Synoptic Limnology

The Analysis of British Freshwater Ecosystems

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First published 1979
ISBN 0904282 30 9

The cover shows Fee Burn, a cascading highland burn in Perthshire (Tayside Synoptic Survey). Photograph K East.

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The Institute of Terrestrial Ecology (ITE) was established in 1973, from the former Nature Conservancy's research stations and staff, joined later by the Institute of Tree Biology and the Culture Centre of Algae and Protozoa. ITE contributes to and draws upon the collective knowledge of the fourteen sister institutes which make up the *Natural Environment Research Council*, spanning all the environmental sciences.

The Institute studies the factors determining the structure, composition and processes of land and freshwater systems, and of individual plant and animal species. It is developing a sounder scientific basis for predicting and modelling environmental trends arising from natural or man-made change. The results of this research are available to those responsible for the protection, management and wise use of our natural resources.

Nearly half of ITE's work is research commissioned by customers, such as the Nature Conservancy Council who require information for wildlife conservation, the Forestry Commission and the Department of the Environment. The remainder is fundamental research supported by NERC.

ITE's expertise is widely used by international organisations in overseas projects and programmes of research.

Contents

Background

Surveys of various fresh waters in Great Britain have been carried out in the past, ranging from detailed studies of one particular water body to broader surveys of a large number of waters (often with reference to only one group of organisms). Although individual studies have been of value, the more extensive surveys have proved of greater and longer – lasting worth. Outstanding among such is the study of 562 lochs in Scotland carried out by Murray & Pullar (1910). This work is still used widely among those concerned with freshwater research in Scotland, though it is very incomplete biologically. The normal disadvantage with such accounts is that, within any one study, only a limited number of parameters were described, while, among several studies, not only were different parameters measured, but a wide range of methods may have been used to measure them. The synoptic value of such works is therefore greatly reduced, and, for this and other reasons, 'surveys' are often regarded as having little other than descriptive value in ecology. This account illustrates the importance of a synoptic approach to the study of British fresh waters and outlines how it has been initiated. The primary aim of the research described is to provide a scientific background for the interpretation and classification of aquatic ecosystems in Great Britain – particularly for conservation and management purposes. The synoptic data bank will also be a major source of autecological information.

Apart from the descriptions arising from survey data, their potential predictive worth is something which is often overlooked. The normal experimental approach to predictive problems in fresh waters is difficult both in execution and interpretation. The prediction of the nature of new or modified aquatic systems can also be investigated using simulation models. Experience at a number of IBP sites has demonstrated the difficulties associated with using models developed at a single site as a means of general prediction – absurd results often occurring if the assumed ecosystem dynamics are in error. Without elaborating the topic of mathematical modelling, it is fair to say that the practical use of models demands comparative data on freshwater systems of a quality which is not yet available. In particular, the information obtained through extensive survey can often complement the development of specific site models.

The Synoptic Approach

The project discussed here is a long-term study of British freshwater ecosystems with a view to classifying them, describing their variety, and, eventually, to understanding the structure of their communities and the habitat requirements of different organisms. The initial sections of the research define the national resource and are desk studies aimed at describing the numbers and variety of fresh waters, the range of species of animals and plants which inhabit them, and the published literature relating to freshwater sites and organisms in Great Britain. The philosophy in developing these parts of the project is to be truly synoptic and all types of water and organisms are being considered as objectively as possible. Because of the breadth of this study, and the enormous amount of information being gathered, it is only possible here to summarise the main facets of the work and to describe briefly how the information is being organised (Figure 1). The desk studies are conveniently divided into three sections, covering map studies of running and standing waters, coded check lists and bibliographies.

These desk studies form an invaluable background to current field projects of a more detailed nature. These projects include a major analysis of the fresh waters of Shetland, a more recent parallel study of the fresh waters of Tayside, and a rather briefer account of the inland waters of the Outer Hebrides. It is already possible to place freshwater systems in a general national perspective and to be more certain about their uniqueness or otherwise. Plates 1–11 and cover illustrate a few of the many sites, covering a wide variety of types, which have been studied so far. Several of these are known to be of unique scientific interest.

The two main requirements of the synoptic study – detailed information on the physico-chemical status and biological communities of each water concerned and the inclusion of a reasonable number of waters over a wide geographic area – appear to some extent to be incompatible where available manpower and technical resources are limited. Nevertheless, a scheme involving a relatively small number of people has proved perfectly practical provided the relevant expertise is available within the team concerned, the project itself is carefully planned, and adequate equipment and other resources are available.

The research group concerned in this project is based on a small multi-disciplinary team established in Edinburgh in 1967 and formerly involved in two major

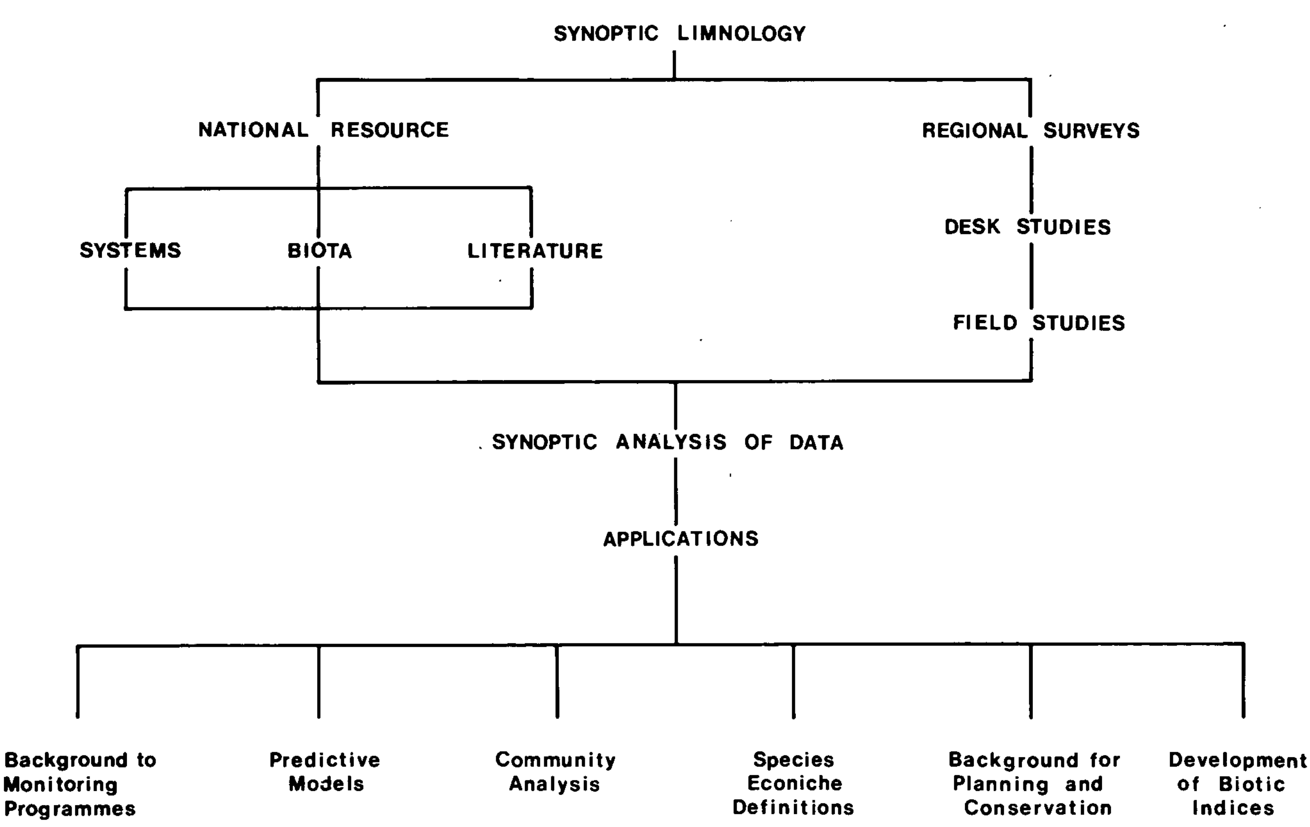


Figure 1 A network diagram illustrating the main aspects of the existing synoptic limnology programme. Only some of the potential applications are listed.

projects covering exactly the contrasting requirements just mentioned: the Loch Leven IBP Project, a detailed study of this important eutrophic lake which is now among the best known in the world, and the Nature Conservation Review of important open water systems in Great Britain with particular reference to their scientific status and conservation: this project is discussed further below. Experience gained during both detailed and general types of project has shown that any scheme for synoptic study must be planned ahead in detail, and that time must be available for preliminary desk studies well in advance of any field work.

There are a number of independent reasons for wishing to develop a comparative synoptic study of the freshwater ecosystems in Great Britain. The fresh waters of this country are a major national resource, yet surprisingly little is known about them in general terms – especially from the biological point of view. For example, we know little about the ecology of Loch Morar (Britain's deepest lake) or the River Tay (Britain's largest river) – both waters of national importance. The present research programme includes both these systems and many others of major importance – some of them apparently unique. Comparable studies are increasingly being carried out in other countries of the world (Martin et al 1953, Gollop 1965, Wright & Lysholm 1975) as pressures on limited resources become greater.

The Nature Conservation Review (Ratcliffe 1977) highlighted our ignorance of the scientific status and conservation value of large numbers of fresh waters in Great Britain – even some which were already nature reserves. It is essential that organisations involved in the assessment and management of waters of national scientific importance have detailed knowledge of the status of these relative to other waters. Because of lack of time, the Nature Conservation Review was far from complete and many sites of possible national importance were excluded from the original survey. On the other hand, several sites thought previously to be of importance were shown to have deteriorated due to changes in land management, etc. Thus, there is a need for continued assessment in this field. It is important too that regular international reviews of major wetlands take place (Leitch 1966, Luther & Rzoska 1968) and that British sites are placed in context.

The importance of changes within ecosystems over a period of time is now widely recognised and several global monitoring schemes are being developed.

Plate 1 Loch Brandy: an oligotrophic highland loch in Angus (Tayside Synoptic Survey). Photo: K H Morris.

Accurate studies carried out on a series of waters from time to time will provide valuable information on rates of change for both national and international purposes. One of the major changes taking place in fresh waters in Britain and highlighted by recent surveys is a decline in the distribution and abundance of higher plants in lowland areas. This decline appears to have been very rapid in some waters and may be related to changes in agricultural practice. Survey and monitoring of selected sites should give a valuable insight into the causal factors and form a firm basis for experimental work on this problem.

In order to allow ecologists and planners to assess the scientific priority of any particular water body, it is essential not only to know a reasonable amount about the water itself but also to have national (and ideally international) baselines against which to assess it. Such comparisons are necessary in the fields of pollution, conservation, fisheries and elsewhere. The essential baselines can only be described adequately through some form of synoptic study covering the necessary range of systems and parameters (Rose & Morgan 1964).

One of the kinds of advice most frequently sought from ecologists, and, indeed, the ultimate aim of many research projects, is related to prediction. What kind of lake will be created if a dam is constructed at site x? What will be the effect on the river of abstraction at site y? Only rarely is it possible to give such advice and that proffered at present is very often intuitive. Synoptic studies offer one of the most promising ways to develop a predictive ability in the aquatic field, if enough accurate information is available from different waters.

Plate 2 Llangorse Lake: a eutrophic lowland lake in Breconshire (Nature Conservation Review).
Photo: R H Britton.

The National Resource

STANDING WATER SYSTEMS

A count has been made of all lakes, reservoirs and other water bodies marked on the 1:250000 OS maps, as an initial step in defining the nature and extent of the freshwater resources of Great Britain. The location of each (by name and National Grid Reference) and physical features, such as depth and area, have been tabulated. This study makes it possible to list all waters meeting specified conditions of location and physical characteristics. It allows research and experimental work (including biological sampling) to be planned more efficiently and also makes more effective use of existing knowledge.

Various tests of the adequacy of the count have been made. These indicate that it will not normally include water bodies less than 4 ha in area, and only account for 10% of all the waters marked on the 1:63360 maps. Thus, the total count of waters in Great Britain in the original study is 5505, while the estimated number missed (ie less than 4 ha) is 57176. The total area occupied by waters included in the original count is 1926 km^2. Regression equations relating mean depth to area and maximum depth to mean depth have been used to estimate the total volume of the waters counted: the total for Great Britain is 38 km^3.

Plate 3 Afon Ffraw: a sluggish lowland weedy stream in Anglesey (Nature Conservation Review). Photo: R H Britton.

Roughly one half of the waters in the original count are in the highlands and islands of Scotland (Figure 2). The absolute total area of inland water in Great Britain is estimated to be 2451 km^2, or just over 1% of the area of land. As might be expected, the results emphasise the dominance of north-west Britain in terms of quantity – Loch Ness alone, for example, contains more water than all the lakes and reservoirs in England and Wales put together. Surprisingly little is known about the ecology of these large bodies of fresh water.

RUNNING WATER SYSTEMS

Basic data have also been tabulated on all river systems in Great Britain which are marked on the 1:625000 OS map. The results, like those for the lake counts, have been summarised for each Hydrometric Area (Figure 3). The main measure of size used is stream order – where a stream without tributaries is defined as first order, the stream below the confluence of two first orders is second order, and so on. The analysis includes both the total number of river systems of each order and the total number of streams within them. The provisional totals for these are 1445 and 7835 respectively.

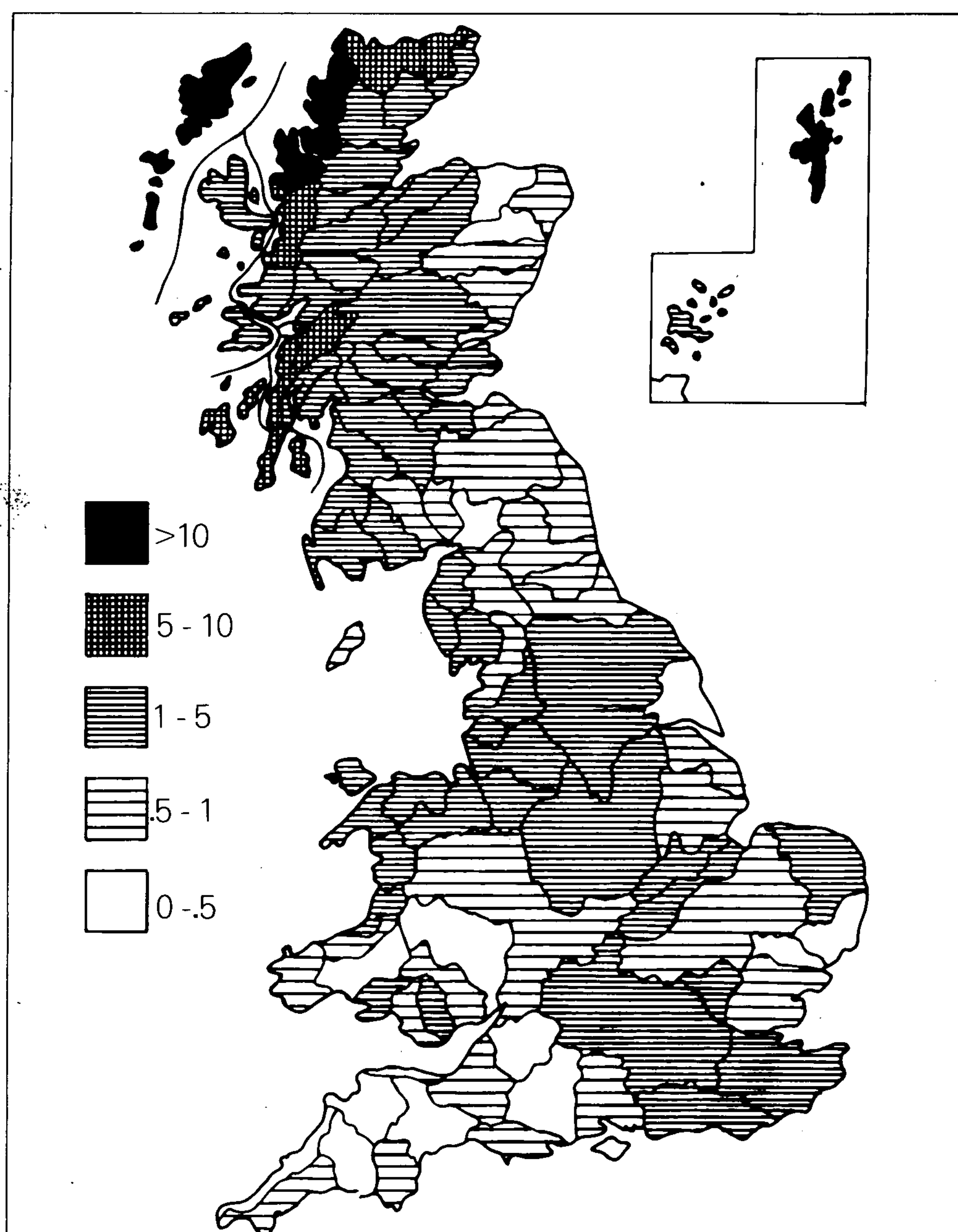


Figure 2 The density of standing waters per 100 km^2 in each of the Hydrometric Areas of Great Britain (from Smith & Lyle 1978). Notice the high number of waters in the north west.

Tests have been carried out on comparisons of the running water systems shown on the 1:625000 and the 1:63360 maps. Thirteen sample lengths of coast were examined. It was found that the number of additional systems on the 1:63360 map, can be estimated if the number on the 1:625000 map is known. The results also show that 67.8% of the streams had the stream order of the sea inflow increased by 2 when comparing the original order with that on the larger scale map. It is therefore possible to estimate, on average, how stream data may be transformed to take account of map scale.

The details of these counts of both standing and running waters (Table 1) are at present in press (Smith & Lyle 1978).

AQUATIC ANIMALS

The purpose of this section of the study is to provide a comprehensive list of all free-living animals, from sponges to mammals (but excluding Protozoa) which occur in or in association with freshwater systems in the British Isles. It is organised in such a way that each species of animal can be represented by a unique 8-

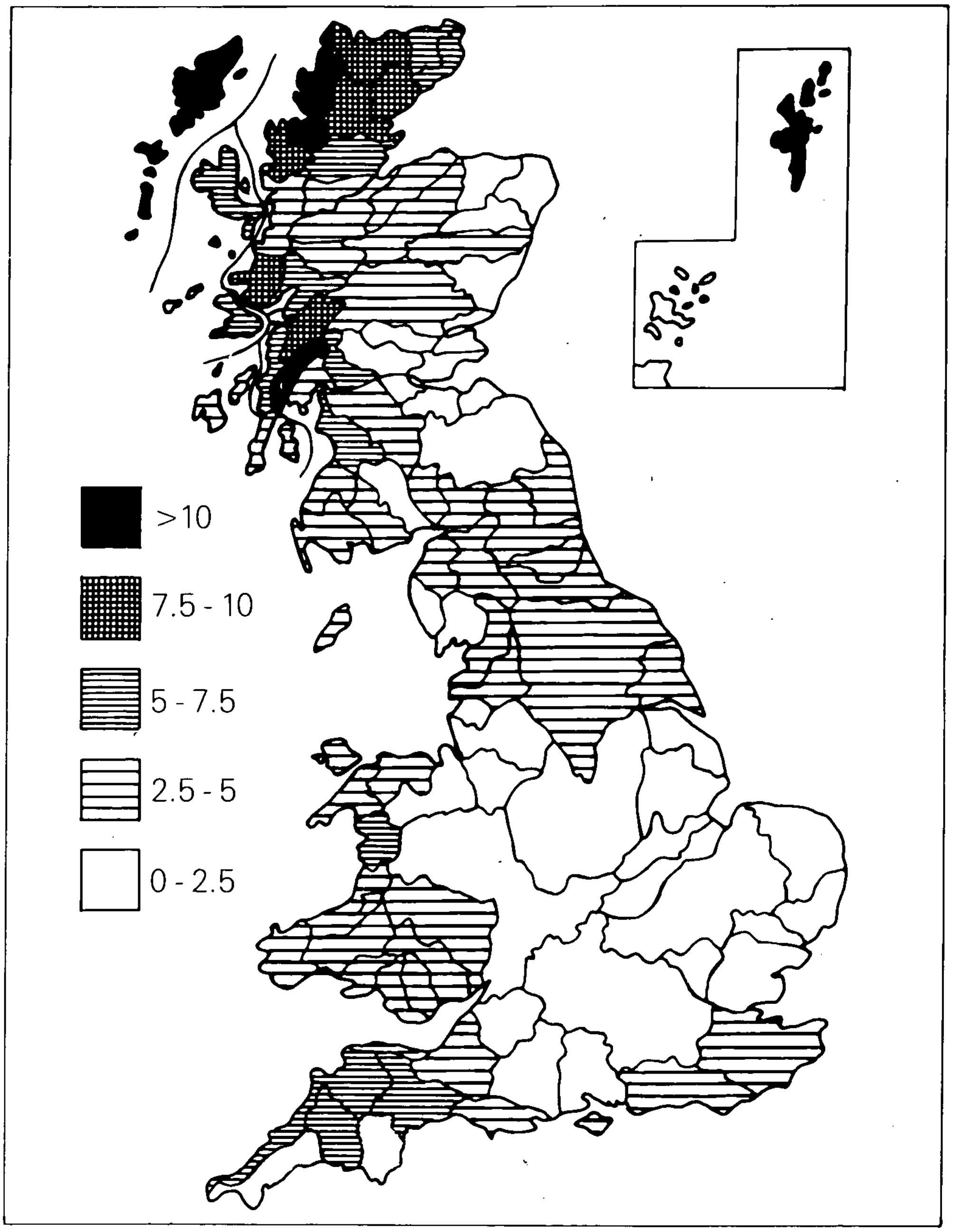


Figure 3 The density of running waters per 100 km^2 in each of the Hydrometric Areas of Great Britain (from Smith & Lyle 1978). Compare with Figure 2.

Table 1 The systems resource: the estimated total number of lakes and streams in different size groups in Great Britain (from Smith & Lyle in press)

Lakes (Area)	Mainly <4 ha	Mainly 4–250 ha	0.25–1 km²	1–4 km²	4–16 km²	16–32 km²	>32 km²
	56,176	4,416	848	177	51	9	4
Streams (Order)	1	2	3	4	5	6	7
	146,853	36,534	8,894	1,937	386	66	4

digit code, thus establishing a standard and relatively easy basis for handling species lists, etc. numerically. This check list (Maitland 1977), containing over 3800 species, has been produced in parallel to the lake and river counts described above. These and associated studies provide a powerful tool for handling and analysing data on freshwater ecosystems in this country and a firm basis for planning and conserving the freshwater environment in Great Britain.

As far as the actual species listed are concerned, it has been necessary to make a number of subjective decisions about those animals to be included or excluded. In general, where a recent taxonomic key or check list to freshwater species is available for any group, then this key has been followed more or less exactly. Where there is doubt about the validity of records of a species, it has normally been included in the list to avoid insertion at a later date. Thus, the presence in the list of a particular species should not be taken as an assurance that it occurs in Great Britain. As far as habitat is concerned, similar decisions have been made where there is doubt as to whether any species is aquatic or terrestrial, freshwater or marine. Thus, parallel check lists of terrestrial or marine animals will be likely to contain some of the same animals.

It is intended that this list will be useful to those freshwater ecologists throughout the country who are concerned with sampling, identifying and analysing mixed collections of animals, and it is closely linked with the taxonomic keys in greatest use. Some problems have arisen, however, related to keys which do not have an accompanying check list, or where new species have been discovered since publication. In these cases, compromises have been reached, based on the best literature and advice available. The main published sources of information used for each group are indicated. Naturally, it will be necessary to revise the list from time to time, as revisions of different groups are published.

Because of the increasing numbers of studies of aquatic animals being carried out by freshwater ecologists, especially in the fields of water supply, pollution prevention, fisheries and conservation, a common check list, particularly a coded one, is becoming more and more desirable. The present list is sufficiently extensive and versatile to meet the needs of almost all freshwater ecologists in the British Isles. It has already been adopted by the Water Data Unit of the Department of the Environment as part of their water archive system and will therefore be the basis of future data banks of freshwater animals for Water Authorities in England and Wales.

Table 2 The biological resource: the approximate numbers of genera and species in the four major groups of aquatic plants and animals in Great Britain.

Group	Genera	Species	Reference
Algae	334	1,000	Whitton, *et al* 1978*
Macrophytes	171	409	Unpublished
Invertebrates	1,132	3,597	Maitland, 1977
Vertebrates	139	277	Maitland, 1977
Totals	1,776	5,283	

*Incomplete list

AQUATIC PLANTS

A draft list of higher plants, containing 409 species, has been produced and is being coded in parallel with the list of animals. This checklist will be published in due course. Consideration is also being given to a coded check list of freshwater Algae, but, in view of the current problems in producing even a preliminary list (Whitton et al., 1978) this list may have to wait for some years. Preliminary figures for the major groups are noted in Table 2. It can be seen that a minimum of 1,776 genera and 5,283 species of plants and animals occur in fresh waters in Great Britain.

LITERATURE

The major effort on the zoological section of a synoptic bibliography has now been completed. Most obvious journals have been searched from their inception up to 1970, and references to papers dealing with freshwater sites or organisms in the British Isles have been extracted (Table 3). The more obscure journals and a number of less easily available (mainly local scientific society) publications remain to be examined and this examination will be done as opportunity arises, as will the up-dating of the bibliography.

References in the bibliography are arranged on two cards. One of these cards is a normal author-index card, and these are filed alphabetically. The other card is an edge punch card which has been punched appropriate to information contained in the paper concerned. Various criteria are used in coding each reference and searches for various combinations of these can be carried out quickly. Cards referring to sites are also marked accordingly to Hydrometric Area and regions within the British Isles so that geographic information can be extracted at short notice. Thus, during the work on Shetland it was relatively easy to produce a bibliography of all work published on the fresh waters of these islands.

Table 3 The literature resource (1961–65): minimum numbers of published papers dealing with plants and animals at freshwater sites in the British Isles.

Year	Algae	Macrophytes	Invertebrates	Vertebrates
1961	10	12	61	17
1962	10	6	34	17
1963	9	15	44	17
1964	13	12	34	21
1965	14	5	25	15
Total 1961–65	56	50	198	87

Plate 4 Lunga Skolla: a peat pool on Shetland (Shetland Synoptic Survey). Photo: K East.

Plate 5 Loch Fiart: a marl loch on the island of Lismore, Argyll (Nature Conservation Review). Photo: P S Maitland.

Plate 6 Loch Lomonf, Britain's largest lake, part of which is a National Nature Reserve of international importance. Photo: P S Maitland.

The statutory powers given to the original Nature Conservancy (the research branch of which was later to form the major part of ITE) under the National Parks and Access to Countryside Act (1949) included the establishment of nature reserves 'to preserve and maintain . . . places which can be regarded as reservoirs for the main types of wild plants and animals represented in this country, both common and rare, typical and unusual, as well as places which contain physical features of special or outstanding interest'. In 1968, it was decided, as official Nature Conservancy policy, to make a thorough scientific appraisal of ecosystems of all types over the whole of Great Britain in order to select as certainly as possible those sites of outstanding scientific value.

Because of the lack of basic survey data, it was agreed that open waters could not be considered fully and that only a preliminary appraisal was possible. The initial selection of sites was based on a desk study of existing information on British freshwater sites of all kinds. These were then classified according to area, depth, and trophic status, and waters for which there was insufficient information were visited to collect further data. Finally, sites were classified into priority grades for conservation purposes and the final selection published (Ratcliffe, 1977). Many potentially important sites were not considered in this study because of lack of time.

The bank of data collected during this survey has never been fully analysed and though the actual choice of sites was subjective, nevertheless, the study covers a wider range of sites than any previous work (Figure 4). Further analyses of the data in relation to those available from the regional synoptic studies described below are at present in progress at both autecological

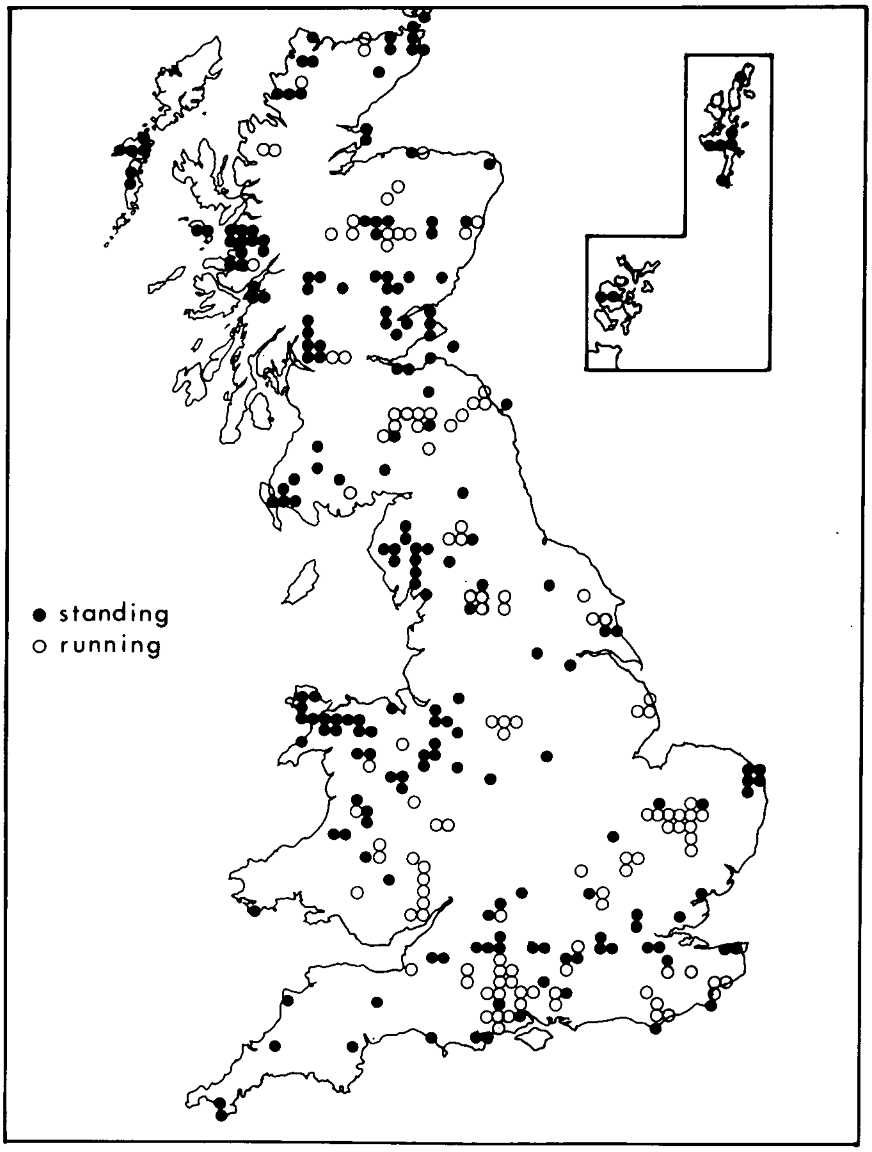


Figure 4 The distribution of freshwater sites in Great Britain examined during the Nature Conservation Review. Information on many other sites is now available.

and synecological levels. The enormous gap in our knowledge of the limnology of many important waters in this country revealed by the Nature Conservation Review was one of the main contributory factors leading to the development of the present synoptic project.

Several new studies of different regions of Great Britain are currently in progress using the synoptic approach introduced above. The principle behind these synoptic projects has been to use topographical and geological maps to produce total counts of all the types of fresh waters in the region concerned and then to use these types as a means of stratification for the random selection of sites for field surveys (Figure 5). Field and desk data are subsequently combined in multivariate analyses of different kinds to explore the relationships among the variables concerned.

SHETLAND SYNOPTIC SURVEY

Desk Study. 1:63360 OS and geological maps were used as sources of information. Each standing water shown on these maps was counted, and, for each, the following variables were measured: altitude (Figure 6), area, inflow streams, outflow, distance from sea, highest point in catchment, catchment area, geology of catchment. For running waters, points of intersection of the 1 km grid with streams were selected as sampling points and the same variables as used for standing waters were measured, except that slope (Figure 7) was substituted for area, stream order for number of inflow streams, and tributary or direct to sea for presence or absence of outflow.

One thousand five hundred and ninety six standing waters and 1970 running waters on Shetland were located and measured for these features. The data were then classified and analysed in various ways. In particular, they were subjected to principal component analysis using a correlation matrix derived from values of all measured variables, and a systematic sample of one seventh of all sites was subjected to least variance analysis. Cluster analysis was terminated at a level of 16 clusters plus 14 aberrant individual sites in the case of standing waters, and 14 clusters plus 9 aberrant sites in the case of running waters.

Field Survey. A random sample of 3 sites from each cluster was chosen for field survey, and these, together with aberrant sites, gave a total of 113 sites for study. Field research included measurements of further physical features not detectable from maps (eg

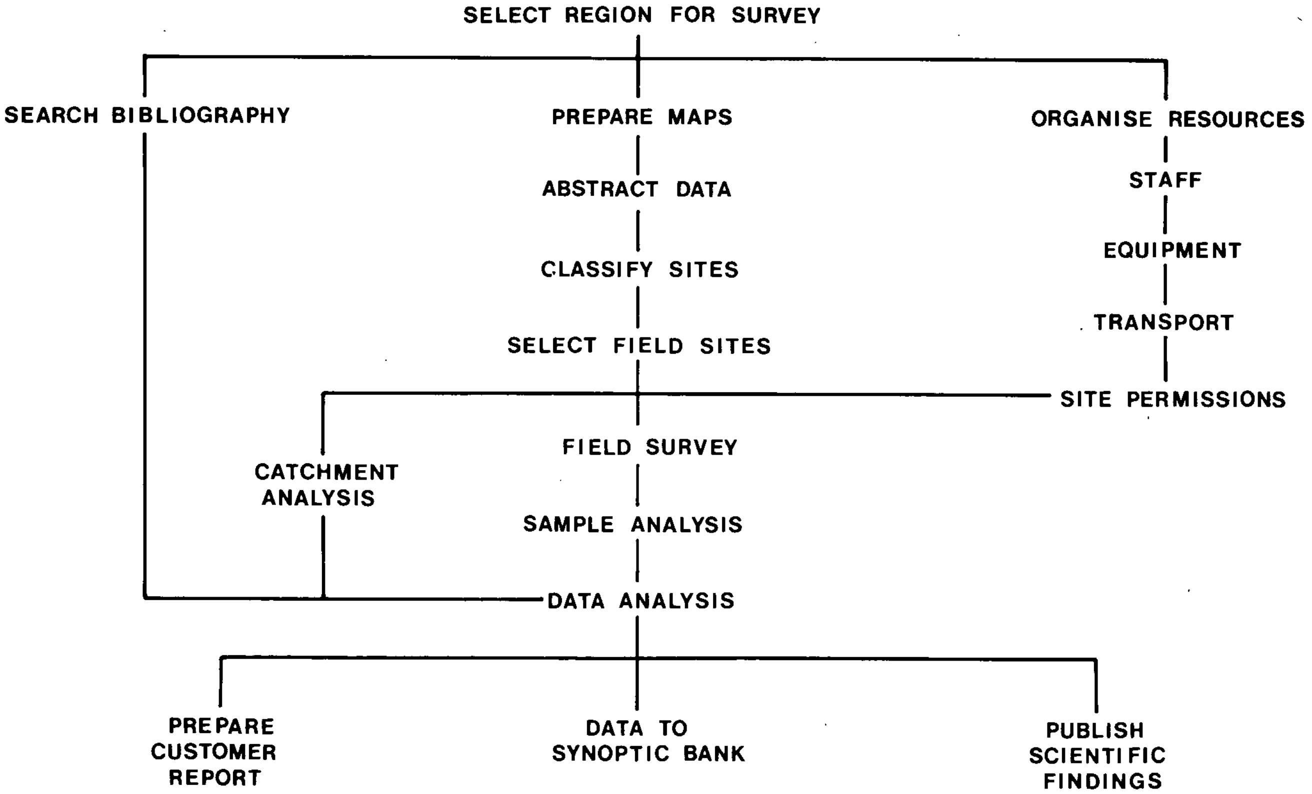


Figure 5 A network diagram illustrating the main aspects of the programme involved in a regional synoptic survey.

Plate 7 Looe Pool: a coastal lake in Cornwall (Nature Conservation Review). Photo: R H Britton.

Plate 8 River Shee: a macrophyte-poor river in Perthshire (Tayside Synoptic Survey). Photo: K H Morris.

substrates), water chemistry, sediment chemistry, phytoplankton, macrophytes, zooplankton and zoobenthos. Analyses of the data collected are still in progress, but many important points have already emerged from different facets of the work, and a broad description of the fresh waters of Shetland is now available.

Among the measured physical attributes there is a very close correlation between those which are a measure of size (eg area, volume, depth and retention time). The area, which can be measured directly from maps, is the best predictor of the depth of a loch. The first axis of a principal component analysis is related to size and accounts for 39% of the variation in the data. The second component accounts for 23% and separates out those lochs with shores of stones, boulders and gravel. A similar analysis of the chemical variables shows that the first axis comprises variables related to base richness (alkalinity, Ca and Mg, as well as conductivity, Na and K), while the second measures peatiness and includes such variables as P, Fe, Hazen and suspended solids. These two components account for approximately 60% of the variation in the chemical data. Some of the desk measurements are correlated with field parameters and therefore have value in predicting the chemical nature of Shetland waters.

Among the phytoplankton communities, the predominance of Chlorococcales and Chrysophyceae is very marked, and the overall importance of the latter and the relative paucity of Bacillariophyceae may be closely related. A total of 109 species of aquatic macrophytes was recorded during the survey. The majority of the waters are peaty pools and streams with a very restricted flora. More diverse and varied floras are found in the relatively few brackish and coastal sites, and especially in the larger lochs (Figure 8). The momentary composition of the zooplankton communities is remarkably simple and generally only two to four species occurred at each site. Only 124 taxa were recorded among the aquatic invertebrates and this greatly impoverished fauna is dominated by a few ubiquitous species. The fish fauna is similarly very restricted in species (Maitland & East 1976).

SCOTTISH RIVERS SURVEY

The use of benthic invertebrates as biological indicators of pollution in running waters is now a common feature of the work of River Purification Boards and Water Authorities. Several methods of analysis have been used to produce a final biological index indicating the quality of the river concerned, the most popular in Great Britain at present being that initiated by Woodiwiss

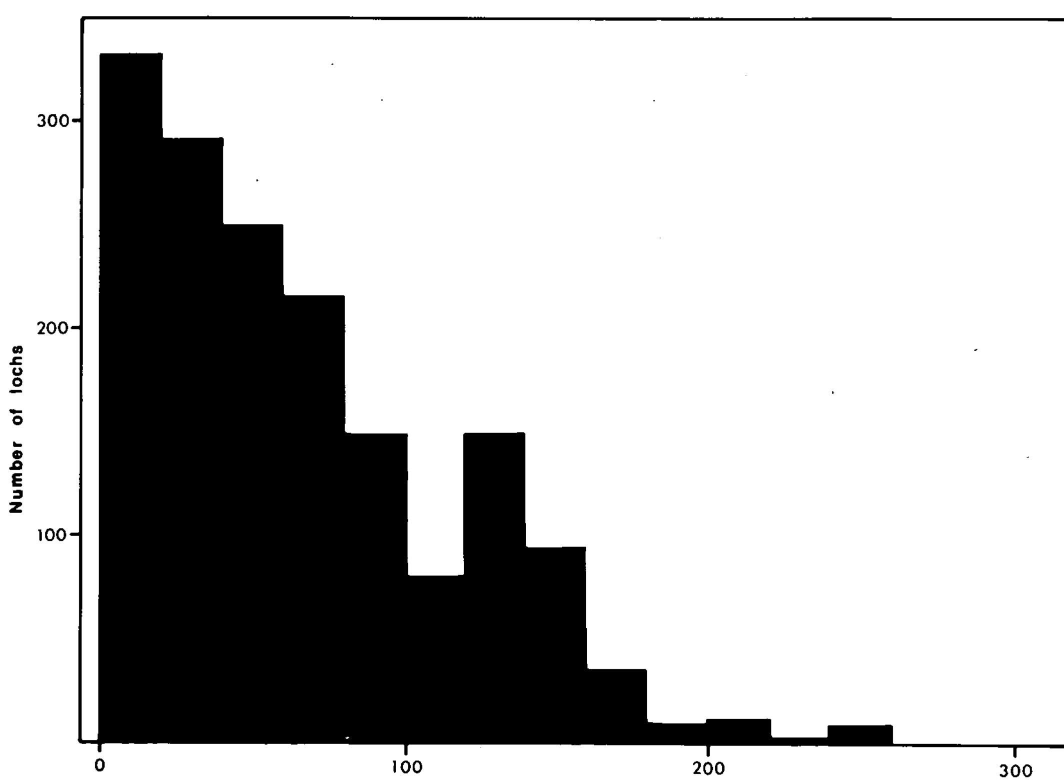


Figure 6 The total numbers of standing waters on Shetland arranged in altitude classes.

(1964). The main problem in developing a national index system is that, until recently, sufficient information was not available from sites covering the full range of conditions in Great Britain. It was known, however, that regular patterns of invertebrate distribution did occur in some rivers (Figure 9).

In 1974, simultaneous to the survey of the fresh waters of Shetland described above, a survey of the benthic invertebrate fauna of the larger rivers on the mainland of Scotland was carried out. This was the first comprehensive survey of its kind for the whole of Scotland and was funded as part of the Scottish Development Department's programme of applied research and development. The project was a collaborative one by research teams from the Institute of Terrestrial Ecology, Paisley College of Science and Technology, the Department of Agriculture and Fisheries for Scotland and the Scottish River Purification Boards.

Eight hundred and twenty three sites were included in the overall coverage of rivers on the Scottish mainland, with some bias towards waters in the more heavily populated areas. A brief summary of the results has now been published (Scottish Development Department 1976), but further analyses are at present being carried out as part of the current synoptic survey programme, especially the relationships among the invertebrate communities and the physico-chemical factors measured at each site. These analyses provide a firm basis for future work on river ecosystems and particularly for investigating the value of various biological indices of river pollution in Scotland (Table 4).

TAYSIDE SYNOPTIC SURVEY

Desk Study. An analysis and count of all the waters in the Tayside Region shown on the 1:50000 OS maps was carried out using a new method of catchment network analysis (Figure 10). This analysis gave a total of 947 lochs and 10,474 stream segments. These waters were then classified using the following variables: geology (base-poor, intermediate, base-rich), size (running waters by stream order number; standing waters by area classes), altitude. Following this classification, a land use study based on the same maps was carried out. Information was extracted by 1 km squares, including altitude, slope, use of land, roads, geology, open water and stream junctions. The main initial purpose of this study is to provide catchment information for each of the sites selected for field examination.

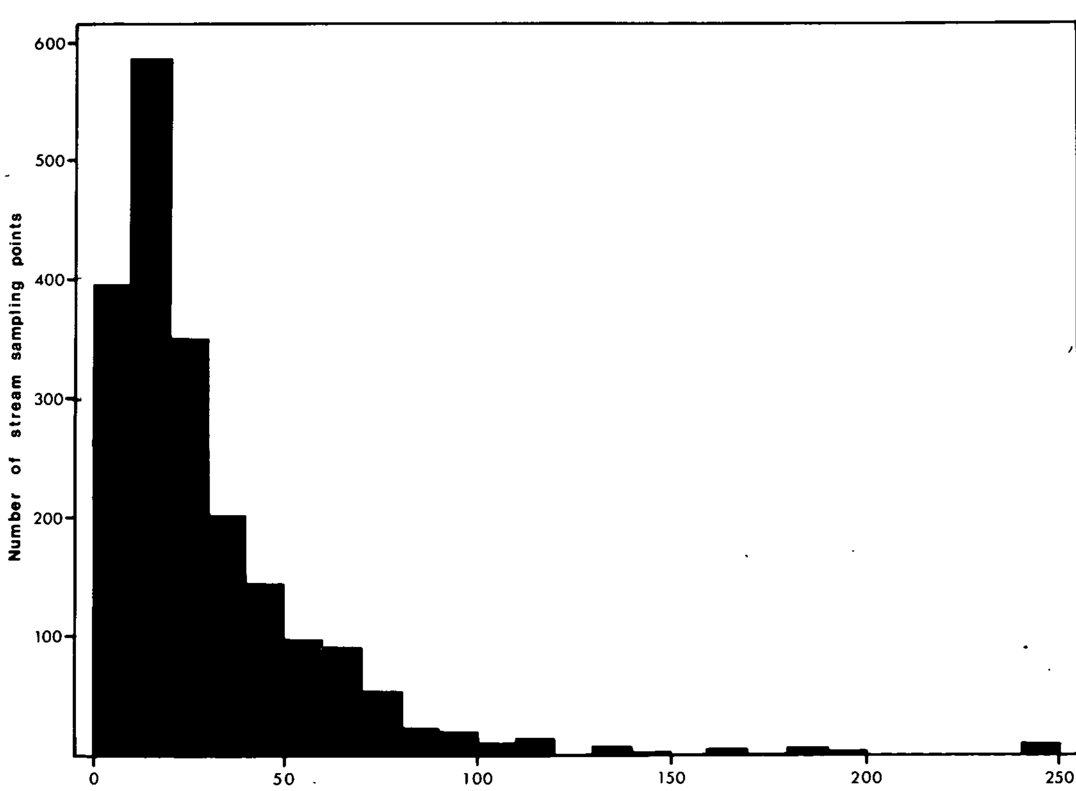


Figure 7 The total numbers of running waters on Shetland arranged in gradient classes.

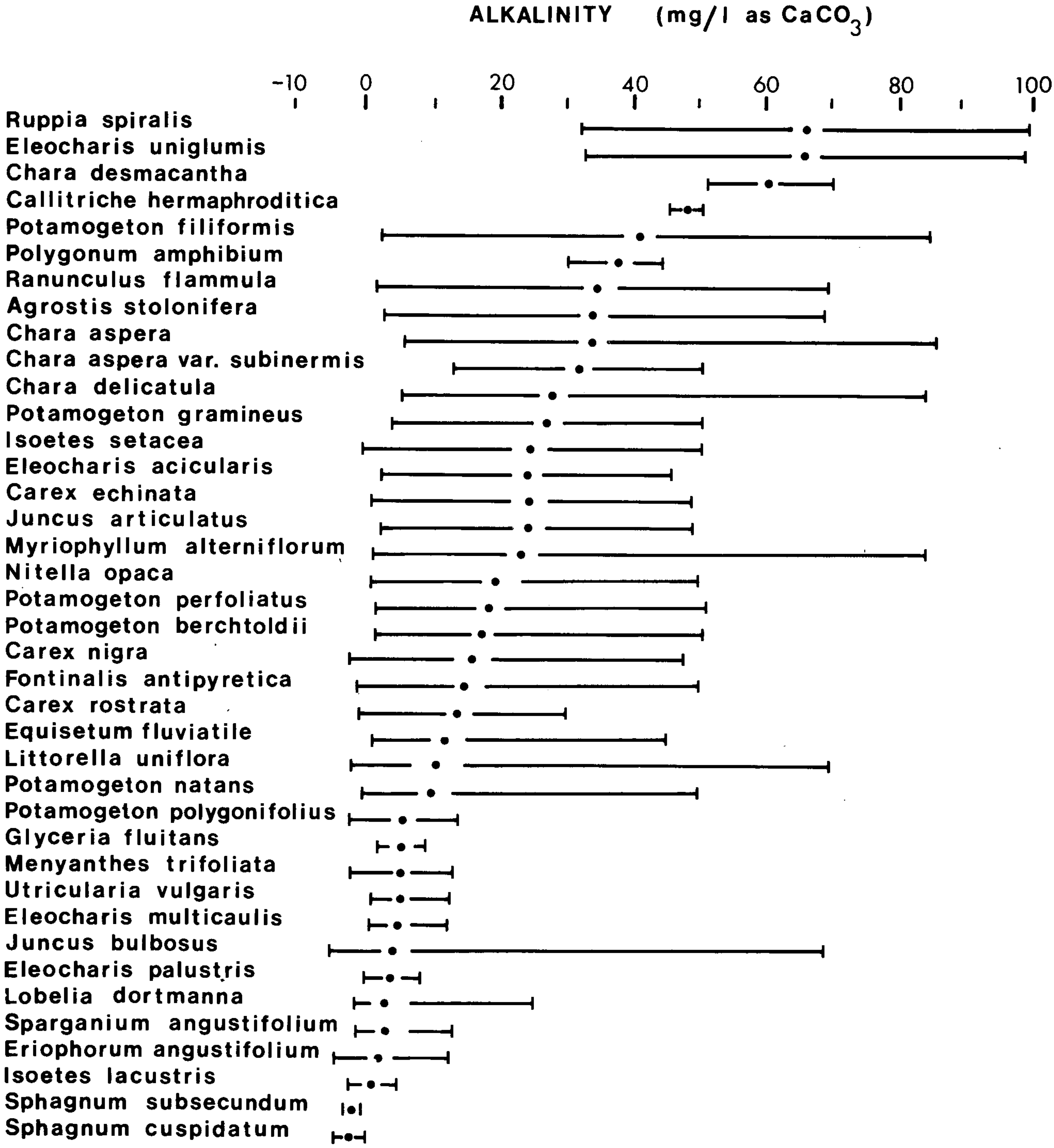


Figure 8 The occurrence of higher plants in the fresh waters of Shetland in relation to alkalinity: the mean and total recorded range are indicated.

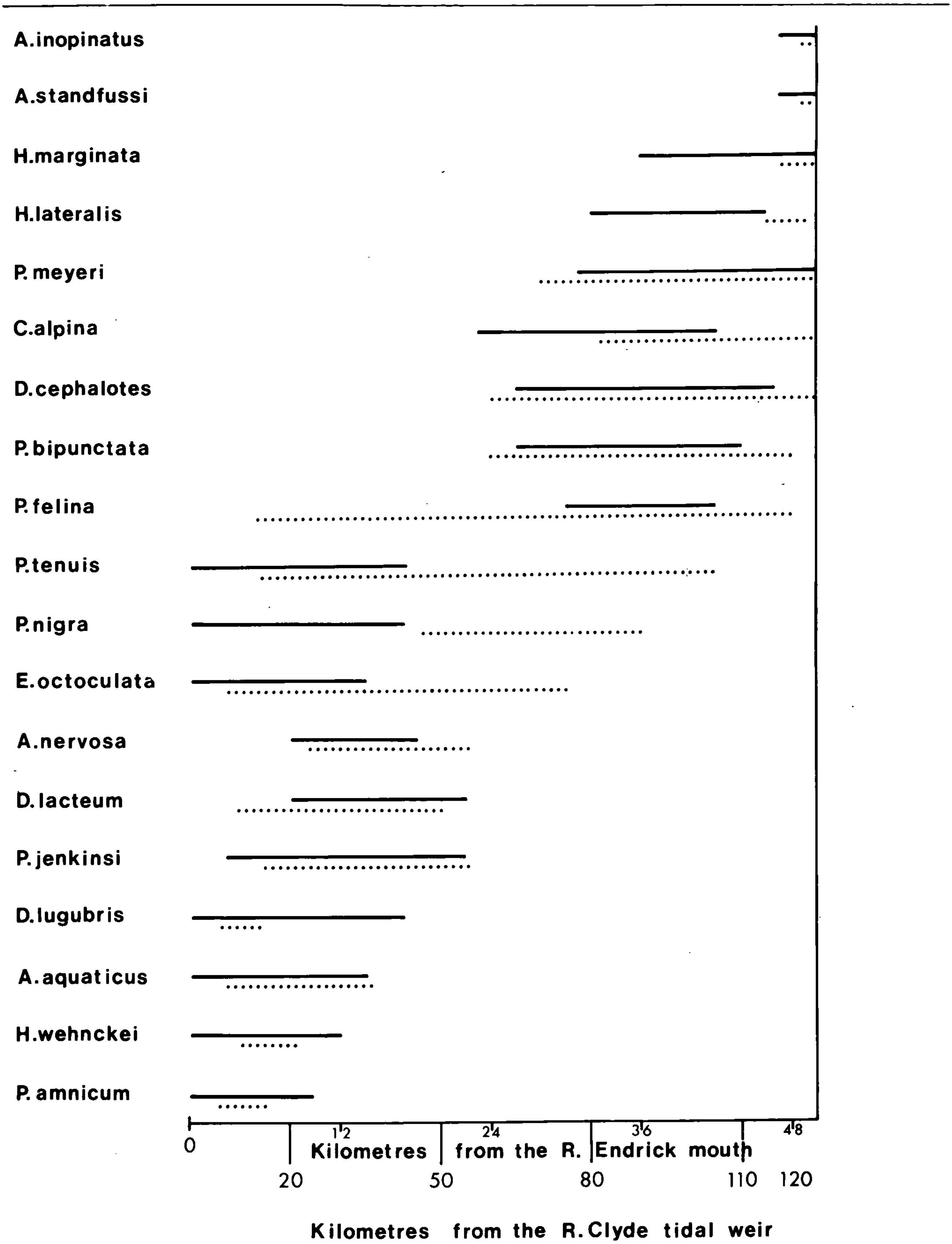
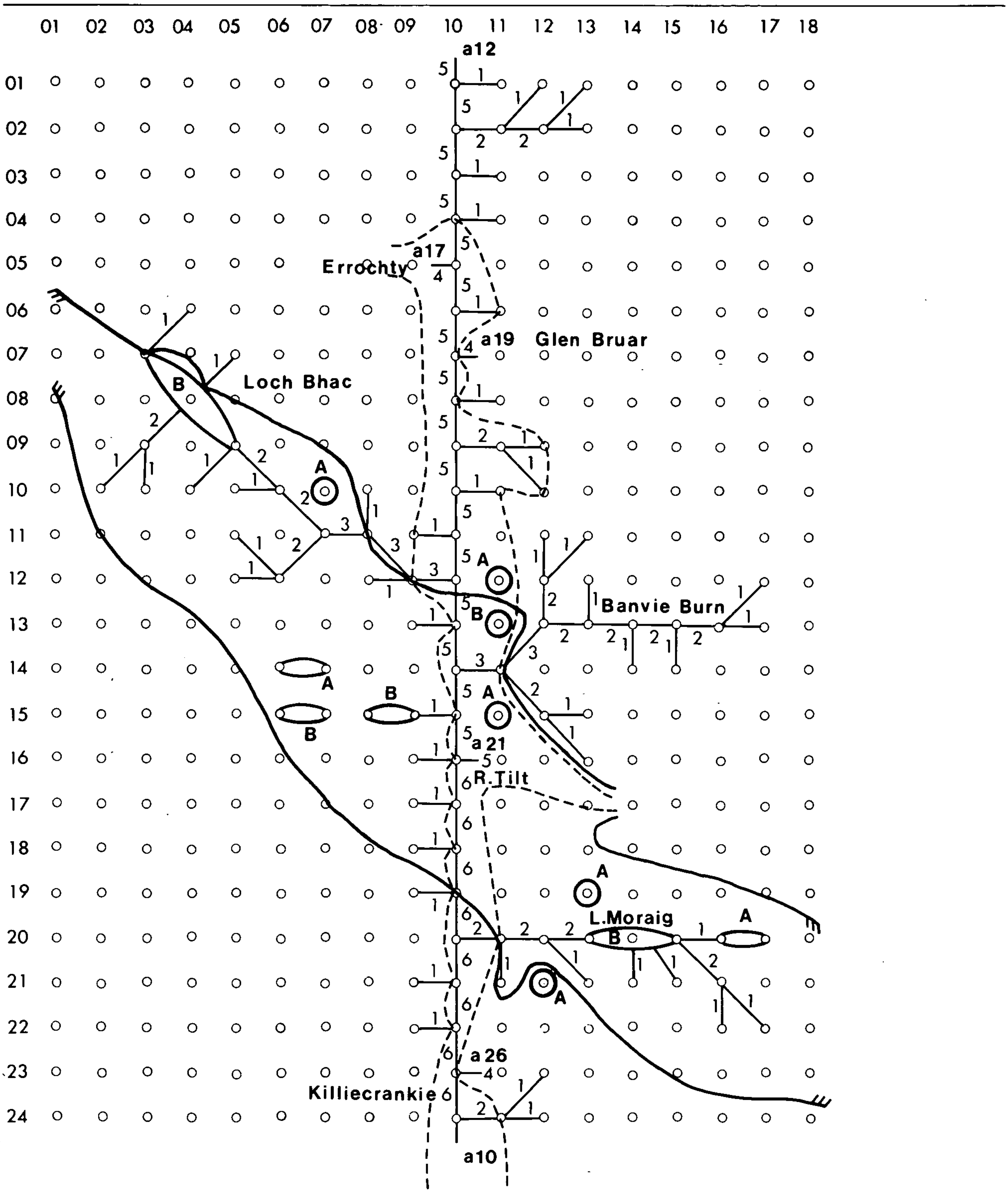


Figure 9 The distribution of a number of invertebrate species of limited occurrence in two Scottish rivers, the River Endrick (–) and the river Clyde (...).



TAYSIDE SYNOPTIC SURVEY **SHEET a 11**

Figure 10 An example of catchment analysis of fresh waters in Tayside in relation to size, (numbers against stream segments, letters against lochs) solid geology (base rich/poor boundary indicated by solid line) and altitude (183m contour indicated by dashed line). The codes a 10, etc indicate parts of the network continued on separate sheets.

Field Survey. Following the desk classification, a group of sites was selected for field survey. The main restrictions on the numbers selected were the manpower available and the fact that the notified conservation sites in the area were to be included. It is of considerable interest to note that, in most cases, the latter restriction was not important for many unique members of classes (which would inevitably be selected) were also already considered to be of conservation status (eg Loch Leven and Loch Brandy: Table 5). Two examples of each class were chosen for survey at random from the group available, with the exception of small streams (order 1 and 2) where only one representative was chosen. Altogether, 125 sites were selected for survey in 1977. Later, a further 19 sites were added for survey in 1978 – these were mainly replacement sites for those regarded during the first survey as being unnatural in one way or another. For example, some stream sites were very badly polluted and one or two lochs had been filled in by dumping.

Field research included the same measurements as on Shetland. Most of the samples are still undergoing analysis, but preliminary comparisons of the water chemistry with solid geology indicate useful correlations and desk data for the latter are thus likely to be of predictive value. In addition, comparisons of the water chemistry of sites from different regions (eg Tayside and Shetland) are providing a much more fundamental understanding of geographic variation (Figure 11), and of the factors influencing the supply of ions to inland waters (Gorham 1961).

Table 4 Classification of running water sites in Scotland using the Trent Biotic Index. The data indicate a much higher proportion of 'good quality' waters in the highland area compared to the lowland. (Scottish Development Department, 1976).

Trent Biotic Index	1	2	3	4	5	6	7	8	9	10
Sites in a highland area	0	0	0	0	1	1	2	5	20	73
Sites in a lowland area	1	3	4	7	15	22	23	24	20	23
All Scottish sites surveyed	1	12	12	22	37	69	65	104	151	348

OUTER HEBRIDES STUDY

This was a synoptic integration of the unpublished data of four authors (Waterston, Holden, Campbell and Maitland in press). A desk study of 1:63360 OS maps showed that the Outer Hebrides comprises approximately 1.3% of the land area, but as much as 15.8% of the area of standing waters of Great Britain. Streams there are generally small and only three are as large as 5th order. The majority of lochs occur below 200 m altitude and are less than 25 ha in area. A total of 1375 stream systems enter the sea, and drain the land mass through 9240 stream segments (Table 6). There are just over 6000 lochs, of which less than half are connected to these networks. Most of the water systems are on geologically base-poor rock or soil, and less than 3%, situated on machair, are base-rich and eutrophic. The islands, due to their situation, receive precipitation in the form of very dilute sea water (with some non-marine sulphate probably derived from fossil fuel combustion) and this contamination leads to unusual concentrations of chloride in the inland waters (cf Shetland: Figure 11). Metamorphic rocks are resistant to weathering, so there is usually little variation in the composition of fresh waters except in the machair areas, where calcareous sands affect calcium concentrations and alkalinities.

Table 5 The classification of standing waters in the Tayside Region using solid geology, area, and altitude. The area classes are: 1:0.01; 2:0.01–0.25; 3:0.25–1; 4:1–4; 5:4 km². The numbers of sites in parentheses indicate the number of notified conservation sites in each group.

Geology	Base Poor					Mixed					Base Rich				
Area	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Altitude >610 m	55 (0)	13 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
183–610 m	136 (0)	82 (0)	10 (0)	7 (0)	3 (1)	6 (0)	7 (0)	4 (2)	2 (0)	1 (0)	30 (0)	30 (1)	5 (0)	0 (0)	0 (0)
15–183 m	26 (1)	8 (0)	3 (3)	0 (0)	0 (0)	10 (0)	6 (0)	3 (2)	0 (0)	3 (0)	356 (2)	89 (2)	8 (6)	0 (0)	1 (1)
<15 m	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	28 (0)	13 (0)	0 (0)	0 (0)	0 (0)

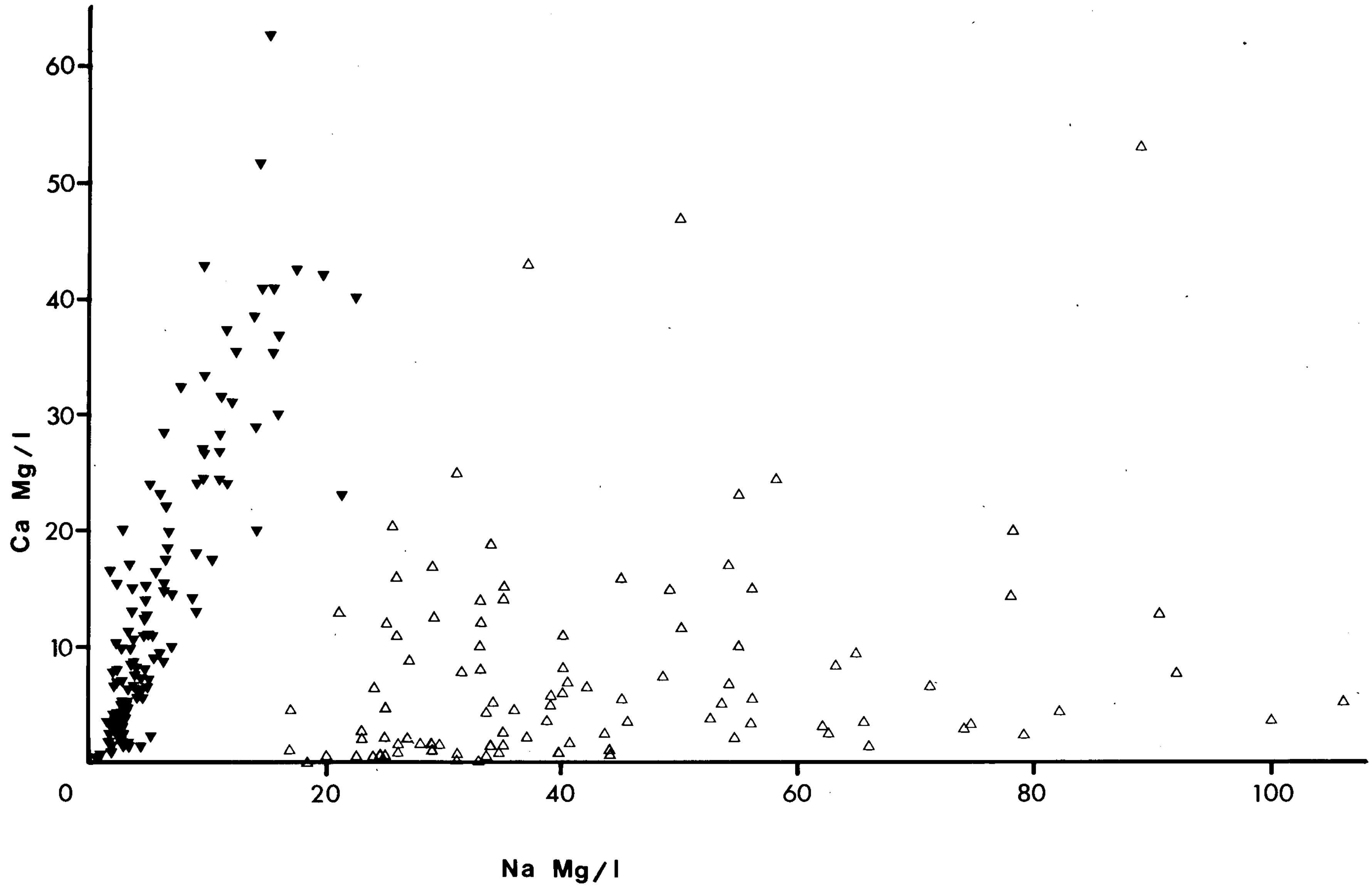


Figure 11 A contrast in background water chemistry. Ca and Na values from freshwater sites in Tayside (▼) and Shetland (△).

The aquatic flora and fauna reflect the chemical conditions and there are some unique successions of species from high to low salinities, even in the same water body. The lochs provide a wide range of habitats for aquatic vegetation, ranging from the rich machair lochs to the oligotrophic peaty lochs (which show marked similarities with their counterparts on the mainland). Three broad categories can be delineated on the basis of their water quality and vegetation: brackish lochs with varying degrees of marine influence, calcareous machair lochs which may also be affected by sea connections, and the peaty lochans of low alkalinity. A few brackish water animals are sufficiently euryhaline to exist in the machair lochs, which are otherwise dominated by freshwater species. The occurrence of chloride in inland waters enables some crustaceans to extend into what are otherwise poor freshwater habitats. The main constituents of the freshwater fauna are molluscs and arthropods, and a few species of euryhaline fishes.

Table 6 The total numbers of stream systems of different sizes in the Outer Hebrides.

	No. of systems in each order					
	1	2	3	4	5	Totals
Lewis and Harris	660	235	102	30	3	1,030
North Uist	91	26	5	0	0	122
Benbecula	32	5	6	0	0	43
South Uist	59	37	8	2	0	106
Barra	57	13	4	0	0	74
Totals	899	316	125	32	3	1,375

Plate 9 Great Eau: a macrophyte-rich river in Lincolnshire (Nature Conservation Review). Photo: R H Britton.

Discussion

The brief account above indicates the nature of the synoptic work at present in progress. The total amount of data potentially available is now large and offers scope for a wide variety of analyses in many different fields. Already, considerable interest has been generated by the project and demands from other scientists and user organisations are likely to increase. In addition, a number of independent schemes have arisen recently which have similar objectives. It is important that close liaison is maintained among the research groups concerned in order that overlap is avoided and parallel methodology adopted where possible.

It is the eventual aim of the present project that all parts of the data bank which are relevant to synoptic analysis will be computerised. So far, only selected portions of the data have been stored and analysed by computer, mainly with specific objectives in mind. Meantime, most of data are stored by conventional manual filing systems, largely by sites using standard pro-formas or, increasingly, edge punch cards. This system has proved invaluable for a number of purposes and will be maintained even after computerisation. Its prime value is the speed and ease with which full site information may be retrieved for examination.

Beyond the value of access to information on individual sites lies the goal of a full synopsis of British fresh waters. A major part of this synopsis will be a comprehensive classification system covering the full range of aquatic habitats in Great Britain. The evidence so far, from both running waters (eg Maitland 1966) and standing waters, indicates that the framework for such a classification will be an arbitrary one – its limits bound by the range of fresh waters occurring in Great Britain, its classes defined partly by natural boundaries and partly by convenient ones proposed by limnologists (Figure 12). This is because, in most cases, there appears to be a more or less complete transition from one extreme type of water to another, with many intermediate types occurring throughout the range.

Synecological studies of animals (Figure 13) and plant communities appear to confirm that a critical definition of discrete communities is not possible, and rather that a continuum exists along which there are important, probably stable, nodes which can be described in detail. Thus, though the coded check list described above (Maitland 1976) indicates that there are about 3,850 freshwater animals in the British Isles and Elton (1946) suggests that the average number of species found in freshwater communities is 70, this does not mean that

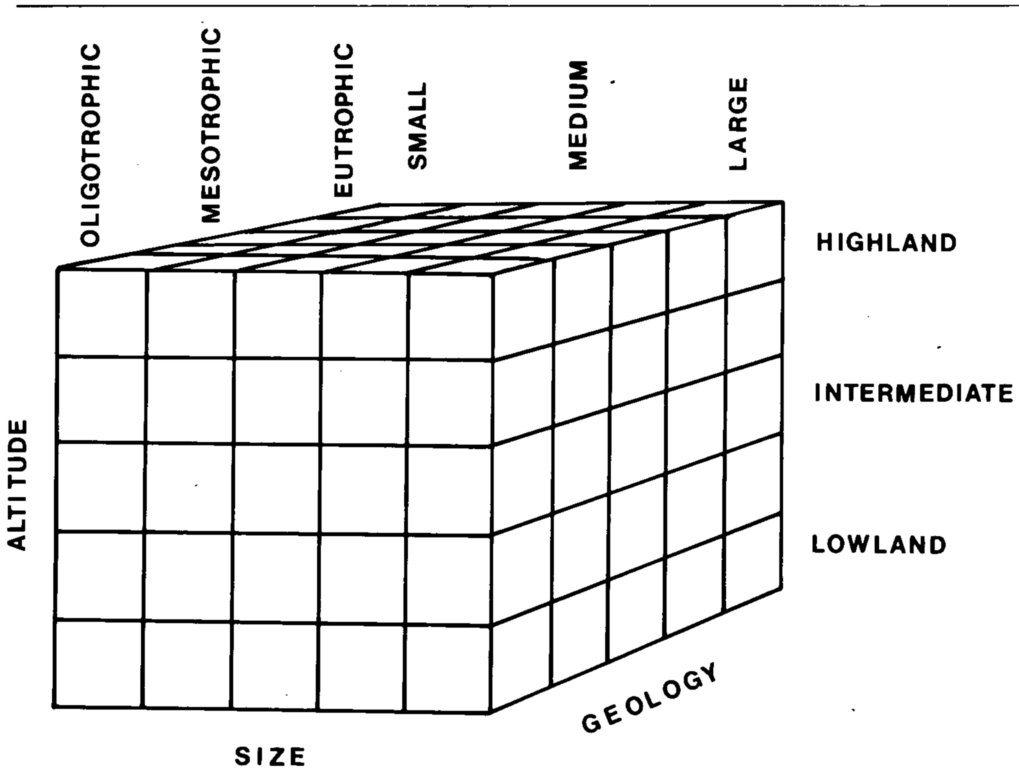


Figure 12 A simplistic classification of fresh waters in Great Britain, according to size, solid geology and altitude. (Cf Table 5).

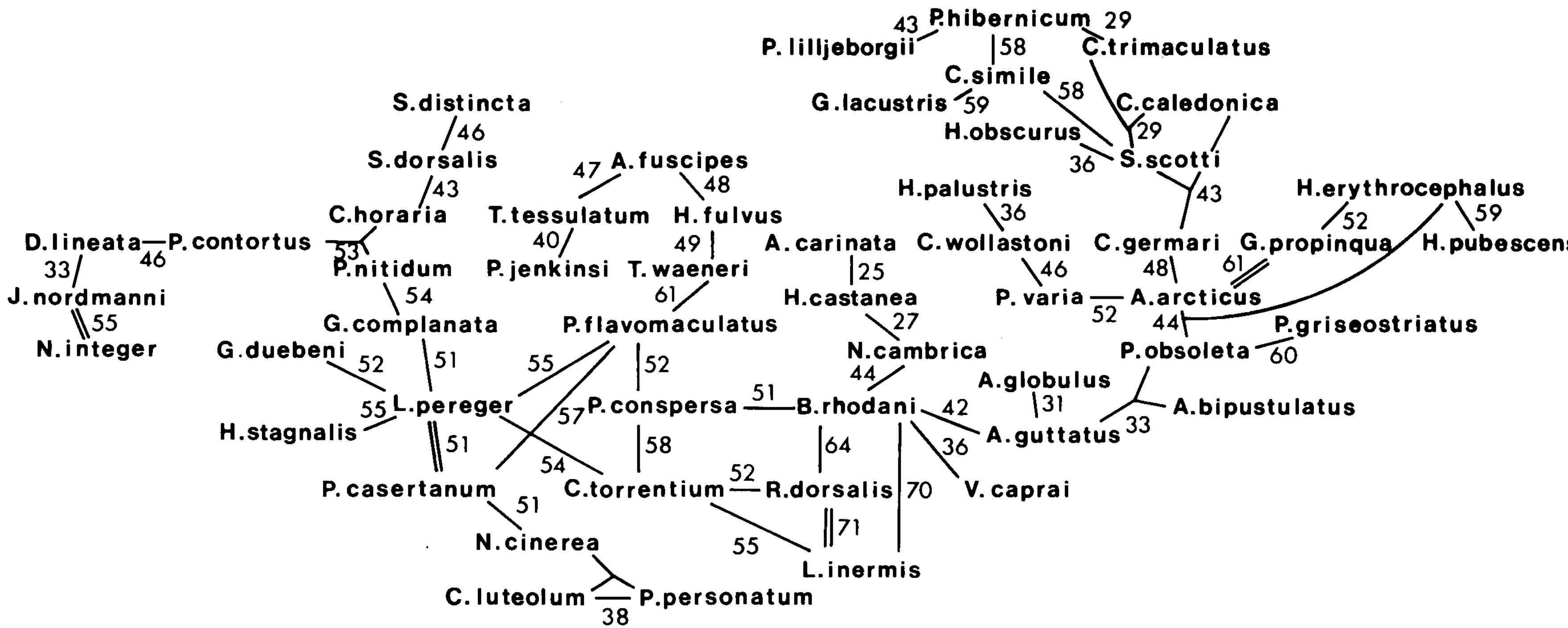


Figure 13 *Association analysis of common freshwater invertebrates in Shetland. Each species is linked to that with which it is most highly associated (Fager 1957), the relevant values being indicated between the species concerned.*

there are $\frac{3850}{70}$ (=55) different types of freshwater community in these islands. Apart from the scientific interest and value of synecological studies, the accurate description and quantification of the natural communities has a number of applied values, particularly for impact studies. Thus, is has been possible for several workers to describe the consistent changes which take place in stream invertebrate communities as organic pollution increases and decreases.

The data derived from the studies in synoptic limnology described here offer a promising field for autecological research (Figure 14). The definition of natural species niches and apparent tolerances to a wide variety of environmental parameters is a relatively straightforward exercise from the comprehensive data available, and such analyses lead naturally to comparisons of the ecological requirements of different species. Again, such studies have both pure and applied values – eg in the case of a species proposed for introduction to any area it is invaluable to have detailed figures for its natural range of habitat. The figures given for *Gammarus duebeni* on Shetland (Table 7) are an example of the type of assessment possible.

Finally, the predictive value of synoptic limnology must be emphasised (Figure 15), especially in the fields of conservation and resource management. The idea of prediction is not new (Rawson 1955) though the methodology being developed here is. One of the realistic developments of the synecological and autecological studies described above is that it should eventually be possible to predict, for example, the type of community found in any water whose geographic position and main physical characters are defined. Likewise, the probability of a particular animal or plant species thriving at a new site or an existing site under new conditions could be estimated. Naturally, as in all biological situations, such predictions could never be completely accurate, nevertheless they must represent one of the most promising methods available to ecologists.

Table 7 Sample ecodata for Gammarus duebeni *in Shetland. Only 10 parameters are listed – 5 from desk and 5 from field studies.*

Ecodata	Background means (all sites surveyed)	High Density means (Upper 33% densities)	Occurrence means (*G. duebeni* present)	Occurrence ranges (*G. duebeni* present)
1 Altitude (m)	57	29	25	1–137
2 Distance from sea (Km)	0.93	0.45	0.54	0–2.10
3 Catchment area (Km²)	1.54	2.06	2.42	1–28.54
4 % arable in catchment	9.9	40.7	21.5	0–100
5 Mean depth (m)	0.69	1.03	0.68	0.01–5.75
6 Sodium (mg/l)	148	104	325	26–9000
7 Calcium (mg/l)	11	21	20	1–255
8 Phosphorus (mg/l)	0.01	0.07	0.09	0.01–0.87
9 Suspended solids (mg/l)	0.04	0.03	0.03	0.01–0.16
10 % Silt on shore	31.3	26.7	22.7	0–100
Ratio-running/standing sites	51:65	7:8	20:23	—

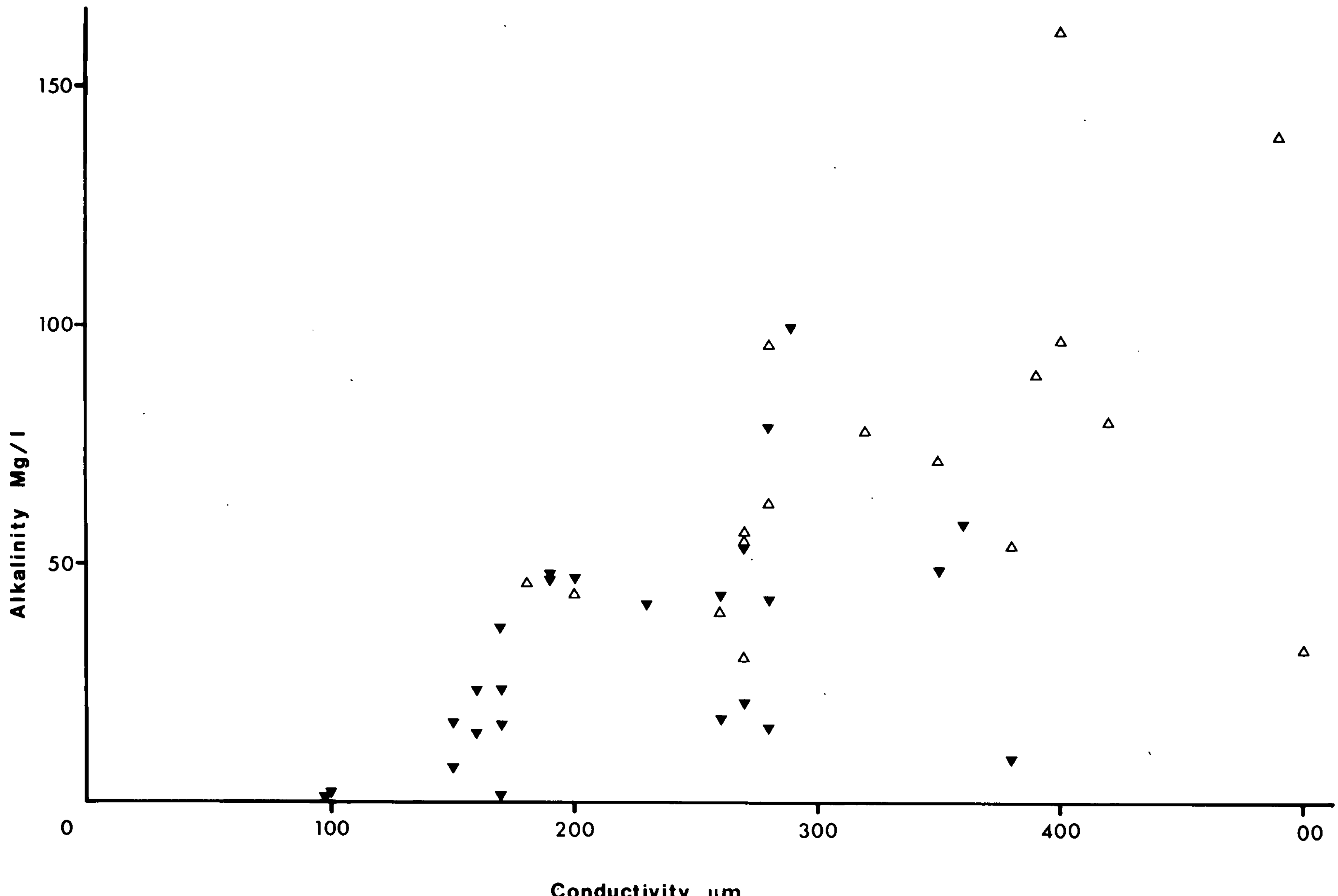


Figure 14 The presence (△) or absence (▼) of Gammarus duebeni *in relation to alkalinity and conductivity of running water sites on Shetland. Note that this species is absent at all sites with low values and present at those with high.*

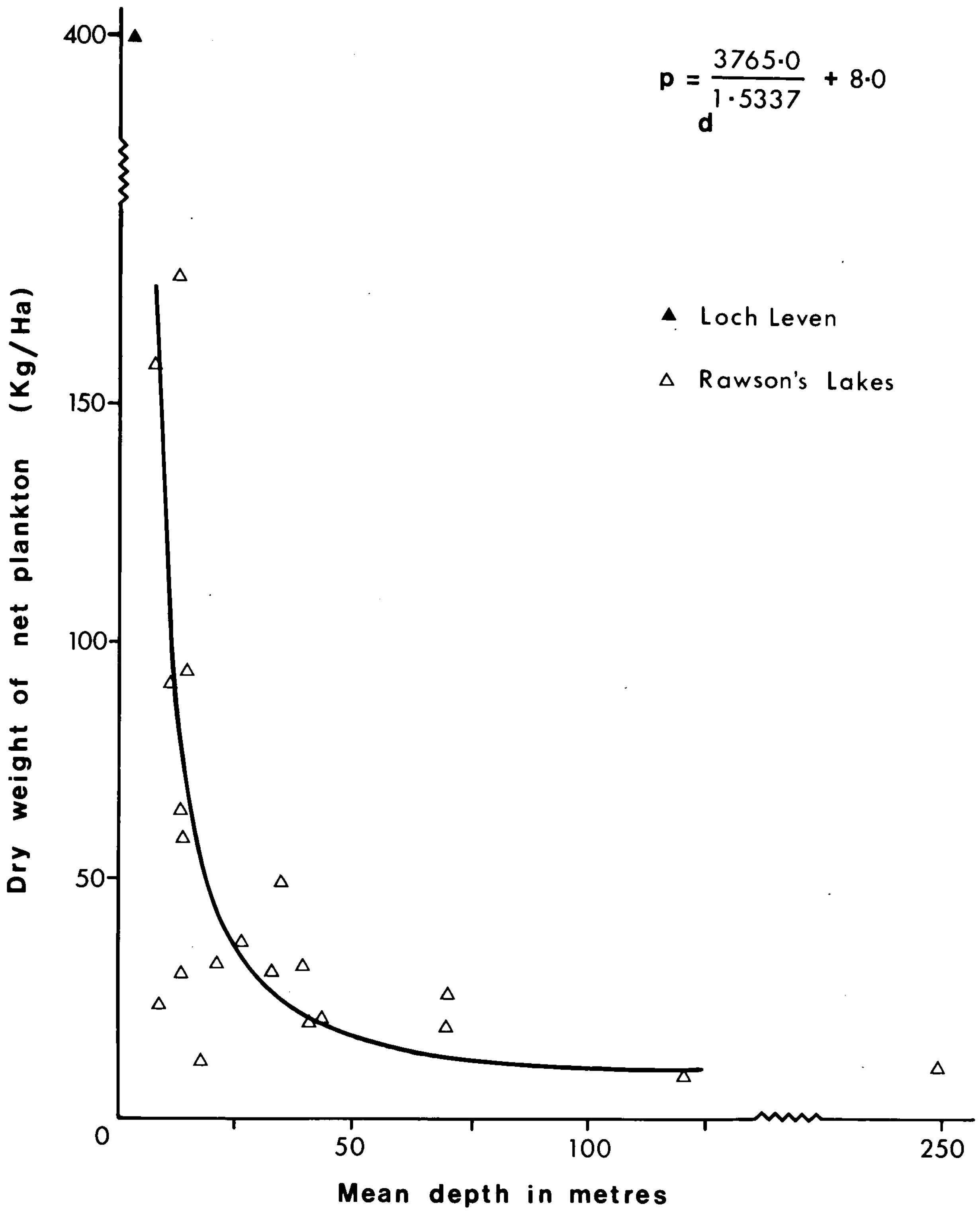


Figure 15 The predictive relationship between the mean depth of a lake and its phytoplankton crop, demonstrated by Rawson (1955). Loch Leven with a very shallow mean depth should predictably have a very high algal crop, and indeed this is the case.

Plate 10 River Tay, Britain's largest river, surveyed during the Tayside Synoptic Survey. Photo: K H Morris.

Plate 11 Ythan Estuary: one of Britain's smaller but best-known estuaries (Aberdeenshire). Photo: M C Morgan.

Acknowledgements

This project is very much a joint multidisciplinary effort, and I gratefully acknowledge the help of other members of the team involved: Mr I. R. Smith, Dr E. Swale, Dr J. H. Belcher, Dr A. E. Bailey-Watts, Mr D. H. Jones, Mr K. East, Mr K. H. Morris, Mr A. A. Lyle, Miss G. Dennis and several other colleagues who have been involved on a temporary basis. Invaluable chemical support has been consistently given by Mr S. E. Allen, Mr J. A. Parkinson, Mr H. M. Grimshaw and other members of the ITE Chemical Services Section. Most of the original work on the open waters section of the Nature Conservation Review was carried out by Mr N. C. Morgan and Mr R. H. Britton. Work on the Scottish rivers survey was funded by the Scottish Development Department, while the North of Scotland Hydro-Electric Board are supporting current comparative impact studies on large Scottish lochs. Most recent research on synoptic limnology has been financed by the Nature Conservancy Council and I am grateful to Dr D. A. Goode, Dr C. Newbold and NCC regional staff for their continued interest in this study. All the figures for this publication were drawn by Mrs S. M. Adair, while Mr J. N. R. Jeffers and Dr D. Jenkins made the constructive comments on the manuscript.

Printed in England for Her Majesty's Stationery Office by Staples Printers St Albans Limited at the Priory Press Dd 074427

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ISBN 0 904282 30 9

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