water areas have now developed marsh forests, while the original areas of deeper water are now at an earlier stage in the hydrosere. Old flood overflow channels ("chutes") and "ancient courses of the river" contain small marshes filled with Juncus inflexus. The old maps show that there had been great human interference with the course of the river at Butterby prior to 1811, which may have affected flow conditions and the spatial pattern of the pool and riffle system. This could be partly responsible for the unusual pattern within the sediment cores from the South Salix Marsh.

Pigott and Wilson (1978) begin their discussion section with the following passage:

> "Knowledge of vegetational succession has to a very large extent been derived from studies of the spatial sequence or zoning of existing vegetation, although the validity of deductions can often be confirmed for hydroseres from the stratigraphy of underlying deposits. It is only rarely that accurate and sufficiently detailed maps of vegetation are available from the past to give direct evidence of the occurrence and exact course of succession. The North Fen at Esthwaite is for this reason a site of quite exceptional value because not only are there maps from over half a century ago which represent an investment whose ecological value increases with the passage of time, but the site itself has meanwhile remained relatively undisturbed."

This passage could equally well describe the case of Butterby Marsh. It is hoped that ecological investigations will be continued at the site and that these will benefit from Dr. Griffiths' extensive research conducted fifty years ago and the results of the present study. The Marsh is of considerable ecological interest within County Durham.

APPENDIX I : FULL SPECIES LIST WITH AUTHORITIES

TREE SPECIES

Acer pseudoplatanus	L.	Sycamore
Alnus glutinosa	L.	Alder
Betula pendula	L.	Silver Birch
Castanea sativa	Mill.	Sweet Chestnut
Fagus sylvatica	L.	Beech
Fraxinus excelsior	L.	Ash
Quercus robur	L.	Common Oak 'Pendunculate Oak'
Populus x canadensis	Moench.	Black Italian Poplar
Salix alba	L.	White Willow
Salix atrocinerea	Brot.	Common Sallow
Salix cinerea	L.	Grey Willow
Salix fragilis	L.	Crack Willow
Salix pentandra	L.	Bay Willow
Salix viminalis	L.	Common Osier
Salix caprea	L.	Goat Willow

SHRUB LAYER SPECIES

Crataegus monogyna	Jacq.	Hawthorn
Ilex aquifolium	L.	Holly
Prunus padus	L.	Bird Cherry
Ribes nigrum	L.	Blackcurrant
Rosa afzeliana	Fr.	(Wild Rose)
Rosa canina	L.	(Wild Rose)
Rubus idaeus	L.	Raspberry
Rubus anisacanthus	G. Braun	Bramble
Rubus dasyphyllus	Rog.	Bramble
Rubus eboracensis	W.C.R. Wats	Bramble
Sambucus nigra	L.	Elderberry
Sorbus aucuparia	L.	Rowan
Ulex europaeus	L.	Gorse
Viburnum opulus	L.	Guelder Rose

Herb Layer Species

ADOXACEAE

Adoxa moschatellina L. — Moschatell, Town Hall Clock.

ALISMATACEAE

Alisma plantago-aquatica L. — Water Plantain.

BALSAMINACEAE

Impatiens glandulifera Royle — Policeman's Helmet.

BORAGINACEAE

Myosotis palustris L. — Water Forget-me-not.

CAMPANULACEAE

Campanula rotundifolia L. — Harebell.

CARYOPHYLLACEAE

Silene dioica (L.) Clairv. — Red Campion.

Spergula arvensis L. — Corn Spurrey.

Stellaria nemorum L. — Wood Stitchwort.

COMPOSITAE

Achillea millefolium L. — Yarrow, Milfoil.

Arctium minus (Hill) Bernh-ssp nemorosa — Lesser Burdock.

Artemisia vulgaris L. — Mugwort.

Centaurea nigra L. — Black Knapweed.

Chrysanthemum vulgare (L.) Bernh. — Tansy.

Cirsium arvense (L.) Scop. — Creeping Thistle.

Cirsium palustre (L.) Scop. — Marsh Thistle.

Hieracium perpropinquum (Zahn.) Druce.

Hieracium vagum Jord.

Lapsana communis L. — Nipplewort.

Petasites vulgaris Desf. — Butterbur.

Matricaria maritima L. (Tripleurospermum m.(L.) Koch. — Scentless Mayweed.

Senecio jacobea L. — Ragwort.

CONVOLVULACEAE

Calystegia sepium L.	Larger Bindweed.

CRUCIFERAE

Cardamine amara L.	'Large Bitter-cress'.
Cardamine hirsuta L.	Hairy Bitter-cress.
Cardamine pratensis L.	Cuckoo-flower, Lady's Smock.
Hesperis matronalis L.	'Dame's Violet'.
Raphanus raphanistrum L.	Wild Raddish, White Charlock.
Rorippa nasturtium-aquaticum agg. (L.) Hayek	Watercress.

CYPERACEAE

Carex acuta L.	Slender Tufted Sedge.
Carex acutiformis Ehrh. (C. paludosa Good)	Lesser Pond-sedge.
Carex hirta L.	Hammer/Hairy Sedge.
Carex paniculata L.	Panicled/Greater Tussock Sedge.
Carex remota L.	Remote Sedge.
Carex riparia Curtis.	Greater Pond Sedge.
Carex rostrata Stokes.	Beaked/Bottle Sedge.
Carex vesicaria L.	Bladder Sedge.
Schoenoplectus lacustris L.	Bulrush.
Scirpus sylvaticus L.	Wood Club-rush.

EQUISETACEAE

Equisetum fluviatile L. (E. limosum L.)	Water Horsetail.
Equisetum palustre L.	Marsh Horsetail.

EUPHORBIACEAE

Mercurialis perennis L.	Dogs Mercury.

GRAMINEAE

Arrhenatherum elatius (L.) Beauv. ex J. & C. Presl	False Oat Grass.
Agrostis stolonifera L.	Creeping Bent.
Dactylis glomerata L.	Cocks Foot Grass.
Festuca gigantea L.	Tall Brome Grass, Giant Fescue.
Glyceria declinata Bréb.	Glaucous Sweet Grass. Small Swamp Grass.
Glyceria fluitans (L.) R. Br.	Flote Grass. Floating Sweet Grass.
Holcus lanatus L.	Yorkshire Fog Grass.
Holcus mollis L.	Creeping Soft Grass.
Phragmites communis Trin	Common/Tall Reed.
Phalaris arundinacea L.	Reed, Reed Canary Grass.
Poa trivialis L.	Rough Meadow Grass.
Lolium perenne L.	Rye Grass.

GERANIACEAE

Geranium pratense L.	Meadow Cranesbill.
Geranium robertianum L.	Herb Robert.
Geranium sylvaticum L.	Wood Cranesbill.

IRIDACEAE

Iris pseudacorus L.	Yellow Flag.

JUNCACEAE

Juncus bufonius L.	Toad Rush.
Juncus effusus L.	Soft Rush.
Juncus inflexus L.	Hard Rush.

LABIATAE

Ajuga reptans L.	Bugle.
Betonica officinalis L.	Betony.
Galeopsis bifida Boenn	(Hemp Nettle).
Galeopsis tetrahit L.	Common Hemp Nettle.

LABIATAE (Cont'd.)

Glechoma hederacea L.	Ground Ivy.
Lycopus europeaus L.	Gipsy-Wort.
Mentha aquatica L.	Water-Mint.
Scutellaria galericulata L.	Skull-cap.
Stachys sylvatica L.	Hedge woundwort, Centurion's Sandle.

LEMNACEAE

Lemna minor L.	Duckweed.
Lemna trisulca L.	Ivy Duckweed.

LILIACEAE

Allium ursinum L.	Ramsons, Wild Garlic.

NYMPHAEACEAE

Nuphar lutea L.	Yellow Water-Lily.

ONAGRACEAE

Circaea lutetiana L.	Common Enchanters-Nightshade.
Epilobium adenocaulon Hausskn.	(Introduced).
Epilobium angustifolium L.	Rosebay Willow-Herb, Fireweed.
Epilobium hirsutum L.	Great Hairy Willow Herb.
Epilobium palustre L.	Marsh Willow-Herb.
Epilobium parviflorum Schreb.	Small-flowered Hairy Willow-Herb.

PAPILIONACEAE

Lathyrus pratensis L.	Meadow Vetchling.
Lotus corniculata L.	Birdsfoot —trefoil.
Lotus uliginosus Schkuhr	Large Birdsfoot-trefoil
Trifolium pratense L.	Red Clover.
Vicia cracca L.	Tufted Vetch.

PLANTAGINACEAE

Plantago lanceolata L.	Ribwort Plantain.
Plantago major L.	Great Plantain.
Polygonum persicaria L.	'Persicaria'.
Rumex acetosa L.	Sorrel.
Rumex hydrolapathum Huds.	Great Water Dock.
Rumex sanguineus L.	Red-Veined Dock.

RANUNCULACEAE

Caltha palustris L.	Marsh Marigold/Kingcup.
Ranunculus aquatilis L.	Water Crow Foot.
Ranunculus ficaria L.	Lesser celandine
Ranunculus repens L.	Creeping Buttercup.
Ranunculus hederaceus L.	Ivy-leaved Water-Crowfoot.

ROSACEAE

Filipendula ulmaria (L.) Maxim.	Meadow Sweet.
Potentilla anserina L.	Silverweed.
Potentilla erecta L.	Common Tormentil.
Potentilla reptans L.	Creeping Cinquefoil.
Sanguisorba officinalis L.	Great Burnet.

RUBIACEAE

Galium aparine L.	Goosegrass/Cleavers.
Galium cruciata (L.) Scop.	Crosswort.
Galium palustre L.	Marsh Bedstraw.
Galium palustre ssp *elongatum* (C. Presl) Lge.	
Galium verum L.	Lady's Bedstraw.

SCROPHULARIACEAE

Veronica agrestis L. — Field Speedwell.

Scrophularia nodosa L. — Figwort.

SOLANACEAE

Solanum dulcamara L. — Bittersweet, Woody Nightshade.

SPARGANIACEAE

Sparganium erectum L. — Bur-reed.

TYPHACEAE

Typha latifolia L. — Great Reedmace/Cats-tail.

UMBELLIFERAE

Aegopodium podagraria L. — Goutweed/Bishopsweed/Ground-elder.

Angelica sylvestris L. — Wild Angelica.

Anthriscus sylvestris L. — Cow-parsley.

Conopodium majus (Gouan) Lor. & Barr. — Pignut.

Heracleum sphondylium L. — Hogweed.

Myrrhis odorata (L.) Scop. — Sweet Cicely.

Oenanthe aquatica (L.) Poir. — Fine leaved water dropwort.

URTICACEAE

Urtica dioica L. — Stinging Nettle.

VALERIANACEAE

Valeriana officinalis L. — Valerian.

VIOLACEAE

Viola arvensis L. — Field Pansy.

BRYOPHYTES

1. Acrocladium cordifolium (Hedw.) Rich & Wall.
2. Acrocladium giganteum (Schimp.) Rich & Wall
3. Amblystegium serpens (Hedw.) B., S. & G.
4. Aulacomnium androgynum (Hedw.) Schwaegr.
5. Brachythecium rutabulum (Hedw.) B., S. & G.
6. Bryum flaccidum Brid.
7. Bryum pseudotriquetrum (Hedw.) Schwaegr.
8. Campylium stellatum (Hedw.) J. Lange & C. Jens.
9. Chiloscyphus pallescens (Ehrh.) Dum.
10. Eurhynchium praelongum (Hedw.) Hobk.
11. Hypnum cupressiforme Hedw.
12. Leptodictyum riparium (Hedw.) Warnst.
13. Lophocolea bidentata (L.) Dum.
14. Lophocolea cuspidata (Nees) Limpr.
15. Lophocolea heterophylla (Schrad.) Dum.
16. Marchantia polymorpha L.
17. Mnium hornum Hedw.
18. Mnium punctatum Hedw.
19. Plagiomnium ellipticum (Brid.) Kap.
20. Plagiothecium denticulatum (Hedw.) B., S. & G.

PTERIDOPHYTES

Dryopteris dilatata (Hoff M.)

Dryopteris filix-mas (L.)

Polypodium vulgare L.

Many of the bryophytes were identified by Dr. B. Huntley and the Rev. G. G. Graham.

NOTES ON ECOLOGY OF BRYOPHYTES

1. Occurs in pools and marshes. Watson (1978 p 333).
2. A Local plant of marshes. Watson (1978 p 333).
3. Grows equally readily on wood, rock and soil. Most characteristic of moist woodlands. Rotting tree stumps are especially favoured. Watson (1978 p321).
4. Typical habitat consists of rotten wood. Watson (1978 p.275).
5. Almost ubiquitous in lowland districts, open and shaded conditions. Any type of moist woodland including fen carr, certain less typical forms occur frequently in grass on river banks and in marshes. Watson (1978 p.340).
6. Soft tufts on tree trunks or branches, very rarely on soil. Smith (1978 p.405, 406).
7. Occurs in various type of bog and marsh habitats. Watson (1978 p 257).
8. Occurs in a wide range of moist habitats. Watson (1978 p.317).
9. A plant of ditches, moist banks and decaying logs. Watson (1978 p.452).
10. Extremely common moss on shaded banks or about the bases of trees in woodland. Most marked ecological feature is its shade tolerance. Watson (1978 p.349-350).
11. The most abundant and most variable British moss. Watson (1978 p.365).
12. Grows on various substrata - rock, wood and soil - it s presence is almost always associated with river bank or pond margin. Watson (1978 p.320).
13. Liverwort. Unlike the other two common species of Lophocolea it grows almost always on soil. Occurs in woods. Watson (1978 p.448).

14. Liverwort. Chief habitat is the rotten wood of decaying logs, tree stumps and fallen branches. Watson (1978 p 450).

15. Liverwort. As in L. cuspidata, decaying logs and tree stumps in moist woodland are the principal habitat, where associated bryophytes are commonly such mosses as Brachythecium rutabulum and Hypnum cupressiforme. Watson (1978 p 451).

16. Liverwort. River banks is one of its distinct habitats. Watson (1978 p 395).

17. Wide habitat range including rotten wood. Watson (1978 268

18. Demands some shade and considerable moisture but will grow on various substrata and is probably indifferent as regards soil reaction. Watson (1978 p 272).

19. Light green tufts or patches in fens, marshes, flushes, wet places, in fields, by streams, rivers and lakes. Smith (1978 p. 444, 445, 448).

20 Rotting logs and tree stumps. Chiefly a woodland plant and always demands some shade. Watson (1978 p.364).

APPENDIX 2. TABLE A. SPECIES RECORDED AT BUTTERBY BY GRIFFITHS (1932a, 1932b, 1936)

1 = Long Pool, 2 = Typha Marsh, 3 = E. Salix Marsh, 4 = Iris Marsh, 5 = Woodside Marsh, 6 = Middle Pasture Marsh, 7 = Boathouse Pool, 8 = W. Salix Marsh, 9 = Great Rumex Marsh, 10 = Phragmites Marsh, 11 = S. Salix Marsh.

TREE AND SHRUB LAYER SPECIES	1	2	3	4	5	6	7	8	9	10	11	Recorded 1982 ?
Alnus rotundifolia (Mill.) Stokes = A.glutinosa (L.) Gaertn.		X	X				X	X				X
Salix alba		X	X									X
Salix Andersoniana Sm = S. nigricans Sm.												O
Salix cinerea			X				X	X	X			X
Salix fragilis		X	X				X	X			X	X
Salix pentandra												X
Salix purpurea x viminalis, S. purpurea L.	X											O
Salix viminalis												X
Viburnum opulus			X									X

Authorities given for species not recorded in 1982.

X = Recorded

O = Not recorded

TABLE A (Continued)

SPECIES RECORDED AT BUTTERBY BY GRIFFITHS

1 = Long Pool, 2 = Typha Marsh, 3 = E. Salix Marsh, 4 = Iris Marsh, 5 = Woodside Marsh, 6 = Middle Pasture Marsh, 7 = Boathouse Pool, 8 = W. Salix Marsh, 9 = Great Rumex Marsh, 10 = Phragmites Marsh, 11 = S. Salix Marsh. 0 = Not recorded 1982

HERB LAYER SPECIES (Authorities listed for Sp. with name changes and those not recorded in 1982)	1	2	3	4	5	6	7	8	9	10	11	Recorded 1982 ?
Achillea ptarmica L.	X											0
Acorus calamus L.			X									0
Adoxa moschatellina	X											X
Alisma plantago-aquatica	X											X
Caltha palustris	X		X			X	X					X
Cardamine pratensis				X								X
Carex ampullacea Good = *C. rostrata* stokes	X	X						X			X	X
Carex distans L.			X					X				0
Carex paludosa Good = *C. acutiformis* Ehrh	X	X			X	X			X		X	X
Carex paniculata											X	X
Carex vesicaria		X										X
Castalia alba (L.) Wood = *Nymphaea alba* L.							X					0

TABLE A (Continued)

HERB LAYER SPECIES (Continued)	1	2	3	4	5	6	7	8	9	10	11	Recorded 1982 ?
Deschampsia caespitosa (L.) Beauv.			X		X		X					O
Digraphis arundinacea = Phalaris arundinacea L.	X		X				X	X			X	X
Eleocharis palustris (L.) R.Br.	X			X								O
Epilobium hirsutum							X					X
Equisetum limosum L. = E. fluviatile L.	X		X	X	X		X	X	X	X		X
Filipendula ulmaria	X											X
Glyceria fluitans (L.) R.Br.				X	X	X						O
Iris pseudacorus	X			X			X	X			X	X
Juncus communis (L.) E.Mey = J. effusus L.	X	X		X								X
Juncus glaucus Sibth = J. inflexus L.	X		X	X	X	X	X					X
Lemna minor	X											X
Limnanthemum nymphaeoides (L.) Link = Nymphoides peltatum (Gmel.) O. Kuntze												O
Lycopus europaeus	X											X
Mentha aquatica	X		X									X
Myosotis scorpioides	X			X	X							X

TABLE A (Continued)

HERB LAYER SPECIES (Continued)	1	2	3	4	5	6	7	8	9	10	11	Recorded 1982 ?
Nuphar lutea	X						X	X		X		X
Oenanthe crocata L.							X					O
Oenanthe phellandrium Lam = O. aquatica (L.) Poir	X				X							X
Petasites vulgaris	X		X									X
Phragmites communis	X						X	X	X	X	X	X
Polygonum amphibium L.	X			X	X							O
Potamogeton crispus L.	X											O
Potamogeton natans L.			X		X				X			O
Potamogeton pusillus L.	X											O
Ranunculus aquatilis					X							X
Ranunculus ficaria	X											X
Ranunculus flammula L.				X								O
Ranunculus sceleratus					X							O
Rumex hydrolapathum	X	X	X	X	X		X	X	X			X
Scirpus lacustris L. = Schoenoplectus l. (L.) Palla	X											X
Scirpus sylvaticus		X	X			X						X
Scutellaria galericulata	X				X							X
Senecio aquaticus Hill.	X			X	X							O

TABLE A (Continued)

HERB LAYER SPECIES (Continued)	1	2	3	4	5	6	7	8	9	10	11	Recorded 1982 ?
Sparganium ramosum Huds. = *S. erectum* L.	X			X								X
Sparganium ramosum ssp neglectum												O
Stellaria uliginosa Murr. = *S. alsine* Grimm	X											O
Typha latifolia	X	X							X			X
Valeriana officinalis	X		X									X
Veronica scutellata L. var *villosa* Schum												O
BRYOPHYTES *Hypnum fluitans* var.												*Hypnum* recorded
Mnium affine var. *elatum*												*Mnium* recorded
Ricciocarpus natans (L.) Corda												O

APPENDIX 3 TABLE B. SPECIES RECORDED AT BUTTERBY 1982

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
	EASTERN MARSH	BOATHOUSE WOOD	POND A	POND B	POND C	S. SALIX MARSH	EMBANKMENT	FOREST	BANKSIDE: OPEN	BANKSIDE: SHADE	MARSH FOREST	FEN	REEDSWAMP	SEDGESWAMP	AQUATIC
TREES															
Acer pseudoplatanus			X	X	X	X			X	X					
Alnus glutinosa		X	X	X	X	X		X	X	X	X				
Betula pendula		X						X							
Castanea sativa		X						X							
Fagus sylvatica		X						X							
Fraxinus excelsior		X						X							
Quercus robur		X						X							
Populus X. canadensis				X	X	X			X						
Salix alba				X	X	X	X		X	X	X				
Salix cinerea		X	X	X	X	X			X	X	X				
Salix fragilis		X	X	X	X	X	X		X	X	X				
Salix pentandra				X					X						
Salix viminalis				X		X			X						

TABLE B (Continued)

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
SHRUB LAYER															
Crataegus monogyna	X	X	X					X	X						
Ilex aquifolium		X						X							
Prunus padus						X			X						
Ribes nigrum				X									X		
Rosa spp.	X	X	X						X						
Rubus spp.	X	X	X	X	X	X			X						
Sambucus nigra	X	X	X	X	X	X			X						
Sorbus aucuparia	X	X		X					X				X		
Ulex europaeus			X						X						
Viburnum opulus	X								X						
HERB LAYER															
Achillea millefolium			X	X					X						
Adoxa moschatellina	X							X	X	X					
Aegopodium podagraria			X	X	X				X	X					
Agrostis stolonifera	X								X	X					
Ajuga reptans	X								X						
Alisma plantago-aquatica			X	X											X
Allium ursinum				X	X	X				X					
Angelica sylvestris	X	X	X	X	X	X		X	X	X	X	X			
Anthriscus sylvestris						X			X						
Arctium minus							X		X						

TABLE B (Continued)

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
Arrhenatherum elatius				X	X	X			X						
Artemisia vulgaris					X	X			X	X					
Betonica officinalis			X						X						
Caltha palustris	X											X			
Calystegia sepium				X	X				X			X			
Campanula rotundifolia			X						X						
Cardamine amara						X				X	X	X			
Cardamine hirsuta						X				X	X				
Cardamine pratensis					X	X				X	X				
Carex acuta	X													X	
Carex acutiformis		X	X		X	X								X	
Carex hirta			X						X						
Carex paniculata						X					X	X			
Carex remota						X					X	X			
Carex riparia		X												X	
Carex rostrata		X												X	
Centaurea nigra			X						X						
Chrysanthemum vulgare							X		X						
Circaea lutetiana						X					X				

TABLE B (Continued)

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
Cirsium arvense						X			X	X					
Cirsium palustre						X					X				
Dryopteris dilatata	X					X					X				
Epilobium adenocaulon			X	X					X			X			
Epilobium angustifolium			X	X		X			X			X			
Epilobium hirsutum			X	X		X			X						
Epilobium palustre						X					X	X			
Epilobium parviflorum			X									X			
Equisetum fluviatile	X		X												X
Equisetum palustre	X	X	X	X				X	X	X	X	X			
Filipendula ulmaria	X					X	X				X	X	X		
Festuca gigantea							X		X	X	X				
Galeopsis bifida			X				X		X						
Galeopsis tetrahit			X				X		X						
Galium aparine			X	X	X	X			X	X	X	X			
Galium cruciata			X						X						
Galium palustre						X					X	X			
Galium verum			X						X						

TABLE B (Continued)

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
Geranium pratense							X		X						
Geranium robertianum			X			X			X		X				
Geranium sylvaticum						X					X				
Glechoma hederacea		X						X							
Glyceria declinata	X											X			
Heracleum sphondylium			X	X	X	X	X		X	X	X				
Hesperis matronalis							X		X						
Hieracium perpropinquum			X						X						
Hieracium vegum						X					X				
Holcus lanatus			X	X	X	X	X		X						
Holcus mollis						X				X	X				
Impatiens glandulifera			X	X	X	X	X		X	X	X				
Iris pseudacorus			X			X					X			X	X
Juncus bufonius		X				X						X			
Juncus effusus	X	X	X	X	X	X						X			
Juncus inflexus	X		X									X			
Lapsana communis			X			X			X						
Lathyrus pratensis			X			X			X						

TABLE B (Continued)

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
Lemna minor	X	X	X	X	X	X									X
Lemna trisulca	X	X	X												X
Lolium perenne						X			X						X
Lotus corniculatus			X						X						
Lycopus europaeus			X	X	X	X					X	X		X	
Lotus uliginosus			X						X						
Mentha aquatica	X		X			X									X
Mercurialis perennis	X							X			X				
Myosotis scorpioides	X		X			X			X		X	X			
Myrrhis odorata						X			X	X					
Nuphar lutea	X	X	X		X										X
Oenanthe aquatilis	X											X			X
Petasites vulgaris				X	X	X	X		X	X					
Phalaris arundinacea						X					X	X			
Phragmites communis			X	X	X	X			X	X	X	X	X		
Plantago lanceolata			X						X						
Polygonum persicaria			X	X	X	X			X						
Polypodium vulgare						X					X				

TABLE B (Continued)

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
Potentilla anserina	X	X					X		X						
Potentilla erecta		X				X		X		X	X				
Potentilla reptans		X				X		X		X	X				
Ranunculus aquatilis	X														X
Ranunculus ficaria	X	X						X	X	X					
Ranunculus hederaceus	X														X
Ranunculus repens			X	X	X	X			X	X					
Raphanus raphanistrum							X		X						
Rorippa nasturtium-aquaticum				X											X
Rumex acetosa			X						X						
Rumex hydrolapathum	X		X									X			
Rumex sanguineus	X		X						X						
Sanguisorba officinalis			X						X						
Scirpus sylvaticus						X					X	X			
Scrophularia nodosa	X										X				
Scutellaria galericulata		X	X					X				X			
Senecio jacobea						X			X						
Silene dioica				X	X	X	X		X	X	X				
Solanum dulcamara						X					X	X	X		

TABLE B (Continued)

SPECIES RECORDED AT BUTTERBY 1982	GEOGRAPHICAL LOCATION							HABITAT TYPE							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
Sparganium erectum	X											X			
Spergula arvensis							X		X						
Stachys sylvatica		X	X	X	X	X			X	X					
Stellaria nemorum						X				X	X	X			
Tripleurospermum maritimum					X	X	X		X						
Typha latifolia	X		X									X		X	
Urtica dioica	X	X	X	X	X	X	X	X	X	X	X				
Valeriana officinalis	X					X					X	X			
Veronica agrestis			X	X	X	X			X						
Vicia cracca						X			X						
Viola arvensis						X	X		X						

APPENDIX 4

TABLE C: VEGETATION SUMMARY = POND A, WEST BANKSIDE 2 × 2 m QUADRATS. DOMIN SCALE VALUES (D)

1 = 330m. 2 = 370m. 3 = 420m. 4 = 440m. 5 = 460m. 6 = 500m. 7 = 520m. 8 = 540m. (distance from embankment).

	BANKSIDE										WATERS EDGE										BEYOND H.W.M. (2,3,4 = Open Water)									
QUADRAT NO.	1	2	3	4	5	6	7	8	F	ΣD	1	2	3	4	5	6	7	8	F	ΣD	1	2	3	4	5	6	7	8	F	ΣD
TREE & SHRUB COVER	0	0	0	0	0	0	0	0	-	-	5	10	0	5	7	8	8	8	7	51	3	10	0	0	5	7	7	7	6	39
HERB LAYER COVER	10	10	10	10	10	10	10	10	8	80	10	10	10	10	10	10	10	10	8	80	9	8	5	6	7	9	7	7	8	58
"BANKSIDE" SPECIES :																														
Achillea millefolium	2	4	4	1	5	1	1	1	8	14																				
Angelica sylvestris			4			3			2	7			4			2														
Arrhenatherum elatius		5	3	5	2	+	+	+	4	15																				
Betonica officinalis	2		3	5					3	10			3						1	3										
Campanula rotundifolia	+	2							1	2																				
Cardamine amara (seedlings)													1			1			2	2										
Carex hirta	3	+							1	3																				
Centaurea nigra			5						1	5																				
Cirsium sp.			+															3	1	3										
Conopodium majus	5	3	4	5		+	3		5	20	3							4	2	7										
Dactylis glomerata		4	2	3	2	2	2	2	7	17		+																		
Epilobium adenocaulon																1			1	1					3				1	3
Epilobium angustifolium			6		4	4	5		4	19						2			1	2										
Epilobium hirsutum													3			1			2	4					3				1	3
Ferns								4	1	4																				
Galium aparine		3	5		3		3	4	5	18			4						1	4										
Galium cruciata			2						1	2																				
Galium verum	2	2	3	4	3				5	14																				
Galeopsis tetrahit						3			1	3																				
Geranium robertianum			+																											
Glechoma hederacea								3	1	3																				
Heracleum sphondylium			+			3	4	4	3	11	+							4	1	4										
Hieracium perpropinqum												+																		
Holcus lanatus					+	4	3	4	3	11																				
Impatiens glandulifera	2	+	3	4	3	+	+	+	4	12	+		+	2					1	2					2				1	2
Lathyrus pratensis		4				2			2	6																				
Lolium perenne	3								1	3																				
Lotus corniculatus	2	4		1					3	7		+																		
Plantago lanceolata	5			5					2	10		4							1	4										
Poa trivialis	2		1	2		1		1	5	7																				
Ranunculus repens	2				2		4		3	8								3	1	3										
Rumex acetosa	+	2	3	5	4		3	+	5	17		4							1	4										
Rumex sanguineus			+		+																									
Scutellaria galericulata			5						1	5			2						1	2										
Stellaria nemorum			3						1	3																				
Trifolium medium				6					1	6																				
Urtica dioica						5		5	2	10																				
Vicia cracca							3		1	3																				

TABLE C (Continued)

"Fen + Aquatic Species"	BANKSIDE 1	2	3	4	5	6	7	8	F	ΣD	WATERS EDGE 1	2	3	4	5	6	7	8	F	ΣD	BEYOND H.W.M. (2,3,4 = Open Water) 1	2	3	4	5	6	7	8	F	ΣD
Alisma plantago-aquatica											+			3	+				1	3	+			1					1	1
Carex acutiformis														6					1	6	+		2						1	2
Carex riparia															2				1	2								+		
Epilobium palustre																									2				1	2
Equisetum fluviatile												1		5	5	1			4	11			2						1	2
Equisetum palustre												2	4			1		4	4	11			1						1	1
Galium palustre											2					2			1	2										
Glyceria declinata												8					3		2	11										
Iris pseudacorus														5	6	6			3	17		9	7	5	6	3	6	6	6	42
Juncus effusus											5		9	4	7	6	5	5	7	41										
Juncus inflexus													+																	
Lemna minor													+	+	+	2	+	+	1	2	1	2	4	3		3	2	2	7	17
Lemna trisulca																1			1	1		1	2	1					3	4
Lycopus enropaeus																					1				2				2	3
Mentha aquatica																2	3		2	5							2		1	2
Myosotis scorpioides						3			1	3																				
Nuphar lutea																							4						1	4
Phragmites communis											5					6			2	11	10			+	7	6	3	3	5	29
Rumex hydrolapathum														5	3	1			3	9	+		1						1	1
Typha latifolia																							7	7					2	14
No. sp in quadrat	11	10	15	12	8	10	10	9			3	3	8	7	5	15	3	4			3	3	9	5	7	3	4	3		

(Bankside + Fen + Aquatics)

APPENDIX 5

TABLE D : VEGETATION SUMMARY, POND B AND POND C

1 = 160m., 2 = 200m., 3 = 240m., 4 = 280m., 5 = 300m.

WEST BANKSIDE TRANSECTS DOMIN VALUES

From embankment 2×2 m quadrats

	FIELD EDGE							MIDDLE BANKSIDE							WATERS EDGE							1 METRE BEYOND H.W.M.						
	1	2	3	4	5	F	ΣD	1	2	3	4	5	F	ΣD	1	2	3	4	5	F	ΣD	1	2	3	4	5	F	ΣD
Tree & Shrub layer cover	0	0	7	3	6	3	16	0	0	8	3	8	3	19	0	0	8	0	8	2	16	0	0	8	0	8	2	16
Herb layer cover	10	10	10	10	10	5	50	10	10	10	10	10	5	50	10	10	10	10	10	5	50	9	9	2	9	3	5	32
Herb layer species:																												
<u>Achillea millefolium</u>												4	1	4														
<u>Aegopodium podagraria</u>	4	8	8	7		4	27	3	3	6	5		4	17	7					1	7							
<u>Arrhenatherum elatius</u>	4	5	6	7		4	22	4	4	6	8	6	5	28														
<u>Calystegia sepium</u>									4				1	4	3	5				2	8							
<u>Cardamine amara</u>															5	6				2	11							
<u>Cirsium</u> sp										5	5		2	10				5		1	5							
<u>Conopodium majus</u>				3		1	3					4	1	4					3	1	3							
<u>Dactylis glomerata</u>				4	9	2	13																					
<u>Equisetum palustre</u>			3		3	2	6				3		1	3		3				1	3							
<u>Galium aparine</u>	4	4				2	8	4	5				2	9	7	7	7	5		4	26							
<u>Glechoma hederacea</u>	+																											
<u>Heracleum sphondylium</u>			6		4	2	10	4		8	4		3	16														
<u>Impatiens glandulifera</u>	+	+	+	+	+																							
<u>Lapsana communis</u>																			3	1	3							
<u>Lemna minor</u>																						3	3	4	3	+	4	13
<u>Lolium perenne</u>	+																											
<u>Myosotis scorpioides</u>	+								3				1	3														
<u>Phragmites communis</u>	4	4				2	8	8	5		5		3	18	5			4		2	9	10	10	+	10	+	3	30
<u>Poa trivialis</u>				4	3	2	7		3				1	3		5				1	5							
<u>Ranunculus repens</u>												3	1	3			4			1	4							
<u>Rumex sanguineus</u>																	5			1	5							
<u>Scutellaria galericulata</u>												4	1	4														
<u>Tripeurospermum maritimum</u>	3					1	3																					
<u>Urtica dioica</u>					5	1	5	5				7	2	12	5	5	5	8	7	5	30							
No. of species in quadrat	4	4	4	5	5			6	7	4	6	6			6	6	4	4	3			2	2	1	2	0		

N.B. <u>Impatiens glandulifera</u> also present but not recorded in late May in significant quantities.

APPENDIX 6

TABLE E = VEGETATION SUMMARY, POND C

EAST BANKSIDE TRANSECTS. DOMIN VALUES 2×2m quadrats

1 = 160m., 2 = 180m., 3 = 200m., 4 = 220m., 5 = 240m., 6 = 270m., 7 = 290m. from embankment.

	FIELD EDGE								
	1	2	3	4	5	6	7	F	ΣD
Tree & Shrub cover	5	7	7	6	6	6	5		
Herb layer cover	10	10	10	10	10	10	10		
Herb layer species									
Angelica sylvestris									
Arrhenatherum elatius	5	5		5	6	8	4	6	33
Carex acutiformis									
Carex remota									
Cirsium sp									
Epilobium angustifolium									
Ferns:									
Festuca gigantea									
Galium aparine		4	5	5	5	4	4	6	27
Gramineae carpet							5	1	5
Heracleum sphondylium	4	5	6	6	5	5		6	31
Impatiens glandulifera	4				4			2	8
Lemna minor									
Lolium perenne	5		4					2	9
Lycopus europeaus									
Mosses									
Nuphar lutea									
Petasites vulgaris					+	4		1	4
Phalaris arundinacea									
Phragmites communis									
Poa trivialis			3					1	3
Rumex sanguineus									
Silene dioica									
Solanum dulcamara									
Stachys sylvatica	5	5						2	10
Urtica dioica	5	8	7	7	7	4	8	7	46
No. species in quadrat	6	5	5	4	5	5	4		

	MIDDLE BANKSIDE								
	1	2	3	4	5	6	7	F	ΣD
Tree & Shrub cover	9	10	10	10	9	10	10		
Herb layer cover	10	10	10	10	8	10	10		
Herb layer species									
Angelica sylvestris					3	5		2	8
Arrhenatherum elatius				4				1	4
Carex acutiformis						3		1	3
Carex remota									
Cirsium sp						3		1	3
Epilobium angustifolium						3		1	3
Ferns:				4	4			2	8
Festuca gigantea					7			1	7
Galium aparine		3	3	6	4	4	4	6	24
Gramineae carpet						5		1	5
Heracleum sphondylium	4	5		6	3	3		5	21
Impatiens glandulifera	8	7			6		8	4	29
Lemna minor									
Lolium perenne									
Lycopus europeaus									
Mosses		+	2	+	+	+	4	1	6
Nuphar lutea									
Petasites vulgaris	5				4			2	9
Phalaris arundinacea					4	5		2	9
Phragmites communis									
Poa trivialis									
Rumex sanguineus						4		1	4
Silene dioica	3						4	2	7
Solanum dulcamara									
Stachys sylvatica	4				4			2	8
Urtica dioica	4	5	9	6		4	4	7	32
No. species in quadrat	6	4	3	5	9	10	5		

	WATERS EDGE								
	1	2	3	4	5	6	7	F	ΣD
Tree & Shrub cover	10	10	10	10	10	10	9		
Herb layer cover	10	10	10	10	10	10	10		
Herb layer species									
Angelica sylvestris					5			1	5
Arrhenatherum elatius				3			3		
Carex acutiformis						+	2	1	2
Carex remota					4	7		2	11
Cirsium sp						4		1	4
Epilobium angustifolium							3	1	3
Ferns:					4		4	2	8
Festuca gigantea							3	1	3
Galium aparine			5	5		3	3	4	16
Gramineae carpet		5	5	5		3	3	5	21
Heracleum sphondylium	5							1	5
Impatiens glandulifera	7	6	6	5	4	5	6	7	39
Lemna minor									
Lolium perenne									
Lycopus europeaus		5			+	4		2	9
Mosses		+			4	+		1	4
Nuphar lutea									
Petasites vulgaris	7							1	7
Phalaris arundinacea			7	7				2	14
Phragmites communis						+	+		
Poa trivialis			3					1	3
Rumex sanguineus						4		1	4
Silene dioica		3		3	+			2	6
Solanum dulcamara					+		4	1	4
Stachys sylvatica			6	+				1	6
Urtica dioica	4	6	5	4	7	5	5	7	36
No. species in quadrat	4	5	7	7	6	8	10		

	1 METRE BEYOND H.W.M.								
	1	2	3	4	5	6	7	F	ΣD
Tree & Shrub cover	4	3	4	4	4	3	3		
Herb layer cover									
Herb layer species									
Angelica sylvestris									
Arrhenatherum elatius									
Carex acutiformis						+	2	1	2
Carex remota									
Cirsium sp									
Epilobium angustifolium									
Ferns:									
Festuca gigantea									
Galium aparine									
Gramineae carpet									
Heracleum sphondylium									
Impatiens glandulifera									
Lemna minor	1	1	1	1	1	1	1	7	7
Lolium perenne									
Lycopus europeaus									
Mosses									
Nuphar lutea	5	7	7	2	3	2		6	26
Petasites vulgaris									
Phalaris arundinacea									
Phragmites communis							1	1	1
Poa trivialis									
Rumex sanguineus									
Silene dioica									
Solanum dulcamara									
Stachys sylvatica									
Urtica dioica									
No. species in quadrat	2	2	2	2	2	2	3		

APPENDIX 7

VEGETATION SUMMARY, SOUTH SALIX MARSH.
DOMIN COVER SCALE VALUES (D)

TRANSECT LINES PARALLEL TO EMBANKMENT AT 20m. INTERVALS.
F = No. Quadrats a species occurs in (or no. of quadrats with cover in Top Section)

QUADRATS 2m^2 AT 4m INTERVALS

Quadrat No.	1	2	3	4	5	6	7	8	9	10	11
Transect Line	WEST					20m.				EAST	
Tree + Shrub cover	4	7	9	9	9	10	9	10	10	9	11
Herb layer cover	10	10	9	9	10	9	9	9	8	10	10
Water present = X						X					
Herb layer species											
Aegopodium podagraria											
Alisma plantago-aquatica											
Allium ursinum										4	
Angelica sylvestris											
Arrhenatherum elatius											7
Cardamine amara			4	4		4	8	6			
Carex acutiformis			2	4		+		5	8		
Carex paniculata							+				
Carex remota											
Carex vesicaria											
Circaea lutetiana											
Cirsium sp.											
Dactylis glomerata											
Epilobium angustifolium											
Epilobium hirsutum						4					
Epilobium palustre											
Equisetum palustre									4		
Ferns								+			
Festuca gigantea											
Filipendula ulmaria											
Galium aparine	5	4	5	4	4					4	4
Galium cruciata											
Galium palustre											
Geranium robertianum											
Gramineae carpet											
Heracleum sphondylium											4
Hieracium perpropinquum											
Holcus lanatus											
Impatiens glandulifera	6	8	7	7	5	7	6	4	4	4	
Iris pseudacorus							4				
Juncus effusus											
Lapsana communis										4	4
Lathyrus pratensis											
Lemna minor											
Lolium perenne											
Lycopus europaeus					4		4		4		
Mosses											
Myosotis palustris											
Myrrhis odorata											
Nuphar lutea											
Petasites vulgaris										8	6
Phalaris arundinacea			5	6	5	5	5	5			
Phragmites communis	6	5	5	5							
Poa trivialis	5			4	6	5				4	5
Ranunculus repens	4										
Rumex sanguineus					4						
Scirpus sylvaticus											
Silene dioica					4					4	
Solanum dulcamara		4	4		4			4	4		
Stachys sylvatica											
Stellaria nemorum											
Tripleurospermum maritimum											
Urtica dioica	5	4			4	4	4			6	6
Valeriana officinalis											
Veronica agrestis											
Vicia cracca											
No. species in quadrat	7	5	7	7	9	6	6	5	5	8	7

Quadrat No.	1	2	3	4	5	6	7	8	9	10	11	12
Transect Line	W					40m.						E
Tree + Shrub cover	-	2	3	7	9	10	10	10	10	10	10	6
Herb layer cover	10	10	10	10	6	8	8	8	6	9	10	10
Water present = X					X							
Herb layer species												
Aegopodium podagraria												
Alisma plantago-aquatica												
Allium ursinum											+	
Angelica sylvestris						+				2		
Arrhenatherum elatius		4										7
Cardamine amara												
Carex acutiformis						8	10	9	9	7		
Carex paniculata												
Carex remota						2						
Carex vesicaria												
Circaea lutetiana												
Cirsium sp.	4											
Dactylis glomerata												
Epilobium angustifolium												
Epilobium hirsutum												
Epilobium palustre										2		
Equisetum palustre					+							
Ferns						+						
Festuca gigantea												
Filipendula ulmaria						+		+	2	2		
Galium aparine	4	5	5	4							6	
Galium cruciata												
Galium palustre												
Geranium robertianum												
Gramineae carpet												
Heracleum sphondylium	5											
Hieracium perpropinquum												
Holcus lanatus												
Impatiens glandulifera	6	8	7	6	4	+			2		4	5
Iris pseudacorus												
Juncus effusus					5							
Lapsana communis												
Lathyrus pratensis												
Lemna minor					+	+	1	1	+	+		
Lolium perenne												
Lycopus europaeus					7	+		2				
Mosses									1	2	2	
Myosotis palustris										3		
Myrrhis odorata												
Nuphar lutea												
Petasites vulgaris											8	
Phalaris arundinacea	4	4	6	6	6	6						
Phragmites communis					+							
Poa trivialis	4											
Ranunculus repens												
Rumex sanguineus												
Scirpus sylvaticus												
Silene dioica												
Solanum dulcamara				4								
Stachys sylvatica							2			2		6
Stellaria nemorum												
Tripleurospermum maritimum	5											
Urtica dioica	4		+									5
Valeriana officinalis										2		
Veronica agrestis												
Vicia cracca	5	4										
No. species in quadrat	9	5	3	4	4	3	3	3	4	8	4	4

Quadrat No.	1	2	3	4	5	6	7	8	9	10
Transect Line	W					60m.				E
Tree + Shrub cover	7	7	7	9	9	10	9	7	10	7
Herb layer cover	10	10	10	10	8	8	8	1	7	10
Water present = X								X		
Herb layer species										
Aegopodium podagraria	8	6	5							
Alisma plantago-aquatica								5	+	
Allium ursinum									6	
Angelica sylvestris					4					
Arrhenatherum elatius	7	5		4						7
Cardamine amara					4	1				
Carex acutiformis							9			
Carex paniculata					2					
Carex remota					3		1			
Carex vesicaria										
Circaea lutetiana										
Cirsium sp.	4	5	4							
Dactylis glomerata										
Epilobium angustifolium						4				
Epilobium hirsutum										
Epilobium palustre							4			
Equisetum palustre										
Ferns									+	+
Festuca gigantea										
Filipendula ulmaria					4	5				
Galium aparine	1	4	4	4						
Galium cruciata		4								
Galium palustre										
Geranium robertianum					5				5	
Gramineae carpet										
Heracleum sphondylium	5	5								5
Hieracium perpropinquum										
Holcus lanatus										
Impatiens glandulifera		4	5	8	5	7	1			
Iris pseudacorus										
Juncus effusus					5					
Lapsana communis										
Lathyrus pratensis	3	3	3							
Lemna minor							+	4		
Lolium perenne										
Lycopus europaeus					5	1		+		
Mosses									7	2
Myosotis palustris										
Myrrhis odorata									5	
Nuphar lutea										
Petasites vulgaris										
Phalaris arundinacea		5		4	6				2	
Phragmites communis		4								
Poa trivialis	4			4		4			5	4
Ranunculus repens			4							
Rumex sanguineus										
Scirpus sylvaticus										
Silene dioica			4							
Solanum dulcamara					5	4				
Stachys sylvatica										6
Stellaria nemorum		4								
Tripleurospermum maritimum	4									
Urtica dioica	5	4	6	4	4					5
Valeriana officinalis										
Veronica agrestis										
Vicia cracca	4	4								
No. species in quadrat	10	13	8	6	11	8	4	2	6	6

Quadrat No.	1	2	3	4	5	6	7	8	9
Transect Line	W				80m.				E
Tree + Shrub cover	9	10	10	10	8	-	5	5	4
Herb layer cover	10	10	10	10	8	-	9	10	10
Water present = X						X			
Herb layer species									
Aegopodium podagraria									
Alisma plantago-aquatica									
Allium ursinum							7	6	
Angelica sylvestris			4						
Arrhenatherum elatius	3								4
Cardamine amara		3		3					
Carex acutiformis				2	+				
Carex paniculata			+	+					
Carex remota				4					
Carex vesicaria				2					
Circaea lutetiana		+	+	+					
Cirsium sp.									
Dactylis glomerata	4								
Epilobium angustifolium									
Epilobium hirsutum									
Epilobium palustre									
Equisetum palustre									
Ferns					+			4	
Festuca gigantea									
Filipendula ulmaria									
Galium aparine			3	5			5	4	4
Galium cruciata									
Galium palustre				4					
Geranium robertianum									
Gramineae carpet									
Heracleum sphondylium	4								4
Hieracium perpropinquum					1				
Holcus lanatus									
Impatiens glandulifera	4	6	6	4			7	6	4
Iris pseudacorus				+					
Juncus effusus			5						
Lapsana communis									
Lathyrus pratensis									
Lemna minor						1			
Lolium perenne									
Lycopus europaeus				5	4				
Mosses				5	5		4	4	
Myosotis palustris									
Myrrhis odorata									
Nuphar lutea									
Petasites vulgaris									
Phalaris arundinacea		6	4		3				
Phragmites communis	3					6	3		
Poa trivialis	2	4	5	4				4	4
Ranunculus repens									
Rumex sanguineus									
Scirpus sylvaticus				6					
Silene dioica			4				5		
Solanum dulcamara			4	5	4				
Stachys sylvatica							4		5
Stellaria nemorum	7	4	7						
Tripleurospermum maritimum	2								
Urtica dioica		6	6				5	6	8
Valeriana officinalis									
Veronica agrestis									
Vicia cracca									
No. species in quadrat	8	6	11	12	5	2	8	7	7

Quadrat No.	1	2	3	4	5	6	7	8	9	10
Transect Line	W					100m.				E
Tree + Shrub cover	4	8	9	9	7	3	+	5	9	9
Herb layer cover	10	10	9	7	-	8	-	9	10	10
Water present = X					X	X	X			
Herb layer species										
Aegopodium podagraria	5									
Alisma plantago-aquatica										
Allium ursinum								5	6	
Angelica sylvestris			2					3		
Arrhenatherum elatius										5
Cardamine amara			4	3						
Carex acutiformis		5	7	+						
Carex paniculata										
Carex remota		6	5	5						
Carex vesicaria										
Circaea lutetiana										
Cirsium sp.										
Dactylis glomerata										
Epilobium angustifolium				3	+					
Epilobium hirsutum										
Epilobium palustre		3			+					
Equisetum palustre		3								
Ferns				3				3	3	
Festuca gigantea										
Filipendula ulmaria			3							
Galium aparine	3	3						4	5	4
Galium cruciata										
Galium palustre			3							
Geranium robertianum			5							
Gramineae carpet				4				5		
Heracleum sphondylium	6	3								5
Hieracium perpropinquum										
Holcus lanatus										
Impatiens glandulifera	4	5						7	3	1
Iris pseudacorus										
Juncus effusus		5		4						
Lapsana communis			3							
Lathyrus pratensis										
Lemna minor				3	2	2	2			
Lolium perenne										
Lycopus europaeus			3	5	+					
Mosses				5	+				5	
Myosotis palustris										
Myrrhis odorata										
Nuphar lutea										
Petasites vulgaris	6									
Phalaris arundinacea	3	3	3	3						
Phragmites communis	4	4				9				
Poa trivialis	3	3	2							5
Ranunculus repens	4									
Rumex sanguineus										
Scirpus sylvaticus										
Silene dioica										3
Solanum dulcamara			3	5						
Stachys sylvatica										5
Stellaria nemorum										
Tripleurospermum maritimum										
Urtica dioica	4	4	3					7	7	5
Valeriana officinalis										
Veronica agrestis										
Vicia cracca										
No. species in quadrat	10	12	13	11	1	2	2	7	6	8

Quadrat No.	1	2	3	4	5	6	7	8
Transect Line	W			120m.				E
Tree + Shrub cover	8	10	8	+	+	7	9	9
Herb layer cover	10	10	2	8	7	9	10	10
Water present = X			X	X	X			
Herb layer species								
Aegopodium podagraria								
Alisma plantago-aquatica								
Allium ursinum								
Angelica sylvestris	5	5						
Arrhenatherum elatius	7					2	4	8
Cardamine amara								
Carex acutiformis								
Carex paniculata								
Carex remota								
Carex vesicaria								
Circaea lutetiana								
Cirsium sp.								
Dactylis glomerata								
Epilobium angustifolium								
Epilobium hirsutum								
Epilobium palustre			2					
Equisetum palustre	5						2	
Ferns							4	
Festuca gigantea								
Filipendula ulmaria								
Galium aparine		5				7	4	3
Galium cruciata								
Galium palustre		1					4	
Geranium robertianum								
Gramineae carpet								
Heracleum sphondylium	6	5						6
Hieracium perpropinquum								
Holcus lanatus								3
Impatiens glandulifera						6		
Iris pseudacorus								
Juncus effusus								
Lapsana communis								
Lathyrus pratensis								
Lemna minor			2	2	1			
Lolium perenne								4
Lycopus europaeus			1					
Mosses			+					
Myosotis palustris								
Myrrhis odorata								
Nuphar lutea					7			
Petasites vulgaris								
Phalaris arundinacea		8						
Phragmites communis				9		5	5	
Poa trivialis								
Ranunculus repens	5							
Rumex sanguineus								
Scirpus sylvaticus								
Silene dioica		4						
Solanum dulcamara								
Stachys sylvatica							6	4
Stellaria nemorum								
Tripleurospermum maritimum								
Urtica dioica	5	5				5	6	5
Valeriana officinalis								
Veronica agrestis								2
Vicia cracca								
No. species in quadrat	6	7	3	2	2	5	8	8

Quadrat No.	1	2	3	4	5	6	7	8	No.q = 68	
Transect Line	W			140m.				E	F	ΣD
Tree + Shrub cover	6	8	9	3	+	10	10	7	62	494
Herb layer cover	10	10	4	8	-	8	9	10	64	565
Water present = X			X	X	X					
Herb layer species										
Aegopodium podagraria									4	24
Alisma plantago-aquatica									1	5
Allium ursinum						3	4		8	41
Angelica sylvestris	6	6				3			10	40
Arrhenatherum elatius	7							7	16	88
Cardamine amara									11	44
Carex acutiformis									13	88
Carex paniculata									1	2
Carex remota									7	26
Carex vesicaria									1	2
Circaea lutetiana									-	-
Cirsium sp.									4	17
Dactylis glomerata							4		2	8
Epilobium angustifolium		5							3	12
Epilobium hirsutum									1	4
Epilobium palustre									4	11
Equisetum palustre	3		1						6	18
Ferns						3			6	20
Festuca gigantea							5		1	5
Filipendula ulmaria									5	16
Galium aparine	5	5				5			33	142
Galium cruciata									1	4
Galium palustre									4	12
Geranium robertianum									3	15
Gramineae carpet									2	9
Heracleum sphondylium	5						4	5	16	78
Hieracium perpropinquum									1	1
Holcus lanatus									1	3
Impatiens glandulifera						7	6	3	39	209
Iris pseudacorus									1	4
Juncus effusus									5	24
Lapsana communis									3	11
Lathyrus pratensis									3	9
Lemna minor			2	2	1				14	26
Lolium perenne									1	4
Lycopus europaeus									12	45
Mosses						2			12	44
Myosotis palustris	3								2	6
Myrrhis odorata									1	5
Nuphar lutea					8				2	15
Petasites vulgaris	5	8							6	41
Phalaris arundinacea									24	113
Phragmites communis	5	5	3	9					20	95
Poa trivialis								3	23	93
Ranunculus repens									4	17
Rumex sanguineus									1	4
Scirpus sylvaticus									1	6
Silene dioica									7	28
Solanum dulcamara									13	54
Stachys sylvatica						5			10	45
Stellaria nemorum									4	22
Tripleurospermum maritimum									3	11
Urtica dioica	4	4				5	6	5	36	181
Valeriana officinalis						3			2	5
Veronica agrestis									1	2
Vicia cracca									4	17
No. species in quadrat	9	6	3	2	2	9	6	5		

No. species listed = 56

APPENDIX 8 : POSITION OF QUADRATS IN SOUTH SALIX MARSH

Transect lines were laid out (using string) between markers placed on the 'west' and 'east' field edges of the S. Salix Marsh at distances of 20m., 40m., 60m., 80m., 100m., 120m. and 140m. from the river embankment. They therefore were all aligned parallel to it, n.w. – s.e.

Quadrats were placed at 5m. intervals beginning at the west side of each transect line. Two square metres of vegetation in the Herb layer were recorded, one either side of the position on the line.

Where standing water intervened, or the bankside was too narrow for the regular spacing quadrat positioning was adjusted and the position recorded. The total distance across the marsh did not often allow the last quadrat taken to be at exactly 5m. from the one previously taken. Thus exact positions are given below, with additional notes.

No. 1 TRANSECT. 20m. W→20m. E. 11 Quadrats, 21 species recorded (Herb Layer). 11.6.82.

Quadrat No.	Position	Quadrat No.	Position
1	0 - 1m.	6	20 - 21m.
2	2 - 3m.	7	25 - 26m.
3	5 - 6 m.	8	30 - 31m.
4	10 - 11 m.	9	35 - 36m.
5	15 - 16m.	10	40 - 41m.
		11	45 - 46m.

1 - 3: S. cinerea, S. viminalis cover. 4 - 7: S. alba cover. 8 -11: S. fragilis cover. 6 = adjacent to outflow stream.

No. 2 TRANSECT. 40m. W→40m. E. 12 Quadrats, 27 species 11.8.82.

Quadrat No.	Position	Quadrat No.	Position
1	0 - 1m.	7	30 - 31m.
2	5 - 6m.	8	35 - 36m.
3	10 - 11m.	9	40 - 41m.
4	15 - 16m.	10	45 - 46m.
5	20 - 21m.	11	50 - 51m.
6	25 - 26m.	12	53 - 54m.

1: Open, field edge west side. 2: Open from tree cover. 3: S. alba cover. 5: Winter H.W.M. ; Next to bare mud patch. 6: Phalaris on drier ground, Lycopus on logs. 7: S. fragilis cover. 8: S. fragilis + A. glutinosa cover. 9, 10: Open water to immediate east . 11: Above winter H.W.M. 12: Field edge, east side.

I Where there were large stands of Phragmites (in the centre of the old channel), or where the pond or telmatic bare mud zone occurred, the position of boundaries was recorded (transect lines 3, 4, 5, 6, and 7). An area of $2m^2$ was sampled within this.

No. 3 TRANSECT. 60m. W→60m. E. 10 Quadrats, 36 species. 14.6.82.

Quadrat No.	Position	Quadrat No.	Position
1	0 - 1m.	6	25 - 26m.
2	5 - 6m.	7	29-30m.
3	10 - 11m.	8	31 - 48m. (water)
4	15 - 16m.	9	50 - 51m.
5	20 - 21m.	10	55 - 56m.

10: Field edge East side. Prunus padus cover, sawfly larvae abundant on it. Alnus glutinosa cover increases on this transect line. 4 : Salix fragilis cover.

No. 4 TRANSECT. 80m. W→80m. E. 9 Quadrats, 30 species. 14.6.82.

Quadrat No.	Position	Quadrat No.	Position
1	0 - 1m.	6	20 - 46m. (water)
2	5 - 6m.	7	44 - 45m.
3	10 - 11m.	8	49 - 50m.
4	15 - 16m.	9	53 - 54m.
5	19 - 20m.		

1-3: Stellaria nemorum abundant. A. glutinosa cover.
7-9: Sambucus nigra, A. glutinosa cover. 36-46 collapsed S. fragilis. 4: Iris pseudacorus clumps, Scirpus sylvaticus, Hieracium sp. 10m. to the north.

No. 5 TRANSECT. 100m. W→100m. E. 10 Quadrats, 32 Species. 15.6.82.

Quadrat No.	Position	Quadrat No.	Position
1	0 - 1m.	6	24 - 30m. (Phragmites
2	5 - 6m.	7	30 - 42m. (water)
3	10 - 11m.	8	42 - 43m.
4	14 - 15m.	9	47 - 48m.
5	15 - 24m. water	10	50 - 51m.

8-10: Beneath tall S. fragilis, 109 yrs. old. Nuphar lutea abundant to the north of Q. no. 7. (Water of Pond C.)
1-9 = Populus and S. fragilis cover.

No. 6 TRANSECT. 120m. W→120m. E. 8 Quadrats, 22 Species. 29.6.82.

Quadrat No.	Position	Quadrat No.	Position
1	0 - 1m.	5	30 - 42m. (POND C)
2	4 - 5m.	6	42 - 43m.
3	5 - 15m. (Water)	7	45 - 46m.
4	15 - 30m. (Phragmites)	8	49 - 50m.

27-42 Nuphar lutea abundant.
Q 1,2 - Populus, S. fragilis cover. Q 3 = S. alba cover. Lycopus europeaus, Epilobium palustre, gramineae sp., and bryophytes on logs in the stagnant water. Water level fall >50 cm. May - September, Q 3 dried out, Equisetum palustre and Lemna minor scattered across it.
6, 7: Acer pseudoplatanus, S. fragilis cover to the immediate south. Phragmites abundant to W. of 6, then Nuphar lutea cover 70 - 80% on Pond C before main stand of Phragmites on west bank.

No. 7 TRANSECT 140m. W→140m. E. 8 Quadrats, 21 Species. 8.6.82.

Quadrat No.	Position	Quadrat No.	Position
1	0 - 1m.	5	27 - 42m. (Pond C)
2	4 - 5m.	6	43 - 44m.
3	5 - 10m. (Water).	7	45 - 46m.
4	10 - 27m. (Phragmites)	8	49 - 50m.

Q 1,2,3. Populus, S. fragilis cover. Q 5: Pond C, dense cover of Nuphar lutea. Q 6,7,8. Alnus glutinosa, Sambucus nigra cover.

APPENDIX 9

DESCRIPTION OF STRATIGRAPHY OF BOREHOLES FROM BENEATH DIFFERENT PLANT COMMUNITIES

CORE 1: LOCATION "Typha Marsh". DATE: 19/7/82. Livingstone Corer Water depth 30 cm. *Carex acutiformis* *Typha latifolia* at surface. *Sparganium erectum*, *Juncus effusus*, *Scirpus lacustris* nearby.

Depth below sediment surface (cms.)

0 - 14	Black Organic mud with well preserved roots. Th^{2}2, Dh2 nig4 strf0 elas 1 sicc 2 fibrous, crumbly, *Scirpus lacustris* stem sheaths. *Juncus* stems *Rumex* seed. HUE 10YR 2/1.
14 - 55	Grey silt with yellow bands towards the base. Fine black roots and detritus. Sand band at base of deposit. Particles of mica visible. *Equisetum* remains. Silt 3 Th^2 1 Dh+ nig 3, strf 2, elas 0, sicc 2, het. fib. well laminated. Lim Sup 1. Dark olive grey 5Y 3/2, Lighter grey (5Y 4/1) towards the base. Lighter bands = Olive 5Y 5/4.

CORE 2: LOCATION - Pond A, opposite 420m. W. bankside marker. DATE: 21/7/82. Livingstone corer. Beneath *Nuphar* patch. Water depth 50 cm.

Depth below sediment surface (cms.)

0 - 35	Semi-liquid black mud, inadequately sampled. Sicc 1.
35 - 49	Very dark grey silt with organic mud. Lh2 Dgl Silt 1 Th^1+ clay+ nig 3, strf 0, elas 0, sicc 1, incoherent Lim Sup 0. Hue 5Y 3/1.
49 - 62	Fine black mud. Lh2 Dg2 Silt+ Th^1+ nig 4, strf 0, elas 0, sicc 1 homog. incoherent Lim Sup 0. *Equisetum* remains.
62 - 90	Dark grey silt with detritus bands. Silt 4 Dg+ nig 3, strf 3, elas 0, sicc 2, well laminated, plastic, Lim Sup 1. Hue 5Y 4/1 Dark grey. Fine light bands - Hue 2 - 5Y 5/4 Light Olive brown. Dark bands 5Y 3/1 Very dark grey.

CORE 3: LOCATION - Pond A S. end. DATE 21/7/82. Livingstone corer. Water depth: 1 m., no vegetation. *Phragmites* at waters edge.

Depth below sediment surface (cms.)

0 - 48	Black fine detritus mud inadequately sampled. Lh2 Dg2 Silt+ nig 4, strf 0, elas 0, sicc 1, het. incoherent.
48 - 55	Dark grey silt with detritus. Silt 3 Dg1 clay+ nig 3, strf 0, elas 0, sicc 2, felted, plastic, incoherent Lim Sup. 0.
55 - 66	Black fine detritus mud with fine silt bands. Lh2 Dg2 Silt+ nig 4, strf 2, elas 0, sicc 1 het. plastic, incoherent. Lim Sup 0. Iron oxides in silt bands.
66 - 95	Dark grey silt with light bands and darker bands, and some fine roots. Silt 4 Dg+ Clay+ Th^3+ nig 3, strf 2, elas 0, sicc 2, well laminated, plastic Lim Sup 1. Hue 5Y 3/1.

CORE 4: LOCATION - Pond A, S.E. end opposite 340m. W. bankside marker. DATE 21/7/82. Russian type corer. Water depth 20 cm. *Phragmites* bed.

Depth below sediment surface (cms.)

0 - 55	Semi liquid black-brown fine detritus mud with roots and rhizomes of *Phragmites*. Inadequately sampled.
55 - 63	Black fibrous root mat, fine roots. $Th^1$4 Silt+ nig 4, strf 0, elas 0, sicc 1, homogenous, fib. Lim Sup 0.
63 - 73	Fibrous black roots set in silt with node of *Phragmites*. Silt 2 $Th^1$2 nig 3, strf 1, elas 0, sicc 2, het., fib. Lim Sup 0.
73 - 100	Grey silt with fine black rootlets of *Equisetum*. Silt 2, $Th^2$2 Sand+ Dg+, nig 3, strf 1, elas 0, sicc 1, het. fib. Lim Sup 0. *Carex* leaf.
100 - 104	Peaty organic layer, fibrous black rootlets. $Th^2$2 Dg2 Silt+ nig 4, strf 1, elas 0, sicc 2, het. fib. Lim Sup 1.

104 - 107	Grey silt with fibrous root remains Silt 2 $Th^2$2 Clay+ nig 3, strf 1, elas 0, sicc 2, het. fib., Lim Sup 1.
107 - 115	Peaty black mud, Phragmites node Dg2 $Th^2$2 Lh+ Dh + nig 4, strf 1, elas 0, sicc 1, slightly fibrous, Lim Sup 1.
115 - 130	Grey silt with black plant remains and slight presence of roots. Silt 3 $Th^2$1 Dg+ clay+ nig 2, strf 2, elas 0, sicc 2, het. fib. Lim Sup. 1.
130 - 133	Black plant detritus, slight presence of roots, with grey silt. Flattened tubular sheath 2 cms. wide of Scirpus lacustris. Dg2 $Th^2$1 Silt 1, nig 3, strf 2, elas 0, sicc 2, het. fib. Lim Sup. 1.
133 - 150	Grey silt with slight presence of black roots. Silt 4 clay+ Th^1+ nig 2, strf 2, elas 0, sicc 2, het. well laminated Lim Sup.1.
150 - 200	Well laminated grey silt with plant detritus and fine black roots. Dark organic bands and light yellow-grey silt bands. Black flattened tubular sheaths, finely striated, approx. 15 - 20 mm. wide, hand picked from between 150 and 200 cm. c.f. Scirpus lacustris remains. Silt 4 Dg+ Dh+ Th^2+ Lf+ Clay+ nig 3, strf 4, elas 0, sicc 2, het. fib. well laminated. Lim Sup. 2. Lighter bands (3 mm. wide) at 172.5 - 172.8, 173.4 - 173.7 (Hue 5Y 5/3 Olive - Hue 5Y 6/4 Pale Olive). Thicker dark bands 5 mm. wide also present (very dark grey Hue 5Y 3/1). Very fine black detritus sparsely distributed throughout this core c.f. Equisetum. Denser at 161 - 163 and at 150 cm.

<u>CORE 5</u>: LOCATION - Pond A, 480 m. E. bankside marker, 10 m. beyond h.w.m. DATE 14/7/82. Water depth 30 cm. *Salix cinerea* bushes, *Iris*, *Carex acutiformis* near to old, pollarded *S. fragilis*. (Russian corer).

Depth below sediment surface (cm.)

0 - 20	Brown mud, coarse detritus and roots. Well preserved *S. cinerea* leaf, and *Carex* leaves. Woody fragments. Dl 1 Dgl $Th^{o}2$ nig 4, strf 0, sicc 1, het. incoherent.
20 - 50	Dark grey silt with 25% roots. Very long roots and rhizomes (20 cm. tubers + long fibrous roots). More fibrous than upper layer. Well preserved *Carex* leaf at 40 cm. dark brown in colour. Black flattened tubular sheaths finely striated c.f. *Scirpus lacustris*. Silt 3, $Th^{1}1$, Dh+ nig 3, strf 2, elas 0, sicc 2, het., plastic, fib. Lim Sup 0.
50 - 94	Fibrous black roots in grey silt. *Equisetum* remains. *Carex* leaf. Silt 4 Clay+ Th^{2}+ Dg+ nig 2, strf 2, elas 0, sicc 2, het., well laminated, plastic. Lim Sup. 2. Impenetrable below 94 cm.

<u>CORE 6</u>: LOCATION - Pond A/B transition. 340m. E. bankside marker. 10m. beyond h.w.m. DATE 14/7/82. Water Depth 10 cm. *Phragmites* bed beyond *S. cinerea x.viminalis* bushes. (Russian corer).

Depth below sediment surface (cm.)

0 - 75 cm.	Reed peat with living roots, saturated, inadequately sampled towards surface. $Th^{o}2$ Dhl Dgl Silt+ nig 4, strf 2, elas 1, sicc 1. het. fib.
75 - 140	Dark grey silt with c.25% well preserved roots. One sand band. Black tubular flattened sheaths c.f. *Scirpus lacustris*. Silt 3 $Th^{o}1$ Dh+ Dg+ clay+ strf 2, elas 0, sicc 2, het. well laminated, plastic Lim Sup. 1. Sand layer 135 - 136. Unpenetrable layer below 140 cm. Basal sand?

<u>CORE 7</u>: LOCATION - South Salix Marsh. 80m. W. bankside marker, 30m. from field edge. DATE 27/7/82. Bare mud surface. <u>Carex acutiformis</u>, <u>C. vesicaria</u>, nearby <u>C. remota</u> on fallen branches. (Livingstone corer).

Depth below sediment surface (cms.)

0 - 7	Black organic peaty mud with wood fragments and twigs. Brown stems and roots of <u>Phragmites</u>. Th^{3}2 Dl1 Dh1 nig 4, strf 0, elas 1, sicc 2, het. crumbly.
7 - 15	Dark grey silt with organic detritus and roots. Silt 2 Dg1 Th^{1}1 Sand+ clay+ nig 3, strf 2 elas 0, sicc 2, crumbly, fibrous Lim Sup. 1.
15 - 18	Dark grey-brown organic layer with light brown stems and leaves, well preserved, of <u>Phragmites</u>. Th^{o}4 Dg+ Dh+ Silt+ nig 3, strf 0, elas 1, sicc 2, het., fib. Lim Sup. 1.
18 - 33	Dark grey silt layer with darker bands, lighter yellow-grey silt bands and sand bands, roots penetrate it from above layer. Silt 3 sand 1 Th^{o}+ Dg+ nig 3 strf 3, elas 0, sicc 2, het. plastic/granular. Well laminated, cyclothematic. Lim Sup. 1 .
33 - 50	Medium grain size quartz sand layer. No plant remains visible. Dark grey, drying to a yellow-reddish brown. Sand 4, Silt+, nig 2, strf 0, elas 0, sicc 2, crumbly, granular, Lim Sup. 0.
50 -66	Abundant stem nodes, leaves, roots of <u>Phragmites</u> in dark brown peat with grey silt. Two dark peaty bands 51-53, 56-58. Th^{1}2 Dh1 Silt 1 Dg+ nig 4, strf 2, elas 1, sicc 2, fibrous, Lim Sup. 1.
66 - 85	Dark grey silt, well laminated with light bands and darker bands. Many organic remains, <u>Phragmites leaf</u>, abundant black nodal septa and stems and rootlets of <u>Equisetum fluviatile</u>. Silt 3 Th^{1}1 Lfc+ Dg+ Dh+ nig 3, strf 4, sicc 2, elas 0, felted, plastic, cyclothematic, Lim Sup 1.

CORE 8: LOCATION - South Salix Marsh 60m. W. bankside marker, 20m. from field edge. DATE 28/7/82. VEGETATION - bare mud surface with *Lemna minor*, *Lycopus europaeus* and *Carex remota* on fringes. (Russian sampler).

Depth below sediment surface (cms.)

0 - 20	Dark brown mud with wood fragments and twigs. Some fragments of *Phragmites*, and some fine roots. $Th^3$2 Dh1 Dg1 D1+ silt+ nig 4, strf 1, elas 0, sicc 2, het. crumbly. Hue 10YR 4/2 Dark greyish brown.
20 - 41	Dark grey silt with sand and organic detritus with roots. Silt 3 Sand 1 Th^1+ Dg+, nig 3, strf 2, elas 0, sicc 2, plastic, het., granular Lim Sup. 0. Very dark grey 5YR 3/1, Quartz and mica grains visible.
41 - 45	Peaty silt, dark grey, twig fragments. Silt 2 $Th^1$1, Dh1, Sand+ nig 3, strf 2, elas 0, sicc 2, plastic, slightly fibrous, Lim Sup. 1.
45 - 51	Transition to sand, lighter grey silt and sand. Lumps of coal, 5 mm. across, very hard. Silt 2 sand 2 Dg+, nig 3, strf 1, elas 0, sicc 2, het. plastic, granular, Lim Sup. 1.
51 - 72	Sand layer, with twig fragments. Dark grey when wet, drying to a lighter yellow colour. Sand 4 D1+ strf 0, elas 0, sicc 2, homog., granular, Lim Sup. 0.
72 - 76	Transition to dark grey peaty silt. Well stratified. Large fragments, 5 cm. long, of *Phragmites* stems and nodes. Roots barely discernable - well humified. *Phragmites* peat. Silt 1 $Th^3$1 Dh1 Sand 1 Dg+ nig 3, strf 3, elas 0, sicc 2, crumbly, het., plastic, granular, Lim Sup. 0.
76 - 91	Peaty silt, dark grey mud. $Th^3$2 Silt 2 Clay+ Dg+ Dh+ Sand+ nig 3, strf 2, elas 0, sicc 2, het., plastic, Lim Sup. 0.
91 - 101	Dark grey silt with plant remains, abundant *Equisetum* nodal septa, *Carex* leaf. Silt 3, Dg1 Dh+ Th^1+ Sand+ nig 3, strf 2, elas 0, sicc 2, felted, plastic. Lim Sup. 0.

101 - 141	Grey silt, well laminated, with plant remains and strong black fibrous roots, Carex leaf and Equisetum nodal septa. Silt 3 $Th^2$1 Dg+ Dh+ nig 2, strf 3, elas 0, sicc 2, plastic, Lim Sup. 0.
141 - 191	Well laminated grey silt, with light yellow bands and sand bands. Some plant remains:- some fine black roots and Equisetum nodal septa 146-159, detritus at 164; black rootlets at 176; plant remains and roots at 181, black tubular sheath, finely striated cf. Scirpus lacustris. Silt 4 Th^2+ Dg+ Sand+ Lfc+ nig 3, strf 4, elas 0, sicc 2, cyclothematic, het., Lim Sup. 2. Light layers (nig 1 - 2) present throughout the sample. Sand bands at 141 - 149, 173 - 175.
191 - 216	Grey silt with bands of sand and lighter bands. Cyclothematic. Twig fragment at 194, leaf at 181 c.f. Phragmites. No rooted material and very few plant remains. Silt 4 sand+ clay+ Lfc+ Dl+ Dg+ Dh+ nig 3, strf 4, elas 0, sicc 2, het., plastic, Lim Sup. 2. Sand bands at: 198.5 - 199.5, 202.5 - 204.5, 206 - 207, 210 - 210.5, 219 - 220, 227 - 231, 235 - 239. (The position of Light bands can only be accurately recorded in the field when the sample is fresh).

APPENDIX 10

LEVELLING RESULTS: FIRST TRAVERSE 29.7.82.

Telescope Station	Staff Station	Back Sight	Inter-Mediate	Fore Sight	Rise	Fall	Reduced Level	Upper Stadia	Lower Stadia	Distance from Tripod	Distance from Basemark	Remarks
TS1	SSA	1.015			-	-	100	1.052	0.978	7.4	0	9m from field edge TS1-BM = 7.4m
	SSB		0.958		.057	-	100.057	0.973	0.943	3.0	10.4	Staff at edge of top of steep slope
	SSC			2.870	-	1.855	98.145	2.910	2.830	8.0	15.4	Staff at bottom of steep slope
TS2	SSC	0.610			-	-	98.145	0.628	0.592	3.6	15.4	TS2 at bank edge TS2-BM = 19.0m
	SSD		1.658		-	1.048	97.097	1.675	1.641	3.4	22.4	¼ way across water W. depth = 0.2m
	SSE		1.743		-	1.133	97.012	1.771	1.715	5.6	24.6	½ way across water W. depth = 0.31m
	SSF		1.829		-	1.219	96.926	1.877	1.781	9.6	28.6	¾ way across water W. depth = 0.39
	SSG			1.460	-	.85	97.295	1.523	1.397	12.6	31.6	Seasonal L.W.M. Phragmites extends 3m beyond this
TS3	SSG	1.446			-	-	97.295	1.509	1.383	12.6	31.6	TS3-BM = 44.2m
	SSH		1.402		.044	-	97.339	1.446	1.358	8.8	35.4	Intermediate looking back
	SSI		1.396		.05	-	97.345	1.420	1.372	4.8	39.4	Intermediate looking back
	SSJ		1.233		.213	-	97.508	1.249	1.217	3.2	47.4	
	SSK			1.169	.297	-	97.572	1.214	1.124	9.0	53.2	
TS4	SSK	1.200			-	-	97.572	1.218	1.182	3.6	53.2	TS4-BM = 56.8m
	SSL		1.166		.034	-	97.606	1.180	1.152	2.8	59.6	Staff at bottom of small steep slope
	SSM		0.415		.785	-	98.357	0.446	0.384	6.2	63.0	Staff at top of field bank 0.8m to barley
	SSN			0.477	.723	-	98.295	0.522	0.432	9.0	65.8	Staff in field

1.643 = Difference in height between SSM and SSA

TELES-COPE STATION	STAFF STATION	BACK SIGHT	INTER-MEDIATE	FORE SIGHT	RISE	FALL	REDUCED LEVEL	UPPER STADIA	LOWER STADIA	DISTANCE FROM TRIPOD	DISTANCE FROM B.M.	REMARKS
5	SSM	0.188					100	0.267	0.109	15.8	.0	
	SSG			1.287		1.099	98.901	1.365	1.209	15.6	31.4	
6	SSG	3.721					98.901	3.840	3.602	23.8	55.2	
	SSA			0.947	2.774		101.675	0.985	0.909	7.6	62.8	

1.675 Difference in height between SSM and SSA.

LEVELLING RESULTS CLOSING SHEET 30.7.82. ERROR = .032m.

APPENDIX 10 (Cont.) : RELATIVE LEVELS OF TOP AND BASE OF TRANSECT LINE CORES (METRES)

WATER LEVEL = same level as SSG (97.295 m.) 29.7.82.

	Water Depth	Top	Bottom	Length
CORE 1	-	97.4	95.62	1.78
2	.17	97.125	95.135	1.99
3	.27	97.025	94.935	2.09
4	.33	96.965	94.705	2.26
5	.15	97.145	94.965	2.18
6	-	97.33	94.79	2.54
7	-	97.36	95.17	2.19
8	-	97.46	95.71	1.75
9	-	97.53	96.56	.97

The transect line was laid out and levelled. After this the boreholes were located at regular intervals, adjacent to or in-between the pegs marking levelled staff sites. The relative levels of cores were calculated from the height of the point where the position of the borehole fell on a straight line drawn between the heights of the two levelled staff sites on the section. Thus the position of the boreholes was not first selected and later levelled in as would be preferable for accuracy.

The relative levels of the sediment surface of boreholes beneath the pond were calculated by subtracting the water depth at that point from the relative altitude of SSG (97.295). The soft substrate beneath the pond meant that the exact level of the sediment surface was subject to some small degree of error as the staff would sink in slightly: there is a gradual transition to semi-liquid sediment.

APPENDIX II. : DESCRIPTION OF TRANSECT LINE CORES

TRANSECT CORE 1 (SSC/D) 7/8/82

20 m NW of Basemark, 178 cm. of sediment

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
6	No Water 0 - 10	Fine black mud, tree leaves (Prunus padus, Salix spp.) well humified, Dg2 Lh2 nig 4, strf 0, elas 0, sicc 1, het. incoherent.	SAMPLE 4 0 - 28 cm. (not kept)
	10 - 26	Brown mud, well preserved roots and stems of Phragmites. Dgl Dhl Th^o2 nig4, strf 0, elas 0, sicc 1, fibrous. Lim sup 0.	
5	26 - 28	Silt with brown plant remains. Silt 2 Dgl Th^o1 nig3, strf 1, elas 0, sicc 2, het, plastic Lim Sup 1.	
	28 - 40	Brown peat, with woody fragments, and some silt. Phragmites turfa. Silt 2 Th^o2, Dg+ Dh+ nig4, strf 1, elas 0, sicc 2, spongey, fibrous Lim Sup 1.	SAMPLE 3 28 - 78 Fresh, well preserved Phragmites nodes and roots.
	40 - 47	Grey silt with some roots Silt 3 Th^o1 Clay+ Dg+ nig3, strf 1, elas 0, sicc 2, het, plastic, Lim Sup 1.	
4	47 - 52	Sand, very few plant remains. Sand 4 Dg+ nig 3, strf 0, elas 0, sicc 1, homog, granular, crumbly, Lim Sup 1.	
3	52 - 63	Phragmites remains, roots and twig fragments with some silt. Th^o2 Dgl Dhl Dl+ silt+ sand+ nig 3, strf 1, elas 0, sicc 2, het. fibrous, granular, Lim Sup 1.	Roots penetrate the sand layer
2	63 - 78	Grey silt with some roots and detritus. Silt 3 Th^o1 Dg+ nig 3, strf 1, elas 0, sicc 2, het, plastic, Lim Sup 1. Light band at 72.	

STRA-TUM	DEPTH	DESCRIPTION	WET SIEVING + MICROSCOPY
I	78 - 128	Grey silt laminated with light bands and some sand. Slight presence of plant remains. Silt 4 Lfc + Sand + Dg+ Th^2 + nig 2, strf 3, elas 0, sicc 2, plastic, cyclothematic, het., Lim Sup 2 Black layer of detritus at 94.5 - 95. Light bands at: 93.5 - 94.5, 102.5 - 103, 108.5 - 109, 112.5 - 113, 115.5 - 116.5, 118.5 - 119. Sand at 121-122, 126.5 - 128.	SAMPLE 2 78 - 128 Miscellaneous detritus. Equisetum nodes beetle elytra woody fragments. Slight presence of rooted material.
	128 - 178	Grey silt well laminated with light bands and some sand (cyclothematic) Black detritus bands present. Silt 2 Lfc 1 Sand 1 Dg+ Th^2 + nig 2, strf 4, elas 0, sicc 2, plastic, cyclothematic, het. Lim Sup 2 Black layers nig 4; 3 bands, partial, between 134 and 135 with twigs, and fine detritus plant remains. Light layers at 140, 144.5-145, 161.25 (partial), 165.5 - 168 (diffuse), 173 (very thin). Sand layers at 129 - 129.25, 130 - 130.25, 132 - 132.5, 135.5 - 136.5, 138 - 138.5, 157 - 159, 160 - 161, 128.5 - 129, 171 - 173, very thin at: 146.5, 147.	SAMPLE 1 128 - 178 134 - Black bands with twig and plant remains. 142 twig remains black. 147 twig remains and leaf of Phragmites 150 fine roots 151 wood fragments 154 wood twig, well preserved. 166 Salix leaf 168 Twig fragments

TRANSECT CORE 2 (SSD) 7/8/82

22.5 m NW of Basemark, 199 cm. sediment

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
	Water = + 17	sicc 0	
6	0 - 11	Fine black mud, saturated with water, well preserved plant remains, some twigs. Lh 2 Dg2 Dh+ nig 4, strf 0, elas 0, sicc 1, het., incoherent.	SAMPLE 4 0 - 49 0 - 30, plant remains = 75% Fine detritus mud and unhumified Phragmites roots and rhizomes, brown fine woody detritus. Daphnia egg cases.
	11 - 16	Fine dark brown mud, less saturated woody fragments and some roots. Lh 1 Dgl Dhl Th°1 nig 3, strf 0, elas 0, sicc 1, het. incoherent. Lim sup 0.	
5	16 - 27	Silt with some sand, Brown fragments of twig, and Phragmites stems and roots, still saturated. Silt 2 Sand + Th°1 Dgl Lh+ nig 3, strf 1, elas 0, sicc 1, het, plastic, Lim Sup 1.	
	27 - 30	Brown roots and twigs = 75% of layer, the rest = silt. Th°2, Dl 1 Dg+ Silt 1 nig 4, strf 0, elas 0, sicc 1, het, fibrous, Lim sup 1.	
	30 - 40	Grey silt with some clay. Some fine roots, less than 25%. Silt 4 Clay+ Th¹+ nig 2, strf 2, elas 0, sicc 2, het, plastic Lim sup 1.	
4	40 - 46	Yellow Quartz Sand with some detritus (<25%) Sand 4 Dg+ nig 2, strf 0, elas 0, sicc 1, homog. crumbly, granular, Lim Sup 1.	
3	46 - 57	Black organic mud, 75%, with some sand. Remains of twigs, and some roots, brown and unhumified. Dgl Dl 1 Th°1 Lh+ Sand 1, nig 4, strf 0, elas 0, sicc 1, incoherent, het. Lim sup 0.	SAMPLE 3 49 - 99

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
2	57 - 74	Plant remains throughout the whole sample. Mostly grey silt. Silt with 50% organic plant remains Silt 2 Dgl Th1 Lh+ Dh+ nig 3, strf 2, elas 0, sicc 2, plastic, slightly fibrous, Lim Sup 1.	SAMPLE 3 (cont.) 49 - 99 Detritus and some rooted material 49 - 74 well preserved Phragmites roots twigs, wood fragments and Equisetum nodal septa.
I	74 - 99	Silt with some light bands (cyclothems) of Lfc (Limus ferro-carbonati) but no sand bands. Slight presence of plant material. Silt 4 Th+ Lfc+nig 3, strf 3, elas 0, sicc 2, plastic, slightly fibrous, cyclothematic. Lim Sup 2. Light layers 74.5 - 75, 81, 82.5 - 83 (diffuse) 91, 95-96 (Partial) 97-97.5 98-98.5	74 - 99 Still a slight presence of fine black roots. Leaf fragments of Phragmites well preserved, light green
	99 - 149	Well laminated silt (cyclothematic). Silt 2 Lfc1 Sand 1 Dg+ strf 4, elas 0, sicc 2, plastic, cyclothematic. Lim Sup 3. Black plant remains at 108 - 115 (slight presence). 129 (very fine layer). Twig at 147. Light bands at: 119.5 - 120, 120.5 - 121, 124.5 - 125.5, 132.5 - 133. Very thin light bands at 113, 117, 129, 133.5, 148. Diffuse at 147 - 148. Sand bands at 115.5, 123, 123.75 - 124, 125.75 - 126, 134.5 - 136, 137 - 138, 139 - 139.5, 141 - 141.5, 143.5 - 144.	SAMPLE 2 99 - 149 Slight presence of plant detritus. Equisetum remains and some black roots twig fragments. Potamogeton natans fruit stones. Coal fragments. Atriplex seed

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
I (cont.)	<u>SAMPLE 1</u> 149 - 199	Silt well laminated with light bands and sand. Some plant detritus. Cyclothematic. Silt 2 Lfcl Sand 1 Dg+ nig 2, strf 4, elas 0, sicc 2, het. well laminated, cyclothem., Lim sup 3. Darker layers at 160.75, 197. <u>Light bands</u> (very thin) at: 153, 166, 167, 168, wider at 157.75 - 158.25, 159 - 159.5, 160.25 - 160.75, 162 - 162.5. Diffuse between 171 and 173, 183.5 - 184, 190.25 - 190.5. <u>Sand bands</u> 151 - 152, 163 - 163.25, very thin at 167, 168, 169, 173, 174.25, 177, 179, 180, 184 - 184.5, 186 - 186.5, 188.5 - 190. N.B. If depth number only appears once then layer = < .25 mm. wide.	<u>SAMPLE 1</u> 149 - 209 <u>Equisetum</u> nodal septa and wood fragments. <u>Phragmites</u> stemnode and leaf Coal particles > 425 µm abundant. Some miscellaneous detritus.

TRANSECT CORE 3 (SSE) 6/8/82

25m. N.W. Basemark, 209 cm. of sediment

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
	Water + 27	sicc 0	
6	0 - 9	Black fine detritus mud saturated with water. Lh 2 Dg2 Dh+ nig 4, strf 0, elas 0, sicc 1, het. incoherent.	
	9 - 14	Brown organic coarse detritus mud saturated with water, twigs, roots well preserved. Lh 1 Dg1 Dhl Th°1 nig 4, strf 0, elas 0, sicc 1, het.,incoherent. Lim Sup 0.	<u>SAMPLE 4</u> 9 - 59 <u>Phragmites</u> detritus and unhumified roots.
5	14 - 17	Grey silt with detritus. Silt 2 Lh 1 Dgl nig 3, strf 0, elas 0, sicc 1, het. plastic. Lim Sup 1.	
	17 - 29	Brown organic coarse detritus mud saturated with water, twigs, roots, well preserved. Lh 1 Dg1 Dhl Th°1 Dl + nig 4, strf 0, elas 0, sicc 1, het. incoherent. Lim Sup 1.	
	29 - 39	Grey Silt with detritus. Silt 3 Dgl Lh+ nig 3, strf 1, elas 0, sicc 2, het. plastic. Lim Sup 1.	
4	39 - 46	Sand, no plant remains. Sand 4 nig 2, strf 0, elas 0, sicc 1, homog. crumbly, granular. Lim Sup 1	No plant remains.
3	46 - 50	Black mud with silt and sand. Plant remains 50%. Dg2 Dh+Lh+ silt 1 sand 1 nig 4, strf 0, elas 0, sicc 1, het. incoherent. Lim Sup 1.	Fine detritus mud, seed cases, miscellaneous remains.
2	50 - 52	Grey silt with detritus, lighter than above layer. Silt 3 Dgl Lh+ nig 3, strf 1, elas 0, sicc 2, het. plastic, felted. Lim Sup 1.	

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
2 (Cont.)	52 - 54	Sand layer, quartz grains. Sand 4 silt + nig 2, strf 0 elas 0, sicc 2, crumbly, granular homogenous, Lim Sup 1.	
	54 - 59	Grey silt with some clay and black plant remains 50%. Silt 2 clay + Dgl Dhl nig 4, strf 1, elas 0, sicc 2. plastic, het. felted Lim Sup 1.	
	SAMPLE 3	Whole core has plant remains and is fairly uniform colour, but most abundant between 59 and 80. Predominantly grey silt.	SAMPLE 3 59 - 109
	59 - 80	Silt with detritus and black roots, very fine c.f. Equisetum. Silt 2 Dhl Th²1 nig 3, strf 3, elas 0, sicc 2, het. felted. well stratified, cyclothematic, Lim Sup 1. 71 - 73 Black detritus layer, 75% organic.	Coarse detritus 1 Phragmites node 1 Equisetum node Daphnia egg cases sedge leaf Potamogeton natans. Fruitstone.
I	80 - 109	Lighter grey silt, cyclothematic with light bands of silt (ferrous carbonates) and one fine sand band. Less abundant plant remains than stratum above. Stem node of Phragmites within light band at 99 - 100 cm. Silt 4 Lfc+Dh+ nig 2, strf 3, elas 0, sicc 2, het. well laminated, cyclothematic, plastic Lim Sup 2. Light bands (nig 1) at 81.5 - 82, 89.5 - 91, 99 - 100, 105 - 106. Sand at 89 - 89.5.	Miscellaneous detritus Sedge leaf Equisetum nodal septa.

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
I (cont.)	109 - 159	Grey silt layer, cyclothematic, well laminated with light bands and sand bands. Some organic remains between 109 and 116. Twig fragment in layer at 111.5. Silt 2 Lfcl Sand 1 nig 2, strf 4, elas 0, sicc 2, het., plastic, Lim Sup 3. Light bands at: 113, 119, 123 - 123.5, 124 - 124.5, 129.5 - 130, 141.75 - 142.25, 144.5, 145 - 145.25, 147, 149, 151, 152.5, 157.5 - 158. Most are very thin and diffuse. Sand at: 131.25 - 133.25 (5 very fine bands) 142.25 - 143, 147.25, 153 - 154.25, 154.5 - 155.25, 156.25 - 157.25, 158.5 - 159.	SAMPLE 2 109 - 159 Slight presence of plant detritus all the way down the core light layers form conglomerations > 425 µm. *Equisetum* remains and some fine black roots. Coal fragment. *Potamogeton natans* fruitstone. Twig fragments. *Salix* bud *Sambucus nigra* seed
	159 - 209	Well laminated cyclothematic grey silt layer. Light bands and sand bands. Continuation of stratum above. Sharp black fine bands at 164 - 164.5, 172.5 - 173, 189.5 (very thin). Silt 2 Lfcl Sand 1 nig 2, strf 4, elas 0, sicc 2, het., plastic Lim Sup 3. Light layers very thin and often diffuse. Light bands at 160 - 160.25, 163 - 164, 171.75 - 172.25 (very light), 174, 175, 178, 183, 183.5, 188 - 189, 190 - 190.5, 197 - 197.5, 202 - 202.5, 207 - 208.5. Sand bands (often very thin) at 161, 162, 164, 165.5 - 168.5, 170.75 - 171, 178.5, 179, 180, 183.5, 185, 5 very thin bands between 192 and 153.5, 203 - 203.5, 206 - 207. (If depth only appears as one number then lamination is <2.5 mm. Boulders or pebbles felt at base of core.	SAMPLE 1 159 - 209 Plant remains almost absent. Lots of coal fragments and quartz grains, > 425 µm. 1 *Equisetum* node Wood fragment.

TRANSECT CORE 4 (SSF/E) 6/8/82

27.5 m. W. of Basemark, 226 cm. sediment

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
	Water = + 33 cm.	sicc 0.	
6	0 - 16	Black fine-detritus mud saturated with water. Lh 2 Dg2 Dh+ nig 4, strf 0, elas 0, sicc 1, het. incoherent.	SAMPLE 5 0 - 26
	16 - 21	Fine organic mud. Black-dark brown. Twig fragments, Phragmites - Stem fragments. Slight presence of brown roots. Lh 2 Dh1 Dl1 Th°+ Dg+ nig 4, strf 0, elas 0, sicc 1, incoherent, Lim Sup 0.	
5	21 - 26	Silt with organic detritus (c.25%) Phragmites leaf. Silt 3 Dg1 Dh+ Th°+ nig 2, strf 1, sicc 2, het. plastic Lim Sup 0.	
	26 - 33	Very fine black mud with some silt, saturated. Th°1 Lh1 Dg1 Silt 1 nig 4, strf 0, elas 0, sicc 1, incoherent Lim Sup 1.	SAMPLE 4 26 - 76 Rooting Phragmites down to sand layer Fresh, well preserved roots, rhizomes, tubers etc.
	33 - 47	Dark grey silt with some fine black plant remains. Leaves of Phragmites. Very few roots. Some fine sand bands (cyclothems). Th°+ Silt 3, Dg1, Sand+ nig 3, strf 2, elas 0, sicc 2, het. plastic Lim Sup 0. Sand bands with quartz grains at 42 - 43, 45 - 46.5, very thin at 38.5, 39.5, 42.5, 45.	
4	47 - 56	Sand layer, dark grey drying to yellow. Medium size grains. Quartz. No plant remains. Sand 4 nig 2, strf 0, elas 0, sicc 2, homog. granular, crumbly. Lim Sup 1.	

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
3	56 - 63	Sand with detritus. Phragmites leaf and some fine roots. Sand 1 Lh1 $Th^2$1 Dg1 nig 2, strf 0, elas 0, sicc 2, het. crumbly felted. Lim Sup 1.	SAMPLE 4 (cont.)
	63 - 73	Black mud with silt and sand, abundant plant remains, saturated. Silt 1, Sand + Dg2 Lh1 nig 4, strf 0, elas 0, sicc 1, het. Lim Sup 1.	Below sand: fresh well preserved miscellaneous detritus + coal and quartz and silvery metalliferous material.
2	73 - 76	Silt with some clay and some black plant remains. Silt 3 clay+ Dg1 nig 3, strf 1, elas 0, sicc 2, slightly fibrous, plastic. Lim Sup 1.	
	76 - 93	Very dark grey silt with fine black rooted material. Phragmites leaf. Silt 2 $Th^2$1 Dg1 Dh+ nig 3, strf 1, elas 0, sicc 2. Slightly fibrous, plastic Lim Sup 1.	76 - 126 SAMPLE 3 Equisetum nodal septa. Daphnia egg cases.
I	93 - 126	Grey silt with lighter bands, yellow-light grey (cyclothems.) Very little sand, plant remains only slightly present. Silt 4 Lfc+Dg+ Sand+ nig 2, strf 3, elas 0, sicc 2, het, plastic, well laminated, cyclothematic, Lim Sup 2. Light bands, all very thin and diffuse at: 104.5 - 105.5, 106.5, 113.5, 114, 114.5, 117.5, 118, 119, 110, 111, 113.5. Sand at 110 - 113.	

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
I (cont.)	126 - 176	Grey silt, very well laminated (cyclothematic) with sand bands and light bands (ferrous carbonates). Quartz grains in the sand. Very few plant remains. Fairly uniform sample. Silt 2 Lfc1 Sand 1 nig 2, strf 4, elas 0, sicc 2, well laminated, cyclothematic, het. plastic Lim Sup 3. Lightest bands: 169 - 170, 172 -173 <u>Light bands</u> at: 126 - 129, 131, 132 135, 137, 143, 144, 151, 151.5, 153.5, 164, 165.5, 169.25 - 170, 172. (very thin, diffuse). <u>Sand bands</u> at: 139 - 140, 148.75 - 149.51, 150.25 - 150.5, 150.75 - 160. 160.5 - 162 (3 very thin layers), 156 - 156.25, 157 - 157.25, 158.75 - 159, 161 - 162, 172 - 173, 174 - 174.75, 175 - 175.75.	126 - 176 <u>SAMPLE 2</u> Less detritus 1 fruitstone of <u>Potamogeton natans</u> Lfc = platy conglomerations, > 2 mm. some coal particles
	176 - 226	Grey silt, very well laminated with sand bands and light Lf bands (ferrous carbonates). Quartz grains in sand. Fairly uniform sample. Sand band at 201 is pure sand. Silt 2 Sand 1 Lfc1 nig 2, strf 4, elas 0, sicc 2, het, well laminated, cyclothematic, plastic Lim Sup 3. <u>Light bands</u> at 177, 178, 188, 193 197 (very feint). 202 - 202.25, very white at: 209 - 209.25; 220.5 - 220.75. pale and diffuse 222, 223.75. <u>Sand</u> at: 177.5 - 178, 180.5 - 182, 183 - 183.5, 185 - 186, 186.25 - 187.25, very thin at 190, 193.25 - 194.25, 195 - 195.5, 200.5 - 201, 204 - 205, very thin at 210.5, 212.5, 214, 215.5, 216, 217, 220.25, 223 - 223.25, 223.75 - 224. Very thin at 224.5 and 225.	176 - 226 <u>SAMPLE 1</u> Mica in grey silt. More coal + metalliferous slag particles > 425 μm. Wood fragment.

TRANSECT CORE 5 (SSG/F) 5/8/82

30 m. N.W. of Basemark, 218 cm. sediment

STRA-TUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
	Water = + 15	sicc 0	
6	0 - 35	Black fine detritus mud, inadequately sampled due to saturation. Lh2 Dg2 Dh+ Th°+ nig 4, strf 0, elas 0, sicc 1, incoherent.	SAMPLE 4 18 - 68
	35 - 57	Brown-black mud, with silt. *Phragmites* stems. Silt 1 Dg1 Lh1 Th°1 Dh+ nig 4, strf 0, elas 0, sicc 1, incoherent, het. Lim Sup 0.	
5	57 - 59	Grey silt with some plant remains. Silt 2 Dg2 Dh+ Clay+ nig 4, strf 1, elas 0, sicc 2, het, plastic. Lim Sup 1.	
	59 - 63	Grey silt with less plant remains. Silt 3 Dg1 Clay+ nig 3, strf 1, elas 0, sicc 2, het, plastic Lim Sup 1.	
	63 - 65	Sandy silt. Sand 2 Silt 2 Dg+ nig 3, strf 1, elas 0, sicc 2, het, granular Lim Sup 1.	
	65 - 73	Grey Silt with some detritus. Silt 3 Dg1 nig 3, strf 0, elas 0, sicc 2, plastic Lim Sup 1.	SAMPLE 3 68 - 118
4	73 - 84	Sand layer, very few plant remains. Sand 4 Dg+ nig 2, strf 0, elas 0, sicc 2, granular, homogenous. Lim Sup 1.	
3	84 - 107	Black coarse-detritus mud with some silt, stratified in four minor layers. Dh1 Dg1 Lh1 Th°1 Silt+ nig 4 strf 2, elas 0, sicc 1, incoherent, het. Lim Sup 1. 84 - 93 Black coarse detritus mud, *Phragmites* remains, 93 - 99 Brown mud. 99 - 103 Silty mud. 103 - 107 Black fine detritus mud.	*Daphnia* egg cases *Phragmites* stem node. 50% *Phragmites* remains. Soft roots, not coarse and fibrous No coal particles.

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
2	107 -124.5	Dark grey silt with organic detritus. Silt 3, Dgl nig 3, strf 1, elas 0, sicc 2, het. plastic Lim Sup 1.	SAMPLE 2 118 - 168 no roots
I	124.5-168	Grey silt well laminated with sand and light bands, cyclothematic. Silt 2 Sand 1 Lfc 1 Dg+ nig 2, strf 3, elas 0, sicc 2, well laminated, het. Lim Sup 2. Light bands (Lfc) at 124.5 - 125, 129 - 129.25, 133 - 134.5, 145 - 146, 148 - 149, 151 - 151.15, 151.5 - 151.75, 153-154, 157 - 157.5, 162 - 162.5. Diffuse at: 165.5 - 165.75, 166.5 - 166.53. Sand bands at: 128 - 128.5, 138 - 139, 140 - 141, 142 - 143, 160 - 161 4 bands between 164.5 and 168.	Yellow silts form conglomerations > 2 mm. Coal particles no identifiable plant remains. Miscellaneous detritus, light brown to black in colour.
	168-218	Grey silt well laminated with sand and light bands, cyclothematic. Silt 2 Sand 1 Lfc 1 Dg+ nig 2, strf 4, elas 0, sicc 2, het. Lim Sup 3. Light bands (Lfc) at 169, 171, 172, 175, 177.5, 180, 182.5, 184, 187, 188, 188.5, 191, 192.5, 196, 202.5 - 202.75, 209.5 - 210, 212.25, 213.25, 218. Sand at 184.5 - 187.5 (3 very thin bands) 189 - 190 (3 very thin lines) 200 - 201, 203 - 208 (9 very thin lines) 214 - 215.	SAMPLE I 168 - 218 Small amount of black and brown miscellaneous detritus, wood fragments. Yellow conglomerates. Coal, quartz grains. (SAMPLE I = 168-218)

TRANSECT CORE 6 (SSH) 4/8/82

35 m. from Basemark, 254 cm. of sediment

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
6	(No water) 0 - 9	Black-brown fine detritus mud. Dg3 Lh1 nig 4, strf 0, elas 0, sicc 1, homog. incoherent.	SAMPLE 5 4 - 54
	9 - 31	Brown mud and silt, saturated with woody detritus, Phragmites fragments and roots. Silt+ Dl+ Dg1 Dh1 Th^{o}2 nig 4, strf 1, elas 0, sicc 1, het, fibrous Lim Sup 0.	Phragmites roots.
5	31 - 49	Phragmites turfa with sand and silt Th^{o}2 Sand 1 Silt 1, nig 3, strf 1, elas 0, sicc 2, het., fib. Lim Sup 1.	Sedge leaf miscellaneous detritus.
	49 - 64	Grey silt and some sand, with roots Silt 3 Th^{o}1 Sand+ nig 3, strf 0, elas 0, sicc 2, het. fib. Lim Sup 1.	Phragmites stem nodes.
4	64 - 79	Sand layer, very few visible plant remains. Sand 4 Dh+ nig 2, strf 0 elas 0, sicc 2, granular homogeneous, Lim Sup 1.	SAMPLE 4 54 - 104 Phragmites leaf at 73.
3	79 - 82	Black fine detritus mud. Lh2 Dg2 Th^{1}+ Dh+ nig 4, strf 0, elas 0, sicc 1, het, fib. incoherent Lim Sup 1. Woody fragments and fine black roots	
	82 - 83	Sand band. Sand 3 Silt 1 Dg+ nig 3, strf 1, elas 0, sicc 2, granular, Lim Sup 2.	
	83 - 91	Very black organic fine detritus mud. Lh2 Dg1 Dh1 Th^{2}+ nig 4, strf 0, elas 0, sicc 2, slightly fibrous, het. Lim Sup 1.	Phragmites stem node at 84

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
2	91 - 104	Grey silt with black fine roots 50% Silt 2 $Th^2$2 Clay+ nig 3, strf 1, elas 0, sicc 2, fib. het. plastic Lim Sup 1.	SAMPLE 4 (cont.)
I	104 - 154	Grey silt well laminated with lighter bands and some sand. No darker layers. Slight presence of fine black roots, and a little detritus. Cyclothematic. Fairly uniform grey colour. Silt 3 Lfcl Clay+ Sand+ Th^1+ nig 2, strf 3, elas 0, sicc 2, het. plastic, Lim Sup 3. Light bands (nig 1) at 114 - 114.5 126 - 126.5, 133 - 133.5, 142 - 142.5, 144 - 145, 150 - 150.25, 153.5 - 154. Sand at 143 - 143.5, 154 - 154.5.	SAMPLE 3 104 - 154 Phragmites stem node. 104 - 110 Black roots = 25% 119, 139 Equisetum nodal septa Dg at 114.5, 116.5.
	154 - 204	Grey silt well laminated with lighter bands and sand, cyclothematic. Slight presence of fine roots. Silt 3 Sand+ Lfcl Clay+ Dg+ Th^1+ nig 2, strf 3, elas 0, sicc 2, het, plastic Lim Sup 3. Light bands (Lfc) at: 159 - 159.25, 161 - 161.25, 163 - 163.5, 171 - 171.5, 172 - 172.25, 174 - 174.25, 178 - 178.25, 179 - 179.25, 181 - 181.25, 186 - 186.25, 187 - 187.25, 193 - 195, 201 - 201.5, 203 - 203.5 Sand bands at: 158 - 159, 173 - 174, 176 - 177.5, 179.5 - 181, 185 - 186, 195 - 196, 198 - 199.	SAMPLE 2 154 - 204 Well preserved very fine roots, slight presence wood fragments, coal particles > 425 µm, miscellaneous detritus.

STRA-TUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
I cont.)	204 - 254	Grey silt well laminated with lighter bands and sand, cyclothematic. Some fine detritus. Silt 3 Sand+ Lfc1 Clay+ Dg+ nig 2, strf 4, elas 0, sicc 2, het, plastic, Lim sup 3. <u>Darker silt</u> at 222 - 223.5 <u>Light bands</u> at (Lfc) at: 210-210.25, 213 - 213.75, 218 - 218.25, 218.5 - 218.75, 221.5 - 222, 226 - 226.5, 227 - 227.25, 228.5 - 229, 230 - 231, 233 - 233.5, 235.5 - 235.75, 242 - 242.25, 243 - 243.5, 248 - 248.25, 249.5 - 249.75. <u>Sand bands</u> at: 207 - 209, 212 - 213, 219 - 219.25, 220 - 221.5, 231 - 233, 235 - 235.5, 238 - 238.5, 240.75 - 241, 251 - 253.	<u>SAMPLE 1</u> 204 - 254 Miscellaneous detritus 2 <u>Equisetum</u> nodes.

TRANSECT CORE 7 (SSI) 4/8/82

40 m. from Basemark, 219 cm. Sediment

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
6	(No water) 0 - 9	Watery black mud Dg3 Lh1 nig 4, strf 0, elas 0, sicc 1 incoherent.	Fine black mud
	9 - 26.5	Dark brown peaty layer, spongey, with particles of coal at 15 cm. Th^{2}1 Dh1 Dg1 Lh1 Silt+ nig 4, strf 1, elas 1, sicc 1, slightly fibrous Lim Sup 0.	<u>SAMPLE 4</u> 16 - 69
5	26.5 - 34	Silt with sand and roots. Silt 2 Th^{1}1 Dh+ Clay+ Sand 1 nig 3, strf 1, elas 0, sicc 2, het, plastic, slightly fibrous Lim Sup 0.	<u>Phragmites</u> roots and stems well preserved, + wood fragments.
	34 - 38	Brown peaty fibrous layer with stem node of Phragmites, roots 75% Th^{1}3 Silt 1 nig 3, strf 0, elas 1, sicc 2, het. fib. Lim Sup 1.	
	38 - 45	Silt with sand and roots Silt 3 Th^{1}1 Sand+ Dh+ nig 3, strf 0, elas 0, sicc 2, het. plastic, Lim Sup 1.	Slight presence of fine black roots.
	45 - 56	Dark grey silt with thin black bands through it. Laminated, cyclothematic. Silt 3 Dg1 Clay+ Th^{2}+ nig 3, strf 1, elas 0, sicc 2, het, plastic. Lim Sup 1.	<u>Phragmites</u> leaf at 55
4	56 - 76	Sand (dries to yellow colour). 68 - 69 Black in colour. Sand 4 Dg+ nig 2, strf 2, elas 0, sicc 2, granular, laminated. Lim Sup. 1.	<u>SAMPLE 3</u> 69 - 119
3	76 - 77.5	Black mud with <u>Phragmites stems</u> above and below. Dh2 Dg2 Sand+ nig 4, strf 0, elas 0, sicc 1, incoherent, homog. Lim Sup 1.	<u>Phragmites</u> stems at 74, 79, 84.

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
3 (cont.)	77.5 - 79	Dark grey silt. Silt 3 Clay+ Dg1 nig 3, strf 2, elas 0, sicc 2, homog. plastic. Lim Sup 1.	Miscellaneous detritus.
	79 - 81	Dark grey silt with sand and detritus. Silt2 Sand1 Dg1 nig 3, strf 2, elas 0, sicc 2, homog, granular. Lim Sup 1.	Quartz and mica in the sand.
	81 - 86.5	Very dark grey mud. Silt 1 Dg1 Dh1 Lh1, nig 4, strf 0, elas 0, sicc 2, homog. Lim Sup 1.	*Sphagnum* leaf (plicate) *Daphnia* egg case *Ranunculus* seed *Rumex* sp. seed.
2	86.5 - 93	Dark grey silt. Silt 3 Clay + Dg1 Lh+ nig 3, strf 1, elas 0, sicc 2, homog, laminated, plastic, Lim Sup 1.	
	93 - 94	Dark grey mud with roots Silt 2 Th³1 Dg1 nig 4, strf 1, elas 0, sicc 2, fib, incoherent het. Lim Sup 1.	*Phragmites* stem node.
	94 - 97	Lighter grey silt with clay and detritus Silt 3 Dg1 Clay+ nig 2, strf 1, elas 0 sicc 2, homog, laminated, plastic Lim Sup 1.	
	97 - 98	Very thin layer of black mud. Lh2 Dg2 nig 4, strf 0, elas 0, sicc 2, homog. Lim Sup 1.	
	98 - 99	Black peaty layer, roots 50%, black and partly decayed. Lh2 Th²2 Dg+ nig 4, strf 1, elas 0, sicc 2, het. Lim Sup 1	
I	99 - 129.5	Grey silt layer, uniform colour Silt 4 clay+ nig 2, strf 2, elas 0, sicc 2, homog. plastic Lim Sup 1.	SAMPLE 2 119 - 169 Slight presence of fine black roots.

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
I (cont.)	129.5 - 169	Grey silt layer well laminated with lighter bands (nig 1). Some plant remains present. Cyclothematic. No sand visible. Silt 3 Lfc1 Clay+ Dg+ Th^2+ nig 2, strf 3, elas 0, sicc 2, het. Lim Sup 2. Light bands (Lfc) at: 152 - 152.25 152.5 - 152.75, 157. Feint at: 128.5 - 128.75, 137.25 - 138, 141.75 - 142, 144 - 144.5, 149 - 149.5, 160.5 - 161, 164 - 164.25, 168.5 - 169.	 Light bands form granules.
	169 - 219	Grey silt layer well laminated with light bands (nig 1) and sand bands (granular). Cyclothematic. Some black detritus bands of humus substance. Silt 2 Sand1 Lfc1 Clay+ Lh+ nig 3, strf 4, elas 0, sicc 2, het. plastic. Lim Sup 2. Black detritus bands at: 177.75 - 179, 183 , 195.75 - 198.25. Light bands (Lfc) at: 173.5 - 174, 176.5 - 177, 179.25 - 179.75, 182 - 182.5, 183 - 183.5, 185.5 - 185.75, 187 - 187.25, 188.5 , 190.5, 191, , 191.5 - 191.75, 193 - 193.25, 208 - 208.25 213 - 213.75, 214.75 - 215. Sand at: 170 - 171, 176 - 176.5 179 - 179.25, 184 - 185.5, 190 - 190.5, 192 - 192.25, 204 - 204.25, 205 - 206, 216 - 218. Sand layer felt at base of core.	SAMPLE 1 169-219 No identifiable plant remains. Mica and quartz in the sand.

TRANSECT CORE 8 (5.5 m.W SSI) 7/8/82

45 m. from Basemark 175 cm. Sediment

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
6	(No water) 0 - 16.5	Brown wood peat, fibrous, well preserved roots and brown twig fragments. $Tl^1$2 Sh2 nig 3, strf 1, elas 1, sicc 2, het. fib.	SAMPLE 4 0 - 25
5	16.5 - 19	Sandy silt with well preserved roots. Silt 2 Sand 1 $Th^1$1 nig 3, strf 1, elas 0, sicc 2, plastic, fibrous, granular. Lim Sup 0.	
	19 - 23	Yellow quartz sand with some silt and some rooted material. Sand 3 Silt 1 Th^1+ nig 3, strf 0, elas 0, sicc 2, granular. Lim Sup 1.	
	23 - 26	Brown peat, fibrous, with detritus (sedge leaf). $Th^2$4 Silt+ nig 4, strf 1, elas 0, sicc 2, het. fib. Lim Sup 1.	
	26 - 27	Silt with sand and rooted material Silt 2 Sand 1 $Th^1$1 strf 1, elas 0, sicc 2, het., granular, fibrous. Lim Sup 1.	SAMPLE 3 25 - 75 Slight presence of fine black roots. Some *Equisetum* nodes. *Juncus* detritus. sedge leaf.
	27 - 30	Silty sand and rooted material Sand 2 Silt 1 $Th^1$1 nig 3, strf 0, elas 0, sicc 2, het. Lim Sup 1.	
	30 - 31	Black organic layer. Dg2 $Th^1$2 Silt+ nig 4, strf 2, elas 0, sicc 0, Incoherent. Lim Sup 1.	
	31 - 32.5	Dark grey silt. Silt 4 Dg+ nig 3, strf 2, elas 0, sicc 0, plastic, Lim Sup 1.	

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
5 (cont.)	32.5 - 44	Sand layer with bands of silt. Cyclothematic, alternating bands Sand 3 Silt 1 Lh+ Dg+ nig 3, strf 3, elas 0, sicc 2, granular/plastic. Lim Sup 1. Sand at 32.5 - 36.5, 39 - 41, 42.5 - 43.	Quartz grains Coal particles > 425 μm Woody fragments. Slight presence of rooted material and detritus.
4	44 - 68.5	Yellow quartz sand layer, with dark streaks in it. Sand 4 Lh+ Th1+ nig 2, strf 2, elas 0, sicc 2, granular/cyclothematic. Lim Sup 1. Dark bands at: 59 - 60, 61.5 - 62.5 65 - 65.25, 67 - 67.25.	3 large roots 62 - 65
3	68.5 - 71	Black organic layer, with rooted material. Dg1 Lh1 Th2 2 nig 4, strf 0, elas 0, sicc 2, het, Lim Sup 1.	
	71 - 72.5	Silt with black humus substance. Silt 3 Lh1 Sand+ nig 3, strf 1, elas 0, sicc 2, plastic, Lim Sup 1.	
	72.5 - 77	Dark grey sand with silt. Sand 2 Silt 2 Dg+ nig 3, strf 0, elas 0, sicc 2, het. granular - plastic. Lim Sup 1.	SAMPLE 2 75 - 125
	77 - 82	Black peaty organic layer with some sand. Phragmites stems. Th1 2 Dh1 Sand 1 Sand+ nig 4, strf 1 elas 0, sicc 2, het. fib. Lim Sup 1.	
2	82 - 86	Lighter grey silt with brown twig fragments and Phragmites stems and some roots. Silt 2 Dh1 Th1 1 nig 3, strf 1, elas 0, sicc 2, het. fib. laminated. Lim Sup 1.	

STRATUM	DEPTH (CMS.)	DESCRIPTION	WET SIEVING + MICROSCOPY
2 (cont.)	86 - 88	Diffuse lighter grey silt with some clay and some roots and detritus. Silt 3 Clay+ Th[1] 1 Dg+ nig 2, strf 1, elas 0, sicc 2, fib. well laminated, plastic. Lim Sup 1.	
	88 - 92	Fine black rooted material 50% with silt and sand. Th[2] 2 Silt 1 Sand 1 nig 3, strf 1, elas 0, sicc 2, fib. Lim Sup 1.	
I	92 - 125	Plant material less than 25% some sedge leaves at 90 and 124. Fine black roots scattered throughout this layer. (c.f. *Equisetum*?) Silt 4 Clay+ Th[2]+ nig 2, elas 0, strf 2, sicc 2, plastic. Lim Sup 1.	
	125 - 175	Grey silt well laminated with light yellow bands and sand bands and two fine bands of black humus substance. Slight presence of fine black roots. Cyclothematic. Silt 2 Sand 1 Lfc 1 Dg+ Th+ nig 2, strf 2, elas 0, sicc 2, plastic/granular Lim Sup 2. Black Lh layers, nig 4 at 130 - 130.25, 132.5 - 133. <u>Sand bands</u> at: 134 - 135, 149 - 149.75, 158.5 - 159, 162 - 162.25, 169.25 - 170, 170.75 - 172. <u>Light bands</u> (Lfc) at: 129 - 129.25, 135.75 - 136. Diffuse at 130.5 - 131, 132 - 133, 139 - 139.25, 144.5 - 144.75, 145.25 - 145.75. Partial : 157-157.5, 158-158.5 159-159.5, 160-160.5	SAMPLE 1 125 - 175 Some miscellaneous detritus in this core, slight presence of black rootlets

TRANSECT CORE 9 8/8/82

55 m. from Basemark, 97 cm. Sediment

STRATUM	DEPTH (CMS.) SAMPLE 2:0-47 3cm overlap with Sample 1	DESCRIPTION	LOSS OF WEIGHT ON IGNITION (275°C 16 h.)	
			Depth of sample.	% Loss
6 (6+5)	0 - 15	Brown wood peat well preserved roots and twigs, (brown earth). Sh2 Tl°2 nig 3, strf 0, elas 1, sicc 2, het. fib. crumbly.		
5 (4?)	15 - 24.5	Yellow quartz sand layer with well preserved twig fragments at 19, 22. Roots absent. Sand 4 Silt+ Dl+ nig 2, strf 0 elas 0, sicc 1 homog. granular Lim Sup 0.	17-18	2.2%
	24.5 - 31	Silty sand with humus substance and roots. Silt 2 Sand 2 Th^1+ Lh+ nig 3, strf 0, elas 0, sicc 2, het. fib. granular Lim Sup 1.	25-26	2.6%
	31 - 34	Black-brown fibrous peaty layer with wood fragments and some roots $Th^1$2 Silt 1 Sand 1 Dl+ nig 4, strf 1, elas 0, sicc 2, het. fib. Lim Sup 1.		
	34 - 37.5	Lighter grey silt with sand and some roots. Silt 3 $Th^1$1 Sand+ nig 3, strf 0, elas 0, sicc 2, het. fib. plastic. Lim Sup 1.		
	37.5 - 38	Sandy silt with some roots. Silt 2 Sand 2 Th^1+ nig 3, strf 0 elas 0, sicc 2, plastic, granular, fib. Lim Sup 1.		
	38 - 40	Grey silt with humus substance and roots. Silt 2 Lh1 $Th^1$1 Sand+ nig 3, strf 1, elas 0, sicc 2, het. fib. Lim Sup 1.		

STRATUM	DEPTH (CMS.) SAMPLE 1:0-47	DESCRIPTION	LOSS OF WEIGHT ON IGNITION (275°C 16h.)	
			Depth of sample.	% Loss
	40 - 41	Silty sand with fine roots. Sand 3 Silt 1 Th^1+ [illegible] nig 3, strf 1, elas 0, sicc 2, granular Lim Sup 1.		
	41 - 44.5	Grey silt with humus substance and well preserved fine roots. Some clay. Silt 3 $Th^1$1 Clay+ nig 3, strf 1, elas 0, sicc 2, het. fib. Lim Sup 1.		
4	44.5 - 53 (SAMPLE 1 = 47 - 97)	Medium grain yellow quartz sand with some plant detritus (sedge leaf). Sand 4 Dl+ Dh+ nig 2, strf 0, elas 0, sicc 2, homog. granular. Lim Sup 1.		
	53 - 56	Yellow sand + silt. Sand 3 Silt 1 nig 3, strf 1, elas 0, sicc 2, homog. granular. Lim Sup 1.	55-56	2.6%
3 (3+2?)	56 - 61	Grey silt with fibrous plant remains and some clay. twig fragment Silt 2 $Th^1$2 Clay+ nig 3, strf 1, elas 0, sicc 2, plastic, fib. Lim Sup 1.		
2 (1?)	61 - 61.25	Light grey silt band, Silt 2 Lfc 2 nig 2, strf 1, elas 0, sicc 2, plastic. Lim Sup 2.		
	61.25 - 97	Uniform grey silt layer with dark partial streaks of humus substance and abundant well preserved fine detritus and roots. <u>Phragmites</u> leaf 72 - 77 (H.O.) Silt 4 Th^1+ Clay+ nig 3, strf 4, elas 0, sicc 2, fib, plastic, cyclothematic. Lim Sup 2. Dark streaks: 86, 92, 93.5	90-91	3.2%

It was difficult to relate the strata within this core accurately to those within the other cores. Two possible alternatives are given above. (See text Section 5.4.3., p. 112)

APPENDIX I2

NOTES ON THE KNOWN FLOOD EVENTS OF THE RIVER WEAR

Source: Anon (1849), Kirby (1968).

1771 November 17th. Frosterley, Wolsingham and Witton bridges destroyed. Water at Durham 8 ft. 10 ins. higher than ever known before. Two houses at the end of Framwellgate Bridge were swept away. One of the Abbey Mills, and the bridge belonging to the Dean and chapter were demolished, as were four arches of Elvet bridge and all the lower buildings of the City, garden walls etc. The low grounds around Finchale Abbey were under water. Chester-le-Street, Cocken Mill, Lumley boat-house, North Biddick, Chaters haugh and Low Lambton were also affected. (Witton-le-Wear Mill destroyed : Kirby 1968). Many lives were lost and many livestock drowned.

1773 July 23rd. The River Wear "was so much swollen that the mail coach was obliged to wait upwards of 7 hours till it was passable at the north end of Sunderland Bridge." (Near Butterby and Croxdale). "Considerable damage was done in the City of Durham. The river was more swollen than at any time since the great flood of 1771."

1791 October 22nd. Considerable damage was done at Durham and on the banks of the River Wear.

1818 July 19th. Flood at Otterburn (river Reed). It is possible other rivers of the N.E. were affected.

1822 February 2nd. Rain caused a considerable flood in the rivers Tyne, Wear and Tees. Flood damage occurred at Chester-le-Street. "The Wear extended above the arch of the new bridge, which is more than a quarter of a mile from the channel of the river; the River Wear rose 12 ft. above its usual height at Durham. Its banks were overflowed and the lowlands completely inundated."

1824 October 10th. "Much damage was done on the river Wear by its rising to a tremendous height. At the end of December the river Tyne was swollen and villages inundated.

1825 February 2nd. Flood on the River Tyne.
December 20th. "The rivers ..... were greatly flooded, particularly the Wear and the Brownie, which were much swollen. At Sunderland Bridge, three miles south of Durham, the road was completely overflown, and all passage stopped for a considerable time.

1839 June 18th. Newcastle's streets inundated.
November 29th - 30th. River Tyne swollen to an unusual height.

1841 January 18th. "the Wear above Sunderland Bridge presented one sheet of ice, as far as the eye could reach. Shortly after, the rain came down in torrents; the river rose rapidly and the pressure of the ice urged on by the flood, carried away some ships from near the patent ropery at Deptford before 5 o'clock." Ships at Sunderland were destroyed.

APPENDIX 13

KNOWN EVENTS RELATING TO THE HISTORY OF BUTTERBY MARSH

1771 ---- Major flood on River Wear, Durham badly affected. (Anon 1849, Kirby 1968).

1773 ---- Flood, River Wear. Sunderland Bridge and Durham affected. (Anon 1849).

1787 ---- Hutchinson's description of the River Wear at Low Butterby (Griffiths 1932).

1791 ---- Flood, River Wear, Durham Affected (Anon 1849).

1802 ---- Pickering's map of river Wear at Low Butterby (C.R.O.) River flows to the West of Griffith's "East Salix Marsh".

1805 ---- John Bell's map of the River Wear at Low Butterby. River flows to the east of Griffith's "East Salix Marsh".

1806 ---- The land within the loop, formerly part of the Burn Hall estate, is added to the Croxdale Estate. (Surtees 1840, Griffiths 1932).

1811 ---- New channel dug across the neck of the loop (Griffiths 1932 : note on old map).

1818 ---- Flood on the River Reed Northumberland (Anon 1849). Other rivers may also have been affected.

---- Greenwood's map of Durham, showing cut across the neck of the loop (Griffiths 1932).

1820 ---- Low Butterby added to the Croxdale Estate (Surtees 1840, Griffiths 1932).

1824 ---- Flood, river Wear (Anon 1849). River rose "to a tremendous height".

1825 ---- Floods on the rivers Wear, Browney, Tyne. Sunderland bridge road impassable. (Anon 1849).

1840 ---- Surtees' description of river Wear at Low Butterby.

1841 ---- Flood on the River Wear, Sunderland Bridge affected (Anon 1849).

1842 ---- Tithe plan for Sunderland Bridge. New channel across the neck of the loop not marked on. Still shown as part of Elvet township.

---- Iron ore mining increases in North Pennine Orefield (Dunham 1948).

1857 ---- First edition O.S. map 1 : 2500. Shows embankments in place, Croxdale Beck redirected, loop cut off and isolated. Griffith suggests that they had been built within twenty years after 1811. The map also shows the area of the South Salix Marsh partly wooded.

1860's --- Peak level of lead extraction ? (B.K. Roberts pers. comm.)
1815 - 1880 maximum lead output from N. Pennine orefield (Dunham 1948).

1874 ---- Reference to pollution in Croxdale Beck (Kirby 1968).

c.1882 ? -- Calcium fluorite ceases to be dumped in River Wear (G.A.L. Johnson pers comm.)

1897 ---- Second edition O.S. map 1:2500 shows woods cut down on west side of the "Long Pool".

1919 ---- Third edition O.S. map 1:2500.

1932 ---- Publication of Dr. B.M. Griffiths study of the ecology of Butterby Marsh in the Journal of Ecology. Notes on the flora of Butterby Marsh published by Dr. Griffiths in The Vasculum.

1936 ---- Publication of studies of the Long Pool, Butterby Marsh, Durham by Dr. B.M. Griffiths in Journal of the Linnean Society - Botany.

---- A preliminary list of the freshwater algae of Northumberland and Durham Vasculum 22 89 - 95 by B.M. Griffiths. References to Butterby.

1957 ---- Records begin for river levels at Sunderland Bridge gauging station - Northumbrian Water Authority.

1960 ---- O.S. 1:2500 map revised, levelled.

1971 ---- Air Photograph coverage of Butterby Marsh. B.K.S. Surveys Ltd.

APPENDIX I4

TROELS-SMITH'S SCHEME FOR THE DESCRIPTION OF UNCONSOLIDATED SEDIMENTS (1955)

Three elements are described for each layer of stratigraphy identified (after Tooley 1981).

1. the components of the layer
2. the degree of humification
3. the physical properties.

1. The components of the layer are described: e.g. roots, stems, leaves, twigs, branches, mud, sand, silt, clay. Proportions are estimated of the main components on the scale

   1. 0 - 25%
   2. 25 - 50%
   3. 50 - 75%
   4. 75 - 100%

   + indicates the slight presence of any component.

2. The degree of humification of the components of organic material comprising rooted materia (Turfa) is estimated on the following scale:

   $Th.^0$ Plant structure fresh and well preserved. If squeezed, clear water is derived.

   $Th.^1$ Plant structure decayed, but squeezing yields a dark coloured water, and 25% of the material can be squeezed between the fingers.

   $Th.^2$ Plant structure decayed, but part still capable of identification, 50% of material can be squeezed through the fingers.

Th.3 Plant structure indistinct, and the bulk is decayed, squeezing yields 75% through the fingers.

Th.4 Plant structure scarcely discernible or absent. All material can be squeezed through the fingers.

3. Physical Properties

3.1 Colour can be estimated using a Munsell Chart, or the shades of darkness or nigror can be estimated:

nig. 0. Lightest shades, white e.g. quartz sand.

nig. 1. Light shades.

nig. 2. Medium shades.

nig. 3. Dark shades e.g. coarse detritus gyttja.

nig. 4. Darkest shades, e.g. well humified peat.

3.2 Stratification indicates the degree of horizontal layering of a deposit and can be estimated by the ease by which the deposit splits horizontally compared to vertical splitting.

strf. 0. Complete homogeneity. Deposit breaks equally in all directions.

strf. 4. Deposit splits markedly along horizontal laminations, or (and) consists of very thin minor layers.

3.3 Elasticity indicates the degree to which a deposit can regain its shape after squeezing.

elas. 0. No elasticity, e.g. clay, sand, fen peat.

elas. 4. Deposit highly elastic, i.e. it regains its shape after squeezing, e.g. fresh sphagnum.

3.4 Dryness or "Siccitas"

sicc. 0. Clear water.

sicc. 1. Deposit completely saturated with water, so that it is sloppy and soft, like thin porridge.

sicc. 2. Deposit saturated with water, but coherent. All deposits below the water table are sicc. 2.

sicc. 3. Deposit not saturated.

sicc. 4. Deposit air-dry and feels warm.

3.5 Structure Estimate whether the deposit comprising the layer is homogenous or heterogenous; whether it is crumbly, fibrous, felted or well laminated; whether it is plastic or incoherent.

3.6 Boundary or Limes The width or transition between two layers can be estimated on the following scale:

Lim. 0. Diffuse boundary, greater than 1 cm.

Lim. 1. Boundary zone 2 mm. to 1 mm.

Lim. 2. Boundary zone 1 mm. to 0.5 mm.

Lim. 4. An acute, sharp boundary, less than 0.5 mm.

As a rule it is always useful to make a note of the upper limit of a deposit : limes superior - lim. sup.

APPENDIX 15 :

GLOSSARY

TERMS USED IN THE DESCRIPTION OF THE SEDIMENTS

Minerogenic (or inorganic) sediments are:

deposits made up of particles derived from the erosion of geological substrates or other minerogenic sediment previously deposited.

Biogenic (or organic) sediments are:

deposits made up of particles or other material derived from living organisms or from the erosion of previously deposited biogenic sediments.

Allochthonous sediments are:

biogenic sediments in which the organic remains have undergone lateral transport between death and decomposition.

Autochthonous sediments are:

biogenic sediments in which the organic remains have been incorporated into the sediment at the point in space where the organism lived, or at least vertically, below that point.

Allochthonous sediments are usually termed muds or gyttjas in contrast to autochthonous sediments which are usually termed peats.

Limnic sediments are:

deposited below low water level i.e. in the water.

Telmatic sediments are:

deposited between the low and high water levels i.e. at around the mean water table.

Terrestrial sediments are:

deposited above the high water level, i.e. on water-logged ground but not ground subject to regular inundation.

<u>Turfa</u>: rooted plant material. (Autochthonous deposit).

<u>Detritus</u>: plant fragments that are unconnected to a root system. (Allochthonous deposit).

<u>Limus</u>: small organic particles (often microscopic) arising from the productivity of lakes and the input of organic and inorganic material from the drainage basin. (Tooley 1981).

<u>Gyttja</u>: mud.

<u>Turfa</u>

Tl^{0-4} T. lignosa: root systems of woody plants, e.g. wood peat = Tl^{o}

Th^{0-4} T. herbacea: root systems of herbaceous plants e.g. reed peat or sedge peat = Th^{o}

<u>Detritus</u>

Dl D. lignosus: fragments of wood, twigs etc.

Dh D. herbosus: fragments of herbaceous plants.

Dg D. granosus: fragments of ligneous and herbaceous plants 2 mm. – 0.1 mm.

<u>Limus</u>

Ld^{o} Limus detrituosus: homogeneous deposit element, highly elastic, non-greasy, non adhesive deposit, consisting of decayed micro-organisms or parts of higher plants.

Ld^{4} (Lh) Limus humosus: homogeneous deposit element, slightly gritty, little elastic, very greasy and adhesive, consisting of humous substance. Colour is dark brown or nearly black. Distinguished from highly humified Turfa by its absence of partly decayed roots.

Lf Limus ferruginous - iron oxides which may be of organic as well as of mineral origin.

L fc Limus ferro carbonati - non hardened layers of ferrous carbonate.

Sh Substantia humosa - "humous substance, consists of completely disintegrated, or nearly disintegrated, or decomposed, organic substances or precipitated humic acids, and appears as a dark or blackish homogeneous substance without macroscopic structure. When the deposit is heated with KOH, this liquid will become brown or blackish brown. If, by investigations in the field, it cannot be ascertained whether a given deposit, or part of it, is Limus humosus (dy, or gel mud), completely disintegrated or decomposed Detritus (deposit containing small fragments of plants), or Limus detrituosus (detritus gyttja), the deposit (or part of it) may be characterised as Substantia humosa." (Troels-Smith 1955 p.57).

Descriptions abbreviated from Troels-Smith (1955). See also Birks and Birks (1980), Fig. 4.2. "A chart indicating the types of sediment deposited with increasing water depth under oligotrophic and eutrophic conditions."

APPENDIX I6

SOURCES OF SECONDARY INFORMATION

O.S. Maps

1857	1:2500	1st ed.	Co Durham Sheet	XXVII-9	D/XP/OS189
1897	1:2500	2nd ed.		XXVII-9	D/XP/OS93
1919	1:2500	3rd ed.		XXVII-9	D/XP/OS235
1923	6 Inch			XXVII S. W. Durham	
1952	6 Inch			NZ 23 NE	
1960	1:2500			NZ 2738-2739	
				NZ 2638-2639	

Air Photos

B.K.S. Surveys Ltd., Ballycairn Road, Coleraine BTS1 3H2 Co. Londonderry, N. Ireland.

1971 2150 ft. 1.27 p.m. No.s U05 3739-U05 3741

County Records Office

Plans of River Wear at Sunderland Bridge, Butterby, Croxdale etc. 1649-1882.

1. River between Croxdale and Burn Hall Estates by J. Pickering, 1802 (1 plan) D/Sa/P43.

2. River between Croxdale and Old Burn Hall Estates by John Bell, showing alterations of course. Re. case Hall v. Salvin, 1805 (5 plans) D/Sa/P.49-53.

3. Low Butterby Farm Plan D/Sa/P.5. (1800 ?).

Department of Palaeography

Tithe Plan for Sunderland Bridge (1842).

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Phot. 2 : The north end of the 'Long Pool', and the 'Typha Marsh'. Taken from the East Pasture looking north west. Scirpus lacustris (centre-left) has spread at this location since 1929. In the immediate foreground is heavily grazed and trampled Sparganium erectum and Juncus inflexus.

Phot. 3 : The 'Typha Marsh', taken from the East Pasture looking south west. Juncus inflexus, Sparganium erectum, and Iris pseudacorus are heavily grazed and trampled. The Typha Marsh had almost completely dried up by the end of August 1982, when the photo. was taken

Phot. 4 : Pond A - Pond B transition. Taken from 320 West bankside marker, looking S.E. across the marsh to the 320 East bankside marker, where Salix cinerea bushes are colonizing beyond h.w.m. At this point the Phragmites completely fills the old channel. In 1929 the south end of Pond A was connected with the north end of Pond B by a wedge of Equisetum fluviatile. Since that time the boundary of the Phragmites has advanced northwards by at least 60 m., replacing two previous communities of 1) Carex acutiformis with Iris pseudacorus and 2) Rumex hydrolapathum with Equisetum fluviatile.

Phot. 5 : N.W. of Butterby Marsh. Taken from E. bankside marker looking north west. Phragmites blocking the old channel. Salix cinerea bushes are colonizing from the west bankside (right foreground), and from the western limit of the West Salix Marsh (background). The lateral spread of this marsh forest may replace the Phragmites at some future date, although there has been no noticeable extension of its limits since 1929.

Phot. 6 : Pond A. Taken from 440 W. bankside marker, looking south across the pond. Juncus effusus and then Typha latifolia and Iris pseudacorus zone in foreground. At the other side of the pond : Iris and Typha community (left); Carex acutiformis forming a floating mat (centre) ; and the taller herbaceous vegetation of Phragmites that has advanced into this area since 1929 (right, distance).

Phot. 7 : West end of South Salix Marsh and embankments. Taken looking north. Petasites vulgaris and Impatiens glandulifera have sprad onto the disturbed ground of this narrow track that is occasionally used for farm machinery. The latter plant grows vigorously in the South Salix Marsh, but was unrecorded in 1929. Pictured : Dr. B. Huntley.

PHOT. 8

Five transitional zones are covered by the area included in the photograph. The zone of the immediate foreground is a bare mud area which in winter would be open water. Herb layer cover is less than 20%, attributable to the mean water level and the shade of the trees. *Equisetum palustre* and *Lemna minor* occur on the bare mud surface. *Epilobium angustifolium*, *Ep. palustre*, *Polypodium vulgare* and *Dryopteris dilatata* grow on fallen tree branches, together with bryophytes and lichens.

The second zone consists of a narrow margin of *Juncus effusus* and *Lycopus europaeus* around the bare mud.

The third zone, 4 m. wide, is dominated by *Scirpus sylvaticus*, *Carex paniculata*, and *C. vesicaria*. *Phalaris*, *Angelica sylvestris*, *Lycopus europeaus*, *Galium palustre* and *Filipendula ulmaria* also occur, with *Hieracium perpropinqum* and *Carex remota* on tree stumps and fallen branches.

The fourth zone (c. 3m. wide) is dominated by *Impatiens*, *Phalaris* and more *Juncus effusus*. An isolated patch of *Iris* also occurs here. *Lycopus europeaus*, *Solanum dulcamara* and *Phragmites* occur infrequently, *Filipendula ulmaria*, *Galium palustre*, *Cardamine amara* and *Geranium robertianum* grow in the lowest layer.

The fifth zone consists of very mixed vegetation up to the field edge. *Impatiens glandulifera*, *Heracleum sphondylium*, *Festuca gigantea*, *Poa trivialis*, *Phalaris* and *Phragmites* grow together and nearby *Circaea lutetiana* and *Cirsium palustre* also occur. Next to the field edge *Aegopodium podagraria*, *Impatiens glandulifera*, *Urtica dioica*, *Galium aparine* and a variety of common grasses are the dominant species, with subordinates of *Ranunculus repens* and *Tripleurospermum maritimum*.

Phot. 8 : SOUTH SALIX MARSH

Photograph taken 95 m. from the embankment on the western side of the marsh forest, 20 m. from the field edge, looking n.w . Tree cover : 50%, 10 m. high, Salix alba, Salix fragilis and Alnus glutinosa. Herb layer cover (in middle distance) : 80%, 1.5 m. high.

The main species visible are Epilobium angustifolium on logs in the immediate foreground, and a tussock of Carex paniculata in the centre with Scirpus sylvaticus (a sedge relative) growing around it. In the background is Impatiens glandulifera and the projecting dark leaves of Iris pseudacorus. In the far distance is a large cracked trunk of Salix alba, at least 100 years old.

Phot. 9 : South Salix Marsh. Transect line layed out with string between field edges on a line 350° magnetic north, parallel to embankments, 84 m. from them. Position of levelled cross-channel stratigraphic profile. Phot. taken from 'Staff Site I' in telmatic bare mud zone, looking S.W.

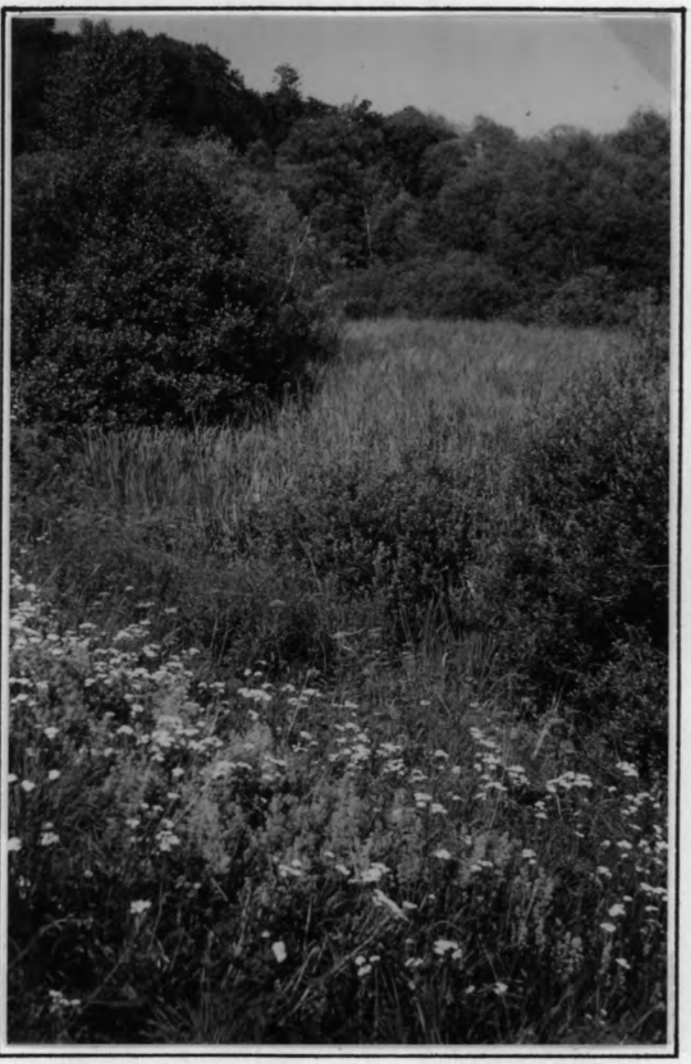
Cover of Alnus glutinosa saplings. Phragmites zone around 'Staff Site H' in foreground. Fallen Salix fragilis blocking the channel (the S.W. of Pond C) in background, and bankside Salices.

Phot. 10

N.W. of Butterby Marsh. Taken looking N.W. from 450 East bankside marker (similar to Phot. 6). Galium verum and Achillea millefolium on bankside in foreground. Phragmites blocks the old deep-water channel in the middle distance. The Alnus glutinosa and Salix cinerea bushes growing at the waters edge have not extended into the marsh at this side, whereas marsh forest has become extensively developed on the former point-bar (distance).

Phot. II

East bankside vegetation of Pond A. Taken from 440 m. marker. Looking South (similar location to Phot. 6). Betonica officinalis and Galium verum on bankside in foreground. This photograph was taken at approximately the same location as the fourth photograph in Griffiths' paper of 1932. Since his photo. was taken the bankside trees have grown to obscure the view south. His description was that the "Rumex-Equisetum community occupies all the channel. The floating-leaved aquatic plant is Pot. natans. The lighter-coloured vegetation in the distance is Phragmites. The marsh-forest vegetation is Salix cinerea." The marsh forest has hardly extended its range since then. The Phragmites has advanced north by at least 60 m. The Rumex-Equisetum community has almost disappeared, being replaced by the Iris-Typha community (opposite side of pond, left) and the Carex acutiformis community (opposite side of pond, right). The wedge of Equisetum dividing pond A into two has also disappeared. Thus the area of open water free of vegetation has actually increased on this pond in the last 50 years, a reversionary change in the hydroseral succession model.



Phot. IO

Phot. II

Face p.299

Phot. 12

Pond A, taken from north end looking south. Nuphar lutea at right. Phragmites communis at left. Carex acutiformis community in centre distance. The maximum depth of water recorded in early summer 1982 was 2 m.

Phot. 13

Pond A, East Side.
Carex acutiformis community, with Typha latifolia rising above it. The Carex forms a floating mat or 'raft' of vegetation which may spread across the pond at some future date.

Phot. I2

Phot. I3