A Study of Benthic Macroinvertebrate Communities of Fifteen Norfolk Broads During Summer 1990

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A STUDY OF BENTHIC MACROINVERTEBRATE COMMUNITIES OF FIFTEEN NORFOLK BROADS DURING SUMMER 1990

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CONTENTS

Contents (i)

Summary (iii)

1 INTRODUCTION 1

1.1 Recent changes in the ecology of the Norfolk Broads 1

1.2 Recent developments in the study of community structure 5

1.2.1 Multivariate statistical techniques 6

1.2.2 Factors affecting macroinvertebrate distribution 7

1.3 Aims of the present survey 8

2 METHODS 10

2.1 Sampling the benthic macroinvertebrate community 10

2.2 Treatment of data with multivariate statistics 11

3 RESULTS 12

3.1 Analysis of habitat-related data 12

3.2 Analysis of broad-related data 15

4 DISCUSSION 19

4.1 Distribution of macroinvertebrates 19

4.1.1 Littoral and submerged vegetation of freshwater broads isolated from the River Bure 19

4.1.2 Littoral and submerged vegetation of freshwater broads linked to the River Bure (plus Ormsby and Cockshoot sediments) 20

4.1.3 Littoral and submerged vegetation of brackish broads (plus sediment of Hickling Broad and lilies of Hoveton Great Broad) 21

4.1.4 Sediment of all broads (except Ormsby and Cockshoot) 22

4.2 Interrelationships between lake communities and the physico-chemical environment 22

5 CONCLUSIONS AND SUMMARY 26

6 ACKNOWLEDGEMENTS 28

References 29

Appendix 30

SUMMARY

Broadland in eastern England features fifty shallow, freshwater and brackish lakes (broads) and five lowland river systems. The Broads, which occupy basins created between the ninth and fourteenth centuries by local inhabitants who dug peat for fuel, were once low in plant nutrients which helped limit the growth of algae in the water. During the last fifty years, the Broads have received nitrogen and phosphorus compounds from fertilised land and sewage effluent and, as a result, several have undergone ecological changes. These changes are the symptoms of accelerating eutrophication.

The National Rivers Authority is presently researching problems associated with the eutrophication of the Norfolk Broads. The study has concentrated on relationships between nutrient supply and plankton community dynamics, and has included little work on the macroinvertebrate communities.

The present study provides information on the distribution of benthic macroinvertebrates within fifteen broads and discusses factors controlling the distribution. A mechanism is presented, based on multivariate statistics, for assessing factors affecting communities within individual broads.

The system is based around TWINSPAN and DECORANA routines but may be modified to incorporate more recent delelopments in multivariate methodology such as CANOCO.

Analysis of data collected in summer 1990 revealed distinct differences between the macroinvertebrate communities of three groups of broads. The groups were:

i) Broads isolated from the Bure river system

ii) Broads linked to the Bure river system

iii) Brackish Broads associated with the River Thurne system.

Broads isolated from the River Bure supported more diverse communities than those which were linked to the river system. These in turn supported more diverse communities than the broads associated with the saline River Thurne. Future movement of broads in Group (iii) to a lower group would be symptomatic of a deterioration in the macroinvertebrate community, and vice versa.

The analyses also revealed distinct differences between macroinvertebrate communities associated with different habitat types. The habitats were:

a) Sediment

b) Submerged and marginal vegetation

c) Tree roots.

Sediment habitats within Cockshoot Broad, which has recently been mud-pumped, and the isolated Ormsby Broad supported more diverse communities than those of other Bure Broads or the brackish broads associated with the River Thurne.

The system should be further developed so that environmental variables can be correlated with the macroinvertebrate-based classification. This could be achieved as follows:

Variance within the environmnental data set could be analysed with multiple discriminant analysis (MDA), which would distribute the sites within the prescribed TWINSPAN/DECORANA-derived group structure. Provided MDA allocates sites in a similar way to

TWINSPAN/DECORANA, it will be possible to suggest the environmental factors most influencing each site group.

Alternatively, the combined macroinvertebrate and environmental data sets could be reordinated with canonical correspondence analysis (CANOCO) (ter Braak, 1988).

Finally, it would be very interesting to manipulate the NRA's archived data relating to broads' plankton populations with multivariate statistics, with a view to integrating macroinvertebrate, plankton and environmental data.

1 INTRODUCTION

1.1 Recent changes in the ecology of the Norfolk Broads

In the easternmost region of England, there are areas of shallow open water (1-2m deep) surrounded by wetland known as the Norfolk Broads. The Broads lie along the lower reaches of the Rivers Yare, Bure, Thurne, Ant and Waveney and occupy basins created between the ninth and fourteenth centuries by local inhabitants who dug peat for fuel (Figure 1). Some are simply widenings of the river whereas others are separate basins linked to the river by channels.

The Broads were once low in plant nutrients, which helped limit the growth of algae in the water. During the last fifty years, the region has been intensively farmed and has undergone substantial residential and industrial development, which have increased both water demand and surface water discharge as sewage effluent and agricultural run off. This has increased the input of nitrogen and phosphorus compounds to the waterways and caused a number of the broads to undergo ecological changes. Aquatic vascular plants have declined and summer algal standing crops have increased, both of which are symptoms of the rapid rate at which the lakes are now undergoing eutrophication.

There are exceptions. Upton Broad, which is not connected to the river systems and has received relatively few fertilising nutrients, still retains clear water in summer and a luxuriant vascular plant community. The situation for the other Bure Broads is not irreversible. A small broad associated with the River Bure (Cockshoot Broad) has been experimentally isolated

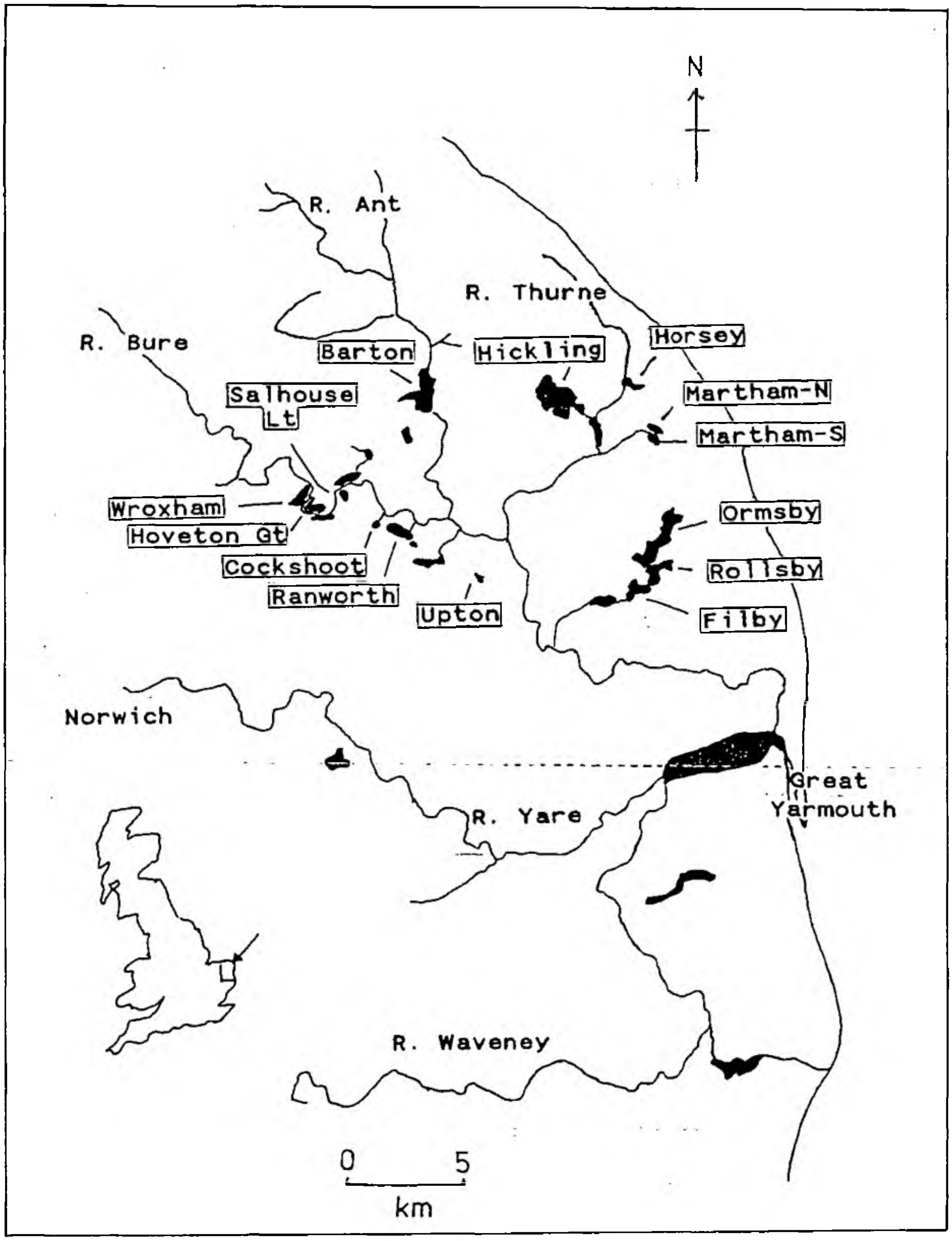

Figure 1 The location of fifteen Norfolk Broads in which aquatic macroinvertebrate communities were sampled during summer 1990

from the river from which the fertilising nutrients derived. During the first years after isolation, there were signs of recovery (Moss et al, 1986). However, large numbers of small zooplanktivorous fish developed in the Broad and consumed the herbivore zooplankters which would normally regulate phytoplankton numbers through their grazing. The result was further increases in summer phytoplankton standing crops. The fish populations have recently been reduced through systematic electrofishing, and the Broad is again under observation for signs of resumed recovery.

The diversity of fen vegetation once in Broadland probably supported an equivalent variety of invertebrates, although only limited studies have been made of these communities. Broads which have been traditionally managed and are isolated from nutrient-enriched water, have retained a diverse plant community and probably also retain a diverse invertebrate fauna. However, broads which have lost their submerged vegetation will also have lost much of their invertebrate community, including molluscs, crustaceans and many kinds of insect larvae. Invertebrate communities in these broads are now invariably dominated by dipteran larvae and oligochaete worms.

Loss of the habitat previously provided by aquatic plants, may be more important than changes in water chemistry in altering the invertebrate communities (Mason and Bryant, 1974). A change in dominance from submerged plants to phytoplankton might be expected to favour benthic detritivores, but increases in such populations have not occurred. This may reflect deterioration of the mud habitat through greater periods of deoxygenation, or increased foraging by predators denied the rich food source previously provided by fauna associated with the vegetation.

The major rivers in Broadland converge in an estuary, Breydon Water, which discharges to the sea at Great Yarmouth (Figure 1). The rivers are tidal to within 20 km inland, and athough they are not normally saline in their upper reaches, vigorous offshore storms and spring tides periodically send salt water upstream into sections which are usually freshwater.

The River Thurne is normally brackish in its upper reaches, since it drains marshland close to the coast in an area of permeable peat and sand. One of the feeder streams to the Thurne supplies the Martham Broads which still retain rich vascular plant communities. However, the River Thurne's major sources develop north of Hickling Broad, close to the coast and discharge into Horsey Mere. Horsey Mere is connected to Hickling Broad by way of Meadow dyke, and although summer discharge is low, in winter, flow from Horsey Mere forms the major input to Hickling Broad.

Hickling Broad is the largest of the Broads and is a National Nature reserve. It has not received sewage effluent in the past but has suffered ecological decline. Research by Moss and Leah (1982) suggests that this may have been caused by the release of guano, from roosting populations of black-headed gulls, into the open water of Hickling Broad in the recent past.

The Trinity Broads (Ormsby, Rollsby and Filby) are linked by way of Muck Fleet to the River Bure, downstream of the confluences of the River Bure with the Rivers Ant and Thurne. However, there appears to be little interchange of water along Muck Fleet and the Broads remain largely isolated from the river system.

The National Rivers Authority (NRA) is presently completing a programme of research into the advancing eutrophication of the Norfolk Broads. This study has concentrated on the relationship between nutrient supply and plankton community dynamics and includes only limited data on the macroinvertebrate communities. The aim of the present survey is to provide information on the distribution of macroinvertebrate species within the Broads and to discuss factors constraining the distribution.

1.2 Recent developments in the study of community structure

The importance of habitat features in the Broads ecosystem is increasingly accepted (Mason and Bryant, 1975; Phillips et al., 1978, Timms and Moss, 1984; Moss et al., 1985). Consideration of the role of habitat in the ecology of lotic systems provoked research in North America and New Zealand during the late 1970's and early 1980's. This work aimed to quantify the needs of the various freshwater stream communities (Gore 1977, 1978), the most important component of which was considered to be the commercially valuable game fish populations. To protect the welfare of these fisheries, the Co-operative Instream Services Group of the US Fish and Wildlife Service developed the 'Incremental Flow Method' (IFM) in 1976 (Wesche and Rechard, 1980). In Canada, the IFM method has been adapted for invertebrate habitat management with encouraging results. Similar methodology (Physical HABitat SIMulation - PHABSIM, NRA R&D topic 2.1; The Institute of Freshwater Ecology's RIVer Invertebrate Prediction And Classification System - RIVPACS) is being investigated for application to lotic ecosystems in the UK.

Moss et al. (1985; 1986) have studied relationships between habitat availability and plankton population dydnamics in various broads, but there have been few other studies of the role of habitat in the functioning of lentic environments.

1.2.1 Multivariate statistical techniques

When considering the effects of environmental changes on communities, multivariate statistical methods are often used to analyse simultaneously suites of species collected at various sites and times. Many of these techniques use multivariate ordination and classification routines (Manly, 1986).

Ordination techniques: Ordination methods condense the variation within a data set into components which are easier to manipulate, the hope being that each component will describe a pattern of species abundance determined by a dominant environmental factor. Correspondence analysis is an ordination system which scores species response to an arbitrary environmental gradient. The scores are refined through a system of successive averaging and positioned along a single axis. Further uncorrelated axes can be produced and plotted, so that related sites, indicated by similarities on more than one axis, group together. In this way, sites with similar communities can be revealed. Detrended correspondance analysis (DECORANA) is a refined version in which certain shortcomings in the original routine have been eliminated (Hill, 1979). DECORANA has recently undergone further modifications which may enable the influence of environmental variables on community structure to be established during the analysis (ter Braak, 1988).

Classification techniques: Two-way indicator species analysis (TWINSPAN) groups sites by progressively dividing the total species list into subgroups of two, according to the presence or absence of species. At the same time, the species are classified on the basis of their occurence in site groups. Indicator species are then highlighted, the presence or absence of which demonstrates large differences between sub-groups.

The process can be continued until each site resides in a subgroup of its own, but to have any ecological relevence, classification is stopped when there is still considerable difference between numbers of sites in the subgroups following division. This of course, is arbitrary, and groups so formed are not evidence that discrete communities exist. The analysis is therefore invariably used in conjunction with an ordination.

Clearly, the interpretation of these analyses must be based on an understanding of the factors controlling macroinvertebrate distribution.

1.2.2 Factors affecting macroinvertebrate distribution

Temperature, flow regime, habitat availability and water quality affect the distribution of aquatic macroinvertebrates. Flow regime determines the nature of the lotic habitat, by combining the effects of current velocity and geology upon substrate particle size. In contrast, the characteristics of lentic environments, which usually feature depositing, less varied habitats, reflect the influence of temperature, depth and water chemistry on production and nutrient transport within the ecosystem. In lentic ecosystems, flow changes affect the rate at which material accumulates in or is flushed from the lake basin, but have less marked effects on habitat structure than in lotic environments. However, established habitat features such as emergent and submerged vegetation, which are essential for a balanced and stable community, may be threatened by alterations in water quality and sedimentation associated with changes in flow and production.

The macroinvertebrate community is an important component of the freshwater ecosystem and forms a link in the food chain through which energy from primary production is transferred to higher trophic levels. Certain invertebrate species graze algae and other plant material colonising the river, while others feed on faecal and decomposing material. These animals may all be prey to larger carnivorous invertebrates and fish. So, providing water quality is high, a diverse macroinvertebrate fauna may develop, including carnivores, herbivores and detritus feeders, each of which are adapted to exploit particular habitat niches.

1.3 Aims of the present survey

The exposed sediment of the Norfolk Broads supports a limited macroinvertebrate fauna dominated by dipteran larvae and oligochaete worms. The production and diversity of the macroinvertebrate community will reflect first, the availability of habitat features such as littoral, emergent and submerged vegetation, and secondly, water quality, either as base flow from the underlying strata, or via rainfall, surface water discharge or tidal incursion.

The aim of the present study is to provide information on the distribution of macroinvertebrate species within the Broads and to discuss the factors constraining their distribution.

Table 1 The locations of the broads sampled during summer 1990

Site	National Grid Reference
Hickling Broad	TG 415215
Horsey Mere	TG 448223
Martham North Broad	TG 459206
Martham South Broad	TG 459202
Barton Broad	TG 361215
Wroxham Broad	TG 310167
Hoveton Great Broad	TG 318164
Salhouse Little Broad	TG 326162
Salhouse Broad	TG 317158
Cockshoot Broad and dyke	TG 344155
Ranworth Broad	TG 354155
Ormesby Broad	TG 465155
Rollesby Broad	TG 463142
Filby Broad	TG 457135
Upton Great Broad	TG 389135

2 METHODS

2.1 Sampling the benthic macroinvertebrate community

The aim of the macroinvertebrate sampling was to obtain semi-quantitative data for communities colonising the various habitats occurring in the broads. This in turn should generate a comprehensive species list for each broad.

Invertebrates colonising the following habitats were semiquantitatively sampled with a standard hand net (frame size 0.35m x 0.25m, net depth 0.3m, mesh 1 mm).

Habitat 1 - marginal vegetation (M)
Habitat 2 - submerged vegetation (SV)
Habitat 3 - submerged water lillies (L)
Habitat 4 - submerged tree roots (T)
Habitat 5 - exposed sediment (S)

Five 15-second replicate sweeps of plant habitats were made at five points within each habitat. Replicates were bulked but samples from each habitat were kept separate. The replicates were transferred to polyethylene buckets and preserved in the field in 4% formalyn.

Five replicate sediment scoops were taken with a hand net on an extended pole and were agitated in the surface of the broad to dispell as much fine silt as possible. They were preserved as described above. The approximate position of the sampling points and habitat features for each broad are given in sketch maps included in the Appendix.

In the laboratory, the samples were sieved so that the formalyn could be disposed of and larger pieces of plant material removed. The seived samples were then preserved in industrial methylated spirit for sorting. Sieved samples which contained very large amounts of invertebrate and associated material were carefully subsampled to facilitate counting. Sorted specimens were then observed with a binocular stereo microscope and identified with reference to Freshwater Biological Association (FBA) keys.

The following groups were identified to species: Tricladida, Oligachaeta, Mollusca, Hirudinea, Malacostraca, Ephemeroptera, Plecoptera, Trichoptera and Megaloptera. Oligochaetes were mounted in lactophenol and identified under high magnification (x400). Species abundance was estimated on a log scale as follows:

1 individual = 1
1 to 10 individuals = 2
10 to 100 individuals = 3
100 to 1000 individuals = 4
1000 to 10 000 individuals = 5

2.2 Treatment of data with multivariate statistics

Macroinvertebrate species lists were prepared from the data and archived on computer as spreadsheet (SuperCalc 4 files). These were converted to 'comma-separated' form for transformation to a format accepted by the multivariate statistics packages. The data were then manipulated by TWINSPAN and DECORANA with the rare species 'downweighted' option in operation.

3 RESULTS

Data were arranged as species lists, first for individual habitats, and secondly, for individual broads. Results of the analysis of the data in each format by the TWINSPAN and DECORANA routines were as as follows:

3.1 Analysis of habitat-related data

TWINSPAN - Species occurring in each habitat within each broad, and the sequence of habitat and species subdivisions comprising the TWINSPAN classification is shown in Figure 2.

The first cut level generated groups of 24 and 28 habitats respectively. This separated virtually all the sediment habitats and habitats within brackish broads from those associated with vegetation within freshwater broads. Exceptions were Cockshoot and Ormsby sediments which were grouped with habitats associated with vegetation, and the Hoveton Great Broad lily habitats which were grouped with sediment/brackish habitats.

Each group then underwent two further cuts (divisions two and three). On one branch of the first cut, division two separated sediment habitats from brackish habitats. On the second branch of the first cut, division two separated habitats within broads linked to the River Bure from those within the isolated Trinity, Cockshoot and Upton Broads. The third cut sub-divided each of the second level groups, generating eight distinct habitat clusters in all (groups A-H).

DECORANA - The relative strengths of axes 1-4 (in eigenvalues) in the DECORANA ordination and the relative importance of each axis in explaining total variance are given in Table 2. (The

Key to Figures 2 and 3 overleaf

Reference (Fig 2)	(Fig 3)	Broad	Habitat
Barton M	1	Barton	Marginal vegetation
Barton SM	2	Barton	Submerged tree roots
Barton S	3	Barton	Sediment
Cock M	4	Cockshoot	Marginal vegetation
Cock T	5	Cockshoot	Submerged tree roots
Cock S	6	Cockshoot	Sediment
Cock L	7	Cockshoot	Lilies
Cock-d L	8	Cockshoot Dyke	Lilies
Cock-d SV	9	Cockshoot Dyke	Submerged vegetation
Filby M	10	Filby	Marginal vegetation
Filby S	11	Filby	Sediment
Hick M	12	Hickling	Marginal vegetation
Hick S	13	Hickling	Sediment
Hick SV	14	Hickling	Submerged vegetation
Horsey M	15	Horsey	Marginal vegetation
Horsey S	16	Horsey	Sediment
Horsey SV	17	Horsey	Submerged vegetation
Hov-g M	18	Hoveton Great	Marginal vegetation
Hov-g T	19	Hoveton Great	Submerged tree roots
Hov-g S	20	Hoveton Great	Sediment
Hov-g L	21	Hoveton Great	Lilies
Hov-he L	22	Hoveton Great (Haugh)	Lilies
Mart-n M	23	Martham North	Marginal vegetation
Mart-n S	24	Martham North	Sediment
Mart-n SV	25	Martham North	Submerged vegetation
Mart-n L	26	Martham North	Lilies
Mart-s MV	27	Martham South	Marginal vegetation
Mart-s S	28	Martham South	Sediment
Mart-s SV	29	Martham South	Submerged vegetation
Mart-s L	30	Martham South	Lilies
Ormsby M	31	Ormsby	Marginal vegetation
Ormsby S	32	Ormsby	Sediment
Ormsby SV	33	Ormsby	Submerged vegetation
Ormsby L	34	Ormsby	Lilies
Ran M	35	Ranworth	Marginal vegetation
Ran T	36	Ranworth	Submerged tree roots
Ran S	37	Ranworth	Sediment
Rolls M	38	Rollsby	Marginal vegetation
Rolls T	39	Rollsby	Submerged tree roots
Rolls S	40	Rollsby	Sediment
Rolls L	41	Rollsby	Lilies
Salh M	42	Salhouse	Marginal vegetation
Salh T	43	Salhouse	Submerged tree roots
Salh S	44	Salhouse	Sediment
Sal-l L	45	Salhouse Little	Lilies
Wrox M	46	Wroxham	Marginal vegetation
Wrox T	47	Wroxham	Submerged tree roots
Wrox S	48	Wroxham	Sediment
Upton M	49	Upton	Marginal vegetation
Upton S	50	Upton	Sediment
Upton SV	51	Upton	Submerged vegetation
Upton L	52	Upton	Lilies

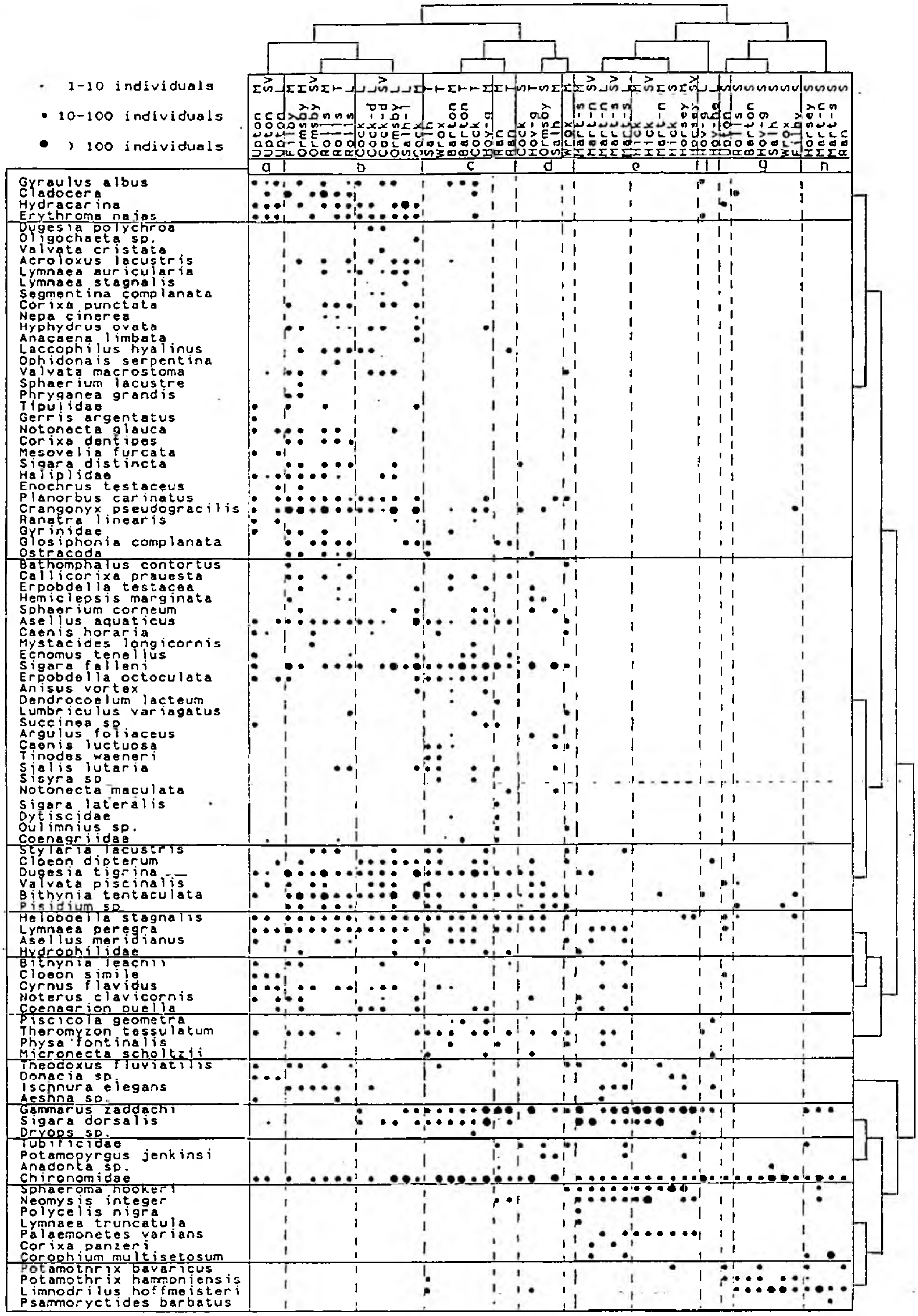

Figure 2 TWINSPAN classification of fifty-five habitats within fifteen Norfolk Broads on the basis of aquatic macroinvertebrate community structure

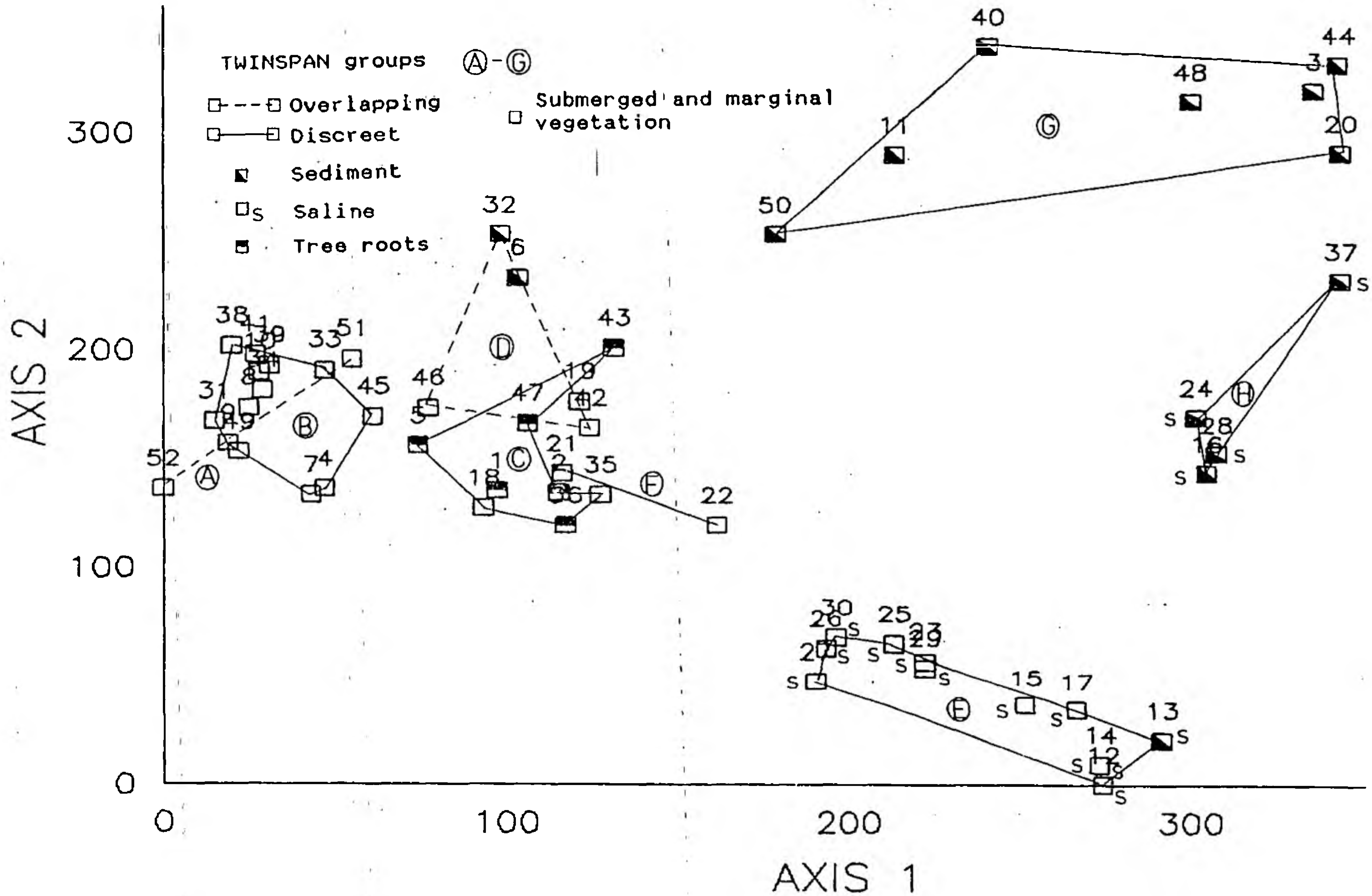

Figure 3 DECORANA axes 1 and 2 for fifty-five habitats within fifteen Norfolk Broads on the basis of aquatic macroinvertebrate community structure

latter values were derived by dividing individual eigenvalues into the eigenvalue total and multiplying by 100).

Table 2 Proportion of between-habitat variation accounted for by DECORANA axes 1-4

DECORANA - rare species downweighted

Axis	Eigen Value	% variation accounted for
1	0.531	54
2	0.238	24
3	0.122	12
4	0.100	10

Most of the variance (78%) is accounted for by axes 1 and 2 so these have been plotted, and habitats grouped by TWINSPAN linked (Figure 3). DECORANA produced habitat groups similar to those produced by TWINSPAN. So, TWINSPAN habitat groups which form discrete DECORANA clusters are linked with solid lines and overlapping habitat groups are linked by broken lines (Figure 3).

3.2 Analysis of Broad-related data

TWINSPAN - Species occurring within each broad, and the sequence of broads and species subdivisions comprising the TWINSPAN classification are shown in Figure 4. The classification was stopped after two divisions.

The first cut level separated the saline broads associated with the River Thurne (Hickling, Horsey, Martham North and Martham South) from the freshwater broads associated with the River Bure system. The second cut level acted upon the Bure Broads to separate the isolated (Cockshoot, Ormsby, Filby, Rollsby and Upton) broads from those linked to the river network.

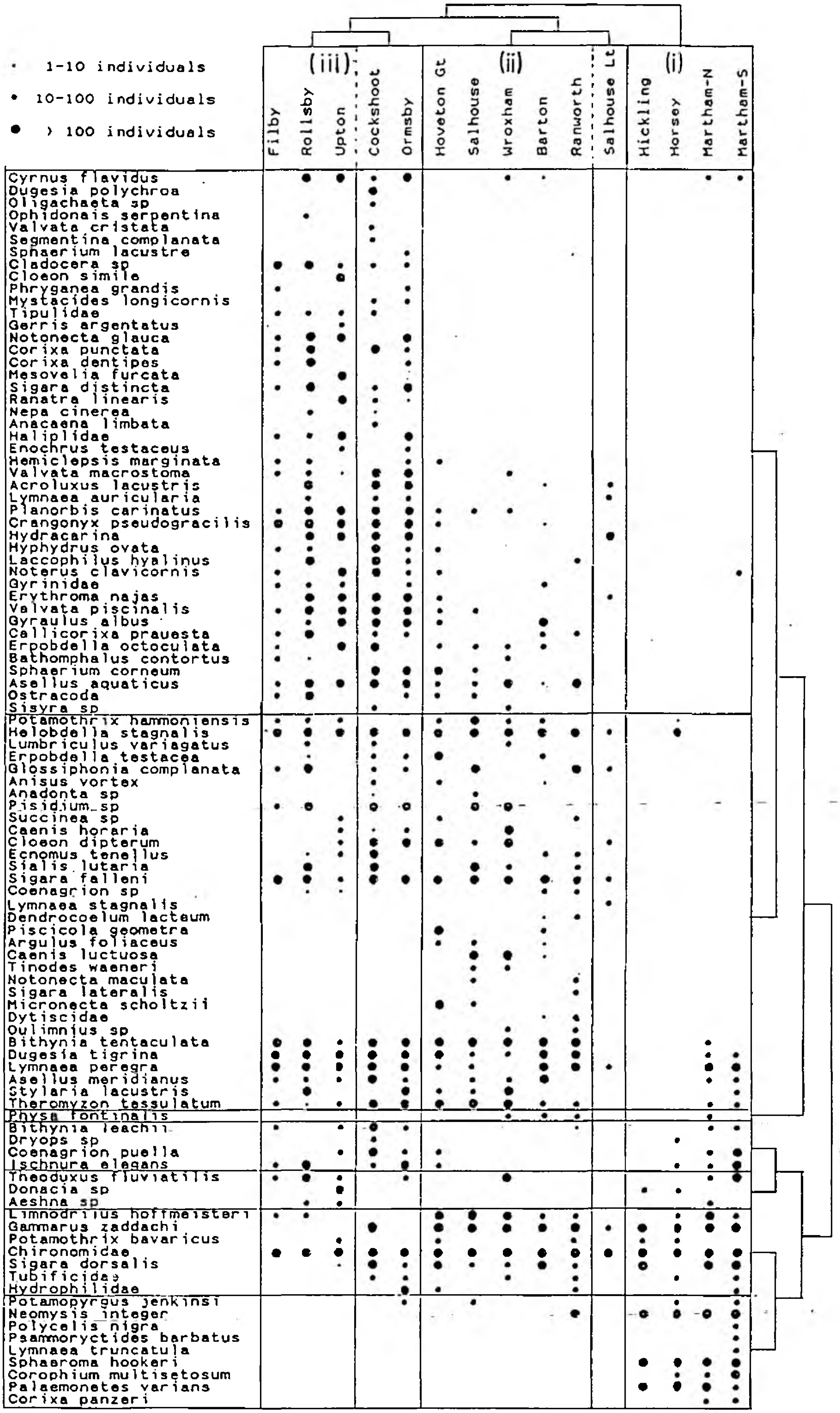

Figure 4 TWINSPAN classification of fifteen Norfolk Broads on the basis of aquatic macroinvertebrate community structure

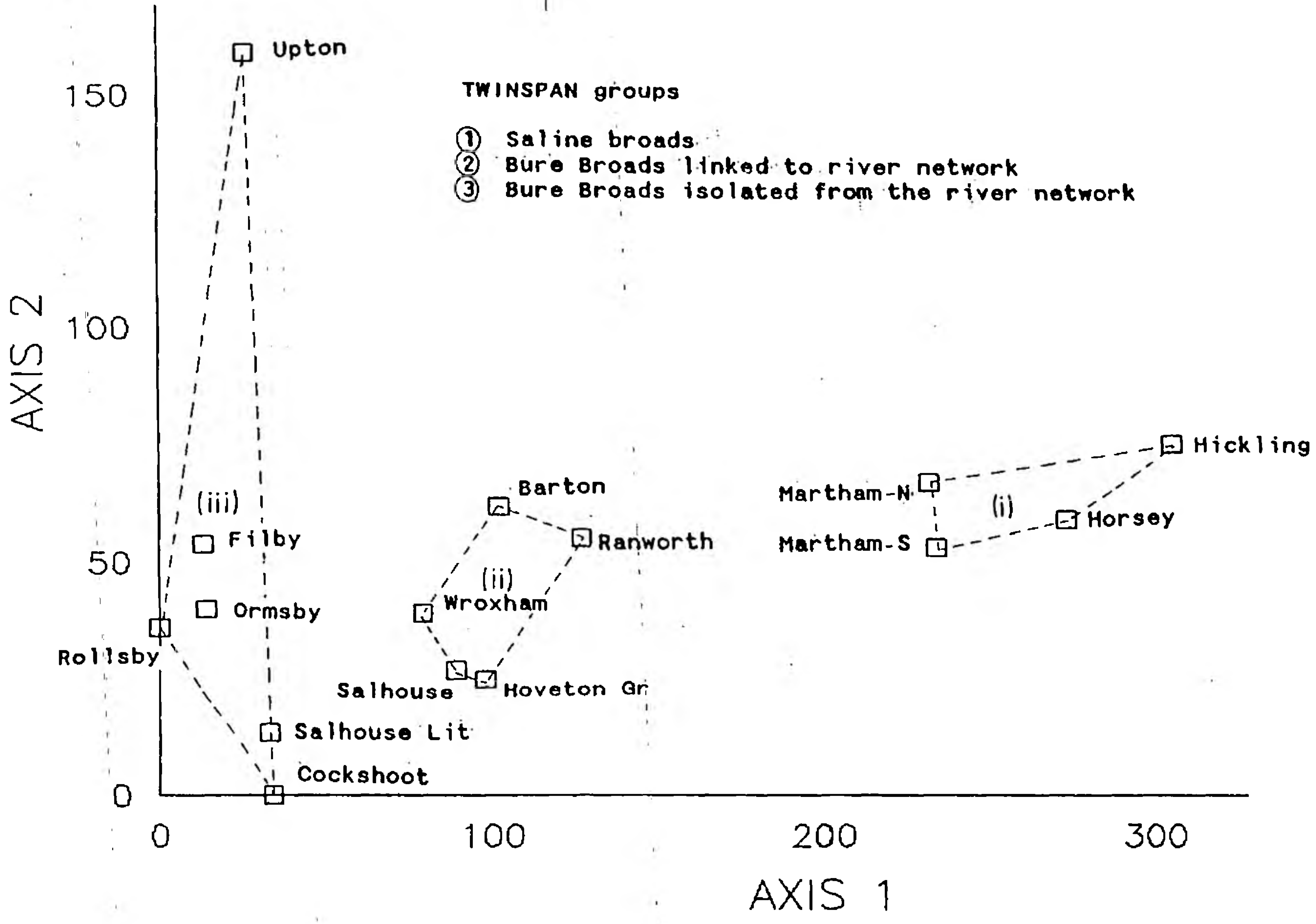

Figure 5 DECORANA axes 1 and 2 for fifteen Norfolk Broads based on aquatic macroinvertebrate community structure

DECORANA - As with the habitat analyses, the relative strengths of axes 1-4 (in eigenvalues) in the DECORANA ordination and the relative importance of each axis in explaining total variance are given in Table 3.

Table 3 Proportion of between-broad variation accounted for by DECORANA axes 1-4

DECORANA - rare species downweighted

Axis	Eigen Value	% variation accounted for
1	0.492	66
2	0.158	22
3	0.067	9
4	0.025	3

Most of the variance (88%) is accounted for by axes 1 and 2 so these have been plotted, and broads grouped by TWINSPAN linked (Figure 5). As was the case with TWINSPAN, DECORANA arranged the broads into three distinct clusters. The first contained saline broads associated with the River Thurne, the second contained freshwater broads isolated from the River Bure system, and the third contained freshwater broads linked to the River Bure network.

4 DISCUSSION

4.1 Distribution of macroinvertebrates within broads and within individual habitats

The TWINSPAN/DECORANA analyses generated three distinct clusters of broads on the basis of macroinvertebrate community structure (Figures 3 and 4). These were as follows:

i) Broads associated with the brackish River Thurne.

ii) Broads linked to the River Bure

iii) Broads isolated from the River Bure

Broads isolated from the River Bure supported more diverse communities than those which were linked to the river system. These in turn supported more diverse communities than the broads associated with the saline River Thurne. Future movement of broads in Group (iii) to a lower group would be symptomatic of a deterioration in the macroinvertebrate community, and _vice versa_.

The multivariate analyses also generated eight distinct habitat clusters on the basis of macroinvertebrate community structure (Figures 2 and 3).

Groups (a) to (d) contained habitats associated with littoral and submerged vegetation in the freshwater broads associated with the River Bure. Sediment habitats within Cockshoot Broad, which has been recently mud-pumped and the isolated Ormsby Broad were also contained within these groups. The sediment of these broads supported more diverse communities than those of other Bure Broads or the brackish broads associated with the River Thurne.

Groups (e) to (h) contained habitats associated with the sediment of all other broads, plus the vegetation of brackish broads linked to the River Thurne. The only exception was the inclusion in these groups of lily habitats within Hoveton Great Broad which supported a restricted fauna, similar in composition to those of the sediments.

4.1.1 Littoral and submerged vegetation of freshwater broads isolated from the River Bure

Habitat group A - This group comprised varied plant habitats in Upton Broad which supported populations of mayflies characteristic of still waters (Caenis horaria and Cloeon dipterum, Cloeon simile), caddisflies (Cyrnus flavidus, Ecnomus tenellus) as well as several invertebrate species with limited distributions. The water bugs, Mesovelia furcata and Gerris argentatus were restricted to Upton Broad, whereas Ranatra linearis, which also occurred, was found in other isolated broads (Cockshoot and Ormsby Broads). The mollusc Succinea sp. occurred only in Upton, Ranworth and Hoveton Great Broads, whereas the elmid beetle Donacia sp. occurred only in Upton, Horsey and Hickling Broads.

In general however, species diversity was lower than in the plant habitats of similarly isolated broads (Cockshoot and Trinity Broads). This reflected the absence of many molluscs, water bugs, and the larvae of several dytiscid beetles and damselflies (see habitat group B below).

Habitat group B - This comprised plant habitats, mainly in Cockshoot Broad and the Trinity Broads, which were associated with diverse communities of macroinvertebrates. These included mayfly (Caenis horaria and Cloeon dipterum) and caddisfly larvae (Phryganea grandis, Ecnomus tenellus,Mystacides longicornis) as well as many molluscs (Acroluxus lacustris, Lymnaea spp Valvata macrostoma), water bugs (Corixa punctata, C. dentipes, Nepa cinerea, Sigara distincta), beetles (Hyphrydus ovata Laccophilus hyalinus, Noterus clavicornis), amphipods (Crangonyx pseudogracilis) and damselflies (Ischnura elegans, Aeshna sp.).

4.1.2 Littoral and submerged vegetation of freshwater broads linked to the River Bure (plus Ormsby and Cockshoot sediments)

Habitat group C - The habitats of this group comprised mainly submerged tree roots, as other plants were less common than in the isolated Upton, Trinity and Cockshoot Broads of groups A and B. The macroinvertebrate community was correspondingly less diverse, and was dominated by water bugs (Sigara falleni, S. dorsalis), isopods, amphipods, (Gammarus zaddachi), leeches (Theromyzon tessulatum, Erpobdella octoculata), dipteran larvae and worms. Larvae of the mayfly Caenis luctuosa and the caddisfly Tinodes waeneri occurred only this group and the related group D. Although Bithynia tentaculata and Lymnaea peregra were common, many of the molluscs characterising group B were absent from group C.

Habitat group D - This group contained plant habitats within broads linked to the River Bure, and sediment habitats in Ormsby and Cockshoot Broads. The communities associated with these habitats were similar to those of group C.

4.1.3 Submerged and marginal vegetation of brackish broads (plus sediment of Hickling Broad and lilies of Hoveton Great Broad)

Habitat group E - This group comprised submerged and marginal vegetation of brackish broads plus the sediment of Hickling Broad. The macroinvertebrate community associated with these habitats differed markedly from those described previously.

Apart from the polycentropid Cyrnus flavidus, which occurred in the Martham Broads, there were no mayfly or caddisfly larvae. The Martham Broads' community was more diverse than those of Hickling Broad and Horsey Mere and featured molluscs (Lymnaea peregra, Bithynia leachii, Physa fontinalis) the isopod Asellus meridianus and damselfly larvae. The amphipod Gammarus zaddachi was common in all three broads, and the waterboatman Sigara dorsalis was common in Hickling and Martham Broads.

This group also featured species characterising the brackish environment such as the isopod Sphaeroma hookeri, the marine mysid Neomysis integer, the amphipod Corphium multisetosum and the prawn Palaemonetes varians which reproduces only in brackish waters.

Habitat group F - This group comprised Hoveton Great Broad's lily habitat, the invertebrate community of which resembled that of group E but without the brackish component.

4.1.4 The sediment of all broads (except Ormsby and Cockshoot)

Habitat group G - This group included sediments within the Bure Broads (except for Cockshoot and Ormsby), the community of which comprised largely chironomid larvae and oligochaete worms.

Habitat group H - This group included sediment habitats of the brackish broads (except for Hickling) and the freshwater Ranworth Broad. The communities associated with these habitats comprised mainly chironomid larvae and oligochaete worms, with the characteristic brackish organisms (Sphaeroma hookeri, Neomysis integer or Corphium multisetosum) occurring occasionally.

4.2 Interrelationships between lake communities and the physico-chemical environment.

The community structure of a lake's secondary producers is influenced by the type of habitat avialable for colonisation, the physico-chemical conditions presiding in the lake and the abundance of predators or prey organisms. Environmental conditions can influence the community either directly, by selecting for, or favouring certain species, or indirectly by influencing the organism's food source or predators (Figure 6).

The interrelationships between plankton, vascular plants, zoobenthos and fish are often so delicately balanced, that changing one component may produce dramatic changes in one or all of the others. However, some pathways within this web of interrelationships, convey energy more efficiently than others, so that changes which occur in the communities responsible for these efficient energy transfers, can severly affect the functioning of the ecosystem. Energy generally moves more efficiently between plankton and fish than between zoobenthos and fish or zoobenthos and plankton, so lake studies have invariably concentrated on nutrient-plankton-fish interactions.

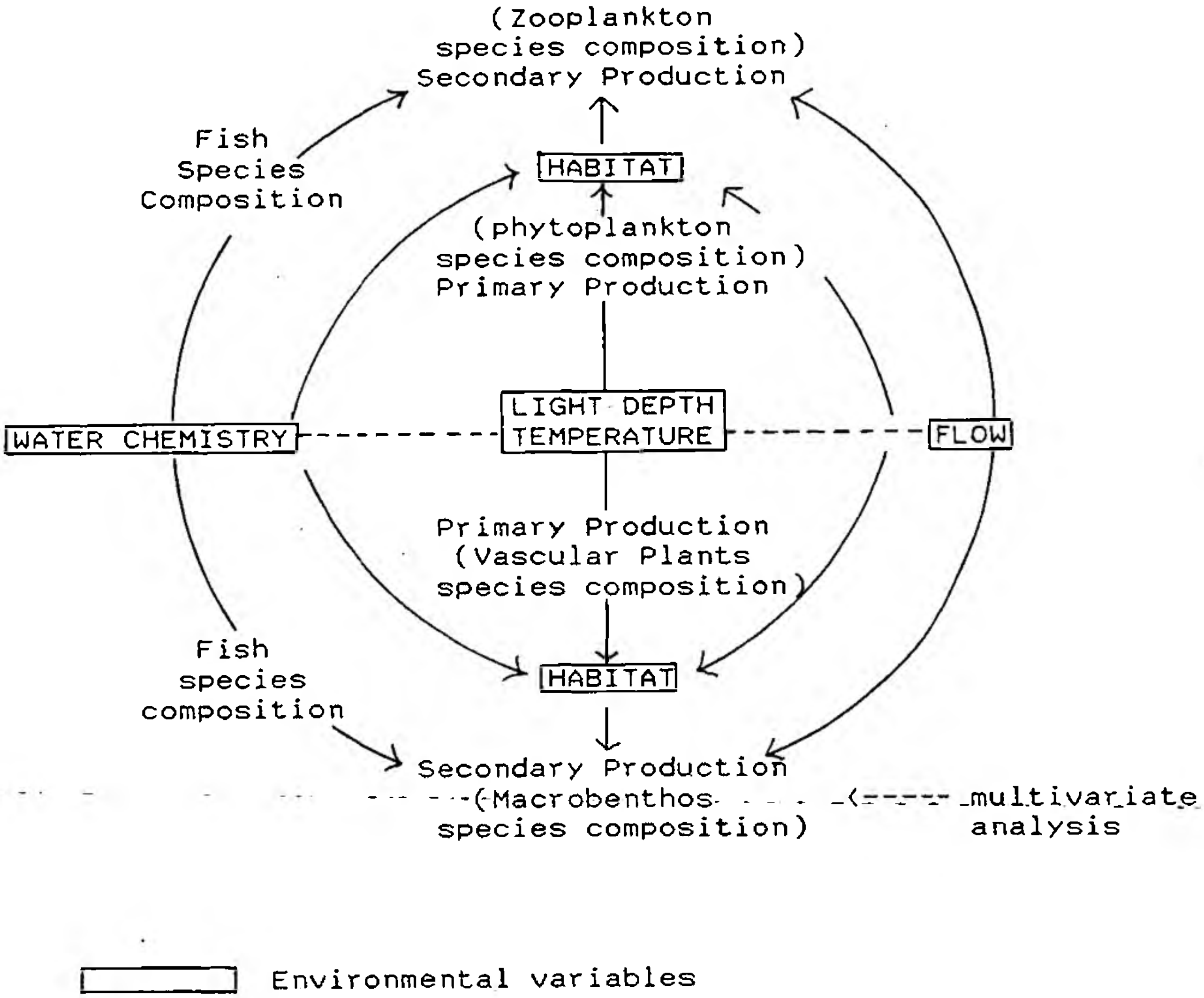

Figure 6 Relationships between environmental variables and biological communities in the lake environment

The long life cycles and static habitat of many benthic invertebrates compared with zooplankters means that the zoobenthos presents a relatively long-term record of conditions within a lake. Conditions within the lake may initially favour certain fast-growing, invasive species, which as they increase in numbers may modify the habitat and water around them to produce conditions favouring other organisms. In this way, the benthic habitat and community may develop into a rich matrix of interacting species. Multivariate techniques, by analysing community structure and environmental variables, can suggest the factors which have exerted most influence on a lake ecosytem over a period of time. Similar analysis of the zooplankton community might reveal factors which exert a strong but shorter-term effect on the ecosystem.

It is therefore important to incorporate the NRA's archive environmnetal data into the multivariate analyses in order to reveal the factors which are important in producing the broads' clusters presented in this report. This could be achieved in two ways. The first possibility would be to analyse variance within the environmnental data set with multiple discriminant analysis (MDA), which would distribute the sites within the prescribed TWINSPAN/DECORANA-derived group structure. Provided MDA allocates sites in a similar way to TWINSPAN/DECORANA, it should be possible to suggest which environmental factors most influence each habitat group (or broad). An alternative method would involve re-ordinating the combined macroinvertebrate and environmental data sets with canonical correspondence analysis (CANOCO), which would indicate the relationship between individual environmental variables and the ordination axes (ter Braak, 1988).

5 CONCLUSIONS AND SUMMARY

1) The study has developed a system, based on multivariate statistics, for investigating the environmental factors affecting benthic macroinvertebrate communities within individual Norfolk Broads.

2) The system is based around the TWINSPAN and DECORANA (Hill, 1979 and 1979a) routines but may be modified to incorporate more recent delelopments in multivariate methodology such as CANOCO (ter Braak, 1988).

3) When applied to data collected in 1990, the system recognised distinct differences between the macroinvertebrate communities associated with three groups of broads. These groups were:

i) Broads associated with saline conditions of the Thurne river system

ii) Broads linked to the Bure river system

iii) Broads isolated from the Bure river system

4) Broads isolated from the River Bure supported more diverse communities than those which were linked to the river system. These in turn supported more diverse communities than the broads associated with the saline River Thurne. Future movement of broads in Group (iii) to a lower group would be symptomatic of a deterioration in the macroinvertebrate community, and *vice versa*.

5) The system also recognised distinct differences between the macroinvertebrate communities associated with various habitats. The habitats were:

a) Sediment

b) Submerged and marginal vegetation

c) Tree roots.

Sediment habitats within Cockshoot Broad, which has been recently mud-pumped, and the isolated Ormsby Broad supported more diverse communities than those of other Bure Broads or the brackish broads associated with the River Thurne.

6) The system should be further developed so that environmental variables can be correlated with macroinvertebrate-based classification. This could be achieved in two ways:

The first possibility would be to analyse variance within the environmnental data set with multiple discriminant analysis (MDA), which would distribute the sites within the prescribed TWINSPAN/DECORANA-derived group structure. Provided MDA allocates sites in a similar way to TWINSPAN/DECORANA, it should be possible to suggest which environmental factors most influence each habitat group (or broad).

An alternative method would involve re-ordinating the combined macroinvertebrate and environmental data sets with canonical correspondence analysis (CANOCO), which would indicate the relationship between individual environmental variables and the ordination axes (ter Braak, 1988).

7) It would also be very interesting to manipulate archived data relating to broads' plankton populations with the multivariate statistics used in the present survey. The results of such manipulations could then be compared with those described in this report, with a view to developing a integral model to unify macroinvertebrate, plankton and environmental data.

6 ACKNOWLEDGEMENTS

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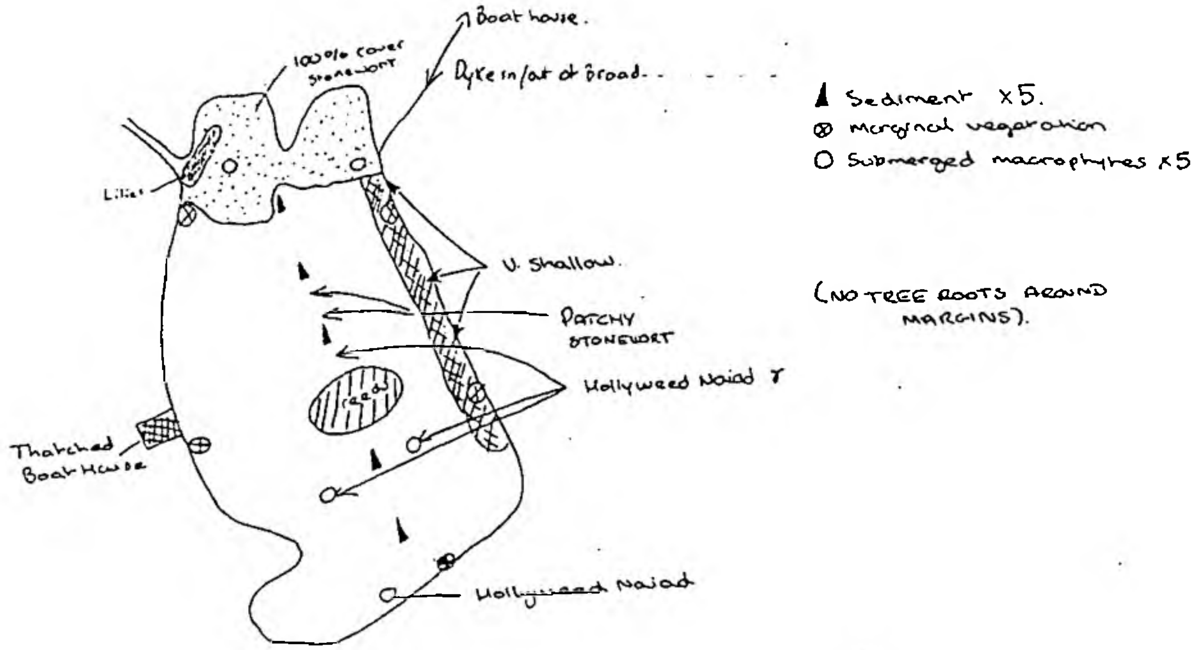
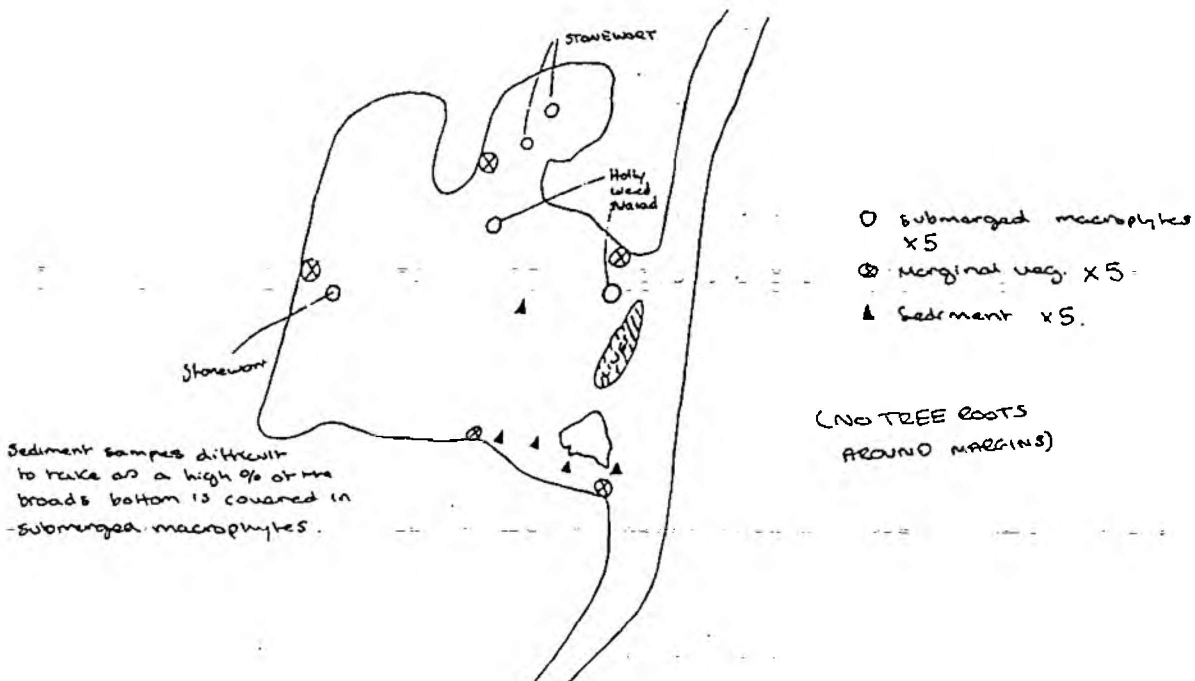
Appendix

(the sketches included in this section are not to scale)

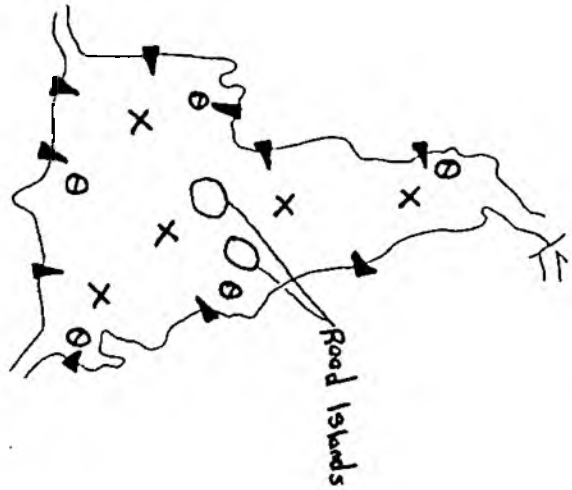
Martham South Broad



Martham North Broad



Horsey Broad



▼ Littoral Emergents - Phragmites, Typha, X10 Bulk (net)
No Tree roots phragmites dominated fringe

X Open water sediment
X5 Net

⦶ Submerged Macrophytes
Dom. by Myriophyllum, some Potamogeton (narrow leaved)

Hoveton Great Broad

▼ Littoral Emergents x 10 Bulk (net)
Carex phragmites

T Tree roots x10 Bulk (net)

⦶ Water-lillies -- Dying back x5

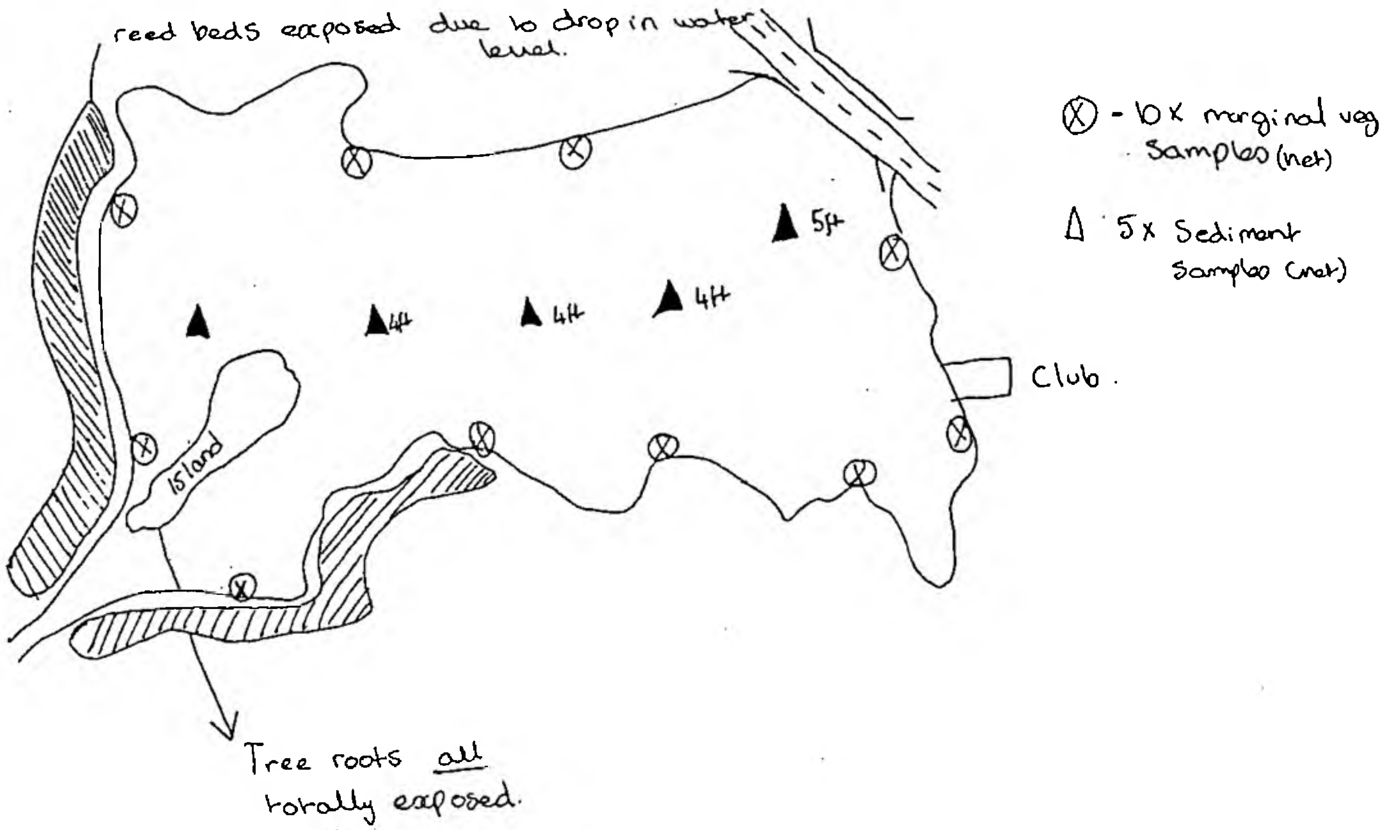
X Open water Sediment x 10 Bulk GRAB

Haughs End - water lilies at South only x 5 bulk

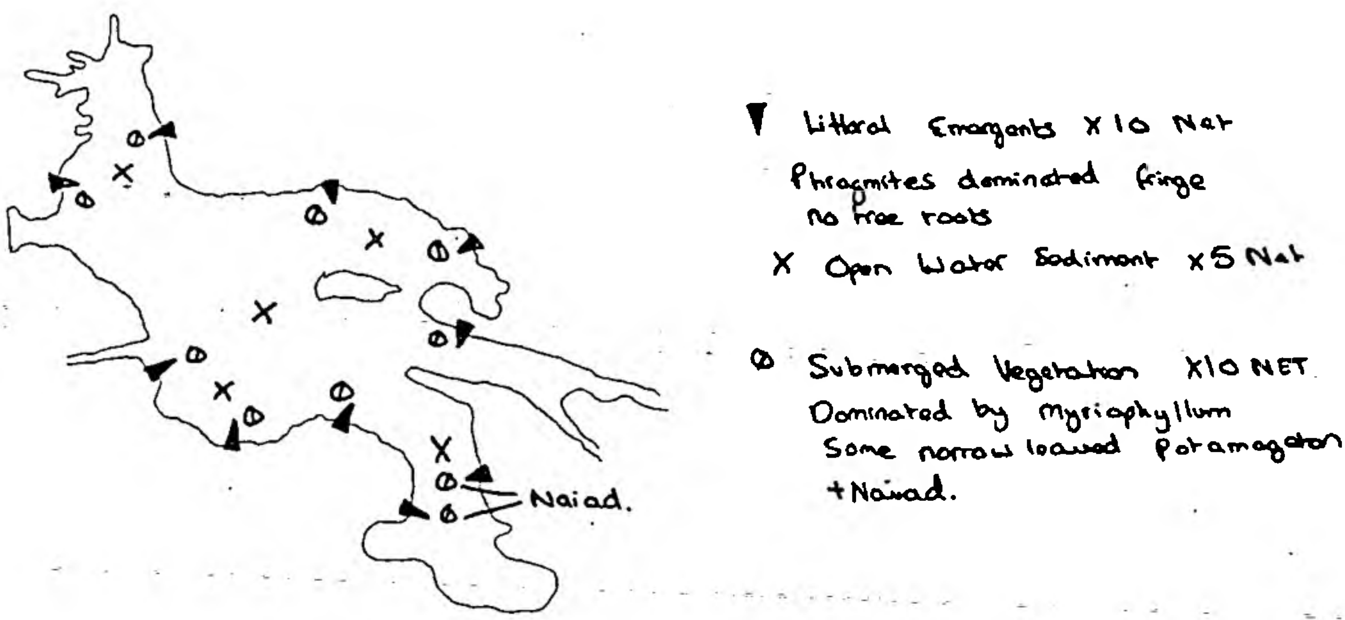
Salhouse Little Broad

Water lillies sampled only 5 x Bulk Net
Dying Back many fruiting bodies

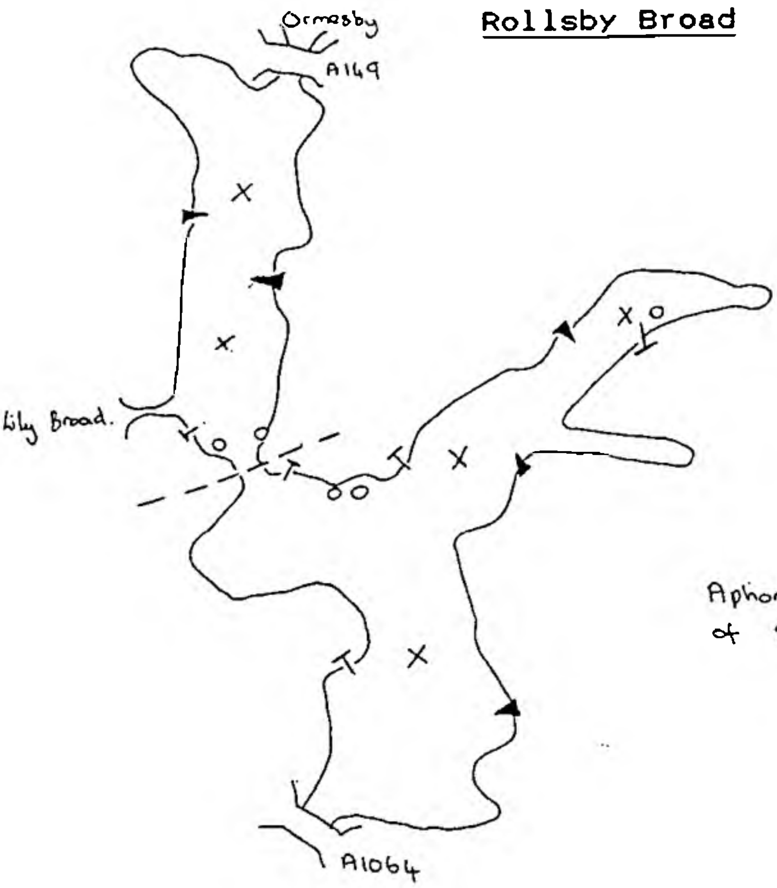
Filby Broad



Hickling Broad



Rollsby Broad



▼ Littoral Emergents – phragmites Typha some Schoenoplectus. x 5 Bulk (net)

T Tree roots x 5 Bulk (net)

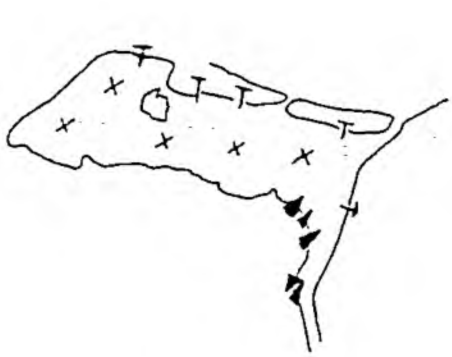
Marginal Veg. dom by littoral Emergents.

O Water lillies x 5 Bulk. (net).

X Open water Sediment. x5 (net) (Deep water)

Aphanizomenon Bloom is southern portion of Broad – ie below – – – – –

Salhouse Broad

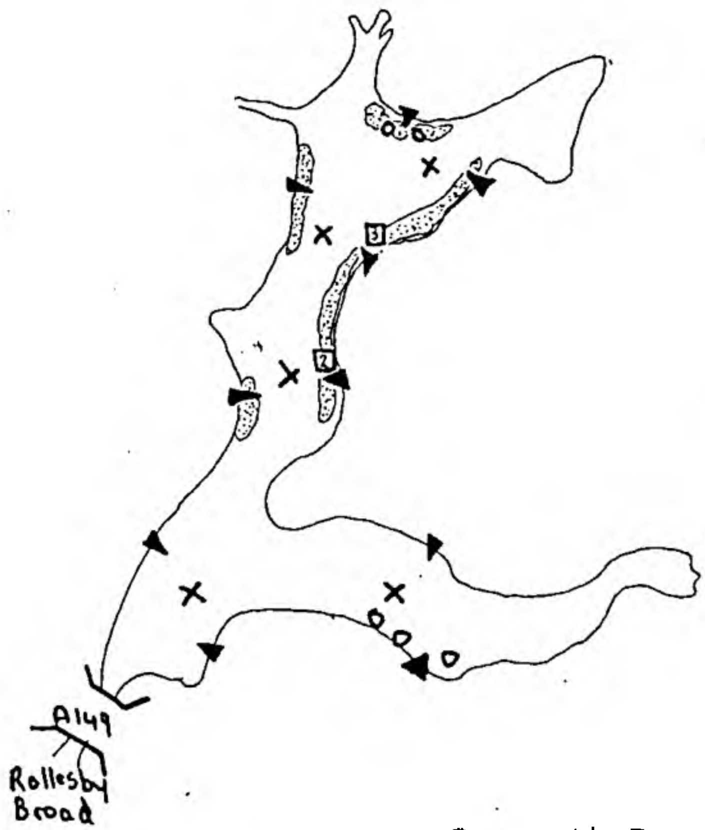


▼ Littoral Emergents 5x Bulk (net)
Phragmites, Glyceria, Carex

T Tree Roots 5x Bulk (net).

X Open Water sediment 5x Bulk (net).

Ormsby Broad



▼ Littoral Emergents - phragmites X10 Bulk Net Typha, Scoenoplectus

No Tree Roots. Phragmites dominated fringe

X Open Water Sediment X5 bulk GRAB

O Water lilies X5 Bulk Net

☐ Submerged Vegetation Chara beds 100% Cover in areas sampled X5 Bulk GRAB

Extent of Chara beds as observed during sampling.

Ranworth Broad

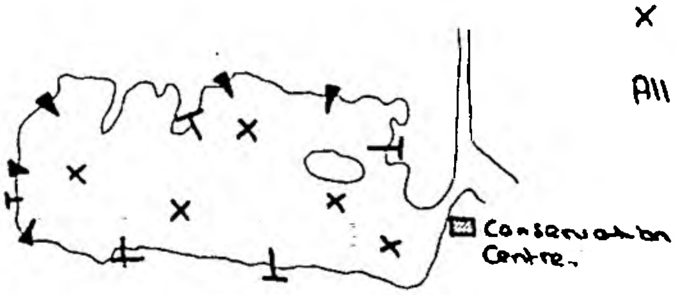
▼ Littoral emergents Net

T Tree Root Net

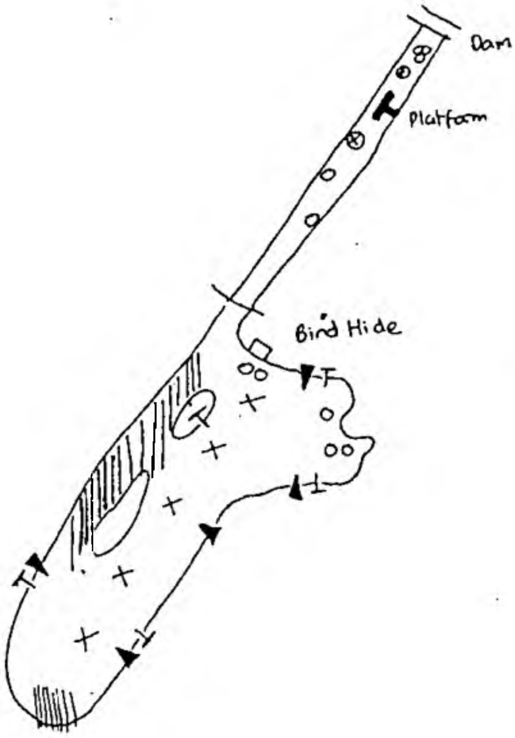
X Open water sediment GRAB

All X5 Bulk

V. little mainly tree lined margins. Small patches of Typha, phragmites. Diff. to sample due to low water level.



Cockshoot Broad



▼	Littoral emergents	Phragmites Carex sp. Typha	5xBulk Net
T	Tree roots	Alder	5x Bulk (net)
O	Water Lillies		5x Bulk (net)
X	Open water Sediment		5x Bulk Grab
////	Exposed Sediment due to low water levels		

Dyke

O	Water lillies	5x Bulk (net).
⊗	Submerged Veg – Ceratophyllum	2x Bulk (net)

Barton Broad

▼	Littoral emergents – phragmites, Typha, Carex	x5 Net
T	Tree Roots	
X	Open Water Sediment	5x Bulk. Grab + Net (often too deep for grab

No submerged vegetation seen.

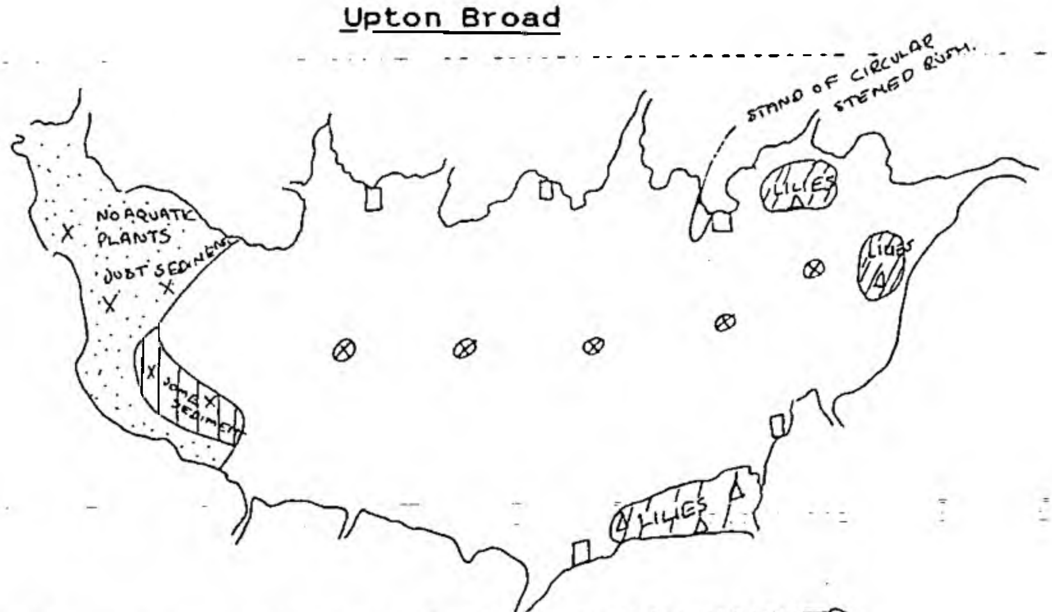
Wroxham Broad

Littoral Emergents x 5 Bulk (Net)
Phragmites, Typha, Carex.

T Tree Roots x 5 Bulk. (Net)

X Open water Sediment. x 5 Bulk (net).

Upton Broad



⊗ Submerged Macrophytes x 5 . - DOMINATED BY HOLLYWEED.

X Sediment x 5

☐ Marginal vegetation x 5

Δ LILIES x 5