ECOLOGY OF LAKE DISTRICT OSTRACODA

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Winter sampling in the Lake District.

All the collections associated with this work are currently kept at the University of Greenwich. A compilation of species is kept at the Natural History Museum, London.

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ECOLOGY OF LAKE DISTRICT OSTRACODA

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ABSTRACT

Freshwater ostracods are potentially useful for environmental monitoring and, since their calcified valves may be preserved in lake sediments, are also valuable in palaeolimnological studies of environmental pollution such as eutrophication and surface water acidification.

To establish a data-base of ostracod ecology, biannual survey work in 1989-1990 was performed in 75 lakes and tarns of a wide range of physico-chemical characteristics in the Lake District in Cumbria, ranging from large eutrophic lakes such as Windermere and Ullswater to tiny, upland acidic tarns. pH ranged from 4.3 (Black Pool) to 8.0 (Browns Tarn). Littoral margin samples were taken from all 75 sites and yielded 31 ostracod species, of which 8 were new to the Lake District fauna. The collection of multiple littoral samples from two sites demonstrated that a single sample produced an adequate faunal representation if it encompassed a variety of microhabitats.

Statistical analysis, incorporating a multistage, multivariate technique, has shown that 18 species make up over 99% of the data set, and that 5 species, Cypria ophthalmica, Cyclocypris ovum, Metacypris cordata, Candona candida and Cypridopsis vidua, dominate the community in 71% of the sites containing ostracods, forming eight distinct assemblage groups. No ostracods were found in 13 of the 75 sites, 11 of which were acidic, having a pH of below 5.7.

Equations were derived to predict both species distribution and diversity. Important predictors of community structures were shown to be pH, $[Ca]^{2+}$, $[Mg]^{2+}$, substrate, lake size and altitude. The equations were tested by further sampling of additional sites in the Lake District. Predictions of total species number and density generally provided an excellent fit to the observed data, although individual species predictions were poorer, especially in alkaline conditions. Substrate was not included in the analysis, due to quantitative difficulties, but this factor must be included in future predictive models as it was shown to be an important parameter in determining distribution.

Deep-water sampling was carried out in 6 lakes. 10 species were collected, including *Candona neglecta*, which was absent in the littoral samples. 9 species contributed to over 99% of the data set, and 2, *Cypria ophthalmica* and *Candona candida* dominated the community in 75% of the sites containing ostracods. Community structure was predominantly determined by water depth (together with the associated temperature effect) and substrate.

The sex ratio of *Cyclocypris ovum* was shown be biased towards the female only at high alkalinities. Other species had sex ratios biased towards the male or female, the values independent of water quality.

Large, swimming ostracod species were absent in sites containing fish. A series of laboratory experiments using three species of Ostracoda, (*Cypria ophthalmica*, *Cypricercus fuscatus*, and *Eucypris virens*), and a predator (*Gasterosteus aculeatus*) correlated increasing ostracod size with an increased rate of predation, suggesting that predation could limit ostracod distribution.

From the results of principal component analysis, it was concluded that the main characteristics that chemically differentiate the sites are calcium, magnesium, hydrogen and sodium ion concentrations. Toxicity tests were used to expose selected species to a wide range of calcium, magnesium, sodium and aluminium concentrations, at both neutral and acidic pH levels. Aluminium was selected as it has been highlighted as a major factor in the toxicity of acid waters. All species tolerated a wider spectrum of ionic concentrations than those in which they were recorded in the field, although the order of species survival in the experiments was similar to that found in the Lake District. It is suggested that whilst adult Ostracoda do not suffer from the acute toxicity of pH or aluminium, they may be unable to successfully reproduce in harsh environmental conditions.

The waters of the English Lake District are not particularly species-rich due primarily to low alkalinity and low levels of dissolved cations, but also because they are cold. Only in small, ion-enriched pools is ostracod density sufficiently high to warrant their consideration as important detritivorous contributors in the cycling of nutrients. The Lake District fauna is compared with those recorded in other parts of Britain and Europe.

CHAPTER 1 - INTRODUCTION.

1.1 - PURPOSE OF THE PROJECT

In terms of local abundance and distribution, the Ostracoda are an important freshwater group which have received insufficient study and have been almost ignored in limnological studies.

Fossil Ostracoda may record historical changes in the water chemistry of lakes and other waterbodies, both in terms of species diversity and in the chemical composition of their bivalved carapaces. Ostracods have been shown to incorporate minerals into their valves when they moult (Turpen & Angell, 1971), the subsequent valve composition reflecting the water quality at that time. As non-marine Ostracoda differ in their environmental requirements (Lowndes, 1952; Neale, 1964; Hiller, 1972; Fryer & Forshaw, 1979; Janz, 1983; Martens & Dumont, 1984; Fryer, 1985; Scharf, 1988; Benzie, 1989), both live and fossil ostracods may be used as indices of environmental parameters. To gain knowledge of the environmental requirements of these organisms, the tolerances of individual species must be evaluated.

Initially, the concept of this study involved description of the relationships between the distribution of both individual ostracod species and communities and water quality, with special reference to acidity. This was intended for the construction of a data-base for using Ostracoda as indicators of surface-water acidification due to 'acid rain'. However, as the study progressed, it became apparent that ostracods were usually absent from acidic waters, hence their value as environmental indicators of acidity was limited. Freshwater Ostracoda have a more limited pH range than diatoms, the most commonly used group for palaeolimnological interpretation, which include acidophilous (acid water) species. However, the data from this study did indicate that ostracods were useful as indicators of other aspects of water quality.

Originally, it was intended to investigate three main topics, with reference to acidity.

1) To survey the ecology and distribution of the ostracod fauna within one geographical region.

2) To assess the range of tolerance of selected species to hydrogen and metal ion concentrations in laboratory cultures.

3) To assess the relationship of valve chemical composition to water chemistry in selected species by use of high-resolution plasma atomic emission spectrometry. This was to have been carried out in the manner described by Chivas et al (1986), De Deckker & Forester (1988) and Carbonel & Farmer (1990), and would use specimens obtained from controlled laboratory cultures as well as those collected from the field.

As the focus of the project began to shift away from the acid rain phenomenon, certain aspects of the ecology and distribution of ostracods began to receive greater attention than initially intended. Consequently, the study of valve chemistry (topic 3) was omitted from the project in favour of spending more time and effort on topics 1) and 2). However, the subject of valve chemistry in relation to environmental variables is still very important and should be studied further.

1.2 - THESIS ORGANISATION

The thesis is arranged as follows:

Chapter One introduces the Ostracoda and the topics to be studied. Chapter Two describes the choice of sampling sites and the techniques used in the field. Following on from this, Chapter Three is the first to describe the results of the survey. Here, the sites are classified and the ostracod communities discussed. Chapter Four describes the water chemistry of the Lake District, whilst Chapter Five describes in detail the environmental parameters determining the distribution of individual species in the sample area, and generates a series of predictions describing ostracod abundance based on these parameters. Chapter Six tests the predictions generated in the previous chapter on a new set of data taken from the same geographical region. The next two chapters, 7 and 8, describe important features of the life-cycles of selected species, namely ontogeny, population dynamics and sex ratios. Chapters 9 and 10 examine factors thought to be potentially important in the distribution of Ostracoda, those of predation by fish, and the influence of water chemistry. The thesis is concluded in Chapter Eleven with a final discussion. Acknowledgements, a full bibliography of the literature cited, and the Appendices are also presented.

1.3 ACID RAIN

The combustion of fossil fuels such as coal and oil for the production of both electricity and heat leads to the emission of large quantities of gaseous sulphur and nitrogen oxide compounds into the environment. These gases dissolve in the atmospheric water vapour to create weak sulphuric and nitric acids which may return to earth *via* wet deposition in rain or snow, or dry deposition of dust, resulting in acid precipitation.

Since the Industrial Revolution, acid deposition has greatly increased in several areas of northern and western Europe. The Scandinavian countries have been particularly badly affected. Pollutants originating from the industrial European areas are carried by the prevailing southerly winds, to be deposited in the form of acid rain in Sweden, Norway and Finland. By 1982, total sulphur dioxide emissions amounted to 145.5 million tons *per annum* in the northern hemisphere, and 5.5 million tons *per annum* in the southern hemisphere (Baum, 1982), more than 90% of this arising from anthropogenic origin. The precipitation of acids has numerous environmental consequences. Increased atmospheric acidity may corrode brickwork and limestone, destroy fabric and paper, and causes the fading of dyes (Hultberg, 1983). It reduces the growth of rooted plants, and is a likely cause of the reduction (and in some cases disappearance) of lichen and Cantharella in parts of western and northern Europe. One of the major problems, however, concerns the acidification of watercourses, a phenomenon which may have dire consequences for the biota.

Certain areas are more susceptible to acidification than others. Oligotrophic (nutrient-poor) lakes located in relatively small basins, with bedrock composed of hard, base-poor granitic material resistant to weathering, and situated in sparsely vegetated areas with little soil development are susceptible to acidification, and indeed are often naturally acidic (Welch & Chamberlain, 1981). In these areas, where there is little or no soil through which acid precipitation may be buffered, the lake water chemistry is directly controlled by that of the rain. As rain water is naturally acidic, often around pH 5.6 (Welch & Chamberlain, 1981), the lake begins to acidify and any buffering capacity (e.g., bicarbonate) in the water is reduced, lowering the pH. Acidic precipitation causes changes in freshwater chemistry by increasing mobilisation of heavy metals in soil, rocks and sediments (Muniz, 1981). These are subsequently leached by drainage and enter surface and ground water. Elevated concentrations of aluminium, cadmium, lead, manganese, zinc, copper and nickel have all been frequently observed in acidified lakes (Muniz, 1981).

Previous work has concentrated on the toxic effects of aluminium, especially in fish (for review, see Muniz,1983). Toxicity appears to vary with ionic speciation, the toxic form being the inorganic hydroxide Al(OH) $^{2+}$ or $Al(OH)_2^+$. Presence of the hydroxide ion itself is determined by pH, the $^{2+}$ ion occurring around pH 5. When mortality occurs at pH 4 or lower, it is the hydrogen ion which is the toxic agent, rather than the aluminium ion which is in the non-toxic $^{3+}$ form at this acidity. It is the combination of elevated metal toxin levels and acidified waters that creates the effects that result from acidic precipitation.

1.4 - EFFECTS ON THE ECOSYSTEM.

Acidified lakes are often characterised by extensive blankets of Sphagnum mosses and filamentous algae, flora which relish a bicarbonate-free medium (Muniz, 1983). Their growth is also aided by acidification reducing both density and diversity of zooplankton and grazing benthic invertebrates (Leivestad et al, 1976; Muniz, 1981; 1983). Dense Sphagnum beds in themselves create poor benthic habitats, acting as nutrient traps interfering with the sediment-water interface, and forming a poor nursery ground for juvenile fish (Muniz, 1983). The whole process creates an impoverished fauna, leading to reduced productivity and lake metabolism. This may be termed an 'acido-oligotrophication' (Grahn et al, 1974). This impoverishment subsequently creates a decline in the fish fauna (through the break in the food chain), although the acidity itself has been shown to directly affect fish. Over 15,000 Swedish lakes had been severely acidified by 1978 (Baum, 1982), causing a decline of the salmonid fisheries. The elevated toxic levels of aluminium created by increased acidity cause mucus to clog the gills, lowering the oxygen tension in the blood to lethal levels (Muniz & Leivestad,1980), hence causing respiratory failure and death.

1.5 - PALAEOLIMNOLOGY.

Lake sediments can provide a chronological history of previous events. The study of the environmental history of lakes as recorded in their sediments is known as palaeolimnology. The microfossils contained within the sediment may provide detailed indications of past environmental conditions, especially if they show intra-group variability with respect to water quality. Cladocera (Alhonen, 1970; Nilssen & Sandoy, 1990), Chydoridae, Chrysophytes (Smol et al, 1984; Cronberg, 1990; Charles, 1990) and Chironomidae (Renberg et al, 1990) display such a quality but have only been sparsely studied, whilst the bulk of the work has been focused on diatoms, the siliceous frustules (outer-cases) of which are readily preserved in the sediment. Diatoms have been studied extensively, the emphasis of the work being on the reconstruction of the pH history of the waterbody. Several techniques distribute the diatom taxa along acid-alkali categories of pH tolerance (Hustedt, 1937-9; Nygaard, 1956; Merilainen, 1967; Davis & Berge, 1980; Renberg & Hellberg, 1982; Battarbee, 1986). pH reconstructions using fossilised material are then based on regression models which are calibrated with large data sets that relate diatoms in the sediment to lake pH. Regression coefficients may then be used to serve as transfer functions to derive a diatom-inferred pH from deep core data (Davies, 1987). This approach has produced important insights into the chronological development of lake acidification.

At present, however, the diatom work seems to have a limitation in that it yields little information on water quality other than pH. Ideally, a palaeolimnological tool should give details on all water quality parameters. In practice, no ideal organism exists, but the Ostracoda have features that could make them a more useful group than many others.

1.6 - INTRODUCTION TO THE OSTRACODA

The Ostracoda are a class or subclass of the Crustacea. Ostracoda are small (0.03-3.0 cm) crustaceans that inhabit almost all waterbodies, both marine and freshwater. The majority of freshwater species are between 0.5 and 2.5mm.

1.61 - General Morphology

Ostracods possess a bivalved carapace which is often heavily calcified, and encloses the body. The main rôle of the carapace is to protect the limbs (appendages) of the animal, of which the adult has six or seven pairs, plus in some groups, paired furcae.

As the carapace is an integral part of the exoskeleton, it is moulted 7 or 8 times during the life cycle; a new carapace of slightly different shape and larger size being formed and calcified each time; the rest of the skeleton remains unmineralised. Impregnation with layers of calcite occurs during moulting and the consequent growth process (Benson, 1981), the layers being separated by very thin sheets of chitin. Undercalcification can lead to valves with thin walls, and this often occurs when the aquatic environment has a low $[Mg]^{2+}$: $[Ca]^{2+}$ ratio (Honigstein, 1986). Consequently, poorly calcified or deformed carapaces may be found in harsh environmental conditions (for example, acidity) where the ostracods suffer physiological stress.

Turpen & Angell (1971), using radioactive tracers, showed that calcium is incorporated directly into the valves from the water after moulting. Calcium is not reabsorbed from the old valves prior to the moult, nor is a major store of calcium built up from other sources preparatory to moulting. It is here that the potential of ostracods in assessing past water quality lies. The valve chemistry should be a representation of the water quality at the time of moulting, and hence, by valve analysis it should be possible to estimate previous levels of calcium, and certain other ions in the waterbody. Further studies (Chivas et al, 1986; Carbonel & Farmer, 1990) using high-resolution plasma atomic emission spectrometry, have shown that this is indeed the case. Like many aquatic organisms, ostracods respond to changes in their environment, and as their calcareous valves may be fossilised in lake sediments, it is possible that they may be useful indicators and recorders of environmental pollution, especially acid rain.

1.62 - Ecology

Several factors have been shown to influence the distribution of freshwater Ostracoda. These include both biotic and abiotic parameters. Physical and chemical factors include temperature (Neale, 1964; Martens, 1985), regional geography (Scharf, 1988; Henderson, 1990), water quality (Lowndes, 1952; Hiller, 1972; Pierre, 1973; Fryer & Forshaw, 1979; Janz, 1983), water depth (Fox, 1967; Ranta, 1979; Kempf & Scharf, 1981), substrate (Martens & Dumont, 1984; Benzie, 1989) and lake size (Fryer, 1985). Among the biotic factors influencing ostracod distribution are: macrophyte presence (Martens & Dumont, 1984; Benzie, 1989; Meisch, 1990), predation by fish and invertebrates (Benzie, 1989; Henderson, 1990) and inter-specific competition (Scharf, 1988)

Freshwater ostracods can exist in almost all environments, from hot springs and hypersaline lakes to temporary pools and even water-filled ruts formed by truck tyres (McClay, 1978). The available abundance and diversity data indicate a preference for soft sediment and macrophytes through which the animals may swim (e.g. Cyclocypris) or burrow (e.g. Candona).

Ostracod feeding habits cover a wide spectrum ranging from detritivores to filterers to predators (Liperovskaya, 1948). One species, Cyprinotus incongruens, has been shown to kill young fish when present in sufficiently high numbers (Liperovskaya, 1948).

Reproduction may be sexual or parthenogenetic or both, parthenogenesis being favoured by species inhabiting temporary environments as the population may be established by a single individual. Parthenogenetic species often develop and grow in the winter, completing their life-cycle in under six months, and producing drought-resistant eggs which will only hatch when the site has refilled with water (McClay, 1978).

Previous research has indicated that acidic waters are generally unsuitable for ostracods (Fryer, 1980). Klie (1938) stated that ostracods are excluded from all waters with a pH of less than 6, although it has since been shown that a few species can tolerate lower levels (Fryer & Forshaw, 1979) and some may exist where calcium levels are extremely low (less than 1 ppm). However, on the whole, the group is clearly intolerant of acidic conditions.

Most studies concerning ostracod distribution have simply related species presence to water quality at the time of sampling (Lowndes, 1952; Hiller, 1972), while others have related the size of the waterbody (Fryer, 1985) and regional geography (Scharf, 1988) to species distribution. There has been little attempt to relate a variety of environmental parameters to the overall community structure.

1.7 - AIMS OF THE PROJECT.

i) The most important aim of this research is to improve knowledge of the British ostracod fauna with particular reference to the Lake District where no systematic study has ever been undertaken.

ii) As both the chemical conditions tolerated by individual species, and the influence of water chemistry on valve chemistry and preservation are inadequately understood, the intention of this study is to attempt to evaluate the influence of water quality, especially acidity, on individual species, and on the structure of the communities. This was to be achieved by taking seasonal samples of ostracods from a large number of sites of varying physico-chemical parameters, and statistically relating both individual species abundance and community diversity to specified environmental factors. The database is then used to generate a series of predictions describing an ostracod fauna at a site based on given physico-chemical data. These predictions are then tested on a further data set to check their validity within the study area. The ultimate aim of this process is to allow the water chemistry at a site to be predicted from the ostracod fauna.

iii) The field data are to be supplemented by laboratory experiments assessing the range of tolerance to specific ions of selected species found in the study area.

These three main areas of research should yield a clear picture relating both individual species and community structure to water quality and permit the calibration of certain species as recorders (in their valve chemistry) of water quality. Once these data are available, freshwater ostracods may then be applied to palaeolimnological studies investigating environmental pollution, and in particular, the problem of acid rain.

CHAPTER 2 - SAMPLING METHODS AND SPECIES LIST

2.1 - SUMMARY

The ostracod fauna of the Lake District, Cumbria was surveyed. Seventy five lacustrine sites were selected on the basis of size and water chemistry. The sites selected for sampling ranged from tiny acidic bogland pools to (Lake) Windermere, the largest natural waterbody in England. Biannual marginal samples were taken from most sites, and deep-water benthic samples, using a Jenkin surface-mud sampler were taken from six lakes. Physico-chemical data were also recorded. At most sites, one marginal sample of ostracods was taken on each visit. For two sites, multiple samples were collected to assess whether this single sample produced an adequate representation of the ostracod fauna. It was concluded that a single sample was sufficient if it included collections from the different marginal microhabitats present.

32 species of Ostracoda were found, 8 of which were not previously recorded in the Lake District, and including one previously undescribed species. A full taxonomic list is presented.

2.2 - AIMS OF THE FIELDWORK

The study aimed to identify the environmental characteristics that determine the ostracod community in northern temperate lakes. This was accomplished by sampling ostracods from a wide range of waterbodies encompassing the available spectrum of physico-chemical variables in one geographical region.

Therefore, the fieldwork aimed to produce an extensive, as opposed to intensive, sampling program resulting in the formation of a large database quantifying ostracod faunas within the study area.

2.3 - INTRODUCTION

2.31 - *Choice of the Study Area*

The Lake District in Cumbria was chosen for a number of reasons.

1) It holds a large number of waterbodies which cover a wide range of size and water chemistry, and for logistical purposes, is within a reasonably confined area. It contains sites varying from small acidic upland bog pools and rich eutrophic tarns to long, deep oligotrophic lakes.

2) The choice was further supported by the long-established presence of the Freshwater Biological Association / Institute of Freshwater Ecology laboratories on Windermere. This has resulted in a wealth of faunal (for bibliography, see Horne & Horne, 1985), floral (Stokoe, 1983) and chemical (Carrick & Sutcliffe, 1982) data, aiding site selection.

3) Little is known about the ostracod fauna of the Lake District. Horne (1988) and Horne, Horne & Horne (1990) have

reviewed the literature and summarised previous records, and updated the list of known species in the area. They made no attempt to quantitatively relate the fauna to its environment.

2.32 - *Physical Geography of the Study Area*

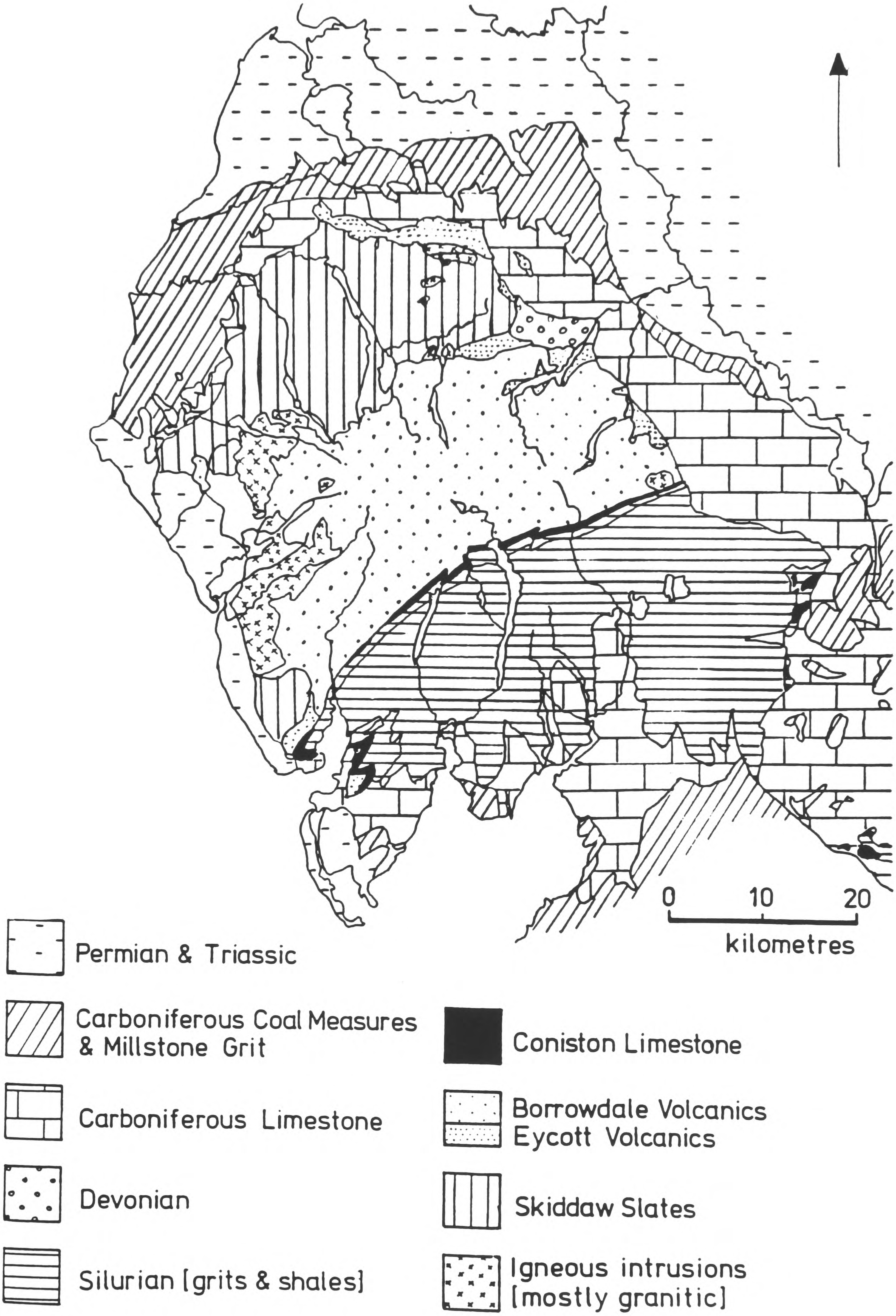
Cumbria is situated in north-west England, bordering the Irish sea south of the Scottish border. The following account is based upon King (1976). The central Lake District (Figure 2.1) consists of a series of glacially deepened river valleys radiating from the central dome-shaped highland. This central zone is formed of Lower Palaeozoic rocks ringed by younger Permo-Triassic and Carboniferous strata. This creates three distinct rock belts, the central Ordovician Borrowdale Volcanic group, the northern Skiddaw Slates and the southern Silurian grits and shales. Large granitic intrusions are found particularly on the west side, and a narrow outcrop of Ordovician Coniston Limestone lies between the Borrowdale volcanics and Silurian rocks. In the north-east, east and south, there are marginal areas of Carboniferous Limestone, whilst on the coastal lands and the Cumberland plain in the north are areas of Permo-Triassic sandstones and shales.

2.33 - *Previous Work in the Lake District*

Few published data on the ostracod fauna of the Lake District exist, and most of the available information relates

Figure 2.1.

Geological Map of the Lake District.



to the planktonic, as opposed to the benthonic Crustacea. One site, Blelham Tarn, which is very productive, has been extensively studied by limnologists, there being a wealth of data especially with respect to the diatoms and chironimids.

The earliest records of Ostracoda from the Lake District are found in Brady (1868a), *Cyclocypris laevis* and *Cyclocypris ovum* being identified from "pools in Ennerdale", and *Cypricercus obliquus* recorded from Loughrigg Tarn. *Potamocypris villosa* was added to the fauna in a separate publication (Brady, 1868b) from moorland pools near Easedale Tarn. Further records include *Cyclocypris globosa* from "pools at the head of Easedale, Westmoreland", and *Cypricercus obliquus* from High Cross Tarn (near Coniston) and Derwent Water (Brady & Norman, 1889). In 1937, Holmes described a new species, *Pseudocandona elongata*, from Windermere (North Basin), together with *Cryptocandona vavrai*, *Candona neglecta* and a single specimen of *Cytherissa lacustris*. Scourfield, (1943) and Smyly (1968, 1973) both collected *Cypria ophthalmica*, it being recorded in 13 out of 17 lakes sampled (Smyly, 1968). In addition, sixteen other species are listed by Horne (1990), which were found by occasional sampling from 1976-1988. A total of 38 species have now been recorded including those found in this study (see Table 2.72).

2.4 - SITE CHOICE WITHIN THE STUDY AREA

Carrick & Sutcliffe, (1982) list 200 static waterbodies in the Lake District for which water chemistry data are available. The sampling of all sites was not undertaken due to time limitations and site similarity. Hence a subset of the Lake District waterbodies had to be selected.

The majority of the waterbodies in the Lake District lie on one of the three main regions of bedrock geology, the Borrowdale Volcanics, Skiddaw Slates and the Silurian Slates. A few lie on the smaller granitic intrusions and Carboniferous rocks. However, some sites are on thick Quaternary deposits which overlie the solid geology in these regions, for example Esthwaite Water.

A total of five different types of bedrock are present, all of which give rise to waterbodies of differing water chemistry (Carrick & Sutcliffe, 1982). For the purpose of the initial subdivision, all the known lotic sites were assigned to one of these five groups. An initial desk study categorised waterbodies on the basis of the underlying solid geology which made the choice of sites an easier task. At this stage, it was thought that physical lake size, (in terms of surface area) might affect ostracod distribution, so the sites in each of the five separate bedrock divisions were then further divided into size classes on the basis of their surface area. The size divisions used were identical for each bedrock group and were based on a logarithmic scale.

Table 2.41 - Size Class Definition

Size Class	**Size Range**
A	More than 1.0 km^2
B	0.1 - 1.0 km^2
C	0.01 - 0.1 km^2
D	0.001 - 0.01 km^2
E	Less than 0.001 km^2

After listing all the waterbodies in each group, available water chemistry data (Carrick & Sutcliffe, 1982) were analysed, the intention being to select sites of variable size covering as wide a range of water chemistries as possible. To do this, factors directly related to the acidity of a lake were chosen, namely pH, calcium concentration and alkalinity. These factors were thought likely to affect ostracod distribution.

Variation in water chemistry within the Lake District is partly controlled by the nature of the bedrock. For example, many of the upland tarns in the central regions of the Lake District are situated on acidic igneous rocks, resulting in a pH of 5 or less and low concentrations of dissolved ions such as calcium and magnesium (Carrick & Sutcliffe, 1988). Conversely, in the Silurian slate region there are fewer acidic sites as alkaline earth metal ions are at greater concentrations in the water due to their proportions being greater in the bedrock.

Final site choice and quantity was restricted by a number of factors. Firstly, due simply to the limited numbers of certain size-class waterbodies with available chemical data, (especially those in size classes A and E), all those with available data had to be chosen as final sites. Within the three remaining groups, B, D and E, factors such as site accessibility and maximum chemical variation were critical in choice. It was attempted to obtain similar numbers of sites within each of the 15 subdivisions for the 3 major bedrock areas and fewer numbers for the other two regions, although this was difficult in the Skiddaw slates region, where there are fewer waterbodies.

After detailed analysis, 75 sites were chosen for sampling, and are shown in Table 2.42.

Table 2.42 - Distribution of Sample Sites in Terms of Size and Bedrock

	SIZE CLASS					
GEOLOGY CLASS	**A**	**B**	**C**	**D**	**E**	**TOTAL NUMBERS**
1. Borrowdale volcanics	3	6	5	6	5	25
2. Skiddaw slates	5	4	4	2	2	17
3. Silurian slates	4	4	6	3	5	22
4. Carboniferous series	0	0	1	4	1	6
5. Igneous intrusions	0	0	3	2	0	5
Total	12	14	19	17	13	75

2.5 - SAMPLING METHODS

Biannual sampling was performed on 75 sites in Cumbria during two visits in the winter (January-February, 1989, 1990) and two in the summer (August-September 1989, August, 1990). This sampling programme was chosen as many ostracod species are known to exhibit different reproductive strategies and life-cycles and therefore occur or reach peak populations at different times of the year (Hoft, 1943; Ferguson, 1944). Nine of the upland acidic sites were only sampled once during the summer period and not during the winter. This was for two main reasons: none of these sites yielded ostracods in the summer period when most species reach their peak abundance, and also access to the upland sites was virtually impossible and potentially dangerous in the harsh weather conditions experienced in the Lake District in January.

The sampling sites are listed in Table 2.51. The values in brackets correspond to the codes used in Table 2.42.

Table 2.51 - List of the Sampling Sites

NO.	SITE.	NO.	SITE.
1.	ESTHWAITE WATER (A3)	39.	BLEA TARN (C5)
2.	WINDERMERE - S.BASIN (A3)	40.	PARKGATE TARN (C5)
3.	WINDERMERE - N.BASIN (A3)	41.	LOW WATER (C1)
4.	CONISTON WATER (A3)	42.	BROWN COVE TARN (D1)
5.	KILLINGTON RESERVOIR (B3)	43.	TOSH TARN (D5)
6.	BLELHAM TARN (B3)	44.	DALEHEAD TARN (D1)
7.	TARN-HOWS TARN (B3)	45.	LILY TARN (D1)
8.	POAKA BECK RESERVOIR (C3)	46.	SINEY TARN (D5)
9.	PENNINGTON RESERVOIR (B3)	47.	BLACKBECK TARN (D1)
10.	BIGLAND TARN (C3)	48.	INNOMINATE TARN (D1)
11.	WITHERSLACK HALL POND (C4)	49.	WHITE MOSS TARN (E1)
12.	RATHER HEATH TARN (C3)	50.	HARD TARN (E1)
13.	HIGH DAM RESERVOIR (C3)	51.	HOW TOP TARN (E1)
14.	YEW TREE TARN (C1)	52.	HAYSTACKS TARN A (E1)
15.	SKEGGLES WATER (C3)	53.	HAYSTACKS TARN B (E1)
16.	KNITTLETON TARN A (C3)	54.	ULLSWATER (A2)
17.	MOSS-SIDE TARN (D4)	55.	BASSENTHWAITE LAKE (A2)
18.	HOLEHIRD TARN (D3)	56.	DERWENT WATER (A2)
19.	HIGH ARNSIDE TARN (D1)	57.	CRUMMOCK WATER (A2)
20.	GRIZEDALE TARN (D3)	58.	ENNERDALE WATER (A2)
21.	KNITTLETON TARN B (D3)	59.	LOWESWATER (B1)
22.	CLAY POND (E3)	60.	BUTTERMERE (B2)
23.	BARROW PLANTATION TARN A (E3)	61.	OVERWATER (B2)
24.	BARROW PLANTATION TARN B (E3)	62.	ARLECDON TARN (B1)
25.	BARROW PLANTATION TARN D (E3)	63.	MOCKERKIN TARN (C2)
26.	BARROW PLANTATION TARN Q (E3)	64.	LITTLE TARN (C2)
27.	HAWESWATER (A1)	65.	TEWET TARN (C5)
28.	WAST WATER (A1)	66.	BLEABERRY TARN (C5)
29.	THIRLMERE (A1)	67.	FLOUTERN TARN (C2)
30.	GRASMERE (B1)	68.	HIGH NOOK TARN (D2)
31.	BROTHERSWATER (B1)	69.	BROWNS TARN (D2)
32.	DEVOKE WATER (B1)	70.	HIGH STOCK POOL (D2)
33.	SEATHWAITE TARN (B1)	71.	PARSONBY TARN (D4)
34.	LEVERSWATER (B1)	72.	MANESTY PARK TARN (E2)
35.	BURNMOOR TARN (B1)	73.	BLACK POOL (E2)
36.	LOUGHRIGG TARN (C1)	74.	SKELSMERGH TARN (D4)
37.	LITTLEWATER TARN (C1)	75.	BOO TARN (E4)
38.	WATENDLATH TARN (C1)		

Further details of each site may be found in Appendix 14.2.

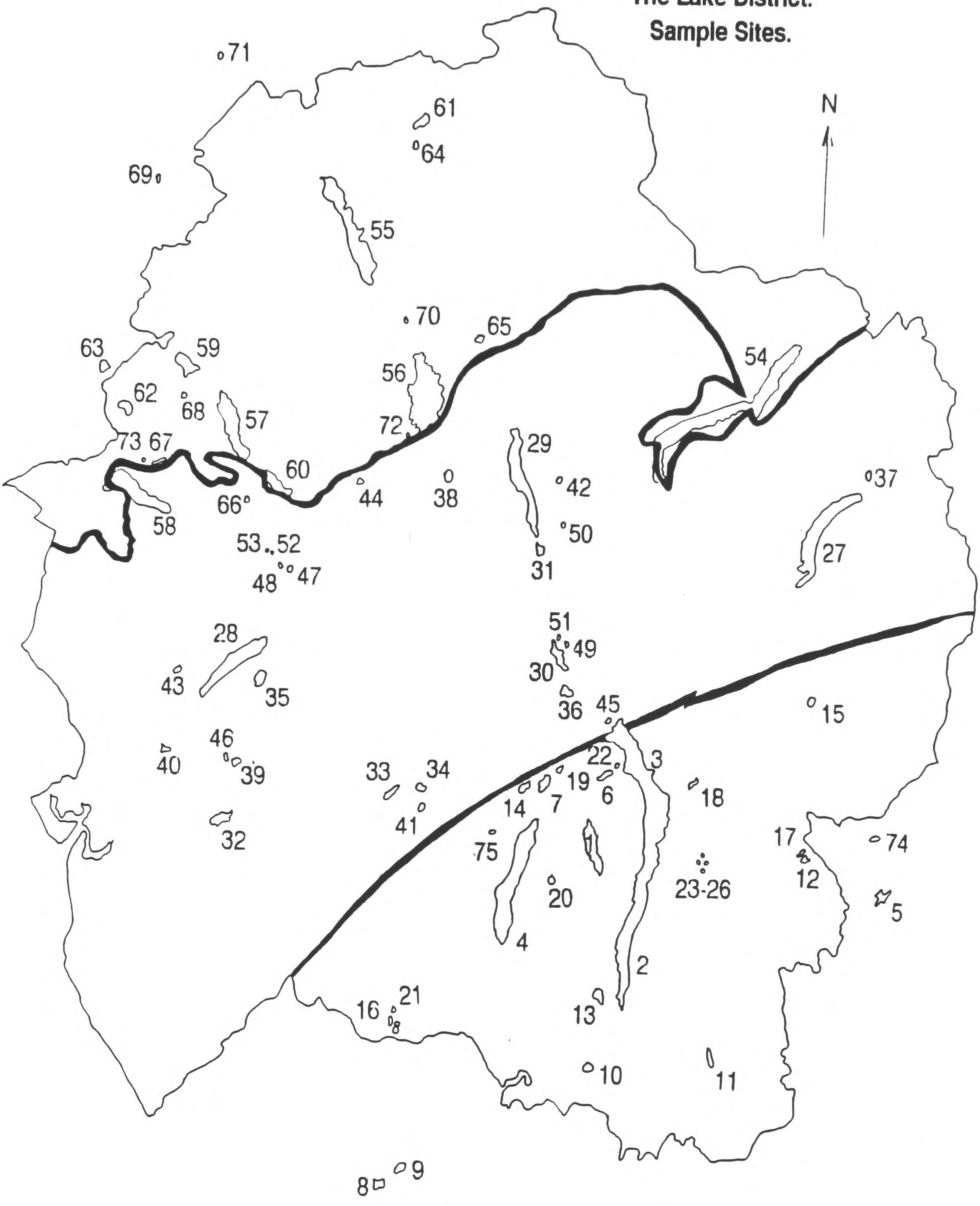
The position of these waterbodies sampled is shown in Figure 2.2.

Sampling techniques were evaluated for maximum efficiency and to gain experience by trial with several methods on sites in the New Forest, Hampshire. Eventually, marginal samples from the littoral zone were found to be most suitably collected by scooping through the sediment with a plastic pot (of volume 791 cm ^{3}), taking a constant volume of material each time.

If several microhabitats were present in a small area, such as a small growth of Potamogeton near a patch of sand, a total of 10 pots were taken from both areas to make up a sample for that site. This regime of attempting to collect from the maximum number of potential ostracod habitats maximised the chances of collecting a representation of all the ostracod species living at a particular site. It was attempted to take an equivalent volume from each microhabitat within a sample area at a site so that the relative proportions of each species would reflect those found in the waterbody.

Although not truly quantitative, the samples taken at each site were of similar volume and were collected by the same person using the same technique, and so may be considered to represent comparable semi-quantitative samples. Some deeper water benthic sampling was also performed in the Lake District, using a Jenkin Surface-Mud sampler, lowered by hand from a boat. Four replicate

Figure 2.2.
The Lake District.
Sample Sites.



samples were combined from each sample site to minimise the potential of one core misrepresenting the fauna at a site. All samples were sieved in the field using a 50 μm mesh plankton net, immediately preserved in 30% alcohol and later washed through a series of sieves (of mesh-size 1mm / 250μm / 125 μm); ostracods retained on the sieves were picked out under a binocular microscope and placed in standard micropalaeontological microscope slides. Only whole carapaces containing appendages (single valves and empty carapaces were ignored) were picked wet from the sample using a pipette, as only these could be considered alive at the time of sampling.

Dissection of the appendages was performed by use of entomological pins mounted in pin chucks, according to the method described by Henderson (1990). Initially, the ostracod was placed in a drop of water and the valves removed and mounted dry on a separate micropalaeontological slide. A small drop of glycerol was then added to the body and the limbs teased apart by use of the entomological pins. Polyvinyl lactophenol (PVL) containing the stain methyl blue was then added and a cover slip placed over the dissection. Identification was achieved on using valve shape, ornament and appendage characteristics, initially using the key of Henderson (1990); reference was made to other publications (eg. Klie, 1938 and Meisch, 1985) when necessary.

Water samples were collected simultaneously with the faunal samples and were analysed for pH and major ion content at both the Institute of Freshwater Ecology, Windermere and Central Electricity Research Laboratories, Fawley. The samples were stored in washed plastic bottles at a temperature of 4 °C in a refrigerator and were analysed within four months of sampling. Field notes were taken at each site on other factors potentially affecting ostracod community structure, such as macrophyte availability, substrate type, fish presence and land use in the catchment area.

At most margin sample sites only a single sample was taken, from a region which was thought most likely to yield a good ostracod assemblage, as the study was aimed at recognising between-site variability. However, to test whether a sample was representative of the marginal fauna of a particular waterbody, multiple samples were taken from two sites, High Dam Reservoir (Site 13) and Loughrigg Tarn (Site 36). At Loughrigg Tarn, four margin samples were taken in both the winter and summer from different microhabitats, and two deep-water samples were collected using the Jenkin Surface-Mud sampler in August, 1989. At High Dam Reservoir, three margin samples were taken from different microhabitats in both winter and summer. Maps of sample areas within both sites are shown in Figures 2.3 and 2.4.

2.6 - SUMMARY OF RESULTS

The collections from the marginal sites yielded 141 samples from 75 sites, and a total of 18,323 individual ostracods were

Figure 2.3.
High Dam Reservoir.
Sample sites.

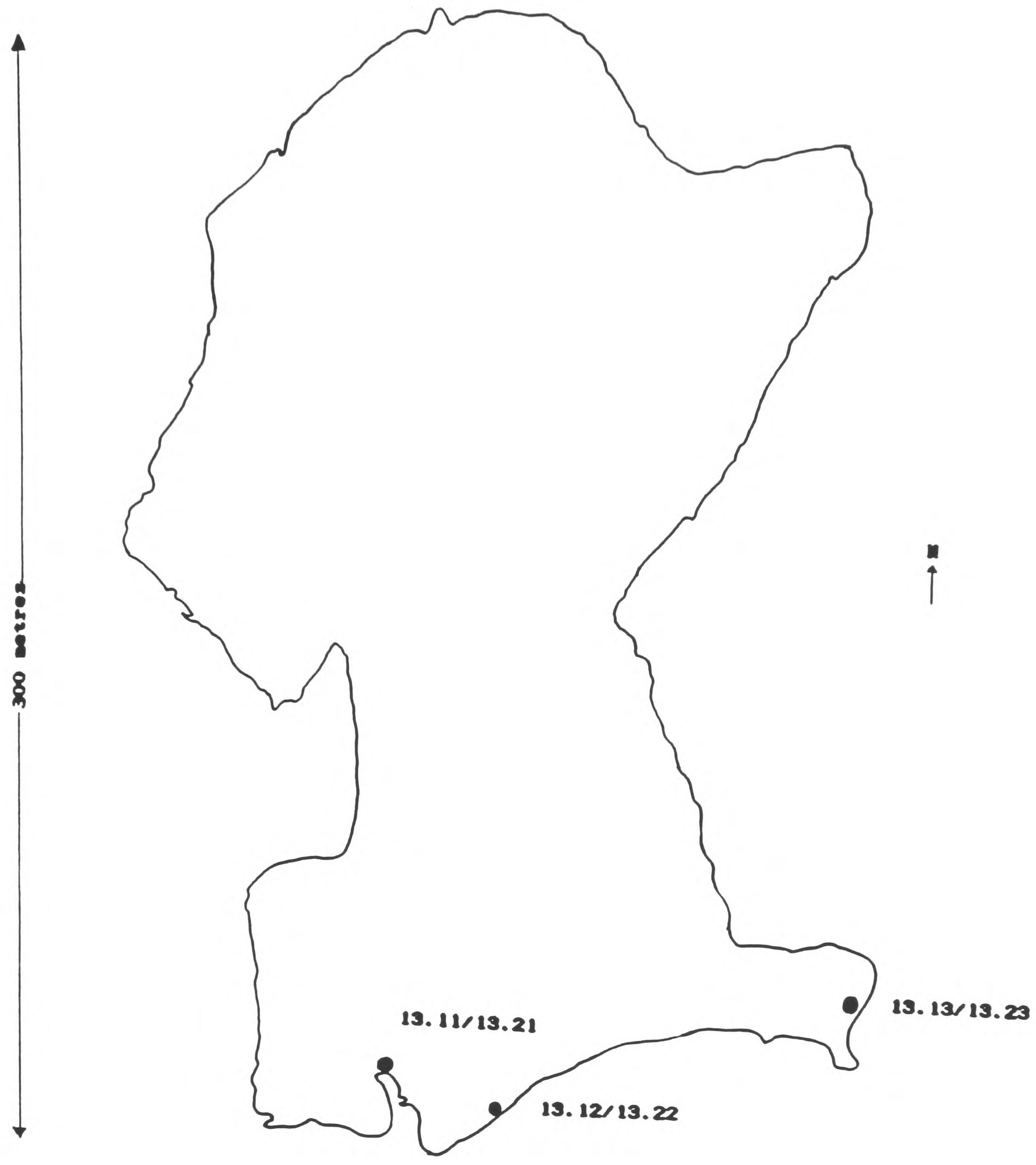


Figure 2.4.
Loughrigg Tarn.
Sample sites.

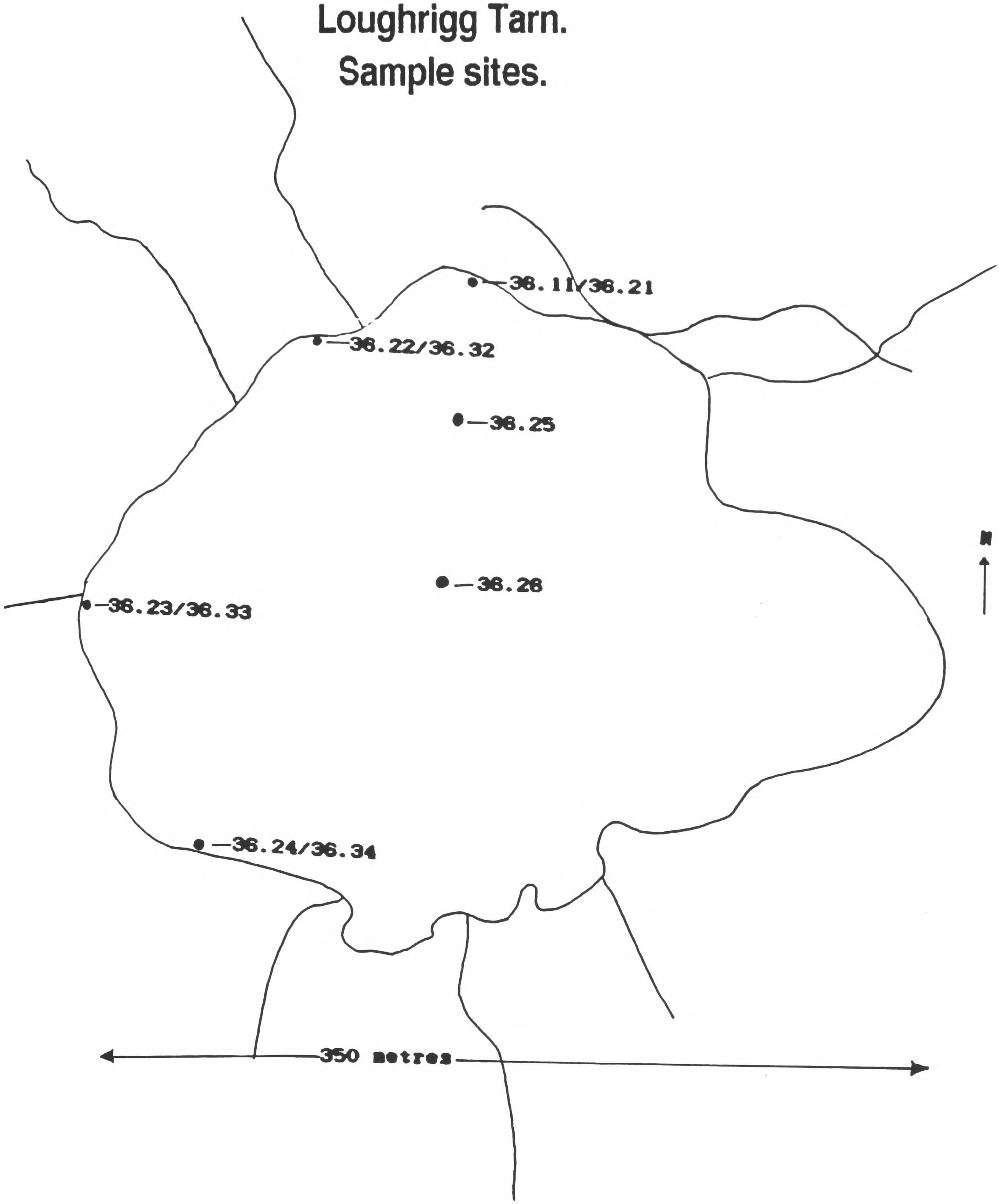


Figure 2.5.

Windermere (North Basin)

Sample sites.

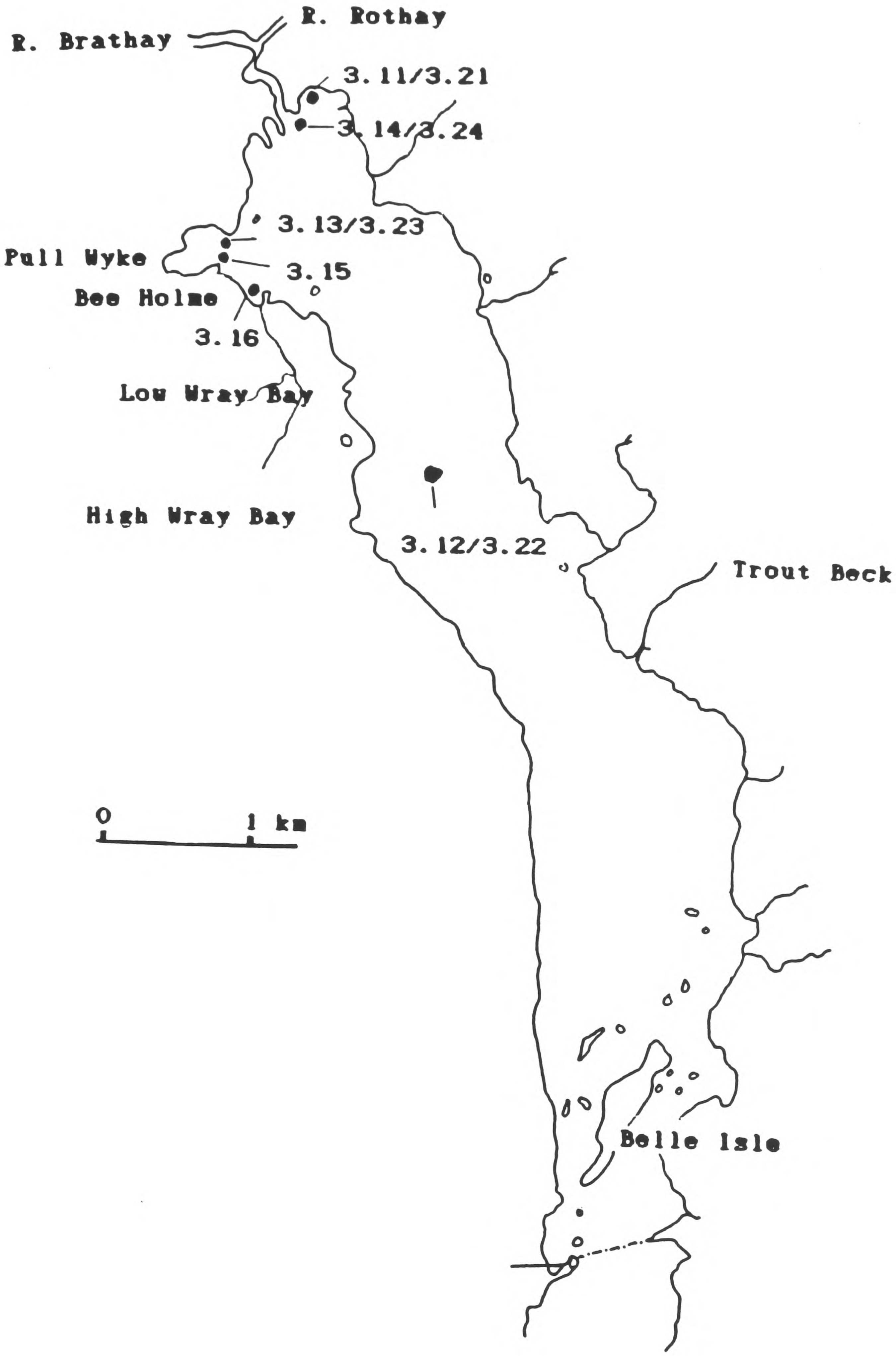


Figure 2.6.
Windermere (South Basin).
Sample sites.

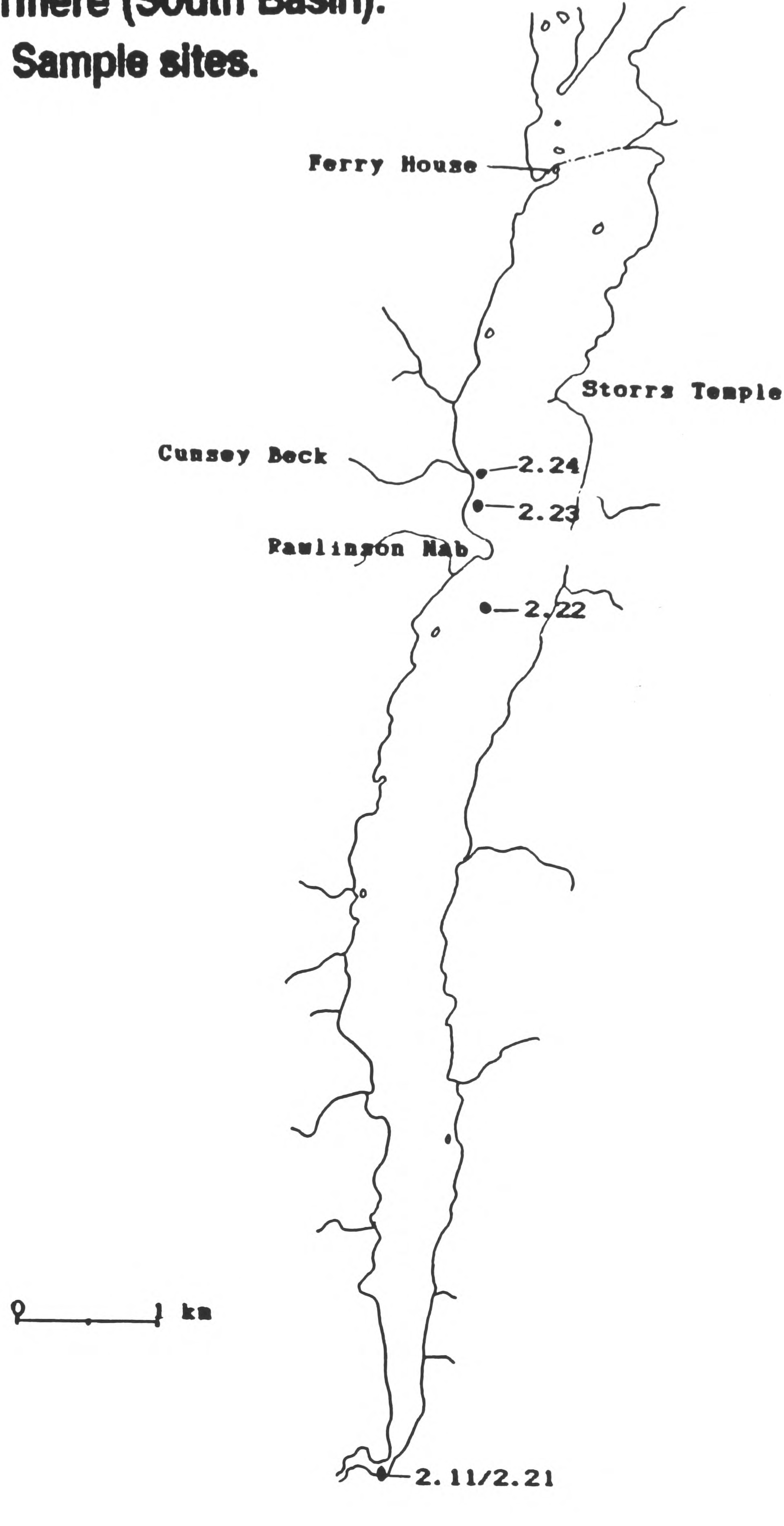


Figure 2.7
Esthwaite Water
Sample sites.

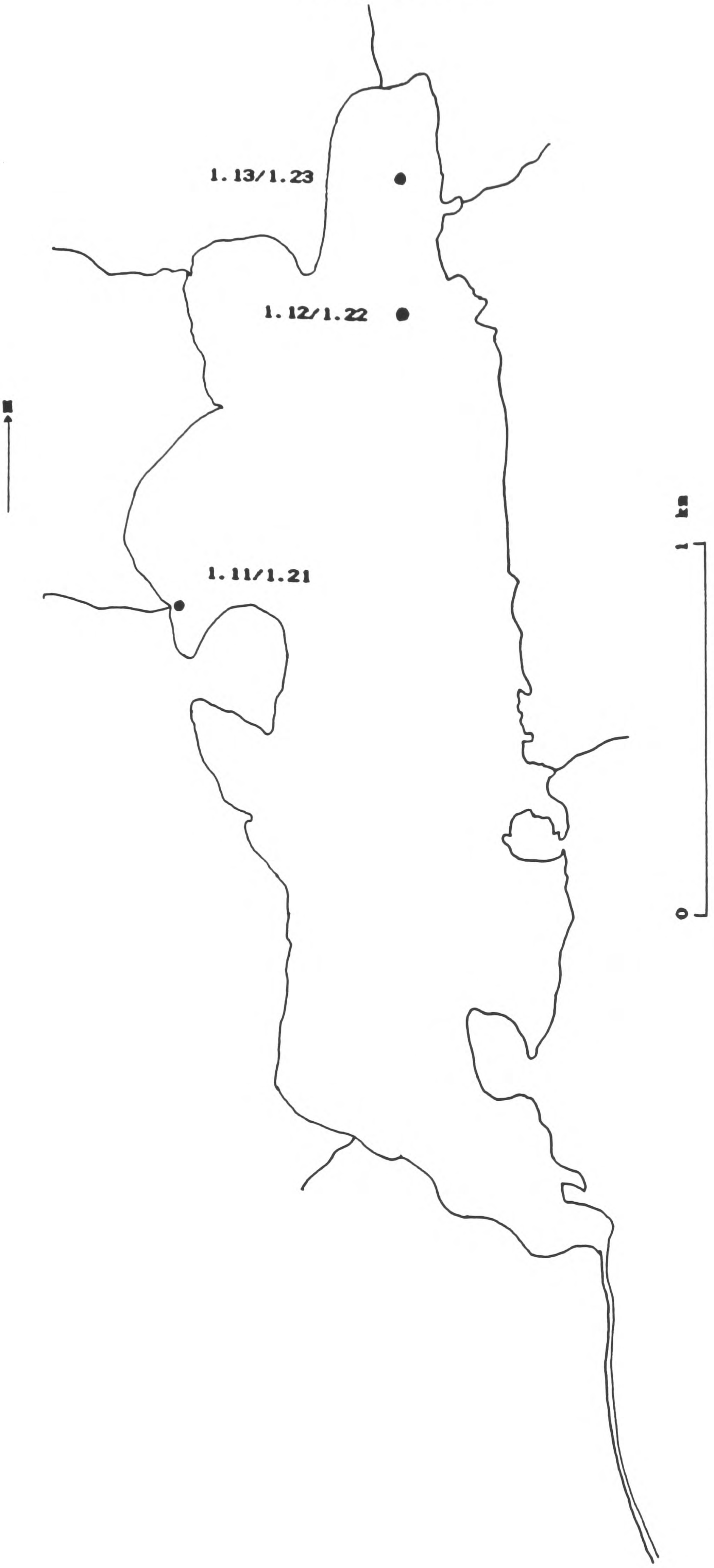


Figure 2.8.
Blelham Tarn
Sample sites.

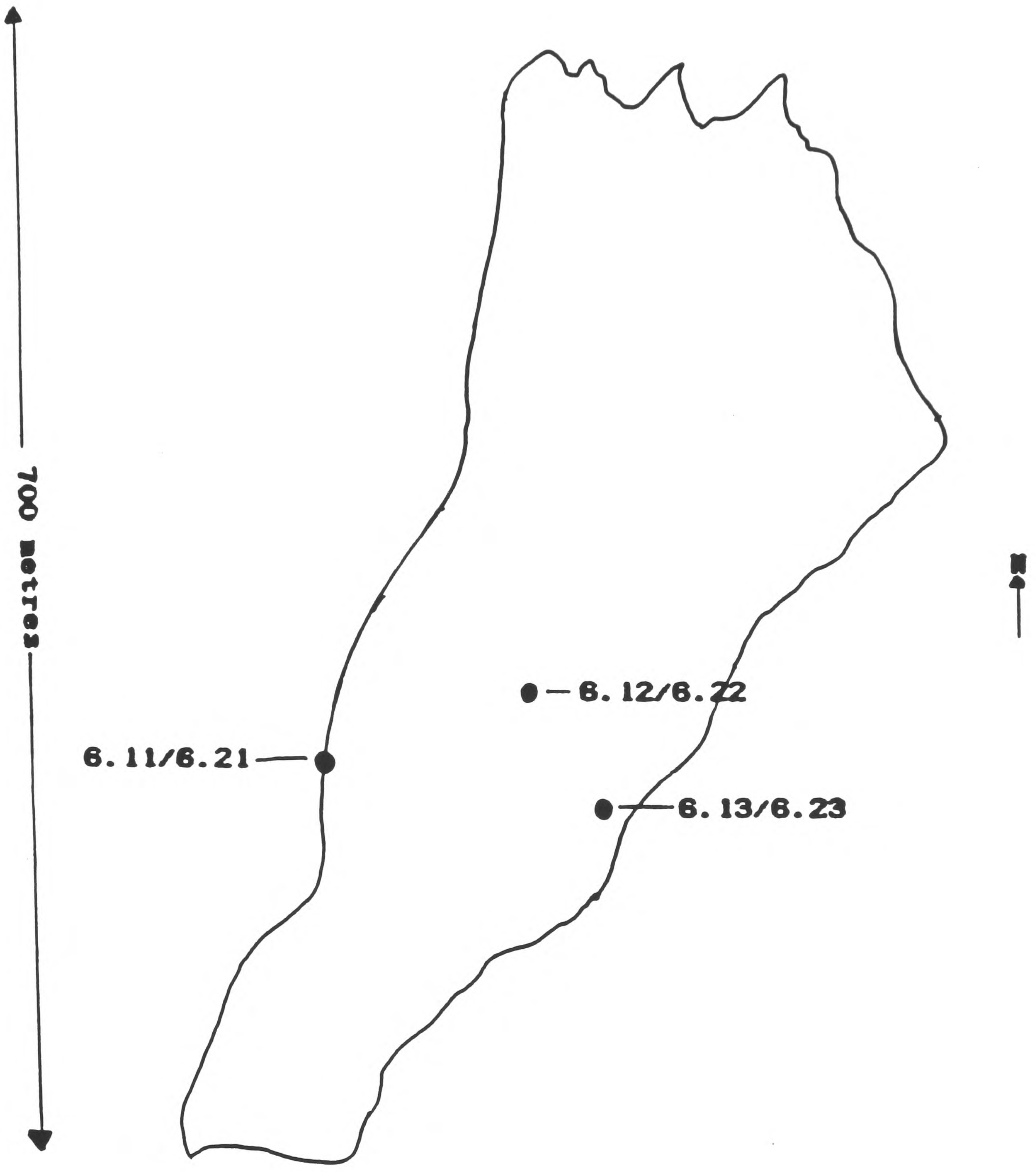
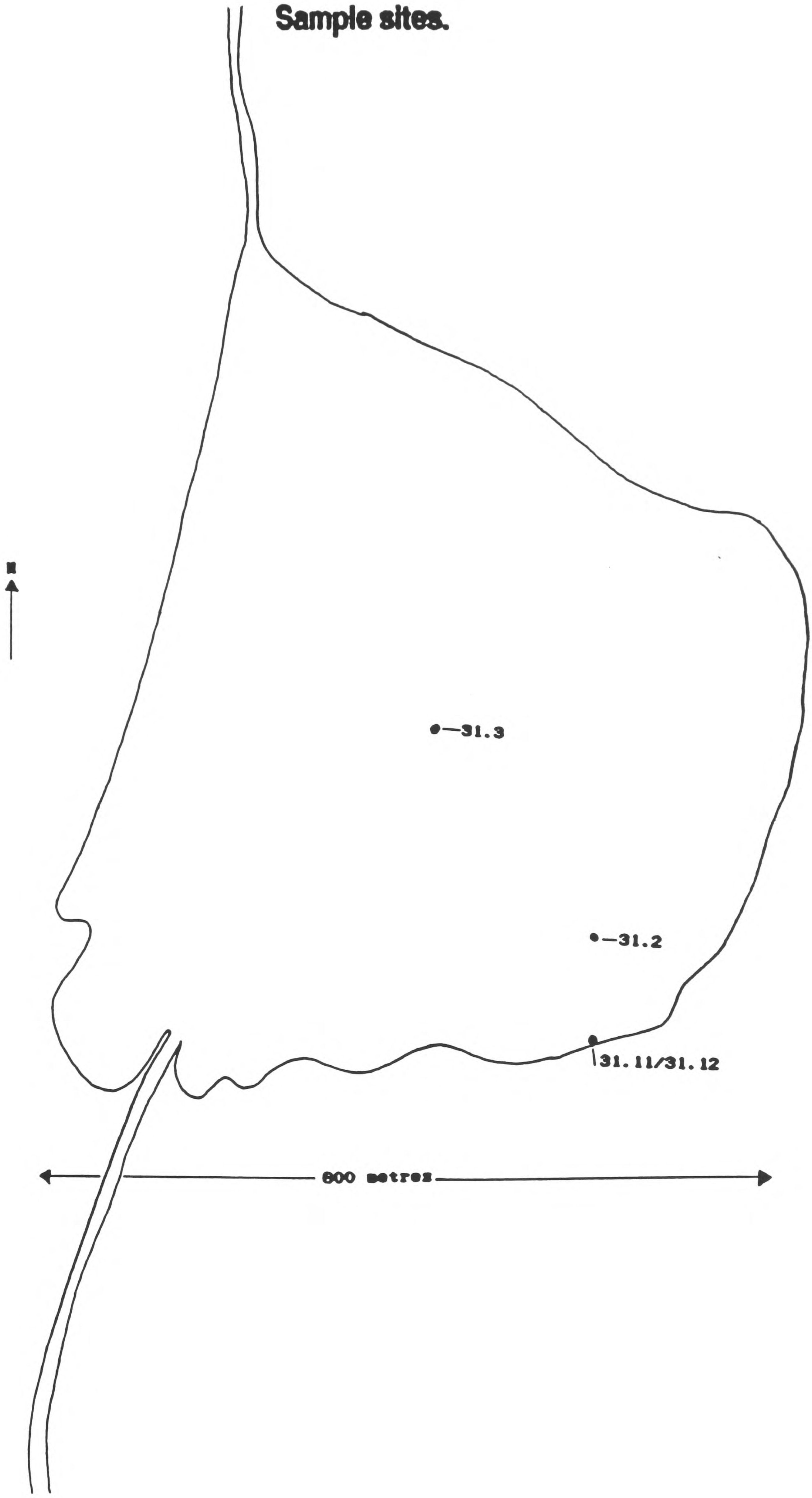


Figure 2.9.
Brotherswater
Sample sites.



picked, representing 32 species belonging to 15 different genera. The summer samples were taken in August-September 1989, and August 1990, while the winter samples were taken in January-February, 1989, 1990. The species found account for over one-third of the total British freshwater ostracod fauna, ten of these being new records for the Lake District, and one, Potamocypris sp. A (ranked 22) being a species new to Great Britain (and possibly undescribed).

The multiple samples data taken at both High Dam Reservoir (site 13) and Loughrigg Tarn (site 36) are shown in Table 2.61.

Table 2.61 - Ostracoda from Multiple Samples

HIGH DAM RESERVOIR
SAMPLING DATES : 13.1 - 30/1/89
13.2 - 21/8/89

FAUNA :	13.11	13.21	13.12	13.22	13.13	13.23
Metacypris cordata	0	1	0	0	0	0
Cyclocypris ovum	24	62	2	7	0	0
Candona candida	7	9	0	0	0	0
Candona reducta	19	20	0	0	0	0
Candona vavrai	27	4	0	0	0	0
Cypria ophthalmica	1	1	2	1	0	0
Cypridopsis vidua	1	24	1	4	2	4
Tot/species	6	7	3	3	1	1
Tot/no.	79	121	5	12	2	4
Tot/overall species	7					

Samples 13.11/13.21 were taken from a small bay containing soft sediment underneath a coniferous tree-lined bank, and the substrate consisted of organic silt and leaves. Samples 13.12/13.22 were taken from sandy margins with a very small amount of fine organic sediment, while samples 13.13/13.23 were taken from exposed rocks and gravel where there was no organic sediment or macrophyte.

LOUGHRIGG TARN
SAMPLING DATES : 36.11 - 31/1/89
36.21-.24 - 21/8/89
36.32-.34 - 31/1/90

FAUNA :

	.11	.21	.22	.32	.23	.33	.24	.34
Cypria ophthalmica	0	2	1	2	0	0	0	0
Cypria exsculpta	0	45	8	1	0	0	0	0
Cyclocypris ovum	0	1	2	0	0	0	1	0
Cyclocypris globosa	0	0	2	0	49	235	0	6
Candona albicans	2	0	1	0	7	4	0	0
Candona candida	1	5	20	1	117	25	7	1
Candona rostrata	1	1	6	2	70	2	0	0
Paracandona euplectella	0	5	1	0	4	0	2	0
Cypridopsis vidua	3	25	13	1	28	0	14	2
Metacypris cordata	9	163	236	17	316	6	47	0
Candona vavrai	0	0	0	0	0	12	0	0
Tot/species	5	8	10	6	7	6	5	3
Tot/no.	16	246	290	24	591	284	71	9
Tot/overall species	11							

Samples 36.11/36.21 were taken from the N margin of the tarn, amongst soft sediment, lilies and *Elodea*.

Samples 36.22/36.32 were taken from the NW corner, underneath overhanging trees with very boggy margins, among soft sediment and submerged macrophyte.

Samples 36.23/36.33 were taken half way along the W margin in marshy bogland adjoining the reedmace-fringed margin of the lake.

Samples 36.24/36.34 were taken from the SW margin among a small amount of organic material, set in discontinuous patches, overlying a gravel base.

2.7 - Testing for Sample Completeness

The multiple samples from both Loughrigg Tarn and High Dam Reservoir both show a similar pattern, in that they display the importance of substrate in controlling ostracod abundance and diversity. It appears that for the full species complement of a site to be obtained, a sample should be collected from an area of soft organic mud and silt, combined with rich macrophytic growth, if available.

The samples collected from High Dam Reservoir showed that both an increased species diversity, and an increase in ostracod density was recorded from samples 13.11 / 13.21, a region rich in soft, organic sediment, compared to samples 13.12 / 13.22 and 13.13 / 13.23, areas dominated by sand, or gravel and rock. Only swimming ostracod species were recorded at the latter two sites; three, C. ophthalmica, C. ovum and C. vidua at 13.12 / 13.22, and only C. vidua at 13.12 / 13.22. The four species absent from these two sites, M. cordata, C. candida, C. reducta and C. vavrai are all non-swimming species that burrow in soft sediment. Therefore, it appears that their absence is due to the lack of a suitable substrate.

The full species complement of 11 species was not collected from any one site at Loughrigg Tarn, although 10 species were collected from samples 36.22 / 36.32, from an area that seemed to contain the greatest number of microhabitats available at the site. Only Candona vavrai was absent from this area. The dominance of Cyclocypris globosa in samples 36.23 / 36.33 is attributable to the nature of the substrate. The samples were collected from marshy bogland fringing the east margin of the lake, and C. globosa has previously been shown to demonstrate a preference for moorland marsh habitats (Fryer & Forshaw, 1979).

A distinctly lower species number was recorded from samples 36.24 / 36.34, an area with a predominately gravel bottom, the non-swimming forms, with the exception of Metacypris cordata, being poorly represented. The density of *M. cordata* at Loughrigg Tarn appears to be so great, that even in microhabitats where the species might not be expected, it tends to occur, albeit in a reduced capacity.

2.8 - Systematics

Figure 2.5 lists the full taxonomic nomenclature, following the usage of Henderson (1990), of the species found.

Figure 2.5 - Ostracod Nomenclature.

PHYLUM - Arthropoda
CLASS - Crustacea
SUB-CLASS - Ostracoda
ORDER - Podocopida
SUBORDER - Podocopina

SUPERFAMILY - Cytheroidea
FAMILY - Limnocytheridae
SUB-FAMILY - Metacypridinae
Metacypris cordata (Brady & Norman, 1870)

SUPERFAMILY - Darwinuloidea
FAMILY - Darwinulidae
SUB-FAMILY - Darwinulinae
Darwinula stevensoni (Brady & Robertson, 1870)

SUPERFAMILY - Cypridoidea
FAMILY - Ilyocyprididae
SUB-FAMILY - Ilyocypridinae
Ilyocypris bradyi (Sars, 1890)
Ilyocypris decipiens (Masi, 1906)

FAMILY - Candonidae
SUB-FAMILY - Candoninae
Candona albicans (Brady, 1864)
Candona candida (Müller, 1785)
Candona compressa (Koch, 1838)
Candona fabaeformis (Fischer, 1854)
Candona neglecta (Sars, 1887)
Candona pratensis (Hartwig, 1901)
Candona reducta (Alm, 1914)
Candona rostrata (Brady & Norman, 1889)
Candona siliquosa (Brady, 1910)
Candona vavrai (Kaufman, 1900)
Candonopsis kingsleii (Brady & Robertson, 1870)
Paracandona euplectella (Brady & Norman, 1889)

SUB-FAMILY - Cyclocypridinae
Cypria exsculpta (Fischer, 1855)
Cypria ophthalmica (Jurine, 1820)
Cyclocypris globosa (Sars, 1863)
Cyclocypris laevis (Müller, 1776)
Cyclocypris ovum (Jurine, 1820)
Cyclocypris serena (Koch, 1837)

FAMILY - Cyprididae
SUB-FAMILY - Notodromatinae
Notodromas monacha (Müller, 1776)

SUB-FAMILY - Cyprinotinae
Cyprinotus incongruens (Ramdohr, 1808)

SUB-FAMILY - Eucypridinae
Eucypris virens (Jurine, 1820)
Cypricercus fuscatus (Jurine, 1820)
Cypricercus obliquus (Brady, 1868)

SUB-FAMILY - Herpetocypridinae
Herpetocypris chevreuxi (Sars, 1896)
Herpetocypris reptans (Baird, 1835)

FAMILY - Cypridopsidae
SUB-FAMILY - Cypridopsinae
Cypridopsis vidua (Müller, 1776)
Potamocypris villosa (Jurine, 1820)
Potamocypris sp. A (?)

These species, and those previously found are shown in Table 2.81.

Table 2.81 - Summary of Lake District Ostracoda.

	Source									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**J**	**K**
Species										
Cytherissa lacustris				*						
Metacypris cordata								*	*	*
Limnocythere inopinata									*	
Darwinula stevensoni								*		*
Ilyocypris bradyii										*
Ilyocypris decipiens										*
Cypria exsculpta								*	*	*
Cypria ophthalmica					*	*	*	*	*	*
Cyclocypris globosa			*					*	*	*
Cyclocypris laevis	*							*	*	*
Cyclocypris ovum	*							*	*	*
Cyclocypris serena								*		*
Paracandona euplectella								*	*	*
Candona albicans								*		*
Candona candida								*	*	*
Candona compressa									*	*
Candona fabaeformis									*	*
Candona neglecta				*						*
Candona pratensis										*
Candona reducta								*		*
Candona rostrata								*		*
Candona siliquosa								*		*
Candona vavrai				*				*	*	*
Candonopsis kingsleii										*
Pseudocandona elongata				*						
Notodromas monacha								*	*	*
Cyprinotus incongruens										*
Eucypris pigra								*		
Eucypris virens										*
Cypricercus affinis								*		
Cypricercus fuscatus										*
Cypricercus obliquus	*		*						*	*
Psychrodromas robertsoni								*	*	
Herpetocypris chevreuxi										*
Herpetocypris reptans								*	*	*
Cypridopsis vidua								*	*	*
Potamocypris villosa		*						*	*	*
Potamocypris sp. A ?										*

KEY:

A - Brady (1868a)
B - Brady (1868b)
C - Brady & Norman (1889)
D - Holmes (1937)
E - Scourfield (1943)
F - Smyly (1968)
G - Smyly (1973)
H - Horne (1990)
J - K. Martens (pers. comm)
K - Present study.

CHAPTER 3 - COMMUNITY ECOLOGY.

3.1 - SUMMARY

31 species of Ostracoda were collected from 141 margin samples taken from 75 waterbodies. Multiple samples collected from two sites demonstrated the efficiency of the chosen sampling technique; as long as a sample was taken from an area encompassing a number of microhabitats, the full species complement for that site could be obtained.

Cypria ophthalmica was the most common species both in overall density and number of sites from which it was recorded. Three species made up almost 75% of the data set, and 18 contributed to over 99% of the total ostracods identified. One species previously undescribed was recorded.

Hierarchical Classification Analysis classified 56 of the 75 sites into eight distinct assemblage groups, the diversity of which were controlled by five dominant species. The community structure of the remaining 19 sites was either dominated by a species ranked lower than 5, or by no single species.

The deep-water samples yielded 10 species of Ostracoda, again dominated by Cypria ophthalmica, which comprised over 50% of the number of individuals identified. Hierarchical Classification Analysis showed community structure to be determined more by water depth (together with the associated temperature effect) and substrate, than by water chemistry.

3.2 - AIMS OF THE CHAPTER

The intention of this chapter is to classify the ostracod communities collected in the Lake District, both marginal and deep-water sites.

Comparable ecological studies involving large sets of data (Green & Vascotto, 1978; Pitblado *et al*, 1980) have made use of a multistage, multivariate statistical approach for the analysis. This procedure, which is utilized in the present study, incorporates two major techniques, Hierarchical Classification Analysis and Principal Component Analysis.

This chapter is divided into two sections. The first analyses the results from the margin samples, all of which may be thought of as being taken from the epilimnion, the upper, warmer, isothermal water layer (Moss,1980). The second section analyses the data from the deep-water samples, the majority of which were derived from the hypolimnion, the cooler, denser water lying beneath the epilimnion.

3.3 - OSTRACOD RELATIVE ABUNDANCE IN THE MARGIN SAMPLES

Table 3.31 represents the data obtained from the marginal sampling in the Lake District. Of the 32 species collected, 31 were found in the margins. *Candona neglecta* was the exception, being collected only from deep-water stations.

Table 3.31 - Species Abundance in the Margin Samples

SPECIES	**RANK**	**NO.**	**SITE PRES.**	**In.**	**% TOTAL NUMBERS.**	**CUMUL %.**
Cypria ophthalmica	1	5909	46	8.68	32.25	32.25
Cyclocypris ovum	2	4419	42	8.39	24.12	56.37
Metacypris cordata	3	3275	9	8.09	17.87	74.24
Candona candida	4	1332	44	7.19	7.27	81.51
Cypridopsis vidua	5	958	38	6.86	5.23	86.74
Cypria exsculpta	6	548	15	6.31	2.99	89.73
Cyclocypris serena	7	305	8	5.72	1.66	91.39
Potamocypris villosa	8	250	8	5.52	1.36	92.75
Cyclocypris laevis	9	246	11	5.51	1.34	94.09
Herpetocypris reptans	10	165	15	5.11	0.90	94.99
Cypricercus obliquus	11	158	9	5.06	0.86	95.85
Candona fabaeformis	12	112	3	4.72	0.61	96.46
Candona reducta	13	104	5	4.64	0.57	97.03
Candona rostrata	14	101	7	4.62	0.55	97.58
Candonopsis kingsleii	15	84	2	4.43	0.46	98.04
Paracandona euplectella	16	71	7	4.26	0.39	98.43
Candona vavrai	17	68	9	4.22	0.37	98.80
Herpetocypris chevreuxi	18	55	1	4.01	0.30	99.10
Candona siliquosa	19	34	7	3.53	0.19	99.29
Ilyocypris decipiens	20	25	1	3.22	0.14	99.43
Cypricercus fuscatus	20	25	4	3.22	0.14	99.57
Potamocypris sp. A	22	20	1	3.00	0.11	99.68
Notodromas monacha	23	18	2	2.89	0.10	99.78
Cyclocypris globosa	24	12	5	2.48	0.06	99.84
Candona compressa	25	8	1	2.08	0.04	99.88
Darwinula stevensoni	26	7	1	1.95	0.04	99.92
Candona pratensis	27	5	2	1.61	0.03	99.95
Candona albicans	28	4	3	1.39	0.02	99.97
Eucypris virens	29	3	1	1.10	0.01	99.98
Cyprinotus incongruens	30	1	1	0	0.01	99.99
Ilyocypris bradyi	30	1	1	0	0.01	100.00
TOTAL	31	18323	-	-	-	100.00

(**NO** = total number of specimens, adult and juvenile found in all the marginal sites: **SITE PRES.** = number of sites in which that species was found: **In** = natural logarithm of **NO**: **% TOTAL NUMBERS** = % of the total ostracod numbers that the species represents: **CUMUL %.** = cumulative proportion of the total represented by that number of ranked species.)

3 species make up almost 75% of the total ostracod numbers. Two of these, C. ophthalmica and C. ovum are among the most

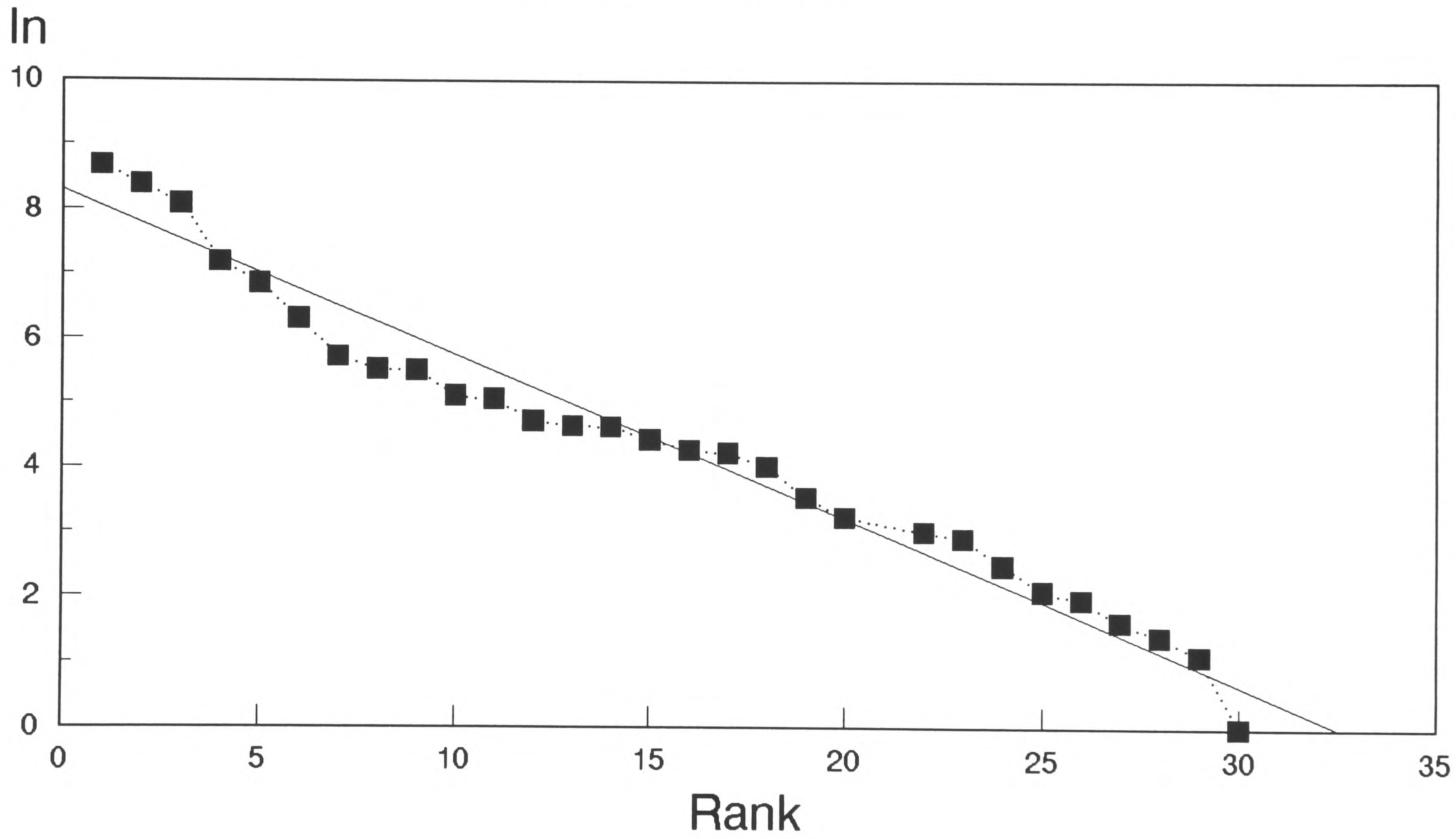
common European freshwater species (Henderson, 1990), and are the first and third most common species in terms of the number of sites in which they appear. The third-ranked species, Metacypris cordata is only found at 9 of the sample sites, but often occurs at high (to a maximum of over 1000 individuals per sample) density. Interestingly, this is the only region of England in which living populations of M. cordata have been found.

Figure 3.1 plots the natural logarithm of species abundance against the rank in order of abundance for the data set. For the Lake District, with the exception of 3 species, C. ophthalmica, C. ovum and M. cordata which at some sites occur at high densities, the ranked number of ostracod species is well fitted by a straight line, giving a geometric series of abundance.

3.4 - HIERARCHICAL CLASSIFICATION ANALYSIS OF THE MARGINAL SAMPLE DATA.

In similar population studies incorporating large data sets (for example, Green & Vascotto, 1978; Pitblado et al, 1980), a method of analysis was selected which efficiently reduced the biological data and related those reduced data to potentially explanatory environmental variables. This was done by use of a multistage, multivariate approach. Firstly, Hierarchical Classification Analysis was used to divide the sites into groups displaying similar faunal assemblages, yielding a dendrogram as a graphical representation of this. These groups were then subjected to Principal Component Analysis (PCA) (Hotelling, 1933)

Figure 3.1.
Plot of In v. Rank.
Margin Samples.



to correlate them with the measured physical and chemical parameters. This procedure was chosen for this study.

For the initial section of the multistage analysis approach, the 18 species that contributed over 99% of the total ostracod numbers were used. Rarer species were excluded because of the large number of zero elements they would have introduced which would have distorted the results (Henderson, 1989), and which in Figure 3.1 show as a long tail of infrequent species. The 13 sites that contained no ostracods were omitted at this stage, as the Hierarchical Classification Analysis makes a measure of similarity at each site, and all these sites with no ostracods obviously have a 100% similarity.

The dendrogram plotted in Figure 3.2 indicates that there are seven main groups of sites which may correspond to seven ostracod community groups in 43 out of the 62 sites analysed, the other 19 sites displaying little or no similarity to any other site. A key to these 7 main ostracod groups is presented in Figure 3.3, and incorporates an eighth group representing the 13 sites containing no ostracods. It should be noted that this key refers only to the averages of summer and winter samples and should only be applied to help explain Figure 3.2.

Figure 3.2.
Dendrogram.
Marginal Data Set.

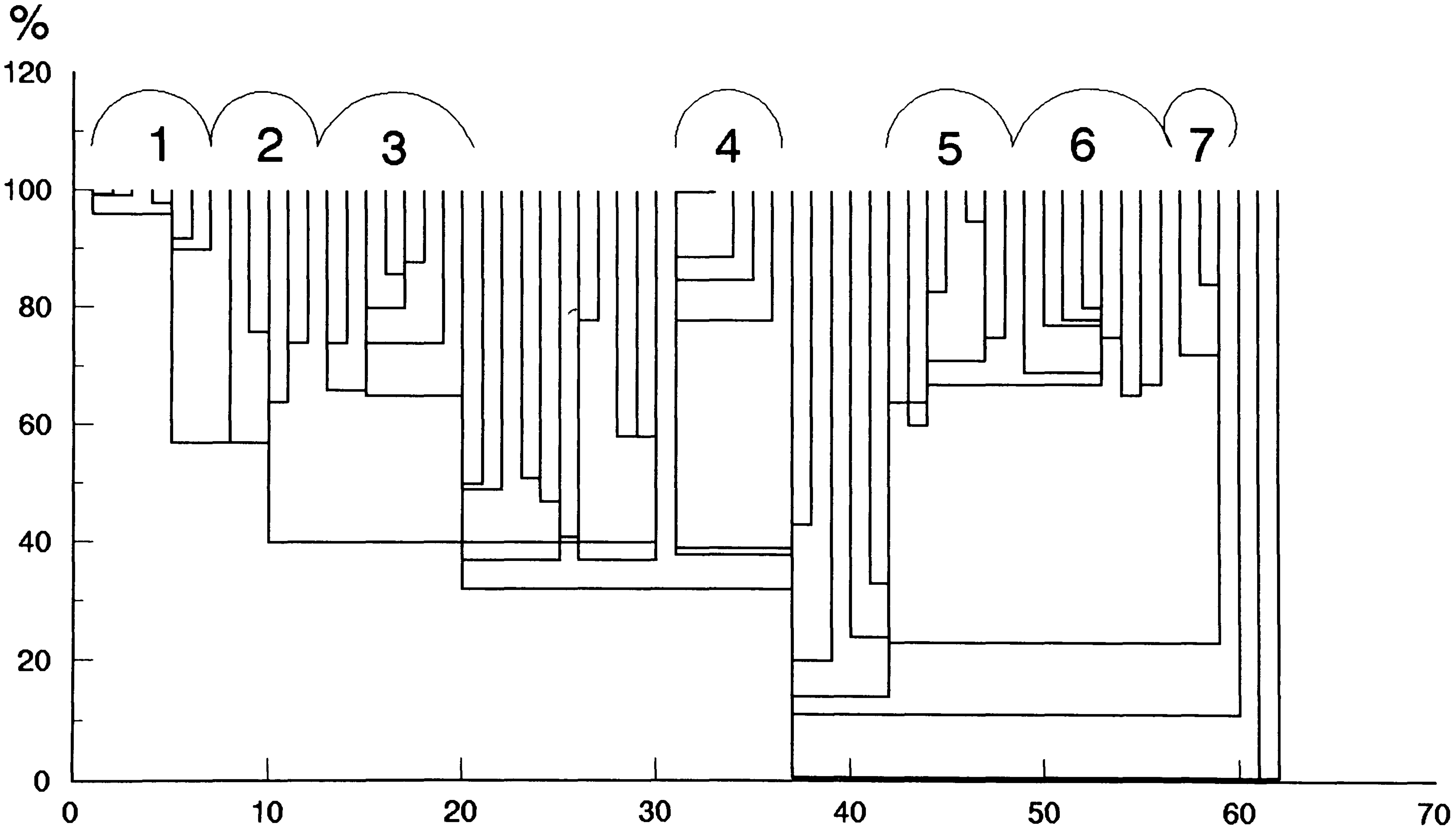


Figure 3.3 - Key to the Community Groups.

1A.....Ostracods present................2
1B.....Ostracods absent.......... GROUP 8

2A.....*Metacypris cordata* is the dominant species and > 60% of the total numbers....GROUP 7
2B.....*Metacypris cordata* < 60% of the total numbers................................3

3A.....*Cypridopsis vidua* is the dominant species and > 75% of the total numbers....GROUP 4
3B.....*Cypridopsis vidua* < 75% of the total numbers................................4

4A.....*Candona candida* is the dominant species and > 55% of the total numbers....GROUP 3
4B.....*Candona candida* < 55% of the total numbers................................5

5A.....*Cypria ophthalmica* is the dominant species and > 90% of the total numbers....GROUP 1
5b.....*Cypria ophthalmica* < 90% of the total numbers................................6

6A.....*Cypria ophthalmica* is the dominant species, and *Cyclocypris ovum* (if present) < 20% of the total numbers..........................GROUP 2
6B.....*Cyclocypris ovum* > 20% of the total numbers................................7

7A.....*Cyclocypris ovum* is 40-60% of the total numbers..........................GROUP 5
7B.....*Cyclocypris ovum* is > 60% of the total numbers..........................GROUP 6

GROUP 1

22) Clay Pond, 44) Dalehead Tarn, 57) Crummock Water
67) Floutern Tarn, 70) High Stock Bridge Pool,
71) Parsonby Tarn, 72) Manesty Park Tarn.

GROUP 2

6) Blelham Tarn, 9) Pennington Reservoir,
18) Holehird Tarn, 63) Mockerkin Tarn, 64) Little Tarn.

GROUP 3

2) Windermere (South Basin), 14) Yew Tree Tarn,
27) Haweswater, 28) Wast Water, 38) Watendlath Tarn,
56) Bassenthwaite Lake, 59) Loweswater, 69) Browns Tarn.

GROUP 4

8) Poaka Beck Reservoir, 10) Bigland Tarn,
41) Low Water, 43) Tosh Tarn, 60) Buttermere,
65) Tewet Tarn.

GROUP 5

13) High Dam Reservoir, 17) Moss-Side Tarn,
21) Knittleton Tarn B, 24) Barrow Plantation Tarn B,
45) Lily Tarn, 55) Derwent Water, 75) Boo Tarn.

GROUP 6

23) Barrow Plantation Tarn A, 31) Brotherswater,
26) Barrow Plantation Tarn Q, 32) Devoke Water,
40) Parkgate Tarn, 42) Brown Cove Tarn, 61) Overwater.

GROUP 7

36) Loughrigg Tarn, 37) Littlewater Tarn,
74) Skelsmergh Tarn.

GROUP 8

5) Killington Reservoir, 33) Seathwaite Tarn,
34) Leverswater, 39) Blea Tarn, 46) Siney Tarn,
47) Blackbeck Tarn, 48) Innominate Tarn,
52) Haystacks Tarn A, 53) Haystacks Tarn B,
58) Ennerdale Water, 66) Bleaberry Tarn,
68) High Nook Tarn, 73) Black Pool.

Although 56 out of the 75 sample sites are covered by this key, 18 sites were shown by the classification analysis to be only poorly related to any others. There are two possible explanations for this. Firstly, these sites may be dominated by a species making up < 3% of the total ostracod numbers, i.e. a species of rank > 5. The sites displaying this distribution are listed in Table 3.41.

Table 3.41 - Sites Dominated by a Species of Rank > 5.

Site	**Dominant Species**
3) Windermere (North Basin)	Cyclocypris serena (51%)
4) Coniston Water	Cyclocypris serena (74%)
7) Tarn-Hows Tarn	Candona siliquosa (30%)
11) Witherslack Hall Pond	Cyclocypris laevis (63%)
12) Rather-Heath Tarn	Candona fabaeformis (52%)
15) Skeggles Water	Cyclocypris laevis (61%)
16) Knittleton Tarn A	Potamocypris villosa (41%)
25) Barrow Plantation Tarn D	Paracandona euplectella (38%)
30) Grasmere	Cypria exsculpta (66%)
35) Burnmoor Tarn	Candona rostrata (64%)
50) Hard Tarn	Candona vavrai (100%)
51) How Top Tarn	Herpetocypris reptans (57%)
54) Ullswater	Cyclocypris serena (47%)
62) Arlecdon Tarn	Cypricercus obliquus (81%)

The second option is that the site is not strongly dominated by any species, and possesses a community consisting of a number of species exhibiting similar densities. These sites are listed in Table 3.42.

Table 3.42 - Sites not Dominated by any Single Species

Site

1) Esthwaite Water
19) High Arnside Tarn
20) Grizedale Tarn
29) Thirlmere
49) White Moss Tarn

Both possibilities could be the result of a different water quality or substrate form than the 8 main groups classified in Figure 3.3. This will be discussed later.

3.5 - Results - Hierarchical Classification Analysis

In group 1, Cypria ophthalmica makes up > 90% of the total ostracod numbers. There are 7 sites in this group, 6 of which are in the smaller size classes C,D or E. The larger site, Crummock Water, appears limited in terms of potential faunal diversity by its rocky substrate, with little macrophyte growth or soft sediment, rather than by its chemistry. Floutern Tarn however, is faunally limited by its acidity (pH 5.0), only containing C. ophthalmica. This species is one of the few that appears tolerant of acidic conditions, having been recorded from a pH as low as 3.0 (Lowndes, 1952), although this value is extremely low for the pH of natural water. The other five sites are all quite similar, being of size class D or E, shallow (1m maximum) and all rich in deep soft sediment and aquatic macrophytes.

In group 2, Cypria ophthalmica is again the dominant species, but only makes up 30-65% of the total numbers at each site, and Cyclocypris ovum (when present) is always < 20% of the total numbers. All these sites are of size class B,C or D, have both soft organic substrate and extensive macrophyte growth and are relatively rich in dissolved ions.

Candona candida makes up > 55% of the total numbers represented by the 8 sites in group 3. There is a bias towards larger water bodies, five of the sites being in the largest size class A. Fryer (1985) also noted that this species was often found in large lakes. The five larger sites and the three smaller ones had similar dissolved ion contents, and a substrate of a few millimetres of soft organic detritus overlying a firm gravel base, with little macrophyte growth. None of these sites had a pH of less than 6.5.

The six sites representing group 4 were dominated by Cypridopsis vidua which contributed a minimum of 78% to the total number of ostracods collected at any site. Five sites are in size classes C or D and are similar with respect to a marginal substrate of rock and fine gravel with small amounts of organic sediment but plentiful growth of macrophytes, especially Elodea sp. A different sampling method involving a plankton net being towed through a bed of Elodea without touching the bottom in Windermere (South Basin) in August 1989, yielded an ostracod fauna of entirely Cypridopsis vidua.

In group 5, Cyclocypris ovum makes up 40-60% of the total numbers at 7 sites and Cypria ophthalmica is always present.

Derwent Water differs from the other sites in this group, being of size class A, having no aquatic macrophytes and not being in the southern half of the Lake District. Five of the other sites were in size classes D or E, had very rich macrophyte growth, especially Potamogeton, and areas of shallow organic detritus. A point of note here is the high similarity of two sites within this group, Moss-side Tarn and Barrow Plantation Tarn B, which cluster next to each other in the hierarchical classification analysis. These are the only two sites in the data set which included the species Notodromas monacha in their fauna, although this species was not used in this analysis. Both sites contain no fish, a factor potentially important to the distribution of this species, as it is the sole British ostracod which swims in the upper water layers and actually feeds from the surface film, making it susceptible to predation. However, it should be noted that this species has been previously sampled in sites containing fish in the New Forest (P. Henderson, pers. comm.).

Group 6 sites are dominated by Cyclocypris ovum making up over 60% of the total numbers at each site. It is difficult to see any relation on the whole between these sites.

Metacypris cordata is the dominant species in the 3 group 7 sites. These sites all have high total ion contents, marshy (boggy) margins and extensive reedmace growth, and were in size class C or D.

The group 8 sites represent the 13 sites containing no ostracods. 11 of these sites were acidic, while the other two, Killington Reservoir (5) and Ennerdale Water (58) were large rocky lakes with no soft sediment or macrophyte growth anywhere at their margins.

Of the 19 sites sampled that do not fit the key to the dendrogram, five, Windermere (North Basin), Coniston Water, Witherslack Hall Pond, Skeggles Water and Ullswater are dominated by either Cyclocypris serena or Cyclocypris laevis, both of which have previously been shown to exhibit a preference for larger waterbodies (Fryer, 1985; Henderson, 1990). All three of the sites dominated by C. serena are of the largest size class A, which corresponds to the literature, although why other sites within the same size class are not dominated by this species is difficult to assess.

The other nine sites dominated by a species of rank lower than five are all dominated by a different species, and it is difficult to isolate any factors which may explain this phenomenon for most of these sites.

Of the five sites not strongly dominated by any species, that possesses a community consisting of a number of species exhibiting similar densities, two, Thirlmere and White Moss Tarn have very low ostracod densities, and this is a factor which could distort the results. Grizedale Tarn (site 20), which contained similar densities of Candona candida, Candona rostrata and Paracandona euplectella was viewed as a peculiar site in that it had a non-acidic pH (6.6) and a reasonable concentration of dissolved ions, yet was set amongst coniferous forest, and had black water which was characteristic of many of the acidic sites in the Lake District that contained no ostracods.

3.6 - Principle Component Analysis of the Marginal Data Set.

Principle Component Analysis (PCA) (Hotelling, 1933) was used to examine the relationships between the measured physico-chemical variables and the 18 ostracod species used in the first step of the statistical analysis. PCA is an ordination technique which may be applied to a correlation matrix of the number of each species between all the samples to enable a few important dimensions to summarise the species relationships. The total variability within the data set is measured by the sum of the eigenvalues. Associated with each eigenvalue there is an eigenvector which defines the orthogonal axes within which the samples may be plotted.

The eight groups of site identified in terms of their ostracod faunas were calculated and the data were then classified using PCA. These new values used in the analysis are given in Table 3.61.

Table 3.61 - Database for Principle Component Analysis

Group	pH	[Ca]	[Mg]	[K]	[Na]	ALK	Size	Alt
1	6.4	457	231	17	502	378	3.7	184
2	7.2	637	206	38	341	563	2.8	117
3	6.9	393	126	16	240	308	2.0	121
4	7.1	319	133	19	237	238	3.0	208
5	6.8	503	135	11	262	511	3.7	162
6	6.3	256	141	13	297	180	3.3	230
7	7.3	1311	571	17	203	1796	3.3	154
8	5.4	103	63	9	237	30	3.4	370

Values for [Ca], [Mg], [K], [Na] and ALK are given in μel^{-1}, Alt as metres above sea level.

On plotting the eigenvalues obtained from the PCA, the orientations of groups 1 to 8 with respect to principal axes 1 and 2 could not be interpreted in terms of differences in their ostracod faunas. Closer examination of the data revealed the reason for this failure. The analysis exposed absolute differences in concentration. For example, the technique appointed less difference between the sites in group 8 (in which ostracods are absent) and those in groups 1 to 6, than between group 7 (which has high cationic concentrations) and the other groups containing ostracods.

Therefore, an alternative analytical approach was required to understand the responses of individual species to variability in physico-chemical parameters. This will be illustrated in Chapter 5. However, at this point, a few qualitative observations between the group differences may be made.

Group 1, which was dominated by Cypria ophthalmica, had higher average $[Na]^+$ values than the rest of the groups, while the mean lake size was larger for those sites in group 3, which was dominated by Candona candida. The highest mean concentrations of Ca^{2+} and Mg^{2+}, together with high pH and overall alkalinity were recorded in group 7, that characterised by large densities of Metacypris cordata. Group 8 sites, those containing no ostracods, had the lowest mean pH, Ca^{2+}, Mg^{2+} and alkalinity values, together with the highest mean altitude.

3.7 - Ostracod Distribution in the Deep-Water Samples

The 14 deep-water samples taken by the Jenkin Surface-Mud Sampler from six sites at depths of between 2 and 64 metres in August 1989 yielded a total of 281 individuals from ten species belonging to six genera. One species, Candona neglecta, was only found in deep water samples, never being collected from marginal areas.

The sample sites and descriptions are presented in Table 3.71.

Table 3.71 - Description of the Deep-Water Samples

Site	**Site no.**	**Sample depth**	**Substrate**
Esthwaite Water	DW1	12 m	mud
Esthwaite Water	DW2	4 m	mud
Windermere (South Basin)	DW3	42 m	mud
Windermere (South Basin)	DW4	11 m	mud
Windermere (South Basin)	DW5	3 m	mud with *Elodea*
Windermere (North Basin)	DW6	64 m	mud
Windermere (North Basin)	DW7	15 m	mud
Windermere (North Basin)	DW8	3 m	sand
Blelham Tarn	DW9	14 m	mud
Blelham Tarn	DW10	2 m	mud with *Phragmites*
Brotherswater	DW11	19 m	mud
Brotherswater	DW12	11 m	mud
Loughrigg Tarn	DW13	8 m	mud with faecal pellets
Loughrigg Tarn	DW14	10 m	mud with faecal pellets

Figure 3.4.

Plot of ln v. Rank.

Deep - Water Samples

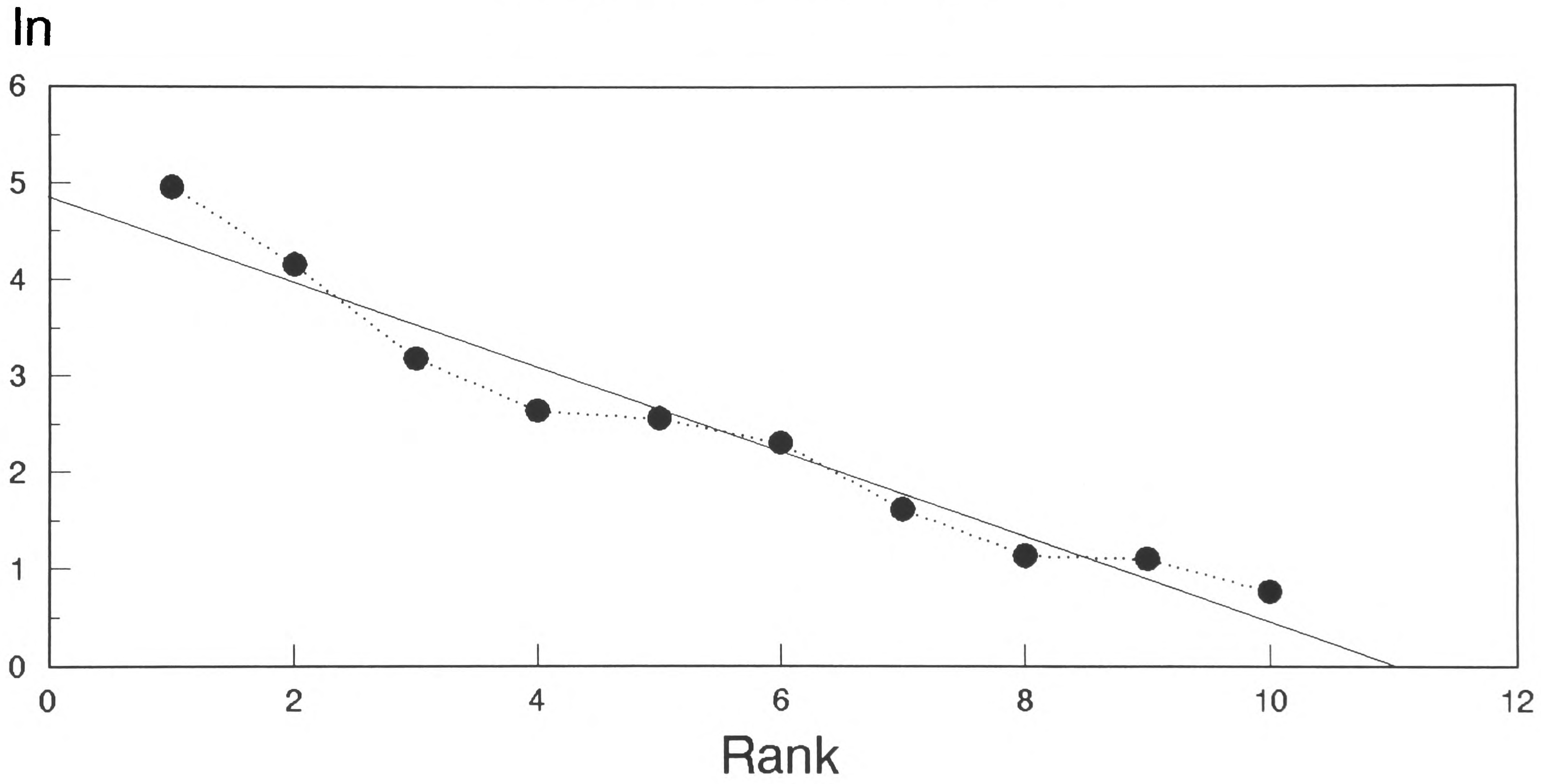


Table 3.72 - Species Abundance in the Deep - Water Samples.

SPECIES	**RANK**	**SITE PRES.**	**NO.**	**IN**	**% TOTAL NUMBERS.**	**CUMUL %.**
Cypria ophthalmica	1	9	142	4.96	50.53	50.53
Candona candida	2	7	64	4.16	22.78	73.31
Candona neglecta	3	5	24	3.18	8.54	81.85
Cypridopsis vidua	4	5	14	2.64	4.98	86.83
Cyclocypris serena	5	1	13	2.56	4.63	91.46
Cyclocypris laevis	6	1	10	2.30	3.56	95.02
Cyclocypris ovum	7	1	5	1.61	1.78	96.80
Metacypris cordata	8	1	4	1.39	1.42	98.22
Herpetocypris reptans	9	2	3	1.10	1.07	99.29
Cypria exsculpta	10	1	2	0.76	0.71	100.00

(**NO** = total number of specimens, adult and juvenile found in all the marginal sites: **SITE PRES.** = number of sites in which that species was found: **In** = natural logarithm of **NO**: **% TOTAL NUMBERS** = % of the total ostracod numbers that the species represents: **CUMUL %.** = cumulative proportion of the total represented by that number of ranked species.)

These faunas are dominated by two species, *Cypria ophthalmica* and *Candona candida* which make up almost 75% of the total ostracod numbers. *C. ophthalmica* was the dominant species in both lake marginal and deeper water benthic samples.

Figure 3.4 plots the natural logarithm of species abundance against the rank in order of abundance for the data set. With the exception of the most abundant species, *C. ophthalmica*, a straight line fits the data well, indicating a geometric series of abundance.

3.8 - Hierarchical Classification Analysis of the Deep-Water Sample Data

Hierarchical Classification Analysis was used to divide the sites into groups displaying similar faunal assemblages, yielding a dendrogram as a graphical representation of this. This analysis incorporated the 9 species which comprised over 99% of the fauna, rarer species were being again excluded due to the large amount of zero elements they would have introduced which would have distorted the results (Henderson, 1989). Twelve out of the 14 samples were included in the analysis, as two sites were barren and showed, therefore, a 100% similarity and were excluded from this stage of the analysis.

The resulting dendrogram is shown in Figure 3.5 and indicates that eight out of the twelve sample sites are covered by two main ostracod groups. If the three unrelated sites 5, 8 and 10, and the two barren sites fauna are also considered as separate groups, then 13 of the 14 sites may be described. A key to these groups is presented in Figure 3.6. This key refers only to the summer samples and should only be applied to help explain Figure 3.5.

Figure 3.6 - Key to the Community Groups.

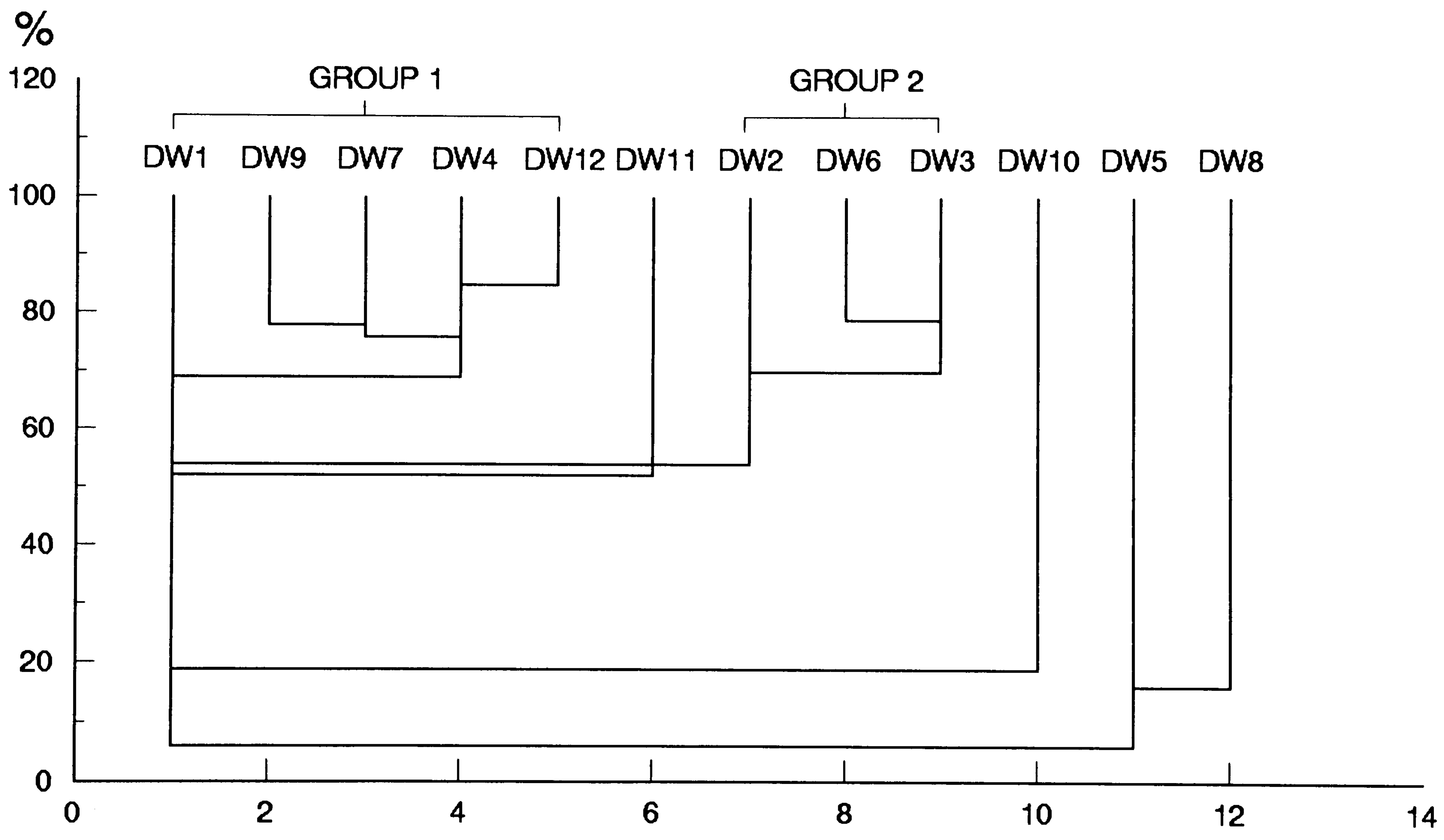
1A.....Ostracods present................2
1B.....Ostracods absent.......... GROUP 3

2A.....*Cypria ophthalmica* is the dominant species
and > 65% of the total numbers....GROUP 1
2B.....*Cypria ophthalmica* < 65% of the total
numbers...............................3

3A.....*Cypria ophthalmica* and *Candona candida*
both present......................GROUP 2
3B.....*Cypria ophthalmica* absent.........4

4A.....*Candona candida* is the dominant species
and > 50% of the total numbers....SITE 10
4B.....*Cyclocypris serena* is the dominant species
and > 50% of the total numbers.....SITE 5
4C.....*Cypridopsis vidua* is the dominant species
and > 50% of the total numbers.....SITE 8

Figure 3.5.
Dendrogram.
Deep-Water Samples.



3.9 - Results - Hierarchical Classification Analysis

The dendrogram indicates that a relevant factor in the analysis of the Jenkin Surface-Mud Sampler data is the depth at which the sample was taken. This will now be briefly considered.

In the 5 samples represented by group one, samples DW1, DW9, DW7, DW4 and DW12, Cypria ophthalmica makes up at least 65% of the total ostracod fauna. All samples in this group were closely related, in that whilst they originated from different water bodies, all were taken from regions of organic mud, and at depths between 11 and 15 metres, the only five sites of this depth in the data set.

Group two represented 3 sites, DW2, DW6 and DW3, containing both C. ophthalmica and Candona candida at similar proportions of 20-40% per sample. Sites DW3 and DW6 were the deepest stations sampled at 62m and 42m respectively, and also contained Candona neglecta, a noted deep water benthic species (Munro-Fox, 1965; Danielopol et al, 1985; Fryer, 1985). Site DW2 is more distantly related to the other two sites, lacking C. neglecta and was sampled at a depth of 4 metres.

The two sites in group 3, samples DW13 and DW14, both taken in Loughrigg Tarn at depths of 8m and 10m were barren. This may appear at first a rather surprising result when one considers the rich marginal fauna of 11 species collected there. However, the deep-water sediments consisted almost entirely of faecal pellets (0.5-1mm), there being no other fauna present. This suggests that possibly the environmental conditions in the profundal zone of this lake are inimical to life due to deoxygenation of the hypolimnion.

The samples from all of the above deep-water sites may be considered as having been collected from the hypolimnion. Ostracod assemblages in the remaining three samples, DW5, DW8 and DW10, taken from shallower water can be considered as having been collected from the warmer waters of the epilimnion. These were shown by the analysis to differ significantly from the cold water hypolimnion collections in their faunas.

At site DW5, Cyclocypris serena dominated, comprising 68% of the total ostracod fauna. This sample was from Windermere (South Basin) and differed from all other sites in that it was taken in 3 metres of water amongst extensive growth of Elodea sp.

Site DW8 was entirely dominated by Cypridopsis vidua, the only species present. This sample was from Windermere (North Basin), and differed from other sites in being from a firm sandy-gravel bottom at 3 metres depth at the delta of the River Brathay.

Candona candida dominated site DW10, representing 86% of the community. This site was unique, being from Blelham Tarn at 2m depth, close to the margin of a large bed of Phragmites.

This analysis illustrates the influence of depth combined with temperature, substrate type and macrophyte presence in determining benthic community structure.

CHAPTER 4 - WATER CHEMISTRY IN THE LAKE DISTRICT

4.1 - Summary

Principal component analysis was performed on the entire water chemistry database from the Lake District. Two principal components accounted for over 71% of the variability within the data set, and corresponded to the first principal component carrying a high loading for calcium and magnesium ion concentration, while the second principal component had a high loading for hydrogen and sodium ion concentration. It was, therefore, concluded that the main characteristics that chemically differentiate these lakes are the concentrations of these four elements.

The plot of the first two principal components of each site identified five distinct groups of sites which were shown to clearly correspond to a lake quality key published by the Institute of Freshwater Ecology. Several sites not previously classified by this key are added to it herein by the analysis.

4.2 - Aims of the Chapter

This chapter will:

Present the results of statistical analysis of the water chemistry data by use of Principal Component Analysis. The data obtained in the present study are to be added to those recorded from the available literature. This method of analysis allows the sample sites to be divided into distinct groups on the basis of specific chemical parameters.

4.3 - Methods

Water samples taken simultaneously with the faunal samples were analysed at both the Institute of Freshwater Ecology, Windermere, and C.E.R.L., Fawley. Concentrations of major cations were measured using Atomic Absorption flame spectroscopy (Perkin Elmer HB660). The samples were analysed at the I.F.E. by Dr. T. Carrick, and at C.E.R.L. by the author and Dr. P. Henderson. pH was measured using a glass electrode pH meter calibrated against buffer solutions of pH 4 and pH 7.

Values for pH, alkalinity and major cations were selected for the statistical analysis. Concentrations of the major ions are expressed as micro-equivalents (μel $^{-1}$) per litre. Division of such values by the ionic charge, e.g. 2 for Ca $^{2+}$, will convert to μmol $^{-1}$.

4.4 - Results - Statistical Analysis of the Water Chemistry Data

Field data were combined with both published and unpublished (T. Carrick, pers. comm) data to create a large data set of variables with which the faunal data could be correlated. It is more suitable to relate the faunal community to chemical values known to be approximately average for that site, as opposed to one-off readings which could create misleading results. Isolated values may yield problems in that water chemistry may vary in certain environmental conditions. After snowfall a waterbody may take on a more acidic pH than usual. For example, in January 1984, the pH of Blea Tarn (Thirlmere) fell from 6.0 to 4.1 (Sutcliffe & Carrick, 1988) and had not recovered normal alkalinity by June. In contrast, there may be a rise in alkalinity at the surface of some lakes on warm, bright summer days. This effect is most pronounced in very productive medium hard waters, such as Esthwaite Water, where pH may rise to 10.0 due to photosynthesis by dense algal blooms, which temporarily remove dissolved carbon dioxide from the surface water and upset the normal pH buffering system.

Principal Component Analysis (Chapter 3) was used for the data analyses.

The resultant correlation matrix from the Principle Component Analysis of the water chemistry data from the Lake District is shown in Figure 4.41.

Table 4.41 - Correlation Matrix derived from PCA.

	H^+	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**Alk**
H^+	1.000	-.251	-.159	0.067	-.159	-.218
Ca^{2+}	-.251	1.000	0.839*	0.309	0.487	0.969*
Mg^{2+}	-.159	0.839*	1.000	0.344	0.306	0.895*
Na^+	0.067	0.309	0.344	1.000	0.477	0.194
K^+	-.159	0.487	0.306	0.477	1.000	0.366
Alk	-.218	0.969*	0.895*	0.194	0.366	1.000

The matrix indicates that calcium and magnesium are highly positively correlated and that alkalinity shows a very significant correlation with both calcium and magnesium. These relationships have been previously recorded in the Lake District (Carrick & Sutcliffe, 1982). Plots of these relationships may be seen in Figures 4.1 to 4.3.

The term 'alkalinity' is approximately equivalent to the concentration of bicarbonate ions (Carrick & Sutcliffe, 1982) and this amount represents the capacity of the alkalinity in the water to neutralise acids. As the measure of alkalinity in itself is so closely related to the calcium and magnesium ion concentration (Carrick & Sutcliffe, 1982), and calcium and magnesium both most commonly exist in the form of the metal carbonate (Carrick & Sutcliffe, 1982), the proportions in solution must be directly related. Therefore, for the purpose of the statistical analyses, alkalinity was removed as an independent variable from the model at this stage.

The eigenvectors, together with the eigenvalues and the proportion of the total variability they represent for each of these principal components, excluding alkalinity, are represented in Table 4.42.

Figure 4.1.

Plot of [Calcium] v. [Magnesium].
Microequivalents per litre.

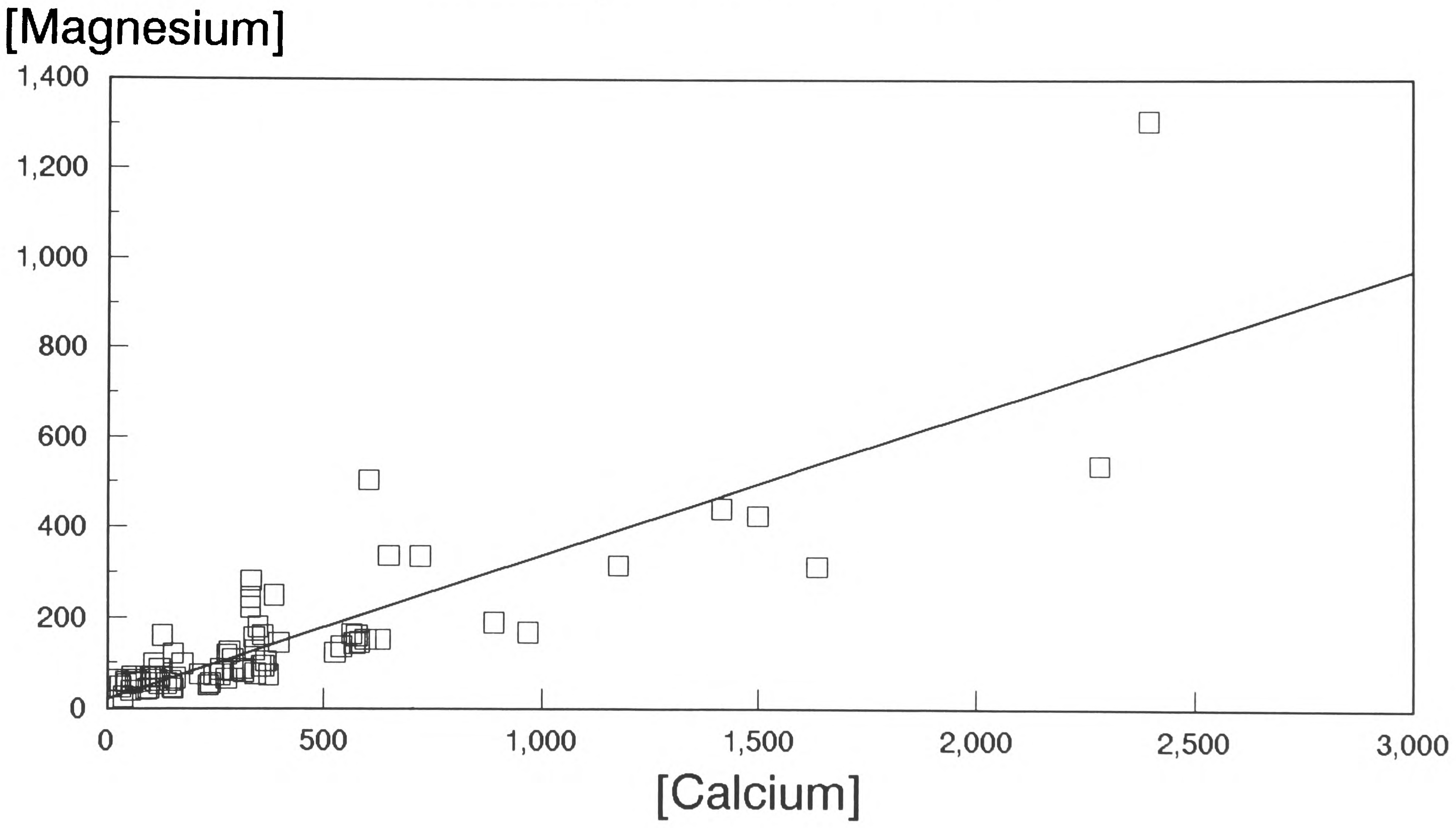


Figure 4.2.

Plot of [Calcium] v. Alkalinity.
Microequivalents per litre.

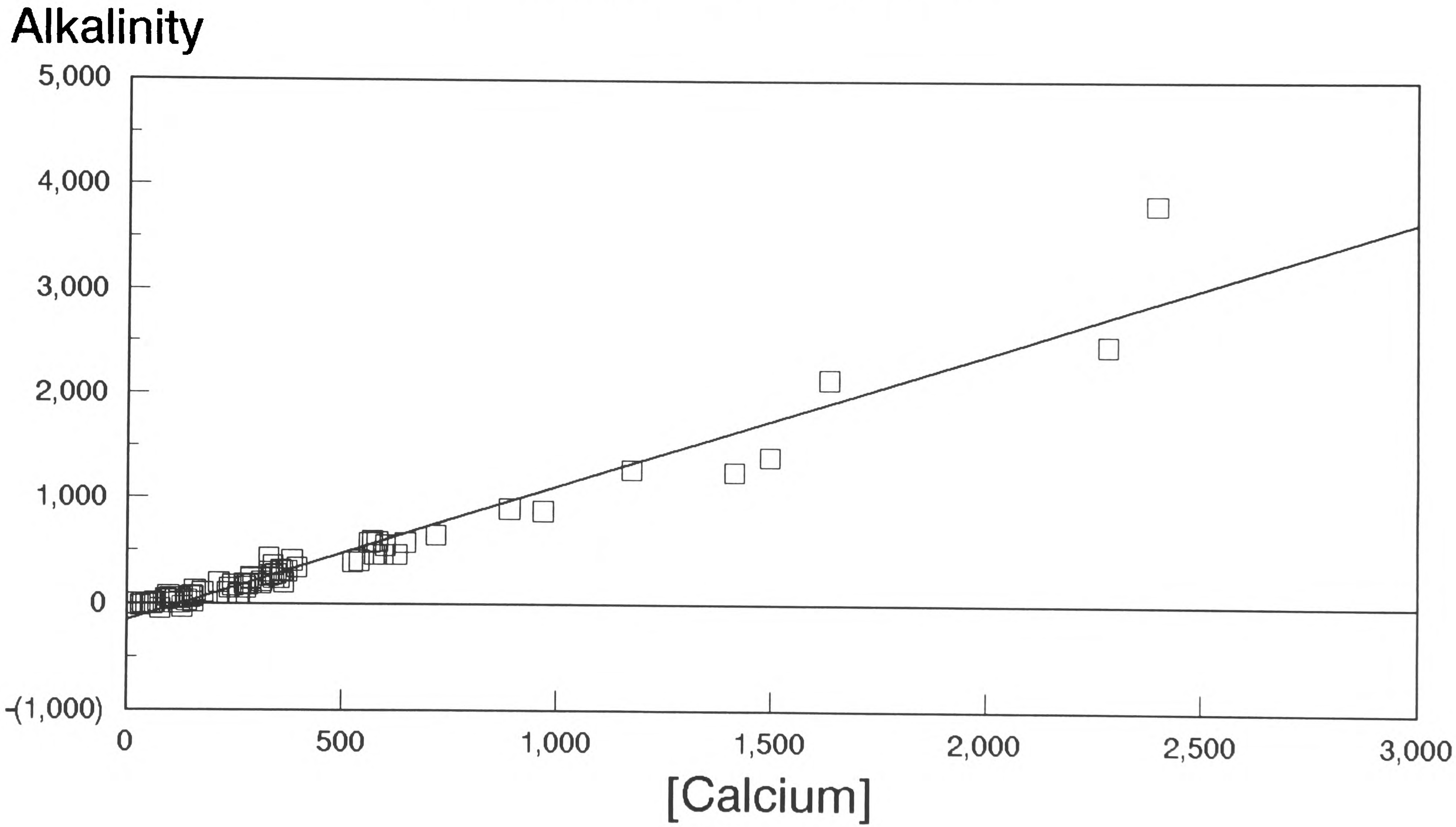


Figure 4.3.

Plot of [Magnesium] v. Alkalinity.
Microequivalents per litre.

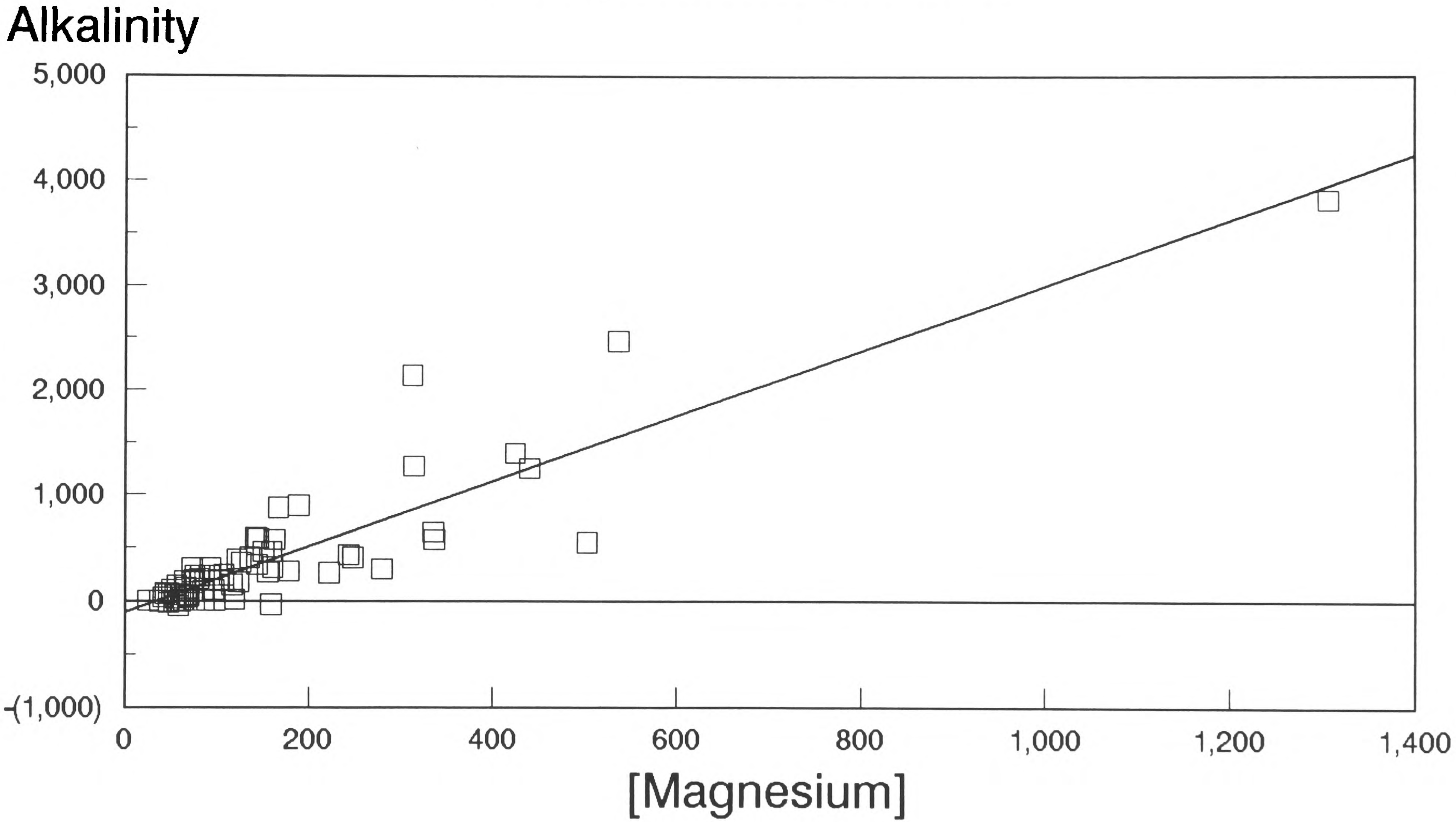


Table 4.42 - Eigenvalues, and Eigenvectors of the Correlation Matrix.

A) Eigenvalues of the Correlation Matrix.

	Eigenvalue	**Difference**	**Proportion**	**Cumulative**
PRIN 1	2.45892	1.36606	0.49178	0.49178
PRIN 2	1.09285	0.26338	0.21857	0.71035
PRIN 3	0.82947	0.33547	0.16589	0.87625
PRIN 4	0.49401	0.36926	0.09880	0.97505
PRIN 5	0.12475	-	0.02495	1.00000

B) Eigenvectors

	PRIN 1	**PRIN 2**	**PRIN 3**	**PRIN 4**	**PRIN 5**
H^+	-0.18802	0.75850	0.52503	0.33523	-0.03585
Ca^{2+}	0.57192	-0.18536	0.30574	0.18489	-0.71476
Mg^{2+}	0.53487	-0.13153	0.51112	-0.13383	0.64611
Na^+	0.38603	0.56969	-0.27130	-0.66105	-0.12590
K^+	0.44995	0.22016	-0.54407	0.63130	0.23350

The Principal Component Analysis showed that the total variability of the chemistry set could be contained within five principal components. By the criterion of Ibanez (1973) only the first two principal components are interpretable as their corresponding eigenvalues were larger than the average eigenvalue. The first two principal components account for about 71% of the total data set variability. This much of the information content can be presented in a two-dimensional graph.

The values for the eigenvectors indicate that PRIN 1 is an axis that has a high loading for calcium and magnesium ion concentration. High positive loadings for this axis correspond to the greatest concentrations of calcium and magnesium in the data set. Principle component 2, however, is more difficult to explain. It is an axis with high loadings for hydrogen ion, and to a lesser extent sodium ion, concentrations. The highest values for PRIN 2 correspond to sites with the highest hydrogen ion concentrations, but also the highest sodium ion concentrations.

The principle component values for each individual site may be found in Appendix 14.4.

The Freshwater Biological Association / Institute of Freshwater Ecology (I.F.E.) has categorised the majority of lakes and tarns in the Lake District within one of five classes (Sutcliffe & Carrick, 1988), based on alkalinity. This classification corresponds very approximately with the aquatic biota within the Cumbrian lakes. The I.F.E / F.B.A classification is outlined in Table 4.43.

Table 4.43 - I.F.E. Categories of Waterbodies

I.F.E. Classification	**Surface Water Type**
1	Acid
2	Very soft
3	Soft
4	Medium hard
5	Very hard

If the I.F.E classification is applied to the sample sites in this survey, then the position of waterbodies of each class can be plotted for their site on the graph representing the axes of the significant principal component values PRIN 1 and PRIN 2. The plot of the species axes with respect to the first two principal components is shown in Figure 4.4. This grouping of the study lakes in this case provides a useful framework for the examination and comparison of chemical characteristics, and allows the assignment of a significant 'lake status' to each site previously unclassified by the key given in Sutcliffe & Carrick (1988).

Figure 4.4 indicates that the Principal Component Analysis may be used to key each individual site by the I.F.E. classification (Sutcliffe & Carrick, 1988). The five groups can be identified on the graph, a small amount of overlap only occurring between groups 3 and 4. The classification of the 63 sites previously classified by the I.F.E. is given in Table 4.44.

Figure 4.4.

Principal Component Analysis. Water Chemistry.

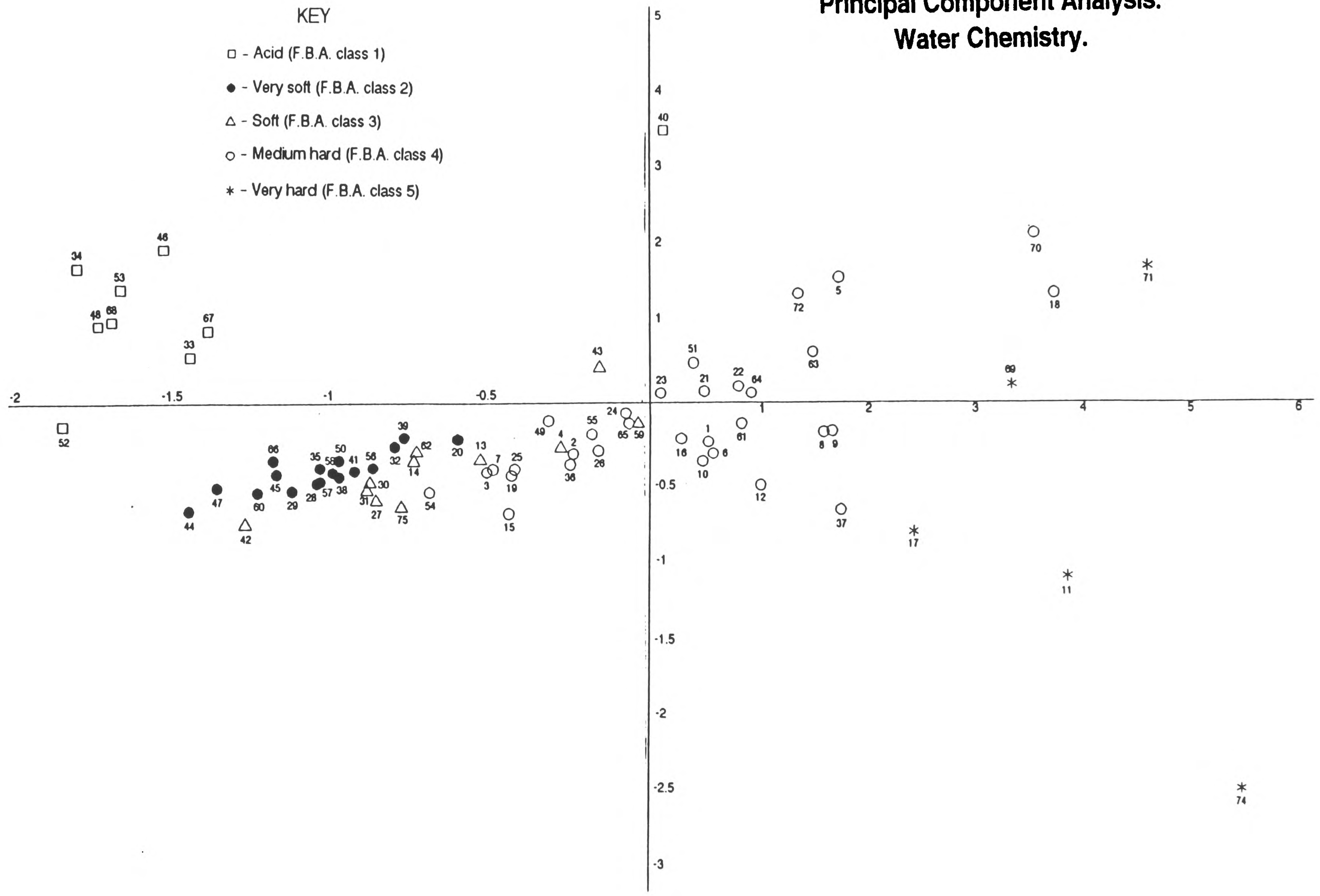


Table 4.44 - I.F.E. Classification of the Sample Sites.

Group 1
Seathwaite Tarn (33), Leverswater (34), Parkgate Tarn (40), Siney Tarn (46), Innominate Tarn (48), Haystacks Tarns A & B (52 & 53), Floutern Tarn (67), High Nook Tarn (68).

Group 2
Grizedale Tarn (20), Wast Water (28), Thirlmere (29), Devoke Water (32), Burnmoor Tarn (35), Watendlath Tarn (38), Blea Tarn (39), Low Water (41),Dalehead Tarn (44), Lily Tarn (45), Blackbeck Tarn (47), Hard Tarn (50), Derwent Water (56), Crummock Water (57), Ennerdale Water (58), Buttermere (60), Arlecdon Tarn (62), Bleaberry Tarn (66).

Group 3
Coniston Water (4), High Dam Reservoir (13), Yew Tree Tarn (14), Haweswater (27), Grasmere (30), Brotherswater (31), Brown Cove Tarn (42), Tosh Tarn (43), Loweswater (59).

Group 4
Esthwaite Water (1), Windermere-South Basin (2), Windermere-North Basin (3), Killington Reservoir (5), Blelham Tarn (6), Tarn-Hows Tarn (7), Poaka Beck Reservoir (8), Pennington Reservoir (9), Bigland Tarn (10), Rather Heath Tarn (12), Skeggles Water (15), Knittleton Tarn A (16), Holehird Tarn (18), High Arnside Tarn (19), Knittleton Tarn B (20), Loughrigg Tarn (36), Littlewater Tarn (37), White Moss Tarn (49), Ullswater (54), Bassenthwaite Lake (55), Overwater (61), Mockerkin Tarn (63), Little Tarn (64), Tewet Tarn (65).

Group 5
Witherslack Hall Pond (11), Moss-Side Tarn (17), Skelsmergh Tarn (74).

Twelve of the sample sites have not previously been assigned any I.F.E. group classification. From Figure 4.4, these sites may be classified as following;

Table 4.45 - Assignment to I.F.E Classification of Sites Previously Unclassified

Site no.	**Site.**	**Group Code.**
22	Clay Pond	4
23	Barrow Plantation Tarn A	4
24	Barrow Plantation Tarn B	4
25	Barrow Plantation Tarn D	4
26	Barrow Plantation Tarn Q	4
51	How Top Tarn	4
69	Browns Tarn	5
70	High Stock Bridge Pool	4
71	Parsonby Tarn	5
72	Manesty Park Tarn	4
73	Black Pool	1
75	Boo Tarn	3

The mean values of the four parameters described by the axes PRIN 1 and PRIN 2, calcium, magnesium, sodium and hydrogen (pH) ion concentrations, for the five I.F.E. groups are given in Table 4.46.

Table 4.46 - Mean values of chemistry data for the 5 I.F.E. Groups

	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Ca $^{2+}$	56.20	131.17	240.67	483.37	1845.20
Mg $^{2+}$	62.30	67.94	84.44	172.00	604.00
Na $^{+}$	231.80	188.39	208.22	333.24	422.20
pH	4.81	6.32	6.82	6.95	7.62

[Ca] $^{2+}$, [Mg] $^{2+}$ and pH all increase from groups 1-5 by each incremental step. [Na] $^{+}$ appears to increase significantly from group 1 only on reaching groups 4 and 5, although the data for group 1 are somewhat distorted by the presence of two acidic sites containing high [Na] $^{+}$, Parkgate Tarn (site 40) and Black

Figure 4.5.

Plot of I.F.E. Group v. Water Chemistry.

Microequivalents per litre.

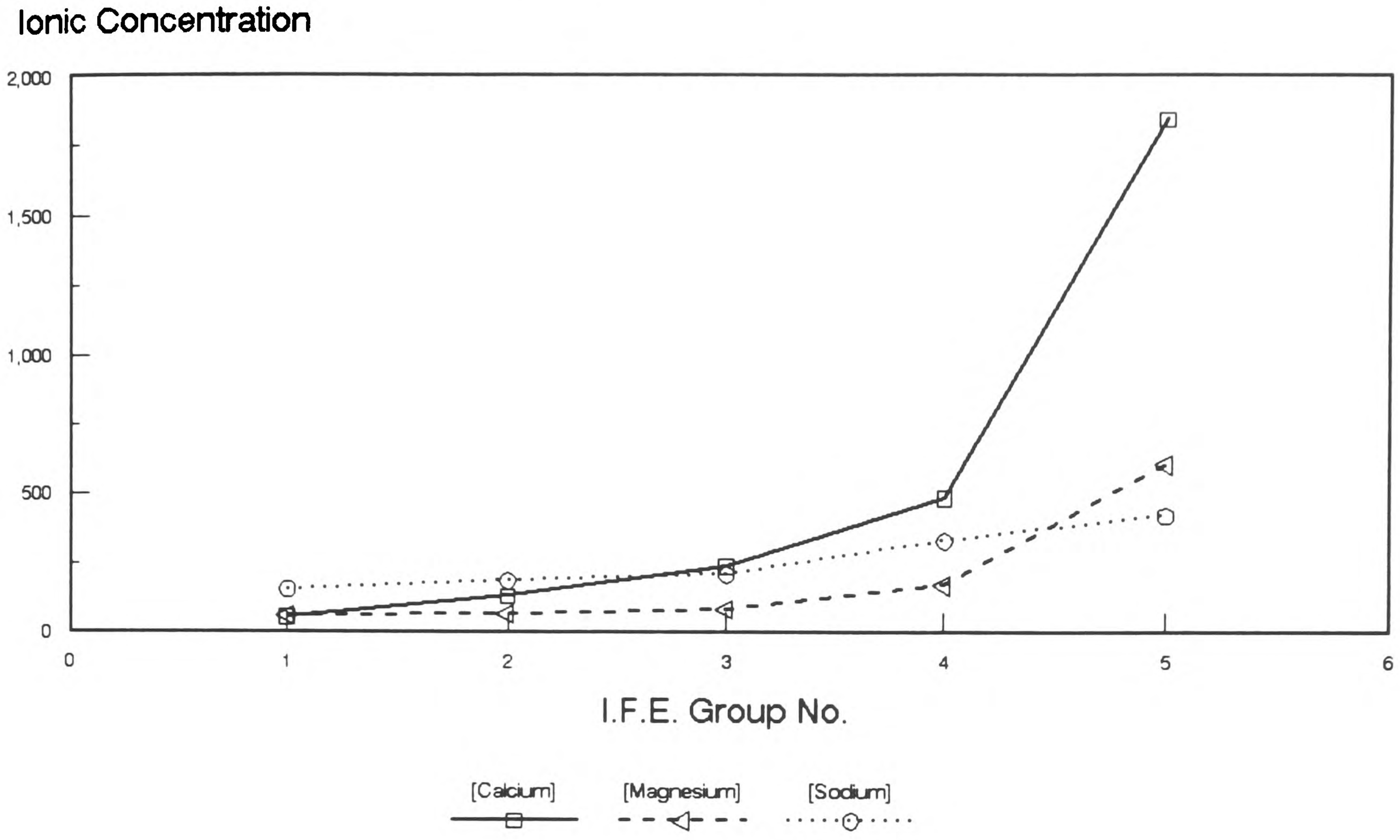
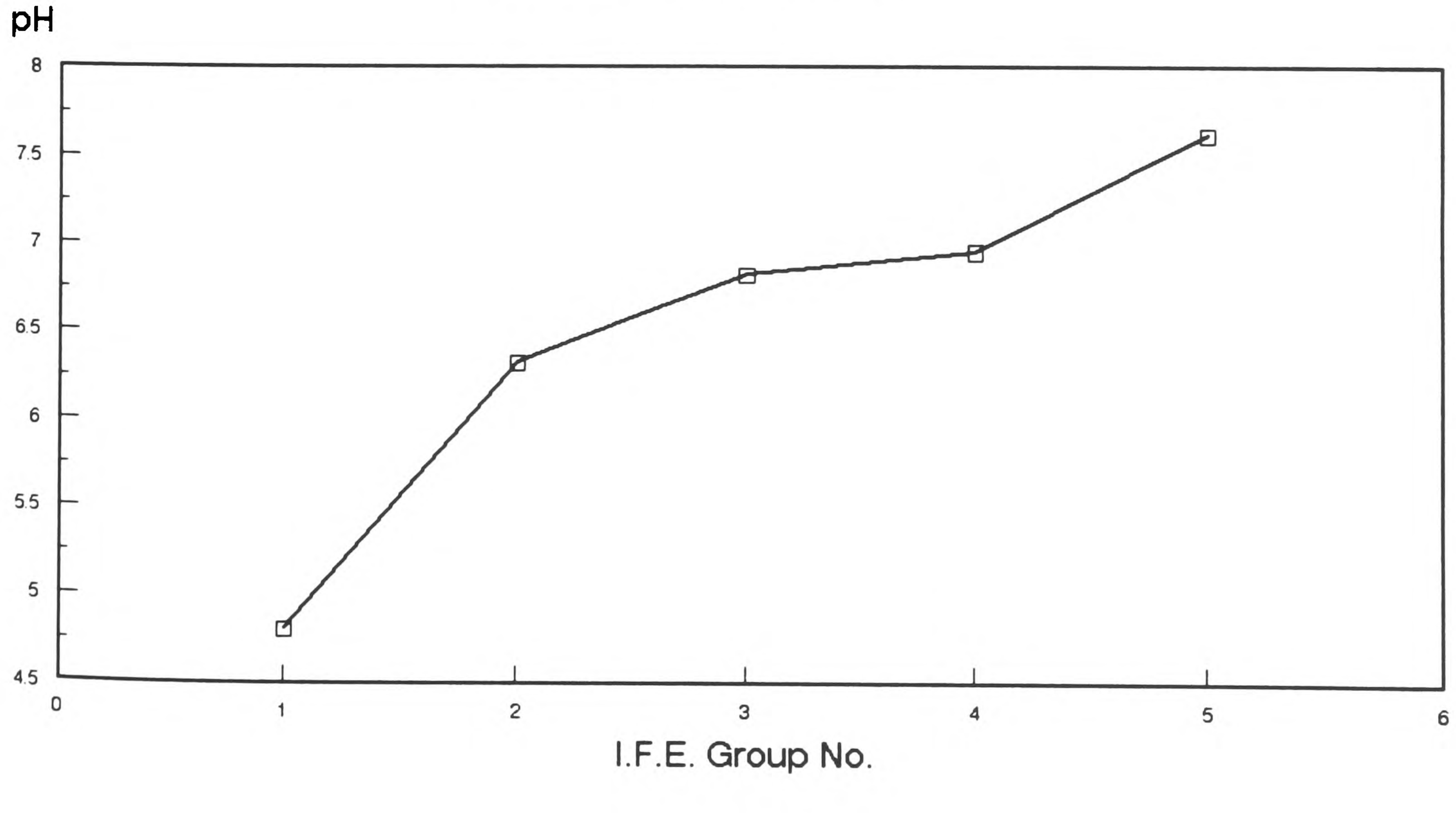


Figure 4.6.

Plot of I.F.E. Group v. pH.



Pool (site 73). Indeed, if these two sites are omitted from the data set, the mean sodium concentration for group 1 sites is 156.50, a value which would allow the sodium ion data to show the same trend as the other three parameters. This adjusted sodium ion value is included in the plots shown in Figure 4.5 of group number against ionic concentration. Figure 4.6 plots pH against group number.

4.5 - Discussion

Principal Component Analysis has proved useful for the classification of Lake District waterbodies in terms of their chemistry. The advantage of this technique is the reduction of a multidimensional data set to one which may be described by a solitary biaxial plot.

In the analysis, the first two Principal Components which described the influence of primarily $[Ca]^{2+}$ and $[Mg]^{2+}$, and to a lesser extent pH and $[Na]^{+}$, accounted for over 71% of the total information of the entire data set, an excellent representation of the data. As $[Ca]^{2+}$ and $[Mg]^{2+}$ are the main features of alkalinity (Carrick & Sutcliffe, 1982) and represent PRIN 1, the statistic which comprises the greatest proportion of variability within the data set, alkalinity itself is an extremely useful criterion for classification of Lake District waters. The plot of the first two Principal Components has shown that the resulting cluster of five groups classified by this method show excellent similarities to the I.F.E. group designations which were derived solely from the alkalinity data. The only poorly defined inter-group boundary is that between groups 3 and 4. This is probably due to the lack of difference in pH between the two groups, which is only 0.13 (6.82-6.95).

There is significant chemical difference between each group class. [Ca] $^{2+}$ approximately doubles from one group to the next from groups 1 to 4, but then increases by a factor of four in group 5. [Mg] $^{2+}$ varies in a somewhat different pattern in that groups 1 to 3 have relatively similar concentrations, which then doubles in group 4 and then again shows a four-fold increase in group 5.

Two group 1 sites, Parkgate Tarn (site 40) and Black Pool (site 73) distort the trend in what would otherwise be a linear inter-group increase in [Na] $^{+}$. Both sites have much higher ion concentrations than are normally associated with acidic sites. The high [Na] $^{+}$ of 563 μel $^{-1}$ in Parkgate tarn is not due to salt originating from roads as the site is situated in dense coniferous woodland, but could be due to the underlying bedrock, which is a granitic intrusion. The high value at Black Pool is difficult to explain, the site lies on the base-poor Skiddaw Slates, but perhaps may be due to a single erroneous value (due possibly to sample contamination) which was recorded at the site in September 1989. This is the only time [Na] $^{+}$ had been measured for this site.

pH change between groups is most marked from group 1 to the other groups, there being an increase in alkalinity of 1.51 pH units from group 1 to 2. Groups 3 and 4 have similar pH values, and there is again a large increase of 0.67 pH units from groups 4 to 5, the latter being very alkaline. The high pH in Group 5 is coupled with elevated $[Ca]^{2+}$ and $[Mg]^{2+}$, and classifies these sites very alkaline.

In conclusion, Principal Component Analysis allowed sites within Cumbria that had not previously been classified by the I.F.E. key to be assigned a group number.

CHAPTER 5 - INDIVIDUAL SPECIES DYNAMICS

5.1 - Summary

Using Pearson Correlation Coefficients significant inter-specific correlations were found between 15 out of the 18 top-ranked species.In total 16 significant correlations between ostracod species were found. Some of these relationships have been previously recorded, while others are new.

A multistage statistical approach, incorporating correlation analysis, and step-wise multiple regression, was used to identify the factors which were the optimal predictors of species abundance. Equations were derived to predict the distribution of nine species, total species number at each site, and total density per site. Factors identified as important predictors of community structures were pH, $[Ca]^{2+}$, $[Mg]^{2+}$, substrate, lake size and altitude.

The distribution of the species in relation to their spatial habitats is also discussed.

5.2 - Aims of the Chapter

Chapter 3 showed that five major species dominated ostracod community structure in most of the waterbodies in the Lake District.

This chapter will:

A) Use statistics derived from SAS to link the distribution of the 18 dominant species collected from the margin samples in the Lake District to a series of physico-chemical parameters.

B) Create a series of equations to predict an ostracod fauna at a site, solely from known physico-chemical variables. The predictions will be tested on a separate data set in the following chapter.

5.3 - Pearson Correlation Data for Species Interactions

Species association in the Lake District marginal faunas were investigated using Pearson Correlation Coefficients.

The analysis was undertaken on the commonest 18 species which made up more than 99% of the total ostracod numbers. Statistically significant ($P < 0.05$) correlations, all of which were positive, occurred in 16 cases. These are listed below in Table 5.31.

Table 5.31 - Significant Species Interactions

Species Interaction	**Pearson Value**
C.ophthalmica*C.candida	0.2537
C.ovum*M.cordata	0.4185
C.ovum*C.candida	0.3210
C.ovum*C.exsculpta	0.4652
C.ovum*C.reducta	0.2382
M.cordata*H.reptans	0.5213
C.candida*C.exsculpta	0.3860
C.candida*C.serena	0.3315
C.candida*C.rostrata	0.3048
C.exsculpta*C.rostrata	0.2214
C.exsculpta*C.vavrai	0.2285
P.villosa*H.reptans	0.2061
C.fabaeformis*C.kingsleii	0.8863
C.reducta*C.vavrai	0.5844
C.rostrata*P.euplectella	0.6530
P.euplectella*H.chevreuxi	0.6700

Values of greater than 0.2000 indicate a significant positive species association.

The data shows that 15 out of the 18 species show a statistically significant positive interaction with another species. This will be discussed later in the chapter. No significant negative interactions occurred.

5.4 - The Relationship between Individual Species Abundance and Physico-Chemical Variables

To evaluate the relationship between the measured environmental parameters and the distribution of the individual ostracod species, a multiple regression model was used. This system of analysis has been used to model the population density of Brown Trout, Salmo trutta (Milner & Varallo, 1990).

The SAS programme incorporating Principal Component Analysis was used to predict the numbers of each ostracod species at a site. A three stage procedure was used.

1) Correlation analysis to evaluate the significant factors determining both the distribution and density of an ostracod species at a site. Those factors found to significantly influence population dynamics were further examined in stage 2).

2) This stage evaluated how the significant factors identified in stage 1) could explain the differences in species distribution. This was done by use of a step-wise multiple regression analysis and allowed the ranking of significant factors in order of increasing importance.

3) The final multiple regression model incorporated the results of the first two stages in order to obtain predictive equations, often by the use of a threshold model describing the limits of the distribution of the species.

The data will be analysed species by species.

5.4A - Cypria ophthalmica

1) The Pearson Correlation Coefficients derived from the correlation analysis are shown below.

Parameter	**Pearson value**	**P (significance)**
pH	0.13077	0.2634
$[Ca]^{2+}$	0.16017	0.1699
$[Mg]^{2+}$	0.17441	0.1345
$[K]^{+}$	0.15445	0.1858
$[Na]^{+}$	0.47744	0.0001***
Alkalinity	0.11567	0.3230
Logsize	0.30058	0.0088**
Altitude	-0.13095	0.2628

These values initially indicate that two factors are important in structuring the distribution of Cypria ophthalmica, sodium ion concentration and lake size (Logsize).

2) Step-wise regression analysis was used to then evaluate the loadings upon each of these significant factors.

Variable entered	**F**	**Prob > F**
$[Na]^{+}$	21.5530	0.0001
Logsize	2.7398	0.1022

Of the two factors, $[Na]^{+}$ was entered first into the model and appears to exert the greatest influence on overall density and abundance of Cypria ophthalmica.

3) The next stage of the analysis involved use of the results from the previous two sections to create a predictive equation for the abundance of C. ophthalmica in terms of $[Na]^{+}$ and logsize. C. ophthalmica abundance was regressed against the above

two variables using the SAS multiple regression procedure.

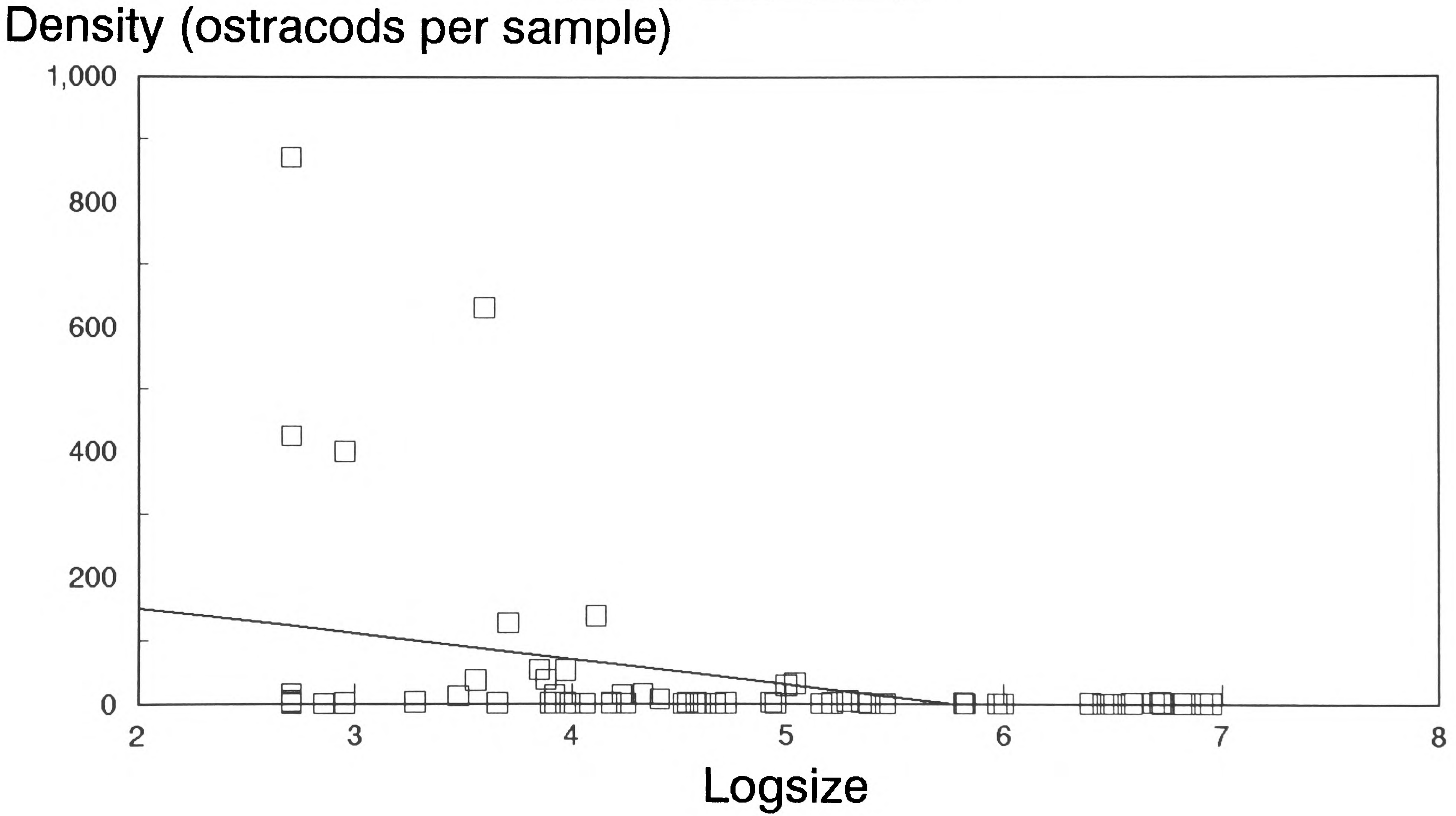
The model gave a poor fit to the data. To explore the distribution of *C. ophthalmica* further, plots of density against each individual environmental parameter were formulated. An interesting relationship that was not initially shown by the regression model occurred between pH and species distribution, as the species is very rarely found below a pH of 5.9 in the Lake District, and above this value there is no relationship between density and pH. This fact was then incorporated into a threshold model which only included the influence of $[Na]^+$ and logsize at sites with a pH 5.9 or greater.

This new model removed the significant effect of $[Na]^+$ on distribution and highlighted the effect of logsize upon the density of *Cypria ophthalmica*. Generally, as the size of the site decreased, at values of pH 5.9 or greater, the density of *C. ophthalmica* increased, as can be seen in Figure 5.1. The model thus formulated was a threshold model, incorporating logsize at pH > 5.8.

Figure 5.1.

Plot of Density v. Logsize (at pH > 5.8).

Cypria ophthalmica.



Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	1	181453.5	181453.5	9.056	0.0038**
Error	61	1222215.7	20036.3		
C Total	62	1403669.3			

Root MSE 141.5 R-Square 0.0293 Dep Mean 47.3
Adj. R-Sq. 0.1150 C.V. 299.5

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	245.275	68.160	0.0006***
Logsize	1	-42.475	14.114	0.0038**

Thus, the equation predicting abundance of <u>C. ophthalmica</u> can be given as;

Density = 245.275 - 42.475 (Logsize), when pH ≥ 5.9.
Density = 0, when pH < 5.9.

The prediction power of this equation when tested against the Lake District data set is shown in Appendix 14.5.

76% of the sample sites (57 out of 75) showed no significant deviation from the model, whereas 18 did show significant deviations (shown by the Cook's D value) from the model. These 18 sites were then split into two groups, those in which the model gave predicted values significantly greater than the observed densities, and those in which the model underestimated the observed values.

A) Estimated values > Observed values

19) High Arnside Tarn
20) Grizedale Tarn
23) Barrow Plantation Tarn A
24) Barrow Plantation Tarn B
25) Barrow Plantation Tarn D
26) Barrow Plantation Tarn Q
43) Tosh Tarn
45) Lily Tarn
47) Blackbeck Tarn
49) White Moss Tarn
51) How Top Tarn
66) Bleaberry Tarn
69) Browns Tarn
70) High Stock Bridge Pool

B) Observed values > Estimated values

22) Clay Pond
71) Parsonby Tarn
72) Manesty Park Tarn
75) Boo Tarn

A discussion of the suitability of the model is presented later in the chapter.

5.4B - Metacypris cordata

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.20084	0.0840
$[Ca]^{2+}$	0.48660	0.0001***
$[Mg]^{2+}$	0.59931	0.0001***
$[K]^{+}$	0.02387	0.8389
$[Na]^{+}$	-0.06556	0.5763
Alkalinity	0.58222	0.0001***
Logsize	0.04823	0.6812
Altitude	-0.03374	0.7738

These values indicate that three factors are important in structuring the distribution of Metacypris cordata, $[Ca]^{2+}$, $[Mg]^{2+}$ and overall alkalinity. As alkalinity itself is somewhat of a measure of $[Ca]^{2+}$ and $[Mg]^{2+}$ (Carrick & Sutcliffe, 1982) and shows such a high correlation between both parameters ($P = 0.0001$ in both cases), it was removed from the analysis at this stage.

2) Stage 2 : Step-Wise regression analysis.

Variable entered	**F**	**Prob > F**
$[Mg]^{2+}$	40.9145	0.0001
$[Ca]^{2+}$	10.8457	0.0015

Of the two factors, $[Mg]^{2+}$ was entered first into the model and appears to exert the greatest influence on overall density and abundance of Metacypris cordata.

3) Stage 3 : Creation of the predictive equation describing the abundance of M. cordata in terms of $[Ca]^{2+}$ and $[Mg]^{2+}$.

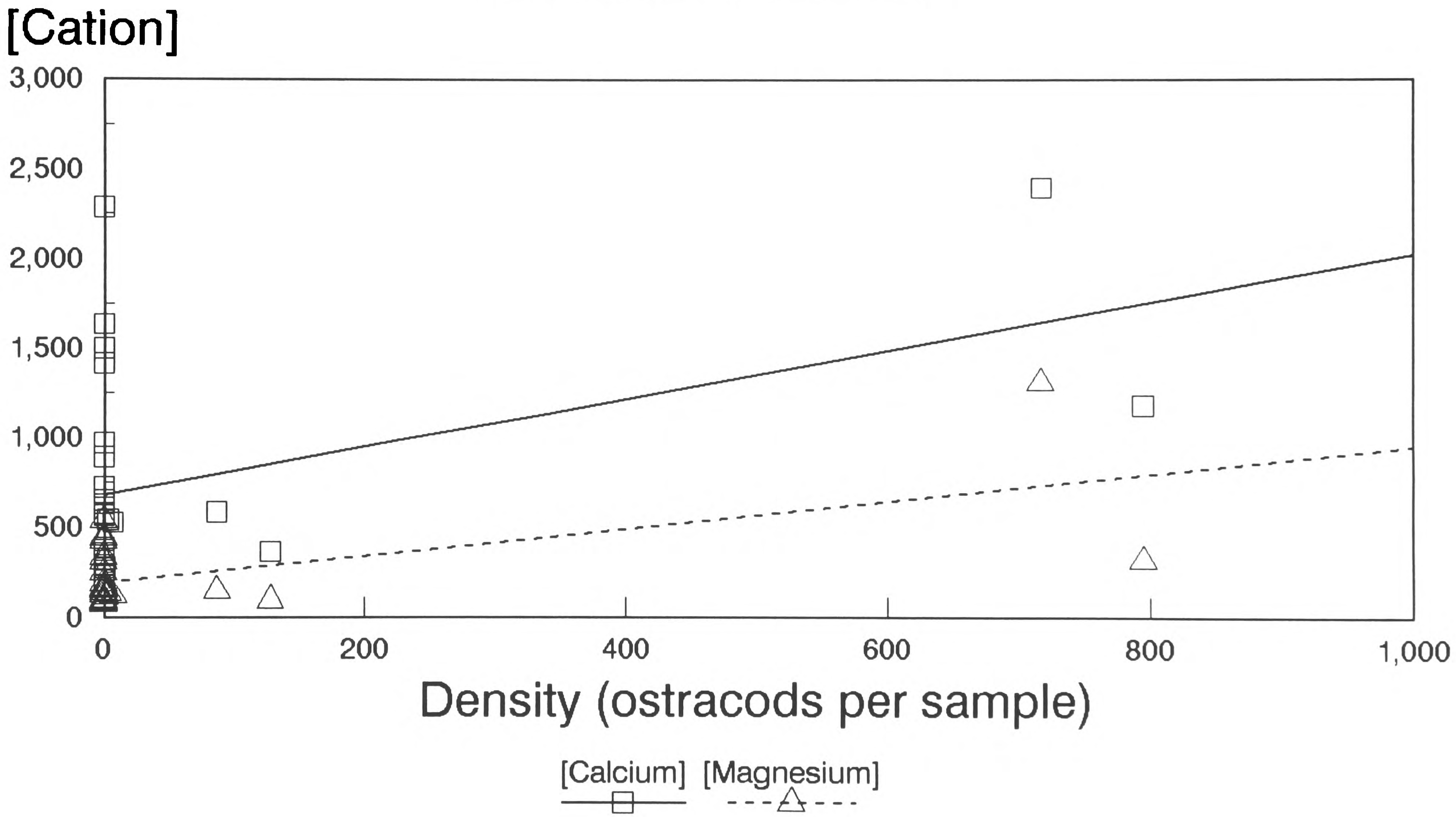
M. cordata abundance was then regressed against the above two variables using the SAS multiple regression procedure.

Graphs of density of M. cordata against the two significant factors, $[Ca]^{2+}$ and $[Mg]^{2+}$ were plotted. Although the significance values for these two parameters against density showed highly significant positive correlations, the plots indicated that only a poor overall relationship could be derived from the total data set. However, on plotting density against pH it was noted that this species is rarely found below pH 7.0 in the Lake District, and above that value, there is no relationship between density and pH. A sub-set of the data was therefore incorporated into a threshold model consisting of density at pH > 6.9 against $[Ca]^{2+}$ and $[Mg]^{2+}$. These plots, shown in Figure 5.2, indicate that both factors have a significant effect on density. As the $[Ca]^{2+}$ and $[Mg]^{2+}$ increased, at a pH of > 6.9, density of M. cordata generally increased.

Figure 5.2.

Plot of Density v. [Calcium] & [Magnesium].

Metacypris cordata.



Analysis of Variance

Source	D.F	S.S	M.S	F-Value	Prob > F
Model	2	414872.5	207436.3	7.725	0.0026**
Error	24	644471.1	26853.0		
C Total	26	1059343.6			

Root MSE 163.9 R-Square 0.3916 Dep Mean 64.3
Adj. R-Sq. 0.3409 C.V. 254.9

Parameter Estimates

Variable	D.F	Parameter Estimate	Standard Error	Prob > [T]
Intercept	1	-35.562	52.383	0.5037
Magnesium	1	0.649	0.240	0.0124*
Calcium	1	-0.072	0.099	0.4727

Thus, the equation predicting abundance of Metacypris cordata can be given as;

Density = $\mathbf{0.649\ [Mg]^{2+} - 0.072\ [Ca]^{2+} - 35.562}$,
when $pH > 6.9$.
Density = 0, when $pH \leq 6.9$.

The predictive power of this equation when tested against the Lake District data set is shown in Appendix 14.5.

The equation provided an excellent fit to the data, with over 89% of the sites (67 out of the 75) showing no significant deviation from the model. Only 8 deviated significantly, as shown by the Cook's D values, and these were again divided into two groups, using the same nomenclature as for Cypria ophthalmica.

A) Estimated values > Observed values

8) Poaka Beck Reservoir
9) Pennington Reservoir
11) Witherslack Hall Pond
61) Overwater
69) Browns Tarn
71) Parsonby Tarn

B) Observed values > Estimated values

36) Loughrigg Tarn
37) Littlewater Tarn

A discussion of the results, including reasons for the deviation of some sites from the model, is given in section 5.6.

5.4C - Cyclocypris ovum

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.13577	0.2455
$[Ca]^{2+}$	0.15452	0.1856
$[Mg]^{2+}$	0.14712	0.2078
$[K]^{+}$	-0.09640	0.4106
$[Na]^{+}$	-0.02034	0.8625
Alkalinity	0.17147	0.1413
Logsize	0.22763	0.0495*
Altitude	0.09205	0.4322

These correlation values reflect the observations made in Chapter 3, in that it is very difficult to evaluate the environmental conditions and the type of habitat preferred by Cyclocypris ovum. Only one parameter, Logsize, appears to significantly influence the distribution of this species.

2) Step-wise regression analysis was used to test the significance of the loading upon this factor.

Variable entered	**F**	**Prob > F**
Logsize	3.9236	0.0514

3) Observation of the plots of the species density per site against the environmental parameters yielded little further on the distribution pattern of the species, except that it was usually found in waters of pH > 6.0, and logsize < 5.5. A weak, albeit non-significant positive correlation occurred in this set of conditions between pH and density, while a significant negative correlation occurred between Logsize and density.

Density increased with decreasing Logsize, and to a minor extent, increasing pH, at a pH level of > 6.0 and logsize < 5.5. The relationship between density and Logsize may be seen in Figure 5.3. These observations were thus entered into a threshold model.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	2	60483.1	30241.6	3.994	0.0240*
Error	55	416472.5	7572.2		
C Total	57	476955.6			

Root MSE 87.0 R-Square 0.1268 Dep Mean 38.2
Adj. R-Sq. 0.0951 C.V. 228.1

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	271.129	188.506	0.1560
Logsize	1	-25.312	9.051	0.0071**
pH	1	-16.295	26.029	0.5339

Thus, the equation predicting abundance of <u>Cyclocypris ovum</u> can be given as;

Density = 271.129 - 25.312 [Logsize] - 16.295 [pH],
when pH > 6.0, logsize < 5.5.
Density = 0, when pH ≤ 6.0, logsize ≥ 5.5.

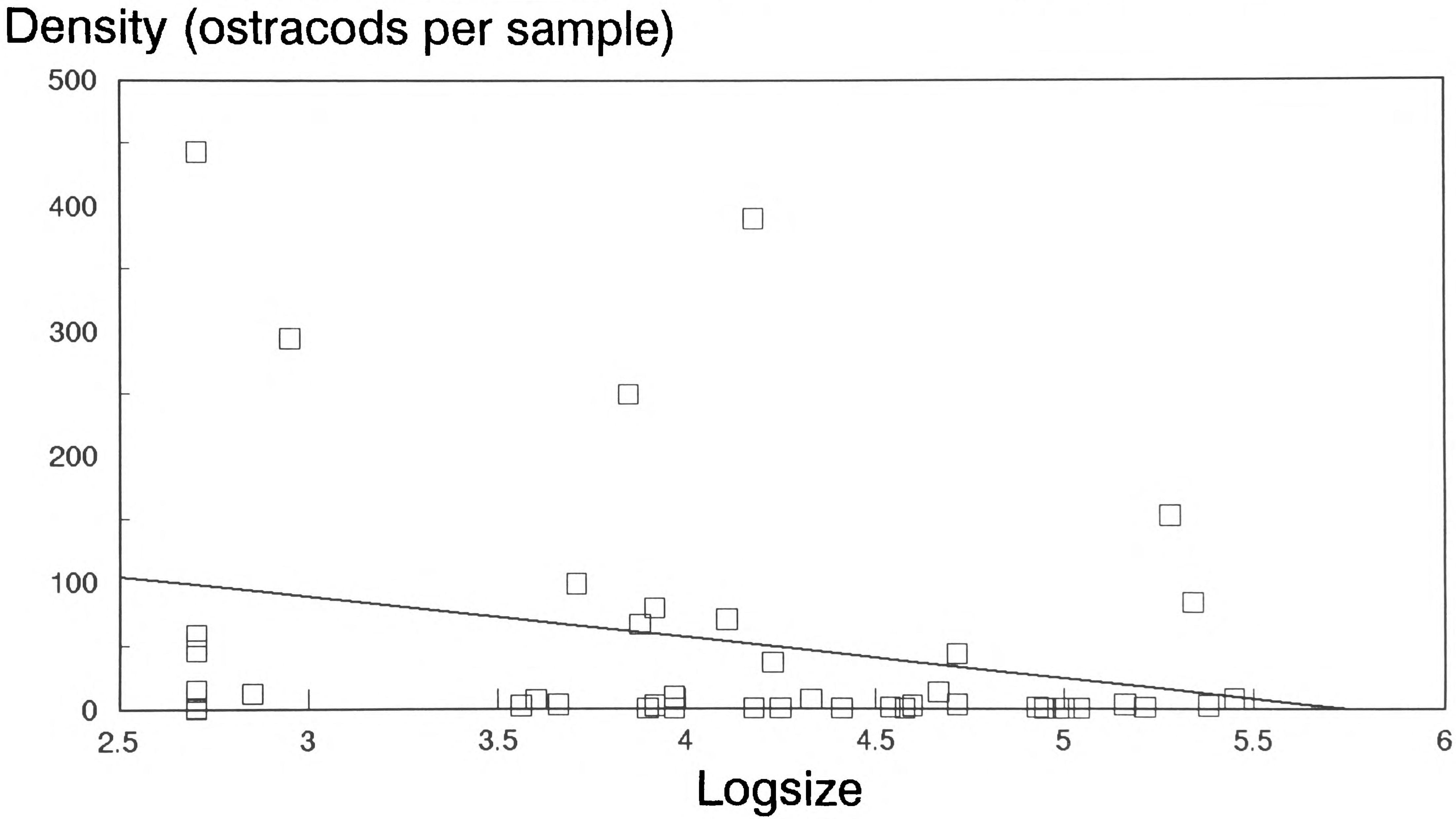
The predictive power of this equation when tested against the Lake District data set is shown in Appendix 14.5.

There was no significant deviation from the model in 55 out of the 75 sample sites (73%), but 20 sites did significantly deviate (shown by the Cook's D value) from the model. These sites are listed below.

Figure 5.3.

Plot of Density v. Logsize.

Cyclocypris ovum. (at pH > 6.0, Logsize < 5.5).



A) Estimated values > Observed values

14) Yew Tree Tarn
19) High Arnside Tarn
20) Grizedale Tarn
22) Clay Pond
24) Barrow Plantation Tarn B
25) Barrow Plantation Tarn D
38) Watendlath Tarn
41) Low Water
43) Tosh Tarn
51) How Top Tarn
69) Browns Tarn
71) Parsonby Tarn
72) Manesty Park Tarn

B) Observed values > Estimated values

23) Barrow Plantation Tarn A
31) Brotherswater
37) Littlewater Tarn
42) Brown Cove Tarn
44) Dalehead Tarn
61) Overwater
75) Boo Tarn

A discussion of the results, including reasons for the deviation of some sites from the model, is given in section 5.6.

5.4D - Candona candida

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.29381	0.0105*
$[Ca]^{2+}$	0.26343	0.0224*
$[Mg]^{2+}$	0.13790	0.2381
$[K]^{+}$	0.21170	0.0683
$[Na]^{+}$	0.13025	0.2653
Alkalinity	0.22738	0.0498*
Logsize	-0.02100	0.8581
Altitude	-0.18484	0.1124

These values indicate that three factors are important in structuring the dynamics of <u>Candona candida</u>, $[Ca]^{2+}$, pH and overall alkalinity. Alkalinity was removed at this stage for the reasons described earlier.

2) Step-wise regression analysis was then used to see the loadings upon each of the significant factors.

Variable entered	**F**	**Prob > F**
pH	6.8970	0.0105
$[Ca]^{2+}$	5.9994	0.0208

Of the two factors, pH was entered first into the model and appears to have the greatest influence on abundance of <u>Candona candida</u>.

Observation of the data indicated that below pH 6.2, <u>C. candida</u> was unlikely to be found at a site in the Lake District. At pH levels of 6.2 or greater, then both $[Ca]^{2+}$ and pH are influential in determining the density of the species. A threshold model was therefore created, regressing abundance of C. candida against the above two variables.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	2	530.9	265.5	1.037	0.0613
Error	55	14076.2	255.9		
C Total	57	14607.1			

Root MSE 16.0 R-Square 0.0363 Dep Mean 11.6
Adj. R-Sq. 0.0013 C.V. 137.3

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	34.497	42.471	0.4202
pH	1	-3.872	6.406	0.5481
Calcium	1	0.0080	0.006	0.1741

Although the model is just statistically non-significant, a predictive equation was generated describing the abundance of Candona candida in terms of pH and $[Ca]^{2+}$.

Density = $34.497 - 3.872\,[pH] + 0.0080\,[Ca]^{2+}$,
when $pH \geq 6.2$.
Density = 0, when $pH < 6.2$.

The predictive power of this equation when tested against the Lake District data set is shown in Appendix 14.5. Due to the low significance of the model, a relatively poor fit to the data was found. Only 68% of the sites (51) showed no significant deviation from the model whilst 24 sites showed a significant deviation (shown by the Cook's D values). These sites are listed below.

A) Estimated values > Observed values

1) Esthwaite Water
5) Killington Reservoir
8) Poaka Beck Reservoir
9) Pennington Reservoir
12) Rather Heath Tarn
25) Barrow Plantation Tarn D
29) Thirlmere
30) Grasmere
32) Devoke Water
35) Burnmoor Tarn
41) Low Water
45) Dalehead Tarn
51) How Top Tarn
57) Crummock Water
58) Ennerdale Water
60) Buttermere
72) Manesty Park Tarn

B) Observed values > Estimated values

14) Yew Tree Tarn
20) Grizedale Tarn
23) Barrow Plantation Tarn
31) Brotherswater
64) Little Tarn
71) Parsonby Tarn
75) Boo Tarn

A discussion of the results is presented in section 5.6.

5.4E - Cypridopsis vidua

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.25231	0.0290*
$[Ca]^{2+}$	0.08516	0.4676
$[Mg]^{2+}$	0.09346	0.4251
$[K]^{+}$	0.13470	0.2492
$[Na]^{+}$	0.00685	0.9535
Alkalinity	0.09367	0.4241
Logsize	-0.02655	0.8211
Altitude	-0.11624	0.3207

The Pearson Correlation values indicate that only pH is important in structuring the distribution of Cypridopsis vidua. Surprisingly, there was no relationship between density and Logsize, as this might have been expected due to the observation of Fryer (1985) who recorded this species as showing a marked preference for lakes of a surface area of greater than 12,000 m^2 in a survey in Yorkshire, a size which would correspond to sites classified to groups A, B or C in Chapter 2.

2) Step-wise regression analysis was used to then see the loadings upon all the variables. It was attempted to enter all the variables into the model at this stage to see if the effect of any other factor had been masked by the influence of pH, but no other factor was significant, even at the $P = 0.15$ level.

Variable entered	**F**	**Prob > F**
pH	4.960	0.0290

Observation of the plot of the density of *Cypridopsis vidua* against pH indicated that the species was very rare or absent below pH 6.2. A plot of density against pH, at pH > 6.1 is shown in Figure 5.4. However, on testing a threshold model introducing this subset of data of pH 6.2 or greater, it was found that a model of greater significance was found by using an original model including the entire data set to generate a predictive equation. *C. vidua* abundance was regressed against pH using the SAS multiple regression procedure.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	1	1722.5	1722.55	4.963	0.0290*
Error	73	25336.1	347.07		
C Total	74	27058.7			

Root MSE 18.6 R-Square 0.0637 Dep Mean 6.5
Adj. R-Sq. 0.0508 C.V. 285.1

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	-31.158	17.055	0.0718
pH	1	5.762	2.586	0.0290

Thus, the equation predicting abundance of *Cypridopsis vidua* can be given as;

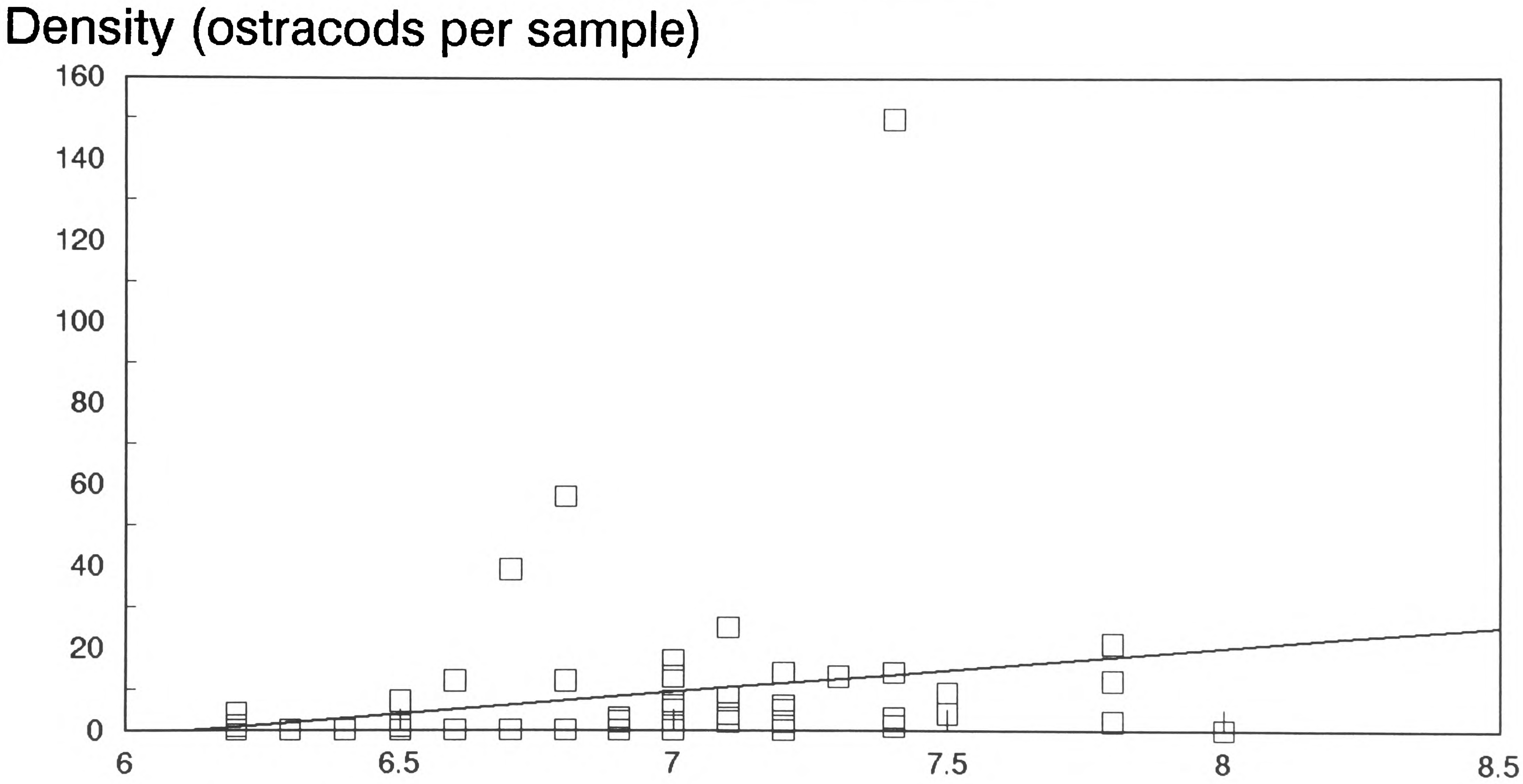
Density = 5.762 [pH] - 31.158

The predictive power of this equation when tested against the Lake District data set are shown in Appendix 14.5. The proposed model gave an excellent fit to the data, over 89% of the sites

Figure 5.4.

Plot of Density v. pH (at pH > 6.1).

Cypridopsis _vidua_.



(67 out of 75) showing no significant deviation from the model and only 8 deviating significantly, as shown by the Cook's D value. These eight sites are listed.

A) Estimated values > Observed values

11) Witherslack Hall Pond
37) Littlewater Tarn
63) Mockerkin Tarn
69) Browns Tarn

B) Observed values > Estimated values

1) Esthwaite Water
10) Bigland Tarn
24) Barrow Plantation Tarn B
64) Little Tarn

The results are discussed in section 5.6.

5.4F - Cyclocypris serena

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.09938	0.3963
$[Ca]^{2+}$	-0.04583	0.6962
$[Mg]^{2+}$	-0.07630	0.5153
$[K]^{+}$	-0.03360	0.7748
$[Na]^{+}$	-0.09432	0.4209
Alkalinity	-0.05391	0.6460
Logsize	0.31351	0.0062**
Area	0.47796	0.0001***
Altitude	-0.15663	0.1796

These values indicate that only one factor is important in determining the distribution of Cyclocypris serena, that of lake size. The significance of this factor was improved further by the creation of a new variable, 'Area', the units of which are M^2 (lake surface area).

2) Step-wise Regression analysis incorporating this factor showed it to be the only statistically significant factor involved and gave the loading upon this factor as;

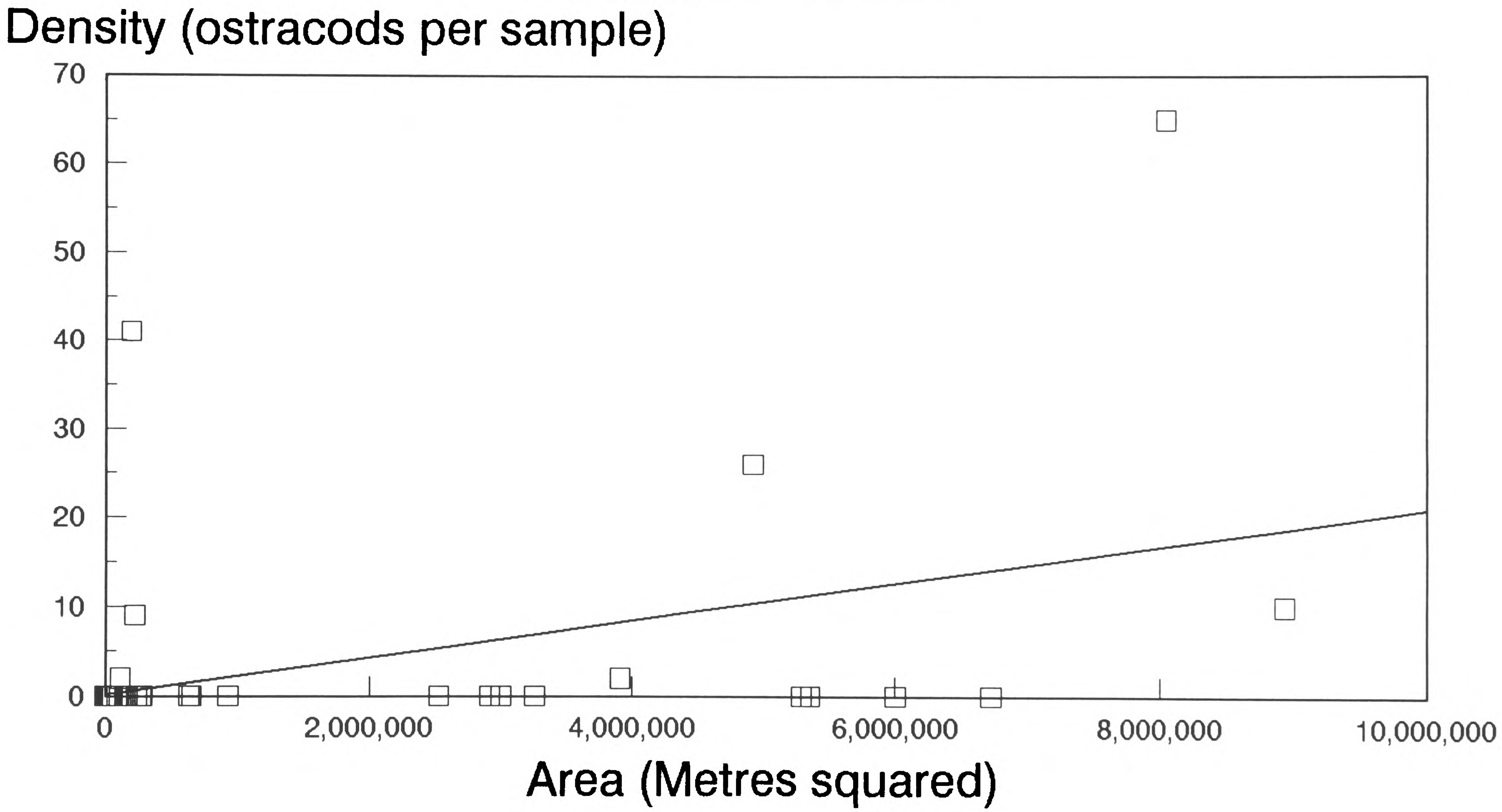
Variable entered	**F**	**Prob > F**
Area	21.6142	0.0001

The results from the previous two sections were used to create a predictive equation for the abundance of C. serena in terms of surface area of the waterbody. A plot of Area against density of C. serena is shown in Figure 5.5.

Figure 5.5.

Plot of Density v. Area.

Cyclocypris serena.



Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	1	1473.6	1473.6	21.614	0.0001***
Error	73	4977.0	68.2		
C Total	74	6450.7			

Root MSE 8.3 R-Square 0.2284 Dep Mean 2.1
Adj. R-Sq. 0.2179 C.V. 399.5

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	0.169	1.037	0.8707
Area	1	0.000002318	0.0000005	0.0001***

Thus, the equation predicting abundance of C. serena can be given as;

Density = 0.169 + 0.000002318 [Area].

The predictive power of this equation when tested against the Lake District data set is shown in Appendix 14.5. The model gave an extremely good fit to the data, 89% of the sites (67) showing no significant deviation (shown by the Cook's D value), only 8 doing so.

A) Estimated values > Observed values

2) Windermere (South Basin)
55) Bassenthwaite Lake
56) Derwent Water
57) Crummock Water
58) Ennerdale Water

B) Observed values > Estimated values

3) Windermere (North Basin)
31) Brotherswater
61) Overwater

These results are discussed in section 5.6.

5.4G - Herpetocypris reptans

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.25404	0.0279*
$[Ca]^{2+}$	0.46302	0.0001***
$[Mg]^{2+}$	0.65862	0.0001***
$[K]^{+}$	0.02003	0.8645
$[Na]^{+}$	-0.02286	0.8457
Alkalinity	0.58326	0.0001***
Logsize	-0.05297	0.6517
Altitude	-0.17076	0.1430

The results suggest that $[Ca]^{2+}$, $[Mg]^{2+}$, pH and total alkalinity all influence the distribution of <u>Herpetocypris reptans</u>. Alkalinity was removed from the data set at this stage, for the reasons described in section 5.4B. No effect on density was observed with the variable describing lake size. This is in contrast to the data of Fryer (1985) who found that <u>H. reptans</u> displayed a distinct preference for sites of greater than 12,000 m^2 (equivalent to class C and larger in this survey).

2) Step-wise regression analysis was used to observe the loadings upon the factors, and significant values were obtained for $[Ca]^{2+}$, $[Mg]^{2+}$ and pH.

Variable entered	**F**	**Prob > F**
$[Mg]^{2+}$	55.9247	0.0001
$[Ca]^{2+}$	10.2750	0.0020
pH	3.5361	0.0641

All three factors show that they are significantly related to density, the most important factor being $[Mg]^{2+}$.

Figure 5.6.

Plot of Density v. [Calcium] & [Magnesium].

Herpetocypris reptans (at pH > 6.4, Alt < 210m)

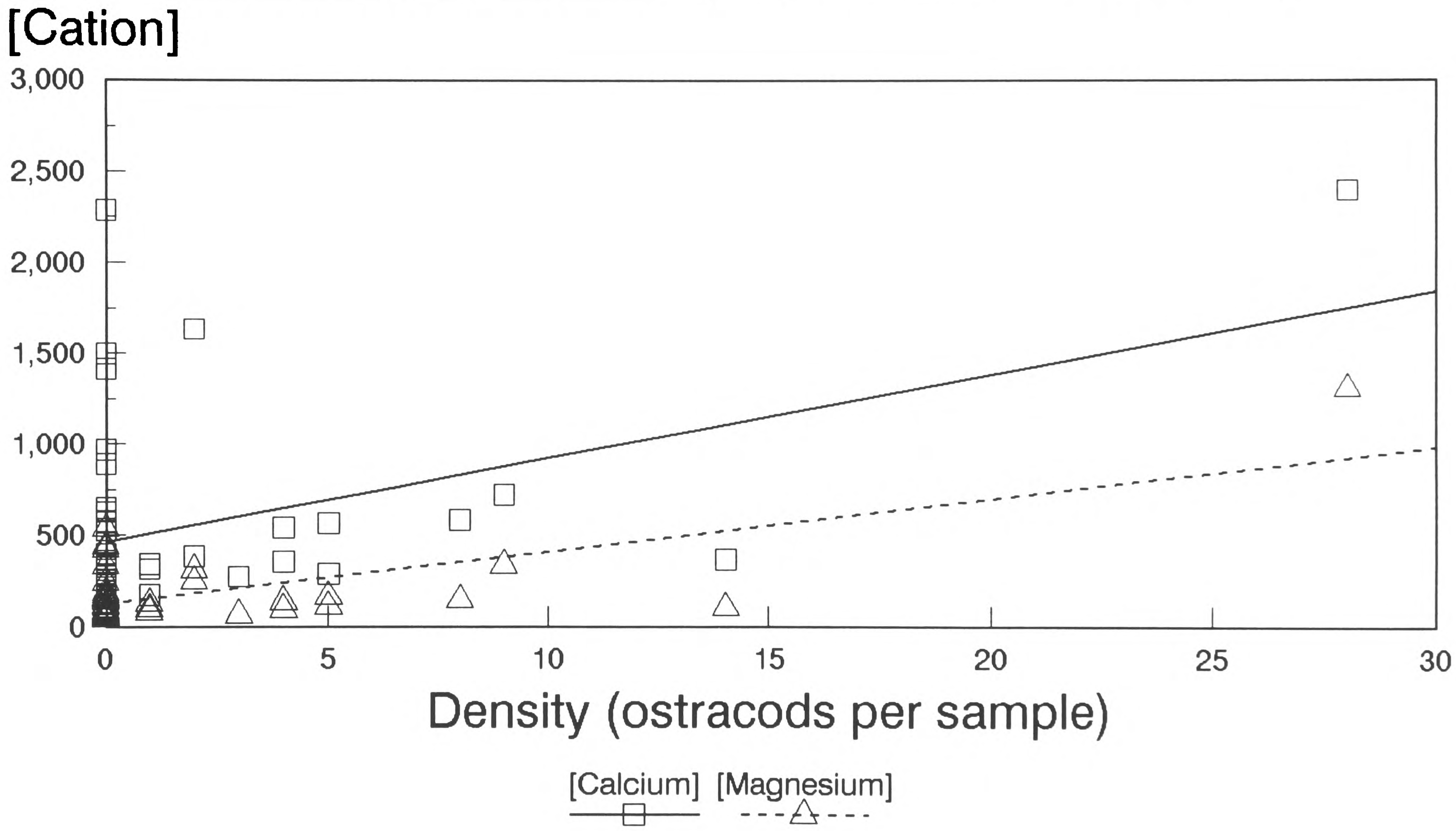
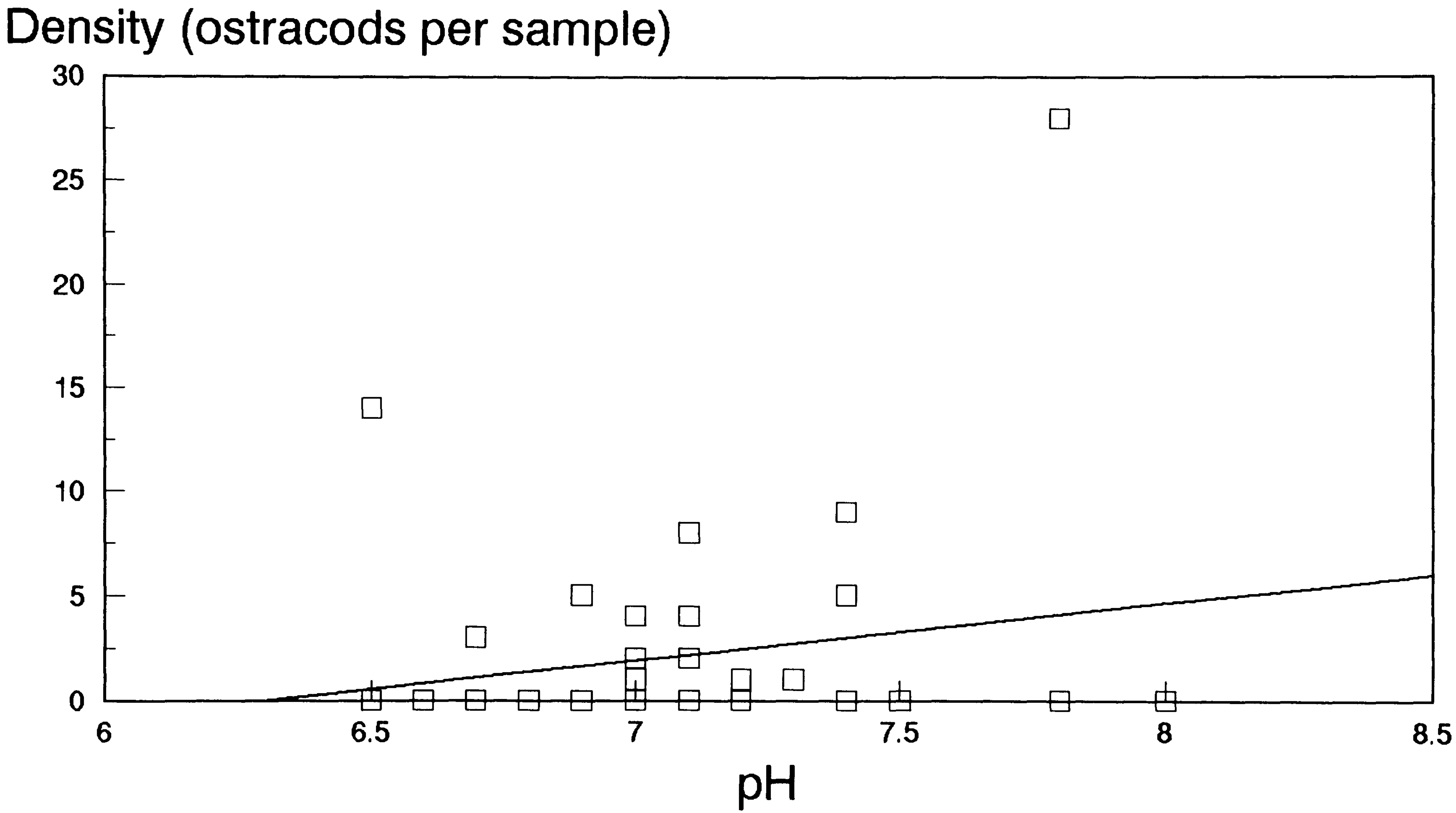


Figure 5.7.

Plot of Density v. pH.

Herpetocypris reptans (at pH > 6.4, Alt < 210m)



3) Observation of the plots of the species density against the individual environmental parameters demonstrated that H. reptans was only present at a pH > 6.40 and an altitude of < 210m. Plots of $[\mathrm{Mg}]^{2+}$ and $[\mathrm{Ca}]^{2+}$, and pH, within these boundaries are shown in Figures 5.6 and 5.7.

The three significant chemical factors within the limits described, were entered into a threshold model. A predictive equation describing abundance of H. reptans in terms of $[\mathrm{Mg}]^{2+}$, $[\mathrm{Ca}]^{2+}$ and pH was created.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	3	602.9	201.0	17.207	0.0001***
Error	38	443.8	11.7		
C Total	41	1046.8			

Root MSE	3.4	R-Square	0.5760	Dep Mean	2.1
Adj. R-Sq.	0.5425	C.V.	165.0		

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	15.870	122.773	0.2217
pH	1	-2.370	1.881	0.2152
$[\mathrm{Ca}]^{2+}$	1	-0.004	0.002	0.0568*
$[\mathrm{Mg}]^{2+}$	1	0.028	0.005	0.0001***

Thus, the equation predicting abundance of Herpetocypris reptans can be given as;

Density = 15.870 - 2.370 [pH] - 0.004 $[\mathrm{Ca}]^{2+}$ **+ 0.028** $[\mathrm{Mg}]^{2+}$, when pH > 6.40, altitude < 210m.
Density = 0, when pH $\leq$ 6.40, altitude $\geq$ 210m.

The predictive power of this equation when tested against the Lake District data set is shown in Appendix 14.5.

The model gave an excellent fit to the data, over 93% of the sites (70) showing no significant deviation (shown by the Cook's D value), only 5 deviating significantly from the model.

A) Estimated values > Observed values

8) Poaka Beck Reservoir
64) Little Tarn
71) Parsonby Tarn

B) Observed values > Estimated values

16) Knittleton Tarn A
51) How Top Tarn

The results are discussed later in section 5.6.

5.4H - Candona fabaeformis

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.11658	0.3192
$[Ca]^{2+}$	0.25906	0.0248*
$[Mg]^{2+}$	0.06684	0.5689
$[K]^{+}$	0.10985	0.3482
$[Na]^{+}$	-0.04619	0.6939
Alkalinity	0.25864	0.0251*
Logsize	-0.06941	0.5540
Altitude	-0.08531	0.4668

The results suggest that only $[Ca]^{2+}$ and total alkalinity significantly influence the distribution of Candona fabaeformis. Alkalinity was removed from the data set at this stage for the reasons described earlier.

2) Step-wise regression analysis was used to observe the loadings upon all factors, but only the one factor was shown to be statistically significant for entry into the model.

Variable entered	**F**	**Prob > F**
$[Ca]^{2+}$	5.2515	0.0248

3) Observation of the plots of the species density against the environmental parameters suggest that the niche for C.fabaeformis is very small in the Lake District. It was only recorded from pH 7.0-7.2, and at $[Ca]^{2+}$ greater than 370 uel $^{-1}$. These limits were entered into a threshold model with $[Ca]^{2+}$ as an independent variable, to create a predictive equation describing the abundance of C. fabaeformis.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	1	251.1	251.1	5.251	0.0248
Error	8	382.6	47.8		
C Total	9	633.7			

Root MSE 9.8 R-Square 0.2461 Dep Mean 5.6
Adj. R-Sq. 0.1549 C.V. 175.1

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	-3.971	6.852	0.7501
Calcium	1	0.013	0.008	0.0248

Thus, the equation predicting abundance of Candona fabaeformis can be given as;

Density = 0.013 $\mathbf{[Ca]^{2+} - 3.971}$,
when pH = 7.0 - 7.2, $[Ca]^{2+} > 370$.
Density = 0, pH < 7.0 & > 7.2, $[Ca]^{2+} \leq 370$.

The predictive power of the equation when tested against the Lake District data set is shown in Appendix 14.5.

The model gave an excellent fit to the data, 96% of the sites (72) showing no significant deviation (shown by the Cook's D value), and only 3 deviating significantly from the model.

A) Estimated values > Observed values

37) Littlewater Tarn

B) Observed values > Estimated values

12) Rather Heath Tarn
75) Boo Tarn

The results are discussed in section 5.6.

5.4J - Candona reducta

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.08782	0.4537
$[Ca]^{2+}$	-0.01206	0.9304
$[Mg]^{2+}$	0.02920	0.8036
$[K]^{+}$	-0.09928	0.3967
$[Na]^{+}$	-0.08523	0.4672
Alkalinity	0.01011	0.9314
Logsize	-0.07219	0.5382
Altitude	0.17971	0.1029

These values indicate that apparently there are no significant factors influencing the distribution of Candona reducta. The best relationship that exists is between density and altitude, but this is not significant even at the P = 0.1 level.

2) However, on closer observations of the results, by plots of the environmental variables against density, significant relationships were seen to occur.

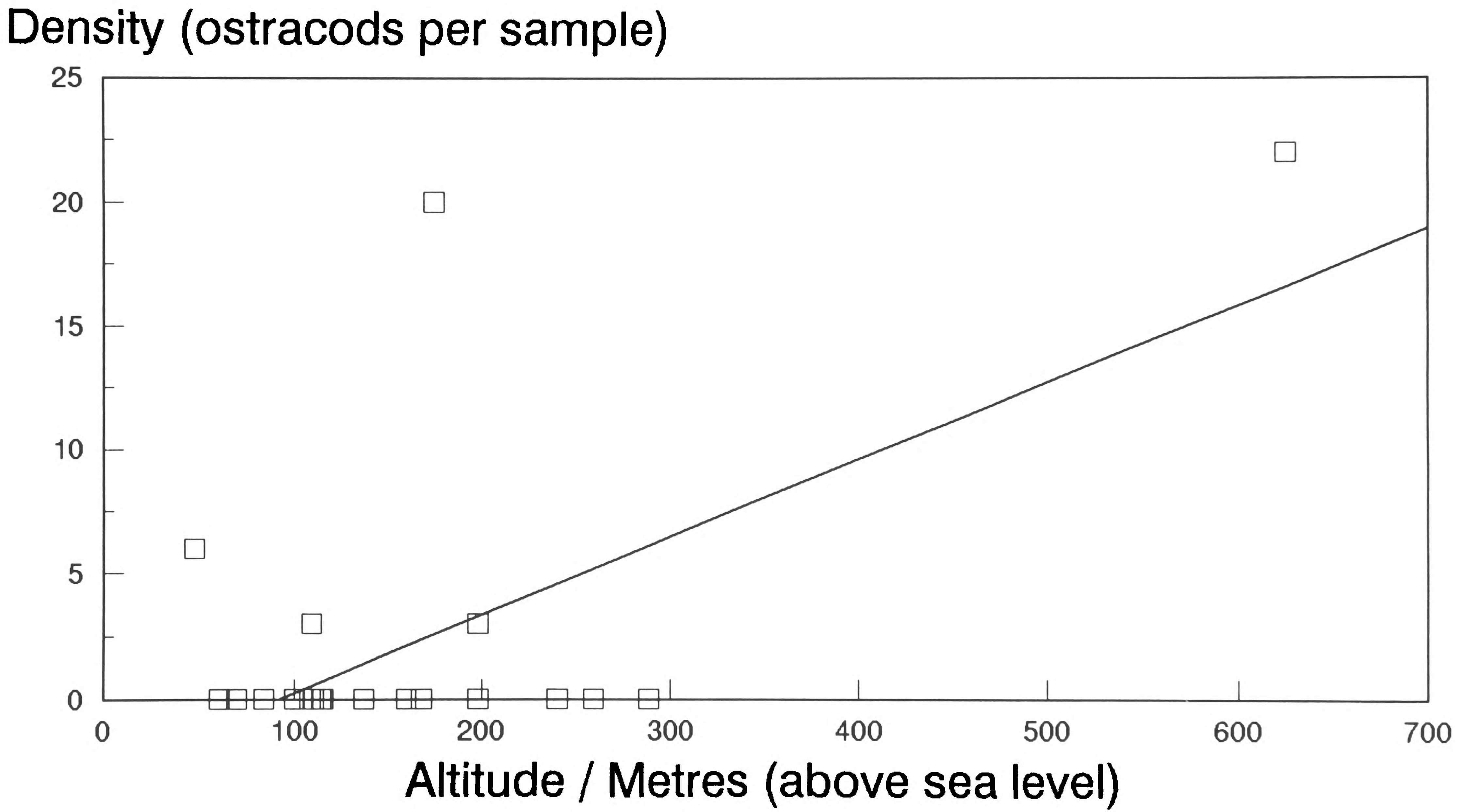
The species only occurred at pH values of greater than 6.5, and a logsize of less than 4.8. The relationship pH is in contrast to that of Lowndes (1952), who records the species as existing at acidities as high as pH 4.7. Within the limits evaluated from this survey, the relationship between altitude and density became statistically significant (P = 0.0024). A plot of density against altitude is shown in Figure 5.8.

3) A threshold model was formulated which incorporated the

Figure 5.8.

Plot of Density v. Altitude.

Candona reducta (at pH > 6.5, Logsize < 4.8).



effects of altitude and logsize within these defined limits, and allowed the creation of a predictive equation describing the abundance of C. reducta.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	2	314.3	157.2	6.326	0.0074**
Error	20	496.9	24.8		
C Total	22	811.2			

Root MSE 4.98 R-Square 0.3875 Dep Mean 2.3
Adj. R-Sq. 0.3262 C.V. 212.3

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	-8.993	7.147	0.2228
Logsize	1	1.581	1.775	0.3837
Altitude	1	0.031	0.009	0.0024

Therefore, the equation predicting abundance of Candona reducta can be given as;

Density = 1.581 [Logsize] + 0.031 [Altitude] - 8.993, when $pH > 6.5$, $logsize < 4.8$.
Density = 0, $pH \leq 6.5$, $logsize \geq 4.8$.

The predictive power of the equation when tested against the Lake District data set is shown in Appendix 14.5. The model provided a good fit to the data, 91% of the sites (68) showing no significant deviation (shown by the Cook's D value), and only 7 deviating significantly from the model.

A) Estimated values > Observed values

10) Bigland Tarn
20) Grizedale Tarn
37) Littlewater Tarn
65) Tewet Tarn
75) Boo Tarn

B) Observed values > Estimated values

13) High Dam Reservoir
22) Clay Pond

The results are discussed in section 5.6.

None of the remaining nine ostracod species that made up the eighteen species used in the statistical analysis showed any significant correlation with any of the variables, even after the testing of threshold limits on the data. Table 5.41 gives the Pearson Correlation Coefficients for these remaining species.

Table 5.41 - Pearson Correlation Coefficients.

K) *Cypria exsculpta*

Parameter	**Pearson value**	**P**
pH	0.00477	0.9676
$[Ca]^{2+}$	-0.01505	0.8980
$[Mg]^{2+}$	0.09596	0.4128
$[K]^{+}$	0.03163	0.7877
$[Na]^{+}$	0.05987	0.6099
Alkalinity	0.01153	0.9218
Logsize	-0.14728	0.2073
Altitude	-0.03390	0.7728

L) *Potamocypris villosa*

Parameter	**Pearson value**	**P**
pH	0.08261	0.4811
$[Ca]^{2+}$	0.04046	0.7304
$[Mg]^{2+}$	-0.00857	0.9148
$[K]^{+}$	-0.06634	0.5717
$[Na]^{+}$	0.05176	0.6592
Alkalinity	0.03964	0.7356
Logsize	-0.02160	0.8541
Altitude	-0.05079	0.6652

M) *Cyclocypris laevis*

Parameter	**Pearson value**	**P**
pH	0.09349	0.4250
$[Ca]^{2+}$	0.11756	0.3152
$[Mg]^{2+}$	0.05430	0.6436
$[K]^{+}$	0.04378	0.7092
$[Na]^{+}$	-0.07682	0.5124
Alkalinity	0.08817	0.4519
Logsize	0.11154	0.3407
Altitude	-0.02972	0.8002

N) Cypricercus obliquus

Parameter	**Pearson value**	**P**
pH	0.07547	0.5199
$[Ca]^{2+}$	-0.07278	0.5349
$[Mg]^{2+}$	-0.01762	0.8807
$[K]^{+}$	-0.13388	0.2522
$[Na]^{+}$	0.00176	0.9880
Alkalinity	-0.07299	0.5337
Logsize	-0.01033	0.9299
Altitude	-0.00676	0.9541

P) Candona rostrata

Parameter	**Pearson value**	**P**
pH	0.02932	0.8028
$[Ca]^{2+}$	-0.05189	0.6584
$[Mg]^{2+}$	-0.03630	0.7572
$[K]^{+}$	0.00039	0.9973
$[Na]^{+}$	-0.01789	0.8789
Alkalinity	-0.05362	0.6477
Logsize	-0.07215	0.5384
Altitude	0.01732	0.8828

Q) Candonopsis kingsleii

Parameter	**Pearson value**	**P**
pH	0.08117	0.4888
$[Ca]^{2+}$	0.13835	0.2365
$[Mg]^{2+}$	0.03165	0.7875
$[K]^{+}$	0.08214	0.4835
$[Na]^{+}$	-0.02569	0.8268
Alkalinity	0.12098	0.3012
Logsize	-0.01903	0.8712
Altitude	-0.07166	0.5412

R) *Candona vavrai*

Parameter	**Pearson value**	**P**
pH	0.06464	0.5817
$[Ca]^{2+}$	-0.07546	0.5199
$[Mg]^{2+}$	-0.03343	0.7759
$[K]^{+}$	-0.02909	0.8043
$[Na]^{+}$	-0.05600	0.6332
Alkalinity	-0.06826	0.5606
Logsize	0.01976	0.8664
Altitude	0.02721	0.8168

S) *Herpetocypris chevreuxi*

Parameter	**Pearson value**	**P**
pH	-0.00578	0.9608
$[Ca]^{2+}$	-0.01667	0.8871
$[Mg]^{2+}$	0.00414	0.9719
$[K]^{+}$	-0.09396	0.4227
$[Na]^{+}$	-0.01228	0.9167
Alkalinity	-0.01825	0.8765
Logsize	-0.14966	0.2000
Altitude	-0.03389	0.7288

T) *Paracandona euplectella*

Parameter	**Pearson value**	**P**
pH	0.02573	0.8266
$[Ca]^{2+}$	-0.04121	0.7256
$[Mg]^{2+}$	-0.03900	0.7398
$[K]^{+}$	-0.11023	0.3465
$[Na]^{+}$	-0.00864	0.9413
Alkalinity	-0.05649	0.6303
Logsize	-0.18311	0.1158
Altitude	-0.01607	0.8912

Now that some of the major environmental factors influencing the distribution of several species have been established, the parameters affecting both the number of species and the total ostracod density at a site must be evaluated.

5.4U - Species Diversity

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.64110	0.0001***
$[Ca]^{2+}$	0.42378	0.0002***
$[Mg]^{2+}$	0.33372	0.0037**
$[K]^{+}$	0.22211	0.0572
$[Na]^{+}$	0.08076	0.4940
Alkalinity	0.41349	0.0003***
Logsize	-0.08702	0.4610
Altitude	-0.42292	0.0002***

The data indicate that pH, $[Ca]^{2+}$, $[Mg]^{2+}$, total alkalinity, and altitude all significantly affect the number of ostracod species that may be recorded from a site.

Total species number increases with increasing pH, $[Ca]^{2+}$, $[Mg]^{2+}$ and alkalinity, and with decreasing altitude. Alkalinity was removed from the analysis at this stage, as discussed earlier.

2) The four remaining significant factors were then entered into a step-wise multiple regression analysis to test the loadings upon each.

Variable entered	**F**	**Prob > F**
pH	52.3647	0.0001
Altitude	1.5964	0.2105

No other variable met the 0.5000 significance level for entry into the model. This indicates that the significant correlations between total species number and $[Ca]^{2+}$ and $[Mg]^{2+}$ were themselves a reflection of their interaction with pH and were not acting independently of pH in controlling species number.

3) A predictive equation describing species number in terms of pH and altitude was then created. Species diversity was regressed against the above two variables using the SAS multiple regression procedure.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	2	273.7	136.8	27.194	0.0001***
Error	72	362.3	5.0		
C Total	74	636.0			

Root MSE 2.243 R-Square 0.4303 Dep Mean 4.0
Adj. R-Sq. 0.4145 C.V. 56.1

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	-8.629	2.679	0.0019
pH	1	2.009	0.371	0.0001
Altitude	1	-0.002	0.002	0.2105

Thus, the equation predicting species diversity per site can be given as;

Density = 2.009 [pH] - 0.002 [Altitude] - 8.629

The values obtained from the equation when tested upon the Lake District data set are shown in Appendix 14.5. The model provides a reasonable fit to the data, as 72% of the sites (54 out of 75) show no significant deviation (shown by the Cook's D value), whilst 21 deviate significantly from the model.

Plots of species diversity against pH and altitude are shown in Figures 5.9 and 5.10.

A) Estimated values > Observed values

5) Killington Reservoir
8) Poaka Beck Reservoir
14) Yew Tree Tarn
30) Grasmere
39) Blea tarn
47) Blackbeck Tarn
57) Crummock Water
58) Ennerdale Water
65) Tewet Tarn
66) Bleaberry Tarn
69) Browns Tarn

B) Observed values > Estimated values

4) Coniston Water
12) Rather Heath Tarn
16) Knittleton Tarn A
17) Moss-Side Tarn
23) Barrow Plantation Tarn A
25) Barrow Plantation Tarn D
31) Brotherswater
36) Loughrigg Tarn
61) Overwater
64) Little Tarn

A discussion of the results is presented in section 5.6.

Figure 5.9.

Plot of Species Diversity per Site v. pH.

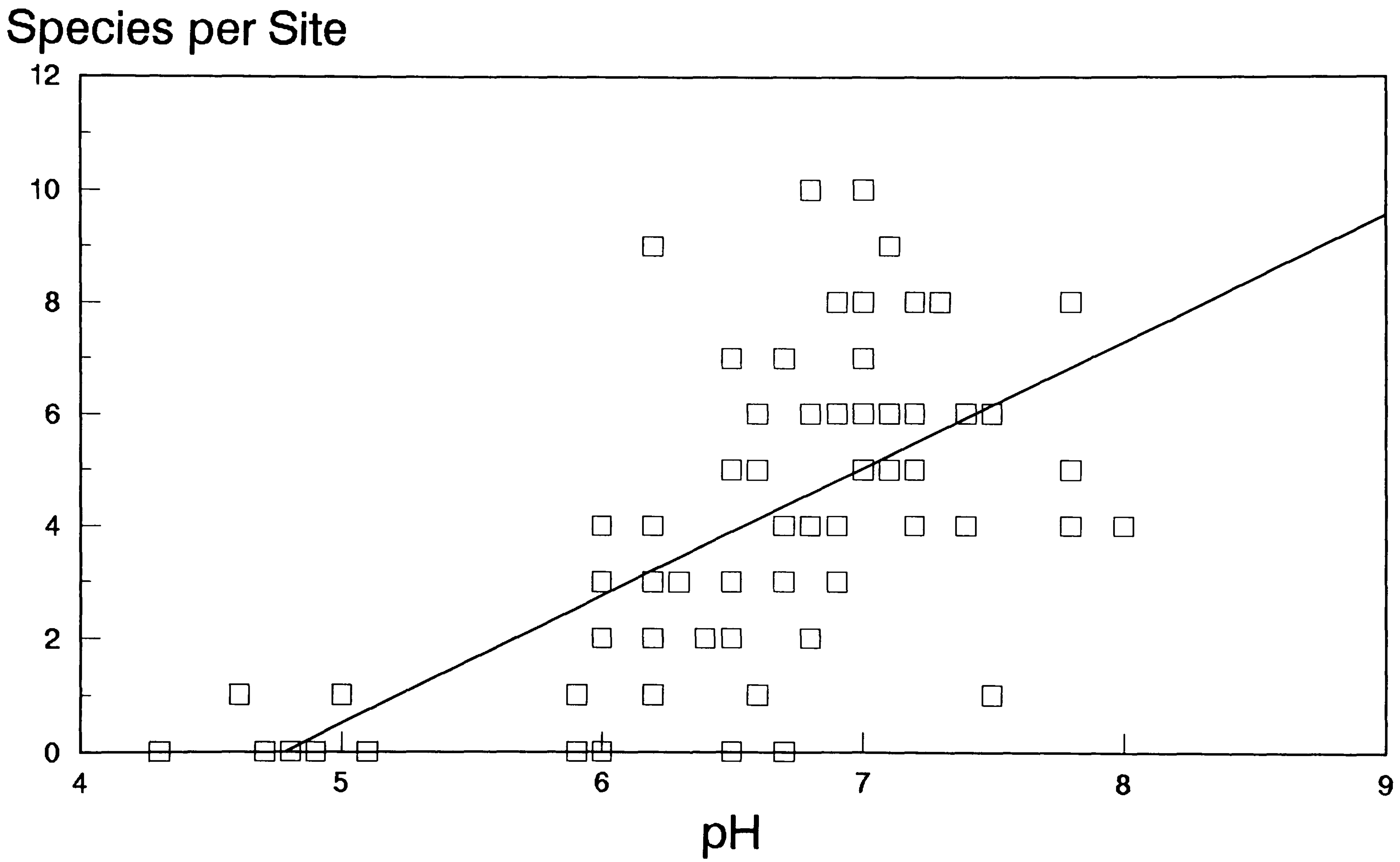
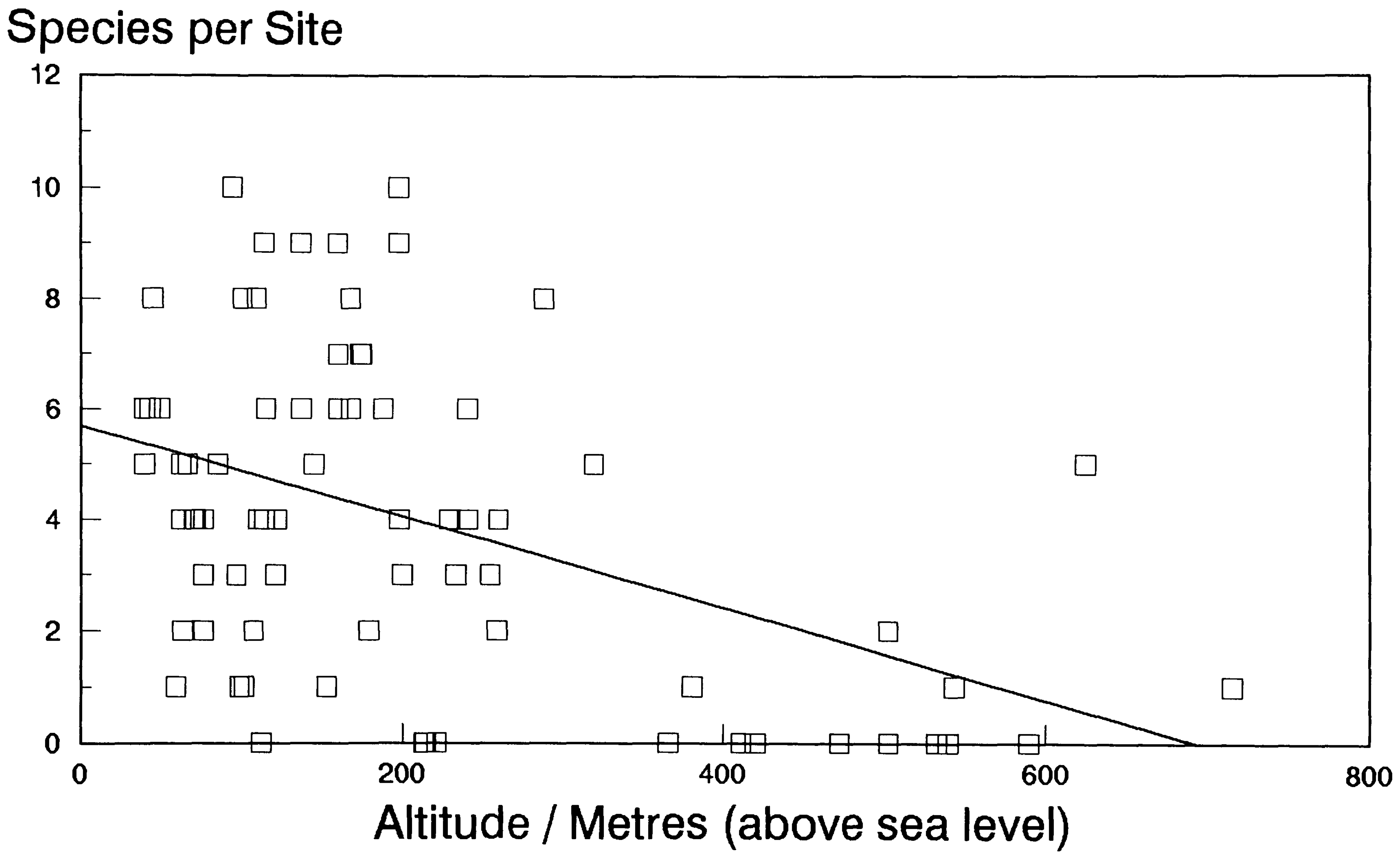


Figure 5.10

Plot of Species Diversity per Site v. Altitude.



5.4V - Ostracod Abundance

1) Stage 1 - Pearson Correlation Coefficients.

Parameter	**Pearson value**	**P**
pH	0.29748	0.0095**
$[Ca]^{2+}$	0.44854	0.0001***
$[Mg]^{2+}$	0.50999	0.0001***
$[K]^{+}$	0.08899	0.4477
$[Na]^{+}$	0.25222	0.0290*
Logsize	-0.29382	0.0105*
Altitude	-0.10232	0.3824

The data indicate that pH, $[Ca]^{2+}$, $[Mg]^{2+}$, $[Na]^{+}$, and logsize all significantly affect the density of Ostracoda at the sites sampled in the Lake District.

Abundance increases with increasing pH, $[Ca]^{2+}$, $[Mg]^{2+}$ and $[Na]^{+}$, and with decreasing logsize.

2) The five significant factors were then entered into a step-wise multiple regression analysis to test the loadings on each.

Variable entered	**F**	**Prob > F**
$[Mg]^{2+}$	25.6604	0.0001
Logsize	5.0724	0.0274
pH	3.7344	0.0573
$[Ca]^{2+}$	1.8511	0.1780
$[Na]^{+}$	0.9344	0.33715

This analysis indicates that the significant effects of $[Ca]^{2+}$ and $[Na]^{+}$ were themselves a reflection of their correlation with $[Mg]^{2+}$ and were not acting independently of $[Mg]^{2+}$ in controlling overall density. The very significant correlation between $[Ca]^{2+}$ and $[Mg]^{2+}$ was identified in chapter

4. The three significant factors remaining from this analysis, $[Mg]^{2+}$, pH and logsize were then used to create a predictive equation describing overall ostracod density. Density was regressed against the above three variables using the SAS multiple regression procedure.

Analysis of Variance

Source	**D.F**	**S.S**	**M.S**	**F-Value**	**Prob > F**
Model	2	1358852.6	452950.9	12.373	0.0001***
Error	71	2599087.0	36606.9		
C Total	74	3957939.6			

Root MSE 191.329 R-Square 0.3433 Dep Mean 122.9
Adj. R-Sq. 0.3156 C.V. 155.7

Parameter Estimates

Variable	**D.F**	**Parameter Estimate**	**Standard Error**	**Prob > [T]**
Intercept	1	-109.633	185.165	0.5557
$[Mg]^{2+}$	1	0.502	0.146	0.0010
Logsize	1	-52.263	18.493	0.0061
pH	1	60.096	31.099	0.0573

Thus, the equation predicting ostracod density per site can be given as,

$$\mathbf{Density = 60.096\ [pH] + 0.502\ [Mg]^{2+} - 52.263\ [Logsize] - 109.633}$$

The values obtained from the equation when tested upon the Lake District data set are shown in Appendix 14.5. The model provides a reasonable fit to the data, 62% of the sites (45 out of 75) show no significant deviation (shown by the Cook's D value), whilst 28 deviate significantly from the model.

A) Estimated values > Observed values

8) Poaka Beck Reservoir
9) Pennington Reservoir
11) Witherslack Hall Pond
17) Moss-Side Tarn
18) Holehird Tarn
19) High Arnside Tarn
24) Barrow Plantation Tarn B
25) Barrow Plantation Tarn D
26) Barrow plantation Tarn Q
43) Tosh Tarn
49) White Moss Tarn
50) Hard Tarn
51) How Top Tarn
63) Mockerkin Tarn
65) Tewet Tarn
69) Browns Tarn
70) High Stock Bridge Pool

B) Observed values > Estimated values

3) Windermere (North Basin)
16) Knittleton Tarn A
22) Clay Pond
23) Barrow Plantation Tarn A
31) Brotherswater
37) Littlewater Tarn
42) Brown Cove Tarn
64) Little Tarn
71) Parsonby Tarn
72) Manesty Park Tarn
75) Boo Tarn

The results are discussed in section 5.6.

Figure 5.11.

Plot of Ostracod Density per Site v. pH.

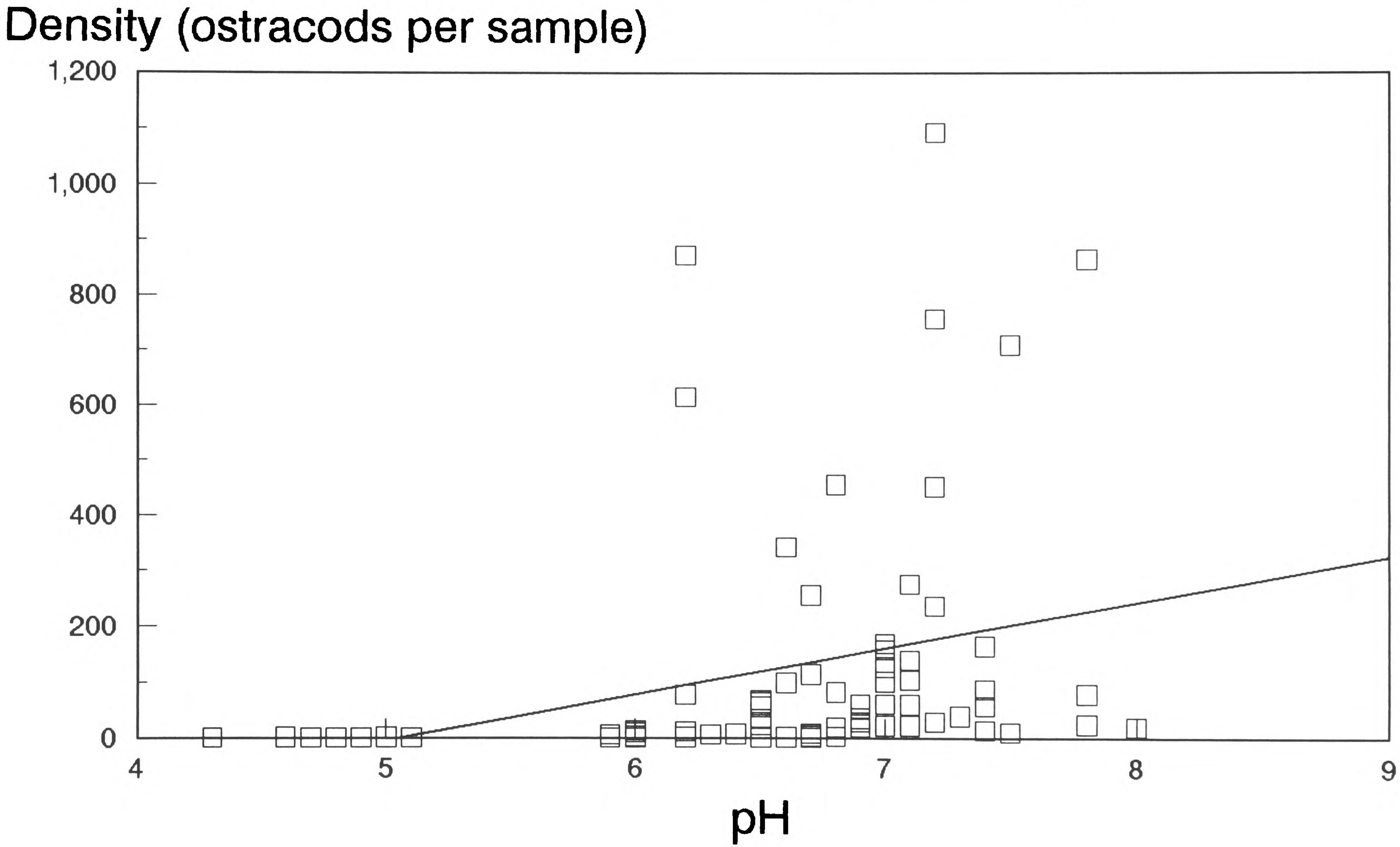


Figure 5.12.

Plot of Ostracod Density per Site v. [Magnesium]

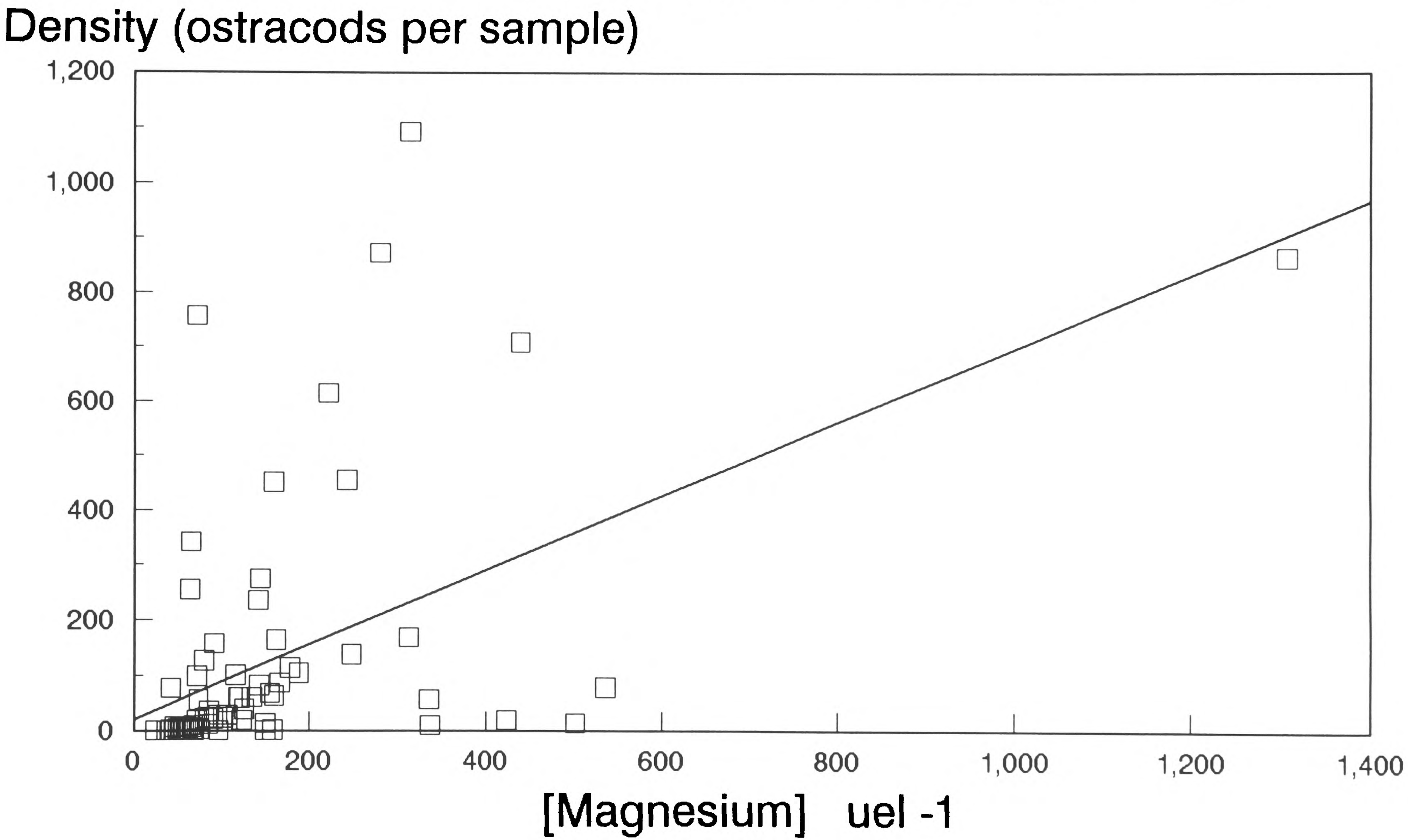
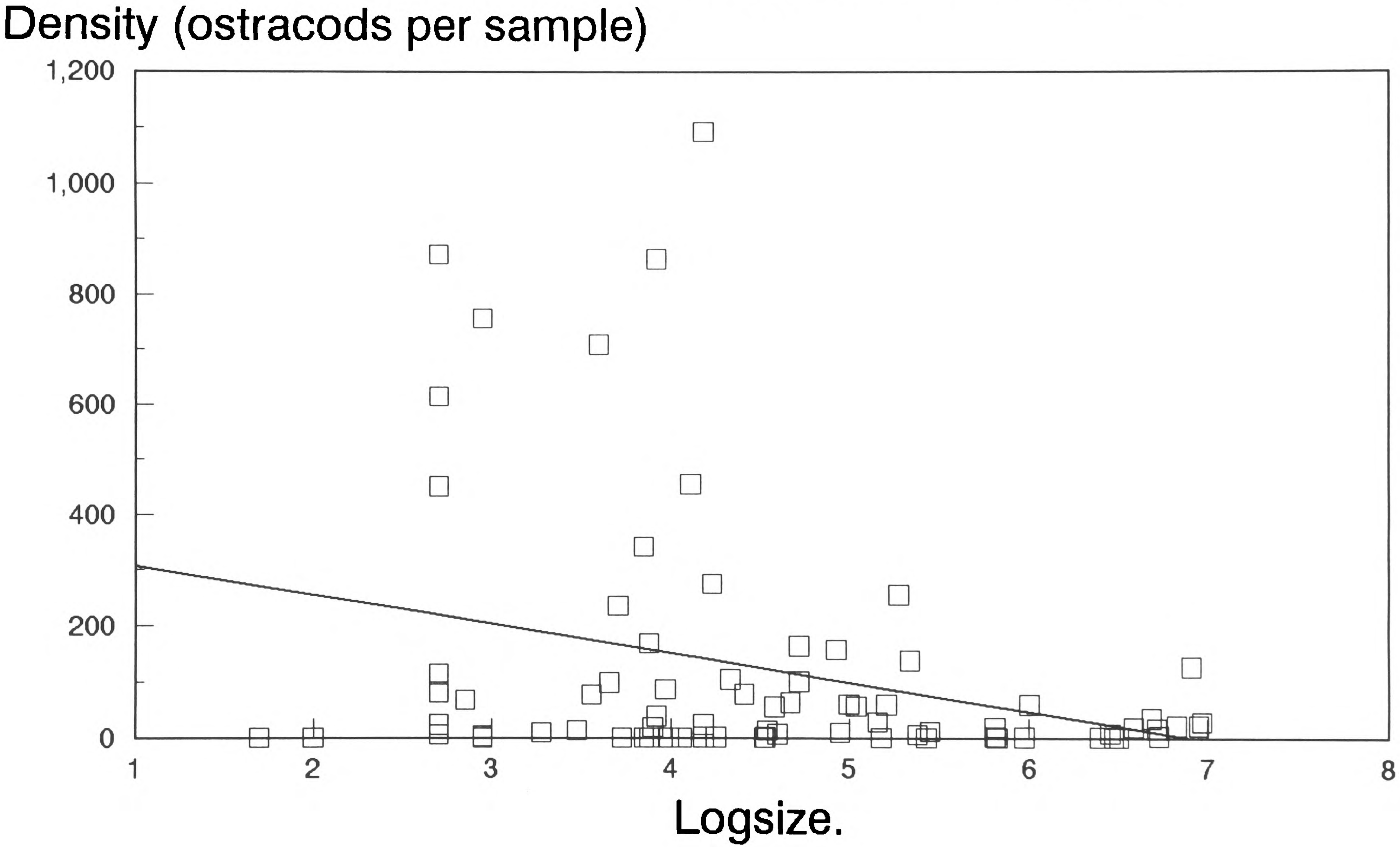


Figure 5.13.

Plot of Ostracod Density per Site v. Logsize.



5.5 - Subdivision of the Habitat

The maximum number of ostracod species observed at any one sample site within a waterbody was 10, which was achieved at two sites, Loughrigg Tarn (site 36) and Little Tarn (site 64). In comparison with other regions of Great Britain, the Lake District fauna is poor. For example, Hatchet Pond in the New Forest, Hampshire contains 19 species (P. Henderson, pers. comm.). Even though most sites have a relatively low species diversity, both temporal and spatial separation between the species must occur, or else inter-specific competition, inter-group competition (for example, with Copepoda) and interference could be intense.

According to their favoured niche in the water column, Ostracoda may be classified as pelagic, natatory or benthic. Pelagic species swim in open water, while ostracods may be classified as natatory if they normally swim close to solid surfaces including submerged periphyton and the lake bottom. The benthic species are defined as non-swimming forms which burrow in or crawl on the sediment or macrophytes.

Lake District species are classified according to these criteria in Table 5.51.

Table 5.51 - Classification of Ostracod Form

Benthic Species	**Natatory Species**	**Pelagic species**
Candona candida	Cypria ophthalmica	Notodromas monacha
Candona albicans	Cypria exsculpta	
Candona rostrata	Cyclocypris ovum	
Candona reducta	Cyclocypris laevis	
Candona siliquosa	Cyclocypris serena	
Candona vavrai	Cyclyocypris globosa	
Candona fabaeformis	Cypricercus obliquus	
Candona pratensis	Cypricercus fuscatus	
Candona compressa	Cypridopsis vidua	
Candona neglecta	Potamocypris villosa	
Candonopsis kingsleii	Cyprinotus incongruens	
Paracandona euplectella	Herpetocypris chevreuxi	
Herpetocypris reptans	Eucypris virens	
Darwinula stevensoni	Ilyocypris decipiens	
Ilyocypris bradyii	Potamocypris sp. A	
Metacypris cordata		

Table 5.52 - Ostracod Distribution within each Habitat

	BENTHIC	**NATATORY**	**PELAGIC**
% PROPORTION OF TOTAL SPECIES.	50.00	46.88	3.12
% OF TOTAL OSTRACOD DENSITY.	29.31	70.59	0.10
% SITES CONTAINING GROUP.	69.33	81.33	2.67

Of the top ten ranked species, seven may be classified as natatory, and only three as benthic, Metacypris cordata (ranked 3), Candona candida (ranked 4) and Herpetocypris reptans (ranked 10). Therefore, the natatory species are the most numerically important. Table 5.52 further illustrates the importance of this species subset, over 81% of the sites include at least one natatory species in their faunal assemblages, as opposed to less than 70% of the sites containing a benthic species.

Reasons for differences in the natatory/benthic dominance can be investigated by first considering the group of ten sites lacking benthic species.

Table 5.53 - Sites lacking Benthic Species

8) Poaka Beck Reservoir	29) Thirlmere
57) Crummock Water	60) Buttermere
40) Parkgate Tarn	41) Low Water
44) Dalehead Tarn	67) Floutern Tarn
70) High Stock Bridge Pool	30) Grasmere

Of these sites, the first four, sites 8, 29, 57 and 60 contain no or very little soft (preferably organic) sediment, at least around the margins where sampling was carried out.
This type of substrate in a habitat is essential for the benthic species that (by definition) burrow through sediment. The next four sites, 40, 41, 44, and 67 were all acidic (maximum pH 6.2 at Low Water and Dalehead Tarn). A natatory species is apparently better able to survive in conditions of low pH than are either benthic or pelagic species. For example, Cypria ophthalmica was recorded from Floutern Tarn (pH 5.0) and Cyclocypris ovum was found at Parkgate Tarn (pH 4.6). These two species have also been recorded as feeding on diatoms (Liperovskaya, 1948), several species of which are acidophilous. The absence of benthic species may be due to the reduction in bacterial decomposition of the sediments in an acidic environment (Moss, 1980). As most benthic Ostracoda are detritivorous/bacterial feeders (Henderson, 1990) there will therefore, be a reduced food supply available. Little explanation can be offered for the lack of benthic Ostracoda in

either Grasmere or High Stock Bridge Pool, although neither site exhibited a rich ostracod diversity, despite having a pH of 6.0 or greater and suitable substrate. However, the sample collected from Grasmere was taken from an area next to a boat house, so it is possible that the increased disturbance of the substrate in the nearby vicinity could have affected the presence of an ostracod fauna.

Of the sites lacking natatory species, there is only one which has a benthic fauna, Hard Tarn (site 50) containing a population of solely Candona vavrai. This demonstrates the tendency of natatory species to dominate within the Lake District.

5.6 - Discussion

The results obtained from the Pearson Correlation Analysis will now be considered. However, care should be taken in the interpretation of the results as in any large data set some significant correlations will be found even when the data is randomly generated.

Cypria ophthalmica was seen to show a positive association with Candona candida (PCC = 0.2537). The wide distribution in the Lake District of these species, both occurring in over 40 of the sample sites, and their similar environmental requirements (the multiple regression analysis indicating that neither regularly occur at a pH of less than 5.9) explain the correlation. These species have previously been recorded together, by Fryer (1955), Horne (1988), Benzie (1989) and by Danielopol et al (1985). Fryer (1955) also found this species association in Cold Hiendley Reservoir, Huddersfield, amongst extensive macrophytic growth in the marginal zone, whilst Horne (1988) recorded it in the Lake District in Rydal Water, a site discussed in Chapter 6. Benzie (1989) found that both species, together with Cypria exsculpta, formed a well defined species group in regions of Phragmites and its associated detritus in a Scottish sand-dune loch of pH 7.5.

Interestingly, a positive species interaction also occurred between C. candida and C. exsculpta in this investigation, the interaction having a Pearson Correlation Coefficient of 0.3860. Horne (1988) recorded these two species together at two sites in the Lake District that were sampled during this survey, Barrow Plantation Tarn A (site 23) and Loughrigg Tarn (site 36). However, there was no positive value for the relationship between C. ophthamica and C. exsculpta (PCC = 0.0224). From this, it appears that the two species occupy slightly different niches in the Lake District, as C. ophthalmica has a greater tolerance to acidity than C. exsculpta. Only at one site, Little Tarn (site 64) do they co-exist in appreciable abundance. At the other sites where C. exsculpta was common, (Knittleton Tarns A & B, Barrow Plantation Tarn A and Loughrigg Tarn), only isolated specimens of C. ophthalmica were recorded.

Candona candida also showed positive associations with 2 other species, Cyclocypris serena and Candona rostrata. The former association was recorded by Horne (1988) in Brotherswater (site 31) in the Lake District, while the latter has never been previously recorded in the Lake District. Cyclocypris serena was shown to prefer larger lakes, a fact previously recorded by Henderson (1990), and 6 out of the 7 sites from which it was recorded also contained Candona candida. The relationship between C. candida and C. rostrata is more difficult to identify, as the latter species was found to have no significant relationship with any environmental variable. C. candida was, however recorded from 5 out of the six sites from which C.rostrata was collected, and these sites all had a pH of 6.6 or greater.

C. candida has been previously recorded with the following species (the appropriate non-significant values from this investigation are given in brackets):

Herpetocypris reptans (-0.0346), (Lowndes, 1931; Fryer, 1955; Horne, 1988; Scharf, 1988; Danielopol et al, 1990).

Cypridopsis vidua (0.0696), (Fryer, 1955; Horne, 1988; Scharf, 1988; Danielopol et al, 1990).

Cypricercus obliquus (-0.0104), (Fryer, 1955).

Potamocypris villosa (0.0407), (Lowndes,1931).

Paracandona euplectella (0.1021), (Horne, 1988).

Candona vavrai (0.0735), (Horne, 1988).

Cyclocypris laevis (0.0023), (Horne, 1988).

Candona reducta (0.0502), (Horne, 1988).

Candona rostrata also showed positive associations with *Cypria exsculpta* and *Paracandona euplectella*, although it has only previously been shown to show a strong correlation with *Potamocypris villosa* (-0.0293 in this study) and *Eucypris virens* among the macrophyte *Eleocharis* (Benzie, 1989). It has also previously been recorded in the Lake District with *Cypridopsis vidua* and *Metacypris cordata* (Horne, 1988). *C. exsculpta* occurred in 3/6 sites inhabited by *C. rostrata*, and *P. euplectella* occurred in 2/6 sites.

Herpetocypris reptans showed positive associations with *Metacypris cordata* and *Potamocypris villosa*. All species were recorded from relatively alkaline, ion-rich sites. *H. reptans* has been previously recorded with *P.villosa* (Lowndes, 1931), and also with (but not significantly in this experiment) :

C.ophthalmica (-0.0780), (Fryer, 1955; Horne, 1988; Danielopol *et al* , 1990).

C.vidua (0.1434), (Fryer, 1955; Horne, 1988; Scharf, 1988; Benzie, 1989; Danielopol *et al*, 1990).

C.obliquus (-0.0293), (Fryer, 1955).

Cyclocypris ovum (0.0076), (Horne, 1988; Danielopol *et al*, 1990).

Cypria exsculpta (-0.0440), (Horne, 1988).

Benzie (1989) showed that the relationship with *C. vidua* was highly correlated with the macrophyte *Eleocharis*, while the distribution of *H. reptans* showed a significant negative association with the predatory mite *Piona sp.*, suggesting that this species may suffer from predation by the mite. Predation on ostracods will be further discussed in Chapter 9.

There was a positive interaction between *Candona reducta* and *Candona vavrai*, this relationship having been previously documented in the literature (Klie, 1938; Fox, 1967; Horne, 1988), both species being suggested as having a preference for springs or flowing water, and a tolerance to acidity, although the latter is not the case in this study.

Candonopsis kingsleii showed a highly significant correlation with *Candona fabaeformis* in this investigation, but has only previously been recorded with *Candona compressa* (Meisch, 1990). In the Lake District, both species were recorded together from two rich, adjacent sites, Rather Heath Tarn, and Moss-Side Tarn.

Cyclocypris ovum showed significant associations with four species, *Metacypris cordata*, *Candona candida*, *Cypria exsculpta*, and *Candona reducta*. It is both difficult to assess these relationships and to describe the distribution of *C. ovum* by an equation of physico-chemical parameters. The relationship with *C. candida* is due mainly to the dominance of the two in the fauna, while *C. ovum* is present in most of the alkaline sites that contain one or more of the other three species. As with the case of there being no relationship between *C. ophthalmica* and *C. exsculpta*, no significant associations occur between *C. ovum* and the other three members of the genus recorded in the Lake District.

The validity of the proposed models will now be discussed.

The model generated for predicting the density of *Cypria* ophthalmica had a reasonable fit, with 76% of the sites exhibiting no significant deviation from the model. There may be several reasons for the poor fit of the other sites to the proposed model, most of which involve parameters that are not clearly quantifiable. The possibility was considered that these sites could have been included in those that were not classified by the hierarchical classification analysis described in Chapter Three. However, this was not the case, as there were only five sites common to analytical failure in both cases, High Arnside Tarn (19), Grizedale Tarn (20), Barrow Plantation Tarn D (25), White-Moss Tarn (49) and How Top Tarn (51).

In the case of the four sites in which the observed density of C. ophthalmica was significantly greater than the expected values derived from the model, this is probably due to the very high densities of the species at these sites which disfigured the model. It often reaches its greatest densities in small eutrophic ponds (Fryer, 1955; Pierre, 1973), rich in dense layers of organic sediment and decaying leaves (Martens & Dumont, 1984; Meisch, 1990), especially alder and beech (Scharf, 1988). All these four sites fitted this category, being small and rich in detritus.

Viable explanations for model deviation for the other sites are;

Lily Tarn (45), White-Moss Tarn (49), Blackbeck Tarn (47), and Bleaberry Tarn (66) are all probably too acidic to contain any significant ostracod fauna, the latter two sites being barren.

The four Barrow Plantation Tarns, A, B, D and Q are generally dominated by another species. Tosh Tarn (43) and Browns Tarn (69) are affected by substrate, both sites having rocky margins poor in organic detritus. High Stock Bridge Pool (70) is dominated by the species but at a lower density than predicted, and while it is not clear why deviations occur with High Arnside Tarn (19) and How Top Tarn (51), it may be noted that they both are included in the sites not classified by their marginal fauna in Chapter 3.

Metacypris cordata has previously been shown to inhabit sites with a high dissolved ion content. Its chemical range recorded by Hiller (1972) was; pH 6.9-8.8, calcium 2184-3086 μel $^{-1}$. This observation fits well with the findings of this survey. The observed values from the two sites where the observed density of M. cordata was significantly greater than the expected values is due to the overall dominance of this species at these sites.

The sites that contain Metacypris cordata, especially those containing a high density of the species, are also all comparable in a way unaccountable by this statistical method. They all have very marshy, boggy margins and are often situated in an arable catchment area, in addition to their rich ionic profile.

The six sites that were predicted by the model to have greater expected values of M. cordata than was observed do not have this substrate form, and mainly possess silty or gravel margins.

Reasons for failure of the model for Cyclocypris ovum are unclear. It seems to be a species with a poorly defined niche, and the literature shows that it is difficult to ascertain its precise habitat, having no selection for lake size range (Fryer, 1985). However, in similarity to this study, it has been seen to display a marked antipathy to more acidic sites (Fryer & Forshaw, 1979; Janz, 1983).

Although 32% of the sites do not fit the proposed model describing the distribution of Candona candida, this is due again to the absence of a mathematical parameter describing substrate in the data set. Candona candida is a burrowing species and has a strong substrate preference for silty mud and marshy vegetation (De Deckker, 1979). In Chapter 3, a group of sites was shown to be dominated by Candona candida, the majority of which were of the largest size class (A) and all having at least a few mm of soft organic detritus overlying a firm gravel base. Looking at the 17 sites with lower abundance than expected from the model, one notices that 11 are of size class A or B and have very little fine substrate, a requirement of Candona candida. Therefore, it appears that this species is absent from several sites that are suitable in terms of both water quality and size, due to the nature of the substrate. It is probable that it would be found in slightly deeper water samples from these sites, where more fine sediment might be expected.

The seven sites where a greater density of Candona candida is observed than predicted in the model are difficult to explain, although each site is rich in organic detritus, the preferred substrate for the species, leading to an abundant food supply.

Cypridopsis vidua has previously been recorded as showing a preference for rich, eutrophic, weedy lakes, ponds and canals (De Deckker, 1979; Fryer & Forshaw, 1979; Carbonel et al, 1988; Henderson, 1990; Meisch, 1990), swimming between the macrophyte fronds (Danielopol et al, 1985). These observations support the findings of the present study (Chapter 3) that C. vidua shows a preference for sites with plentiful growth of macrophytes, especially Elodea sp. Benzie (1989) found that C. vidua ingests primary tissues from macroalgae, but requires some prior breakdown of macrophytic detritus before this can be assimilated.

The four sites in which the observed density was significantly greater than the expected density may be explained by the presence of rich macrophytic growth at these sites.

Although there were only four sites possessing a significantly lower density than expected in this survey, previous studies have suggested that there are certain sites where C. vidua would be expected to be common but is either in very low densities or is absent. Echols et al (1975) suggested this may be explained by the overall dominance of Cypria ophthalmica in these sites and the resulting interspecific competition from which C.vidua loses. However, when submerged periphyton is present, C. vidua appears to occupy these sites more successfully than C .ophthalmica (Scharf, 1988).

In the Lake District, competition with C. ophthalmica at the four significantly different sites does not appear to be the reason for the low densities / absence of C. vidua from a site. However, both Witherslack Hall Pond (Site 11) and Littlewater Tarn (site 37) yielded high densities of members of the genus Cyclocypris, C. laevis and C. ovum which occupy a similar niche to Cypria ophthalmica. It is possible that the resulting interspecific competition is sufficient to limit the densities of C. vidua at these sites.

Although this species shows a wide tolerance of substrate form (Meisch, 1990), the substrates at the two remaining sites with lower densities / species absence, Mockerkin Tarn (site 63) and Browns Tarn (site 69) both have little or no macrophytes. In the case of Browns Tarn, there was no macrophytic growth nor any soft sediment, just a layer of fine sand over coarse gravel, and C. vidua was absent from this site.

The model indicates that Cyclocypris serena is only recorded from the two largest size group classifications, A and B. This preference for large lakes has been previously recorded by Henderson (1990).

The absence of this species from sites 55, 56, 57 and 58 may be attributable to one of two factors, lack of suitable substrate (as all were very much gravel based) or the low values of dissolved ions, especially in sites 57 and 58. The species was not taken from the margin sample at site 2, (Windermere-South Basin) probably because the sample was taken at the lake outflow to a river, almost in running water, this possibly not being an ideal habitat for the species. This suggestion is supported by the fact that C. serena was obtained from the deep-water samples from Windermere (South Basin). The model was unable to cope with large densities of the species, which occurred at two of the sites in which the species was underestimated, Windermere (North Basin) and Brotherswater.

The fact that Herpetocypris reptans is linked to alkaline waters has been previously noted in the literature. It has always been recorded in the pH bracket 7.2-10.7 (Lowndes, 1952; Hiller, 1972; Benzie, 1989). Its absence in sites 8, 64 and 71 may be attributable to lack of a suitable macrophyte, such as Eleocharis palustris, or to the presence of a predator. This species has previously shown a positive correlation with this macrophyte, and a negative correlation for non-Eleocharis macrophyte, chitin, and also the predatory mite, Piona sp (Benzie, 1989).

It is difficult to define the ideal habitat for Candona fabaeformis as it was only recorded from three sites, although all were similar in being small, eutrophic sites. This has been suggested to be its most common habitat (Henderson, 1990).

The distribution of Candona reducta is in contrast to that of the literature, it being typically recorded from oligotrophic lakes and streams (Henderson, 1990). In this survey, small, medium altitude, sites were favoured by the species, although the greatest density was recorded from Brown Cove Tarn (site 42) near a stream inflow.

It will now be considered how the models describing predictions for the species diversity per site, and overall abundance per site fit the data set.

At the 11 sites in which the expected species number exceeded the observed densities, two main reasons may explain this. Three sites, 39), 47), and 66) contained no ostracods due to their acidity. The remaining sites, apart from Grasmere (site 30) are faunally limited by their substrate, which mainly consists of firm rock and gravel, with little organic sediment. The region from which a sample was taken from Grasmere may have been affected by disturbance by boats, as considered earlier.

The influence of substrate is again paramount in nine of the ten sites where the observed densities exceed the predicted values. All sites, with the exception of Coniston water (site 4) had a high diversity and abundance, due to plentiful organic substrate and macrophytic growth. Coniston Water yielded 8 species, a suprising number from a site lacking in fine organics and macrophytes. This possibly indicates the proximity of good substrates in slightly deeper water.

The large amount of sites that significantly deviate from the model predicting total ostracod density may be attributable to the few sites in the data set which have very large numbers of ostracods. Such observations are likely to distort the analysis. This is especially seen in the sites which have a lower density of ostracods than would be predicted by the model as the model will estimate high densities at small, $[Mg]^{2+}$ rich sites with a high pH. Almost all the sites with an overestimated density fit this category. To supplement this, the sites with a greater ostracod density than predicted by the model are all sites with high numbers of individuals. However, the model does not include predation by fish and other invertebrate predators. This will be discussed in Chapter 9.

CHAPTER 6 - TESTING THE MODELS

6.1 - SUMMARY

To test the equations generated in the previous chapter, a further series of sites were sampled for Ostracoda in the Lake District.

10 species were collected from 16 sites, 3 of which, Candona candida, Cypria ophthalmica and Cypridopsis vidua, made up over 80% of the total number of ostracods obtained. Correlation analysis showed that some of the species interactions previously recorded in the Lake District occurred again in this data set.

The predictive equations for total species number and total ostracod density usually provided an excellent fit to the observed data. However, predictions for individual species were poorer. The five acidic sites of pH 5.6 or less fitted the species model perfectly, no ostracods being predicted and none occurring. The distribution of Cyclocypris ovum was exceptional in that adequate predictions could not be produced. The factors controlling the distribution of this species have not been elucidated. The predictive equations for individual species did not refer to substrate. This factor needs to be included with any successful prediction scheme for individual species.

6.2 - AIMS OF THE CHAPTER

In the previous chapter a series of equations were formulated to describe ostracod distribution in relation to the measured physico-chemical variables. These equations were now to be tested on a separate sample data set taken from the Lake District to test the viability of the predictions.

Samples were to be taken, their ostracod fauna recorded and then compared to that which may have been predicted from the equations.

6.3 - CHOICE OF THE STUDY AREA.

For logistical purposes a suitably confined area had to be chosen that contained a reasonable quantity of sites exhibiting a wide variety in both size and water chemistry. The Lake District in Cumbria was again chosen; apart from eliminating the factor of geographical variation, this choice had the advantage of adding previously unsampled sites to the Lake District data set.

6.4 - SITE CHOICE WITHIN THE STUDY AREA

A number of sites that had not been previously sampled in the Lake District were chosen for this study. Sixteen sites covering the maximum possible range of physico-chemical variables were selected. It was not possible to select any sites of the largest size class A, as all such possible sites in the Lake District had previously been sampled. However, it was possible to select waterbodies varying from sizes B-E and F.B.A./ I.F.E. chemistry groups (Sutcliffe & Carrick, 1988) of 1-4 (acidic-medium hard water). The sites chosen are indicated below, the values in brackets corresponding to the key describing the waterbodies in the sample set outlined in Chapter 2.

Table 6.41 - The 'Test Sites'.

1. EASEDALE TARN (B1)
2. RYDAL WATER (B1)
3. LILY MERE (B3)
4. CHAPEL HILL RESERVOIR (C5)
5. WOODHOW TARN (C5)
6. LITTLE LANGDALE TARN (C1)
7. ESKDALE GREEN TARN (C5)
8. KNIPE TARN (C3)
9. LOW BIRKER TARN (D1)
10. LONG MOSS TARN (D3)
11. BORWICK FOLD TARN (D3)
12. CLEABARROW TARN (D3)
13. LAUNCHY TARN (E1)
14. ROSLEY THORNS POOL (E3)
15. CAT CRAG TARN (E3)
16. BURNMOOR POOL (E1)

The position of these sites in the Lake District is shown in Figure 6.1.

6.5 - SAMPLING METHODOLOGY

The sampling techniques used were the same as those described in Chapter 2. Only marginal samples were collected.

Water samples were again obtained simultaneously with the faunal samples and were analysed for pH and major ion content at Central Electricity Research Laboratories at Fawley. Field notes were also taken at each site on other factors potentially affecting ostracod community structure, such as macrophyte availability, substrate type, fish presence and catchment area.

The samples were collected in summer 1989 (sites 13, 16) and summer 1990 (the other 14 sites), but were stored in alcohol

Figure 6.1.
The Lake District.
`Test' Sites.

until January 1991 for analysis once the statistics had been performed on the main data set.

This set of samples was collected during the same time periods as the main data set from which the equations were derived, thus eliminating any seasonal factors.

6.6 - MARGIN SITES - DISTRIBUTION

16 samples from 16 sites yielded a total of 2499 individuals comprising only 10 species belonging to 7 genera. Table 6.61 presents the data.

Table 6.61 - Data from Test Sites

SPECIES	**Rank**	**NO.**	**SITE PRES.**	**In**	**% TOTAL NUMBERS.**	**CUMUL %.**
Candona candida	1	859	7	6.76	34.37	34.37
Cypria ophthalmica	2	755	11	6.63	30.21	64.58
Cypridopsis vidua	3	397	7	5.98	15.89	80.47
Cyclocypris ovum	4	332	7	5.81	13.29	93.76
Herpetocypris reptans	5	90	2	4.50	3.60	97.36
Cypria exsculpta	6	43	3	3.76	1.72	99.08
Candona rostrata	7	10	1	2.56	0.52	99.60
Cypricercus obliquus	8	5	2	1.61	0.20	99.80
Cyclocypris serena	9	3	1	1.10	0.12	99.92
Potamocypris villosa	10	2	1	0.69	0.08	100.00
TOTAL	10	2499	-	-	-	100.00

(**NO** = number of total specimens, adult and juvenile found of that species in all the marginal sites: **SITE PRES.** = number of sites in which that species was found: **In** = natural logarithm of **NO**: **% TOTAL NUMBERS** = % of the total ostracod numbers that the species represents: **CUMUL %.** = cumulative proportion of the total represented by that number of ranked species.)

6.7 - STATISTICAL ANALYSIS OF THE MARGIN SAMPLES

For analysis of the data, Hierarchical Classification Analysis was again used to split the sites into groups displaying similar faunal assemblages, yielding a dendrogram as a graphical representation.

Figure 6.2 shows the plot of the natural logarithm of species abundance against the rank in order of abundance for the data set. It can be seen that there are 3 species which make up over 80% of the total ostracod numbers, and that the series of data fits a straight line. The most widespread species was C.ophthalmica, but the most common species in terms of density was C. candida, which only ranked as 4 in the previous data set described in Chapter 3.

The six species that contributed to over 99% of the total ostracod numbers were analysed. Rarer species were excluded from the analysis due to the large quantity of zero values they would have introduced which would have distorted the results (Henderson, 1989), which in Figure 6.2 show as a tail of infrequent species. The 5 sites that contained no ostracods were also omitted at this stage, as the Hierarchical Classification Analysis makes a measure of similarity at each site, and all these sites with no ostracods obviously have a 100% similarity.

The dendrogram in Figure 6.3 indicates that there are six groups of ostracod communities in the 11 sites analysed. A key to these 6 groups is presented in Figure 6.4, and incorporates a

Figure 6.2
Plot of In v. Rank.
Test Data.

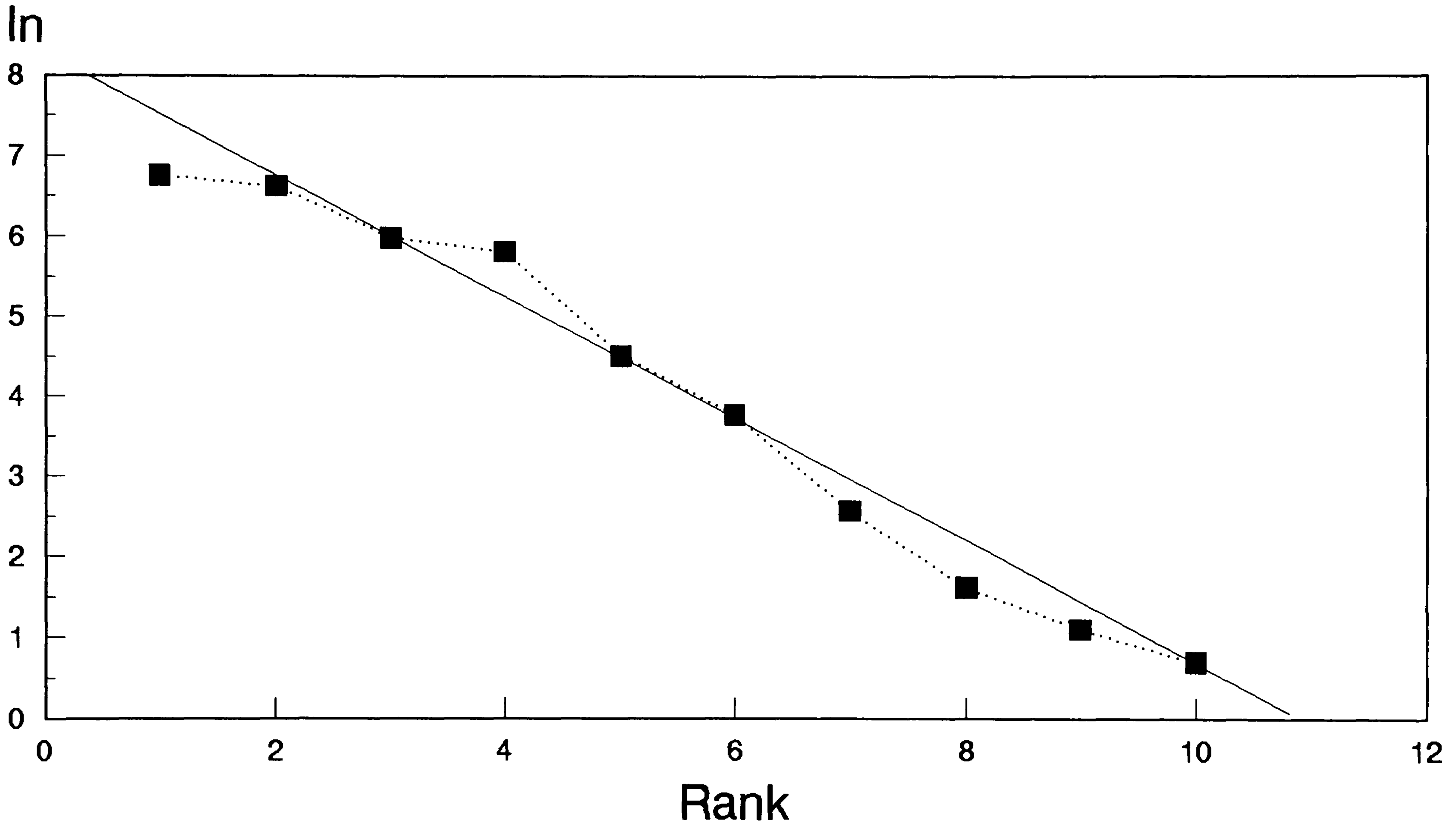
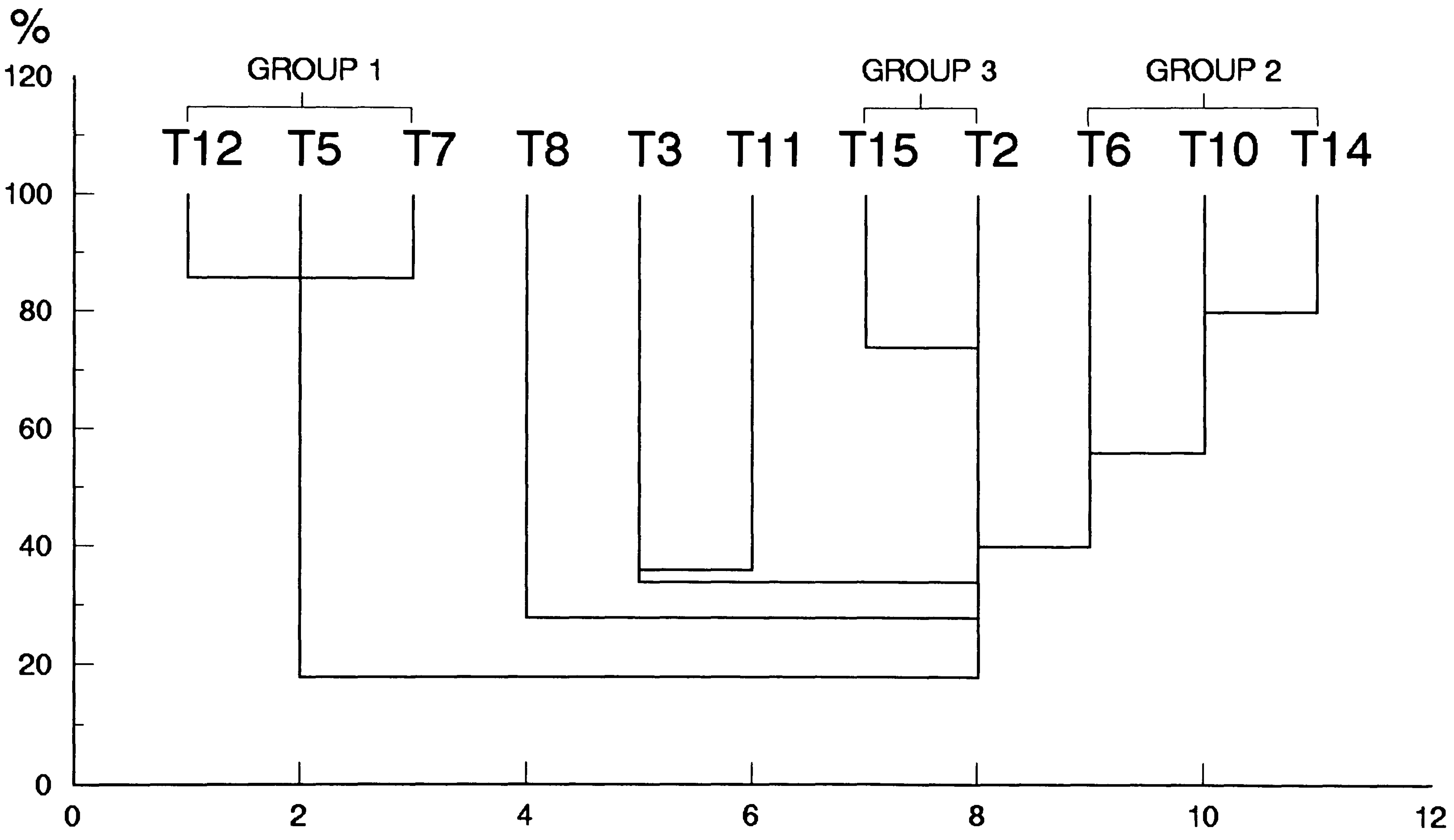


Figure 6.3.
Dendrogram.
Test Data.



seventh group representing the 5 sites containing no ostracods.

It should be noted that this key refers only to these summer samples and should only be applied to help explain Figure 6.3.

Figure 6.4 - Key to the Community Groups.

1A.....Ostracods present.................2
1B.....Ostracods absent.......... GROUP 7

2A.....*Cypridopsis vidua* is the dominant species
.......GROUP 1
2B.....*Cyclocypris ovum* is the dominant species
.......GROUP 2
2C.....*Cypria ophthalmica* is the dominant species
.......GROUP 3
2D.....*Herpetocypris reptans* is the dominant species
.......GROUP 4
2E.....*Cypria exsculpta* is the dominant species
.......GROUP 5
2F.....*Candona candida* is the dominant species
.......GROUP 6

Correlation Analysis yielded the Pearson Correlation Coefficients between all the species. The species to display significant correlations with one another are shown in Table 6.71.

Table 6.71 - Significant Species Correlations

Species pair	**Pearson value**
C.ophthalmica/*C.ovum*	0.5547
C.ophthalmica/*C.candida*	0.9339
C.candida/*C.ovum*	0.4731
C.candida/*H.reptans*	0.2095
C.ovum/*C.rostrata*	0.7116

Of these coefficient values, two of the correlations were previously found in the main data set, suggesting very significant species interactions. These are the relationships between C. ophthalmica and C. candida, and between C. candida and C. ovum.

6.8 - VALIDITY OF HYPOTHESIS

Chapter 5 yielded equations predicting the environmental requirements of 9 ostracod species, together with derivations for diversity and abundance at a site. The equations are listed below.

Table 6.81 - The Equations

1) *Cypria ophthalmica* (section 5.4A)

When pH > 5.80;
$D = 245.275 - 42.275\,[\text{Logsize}]$

2) *Metacypris cordata* (section 5.4B)

When pH > 6.90, marshy-boggy substrate;
$D = 0.649\,[Mg^{2+}] - 0.072\,[Ca^{2+}] - 35.562$

3) *Cyclocypris ovum* (section 5.4C)

When pH > 6.00, & Logsize < 5.50;
$D = 271.129 - 25.312\,[\text{Logsize}] - 16.295\,[\text{pH}]$

4) *Candona candida* (section 5.4D)

When pH > 6.10;
$D = 34.497 - 3.872\,[\text{pH}] + 0.0080\,[Ca^{2+}]$

5) Cypridopsis vidua (section 5.4E)
Macrophytes or gravel substrate;
$D = 5.762\ [pH] - 31.158$

6) Cyclocypris serena (section 5.4F)

$D = 0.169 + 0.000002318\ [Area]$

7) Herpetocypris reptans (section 5.4G)

When pH > 6.40, & Altitude < 210 m;
$D = 15.870 - 2.370\ [pH] - 0.004\ [Ca^{2+}] + 0.028\ [Mg^{2+}]$

8) Candona fabaeformis (section 5.4H)

When pH = 7.0 - 7.2, & $[Ca^{2+}] > 370$ uel^{-1};
$D = 0.013\ [Ca^{2+}] - 3.971$

9) Candona reducta (section 5.4J)

When pH > 6.5, & Logsize < 4.8;
$D = 1.581\ [Logsize] + 0.031\ [Altitude] - 8.993$

10) **Diversity** (section 5.4U)

$D = 2.009\ [pH] - 0.002\ [Altitude] - 8.629$

11) **Abundance** (section 5.4V)

When pH > 5.7;
$D = 60.096\ [pH] + 0.502\ [Mg\ 2+] - 52.263\ [Logsize] - 109.633$

The next section describes the results of the application of these equations to the test set of data collected from the Lake District.

Initially, the total density of Ostracoda was predicted using equation (11). If this gave a positive value, then total species number and finally individual species abundance were predicted.

Table 6.82 - Predicted & Observed Values

(- in the **Predicted** column represents a species for which an equation was unavailable but was collected in the 'test' fauna)

1) Easedale Tarn

	Predicted	**Observed**
Abundance	0	0

2) Rydal Water

	Predicted	**Observed**
Abundance	38 / 29	9
Diversity	5 / 4	4
C. ophthalmica	10	4
M. cordata	0	0
C. ovum	0	3
C. candida	10	1
C. vidua	8	0
C. serena	1	1
H. reptans	0	0
C. fabaeformis	0	0
C. reducta	0	0

3) Lily Mere

	Predicted	**Observed**
Abundance	106 / 85	53
Diversity	5 / 5	5
C. ophthalmica	27	2
M. cordata	14	0
C. ovum	25	2
C. candida	9	8
C. vidua	10	1
C. serena	0	0
H. reptans	0	40
C. fabaeformis	0	0
C. reducta	0	0

4) Chapel Hill Reservoir

	Predicted	**Observed**
Abundance	0	0

5) Woodhow Tarn

	Predicted	**Observed**
Abundance	136 / 146	79
Diversity	5 / 5	3
C. ophthalmica	72	12
M. cordata	0	0
C. ovum	55	0
C. candida	9	0
C. vidua	9	65
C. serena	0	0
H. reptans	1	0
C. fabaeformis	0	0
C. reducta	0	0
P. villosa	-	2

6) Little Langdale Tarn

	Predicted	**Observed**
Abundance	41 / 103	8
Diversity	4 / 4	3
C. ophthalmica	39	1
M. cordata	0	0
C. ovum	47	4
C. candida	12	3
C. vidua	5	0
C. serena	0	0
H. reptans	0	0
C. fabaeformis	0	0
C. reducta	0	0

7) Eskdale Green Tarn

	Predicted	**Observed**
Abundance	128 / 132	66
Diversity	5 / 6	5
C. ophthalmica	47	2
M. cordata	26	0
C. ovum	38	1
C. candida	10	7
C. vidua	9	52
C. serena	0	0
H. reptans	2	0
C. fabaeformis	0	0
C. reducta	0	0
C. obliquus	-	4

8) Knipe Tarn

	Predicted	**Observed**
Abundance	200 / 166	57
Diversity	6 / 7	5
C. ophthalmica	62	4
M. cordata	40	0
C. ovum	40	0
C. candida	9	11
C. vidua	12	9
C. serena	0	0
H. reptans	1	0
C. fabaeformis	0	0
C. reducta	2	0
C. obliquus	-	1
C. exsculpta	-	32

9) Low Birker Tarn

	Predicted	**Observed**
Abundance	0	0

10) Long Moss Tarn

	Predicted	**Observed**
Abundance	135 / 164	82
Diversity	4 / 6	3
C. ophthalmica	79	9
M. cordata	0	0
C. ovum	64	64
C. candida	11	0
C. vidua	7	0
C. serena	0	0
H. reptans	2	0
C. fabaeformis	0	0
C. reducta	1	0
C. exsculpta	-	9

11) Borwick Fold Tarn

	Predicted	**Observed**
Abundance	289 / 284	329
Diversity	6 / 7	5
C. ophthalmica	83	31
M. cordata	113	0
C. ovum	57	0
C. candida	13	245
C. vidua	11	1
C. serena	0	0
H. reptans	4	50
C. fabaeformis	0	0
C. reducta	3	0
C. exsculpta	-	2

12) Cleabarrow Tarn

	Predicted	**Observed**
Abundance	234 / 232	263
Diversity	5 / 8	2
C. ophthalmica	87	6
M. cordata	54	0
C. ovum	59	0
C. candida	12	0
C. vidua	10	257
C. serena	0	0
H. reptans	2	0
C. fabaeformis	5	0
C. reducta	3	0

13) Launchy Tarn

	Predicted	**Observed**
Abundance	0	0

14) Rosley Thorns Pool

	Predicted	**Observed**
Abundance	148 / 123	157
Diversity	3 / 2	3
C. ophthalmica	120	1
M. cordata	0	0
C. ovum	0	143
C. candida	0	0
C. vidua	3	0
C. serena	0	0
H. reptans	0	0
C. fabaeformis	0	0
C. reducta	0	0
C. rostrata	0	13

15) Cat Crag Tarn

	Predicted	**Observed**
Abundance	359 / 370	1396
Diversity	4 / 5	4
C. ophthalmica	203	683
M. cordata	0	0
C. ovum	140	117
C. candida	17	584
C. vidua	6	12
C. serena	0	0
H. reptans	4	0
C. fabaeformis	0	0
C. reducta	0	0

16) Burnmoor Pool

	Predicted	**Observed**
Abundance	0	0

6.9 - DISCUSSION

Before the results of the tests of the predictive equations are discussed, the data obtained from the Hierarchical Classification Analysis will briefly be considered.

The three sites represented by group 1, Woodhow Tarn, Eskdale Green Tarn and Cleabarrow Tarn are all dominated by Cypridopsis vidua, comprising 79%-98% of the total ostracod fauna. These sites are all of size class C and D, and have an F.B.A./I.F.E. chemical range of 2-4. Extensive macrophytic growth at both Woodhow Tarn and Eskdale Green Tarn, and high pH and alkalinity at Cleabarrow Tarn may account for the dominance of this species,

The three sites represented by group 2, Little Langdale Tarn, Long Moss Tarn and Rosley Thorns Pool are all dominated by

Cyclocypris ovum at a density varying between 50-91% of the total ostracod numbers. Site size range varies from classifications C-E and F.B.A./I.F.E chemistry values vary from 2-3. In this data set, this species appears to be dominant in waters of moderate pH and alkalinity. At richer sites, other species tend to dominate.

The two sites represented by group 3, Rydal Water and Cat Crag Tarn, are dominated by Cypria ophthalmica at densities of 44-49%. The size range of these two sites is the maximum allowable within this data set, the large site of Rydal Water (class B),and the tiny Cat Crag Tarn, (class E), and F.B.A./I.F.E. chemistry values are 3-4.

The other three groups described by the key contain just one species which dominates at a particular site.

Lily Mere is dominated by Herpetocypris reptans, Knipe Tarn is dominated by Cypria exsculpta, and Borwick Fold Tarn is dominated by Candona candida.

The group 7 sites represent the 5 sites that contain no ostracods; Easedale Tarn, Chapel Hill Reservoir, Low Birker Tarn Launchy Tarn, and Burnmoor Pool. All show similarity in being acidic, belonging to F.B.A./I.F.E. class 1 or 2.

The viability of the predictive models will now be considered.

At five sites, Easedale Tarn, Chapel Hill Reservoir, Low Birker Tarn, Launchy Tarn and Burnmoor Pool, the data fitted the model exactly, no ostracods being present in any of the samples, as predicted at all sites. This is almost certainly due to the acidity of the sites, which vary from pH 4.5 to 5.7.

Rydal Water fitted the prediction model reasonably well. The number of species predicted by both methods (that of the equation, and that derived from summing the number of positive values for individual species presence) is very close to that found in the field, but ostracod density was over-estimated. C. ophthalmica and C. serena showed predicted values similar to those observed, whilst C. candida and C. vidua were overestimated by the model. C. ovum, not predicted due to the size of the site, did occur, although not in abundance.

Lily Mere had a relatively good fit to the model, in that the number of species predicted was the same as that observed, and 4 out of the 5 species predicted were collected. However, the only species to show a good similarity in predicted to observed density was C. candida, the model overestimating numbers of C. ophthalmica, C. ovum and C. vidua. Although M. cordata was predicted by the model, it was thought to be unlikely to occur in this site which does not have the substrate requirements necessary for this species, those of marshy, boggy marginal zones. The dominance of H. reptans at this site was most unexpected, as it was never previously collected at such a high altitude (Lily Mere is 214m above sea level).

Woodhow Tarn had a reasonable fit to the data in terms of ostracod density but the model overestimated the species number, predicting 5 whereas only three were collected. The lack of species at this site is somewhat surprising, as there was luxuriant macrophytic growth, which allowed *C. vidua* to dominate the site at a much greater density than predicted. The unexpected low density of *C. ophthalmica* and the absence of *C. ovum* are potentially attributable to the dominance of *C. vidua*, the latter having been previously shown to outcompete *C. ophthalmica* in small ponds rich in macrophytes (Echols *et al*, 1975) and to dominate in sites where other swimming species may have been expected (Scharf, 1988). The absence of *Candona candida* however, is difficult to ascertain.

The species diversity predicted at Little Langdale Tarn allied closely to that collected, although the densities of all species were lower than predicted. The three species obtained were all predicted to occur by the model. The absence of *C. vidua* is again possibly due to lack of a suitable substrate, Little Langdale Tarn having little in terms of suitable submerged macrophytes.

The data fit the model well at Eskdale Green Tarn in respect of the species diversity expected and reasonably well in terms of abundance. As with Lily Mere, although *M. cordata* was predicted by the model, it was again thought to be unlikely to occur in this site which does not have suitable substrates. *C. candida* fits the model well, whereas *C. ophthalmica* and *C. ovum* are overestimated and *C. vidua* is underestimated by the model. The dominance of *C. vidua* again is attributed to the abundance of submerged macrophytes and rich organic sediment at the site.

As Knipe Tarn was dominated by *C. exsculpta*, a species for which a significant equation could not be produced, the model fits poorly to the observed ostracod distribution exhibited by this site. Both total density and diversity are overestimated by the model, as are the densities of *C. ophthalmica* and *C. ovum*. Two species are very well described, *C. candida* and *c. vidua*, whilst *M. cordata* is absent for the same reasons as described for previous sites, namely the lack of a suitable substrate.

At Long Moss Tarn both the predicted density and species diversity (from the equation, not that derived from summing the totals for the individual species) fit well to the observed data, but again, many of the species densities are overestimated by the model. One species, *C. ovum*, stands out as having a perfect fit: 64 individuals predicted and 64 observed. *C. ophthalmica*, *C. candida* and *C. vidua* are all overestimated by the model.

At Borwick Fold Tarn, both diversity and abundance predicted by the equations fit well to the observed data, and *C. ophthalmica* makes a considerable contribution to the overall density, as predicted by the model. *M. cordata* was predicted, but was thought unlikely to occur, again due to the lack of soft, boggy ground around the waterbody. The site was dominated by *C. candida*, the density of which exceeded that of any site sampled in the initial survey of 75 sites from the Lake District, and therefore the density at this site could not have been successfully predicted from this model.

Cleabarrow Tarn has a very poor fit of the observed data to the model, except for the observed abundance which is an excellent fit to the equation. Cleabarrow Tarn was entirely dominated by C. vidua, the dominance of which probably reduces the chance of there being a large density of another swimming species such as C. ophthalmica (Scharf, 1988). The dominance of C. vidua is difficult to explain, as although the physico--chemical parameters predicted that the species would occur at this site, there is little in terms of submerged periphyton, the preferred habitat of C. vidua, and one in which high densities of this species, and poor densities of other swimming species (Echols et al, 1975) may be expected. C. vidua has however, been previously recorded as abundant in gravel pits with little macrophyte cover (Scharf, 1988; Henderson, pers. comm.).

Rosley Thorns Pool fitted the models very well with respect to the diversity and abundance predicted, but C. ovum was the dominate species, as opposed to C. ophthalmica as predicted by the model. The main data set from the Lake District suggested that C. ovum would not be present, or that just a few isolated specimens would be collected in a site of pH less than 6.0 such as Rosley Thorns Pool. The results from this site illustrate just how difficult it is to predict the density of C. ovum, as its distribution is seemingly random.

Although an extremely large density of ostracods was recorded from Cat Crag Tarn, the model did predict that this site would have the greatest density of ostracods of any of the sites in this test data set. Added to this fact, the predicted diversity matches for both the observed and predicted data, and that the species predicted are those observed, then the data fits very well to the equation. Very large densities of C. ophthalmica and C. ovum are both predicted and recorded, and the predicted density of C. vidua is similar to that recorded. The only species with a much higher observed density than predicted is C. candida, and as with Borwick Fold Tarn, such a high density could not have been predicted due to no sites in the original data set containing this density of the species.

The results derived from the models show a large amount of variation in species response, and again highlight the importance of an unquantified factor, substrate, in determining the dynamics of an ostracod community.

CHAPTER 7 - ONTOGENY

7.1 - Summary

In order to evaluate the seasonal ontogeny of some of the Lake District Ostracoda, measurements of valve length and height were recorded.

Suitable samples were available for twelve species, these included all 9 Lake District species of the genera Candona and Candonopsis, together with Metacypris cordata, Herpetocypris reptans and Herpetocypris chevreuxi.

Results for these species were compared with published reports of the seasonal aspects of distribution of both adults and juveniles. Care was taken in the interpretation of the results as effective sampling of only two periods, 'summer' and 'winter' was carried out, and this may not have been adequate for description of the life-cycles of some of the species.

7.2 - Introduction

Ostracods, like all arthropods, grow by ecdysis (moulting). Freshwater Ostracoda go through 9 moults to reach maturity (Van Morkhoven, 1962), consisting of 8 post-embryonic larval stages and 1 adult stage. Maturity is only reached after the final moult. Generally, the Ostracoda may be subdivided into two groups on the nature of their life-cycle (Theisen, 1966). Species may be known as stenochronal, if the development and life cycle is seasonal, whereas species which develop and survive throughout the year may be termed eurychronal.

Ostracod development has been shown to be related to several ecological factors, including temperature, which appears to be of primary importance (Schreiber, 1922; Kesling, 1951), and food availability (Hartnoll, 1982).

An increase in temperature generally leads to an increased rate of development (Klugh, 1927; Schrieber, 1952). For example, the life cycle of Cypria ophthalmica, the most common species in the Lake District (see Chapter 3), was determined by Thaler (1977) as lasting 8 months at 13.5 °C and 11.5 months at 9 °C. In addition, overall development time (A-8 to A-1 instar) for Cytherissa lacustris (Sars) is 1.88 years in 12m of water (at a variable temperature of 4-16 °C during the year), and 2.20 years at 20m (at a constant temperature of 4-6 °C throughout the year) (Geiger, 1990), the effect a function of an increased water temperature at the shallower depth. A low number of generations *per annum* is a typical adaptation for the meiobenthos (Heip, 1976), as a long developmental time may be seen as an adaptation to low detrital food levels and a resulting low energy flux. The influence of temperature was also recorded by Latifa (1987) who showed that as temperature was increased from 10 to 30 °C in 5 °C intervals the rate of development of Cyprinotus incongruens also increased and consequently shortened the lifespan of the individuals. In this species, which commonly inhabits ephemeral pools (Robertson, 1880; Janz, 1983; Fryer, 1985; Scharf, 1988;

Hollwedel & Scharf, 1988; Henderson, 1990), reaching maturity quicker is a positive advantage due to the uncertain nature of the habitat.

Obviously, the exact effect of temperature on development varies between ostracod species. For example, Martens et al, (1985) found that although there was no direct correlation between temperature and egg production for the Australian species Mytilocypris henricae, temperatures of less than 5 °C prevented the eggs from hatching. In addition, Martens (1985) discovered that the inter-moult period increased at lower temperatures, but the adults attained a larger size. This also agrees with the data of Elofson (1941) who also recorded that the juvenile stages of some species are larger in winter than in summer.

7.3 - Aims of the chapter

This chapter will investigate the population age structure of selected ostracod species sampled in the Lake District. The following problems are to be discussed:

1) How does the distribution of adults and juveniles vary from summer to winter ?

2) Do the data for these species from the Lake District correspond to those found by previous workers ?

7.4 - Choice of Species

From the Lake District data set, twelve species with sufficient individuals for measurement were selected, including all 9 species of *Candona* and *Candonopsis*. These species are listed in Table 7.41.

Table 7.41 - Species Investigated

Candonopsis kingsleii
Candona albicans
Candona candida
Candona fabaeformis
Candona neglecta
Candona rostrata
Candona siliquosa
Candona reducta
Candona vavrai
Herpetocypris reptans
Herpetocypris chevreuxi
Metacypris cordata

7.5 - Methodology

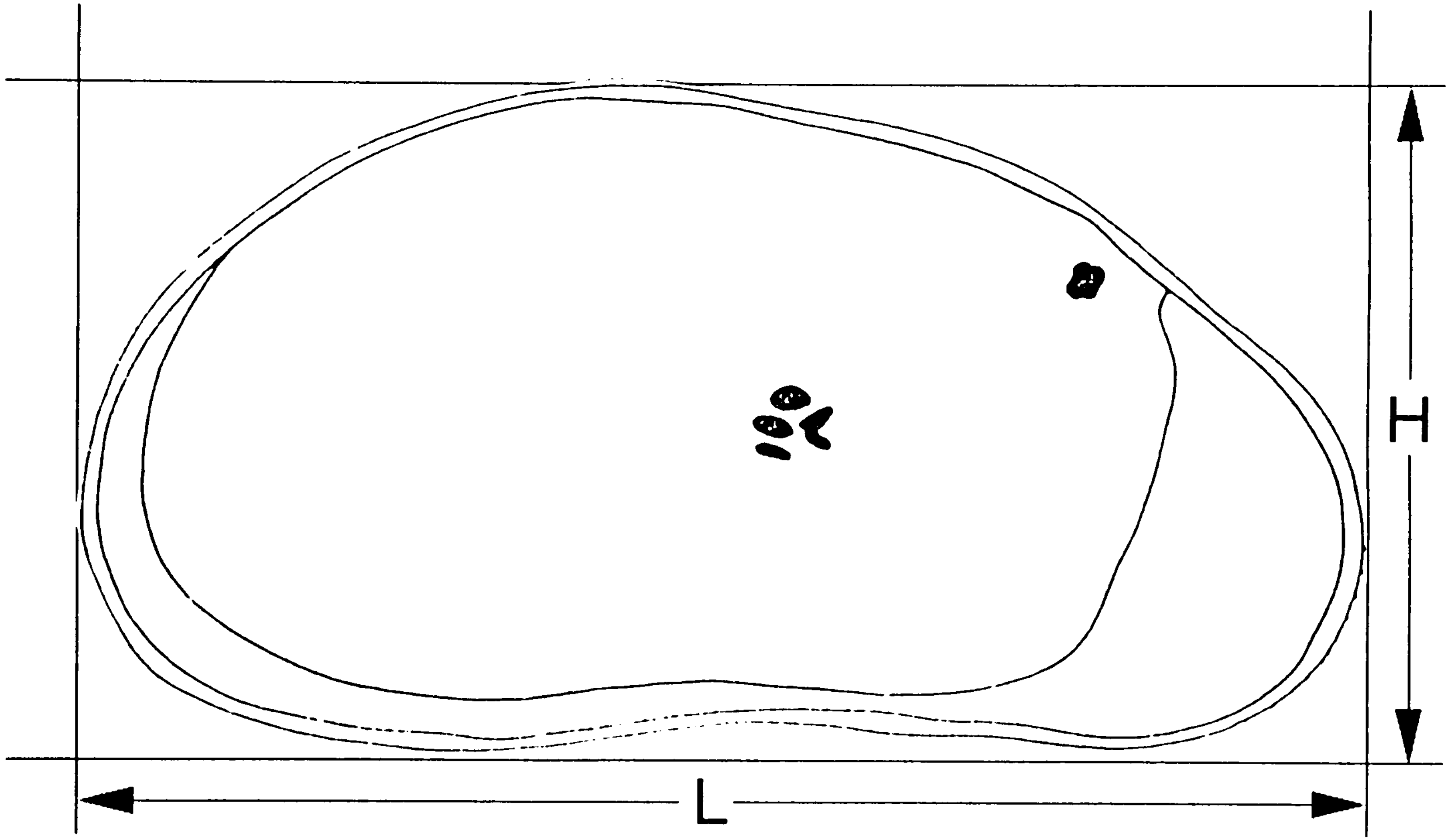
In order to determine the variability in size of the post embryonic instars of each ostracod species, the length and height of left valves were measured, as opposed to whole carapaces or either valve, using a calibrated eyepiece graticule. Measurements of single valves of each specimen ensured consistency in the results. The valves were measured according to the orientation shown in Figure 7.1.

7.6 - Results & Conclusions

The plots of size distribution for each species, together with instar frequency histograms are shown in Figures 7.2-7.25. The graphs may be used to determine the different instars of the

Figure 7.1

Valve Orientation used in Measurements



species collected by dividing the size ranges into separate groups. The plot of length / height is commonly used in studies for the purpose of life history analysis (Szczechura, 1971; De Deckker, 1979; Keen, 1990). Care was taken in the interpretation of the results as size variation within each instar can occur, and may be attributable to sexual dimorphism, neoteny, or simply variability.

7.6A - Herpetocypris reptans

1) *Population structure*

The length-height plot and instar frequency histogram for H. reptans shown in Figures 7.2 and 7.3, indicate that the adults are dominant in the winter period, while juveniles (A-2, A-3 and A-4) dominate in the summer period.

2) *Comparison with previous data*

Previous data describing the development of H. reptans are variable. It has been previously recorded as going through only 7 moults to reach the adult stage (McClay, 1978), although Fox (1964) found it to go through nine moults, as do most freshwater species (Henderson, 1990).

Previous data describing the life-history of H. reptans are also variable. The species is parthenogenetic in Europe, males only being known from North African populations (Henderson, 1990). Horne's (1988) review of Lake District Ostracoda recorded juveniles in March from marshy pools by the west margin of Loughrigg Tarn, adults in March from Podnet Tarn. He also

Figure 7.2.
Herpetocypris reptans.
Development.

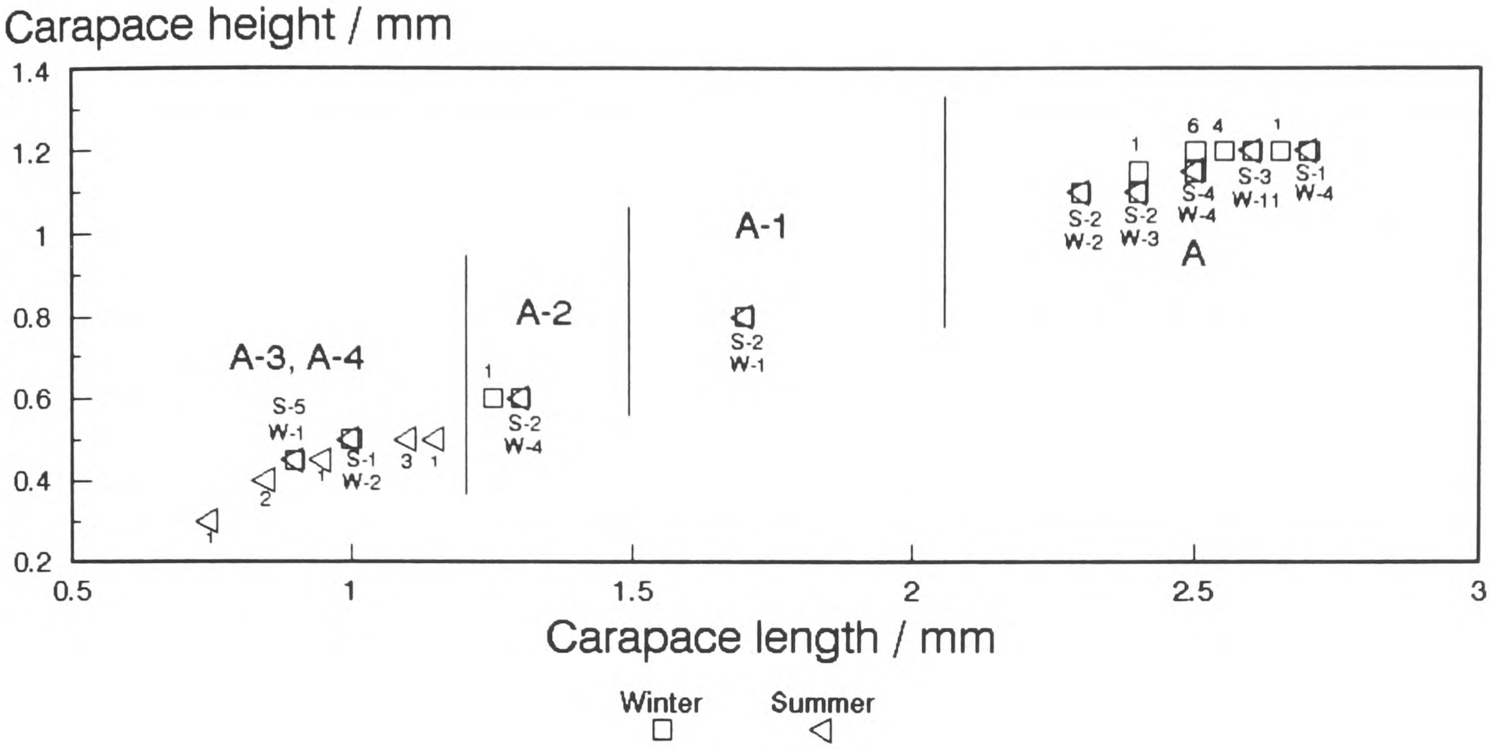
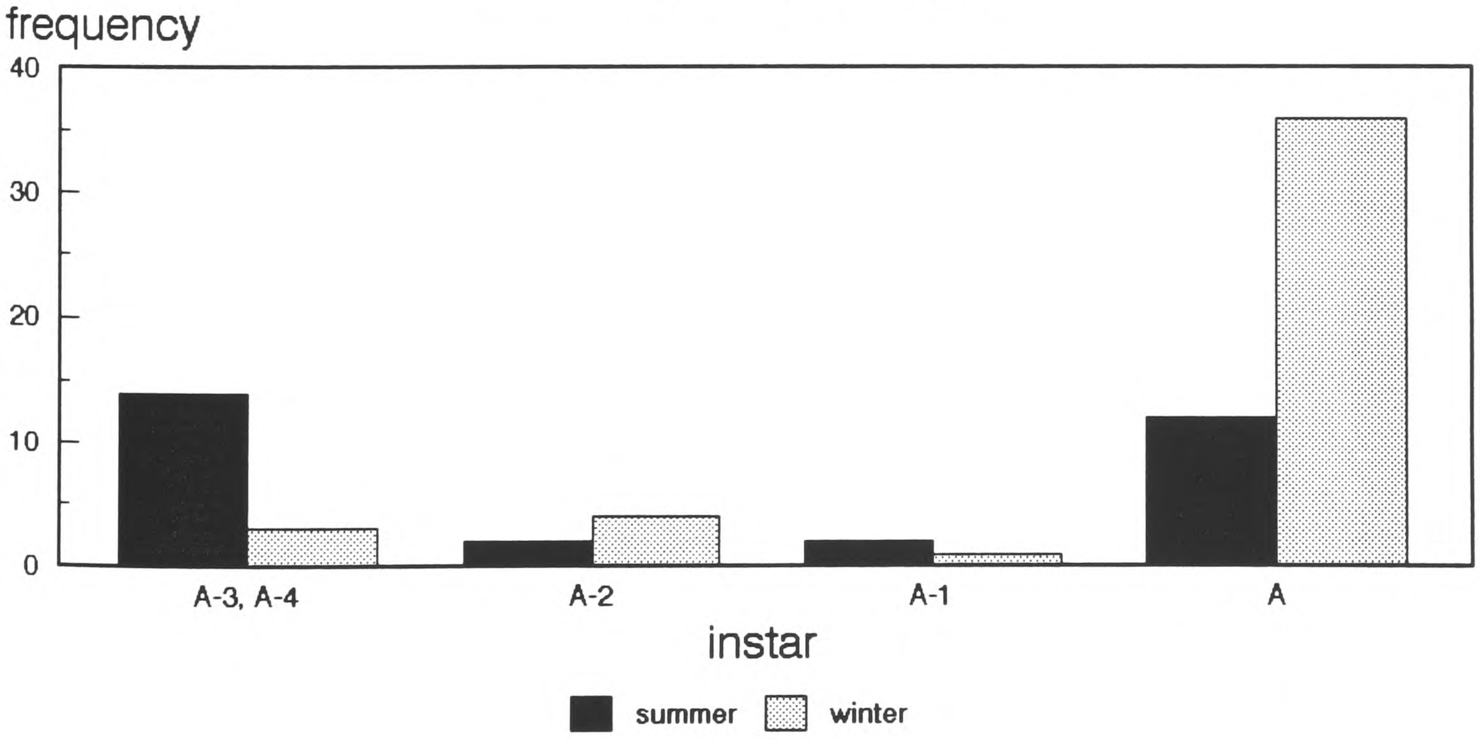


Figure 7.3
Herpetocypris reptans
Instar frequency histogram



recorded adults in April from an unnamed tarn near Rosthwaite Farm (SD 405933). Scharf (1988) found adults and juveniles to be present practically throughout the year, whilst McClay's study (1978) on the ecology of a temporary Canadian wheel-rut pool showed that recruitment occurred in the autumn. The eggs, which were light yellow and placed in hollowed curled grass stems or poked into the soft stem tissue, hatched on arrival of water and density decreased to a low number of egg laying adults during the winter.Density then again increased in spring. Therefore, the life cycle involves the production of one parthenogenetic generation per annum with high survival and low maturation rates. Maturity was reached quicker in the autumn than in the winter, reflecting the effect of temperature.

3) *Summary*

The reproductive strategy described by McClay (1978) is similar to that exhibited by H. reptans in the Lake District. Adults dominate in winter, and juveniles (A-2, A-3, A-4) dominate during the warmer months. Therefore, H. reptans may be defined as eurychronal (Theisen, 1966), in that the species may be found throughout the year.

7.6B - Herpetocypris chevreuxi

1) *Population structure*

This species was only found at one site, Barrow Plantation Tarn D (Site 25). The data from this site, shown in Figures 7.4 and 7.5 suggest that the reproductive pattern is similar to that displayed by the other member of the genus, H. reptans, in that only adults were collected during the winter period. However, adult density was greater during the summer and the two juvenile stages (A-1, A-2) identified were only recorded from the summer collection.

2) *Comparison with previous data*

There have been no previous investigations of the life cycle of H. chevreuxi in the literature. However, H. chevreuxi has also been termed Herpetocypris agilis (Rome) (Henderson, 1990), although Fox (1964) concludes that they are separate species. Fox (1964) states that H. agilis differs from H. chevreuxi in the stepped arrangement of the spine groups on the furcal rami. A description of the development of H. agilis is given in Fox (1964), and shows that there are nine instars, eight juveniles and the adult.

The species has not previously been recorded in the Lake District.

3) *Summary*

It is difficult to draw conclusions concerning the life history of H. chevreuxi due to its limited distribution in the Lake District. However, the collections obtained from Barrow

Figure 7.4

Herpetocypris chevreuxi.

Development.

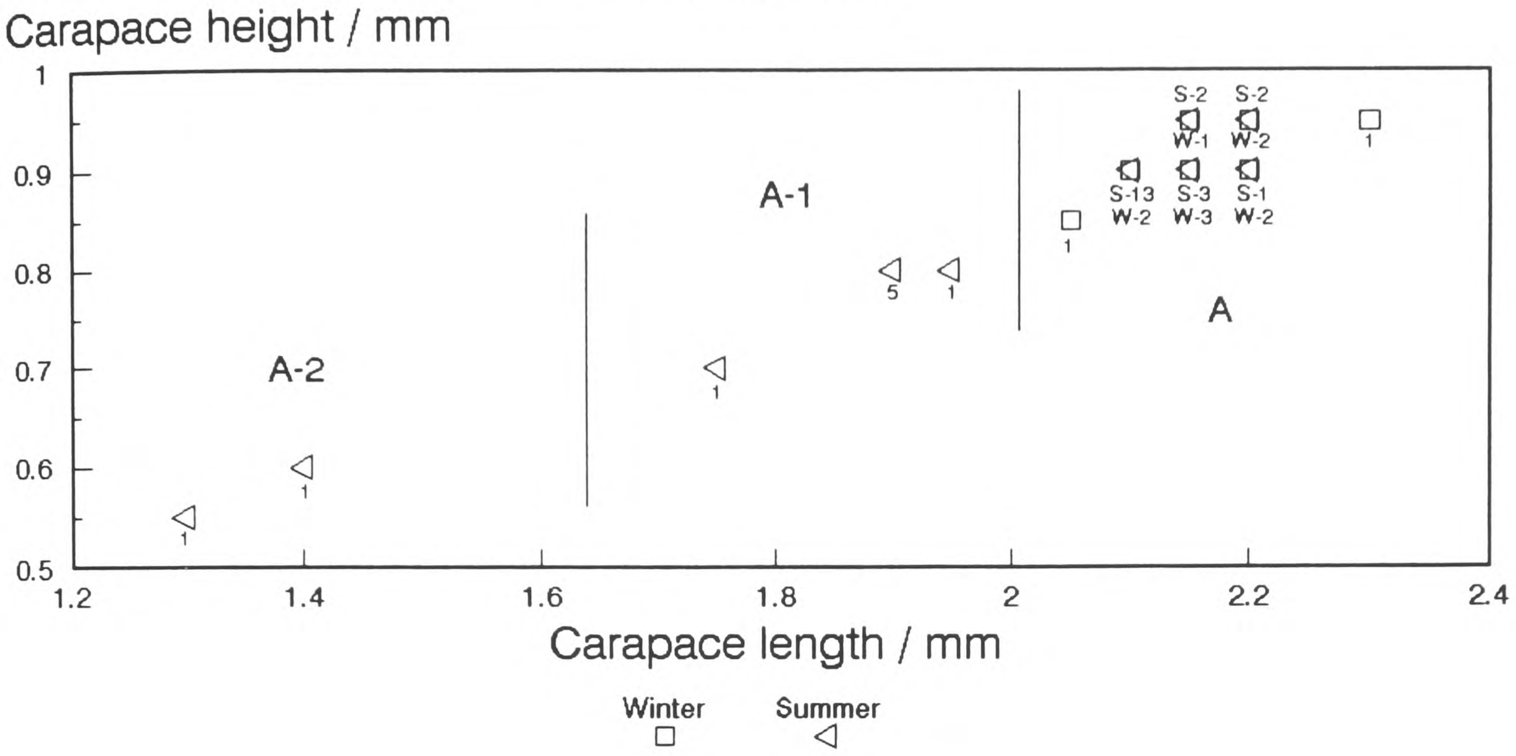
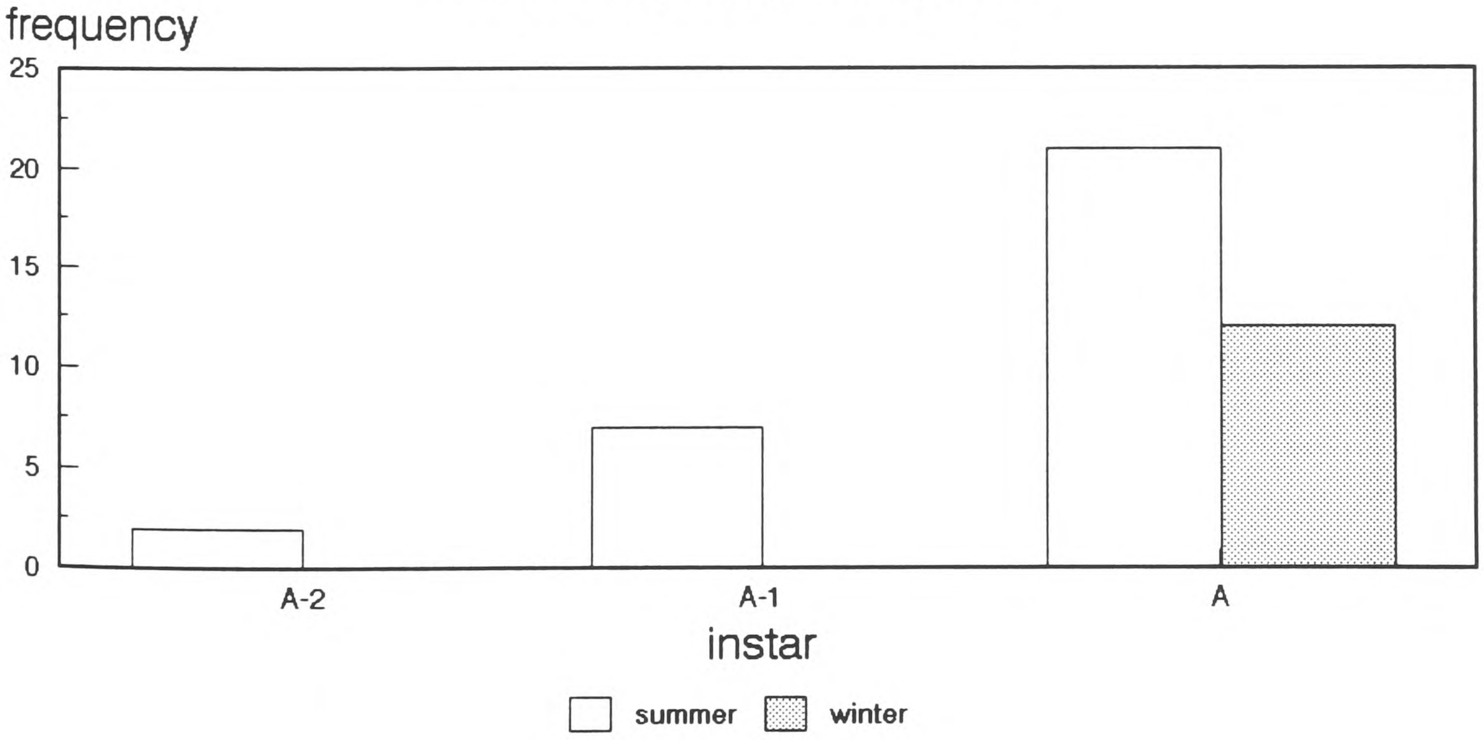


Figure 7.5

Herpetocypris chevreuxi

Instar frequency histogram



Plantation Tarn D show that all the developmental stages identified are more common in the summer period. As only the adults are present during the winter period, it seems that the species overwinters as the adult stage. As with H. reptans, the species may again be defined as eurychronal (Theisen, 1966).

7.6C - Metacypris cordata

1) *Population structure*

Both adult males and females show only two size classes (Figure 7.6), and it is apparent that the adult and last two juvenile stages have been sampled. Figures 7.6 and 7.7 indicate that adult males were collected in both sampling periods but were found to be more abundant during the summer sampling period. Adult females were rare in winter and overall abundance was lower than that of the male in both periods. This phenomenon will be discussed in Chapter 8. The quantity of adult females collected during the summer period, 237 from 6 localities, far outnumbered the isolated examples of females captured during the winter period, numbering 22 from just 2 localities. Late-stage juveniles were recorded throughout the year, greater densities occurring in summer.

2) *Comparison with previous data*

There is little work describing the life cycle of Metacypris cordata. A key feature of this species is brood care, the eggs hatching within the mothers carapace. Mallwitz (1981) recorded adult density at maximum in June decreasing to virtually zero around October. Only juveniles were present during the winter until April. Danielopol & Horne (pers. comm.) recorded only males and juveniles in an Austrian lake during October; early juveniles, males, and females with eggs were recorded during the previous July.

Figure 7.6.

Metacypris cordata

Development.

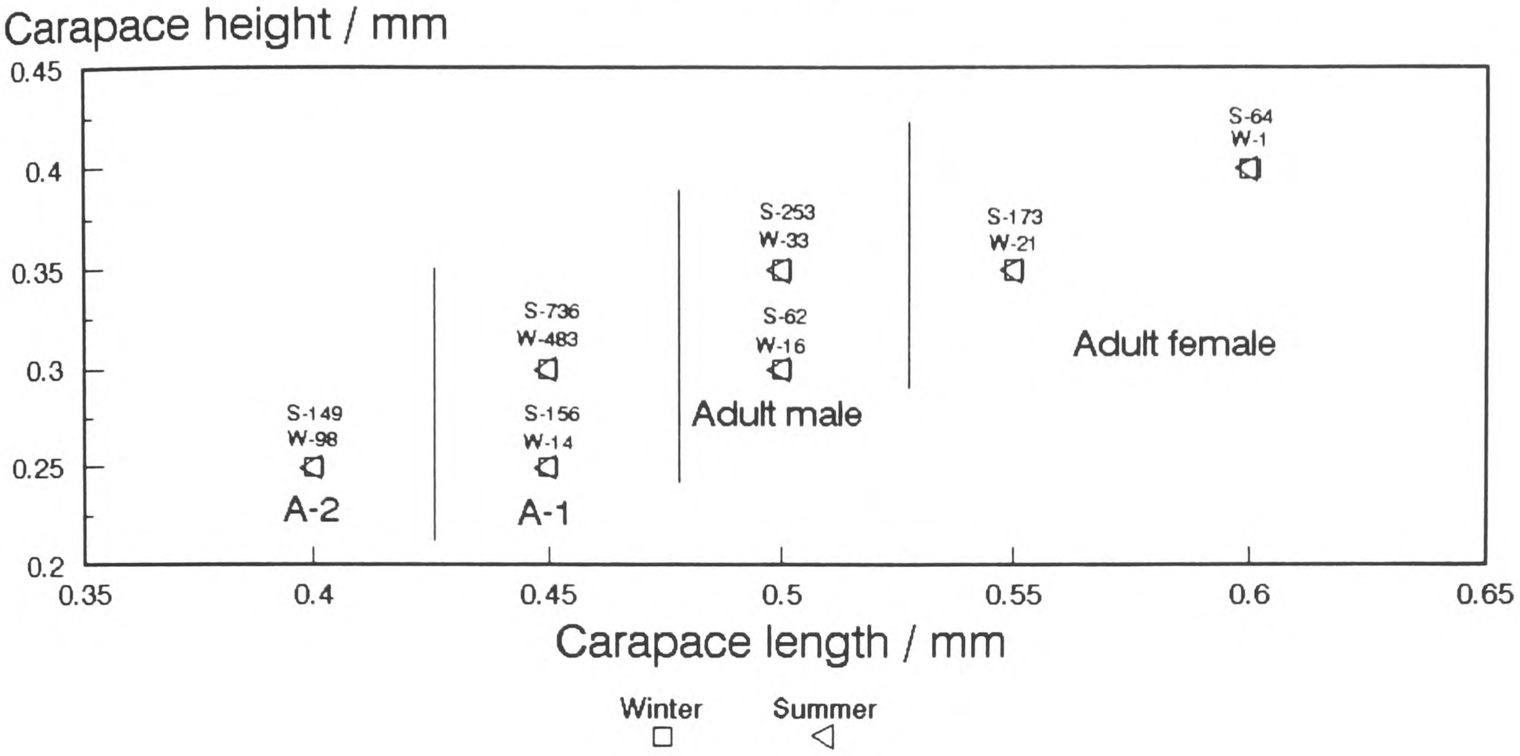
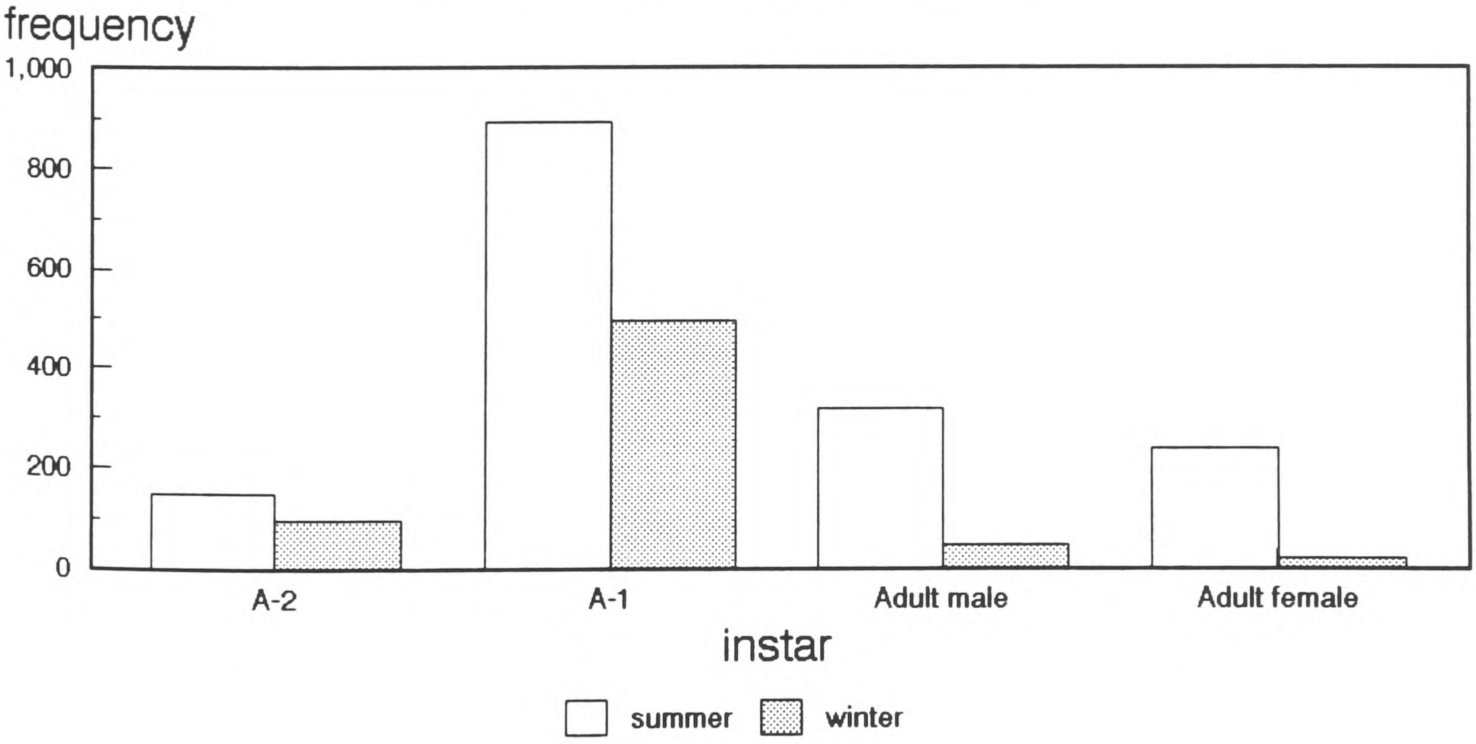


Figure 7.7

Metacypris cordata

Instar frequency histogram



3) *Summary*

Overall density of both sexes tends to decrease in the winter, especially that of the female. The development pattern for M. cordata may be described as eurychronal, there being a single generation per year, with reproduction occurring in the spring / summer.

7.6D - Candonopsis kingsleii

1) *Population structure*

Candonopsis kingsleii was only obtained from two sites, Rather Heath Tarn (Site 12) and Moss-Side Tarn (Site 17). Therefore, precise evaluation of the life history of the species is difficult. Figures 7.8 and 7.9 indicate that only the last two instars were collected from the two sites, the adult and the A-1 juvenile stage. However, only one A-1 specimen was collected during the summer sampling period, as opposed to 56 measured specimens in the winter. It appears that this species may be able to complete its entire life cycle during the winter period.

2) *Comparison with previous data*

The results from this study are in contrast to those found by previous workers in Germany. Here, adult density peaks in June-September (Hiller, 1972), or March-July (Scharf, 1988), juveniles being recorded from December to March (Hiller, 1972). Scharf's study (1988), which showed C.kingsleii to be the fifth most common species in the "Hordter Rheinaue" in Germany, suggested it had two or more generations *per annum*, the main population explosion occurring in early summer time. This species has not been previously recorded in the Lake District.

3) *Summary*

The data from this study suggest that this species has only one generation per annum in the Lake District, the entire life history occurring in winter. However, the low numbers of specimens obtained make this interpretation rather tentative. The

Figure 7.8.

Candonopsis kingsleii. Development.

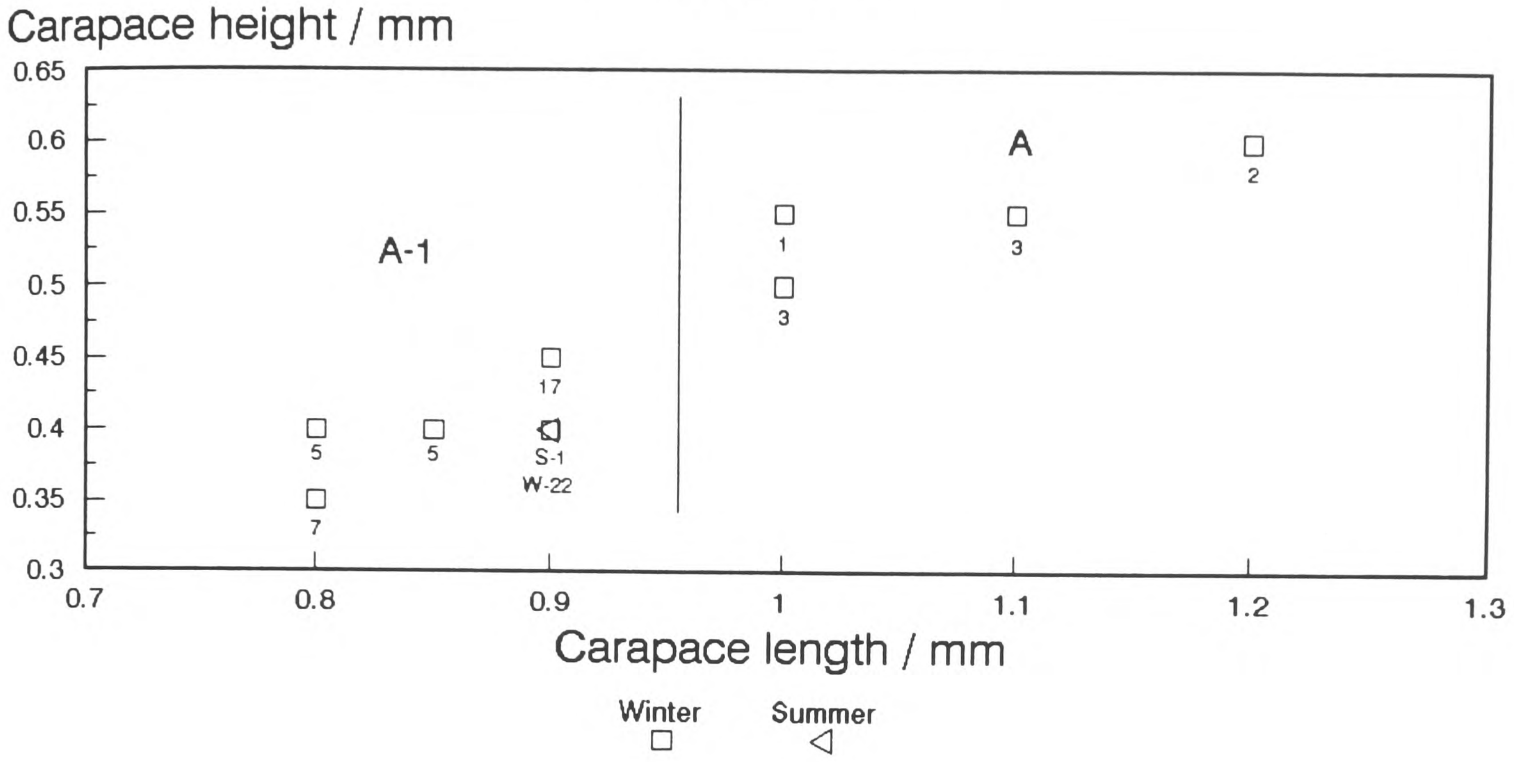
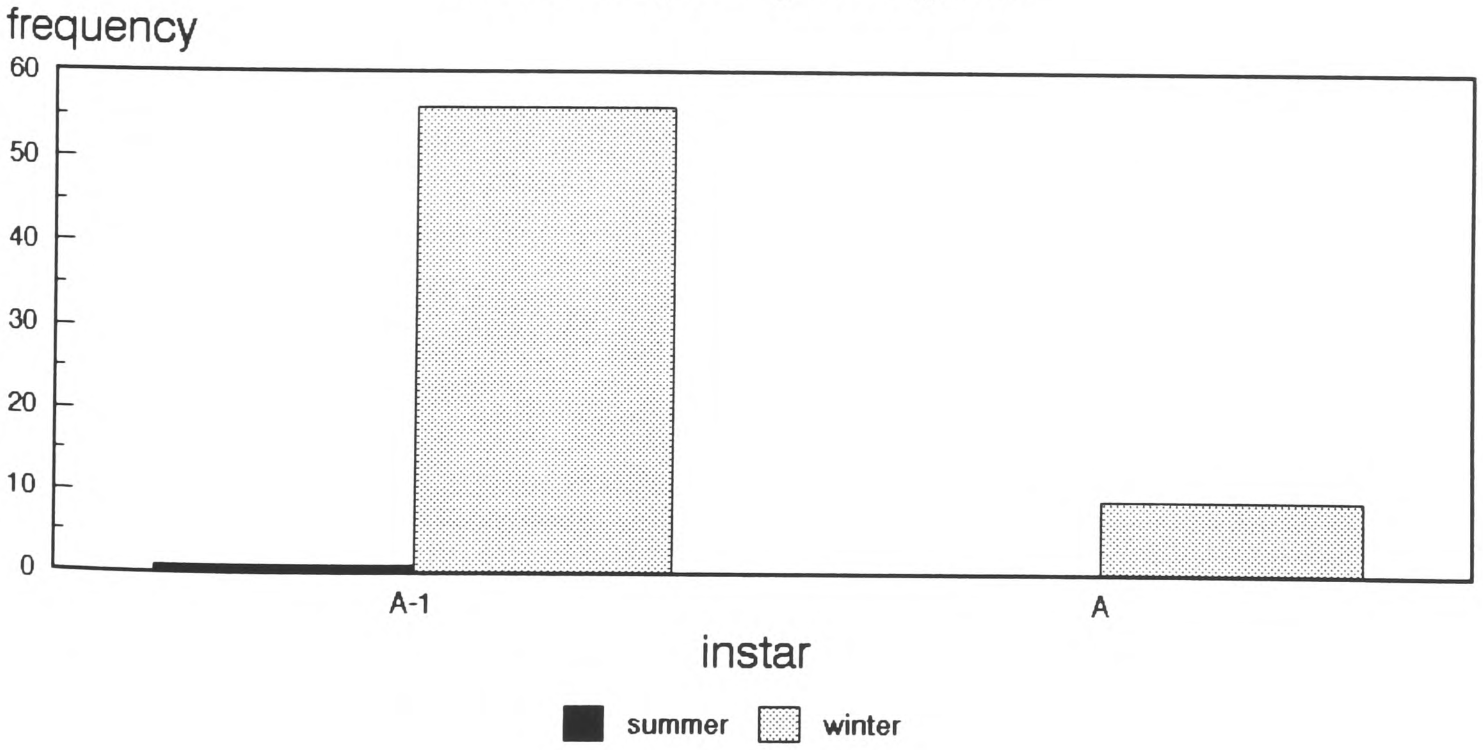


Figure 7.9

Candonopsis kingsleii Instar frequency histogram



species may be defined as stenochronal.

7.6E - Candona albicans

1) *Population structure*

As only a few isolated specimens of Candona albicans were collected from the Lake District, generalisations on the life history of the species are difficult. Specimens were found during both sample periods (Figures 7.10 and 7.11), but there was a tendency for the larger specimens (adult and A-1) to be found during the winter period, and earlier juvenile instars (A-2, A-3) to be collected in the summer.

2) *Comparison with previous data*

Adults of Candona albicans have been recorded between spring and autumn (De Deckker, 1979; Janz, 1983). Although this initially seems in contrast to the findings of this study, the low numbers of specimens collected in the Lake District should be taken into account. This species has been shown to differ from most members of the genus in that it has a post-embryonic development of 3-4 months as opposed to 2 months (Danielopol, 1980). Juveniles were recorded from Loughrigg Tarn in both March and August (Horne, 1988).

3) *Summary*

Lack of information makes conclusions on the development of this species within the Lake District difficult, although it appears there is only one generation *per annum*, adults occurring in the winter. The species may therefore be defined tentatively

Figure 7.10.
Candona albicans.
Development.

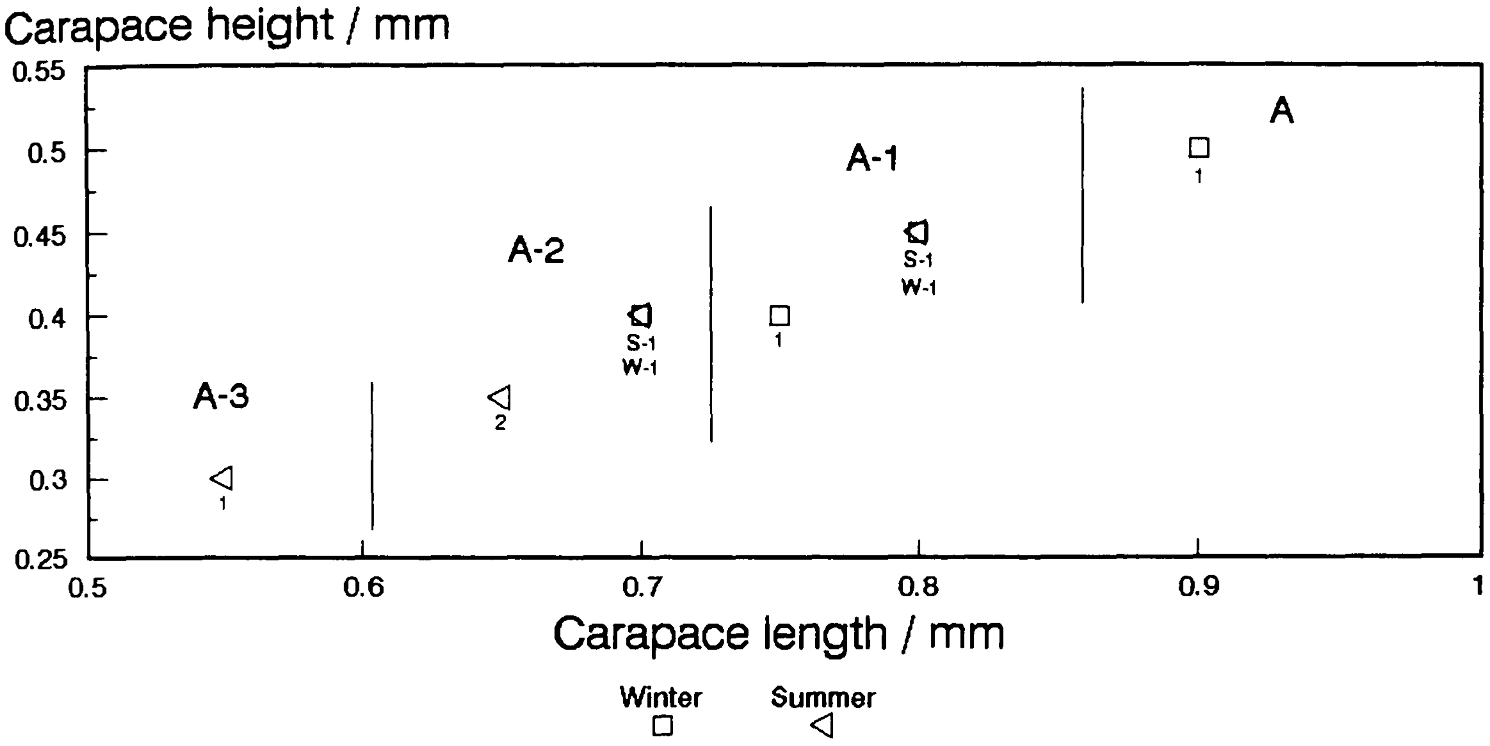
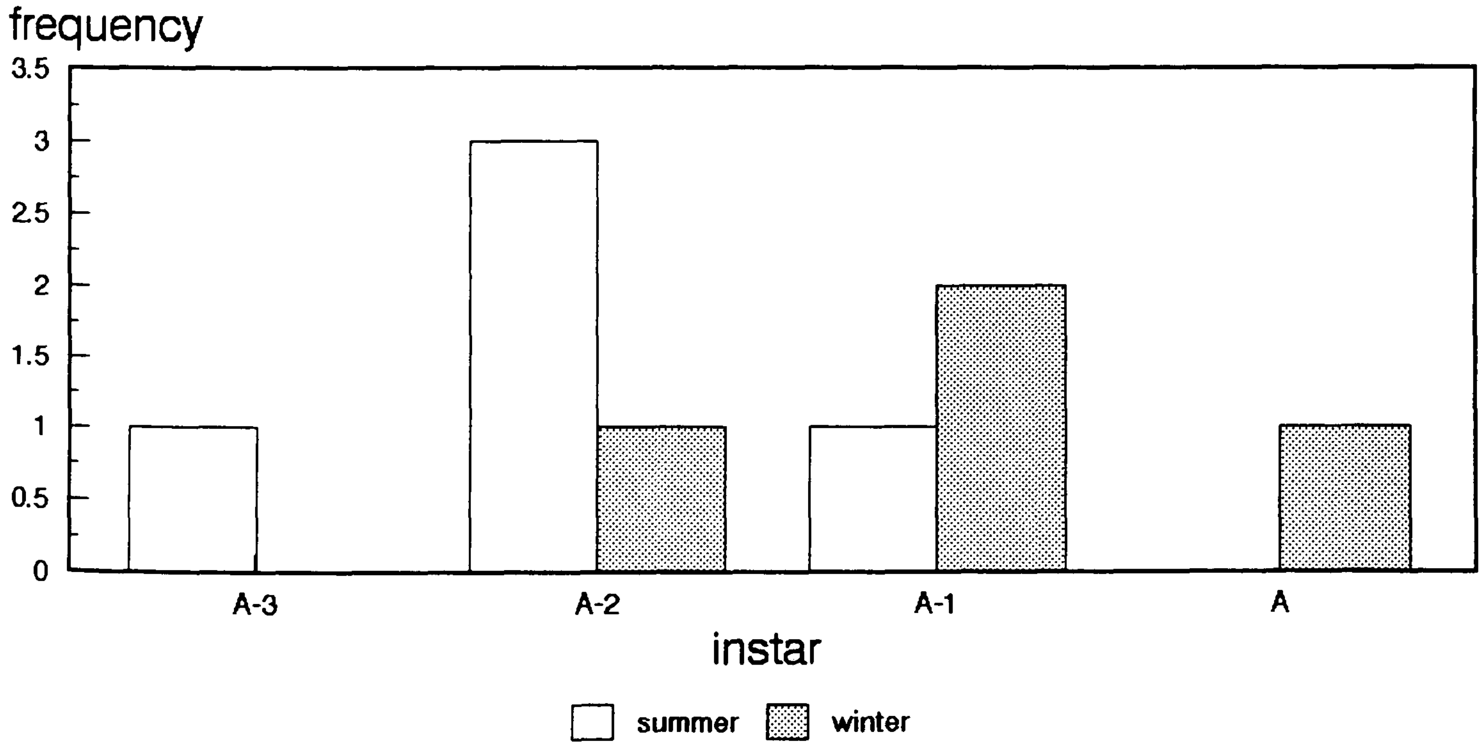


Figure 7.11
Candona albicans
Instar frequency histogram



as eurychronal.

7.6F - Candona candida

1) *Population structure*

Candona candida was collected during both sampling periods in appreciable densities. Figures 7.12 and 7.13 identify the adult stage and 5 juvenile stages. The plots illustrate a very noticeable trend: the larger specimens, the adult and A-1 and A-2 juvenile stages, are far more abundant during the winter than in the summer, whilst the earlier juvenile stages (A-3, A-4, A-5) dominate in the summer period.

2) *Comparison with previous data*

Reproduction in Candona candida is normally parthenogenetic, males being rare. Previous work is in agreement with the data obtained in the Lake District. Typically, there is one generation *per annum*. Adults develop during the autumn, deposit eggs in the winter and post-embryonic development occurs during the spring (Hiller, 1972; Scharf, 1988). Adults of the last generation disappear during the summer when the water temperature is above 18-20 °C and juvenile development then slows down, few specimens maturing during the summer months. At the beginning of autumn, post-embryonic development accelerates, resulting in the production of a large number of adults (Hiller, 1972; Scharf, 1988). This delayed development of the final moult has also been recorded in a brackish-water ostracod, Hirschmannia viridis (Horne, 1983). It was suggested that this strategy was possibly

Figure 7.12

Candona candida.

Development.

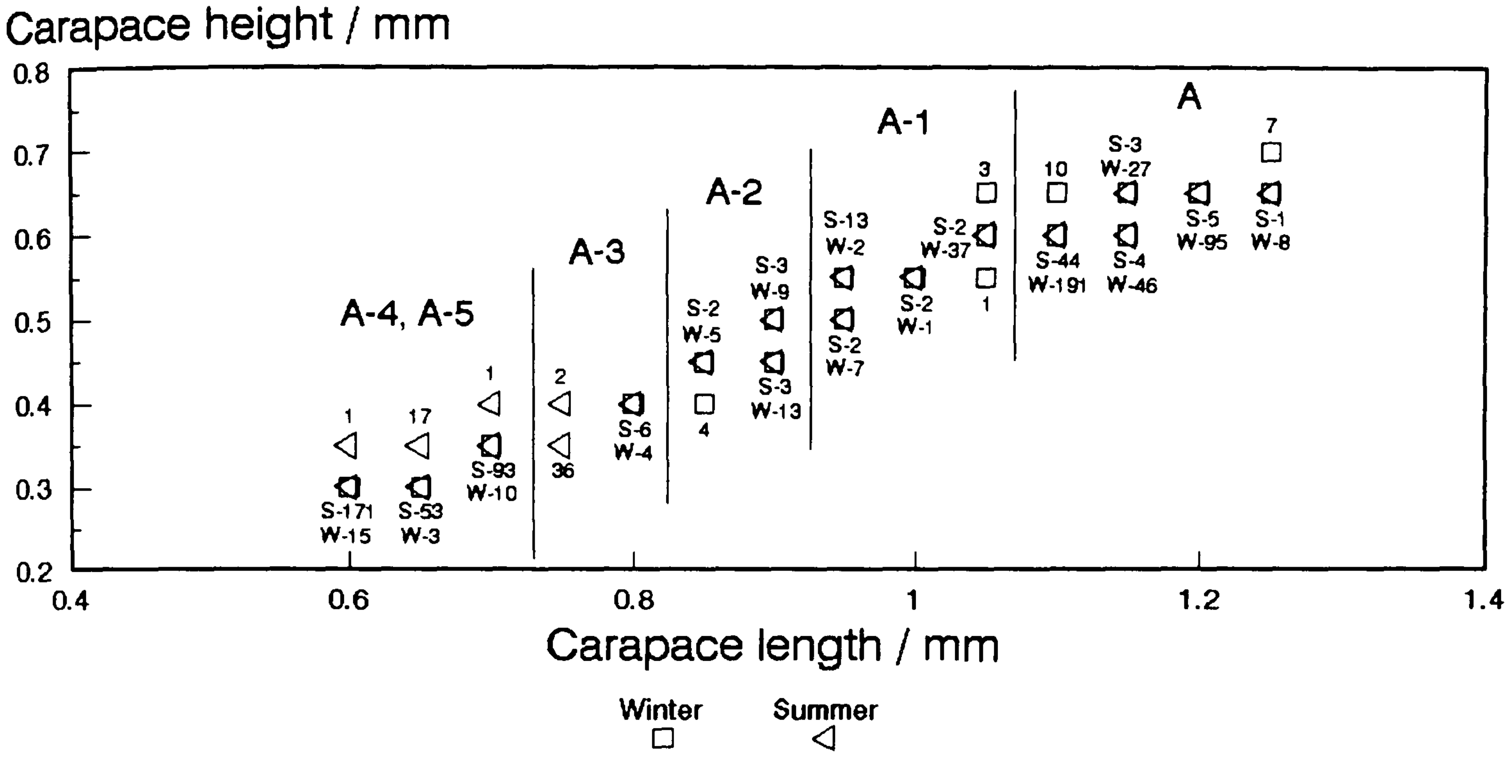
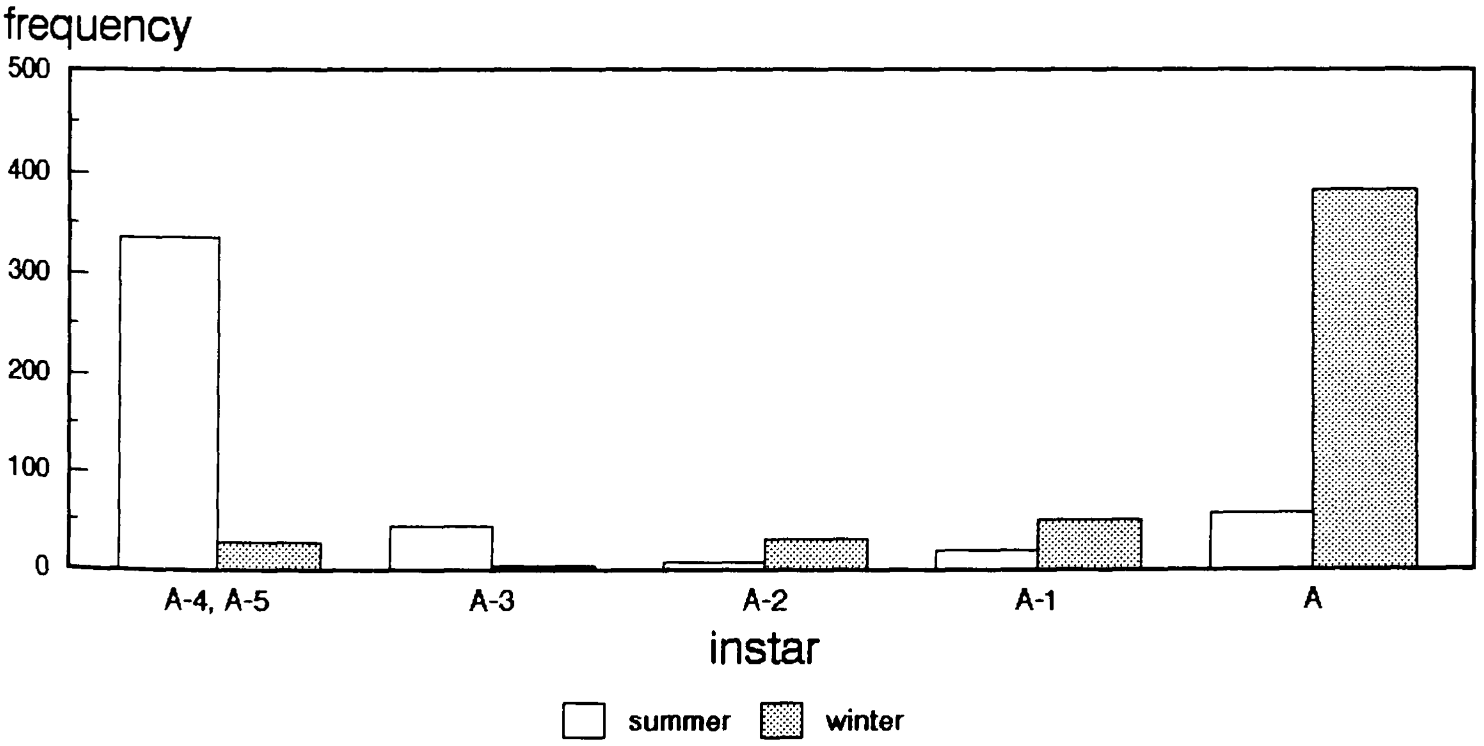


Figure 7.13

Candona candida.

Instar frequency histogram.



an adaptation enabling it to avoid competition with species that have their main reproductive effort in the summer. C. candida has been previously recorded as adults and juveniles in both summer and winter at several sites in the Lake District (Horne, 1988).

3) *Summary*

As with C. albicans, there is only one generation *per annum* of C. candida in the Lake District, adults being present in the winter. The species may, therefore, be defined as eurychronal.

7.6G - Candona fabaeformis

1) *Population structure*

Candona fabaeformis was found at three sites, Rather Heath Tarn (Site 12), Moss-Side Tarn (Site 17) and Boo Tarn (Site 75). Adult males and females were only found during the winter sampling period. Figures 7.14 and 7.15 identify 3 juvenile instars in the winter period, from the A-1 to the A-3 stage, while only single specimens of A-2 and A-3 instars were found in the summer. This species may be similar to Candonopsis kingsleii in its development, in that it survives as a winter species and goes through at least one generation during this period, although 2 juvenile specimens were collected in the summer period at Boo Tarn (site 75). In fact, C. fabaeformis was present at both sites from which C. kingsleii was collected.

2) *Comparison with previous data*

Adults have been reported in southern England in May-June (Henderson, 1990), although Hiller (1972) reports peak populations occurring in the winter period. Hiller (1972) also found that although peak larval density and peak overall density occur between November-March, adults are present between January and June. This species has not been previously recorded in the Lake District.

3) *Summary*

In the Lake District, C. fabaeformis appears to be predominantly a winter species. This is somewhat conflicting when compared to previous records, although it must be noted that the

Figure 7.14
Candona fabaeformis
Development.

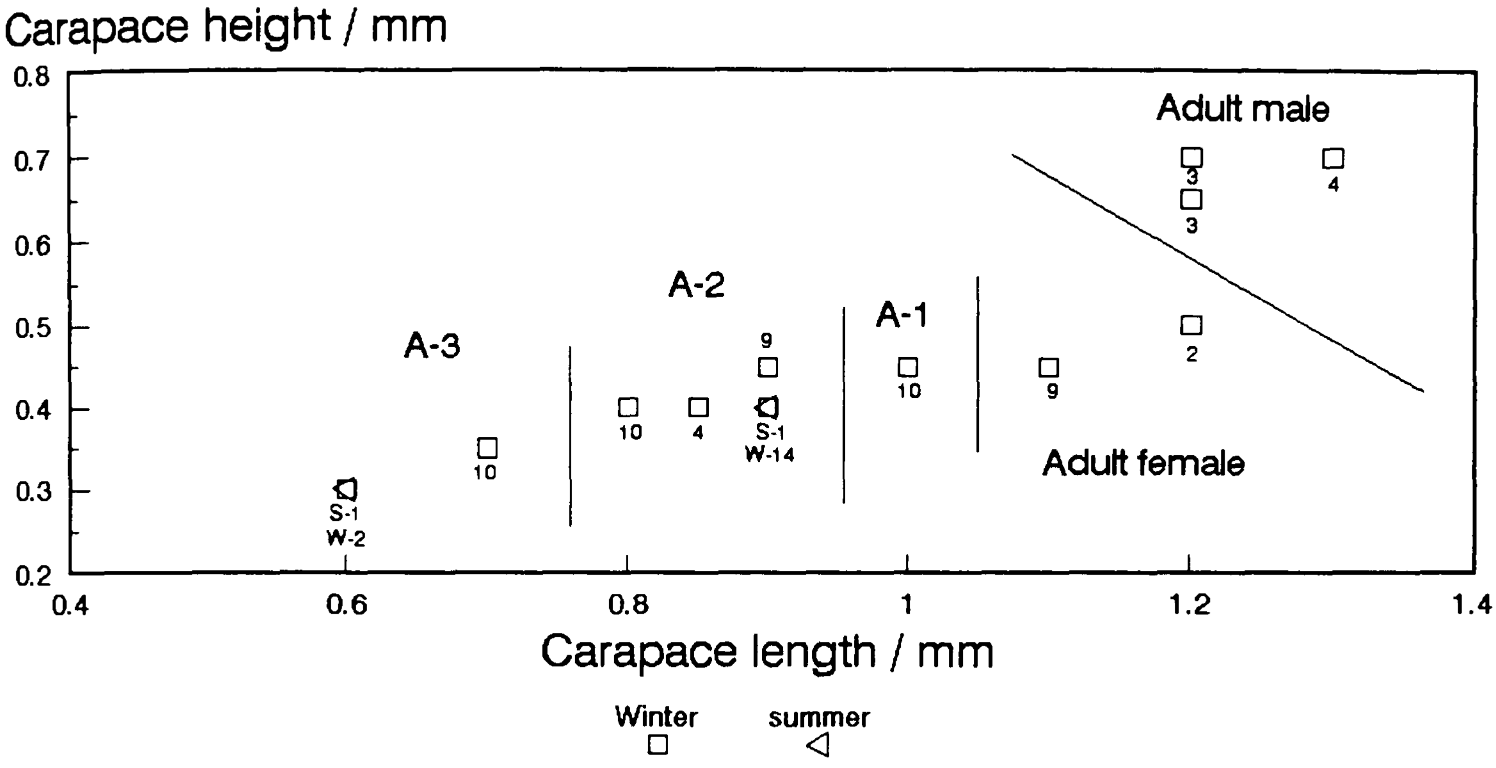
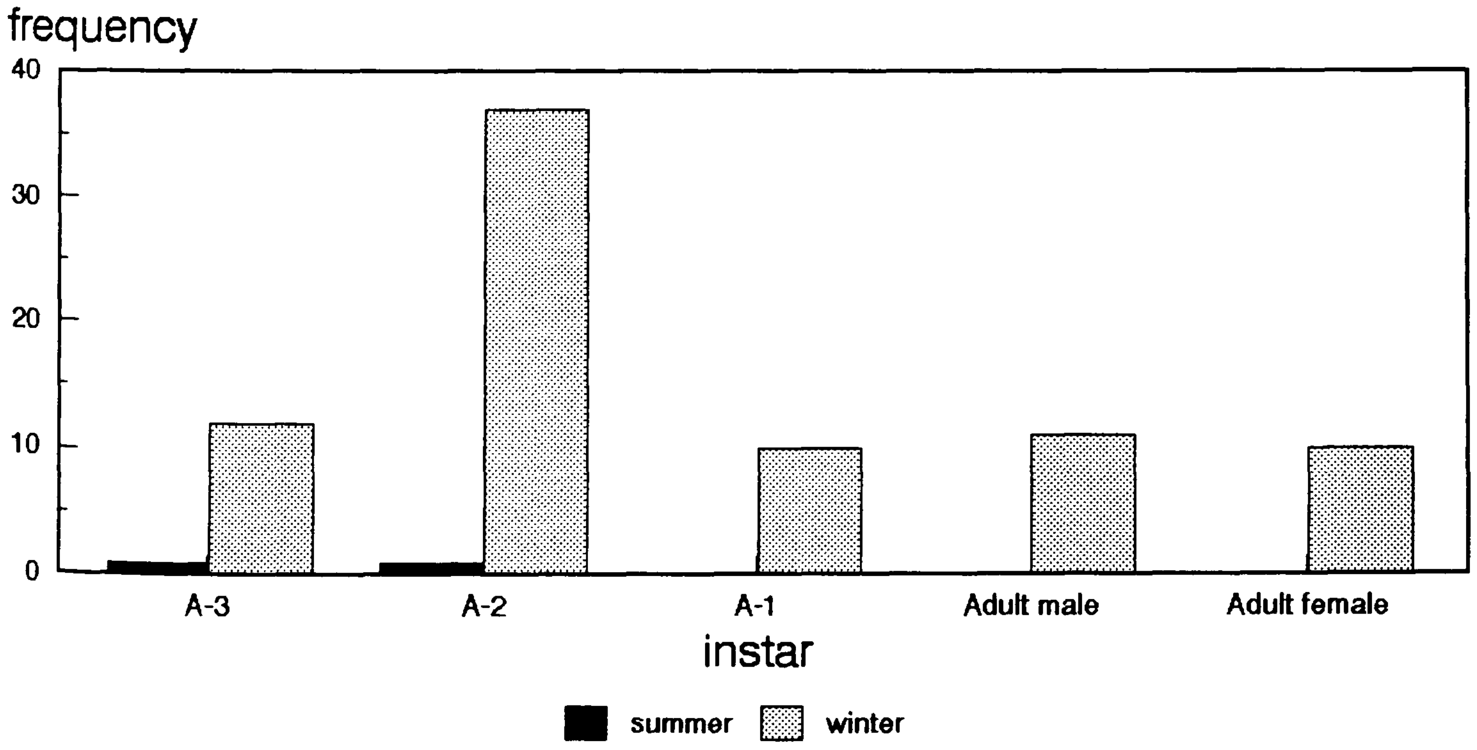


Figure 7.15.
Candona fabaeformis.
Instar frequency histogram.



effective sampling of only two periods, 'summer' and 'winter' may not be adequate for description of the life-cycle of this species. In this study, C. fabaeformis may be described as stenochronal.

7.6H - Candona neglecta

1) *Population structure*

Candona neglecta was taken only from the deep-water samples and is shown in Figures 7.16 and 7.17 to be represented by A-4 to adult instars of both sexes in winter. Density was lower in the summer, and apart from isolated A-3 and A-1 specimens, the species was mainly represented by adults during this period.

2) *Comparison with previous data*

Males are common and there is normally 1 generation *per annum*. Mature individuals are present during the winter, especially between January and April (Scharf, 1988; Henderson, 1990), and juveniles are present at other times, although in Germany, Janz (1983) found adults in May-August.

3) *Summary*

Overall, it appears that only in the winter is C.neglecta present in most developmental stages, and at this time, adult density is also greater.

This species shows a similar developmental pattern in the Lake District to that previously reported in the literature, and may be described as eurychronal.

Figure 7.16.
Candona neglecta.
Development.

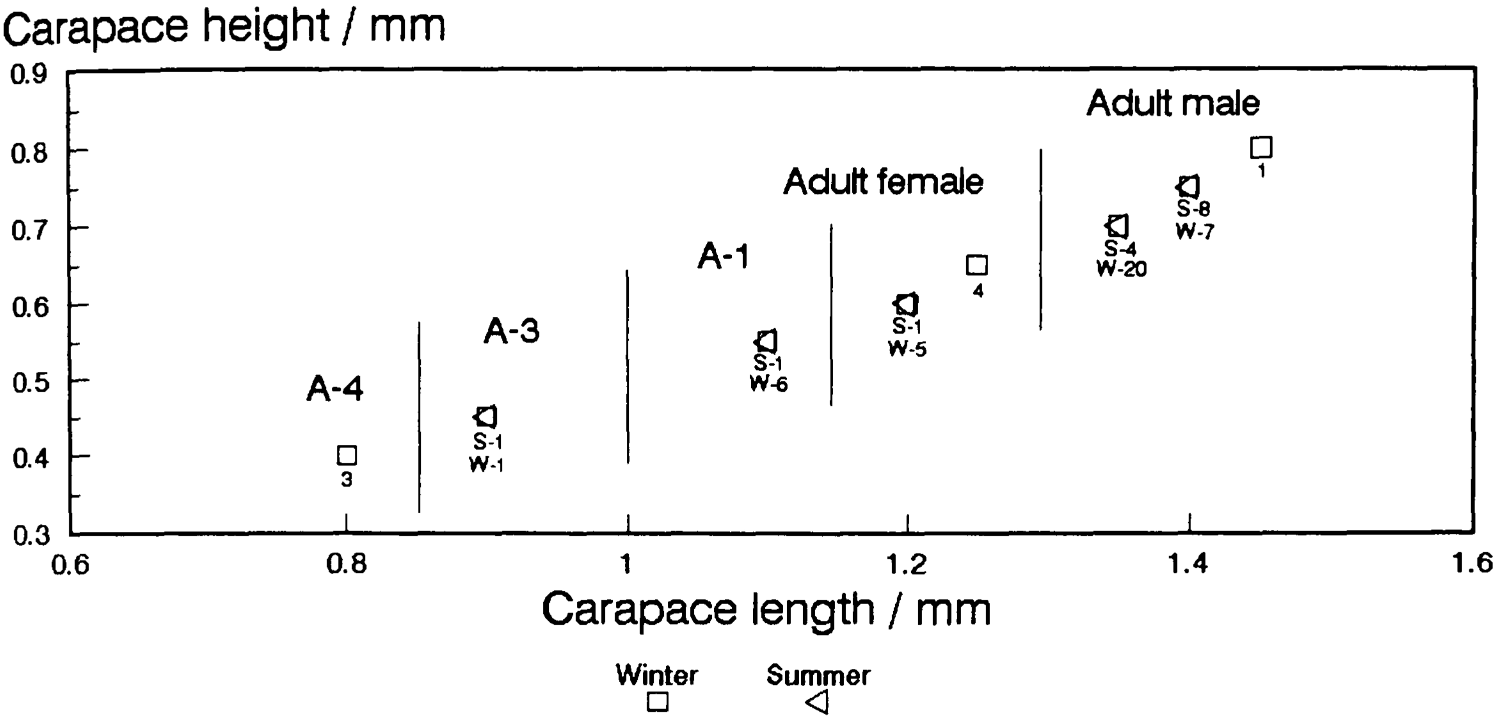
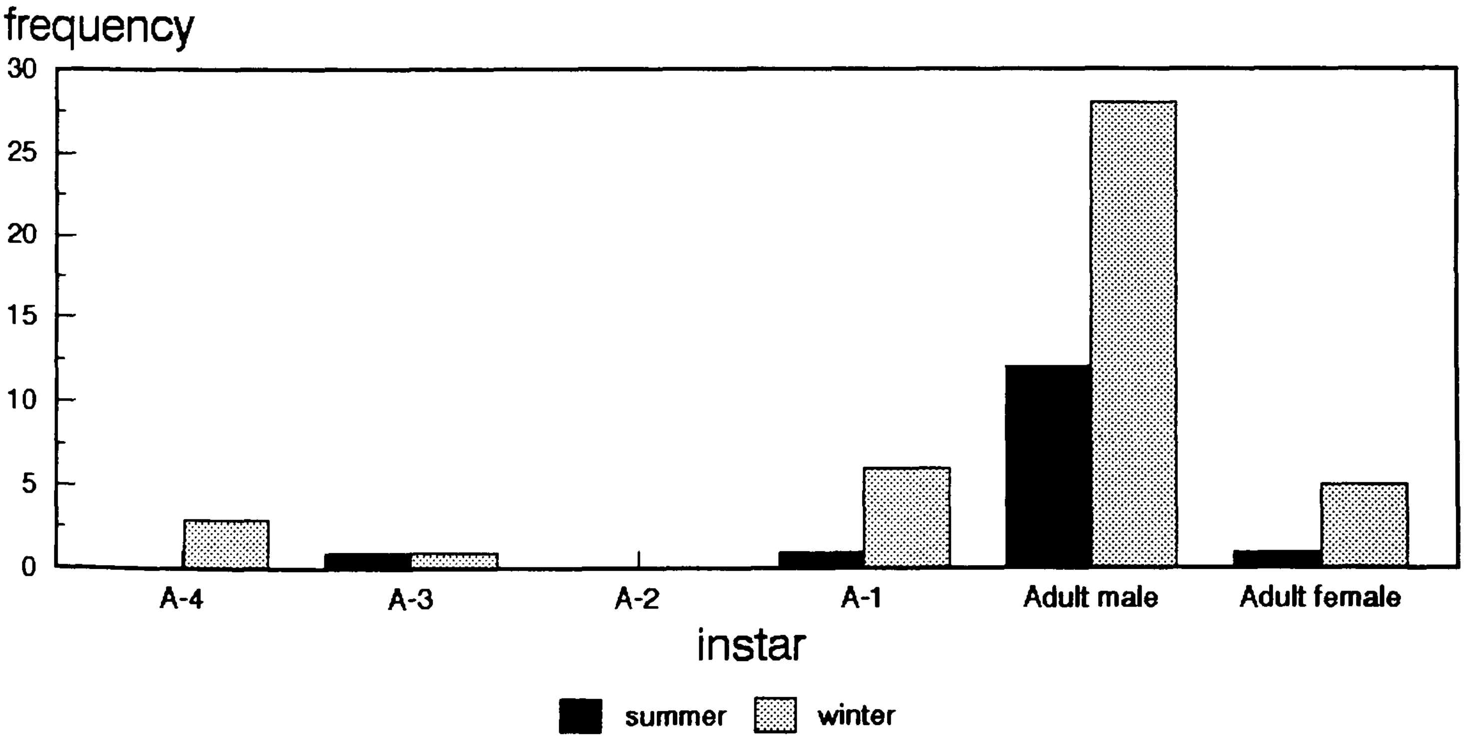


Figure 7.17
Candona neglecta
Instar frequency histogram.



7.6J - Candona rostrata

1) *Population structure*

Specimens of C. rostrata were found throughout the year from adult to A-4 instars (Figures 7.18 and 7.19). The species is slightly more numerous in summer than in winter, most instars being present during both periods, although considerably larger numbers of young juveniles were collected during the summer period.

2) *Comparison with previous data*

There are few previous records describing the development of C. rostrata. The only data are those of Horne, (1988) who records adults from Loughrigg Tarn in the Lake District in August.

3) *Summary*

This species appears to differ from other members of the subfamily in that adult density was similar in both sampling periods but there were more juvenile stages in the summer. However, the species is present throughout the year and may be said to be eurychronal.

Figure 7.18

Candona rostrata.

Development.

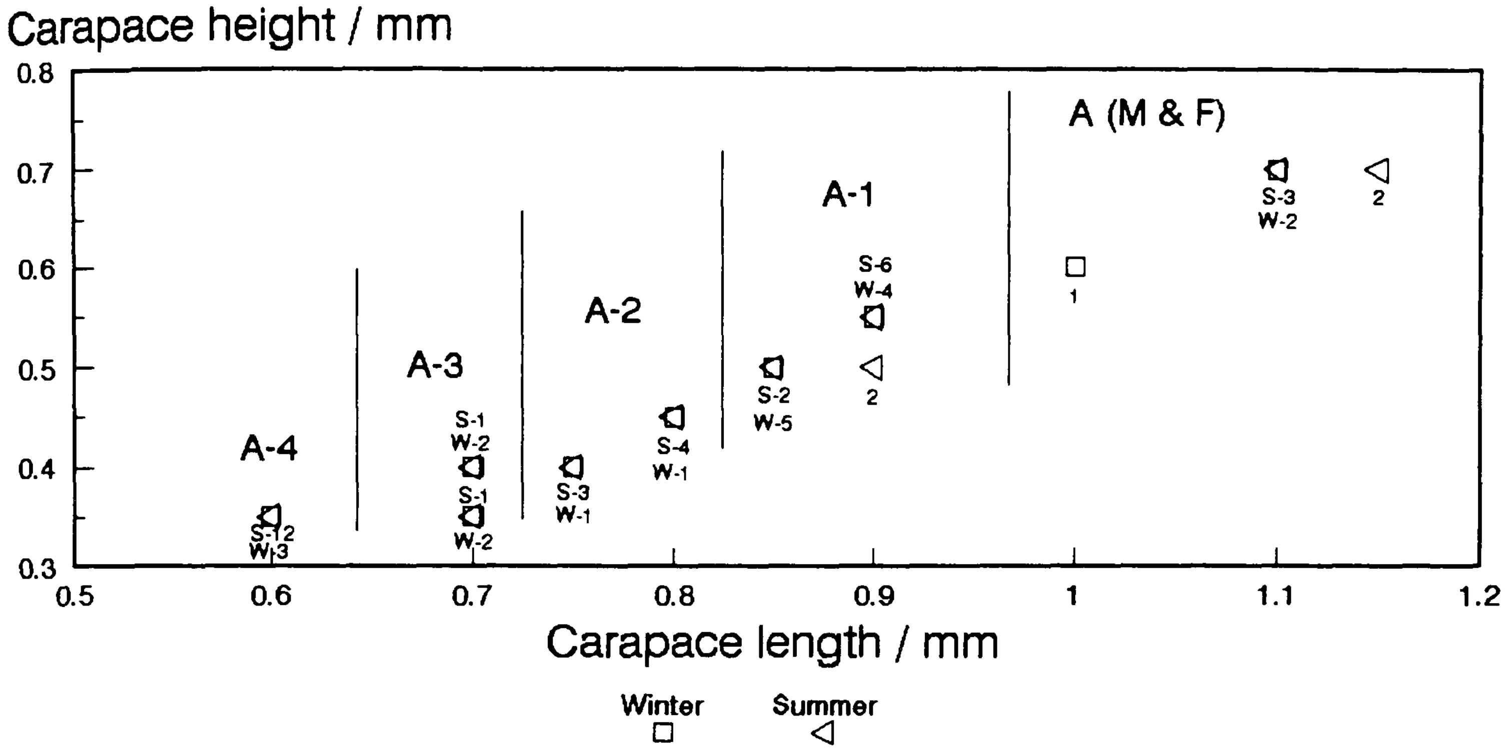
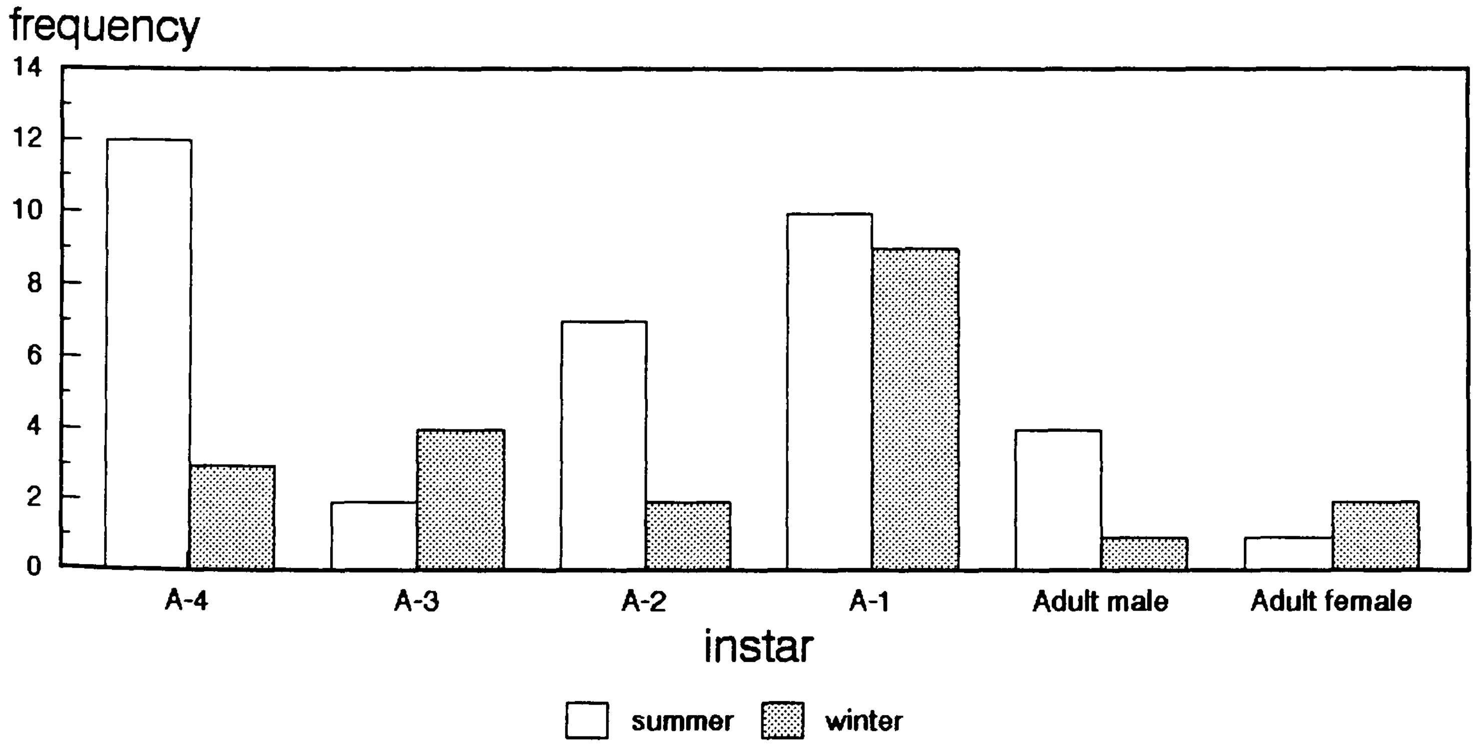


Figure 7.19.

Candona rostrata.

Instar frequency histogram.



7.6K - Candona siliquosa

1) *Population structure*

Figures 7.20 and 7.21 indicate that C. siliquosa is predominantly a winter species, as only a single A-1 specimen was available for measurement from the summer period. The low numbers of this species make division of the data into developmental instars a difficult procedure, although there does seem to be a size range possibly varying from the A-4 juvenile instar to the adult in the winter.

2) *Comparison with previous data*

Data for Candona siliquosa are very scarce, as this species has only been recorded from Great Britain. Henderson (1990) states that males are very rare and females can be found all year round. Horne (1988) records the species in the Lake District at Brotherswater (where it was not collected in this investigation) in September and March, and in an unnamed tarn near Rosthwaite Farm (SD 405933) in April. In this study, all stages were rarely recorded in the summer months.

3) *Summary*

The data suggest that C. siliquosa has only one generation *per annum*. The lack of specimens in the summer collections indicate that the life cycle is shorter for this species than most other members of the genus, in that development is completed within the winter months, as with C. kingsleii and C. fabaeformis. It may be described as stenochronal.

Figure 7.20.

Candona siliquosa.

Development.

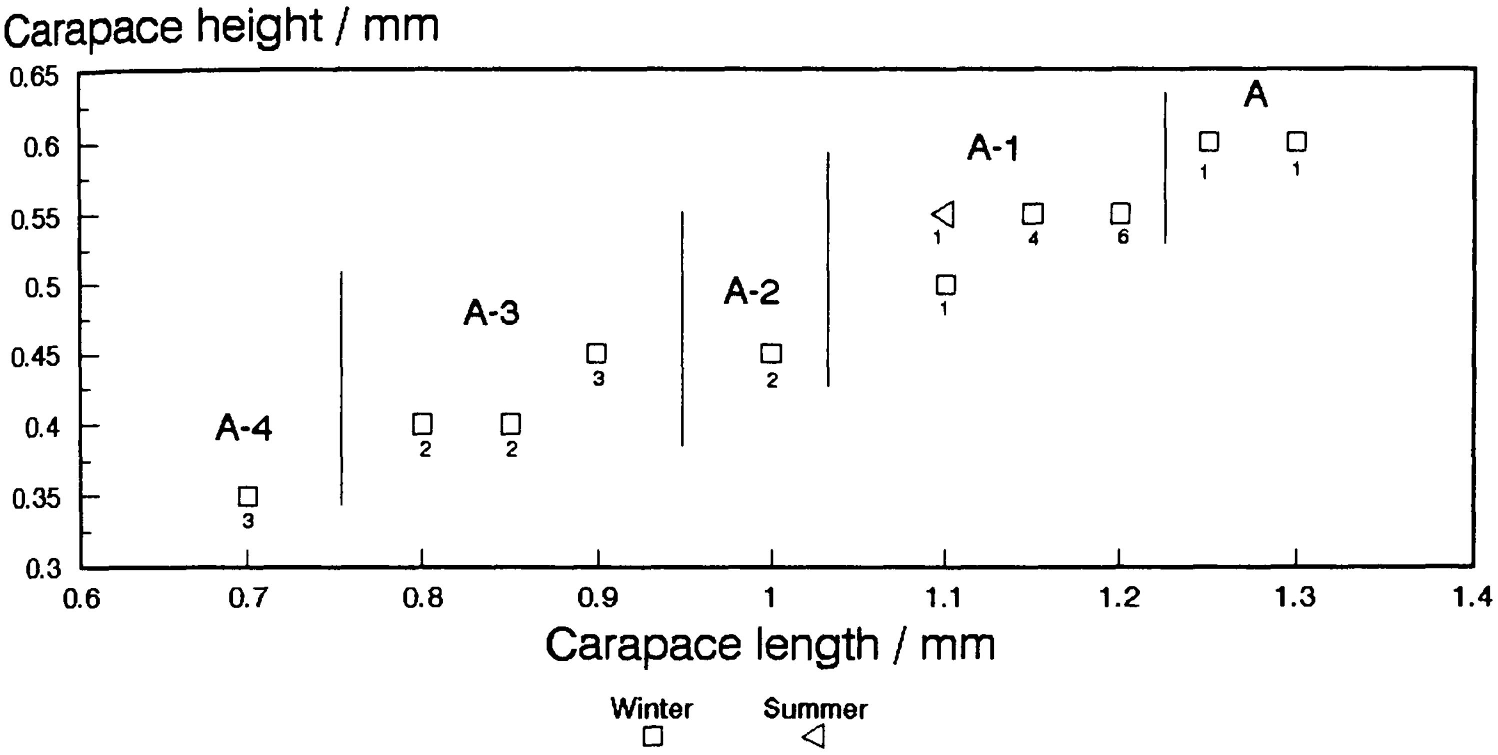
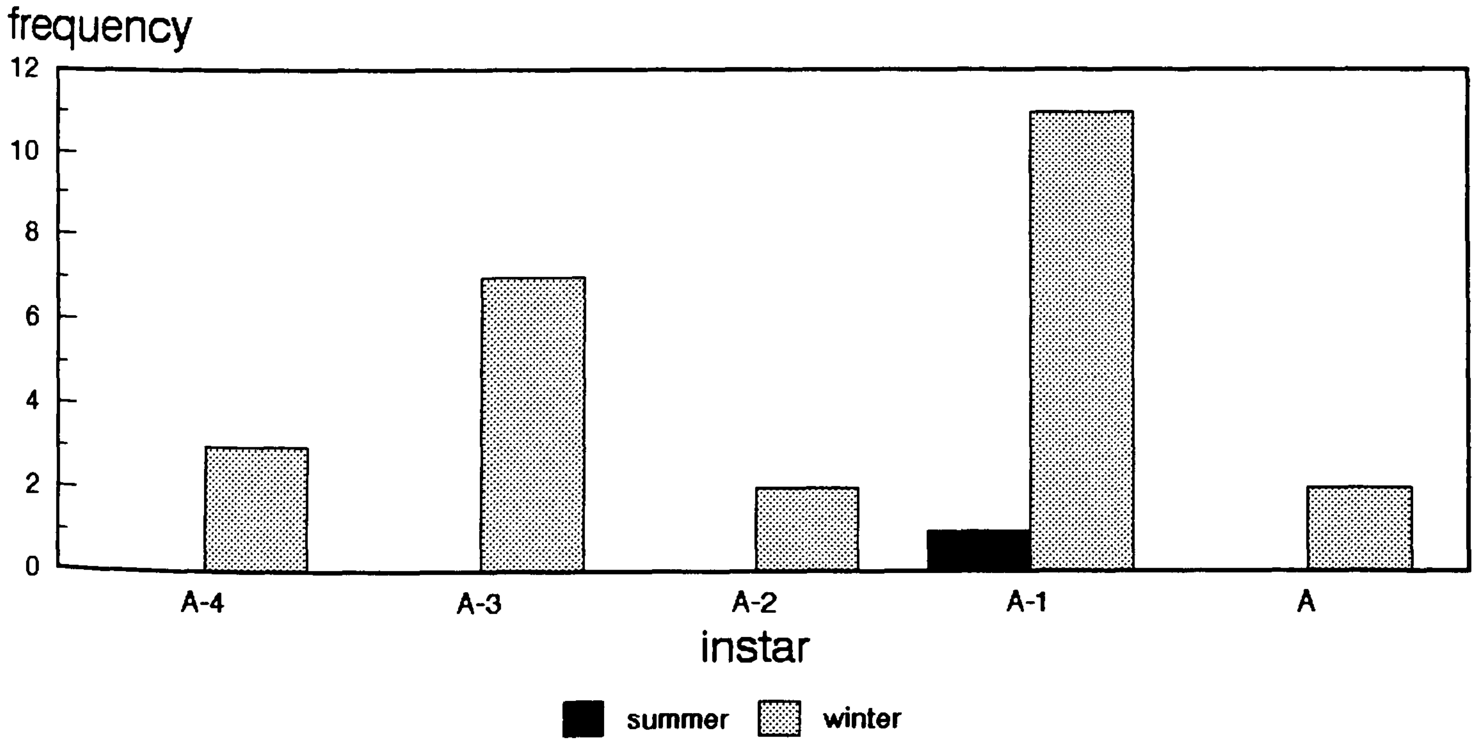


Figure 7.21.

Candona siliquosa.

Instar frequency histogram.



7.6L - Candona reducta

1) *Population structure*

Candona reducta is represented by juveniles and adults in both winter and summer (Figures 7.22 and 7.23), although adults are more abundant in the winter than in the summer. The quantity of young A-4 juveniles in the winter period (2) is lower than that recorded in the summer period (11).

2) *Comparison with previous data*

There is little previous information on the development of C. reducta. The only information available is that of Horne, (1988) who recorded it throughout the year in April, September and December at Gummer's Howe in the Lake District.

3) *Summary*

The data suggest that there is one generation *per annum*, juveniles being present in the summer and developing into adults in the winter, although as the data are limited, it is possible that there may be continuous reproduction throughout the year. Therefore, the species may be described as eurychronal.

Figure 7.22.
Candona reducta.
Development.

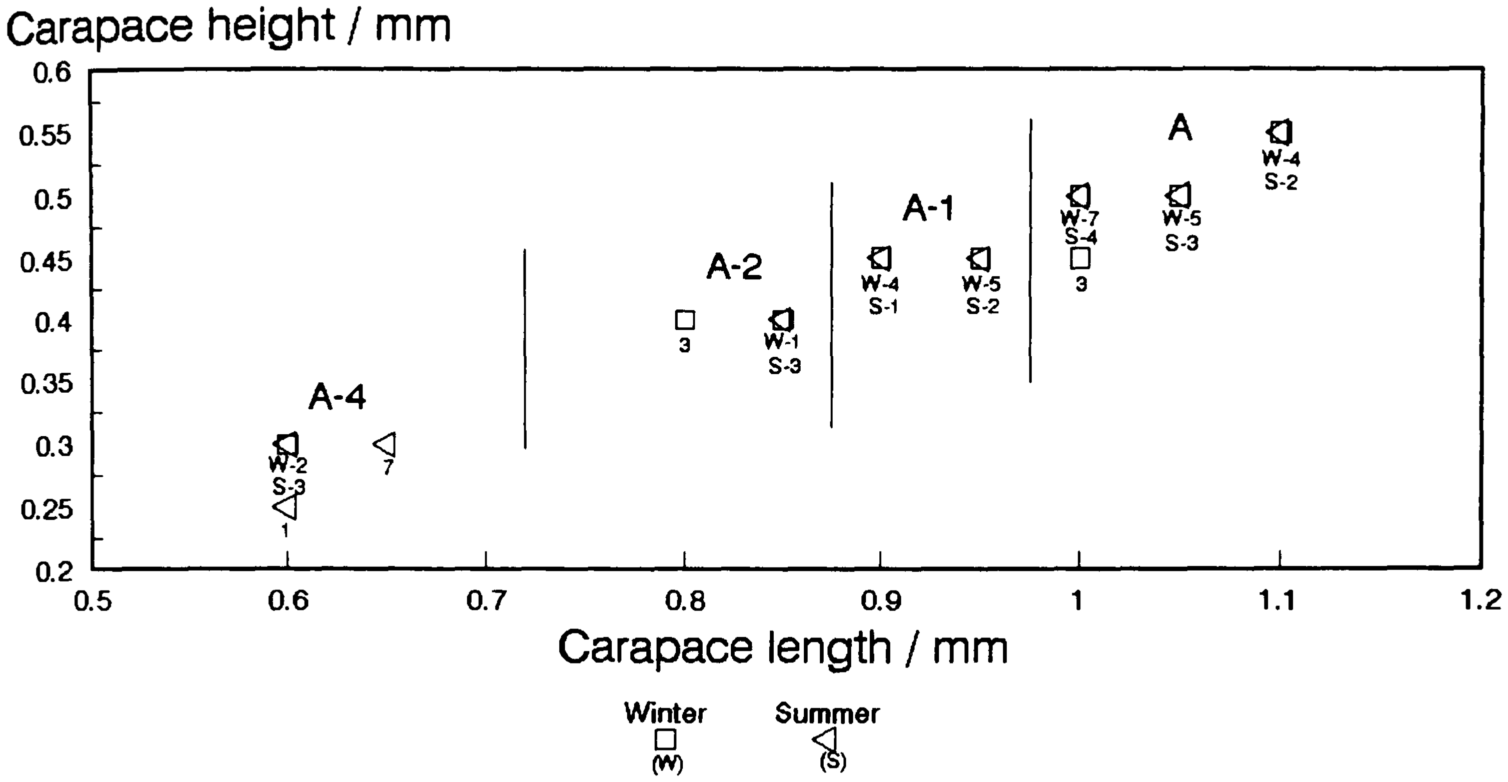
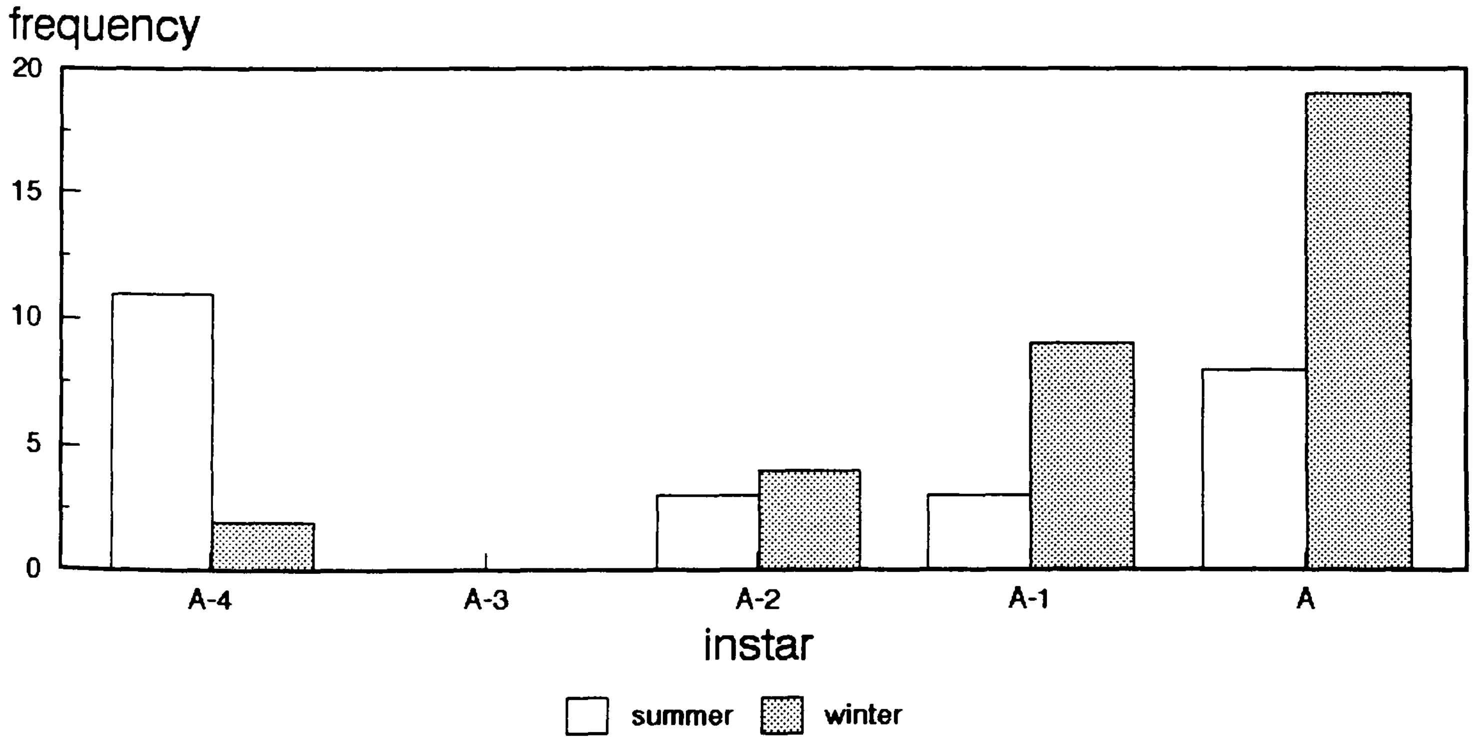


Figure 7.23.
Candona reducta.
Instar frequency histogram.



7.6 M - Candona vavrai

1) *Population structure*

An almost identical life cycle pattern to that of C.reducta is exhibited by the closely related C. vavrai (Figures 7.24 and 7.25). Adults and late stage (A-1) juveniles dominate in the winter period, and early stage A-3 juveniles dominate in the summer.

2) *Comparison with previous data*

There is little previous information on the development of C. vavrai. Horne (1988), recorded adults in March, April and December in the Lake District.

3) *Summary*

The data suggest that there is one generation *per annum*, juveniles being present in the summer and developing into adults in the winter. Therefore, the species may be described as eurychronal.

7.7 - Conclusions

In summary, all members of the subfamily Candoninae show similar developmental strategies in the Lake District. Adult density usually peaks in the winter, juvenile density is usually at its greatest during the summer, and there is one generation *per annum*. Three species especially, C. kingsleii, C. fabaeformis and C. siliquosa, are all very poorly represented in the summer months, just isolated specimens of each species being found.

At this stage, one important point should be considered.

Figure 7.24.
Candona vavrai.
Development.

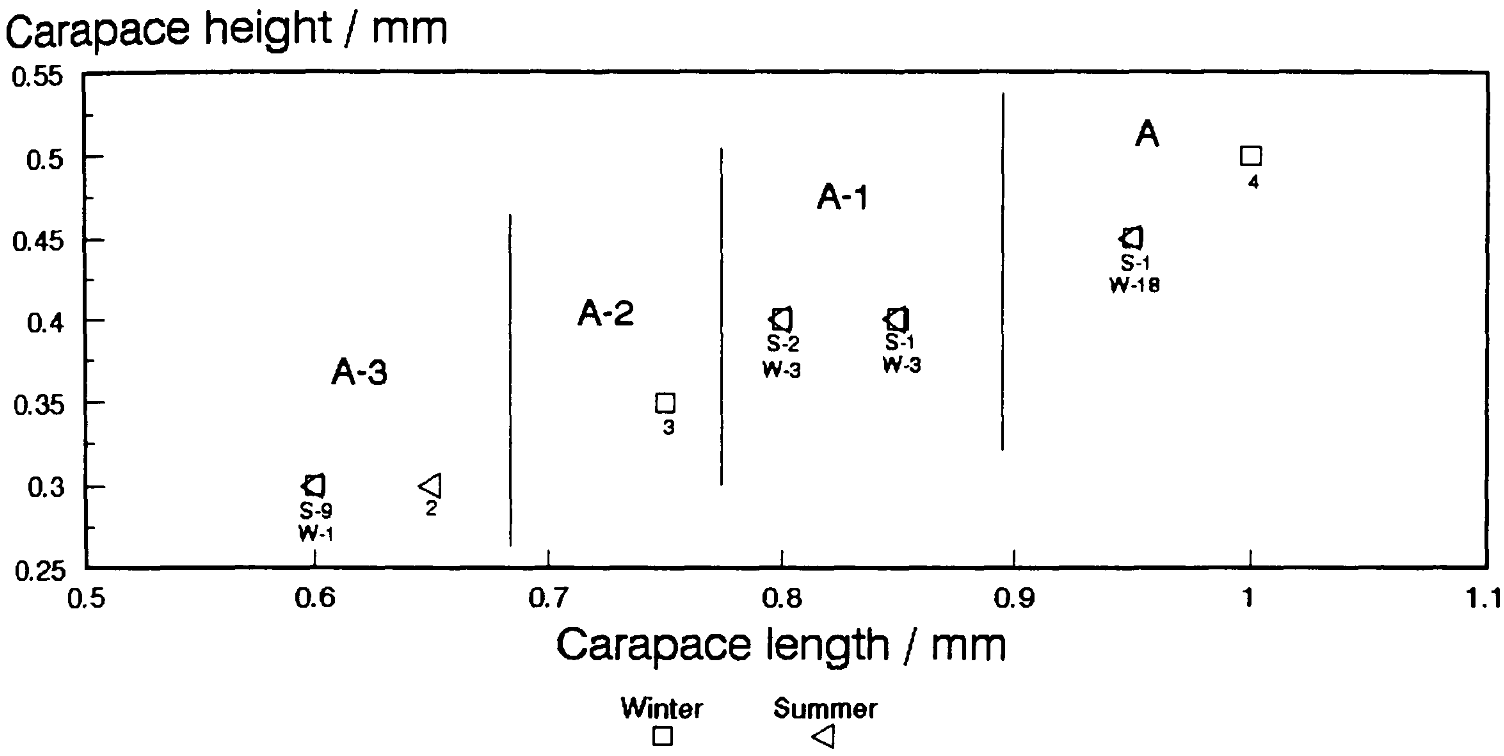
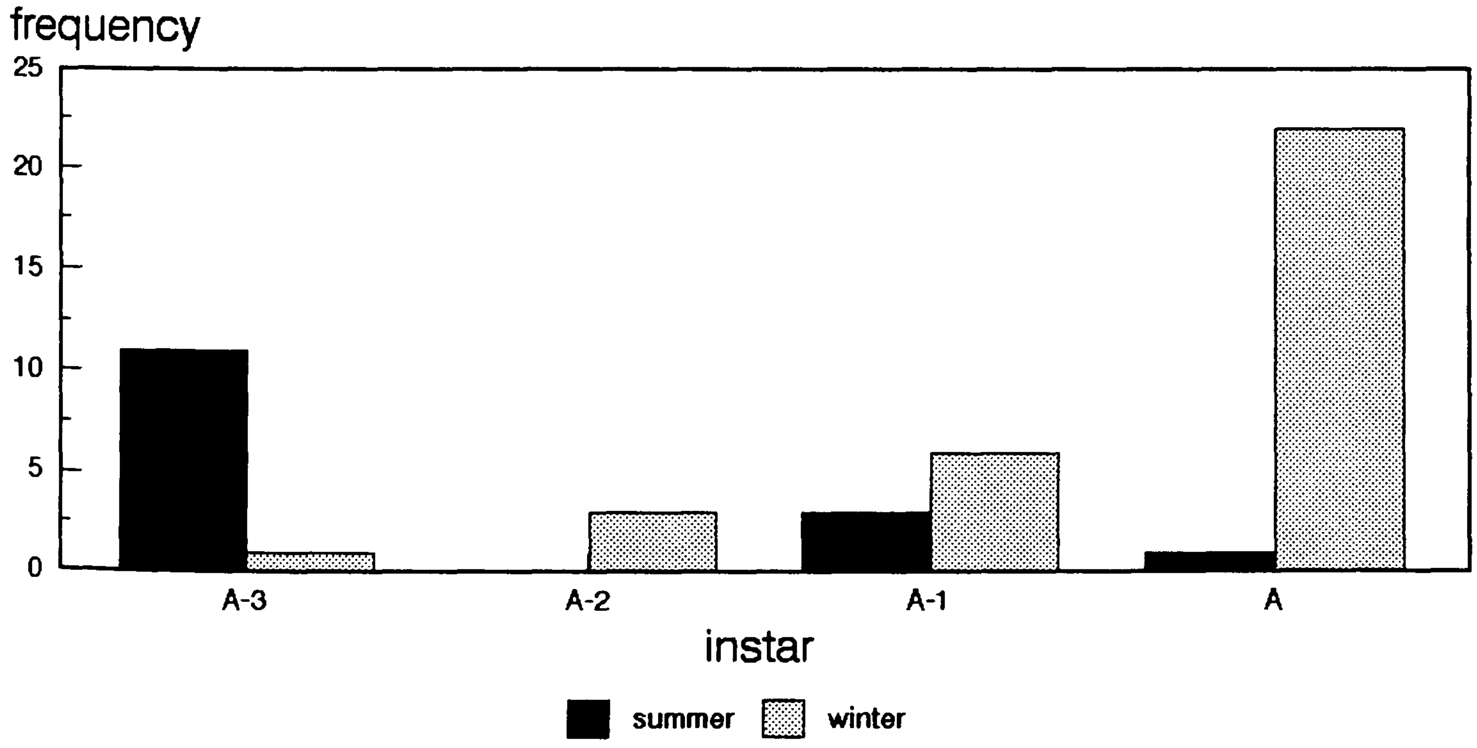


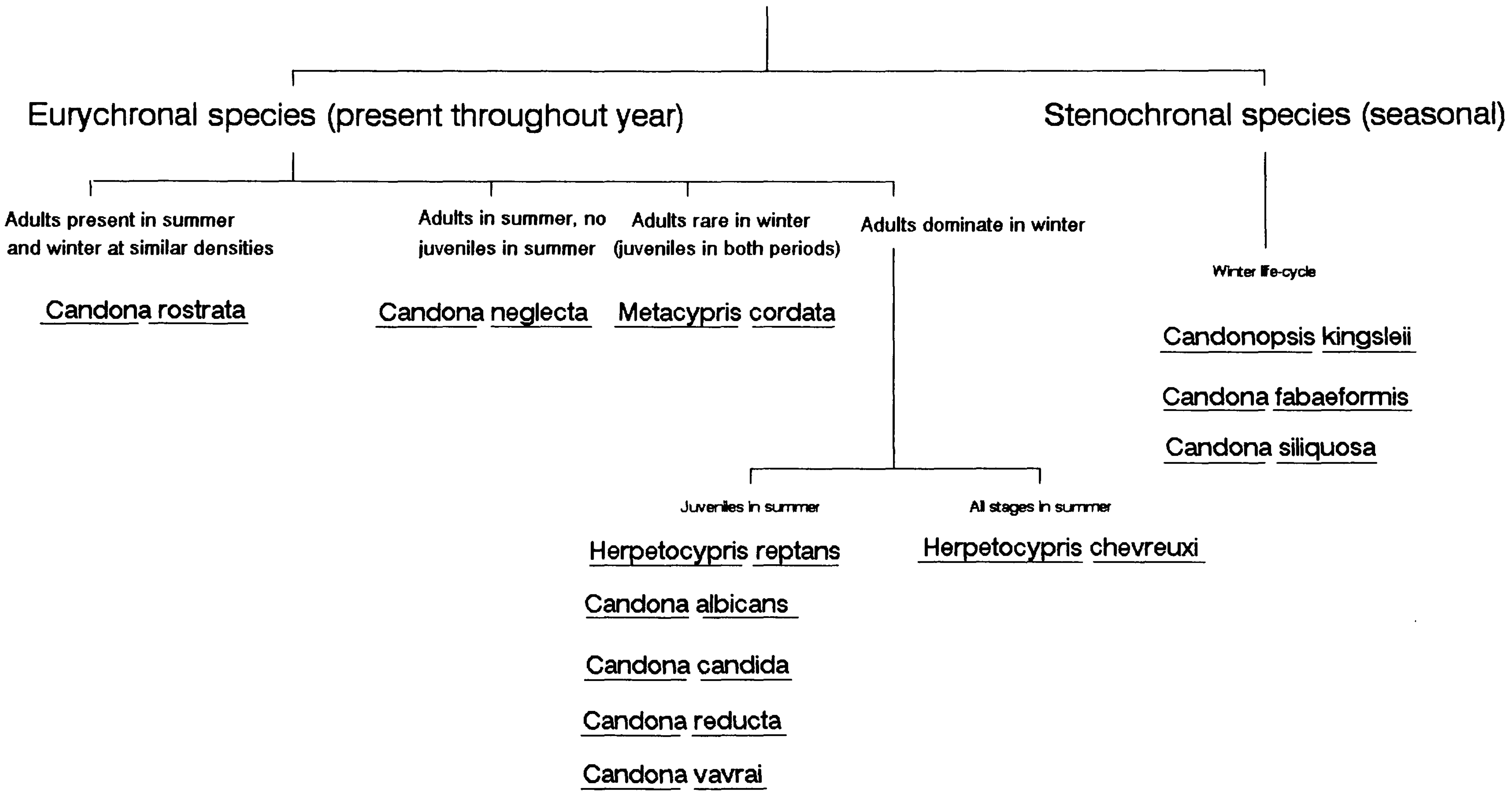
Figure 7.25.
Candona vavrai.
Instar frequency histogram.



Specimens of any species discussed in this chapter were rarely recorded at sizes of less than 0.4mm. This was not due to these size ranges not being collected during the sampling period, but due to decalcification of the valves in the alcohol. Some adults also were subject to decalcification, especially those from waters poor in dissolved cations such as calcium and magnesium which are used to calcify and strengthen the valve walls (Benson, 1981). Young juveniles (A-5 and earlier) were especially decalcified due to their very thin valve walls and, therefore, remained on the microscope slides as distorted crushed, and resultingly unmeasurable, forms.

A diagram summarising the life history strategies of the Ostracoda discussed is presented in Figure 7.26.

Figure 7.26.
Life History Strategies of Ostracoda.
Summary Diagram.



CHAPTER 8 - SEX RATIOS

8.1 - Summary

The sex ratios of 9 species of sexually reproducing Ostracoda sampled in the Lake District were determined. The species selected were representative members of four of the numerically most abundant genera collected in the Lake District.

The four members of the genus *Cyclocypris* (*C. ovum*, *C.serena*, *C. laevis* and *C. globosa*) together with *Candona fabaeformis* all showed a female-biased sex ratio. The sex ratio of *C. ovum* was found to be 1:1 in waters of low alkalinity, but biased towards the female at higher alkalinities. The four other species, *Cypria ophthalmica*, *Cypria exsculpta*, *Metacypris cordata*, and *Candona rostrata* all had sex ratios biased towards the male. This bias was greater during the winter than during the summer sampling period.

8.2 - Aims of the Chapter

The sex ratio may be an important factor when the evolution of sex is examined. This may include the cause of change between sexual reproduction and parthenogenesis. Studies on sexually reproducing marine ostracods have shown that both the sex ratio and population dynamics may vary greatly between species, and each species has its own particular pattern of seasonal change in the sex ratio (Theisen, 1966; Heip, 1976; Abe, 1983; 1990; Martens *et al*, 1985; Kamiya, 1988).

The aim of this chapter was to investigate the sex ratios of Ostracoda found in the Lake District, and to see how they varied between species, between sites, and between the sampling periods.

8.3 - Reproduction in the Ostracoda

The sex ratio of ostracods may change extensively in a living population (Abe 1983; Martens et al, 1985). Freshwater ostracods may reproduce sexually, parthenogenetically or both. Asexual reproduction (parthenogenesis) appears to be the most common method for British freshwater Ostracoda, one advantage of this method is that a single individual can generate a new population of the species. In addition, it can reduce the length of the life cycle because no time is needed for mate selection, and increases the rate of increase of the population. For example, if 100 individuals are produced in an egg clutch of a parthenogenetic species, all will, if surviving to the adult, produce eggs. A clutch of eggs laid by a sexually reproducing species will be lower in future egg producing females.

Asexual reproduction is especially common in the family Cypridopsidae and the subfamilies Eucypridinae and Herpetocypridinae (Henderson, 1990). Males are known for some species, but most populations are parthenogenetic, there often being geographical variation in the reproductive method (for examples, see Table 8.41). There are no proven cases of sexual and asexual forms of a species coexisting within one single population, although in some populations the incidence of males is so low that this may be possible (Henderson, 1990).

The reproductive method employed is often directly related to to the permanence of the waterbody in which an ostracod lives. Some species require permanent waterbodies, others are adapted to reproduction in temporary ones. Hence, geographical distribution can be determined to some extent by reproductive strategy through availability of suitable waterbodies. Asexual forms tend to occur in temporary ponds which exist at irregular periods, often drying out in summer (Henderson, 1990). These habitats are also geographically irregular in distribution, and favour asexual reproduction because the population can be established by a solitary founder member, a major advantage to dispersal. In addition, temporary habitats probably reduce predation (see Chapter 9) and parasitic burdens as although sex has been shown to be an advantage to populations under attack from parasites (Hamilton, 1982), parasitic occurrence in ephemeral habitats is rare.

8.4 - The Choice of Species

Of the 32 species occurring in the samples collected from the Lake District, the majority (19) are syngamic. The remaining 13 species reproduce parthenogenetically. The reproductive methods of all the species collected are listed in Table 8.41.

Table 8.41 - Reproductive Strategies of Ostracoda Sampled in the Lake District

Species	**Reproductive Strategy**
Metacypris cordata	Sexual
Darwinula stevensoni	Asexual
Ilyocypris bradyii	Asexual
Ilyocypris decipiens	Sexual
Cypria ophthalmica	Sexual
Cypria exsculpta	Sexual
Cyclocypris globosa	Sexual
Cyclocypris serena	Sexual
Cyclocypris laevis	Sexual
Cyclocypris ovum	Sexual
Paracandona euplectella	Sexual
Candona albicans	Sexual
Candona candida	Asexual *[1]
Candona compressa	Sexual
Candona fabaeformis	Sexual
Candona neglecta	Sexual
Candona pratensis	Sexual
Candona rostrata	Sexual
Candona siliquosa	Asexual *[2]
Candona reducta	Sexual
Candona vavrai	Sexual
Candonopsis kingsleii	Sexual
Notodromas monacha	Sexual
Cyprinotus incongruens	Asexual
Eucypris virens	Asexual *[3]
Cypricercus fuscatus	Asexual
Cypricercus obliquus	Asexual
Herpetocypris reptans	Asexual *[4]
Herpetocypris chevreuxi	Asexual
Cypridopsis vidua	Asexual *[5]
Potamocypris villosa	Asexual *[6]
Potamocypris sp A.	Asexual

*[1] - Reproduction is normally parthenogenetic and males are rare (Henderson, 1990).

*[2] - Males have not yet been identified with certainty and must be rare (Henderson, 1990).

*[3] - Males have not been recorded from North Europe where reproduction is parthenogenetic, but they have been sampled from a population in North Africa (Gauthier, 1928).

*[4] - Males are known only from populations collected from North Africa (Henderson, 1990).

*[5] - All the populations studied have been shown to be parthenogenetic but there are unsubstantiated reports of males (Henderson, 1990).

*' - Potamocypris villosa is parthenogenetic within Great Britain, but males have been recorded from a high altitude lake in the Cantabrian mountains, North-west Spain (Martens & Meisch, 1985).

For this study, a group of species that played an important role in the ostracod community structures of the Lake District was chosen. Consequently, the species collected from the Subfamily Cyclocypridinae were selected, together with three other sexually reproducing species that appeared in the 18 species that made up over 99% of total ostracod density. The selected species are listed in Table 8.42.

Table 8.42 - Species Selected for Study on the Distribution of Sex within the Lake District Margin Samples

1. Cypria ophthalmica
2. Cypria exsculpta
3. Cyclocypris ovum
4. Cyclocypris serena
5. Cyclocypris laevis
6. Cyclocypris globosa
7. Candona fabaeformis
8. Candona rostrata
9. Metacypris cordata

8.5 - Methodology - Evaluation of Ostracod Sex

Ostracod sex was initially determined by dissecting adults of each species and examining the reproductive organs. With experience, however, it became possible to determine sex reliably from sexually dimorphic carapace features, thereby avoiding the necessity of time-consuming dissection.

The reproductive system of ostracods is of a relatively large size and is very complex. Both the male and the female possess two systems, one on each side of the body. The two female systems are wholly independent, whilst the male copulatory appendages operate together. The following descriptions are based on the cypridoidean Candona suburbana described by McGregor & Kesling (1969).

The female reproductive system (Figure 8.1) comprises two parts, one producing and holding the egg for fertilization and the other holding the sperm. The eggs are transferred to the uterus from the ovary when formed, and then acquire a cuticular shell. The uterus opening to the exterior is on the ventral posterior side of the body on the genital lobe. The vagina is in front of the uterine opening and leads to the seminal receptacle in which the sperm are held following copulation. The mechanism of fertilization is unknown, but it is assumed that the sperms pass back out of the vagina and through the uterine opening to fertilize the eggs.

The male (Figure 8.2) possesses four testes held between the lamellae of each valve, and the ducts from these join to form the vas deferens which enters the body and then re-enters the valve cavity. The vas deferens then divides into the blind section which passes under the testes, and the main tube which loops into the body and then repeatedly within it, enlarging to form the seminal vesicle. The function of the blind section is unclear, but may allow the extremely long sperms to reverse so that the leading tip becomes the posterior. The seminal vesicle then leads to the Zenker's organ which acts as a pump and consists of a

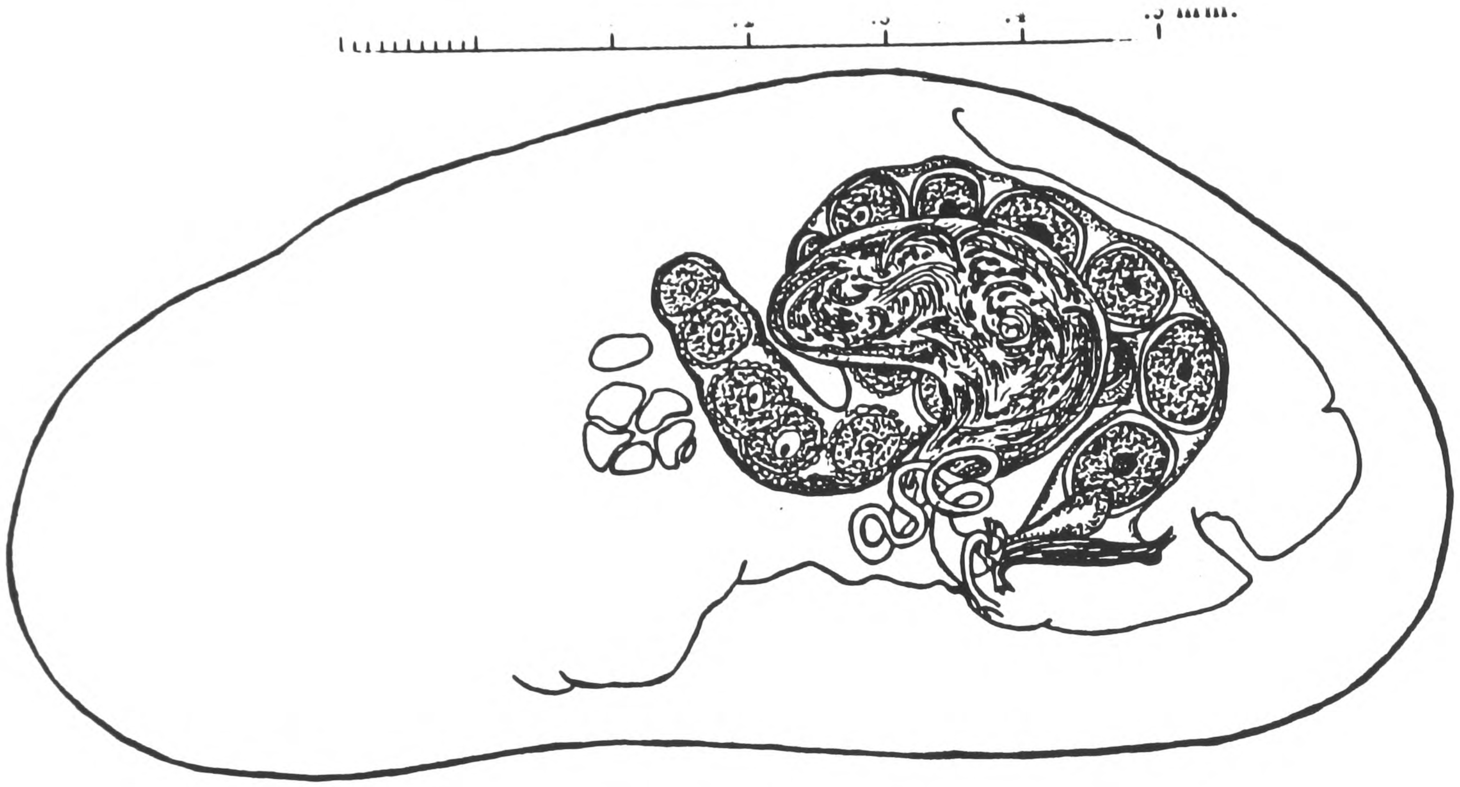
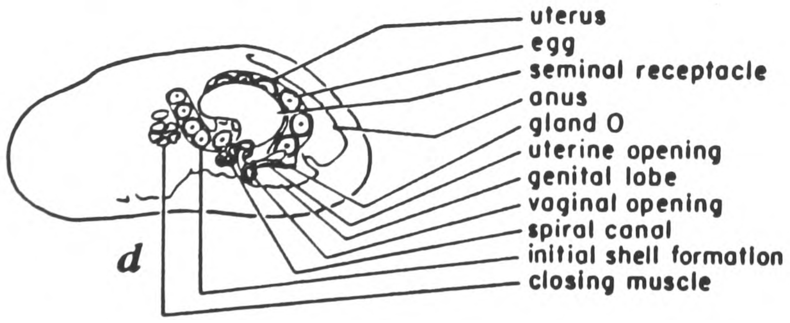


Figure 8.1.

The Female Reproductive System.



Modified from Mcgregor & Kesling (1969).

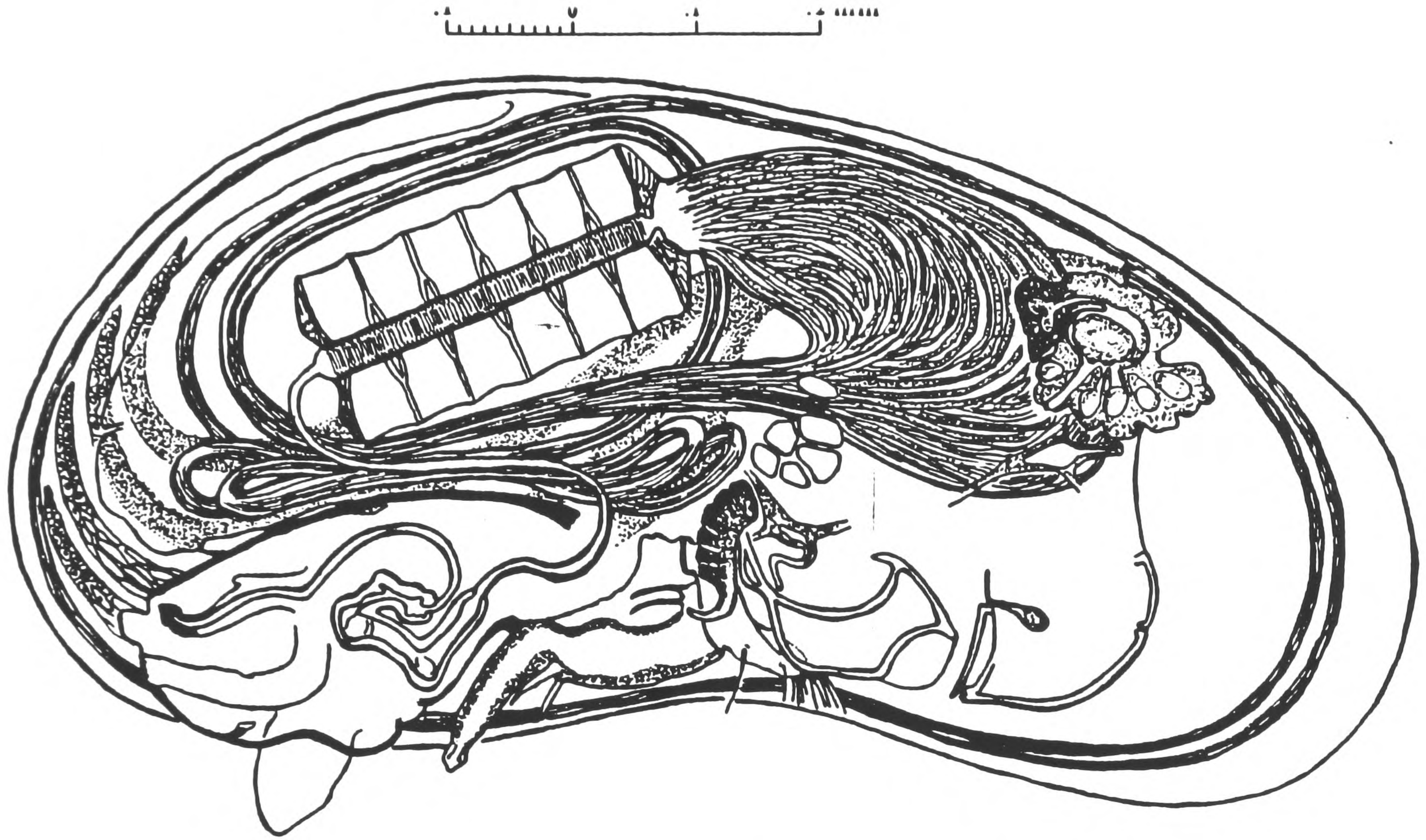
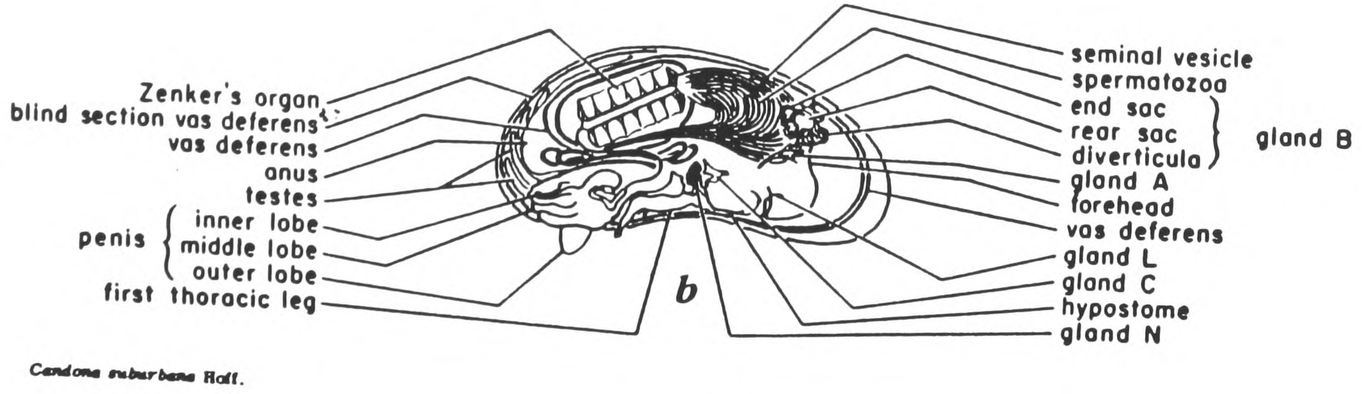


Figure 8.2.

The Male Reproductive System.



Modified from Mcgregor & Kesling (1969).

central tube encircled by a number of sets of chitinous spines to which are attached tiny muscles; muscle contraction then pumps the sperm along the central tube. The Zenker's organ is connected to the hemipenis by a narrow tube through which the sperms pass to the vagina during copulation.

The Ostracoda have the largest sperms in the animal kingdom in relative terms. Cyclocypris ovum produces motile sperms of 6mm in length (Henderson, 1990). There appears to be no known viable explanation of this fact in the literature, although Lowndes (1935) concluded that the sperms of cypridoideans were functionless and that all reproduction was parthenogenetic. This conclusion was derived from a lack of visualisation of how the sperm function and lack of success in producing *in vitro* fertilization. Cypridoideans have a long fossil record. It is difficult to understand in evolutionary terms why completely functionless males should have survived for so long, or why they should have evolved such complex reproductive organs. Although fertilization has not yet been seen to occur, more conclusive evidence should be presented before its occurrence is dismissed.

The eggs are usually shed freely in the water or are attached singly or in groups to vegetation or the lake bed. Hatching results in the formation of nauplius larvae, each of which is enclosed in a bivalve carapace like the adult, but only has head appendages.

8.6 - Results

1) *Cypria ophthalmica*

Table 8.6a - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
6	summer	30/8/89	20	45	55
6	winter	1/2/89	3	67	33
9	summer	29/8/89	28	57	43
11	summer	20/8/89	3	33	67
11	winter	30/1/89	3	100	-
12	winter	30/1/90	13	38	62
17	summer	20/8/89	12	50	50
17	winter	30/1/90	25	52	48
18	summer	20/8/89	40	60	40
21	summer	22/8/89	50	58	42
21	winter	4/2/89	35	49	51
22	summer	21/8/89	15	40	60
22	winter	31/1/89	100	54	46
24	summer	20/8/89	12	58	42
24	winter	30/1/90	2	50	50
31	summer	25/8/89	3	67	33
42	summer	31/8/89	10	50	50
42	winter	2/2/90	22	55	45
44	summer	4/9/89	20	55	45
61	summer	23/8/89	20	50	50
64	summer	23/8/89	30	57	43
64	winter	3/2/89	65	62	38
70	summer	23/8/89	10	30	70
71	summer	23/8/89	100	63	37
71	winter	31/1/90	100	51	49

72	summer	23/8/89	100	59	41
72	winter	29/1/90	100	64	36
74	summer	23/8/90	3	33	67
74	winter	1/2/90	10	60	40
75	summer	21/8/90	60	63	37
75	winter	1/2/90	100	59	41

If the total numbers of C. ophthalmica sexed are summed for both of the sample periods and converted to % values, the male:female ratio may be calculated.

The values calculated were found to be identical for each season.

Male 57% : Female 43%.

The data indicate that there is no variation in the sex ratio with respect to the sampling periods, i.e. season (and consequently, temperature) for C. ophthalmica.

The next stage of the investigation attempted to evaluate whether the sex ratio varies with respect to water chemistry and lake size, two factors that were shown in Chapters 3 and 5 to be important in determining the distribution of individual ostracod species and the overall community structure.

For statistical purposes the male:female ratio is represented by **R**, where;

$$\mathbf{R} = \frac{\textbf{Total number of males in a category}}{\textbf{Total number of females in a category}}$$

For analysis of variation of **R** with lake size, the categories 1 - 5 that were used in the lake size classification described in

Chapter 2 were selected. Variation in **R** with water chemistry was correlated against the I.F.E. classifications which were shown in Chapter 4 to divide water quality into five divisions.

The results are presented in Figure 8.6b.

Table 8.6b - Relationship Between R, Lake Size, and Water Chemistry

Size class	**R - value**	**Chem. class**	**R - value**
A	-	1	-
B	1.114	2	1.222
C	1.375	3	1.188
D	1.253	4	1.353
E	1.433	5	1.327

The data suggest that although the sex ratio is always biased towards the male in all four size classes, and all four water chemistry classifications measured, there is no clear relationship between these variables and the value of **R**.

In conclusion, the sex ratio of Cypria ophthalmica is slightly biased towards the male in the Lake District, and is not influenced by season, lake size, or water chemistry.

2) Cypria exsculpta

Table 8.6c - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
16	summer	22/8/89	4	50	50
16	winter	4/2/89	8	63	37
19	summer	22/8/89	2	50	50
23	summer	20/8/89	60	60	40
23	winter	30/1/90	30	57	43
25	summer	20/8/89	2	-	100
31	summer	25/8/89	2	50	50
36	summer	21/8/89	19	63	37
61	summer	23/8/89	3	33	67
64	summer	23/8/89	64	63	37
64	winter	3/2/89	14	50	50
74	winter	28/1/90	4	75	25

The total numbers of Cypria exsculpta sexed were summed for both sample periods and converted to % values.

The values calculated vary slightly from season to season, the male having an overall majority in both periods.

Summer - Male 60% : Female 40%.
Winter - Male 57% : Female 43%

Variation in sex ratio with respect to water chemistry and lake size was not investigated as there were not a sufficient quantity of sites containing this species at suitable densities for the analysis to be statistically viable.

3) Cyclocypris globosa

Table 8.6d - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
36	summer	21/8/89	25	28	72
36	winter	31/1/90	100	38	62

It is difficult to make any quantitative observations on this species as it was only collected in reasonable numbers at one site, Loughrigg Tarn (site 36). However, there does appear to be a large dominance of females over males.

4) Cyclocypris serena

Table 8.6e - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
3	summer	28/8/89	20	45	55
3	winter	1/2/89	40	26	74
4	summer	22/8/89	25	44	56
9	summer	29/8/89	2	50	50
9	winter	1/2/90	1	100	-
27	summer	25/8/89	2	-	100
31	summer	25/8/89	40	35	65
54	summer	25/8/89	10	30	70
61	summer	23/8/89	4	25	75
61	winter	3/2/89	5	40	60

The total numbers of Cyclocypris serena sexed were summed for both sample periods and converted to % values.

Summer - Male 38% : Female 62%
Winter - Male 30% : Female 70%

In both seasons, the sex ratio was biased towards the female, the level of bias being greater in the winter sample. However, it should be noted that identification in the winter sample was based upon only 46 specimens from 3 separate sites, as opposed to 103 identifications from 7 sites in the summer samples. This lack of data may have influenced a lower accuracy in the winter data.

As both the site size and water chemistry levels tolerated by this species are restricted to A/B and 3/4 respectively, no further analysis was performed to assess any relationship between these variables and the value of the sex ratio.

5) Cyclocypris laevis

Table 8.6f - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
1	summer	30/8/89	22	27	73
1	winter	1/2/89	1	100	-
2	winter	1/2/89	1	100	-
4	summer	22/8/89	4	25	75
6	summer	30/8/89	2	-	100
6	winter	1/2/89	2	-	100
11	summer	20/8/89	21	43	57
11	winter	30/1/89	22	34	66
15	summer	27/8/89	6	33	67
15	winter	30/1/90	32	37	63
16	winter	4/2/89	2	50	50
19	summer	22/8/89	1	100	-
27	summer	25/8/89	3	33	67
61	summer	23/8/89	1	100	-
70	summer	23/8/89	1	100	-

The total numbers of Cyclocypris laevis sexed were summed for both sample periods and converted to % values. The values calculated are shown below.

Summer - Male 36% : Female 64%
Winter - Male 37% : Female 63%

In both seasons, the sex ratio was biased towards the female in a very similar manner to that of Cyclocypris serena, although in this case, the level of bias was completely constant, to within 1%, from season to season.

No further analysis was performed to assess any relationship between these variables and the value of the sex ratio due to the lack of a sufficient quantity of data.

6) Cyclocypris ovum

Table 8.6q - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
7	winter	2/2/89	3	33	67
12	summer	20/8/89	2	-	100
12	winter	30/1/90	5	40	60
13	summer	21/8/89	26	46	54
13	winter	30/1/89	12	33	67
15	summer	27/8/89	4	50	50
15	winter	30/1/90	8	37	63
16	summer	22/8/89	13	54	46
16	winter	4/2/89	20	40	60
17	summer	20/8/89	7	43	57
17	winter	30/1/90	40	32	68
18	summer	20/8/89	4	50	50
18	winter	31/1/89	4	50	50
20	winter	31/1/89	2	-	100
21	summer	22/8/89	50	40	60
21	winter	4/2/89	30	50	50
22	winter	31/1/89	10	20	80
23	summer	20/8/89	100	29	71
23	winter	30/1/90	12	58	42
24	summer	20/8/89	24	37	63
24	winter	30/1/90	16	50	50

25	summer	20/8/89	7	29	71
25	winter	30/1/90	3	-	100
26	summer	20/8/89	36	28	72
26	winter	30/1/90	12	42	58
31	summer	25/8/89	100	35	65
32	summer	29/8/89	4	50	50
32	winter	4/2/89	3	67	33
37	summer	25/8/89	100	37	63
37	winter	29/1/90	62	35	65
42	summer	31/8/89	50	42	58
42	winter	2/2/90	50	35	65
45	summer	21/8/89	3	67	33
54	summer	25/8/89	6	17	83
61	summer	23/8/89	22	41	59
61	winter	3/2/89	40	40	60
64	summer	23/8/89	32	47	53
64	winter	3/2/89	36	42	58
71	winter	31/1/90	5	20	80
74	summer	23/8/90	19	47	53
74	winter	28/1/90	40	42	58
75	summer	21/8/90	40	37	63
75	winter	1/2/90	100	27	73

The total numbers of *Cyclocypris ovum* sexed were summed for both sample periods and converted to % values. The values calculated are shown below.

Summer - Male 39% : Female 61%
Winter - Male 37% : Female 63%

Again, in both seasons, the sex ratio was biased towards the female in a very similar manner to that exhibited by both C. laevis and C. serena, and in this case, the level of bias was approximately constant from season to season.

As there is no seasonal variation in the sex ratio for C. ovum, variation of sex with respect to water chemistry and lake size will now be investigated.

Table 8.6h - Relationship Between **R**, Lake Size, and Water Chemistry

Size class	**R - value**	**Chem. class**	**R - value**
A	0.200	1	-
B	0.607	2	1.000
C	0.658	3	0.597
D	0.676	4	0.568
E	0.463	5	0.573

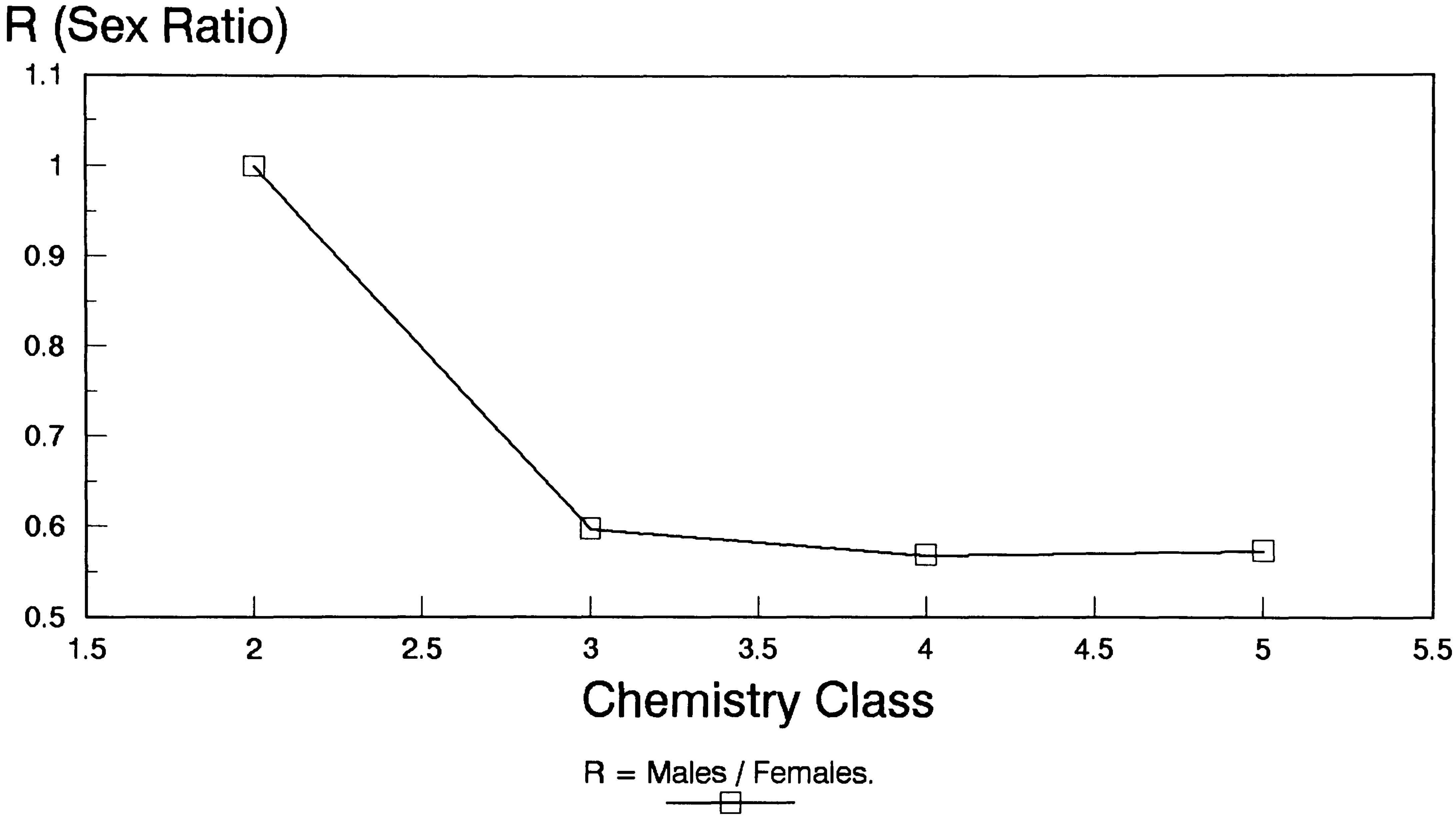
The data detailing the effects of site size indicate that although the sex ratio is always biased towards the female in all four classes, there is no relationship between this variable and the value of **R**. The **R** value for lake size class A was eliminated from the analysis as this data represents a single site, Ullswater (site 54).

A significant relationship does occur between water chemistry and the value of **R**. This is shown in Figure 8.3. The proportions of females in the population significantly decrease on reaching chemistry classification 2, a level of increased acidity and decreased overall water quality. At levels 3 to 5, the sex ratio

Figure 8.3.

Plot of I.F.E. Chemistry Class v. Sex Ratio.

Cyclocypris ovum.



is constant. It is possible that the acidity and subsequently diminished water quality may equate the sex ratio to 1:1 (the females having a lower tolerance to diminished water quality than the males), this being necessary for successful reproduction in the harsh chemical regime.

In conclusion, the sex ratio of C. ovum is biased towards the female in the Lake District. This ratio is not influenced by season or lake size, but shows a decreased female predominance down to a level of an equal sex ratio at a low class of water quality.

7) Candona fabaeformis

Table 8.6j - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
12	winter	30/1/90	13	77	23
17	winter	30/1/90	2	-	100
75	winter	1/2/90	6	-	100

The total numbers of Candona fabaeformis sexed were summed for the winter period only, as the summer collections yielded only juveniles, and converted to % values.

The overall values calculated for the winter period indicate an almost equal sex ratios, 11 adult females collected compared to 10 males.

Winter - Male 48% : Female 52%

Variation in sex ratio with respect to water chemistry and lake size was not investigated as there were not a sufficient quantity of sites containing this species for the analysis to be statistically viable.

8) Candona rostrata

8.6k - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
20	summer	22/8/89	3	100	-
35	summer	3/9/89	1	100	-
35	winter	1/2/90	1	-	100

The total numbers of Candona rostrata sexed were again summed for both sample periods and converted to % values. The values calculated are shown below.

Summer - Male 100%
Winter - Female 100%

The data for C. rostrata is presented here only because the species was sexed for the purposes of Chapter 7, and the extremely low numbers of adults make discussion of the data futile.

9) Metacypris cordata

8.61 - Measured Sex Ratios at all Sites

Site no.	**Season**	**Date**	**No. i.d.**	**% Male**	**% Female**
1	summer	30/8/89	3	67	33
13	summer	21/8/89	1	-	100
16	summer	22/8/89	21	43	57
16	winter	4/2/89	5	100	-
36	summer	21/8/89	266	50	50
36	winter	31/1/89	6	100	-
37	summer	25/8/89	136	62	38
37	winter	29/1/90	8	62	38
74	summer	23/8/90	127	65	35
74	winter	28/1/90	52	63	37

The total numbers of Metacypris cordata sexed were summed for both sample periods and converted to % values. The values calculated are shown below.

Summer - Male 56% : Female 44%
Winter - Male 69% : Female 31%

In both collections, the sex ratio was biased towards the male, the level of bias being 13% greater in the winter sample. This observation will be discussed later.

As this species was only recorded as adults at six sites, no further analysis was performed to assess the relationship between the site characteristics and the values of the sex ratio.

8.7 - Discussion

The two sexes are usually produced in approximately even numbers (Fisher, 1930). If the factor of parental care is ignored, then Fisher's argument, under natural selection assumes the following mechanism (modified from Hamilton, 1967):

1) Suppose male births are less common than female.

2) A newly born male has better mating prospects than a newborn female and, therefore, can expect to have more offspring. i.e. the rarer sex will contribute genetically more zygotes to a population than the more common sex.

3) Therefore, parents genetically disposed to produce males tend to have more than average numbers of grandchildren born to them.

4) Therefore, the genes for male-producing tendencies spread, and male births become commoner.

5) As the 1:1 sex ratio is approached, the advantage associated with producing males declines.

6) The same reasoning holds if males are substituted by females throughout.

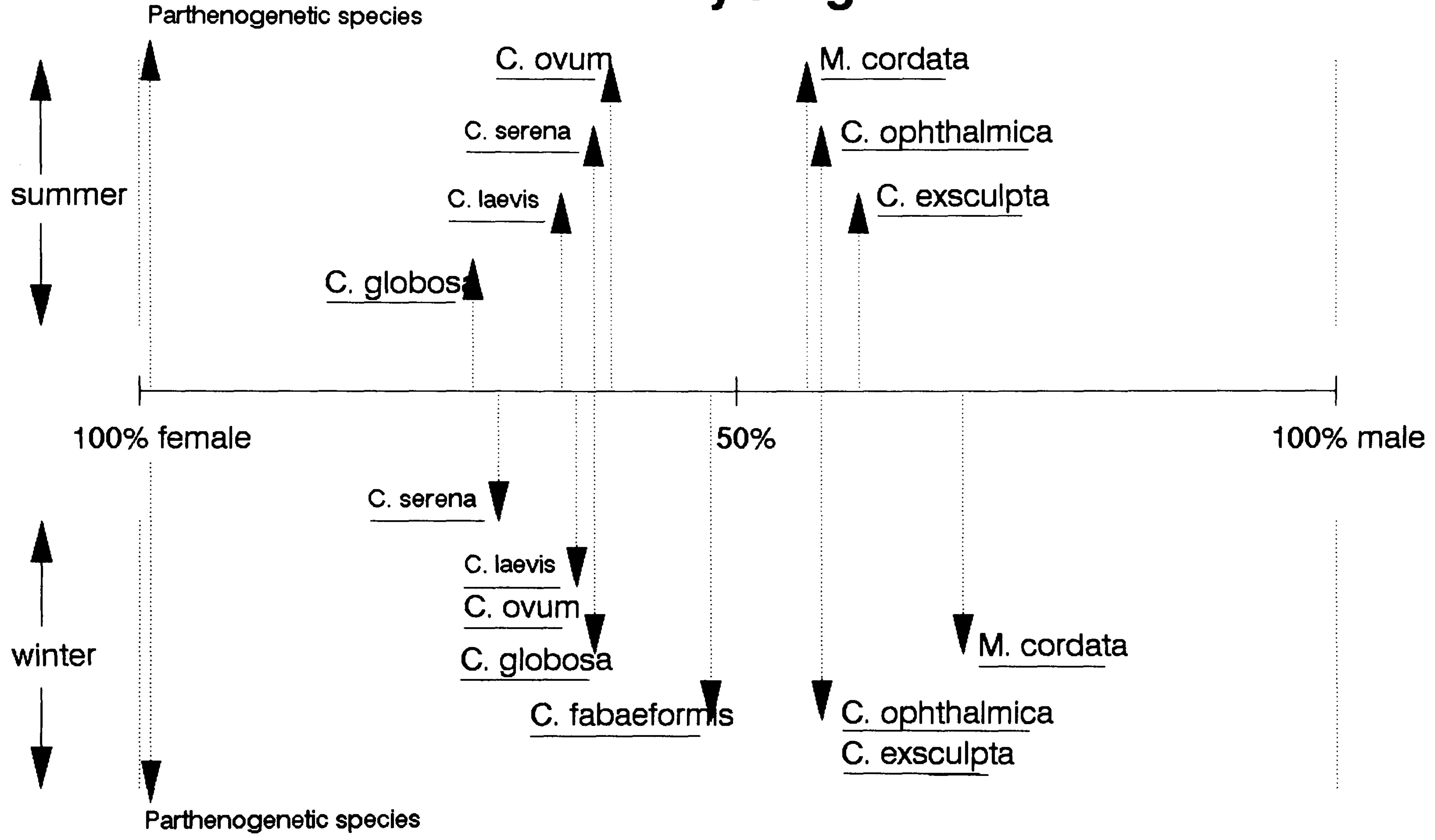
"Fisher's Principle", therefore, states that the sex ratio is in equilibrium when the totals of effort spent by the population in producing the two sexes are equal.

If it is assumed that the frequency of occurrence of males reflects the incidence of sexual reproduction, the ostracod species examined here may be ordered along a gradient ranging from the completely asexual at one extreme to the obligate sexual at the other. This is shown in Figure 8.4. All four species of *Cyclocypris* are situated to the left of the gradient, biased towards the female, and have similar sex ratios with little seasonal variability. *Candona fabaeformis* showed a very slight female bias in winter, the one sampling period in which it was collected. The two species of *Cypria* studied showed a slight inclination to the right of the gradient, a bias towards the production of males, there again being little seasonal variation.

Metacypris cordata differed from the two species of *Cypria* in that there was a distinct seasonal variation in the sex ratio. There was a slight male bias in the sex ratio during the summer period of 56:44, which increased to a value of 69:31 during the winter period, the largest male-biased occurrence in this study. At two sites, Knittleton Tarn A (site 16) and Loughrigg Tarn (site 36) adult females were completely absent during the latter period. There are few available data for comparison on the sex ratio of *M. cordata*. Mallwitz (1981) gives a sex ratio contradictory to that observed in the Lake District, it being biased to the female at a ratio of 2:1 (123:62) in Schmalsee and Lüttauersee in Germany for the period from June-September, juveniles only being recorded from October to March. In contrast, and in close accordance with this study, Scharf (pers. comm.) found that males dominate in the winter, and Danielopol (pers. comm.) recorded only males during a survey in October 1991.

The literature on the sex ratios of Ostracoda, which has

Figure 8.4.
Sex Ratio Gradient.
Summary Diagram.



concentrated on marine species, indicates a general predominance of females over males, although there are records to the contrary (Van Morkhoven, 1962; Whatley & Stephens, 1977). The limited data on freshwater Ostracoda indicate that the sex ratio is usually biased towards the female or tending towards unity (Henderson, 1990). For example, data taken from a study on one of the species examined in this study, Cypria ophthalmica (Wagenleitner, 1990), shows that in one population in the Neusiedlersee (Austria) the sex ratio was biased at 91:9 towards the female, but in all other populations studied, the sex ratio was about 50:50, a similar value to that exhibited by the species in the Lake District. A male biased sex ratio is an unusual feature for a freshwater ostracod (Henderson, 1990), but has been recorded prior to this study by Sars (1925), who noted that in a population of Candona rostrata from a spring, males were more common than females. These data are in agreement with those of this investigation, as although only five specimens of this species were sexed, this quantity not allowing statistical analysis, a male bias does appear to be in operation, the sex ratio being 4:1.

Several hypotheses are presented here concerning the factors which may influence the sex ratios of freshwater Ostracoda. Without further study, beyond the scope of this thesis, it is difficult to identify those which are operating. The important parameters concerned here include: reproductive strategy, habitat and the potential effect of predation.

A) Reproductive Strategy

The costs of reproduction are fundamental in determining the optimal life history of an ostracod species in any environment. The reproductive method, therefore, is likely to influence the sex ratio of the individual species.

The literature offers several potential explanations for the sex ratio being biased towards either female or male.

i) Female biased populations

a) Female bias may result from reproduction by arrhenotoky, the process by which males are always, and only, derived from unfertilised eggs (Hamilton, 1967). In populations of the Insecta (reviewed by Hamilton, 1967), the number of unfertilised eggs is always less than those fertilised, and hence the populations are always biased towards the female.

b) Abe (1983) showed that female predominance in the sex ratio could be attributed to male mortality being approximately twice that of the female in a population of the marine ostracod Keijella bisanensis. During the second half of the reproductive period, when new adults of the fresh generation increase greatly in number, the sex ratio is almost equal, but never exactly reaches the 1:1 ratio as the population still contains a few old females from the previous generation.

c) Highly polygynous inbreeding species populations (as opposed to populations where outbreeding is the selected reproductive strategy) have female-biased sex ratios (Hamilton, 1967). In an inbreeding population, which is a strategy often selected within an area of confined space (Hamilton, 1967), reproduction is arrhenotokous and there is at least one male in every batch of offspring which mates with many females and is unable to emigrate from the batch, due to sexual exhaustion. Consequently, the ideal strategy for spread of the species is for one male to a batch of females in a group, creating a female biased sex ratio.

Without further data on the life history strategies of the individual species, it is impossible to evaluate which of these hypotheses account for the female biased populations of genus Cyclocypris observed in the Lake District.

ii) Male biased populations

a) Studies on other animal groups have shown that high adult female mortality will often occur in species with a high fecundity which invest a large amount of energy, in the form of resources, in reproductive activities. Consequently, for a limited time period, the surviving adult males will create a male biased population. An example of this with reference to freshwater invertebrates is given by Snell & King (1977), who found a negative correlation between future survivorship and current fecundity for the predatory rotifer Asplancha brightwelli.

b) Male biased populations may result from selection pressure, or mortality being significantly different for the sexes sometime during the hatching period, or perhaps simply because more male offspring are produced (Abe, 1983).

Again, exactly those mechanisms responsible for creating the male bias in *M. cordata*, and to a lesser extent, *C. ophthalmica* and *C. exsculpta*, are difficult to identify. The lack of females of *M. cordata* in the winter period only suggests that one option from hypothesis b) may be the correct one, in that adult female mortality increases with the decreasing temperature associated with the winter sampling period. The possibility of migration of adult females to a different microhabitat during this period appears unlikely. Several winter samples were taken from different microhabitats within the marginal zone of Loughrigg Tarn (site 36), and none yielded a single female adult specimen of *M. cordata*.

Seasonal variation in the sex ratio of Ostracoda has been recorded previously. Martens *et al* (1985) showed that for the halobiont species *Mytilocypris henricae* (Chapman), the sex ratio varied over the period of the ten month study. The male was dominant in the period between September and December, the sex ratio reaching a value of 7:3, whereas the female was dominant in the other months, especially during August, January and March, up to a maximum level of 4:1. The overall female dominance was suggested not to be attributable to any significant variability between the sexes in the development time from hatching to moult 7-8, but was potentially due to the female eggs hatching at a faster rate than the males, or that there was a higher differential mortality of the males during the larval development period. The decline in females between September and December was suggested to be due to high mortality of post-mature females after the period of intense egg production.

The variation in the sex ratio during the year has been observed for other ostracod species. Theisen (1966), studying Leptocythere lacertosa, suggested variability may be due to the duration of larval development of the male being shorter than that of the female. Heip (1976) showed that there was a positive correlation between the moult period from the A-1 larvae of Cyprideis torosa to adult and a higher relative adult male abundance, the male undergoing the final moult earlier than the female. Therefore, males become abundant immediately after the final moult begins, female abundance only rising later.

B) Habitat

The microhabitat in which an ostracod species lives may also affect the sex ratio, although this seems not to be the case for M. cordata. This effect was shown to an extent by Kamiya (1988) who found that the marine species, Loxoconcha japonica which lives on the fronds on Zostera marina (sea-grass) (an unstable environment due to the seasonal growth and decay of the macrophyte), has a female biased tertiary sex ratio of 62:38, whilst Loxoconcha uranouchiensis which lives on a sandy bottom just below the sea-grass fronds in a relatively stable environment and has an almost 50:50 tertiary sex ratio. However, it should be said that the conclusions offered by Kamiya are somewhat speculative, as the differing sex ratios of the two species may not be related to habitat.

C) Predation

The mechanism of variation in sex ratio may initially appear to eliminate the problem of predation. Although a predator is unlikely to prefer one sex unless one is significantly larger than the other, one sex may be more active than another, leading to a differing potential for detection by predators. This case has been shown by Abe (1990) who found that in the marine ostracod, Keijella bisanensis, the walking speed of the adult male was approximately one and a half times that of an adult female. This difference in activity may or may not lead to an increase in active predation (see Chapter 9). There may be a difference in the walking speed between the sexes of M. cordata It may be possible that a seasonal increase in a specific predator of the ostracod could reduce the faster moving (or simply larger) females in the population. Although as this species has brood care, a large amount of the early stage juveniles would also be lost by predation of the adult.

CHAPTER 9 - SIZE SELECTIVE FEEDING UPON OSTRACODS BY FISH

9.1 - SUMMARY

The field data suggest that large, swimming ostracod species, and indeed large densities of any swimming ostracod species are absent in sites containing fish. To test the hypothesis that predation could limit the distribution of swimming species, a series of laboratory experiments was performed using three species of Ostracoda, (Cypria ophthalmica, Cypricercus fuscatus, and Eucypris virens), and the predator Gasterosteus aculeatus (three-spined stickleback).

The rate of population decline of each species, due to the effect of predation was found to increase with increasing ostracod size. When offered a choice of prey in differing predator:prey ratios, the larger species was preferentially selected when it comprised more than 50% of the total prey density. At other predator:prey ratios, all three species were selected at similar rates. When offered a pair of prey of different size, the largest was always selected. The data suggest that large swimming species of ostracod, and large densities of small swimming species would suffer a high mortality rate in tarns containing fish. This could explain their absence from such sites.

9.2 - INTRODUCTION

Analysis of qualitative observations derived from the marginal sample data set have suggested that the distribution of certain ostracod species may be influenced by the presence or absence of specific potential predators.

A predator is defined as an animal in a higher trophic level that totally consumes, or partly consumes and harms, an animal or plant in a lower trophic level. The process of predation may involve the location, capture, ingestion, digestion and assimilation of prey. These factors interact, creating adaptations in both the predators and their prey which enhance the survivorship of both species.

The fitness of an allele may be defined as the instantaneous *per capita* rate of increase of that allele (Smith & Sibly, 1985), and an important factor that complicates the relationship between predation-rate and predator fitness is food quality (Begon & Mortimer, 1981). Natural selection is a fitness-maximising process and favours individuals with the highest inclusive fitness values (Begon & Mortimer, 1981). This may be achieved, in foraging, by such short term objectives as maximising the net rate of food intake. Natural selection and hence evolution, therefore favours predators that select profitable prey, fitness being equal to profitability. For a successful foraging strategy, maximally efficient predators would be expected to choose an optimal balance between exploration and exploitation, and any model predicting the behaviour of an efficient predator must take account of the costs and benefits of a precise decision rule (Begon & Mortimer, 1981).

The optimal foraging model predicts that predators can distinguish between food items of differing profitability and select the most profitable in respect of either food size or type. In this case, profitability may be equated to fitness. The hypothesis was supported by Elner & Hughes, (1978) who studied predation on mussels by the shore crab, Carcinus maenas. They found that the optimal benefit in respect of energy gain in joules/second was greatest from an intermediate prey size, the largest mussel not offering the greatest benefit. The intermediate size was the one preferentially selected by the crabs, in terms of number of prey eaten per day.

However, to what extent should an animal include the less profitable items in its diet ? In this case, a 'trade-off' must occur (MacArthur & Pianka, 1966). This may be defined as an improvement in some fitness-related character associated with a decrease in some other fitness-related character. For a predator, the average profitability will decrease with an increasing breadth of the diet (Elner & Hughes, 1978). Therefore, in a habitat where profitable prey are common, a predator will not attain the greatest fitness value by the ingestion of prey that have a low profitability and should hence ignore prey outside the optimal set irrespective of how common they are.

In aquatic habitats, the abundant small benthonic and pelagic crustacea, including the Ostracoda, constitute the major prey of many small fishes in shallow water habitats. Studies by Tressler (1939), Liperovskaya (1948), Kornicker & Sohn (1971), and Vinyard (1979) indicate that ostracods are readily eaten by fish. Juveniles of the fish Vimba elongata were shown to feed extensively on ostracods, they being the most common meiobenthic crustacean group found in the fish stomachs (Uiblein & Winkler, 1988). In one case some 150,000 specimens of the freshwater ostracod Herpetocypris reptans were found in the gut of a single brown trout (Whatley, 1983).

However, there has been no previous study of the influence of ostracod size on the rate of predation.

9.3 - AIMS OF THE CHAPTER

The marginal data set suggests that small, fishless ponds and tarns (assuming that they do not possess a particularly acidic chemical profile) often contain both large densities of small, swimming ostracods (in terms of body volume) and/or larger swimming species. A small freshwater cyprid ostracod may be considered as less than 0.75 mm, while a large species may be defined as greater than 1.25 mm. In contrast, many large swimming species do not occur in larger waterbodies containing fish. This would suggest that direct predation by fish could mould the ostracod community and produce a selection pressure in favour of smaller species.

It is hypothesised that large, swimming ostracods and predatory fish are mutually exclusive, the larger species being present only in sites characterised by the absence of a specific predator. Hence, if a size range of ostracod prey is offered to a predator, it should select the largest individuals, or alternatively may select the most profitable species from which it can derive the maximum benefit.

To test this hypothesis, the predation rate upon a selected range of ostracod sizes was investigated by a series of experiments.

1) Which size range of prey was the most profitable to a predator ?

2) How does the predation rate vary with changes in prey density ?.

9.4 - THE CHOICE OF SPECIES

Initially a predator had to be selected. One of the most common predators of ostracods inhabiting the littoral zone in the Lake District is the 3-spined stickleback, (Gasterosteus aculeatus). This species, whose adults range in length from 3.5-8.0 cm (Wootton, 1976), is considered a polyphagous predator. G. aculeatus has many additional advantages: it is widely available, being found in almost every size and type of freshwater, and is relatively easy to maintain in culture. The male of the species develops a red underbelly during the spawning period, and has been shown to be a particularly voracious predator of pelagic zooplankton (Hynes, 1950), suggesting it can be a heavy predator of ostracods.

It has also been shown to demonstrate prey selectivity based upon species and size, generally consuming larger zooplankton when faced with a choice of prey (Kerfoot, 1975; Gibson, 1980; Campbell, 1991). This prey selectivity is common for other small planktiverous fish (Lazzaro, 1987).

Ostracod species found in the Lake District and displaying a large inter-species adult size variation were selected as prey.

The following three species were selected:

1) *Cypria ophthalmica* (0.60-0.71 mm long)
2) *Cypricercus fuscatus* (1.4-1.5 mm long)
3) *Eucypris virens* (1.6-2.3 mm long)

The smallest species selected, *C. ophthalmica*, had been previously observed being fed upon by fish, Tressler (1939) having identified it in the stomach of the Shad (*Alosa sapidissima*).

9.5 - METHODOLOGY

9.51 - Prey Suitability

Initially, a simple question had to be answered. Are all three ostracod species eaten by the predator ?

To evaluate this, one predator was placed in a 5 litre aquarium containing a monospecies ostracod culture of known number, and left for 24 hours. The number of remaining ostracods was then noted. This procedure was repeated for each ostracod species.

9.52 - The Predation Rate upon Single Species Prey Populations

This stage of the investigation involved monitoring the rate of decline of each prey species when a constant density of ostracods were introduced to an aquarium containing a predator. Each stickleback was starved for at least 24 hours before commencing any experiment. For each ostracod species, two or three aquaria (to act as controls), each containing a stickleback, were arranged in a row, each separated by black plastic barriers. This isolation of each tank ensured that each predator acted independently of the other and was not influenced in its decisions by the behaviour of another fish in another tank.

A constant prey density of 50 ostracods was chosen for the experiments. This density was selected to facilitate comparison with the result of Vinyard (1979), who observed predation upon the freshwater ostracod Cypridopsis vidua by small bluegill sunfish Lepomis macrochirus at a predator : prey ratio of 1:50. Also, it was considered, with reference to the observations of Whatley (1983) who found some 150,000 ostracods in the gut of a single trout, that 50 specimens would not be enough to completely satiate a stickleback, an effect which may potentially distort the results.

Each fish was acclimatised to a tank 24 hours before the commencement of each experiment, and the ostracods were then added to the aquarium. The time intervals at which readings were taken were chosen simply by trial and error, feeding often being irregular or in bursts. Readings were taken regularly for the first 5 minutes of each experiment, when there was often a heavy predation rate, and then at 5 minute intervals until 1 hour had elapsed. The experiment was continued for a further hour, readings being taken at 15 minute intervals, there often being little predatory activity during this second period.

9.53 - The Predation Rate on a Two-Species Culture

Once the rate of decline of all three species in isolation had been evaluated, the concept of prey selection in a two-species culture was monitored.

Most polyphagous predators rarely discriminate between the various types of food that they eat (Begon & Mortimer, 1981). However, there are two general exceptions to this rule. Firstly, if a predator is offered two prey types, it may show a marked preference for one of them, irrespective of availability. An example of this strategy is illustrated by Murdoch (1969). Here, two predatory shore snails selected the thin shelled mussel Mytilus edulis over the thick shelled Mytilus californianus, irrespective of their relative proportions, the former prey being less protected and hence more susceptible to exploitation. The second and rarer occurrence is the concept of 'predator switching'. In this case, a predator may switch its preference to whichever prey is the most common. An example of this is given by Lawton et al (1974), who investigated the predatory response of the water-bug Notonecta glauca on two types of prey, the mayfly larva, Cloeon dipterum and the isopod, Asellus aquaticus. The predator took a disproportionately small number of Asellus when they were scarce, and a disproportionately large number when they were common. It was suggested that this was due to the creation of a 'search-image', the ability to learn being highly developed.

The hypothesis to be tested in this experiment was that, given a choice between large and small ostracods, predators may select the larger species, as more energy is available per unit prey if this strategy is utilised.

However, at this stage an auxiliary hypothesis must be proposed that sticklebacks will not be 'conditioned' by the nature of the prey on which they have previously fed, i.e. no matter what they have been fed upon, they still will always select the largest species that is offered to them. For example, a fish which had only previously been offered C. ophthalmica as a food source, would select C. fuscatus in preference to C. ophthalmica if offered both species.

To test for potential 'conditioning' of the predators, all experiments were performed on two 'types' of sticklebacks:

A) Fish previously fed (In Exp. 8.52) on C. fuscatus .

B) Fish previously fed (In Exp. 8.52) on C. ophthalmica.

In each aquarium, containing 1 fish, under the same conditions as the previous experiment, one of the following combinations of prey density was introduced;

A) 75% (50 specimens) *C. fuscatus*,
25% (17 specimens) *C. ophthalmica*.

B) 50% (50 specimens) *C. fuscatus*,
50% (50 specimens) *C. ophthalmica*.

C) 25% (50 specimens) *C. fuscatus*,
75% (150 specimens) *C. ophthalmica*.

By keeping the same density of *C. fuscatus* in the aquaria, a null hypothesis could be simultaneously tested that the rate of consumption of *C. fuscatus* is constant, irrespective of the density of *C. ophthalmica*.

The experimental matrix, therefore, involved subjecting the three different ratios of prey density to each of the two predator 'types', giving a total of 6 experiments.

9.54 - Prey Selection on a Pair of Prey

Prey selection was tested using a second, and simpler technique. Three predators were each introduced to an isolated aquarium after being starved for 24 hours, as in the previous experiments. Each predator was then offered a single pair of prey, comprising of two different ostracod species. Therefore, three different prey combinations were available to test.

A) C. fuscatus / C. ophthalmica

B) C. fuscatus / E. virens

C) C. ophthalmica / E. virens

Each prey combination was offered ten times to each of the three different predators, creating a total of 90 experiments.

9.6 - RESULTS

9.61 - Prey Suitability

It was found that all three species of ostracod were eaten.

9.62 - The Predation Rate upon a Single Species Population

When the ostracods were introduced to the tanks containing the stickleback, initially all prey attacked were eaten, but after consuming about 10 individuals, the predator subsequently disgorged most of the prey that were attacked. After this initial burst of feeding only moving prey were selected, the predator hovering in mid-water until it saw a moving ostracod, and then attacking it. This observation was previously recorded by Gibson (1980) who found that sticklebacks feeding on Cladocera were seemingly more attracted by individuals or species that exhibited a continuous erratic movement. C. fuscatus and E. virens both tended to 'play dead' when the stickleback was in the close vicinity. Each species stopped swimming and even crawling, appearing motionless, closed the valves, and lay motionless on the bottom of the aquarium. This appeared to be a survival adaptation, the strategy being directed towards reducing the probability of capture and/or ingestion by the predator. They were rarely attacked after the initial feeding burst when adopting this strategy. The other species, C. ophthalmica, however did not adopt this policy.

The mean % survival for all 3 species of ostracod after 2 hours is represented in Table 9.62a.

Table 9.62a - Ostracod Survival after 2 hours

Species	**No. of Duplicates**	**% Mean Survival**
C. fuscatus	3	20
E. virens	2	28
C. ophthalmica	2	72

The results indicate that the two largest species, C. fuscatus and E. virens had a similar decline due to predation in the course of the experiment, there being 70 - 80% loss in total. C. ophthalmica, the smallest species, showed a much lower predation rate of only 28% decline in density, even though it do not adopt the strategy of becoming stationary in the presence of a predator.

The curves of decline rate for each species, plotted in Figure 9.1, shows that in addition to the similarities in final % survival of C. fuscatus and E. virens, the rate of decline shows a very similar pattern, being very different

Figure 9.1.
Predatory Effects upon Ostracoda.
Rates of Decline.

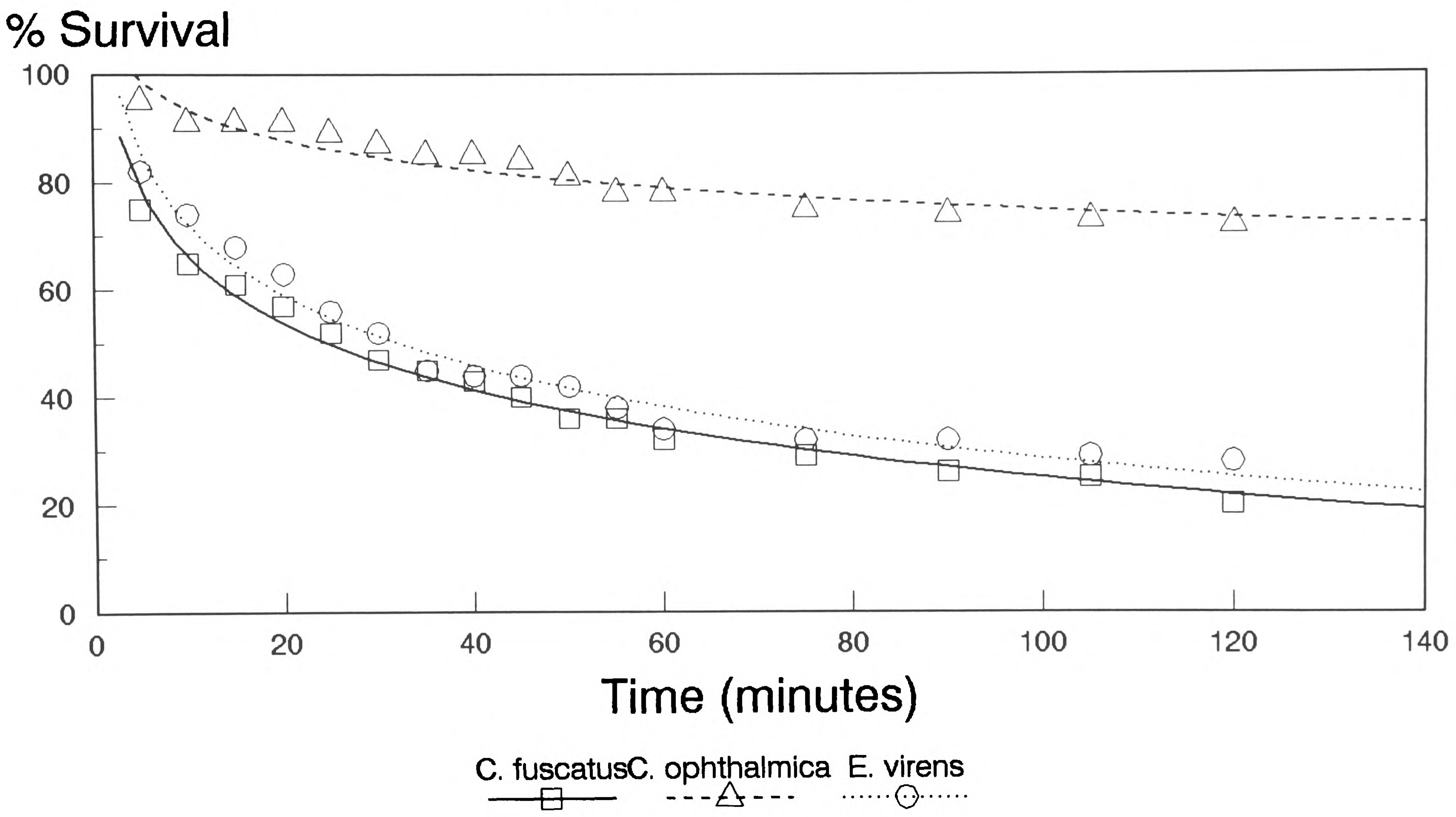
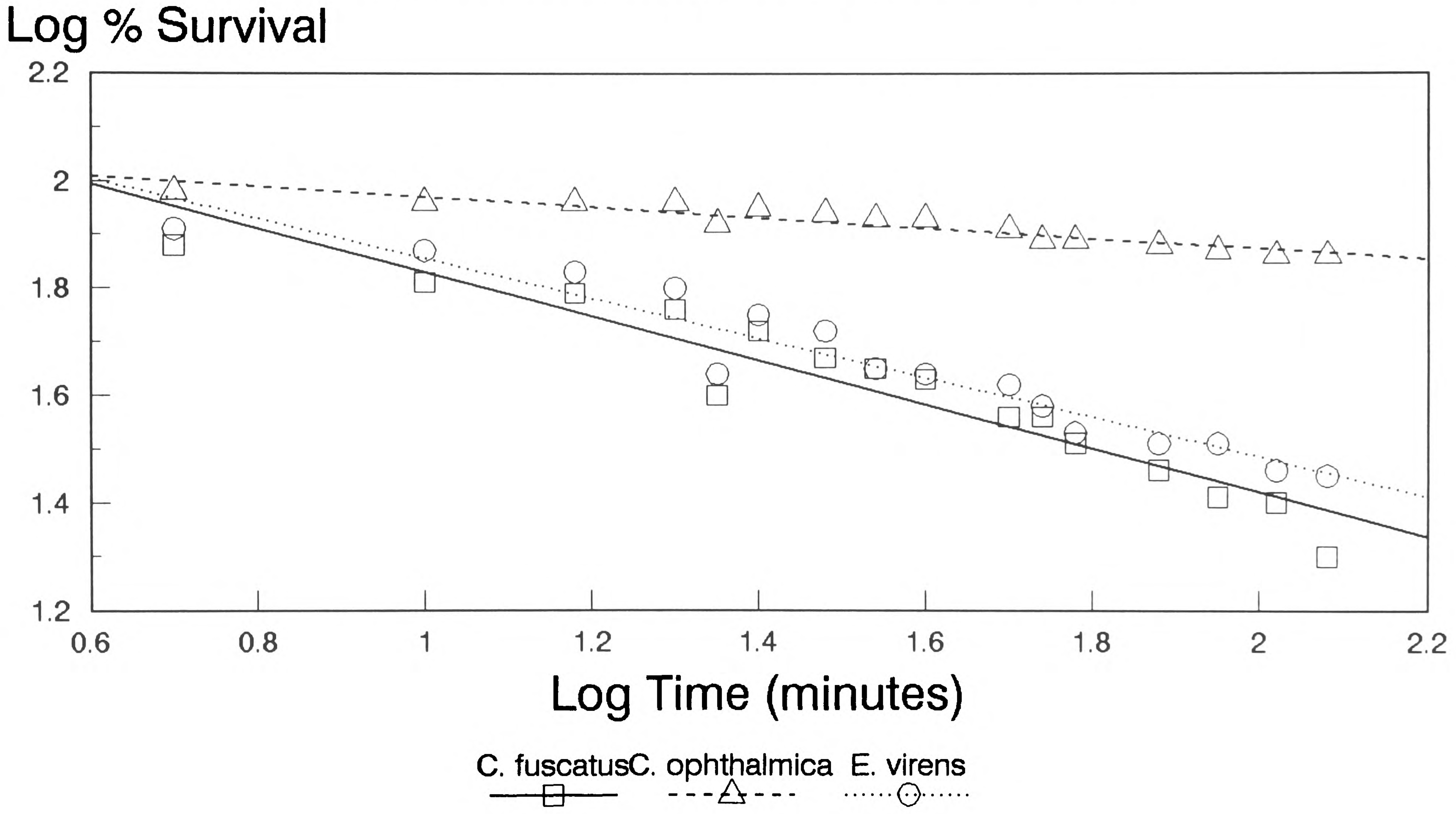


Figure 9.2.
Predatory Effects upon Ostracoda.
Log - Transformed Rates of Decline.



from C. ophthalmica. To enable us to compare the results statistically, the meaned data were log-transformed, and are represented in Table 9.62b.

The plots of the log-transformed data are shown in Figure 9.2.

Table 9.62b - Meaned % Survival with Respect to Time

T/min	**Log T**	**% Surv C.fusc**	**Log C.fusc**	**% Surv C.opht**	**Log C.opht**	**% Surv E.vir**	**Log E.vir**
1	0.00	77	1.89	-	-	94	1.97
2	0.30	-	-	-	-	88	1.94
5	0.70	75	1.88	95	1.98	82	1.91
10	1.00	65	1.81	91	1.96	74	1.87
15	1.18	61	1.79	91	1.96	68	1.83
20	1.30	57	1.76	91	1.96	63	1.80
25	1.40	52	1.72	89	1.95	56	1.75
30	1.48	47	1.67	87	1.94	52	1.72
35	1.54	45	1.65	85	1.93	45	1.65
40	1.60	43	1.63	85	1.93	44	1.64
45	1.65	40	1.60	84	1.92	44	1.64
50	1.70	36	1.56	81	1.91	42	1.62
55	1.74	36	1.56	78	1.89	38	1.58
60	1.78	32	1.51	78	1.89	34	1.53
75	1.88	29	1.46	75	1.88	32	1.51
90	1.95	26	1.41	74	1.87	32	1.51
105	2.02	25	1.40	73	1.86	29	1.46
120	2.08	20	1.30	72	1.86	28	1.45

The graphs indicate little difference in the predation rates upon C. fuscatus and E. virens, but both species display a noticeable difference in their regression coefficients when compared to C. ophthalmica. Analysis of variance was used to check the significance of these differences, the statistics being summarised in Table 9.62c.

Table 9.62c - Statistics of ANOVA and Linear Regression

Statistic	**C.fuscatus**	**C.ophthalmica**	**E.virens**
Coefficient	b = -0.42	b = -0.095	b = -0.38
Equation	y=2.265-0.42x	y=2.07-0.095x	y=2.243-0.38x
Σx^2	2.14	2.14	2.14
Σxy	-0.89	-0.20	-0.81
Σy^2	0.400	0.003	0.321
Regr. SS.	0.3700	0.0193	0.3073
Resid. SS.	0.0300	0.0008	0.0137
Resid. MS.	0.00200	0.00006	0.00098

Table 9.62d - F-Ratio Values.

Species pair	**F-Ratio**	**Significance**
ophthal*virens	16.879	P < 0.0001 ****
ophthal*fuscatus	34.480	P < 0.0001 ****
virens*fuscatus	2.043	P < 0.1 (N.S.)

From the results it may be concluded that the predation rate upon C. ophthalmica is significantly less than that upon C. fuscatus and E. virens.

9.63 - The Predation Rate on a Two - Species Culture

These experiments involved prey selection in a two-species culture. The results from the previous experiment suggested that there was little difference between the predation rates upon C. fuscatus and E. virens, hence only the former of these species was tested here in conjunction with C. ophthalmica.

Analysis of variance of the regression lines was performed to see if there was any 'conditioning' of the predators in respect of prey they had already eaten. The data presented in Table 9.63a compares the predation rate by fish previously fed on C. ophthalmica and C. fuscatus for each prey ratio.

At all three prey ratios, for C. fuscatus, there were no significant differences between the predation rates of fish previously fed on the different species. Therefore, there was no 'prey conditioning'. At prey ratios of 1:1 and 1:3, this was also the case with C. ophthalmica, but at 3:1, a significant difference occurred between the two fish previously fed on the two different species. However, the predation rate by the fish previously fed on C. fuscatus was greater than that previously fed on C. ophthalmica, the opposite response to 'conditioning'.

Table 9.63a - Ostracod Survival after 2 hours

Species	Prey Ratio (*fuscatus* : *ophthalmica*)	Fish 'Type'	% Survival
Cypria ophthalmica	3 : 1	pre-fed on *C. fuscatus*	29%
Cypria ophthalmica	3 : 1	pre-fed on *C. ophthal*	35%
Cypricercus fuscatus	3 : 1	pre-fed on *C. fuscatus*	0%
Cypricercus fuscatus	3 : 1	pre-fed on *C. ophthal*	28%
Cypria ophthalmica	1 : 1	pre-fed on *C. fuscatus*	46%
Cypria ophthalmica	1 : 1	pre-fed on *C. ophthal*	34%
Cypricercus fuscatus	1 : 1	pre-fed on *C. fuscatus*	42%
Cypricercus fuscatus	1 : 1	pre-fed on *C. ophthal*	48%
Cypria ophthalmica	1 : 3	pre-fed on *C. fuscatus*	63%
Cypria ophthalmica	1 : 3	pre-fed on *C. ophthal*	68%
Cypricercus fuscatus	1 : 3	pre-fed on *C. fuscatus*	50%
Cypricercus fuscatus	1 : 3	pre-fed on *C. ophthal*	54%

Table 9.63b - ANOVA in Regression Statistics

Species	**Prey Ratio (F:O)**	**F-value**	**Significance**
C.ophthalmica	3 : 1	4.726	P > 0.05 **
C.ophthalmica	1 : 1	1.954	N.S.
C.ophthalmica	1 : 3	2.783	N.S.
C.fuscatus	3 : 1	3.140	N.S.
C.fuscatus	1 : 1	1.358	N.S.
C.fuscatus	1 : 3	1.500	N.S.

Hence, for further statistical purposes, it is permissable to state that no 'conditioning' occurs, and the data for each of the ratio combinations for each of the two ostracod species may now be blocked and meaned. To enable us to statistically compare the results, the meaned data was log-transformed, and is represented in Tables 9.63 (c-e).

Table 9.63c - Meaned % survival with respect to time
Ratio of 3 : 1 (C. fuscatus : C. ophthalmica)

T/min	**Log T**	**% Surv C.fusc**	**Log C.fusc**	**% Surv C.ophth**	**Log C.ophth**
5	0.70	77	1.89	68	1.83
10	1.00	72	1.86	65	1.81
15	1.18	62	1.79	53	1.72
20	1.30	55	1.74	47	1.67
25	1.40	52	1.72	47	1.67
30	1.48	49	1.69	41	1.61
35	1.54	44	1.64	41	1.61
40	1.60	35	1.54	38	1.58
45	1.65	29	1.46	38	1.58
50	1.70	26	1.41	35	1.54
55	1.74	25	1.40	32	1.51
60	1.78	24	1.38	32	1.51
75	1.88	20	1.30	32	1.51
90	1.95	15	1.18	32	1.51
105	2.02	15	1.18	32	1.51
120	2.08	14	1.15	32	1.51

Table 9.63d - Meaned % Survival with respect to time Ratio of 1 : 1 (C. fuscatus : C. ophthalmica)

T/min	Log T	% Surv C.fusc	Log C.fusc	% Surv C.ophth	Log C.ophth
5	0.70	89	1.95	82	1.91
10	1.00	86	1.93	79	1.90
15	1.18	86	1.93	78	1.89
20	1.30	83	1.92	77	1.89
25	1.40	78	1.89	74	1.87
30	1.48	74	1.87	71	1.85
35	1.54	74	1.87	68	1.83
40	1.60	69	1.84	65	1.81
45	1.65	65	1.81	60	1.78
50	1.70	62	1.79	58	1.76
55	1.74	61	1.79	55	1.74
60	1.78	58	1.76	51	1.71
75	1.88	58	1.76	49	1.69
90	1.95	54	1.73	47	1.67
105	2.02	49	1.69	43	1.63
120	2.08	45	1.65	40	1.60

Table 9.63e - Meaned % Survival with respect to time Ratio of 1 : 3 (C. fuscatus : C. ophthalmica)

T/min	**Log T**	**% Surv C.fusc**	**Log C.fusc**	**% Surv C.ophth**	**Log C.ophth**
5	0.70	92	1.96	87	1.94
10	1.00	85	1.93	80	1.90
15	1.18	81	1.91	77	1.89
20	1.30	81	1.91	74	1.87
25	1.40	78	1.89	72	1.86
30	1.48	76	1.88	70	1.85
35	1.54	72	1.86	68	1.83
40	1.60	70	1.85	67	1.83
45	1.65	68	1.83	64	1.80
50	1.70	64	1.80	62	1.79
55	1.74	60	1.78	57	1.76
60	1.78	56	1.75	55	1.74
75	1.88	54	1.73	51	1.71
90	1.95	53	1.72	50	1.70
105	2.02	52	1.72	48	1.68
120	2.05	52	1.72	47	1.67

Figure 9.3.

Log - Transformed Rates of Decline. Variable Species Ratios.

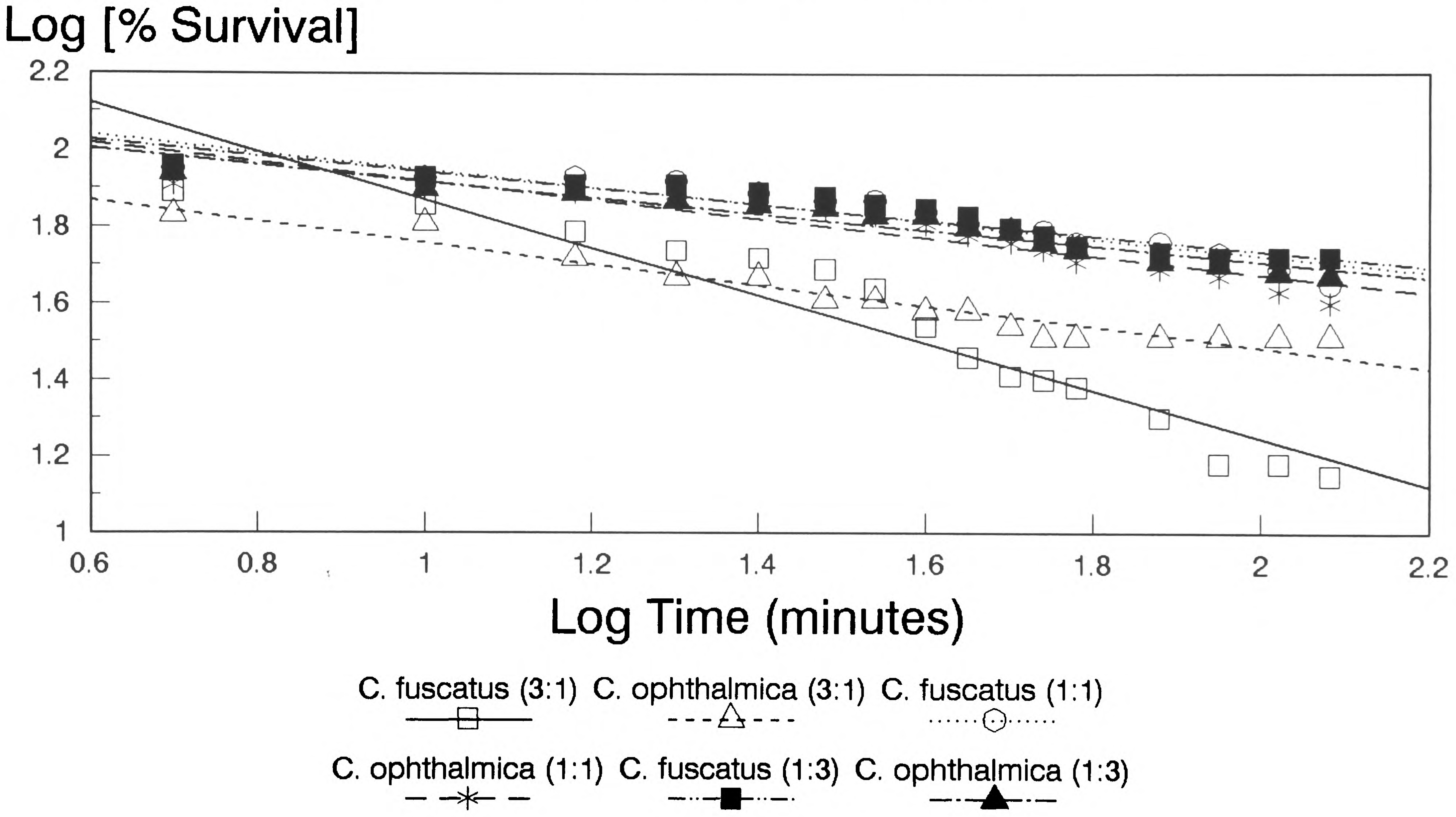


Table 9.63f - Statistics of Linear Regression

Species	**Prey Ratio (F:O)**	**Linear Regression Coefficient**	**Equation**
C.fuscatus	3 : 1	b = -0.629	Y = 2.50 - 0.629x
C.ophthalmica	3 : 1	b = -0.274	Y = 2.03 - 0.274x
C.fuscatus	1 : 1	b = -0.226	Y = 2.17 - 0.226x
C.ophthalmica	1 : 1	b = -0.242	Y = 2.16 - 0.242x
C.fuscatus	1 : 3	b = -0.242	Y = 2.21 - 0.242x
C.ophthalmica	1 : 3	b = -0.239	Y = 1.93 - 0.239x

The graphs of the log-transformed data are shown in Figure 9.3.

Analysis of variance was used to test variability between the proportions of each species that were selected from each ratio combination, as shown in Table 9.63g.

Table 9.63g - ANOVA Statistics

Prey Ratio (F : O)	**F-value**	**Significance**
3 : 1	3.05	P > 0.05 **
1 : 1	1.33	N.S.
1 : 3	1.14	N.S.

Prey selectivity may be defined as 'any difference in the relative proportions of prey species or prey of specific size classes in the diet as compared with the relative proportions of species or size classes in the prey community' (Pastorok,1980).

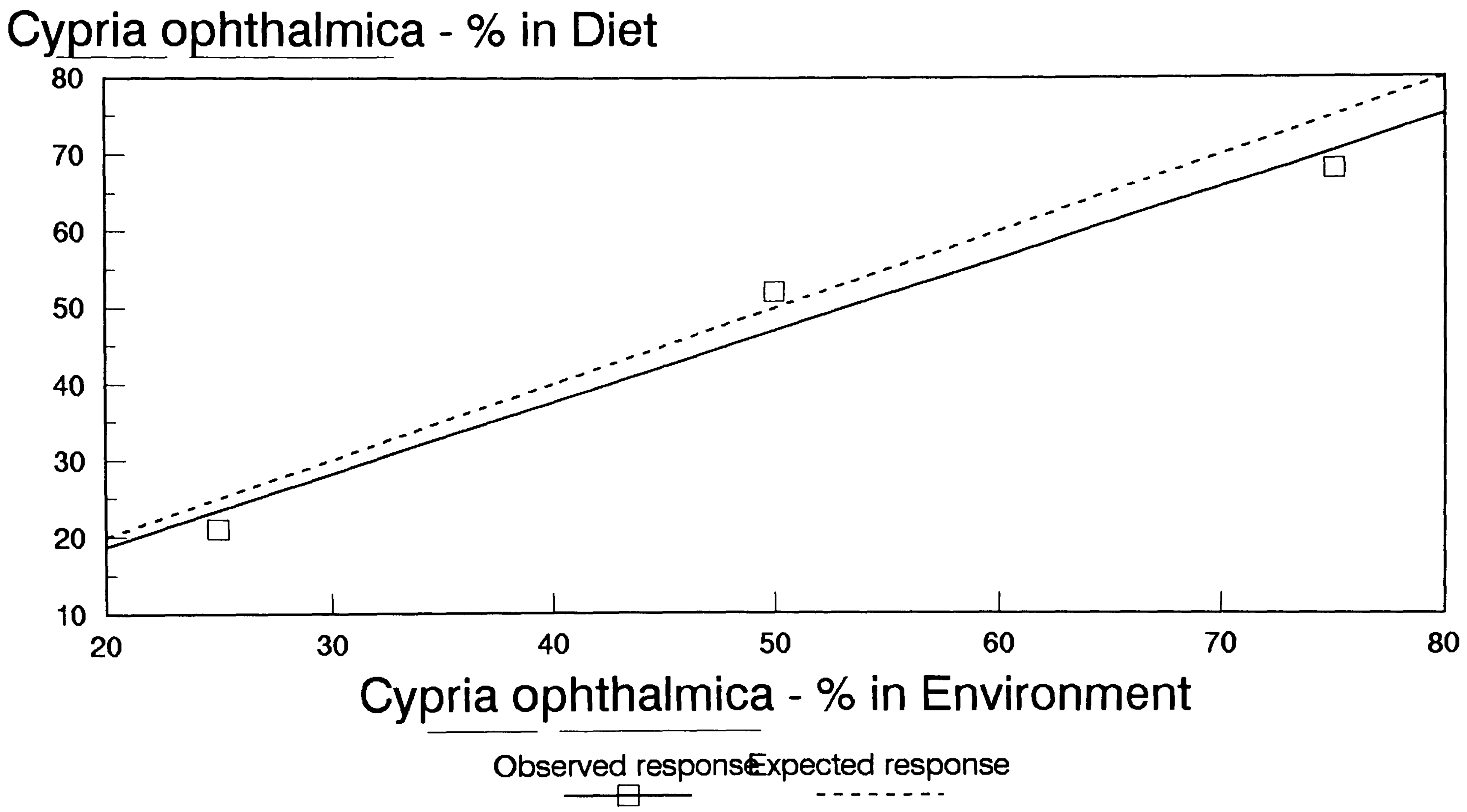
The graphs illustrate that the consumption of C.fuscatus varies according to the different densities of C. ophthalmica. It shows that there is a definite preference for C. fuscatus at a prey density of 3:1, but little difference at the 1:1 and 1:3 ratio levels. The statistics indicate that this may be partly due to the effect of a greater number of one of the species being present, as the proportion of each individual species selected shows only one significant difference at any prey ratio, C. fuscatus being preferentially selected only at the 3:1 ratio. Hence, we may conclude that there is no significant predator preference that operates irrespective of prey availability.

The original hypothesis suggested that there could be three predatory responses in this experiment. One of these possibilities, that there is a marked prey preference irrespective of availability has been disproved and two options remain. Either there is no prey discrimination, or 'predator-switching' occurs. The data initially suggest that the species in the greatest density is the most heavily predated, especially C. fuscatus, but not at a greater rate than the other species, and that 'switching' does not occur. To examine the concept of 'switching' in greater detail, it is necessary to evaluate whether the species of the greatest density is selected at a disproportionate level. Figure 9.4 plots the % of C. ophthalmica in the environment against the % of C. ophthalmica in the diet. If no 'switching' occurs, prey consumption of a

Figure 9.4.

Predation Upon Cypria ophthalmica.

Does `Switching' Occur ?



species should be directly proportional to its density in the environment. In fact, the graph shows that less than the expected quantity of C. ophthalmica are consumed, especially at the 3:1 ratio. Although the relationship here is not statistically significant, the larger species was consumed in a proportionately greater quantity than would be expected in consideration of its density in the environment. Hence, 'switching' in this case is applicable to just one of the species, C. fuscatus being preferentially selected when at a greater density than C. ophthalmica. This agrees with the observations made earlier.

9.64 - Prey Selection on a Pair of prey

The results so far appear to have established two facts. Firstly, in an isolated culture, predation on larger ostracods occurs at a greater rate than on a smaller prey, and secondly, in a mixed culture, predation is greater upon the species which exists in the greatest density, and disproportionately at a high density of C. fuscatus. Predator response is now to be evaluated when offered an instant choice of two species of differing size.

Summing the data for each fish (Appendix 14.9), we get the following statistics:

Table 9.64a - Statistics for Prey Combinations

Prey combination	**X^2 value**	**Significance**
C.fuscatus / C.ophthalmica	$X^2 = 2.133$	$P > 0.1$
C.fuscatus / E.virens	$X^2 = 6.533$	$P > 0.01$
C.ophthalmica /E.virens	$X^2 = 6.533$	$P > 0.01$

There seems to be a strong preference order that is statistically significant, ordered in terms of increasing size. The predator preference order appears to be:

E. virens > C. fuscatus > C. ophthalmica.

This compliments the observations made in the previous section.

9.7 - DISCUSSION

It must be considered how the experimental results relate to the field data from the Lake District.

Large swimming ostracod species are often present in small fishless ponds, or in regions uninhabitable by fish in larger waterbodies. De Deckker (1983) found that in the saline Australian lakes where there were no fish, the ostracods were unusually large, and some species became planktonic and fed on other invertebrates.

On the whole, the larger ostracod species, such as the genus Eucypris, are poorly represented in the Lake District. This genus, which has a preference for temporary pools which may dry out in summer (Henderson, 1990) is almost totally excluded from the collections, due to the absence of suitable waterbodies. Such pools are extremely rare in the Lake District, there being too much rain at all times of the year for the sites to be only temporary. However, the occurrence of large species in fishless temporary pools is illustrated well in the temporary ponds of the New Forest, Hampshire (Henderson, pers. comm). In the Lake District, there is some limited evidence for this phenomenon. Eucypris virens was found only in one site, Parsonby tarn (Site 71), which contains no fish. The large swimming Herpetocypris chevreuxi was also found only in Barrow Plantation Tarn B (Site 24), which is also fishless (local farmer, pers.comm). The largest density of any member of the large swimming Cypricercus genus was found in an isolated bay uninhabitable by fish due to extensive macrophyte growth, at Arlecdon tarn (Site 62), where an abundant population of Cypricercus obliquus was sampled. There are no examples of more than an occasional specimen of a large swimming ostracod species in sites inhabited by fish. Secondly, large densities of small swimming species appear to be present in small, non-acidic sites containing no fish. This is apparent at numerous sites; Knittleton Tarns A and B (Sites 16 & 21), Moss-Side Tarn (Site 17), Clay Pond (Site 22), Barrow Plantation Tarns A and B (Sites 23 & 24), Brown Cove Tarn (Site 42), Parsonby Tarn (Site 71), Manesty Park Tarn (Site 72), Boo Tarn (Site 75) and Cat Crag Tarn (Site T15). All these sites contain large densities of small swimming species, usually *Cypria ophthalmica* or *Cyclocypris ovum*. Two of these fishless sites, Moss-Side Tarn and Barrow Plantation Tarn B are also the only ones to contain the ostracod *Notodromas monacha*, which swims upside down in the surface film, making it a highly visible target for predators. However, in other study areas, this species has been recorded in sites containing fish, e.g. Hatchet Pond in the New Forest. There are no small sites that contain fish that contain large densities of small swimming ostracods. This is supplemented by a previous observation (Horne, Horne and Horne, 1990) that *C. ovum* is often very abundant amongst waterlogged moss on the edges of tarns, a habitat where the potential of predation is greatly reduced.

The experiment investigating the decline rate of single species populations found that the rate of decline was significantly greater for the two larger species *Eucypris virens* and *Cypricercus fuscatus* than for the smaller species, *Cypria ophthalmica*. The experiments performed on the ostracod pairs further substantiate this hypothesis to an even greater extent. In this case, a statistically significant hierarchical selection process was in operation in prey choice, *E. virens*, the largest species being selected over *C. fuscatus*, the middle-sized species which in turn was selected over *C. ophthalmica*, the smallest species. This further substantiates the evidence that large ostracod species do not inhabit sites in which they may suffer from the effects of fish predation.

However when fish were introduced to a two-species population of Ostracoda, disproportionate preferential predatory selection of the larger species only occurred at the greatest density of that species, selection at other prey ratios being more influenced by the density of each prey species. The rate of consumption of the larger species, C. fuscatus was not independent of the density of the smaller species, C. ophthalmica.

In the two-species culture at a prey ratio of 1:1, the numbers of C. ophthalmica eaten were greater than those in a single species culture. This could be attributable to the presence of the larger species, which may have 'highlighted' the smaller species, making it more susceptible to predation as it was now more easily viewed by the predator.

The most abundant species always suffered the heaviest predation, in terms of the total numbers eaten. This observation explains the fact that large densities of ostracods are often present in fishless sites. Although the rate of decline of a large species is greater than that of a small species in isolation, and at a high C. fuscatus : C. ophthalmica ratio, large densities of small swimming Ostracoda would be heavily predated if fish were present. The optimal strategy for stickleback predation upon Ostracoda is, therefore, to consume the largest species at the greatest rate in a single species culture or when offered a simple pair choice. In a mixed species culture, the predator should select the prey species which exists in the greatest density, irrespective of prey size, unless there is a great predominance of the larger species, in which case this species will be disproportionately over-selected. Hence, in a site containing predatory fish, low densities of, or no, large and small swimming ostracod species are to be expected.

At this point it should be mentioned that the situation could indeed be reversed, the predator becoming the prey. Liperovskaya (1948) demonstrated an interesting density-dependant predator/prey relationship between the ostracod Cyprinotus incongruens and one month old fry of the tench Tinca tinca. In an environment of <200 ostracods per fish, the fish ate a proportion of the ostracods, but at a density of 300 ostracods per fish, the ostracods clung on to the fish, sinking it and then eating it, leaving only the skeleton and scales. Hence, if a waterbody is dense in predatory ostracods, there is unlikely to be a successful breeding population of fish present as the survival of the juveniles may be at risk if ostracod density is sufficiently great. There are no large populations of predatory ostracods such as C. incongruens in the Lake District, due to the lack of suitable habitats (temporary pools). This appears to be an example of niche evolution, the ostracod colonialising a habitat unsuitable for fish, due to its temporary nature, and not occurring in sites containing fish due to the detrimental effect of predation.

Throughout all the experiments it was consistently observed that after an initial bout of feeding, many ostracods were attacked by the fish and then ejected. This behaviour had previously been noted on small blue-gill sunfish on feeding on *Cypridopsis vidua* by Vinyard (1979) who attributed it to the carapace being tightly closed, the fish thinking it had picked up some non-living material. In the present experiments, this does not appear to be the case because the predators almost always attacked moving, obviously alive specimens.

Previous studies of predation upon Ostracoda have suggested that there may also be prey adaptations which increase the survival of ingested prey by allowing them to pass through the predators gut unharmed. Vinyard (1979), fed *Cypridopsis vidua* to small blue-gill sunfish (39-59 mm) and found that, by examination of faecal pellets, 26% of the ingested specimens traversed the gut unharmed. However, in contrast to this, when *Cyprinotus incongruens* were fed to the fish *Brachydanio rerio* (Kornicker and Sohn, 1971), they were eaten, but most were found crushed in the faeces and none were defecated alive.

An alternative avoidance mechanism is adaptive colouration of the carapace, leading to cryptic protection against predators. In this manner, an ostracod may resist predation due to the failure of a predator to detect the individual. Danielopol (in Carbonel *et al*, 1988) showed that the pigmentation of *Cypria ophthalmica* increased in the littoral zone of Mondsee as compared to the deeper profundal zone where the predation pressure is low.

The observations may suggest that as the predator expends energy in prey capture and digestion and receives only a limited nutrient return, avoidance of ostracod prey may be expected, especially where more easily digestible prey is available. Ivlev (1961) illustrated this response when offering a choice of prey consisting of 3 species of Cladocera and one ostracod species to bleak (Alburnus alburnus). The ostracod (tentatively identified as Cypris) was the only prey type for which there was constant negative selectivity, indicating avoidance of the prey.

It may be hypothesized that there is some form of ostracod group response to predation. Group living may be an advantage to the individual for one of three reasons; potential earlier predator detection, the dilution effect of mortality to other individuals in the group ("buffering protection"), and predator confusion by group behaviour. In this study a response may be expected by the prey to confuse the predator, as if the prey flee in random directions, the predator will be less able to concentrate on one of them. A typical aquatic vertebrate response was cited by Niell & Cullen, (1974), who studied predation upon young atherinids by pike and perch. In this experiment the prey packed into a closer school on disturbance by the predator. The nearest prey then fled and the rest divided into two halves, swimming in opposite directions to the predator, and reforming behind it. In this case increased shoal size decreased the rate of decline of the prey due to predation. However, there is no evidence that ostracods behave socially or adopt a group response to predation, although in the experiments described in this chapter, there was predator confusion at the greatest prey density. Then the stickleback often had its attention diverted from a prey that it was concentrating on, by viewing another ostracod, a reaction simply due to the numbers of ostracods present in the aquarium.

The prey size and species selection demonstrated here indicates that predation may have a strong influence on species composition and size distribution of ostracod communities.

CHAPTER 10 - OSTRACOD RESPONSE TO ELEVATED METAL ION AND pH LEVELS.

10.1 - SUMMARY

Toxicity experiments using a Mobile Aquatic Toxicity Laboratory were performed on ten ostracod species. In the first experiment, six ostracod species, Cypria ophthalmica, Cypridopsis vidua, Cyclocypris ovum, Herpetocypris chevreuxi, Cypricercus obliquus and Cyprinotus incongruens were subjected to variable concentrations (from 0.01 - 5,000 ppm) of Ca $^{2+}$, Na $^{+}$, Mg $^{2+}$ and Al $^{3+}$ at a neutral pH. Survival was relatively constant at all calcium, sodium and magnesium levels for all tested species. Cypria ophthalmica, Cypridopsis vidua and Herpetocypris chevreuxi all displayed a constant survival at all aluminium concentrations, but the other three species all showed increased mortality at aluminium concentrations greater than 5 ppm.

The second investigation involved subjecting all the above species except Cyprinotus incongruens, and additionally, Candona candida, Candona rostrata, Candona siliquosa, and Cypricercus fuscatus, to a matrix of variables including pH, Al $^{3+}$ and Ca $^{2+}$. Calcium concentration only had an effect on the survival of Cypricercus fuscatus, and no other species. All other species showed significant responses to changes in acidity (pH) and Al $^{3+}$ concentrations. Although survival occurred in a wider range of chemical conditions than that in

which ostracods were found in the Lake District, the order of species survival in the experiments was similar to that found in the field. It is suggested that while adult ostracods do not suffer directly from the acute toxicity of pH or aluminium at normal environmental levels, they may be unable to successfully complete their life-cycles in such regimes.

10.2 - INTRODUCTION

In any field study of aquatic biota, it must be recognised that many variables interact to produce the habitat in which an organism lives. To determine the precise environmental requirements for a species, it is necessary to evaluate the precise factors that determine the presence or absence of that species at a particular site.

The previous chapters have discussed the role of water quality, predation and seasonality (which incorporates the effect of temperature) in determining the distribution of particular ostracod species in the Lake District. The next stage of the investigation is to assess the tolerance of selected species to precise ionic concentrations of elements, in laboratory conditions, to ascertain whether their observed field distributions may be directly explained by water chemistry.

10.3 - AIMS OF THE CHAPTER

The aim of this study was to assess the range of tolerance of selected ostracod species to pH and other major ion concentrations in fresh waters, in controlled laboratory conditions. It has been previously shown in field studies that many ostracod species vary in their chemical requirements (Hiller, 1972) and therefore may be distributed along a chemical gradient.

10.4 - THE CHOICE OF SPECIES

Species that occurred in the sites sampled in the Lake District were chosen to be cultured at C.E.R.L. Fawley, as the experimental data and field data could then be directly compared.

Populations were collected from a variety of localities in Cumbria, the New Forest, Epping Forest, Kent and Derbyshire. This enabled large viable populations of ostracods to be built up in laboratory conditions, and small numbers of animals could then be extracted from their culture medium for the experiments. The populations were kept in controlled culture conditions in 5 litre aquaria. To enable maintenance of the species, a suitable food source and substrate had to be identified.

Food preference tests were performed for each species in a 'choice-chamber', a selection of four food types being available; oak leaves, cooked fish flesh, yeast, and cooked, crushed pea. All species tested favoured cooked, crushed pea as a food source, cooked vegetables previously being noted as an ideal food source for maintaining ostracods in culture (Henderson, pers. comm). A suitable substrate was found to be fine organic silt. This originated from the ponds in the New Forest, and was dried at 90 °C for 24 hours and then rehydrated with de-ionized water.

10.5 - METHODOLOGY

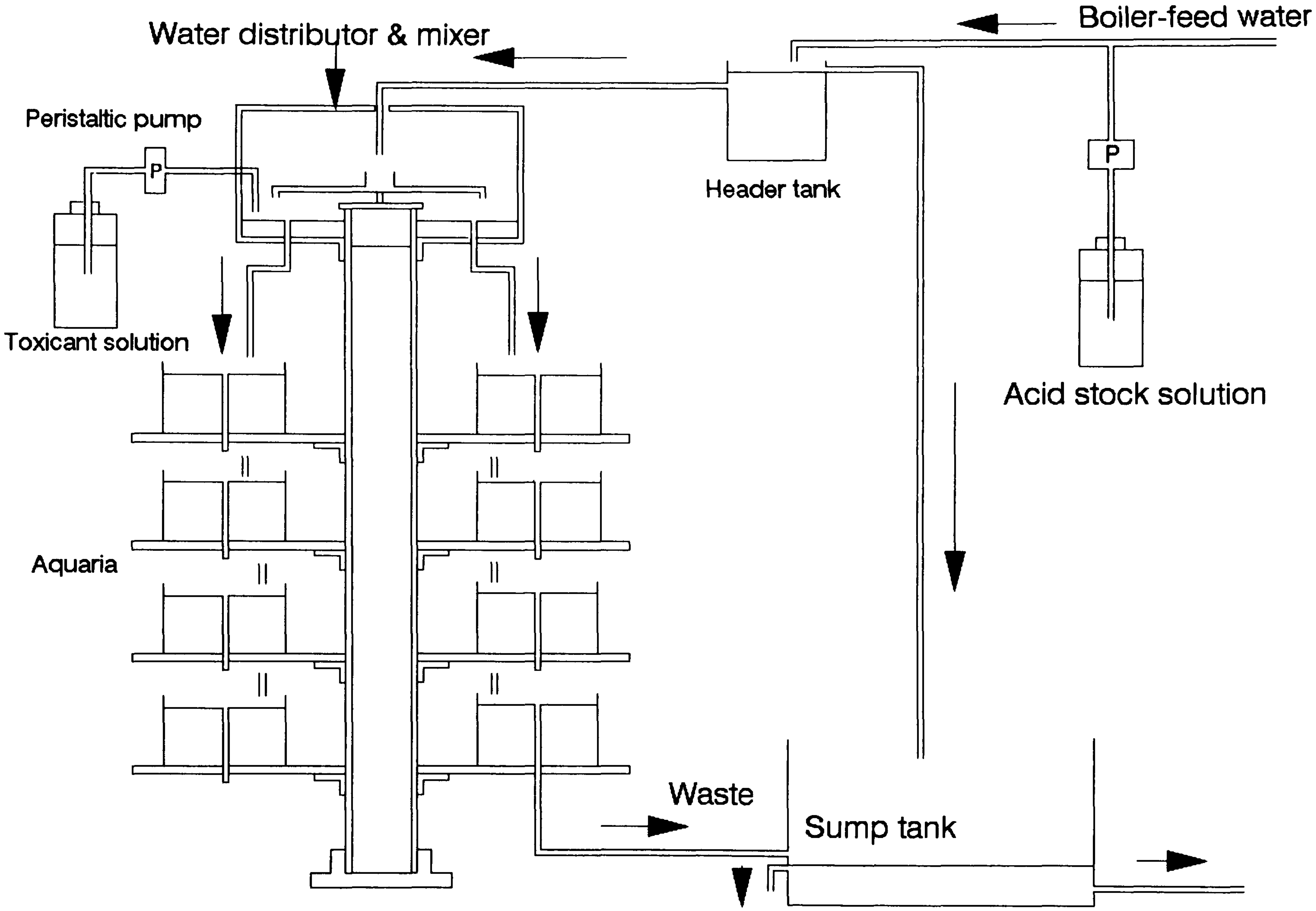
10.51 - Apparatus

Toxin response tests were performed in a Mobile Aquatic Toxicity Laboratory (Figure 10.1) designed and built by the research team at C.E.R.L. to monitor the responses of aquatic organisms to varying dosage levels of toxins. Within the mobile laboratory, water was supplied to circuits feeding four columns of tanks. Each column could be controlled independently and held 16 x 5 - litre experimental tanks, yielding a total of 64 separate aquaria. The flow-through rate in each tank was 0.3 litres per hour (5.0 mil. min.$^{-1}$). Within each column, water quality in any given tank could be modified independently by the controlled addition of chemicals, using variable speed, 16-channel, Watson-Marlow® peristaltic dosing pumps.

Solutions of each ion to be tested were made up in varying

Figure 10.1.

C.E.R.L. Mobile Toxicity Laboratory.

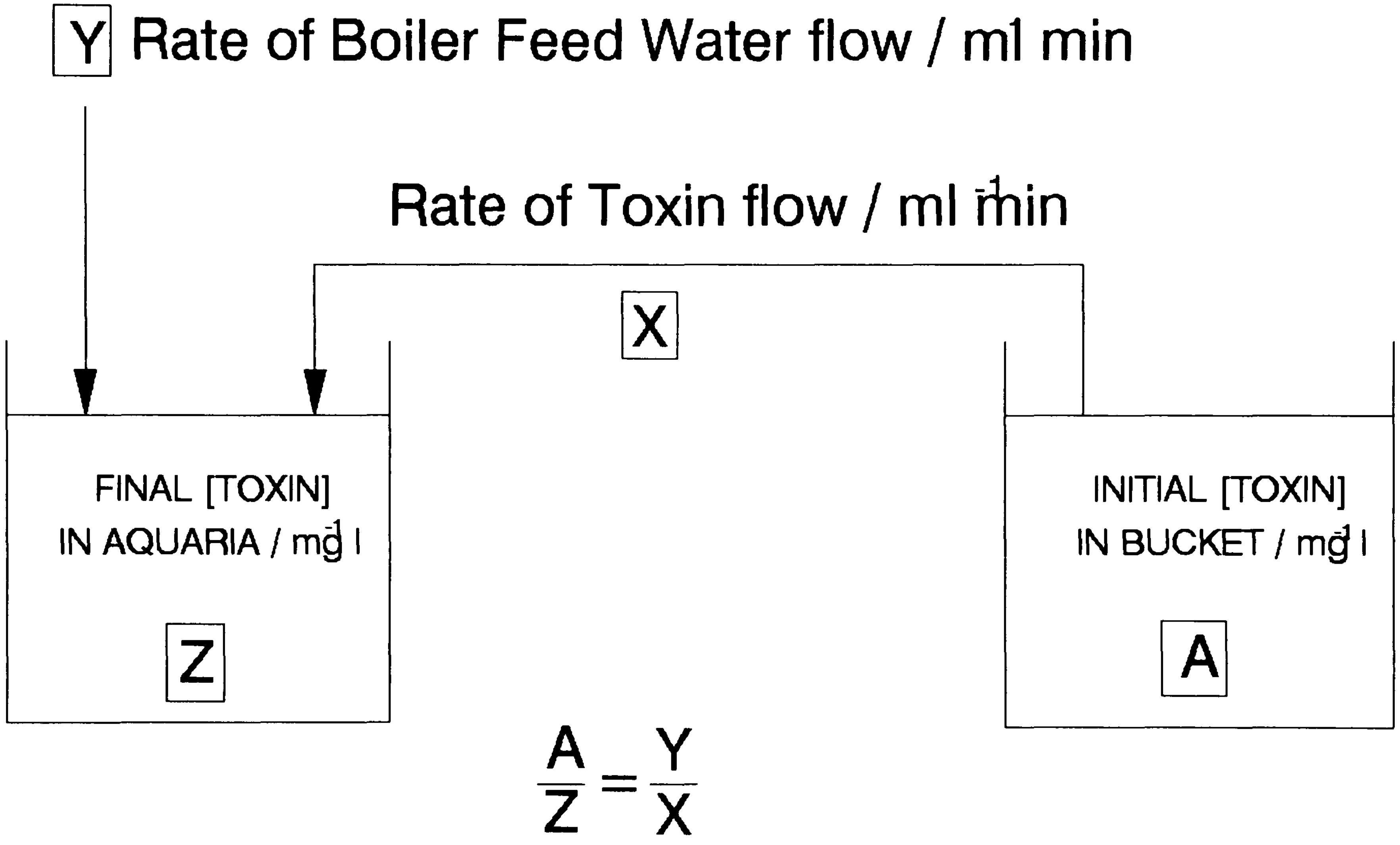


Modified from Turnpenny et al, 1988.

concentrations in 5 litre containers. These were fed through the continuous flow-through system, being diluted in the process addition of boiler-feed water to form the desired ion concentrations in the experimental tanks. A continuous flow system avoids problems of the test animals moderating the water quality. The water source used throughout the experiments was de-ionised boiler-feed water from the power station at the Fawley site. This was used for two reasons; its quantity was unlimited, and it has a negligible content of any dissolved ions. The dosage rates of the ions were controlled by the previously calibrated peristaltic dosing pumps which allowed a maximum of 64 different concentrations to be tested at any one time. The schematic mechanism summarising the technique is shown in Figure 10.2.

Ion source in all cases was derived from the carbonate compound. It was decided to vary the following parameters: pH, aluminium, calcium, magnesium and sodium. pH and aluminium were selected because their toxicity to various organisms other than ostracods has been already observed, as outlined in Chapter One. Aluminium, especially was selected as it is a major factor in the toxicity of acid waters, and is important in several of the empirical biological models used in acidification studies. The three other ions are the most important cations in freshwaters (Carrick & Sutcliffe, 1982). Initial concentration of the ions (factor *Z* in the equation) was varied between 0.01 - 5,000 ppm. The extremes of these

Figure 10.2.
Schematic Diagram.
Mobile Toxicity Laboratory.



concentrations extended well beyond the limits recorded in the Lake District.

Last stage juvenile (A-1) or adult ostracods were placed in 6 x 3 cm glass tubes with a small amount of substrate and food source (a tiny amount of cooked crushed pea), covered at one end by plankton net with mesh fine enough for ostracod retention but allowing adequate water circulation in and out of the tube. These containers were previously tested for ostracod habitat suitability by observing the survival of all the ostracod species in the tubes for a 7 day period. The survival rate in all cases was found to be the same as that experienced in the culture medium and was therefore demonstrated to be adequate for this investigation. Twenty individuals of each species were used in the first experiment, and ten in the second. The experiments were run at a constant temperature of 15 °C for a period of 7 days, water replacement operating at a rate of 10% per hour in each aquarium, giving total replacement 16.8 times in the trial period.

The rate of survival was determined by counting the number of live specimens after expiry of the experimental period.

10.52 - Single ions in solution

Calcium, magnesium, sodium and aluminium concentrations were varied at a neutral pH.

Experiments were performed separately with calcium, magnesium and sodium to assess ostracod survival in varying concentrations of single elements in solution, independent of acidity and aluminium concentrations.

Aluminium concentration in solution was also varied at a neutral pH. No other dissolved cations were added to the solution, so any variation in survival observed from the values obtained from the previous experiments should be attributable solely to the changes in aluminium concentration.

The natural concentration of aluminium in freshwaters varies between 0.005-0.1 ppm in neutral waters, but can reach levels of up to 2.0 ppm in acidified waters (Hultberg, 1983), these levels being toxic to salmonid fish (Paces, 1983). However, the mechanism of how the mortality rate of freshwater organisms varies at both low and elevated aluminium concentrations at a neutral pH is unclear. Therefore, eleven levels varying from 0.01-1000.0 ppm Al^{3+} were tested on the same ostracod species.

10.53 - Multiple ions in solution

This stage of the investigation was designed to evaluate whether the toxicity of aluminium at levels lower than 10.0 ppm is activated by increased hydrogen ion concentrations, this being previously observed for fish (for a review, see Muniz, 1983). A matrix of variables including pH, Ca^{2+} and Al^{3+} levels was formulated to test each species. Solutions of a mixture of Ca^{2+} and Al^{3+} concentrations were introduced by the method described earlier, while pH was dosed separately into the header tanks by a series of calibrated peristaltic dosing pumps. The pH solutions were altered by addition of dilute hydrochloric acid. The pH of the final solutions in each experimental tank was checked with a pH meter calibrated by use of buffers of pH 4.0 and pH 7.0 until the required pH had been attained.

pH was varied from 3-7, Ca^{2+} from 0.1-100.0 ppm and Al^{3+} from 0.01-100.0 ppm.

10.6 - RESULTS

10.61 - Single ions in solution

Observations on the cultures of ostracod species before the experiments had commenced indicated that care would have to be taken in data interpretation, as sometimes large proportions of a culture would die for no obvious reason, a phenomenon recorded previously (Henderson, pers. comm.), although many individuals may have simply completed their life cycles. Juvenile mortality was also common in the cultures, especially for Cyprinotus incongruens, which has a short life-cycle of 90 days (Henderson, 1990). In the investigations involving magnesium and sodium, Cypricercus obliquus had to be omitted from the experimental matrix due to the death of every individual in the culture. For this reason, it was decided to look for a distinct trend in the data sets rather than interpret one-off readings as an indication of species response to a specific water quality.

In consideration of potential natural mortality, the data set for the three cations indicates that survival is relatively constant between 60-100% throughout the range of experiments for all of the species except Cyprinotus incongruens (Tables 10.61 a-c, Appendix 14.10). This species showed a definite increase in mortality once the calcium level had decreased to 1.0 ppm, survival dropping to 35-50%. However, at similar concentrations of sodium and magnesium at 0.01-1.0 ppm, survival was similar to that at higher concentrations, and in these experiments there was no calcium present in the water. This illustrates the point that was qualitatively observed earlier, that there is variability in the survival of some species, especially Cyprinotus incongruens, and care should be taken in interpretation of the results.

Overall, it seems that at least five species, and possibly also Cyprinotus incongruens, exhibit a wide range of tolerance to major cationic concentrations at a neutral pH, suggesting that another variable is significant in determining species distribution in acidic waters.

The results of the investigation of the influence of aluminium on ostracod survival (Table 10.61d, Appendix 14.10) indicate that three species, Cypria ophthalmica, Cypridopsis vidua and Herpetocypris chevreuxi display a relatively constant survival from 65-100% throughout the range of aluminium concentrations, the data not differing significantly from those obtained from the experiments using calcium, magnesium and sodium. Cyclocypris ovum, Cypricercus obliquus and Cyprinotus incongruens, however, all showed increased mortality at aluminium concentrations greater than 5 ppm, this level being the drop-off point in survivorship for all three species. However, although the aluminium concentrations at these high levels appear to be toxic to the ostracods, it must be noted that they are never encountered in natural waters, not even in sites with a pH of 4 or less.

10.62 - Multiple ions in solution

This matrix of data was analysed by means of Analysis of Variance. This technique of analysis examines the variation within a whole group of sample means (Parker, 1979). Despite its name, analysis of variance does not involve an actual analysis of the variance itself, but analyses the partitioning of the total sum-of-squares (Σx^2) to provide several variance estimates which may then be compared. The data are shown in the appendices. The results are presented species by species.

Table 10.61 - ANOVA Statistics

1. *Cypria ophthalmica*

Source	**D.F.**	**ANOVA SS**	**M.S.**	**F-VALUE**	**Pr > F**
Model.	39	1089.34	27.93	22.14	0.0001*
Al.	4	26.74	6.69	5.30	0.0010*
Ca.	3	3.44	1.15	0.91	0.4422
pH.	4	1028.94	257.24	203.89	0.0001*
Al*pH.	16	17.36	1.09	0.86	0.6154
Al*Ca.	12	12.86	1.07	0.85	0.6007

2. *Cypridopsis vidua*

Model	39	1072.74	27.51	16.29	0.0001*
Al.	4	27.04	6.76	4.00	0.0061*
Ca.	3	9.80	3.27	1.93	0.1336
pH.	4	929.84	232.46	137.69	0.0001*
Al*pH	16	93.66	5.85	3.47	0.0002*
Al*Ca	12	12.40	1.03	0.61	0.8236

3. *Herpetocypris chevreuxi*

Model	51	1024.44	20.09	14.53	0.0001*
Al.	4	28.77	7.20	4.98	0.0016*
Ca.	3	8.31	2.77	1.75	0.1956
pH.	4	895.31	223.83	159.95	0.0001*
Al*pH	16	65.12	4.07	2.80	0.0031*
Al*Ca	12	20.58	1.71	1.18	0.3140
Ca*pH	12	6.35	0.53	0.49	0.8895

4. *Cyclocypris ovum*

Model.	51	1170.20	22.95	22.10	0.0001*
Al.	4	414.34	103.59	99.76	0.0001*
Ca.	3	2.04	0.68	0.65	0.5838
pH.	4	594.54	148.64	143.15	0.0001*
Al*pH.	16	142.16	8.89	8.56	0.0001*
Al*Ca.	12	8.86	0.74	0.71	0.7331
Ca*pH.	12	8.26	0.69	0.66	0.7772

5. *Candona candida*

Source	**D.F.**	**ANOVA SS**	**M.S.**	**F-VALUE**	**Pr > F**
Model.	51	1006.47	19.73	13.60	0.0001*
Al.	4	28.56	7.14	4.92	0.0021*
Ca.	3	10.19	3.40	2.34	0.0850
pH.	4	867.66	216.92	149.51	0.0001*
Al*pH.	16	67.64	4.23	2.91	0.0021*
Al*Ca.	12	22.56	1.88	1.30	0.2520
Ca*pH.	12	9.86	0.82	0.86	0.8579

6. *Candona rostrata*

Model.	51	306.53	6.01	2.17	0.0038*
Al.	4	63.94	15.99	5.78	0.0007*
Ca.	3	12.11	4.04	1.46	0.2377
pH.	4	98.64	24.66	8.91	0.0001*
Al*pH.	16	51.06	3.19	1.15	0.3380
Al*Ca.	12	57.74	4.81	1.74	0.0877
Ca*pH.	12	23.04	1.92	0.69	0.7493

7. *Cypricercus fuscatus*

Model.	51	281.94	5.53	1.86	0.0162*
Al.	4	35.54	8.89	2.98	0.0280*
Ca.	3	25.40	8.47	2.84	0.0474*
pH.	4	61.74	15.44	5.18	0.0015*
Al*pH.	16	38.06	2.38	0.80	0.6794
Al*Ca.	12	42.30	3.53	1.18	0.3212
Ca*pH.	12	78.90	6.58	2.21	0.0263*

8. *Candona siliquosa*

Model.	51	276.94	5.43	2.09	0.0069*
Al.	4	57.58	14.39	5.21	0.0010*
Ca.	3	25.40	3.73	3.81	0.2585
pH.	4	56.53	14.13	6.10	0.0004*
Al*pH.	16	45.80	2.86	1.01	0.4952
Al*Ca.	12	57.34	4.78	1.68	0.0955
Ca*pH.	12	48.51	4.04	1.64	0.1004

9. Cypricercus obliquus

Source	**D.F.**	**ANOVA SS**	**M.S.**	**F-VALUE**	**Pr > F**
Model.	51	1230.39	24.13	20.20	0.0001*
Al.	4	483.76	120.94	101.28	0.0001*
Ca.	3	2.67	0.89	0.75	0.5304
pH.	4	562.76	140.69	117.81	0.0001*
Al*pH.	16	142.44	8.90	7.45	0.0001*
Al*Ca.	12	18.08	1.51	1.26	0.2718
Ca*pH	12	20.68	1.72	1.44	0.1799

(**Source** = sources of variation; **D.F.** = degrees of freedom; **ANOVA SS** = sums-of-squares of Analysis of Variance; **M.S.** = mean square; **F-Value** = statistic termed 'the variance ratio'; **Pr > F** = significance level.)

The survival levels of all nine species show statistically significant negative correlations with both increasing Al $^{3+}$ concentration and decreasing pH, but only Cypricercus fuscatus is affected by calcium concentration. However, the types of 'parameter interaction' vary between species. There appear to be three different kinds of response.

A) A significant correlation with both pH and aluminium, but no significant interactions between these parameters occur. This response is shown by Cypria ophthalmica, Candona rostrata and Candona siliquosa.

Examination of the data shows that C. rostrata and C. siliquosa display virtually identical responses to the differing toxin levels. There is a lower mean survival rate at pH 3 of 5.25 for C. rostrata and 5.50 for C. siliquosa than at the other pH levels, the survival values here ranging from 7.40-8.00 for C. rostrata and 7.65-8.20 for C. siliquosa (Tables 10.62f, 10.62h, Appendix 14.10). The survival values of these two species also decreased at elevated aluminium concentrations. At other pH levels this effect is not seen, which explains the lack of correlation for a total interaction between pH and aluminium. C. ophthalmica shows the same pattern of response, but the values at which the response occurs differ from the other two species. At pH 3, there is a very low mean survival rate at all aluminium concentrations, this still being zero at an aluminium concentration of greater than 10 ppm. In addition, at pH 4, survival is decreased at the greatest aluminium concentration of 100 ppm. At other pH levels, no effect is seen.

B) A significant correlation with pH and aluminium, and a statistically significant interaction between pH and aluminium.

This response is shown by Cypridopsis vidua, Herpetocypris chevreuxi, Cyclocypris ovum, Candona candida and Cypricercus obliquus.

This group of five species may be divided into two groups. Firstly, the responses shown by C. candida (Table 10.62e, Appendix 14.10), C. vidua (Table 10.62b, Appendix 14.10), and H. chevreuxi (Table 10.62c, Appendix 14.10) are virtually identical. At pH 3, there is no survival at any aluminium concentrations. At pH 4, there is a very low survival rate at an aluminium concentration of 100 ppm, and a slightly lower survival rate at 10 ppm than at lower concentrations of Al^{3+}. There is no response at other pH levels. The second group, consisting of

C. ovum (Table 10.62d, Appendix 14.10) and C. obliquus (Table 10.62j, Appendix 14.10), displays a different form of interaction. Again, there is no survival at any aluminium concentration at pH 3, but at all other pH levels, from 4-7, there is a significant reduction in survival at an aluminium concentration of greater than 10 ppm. Therefore, at the less acidic pH values, the aluminium is still a toxic agent. This same effect was observed for these two species in the investigation of the effect of aluminium concentration at a neutral pH at varying calcium levels.

C) A significant correlation with pH, calcium and aluminium, and a statistically significant interaction between pH and calcium. This response is shown by Cypricercus fuscatus (Table 10.62g, Appendix 14.10).

This species is the only one to show any statistically significant response to changes in calcium ion concentration. This effect is only seen at pH 3. At this level of acidity, at calcium levels of greater than 10 ppm, ostracod survival is constant at all aluminium levels, but at calcium levels of less than 10 ppm, survival is reduced to zero at aluminium concentrations of greater than 10 ppm, this being a similar reaction as shown by C. rostrata and C. siliquosa.

Previous work on the survival rate of the eggs and fry of the Brown Trout (Salmo trutta) has found that calcium concentrations can mitigate the toxicity of aluminium (Brown, 1982). C. fuscatus is the only species tested which demonstrates this phenomenon.

The data enables the species to be ranked in an order of their response to acute toxicity. Table 10.63 orders the species, in decreasing survival, to pH and [Al] levels.

Table 10.63 - Survival Rankings (in order of decreasing tolerance)

Rank	**Species/pH**	**Rank**	**Species/[Al]**
1	C.fuscatus	1	C.fuscatus
2	C.siliquosa	2	C.siliquosa
2	C.rostrata	2	C.rostrata
4	C.ophthalmica	4	C.ophthalmica
5	C.candida	5	C.candida
5	H.chevreuxi	5	H.chevreuxi
5	C.vidua	5	C.vidua
8	C.ovum	8	C.ovum
8	C.obliquus	8	C.obliquus

It can be seen that the ranking for the two parameters is identical for all the species.

This order of ranking can be seen to correlate with the three types of response. The species ranked as 1, C. fuscatus is the only one to show response (C) (significant responses to all 3 parameters and a pH*Ca interaction). The three species ranked 2 to 4, C. siliquosa, C. rostrata and C. ophthalmica all show response (A), (response to pH and Al, but no interactions between these parameters). Finally, the five remaining species, ranked 5-8 all show response (B), (response to pH and Al, and a significant interaction between these two parameters exists).

In fact, the ranking almost appears to be in an order of increasing aluminium interaction. This will be further discussed later.

10.7 - DISCUSSION

There has been no previous work on the toxicity of aluminium in relation to survival of Ostracoda.
However, data exist on the minimum pH levels tolerable by eight of the nine species in this investigation, there being no recorded data for C. siliquosa.

The previous data ordered into ranks for the pH values is represented in Table 10.71.

Table 10.71 - Species pH tolerance cited by the literature

Rank	**Species**	**Minimum recorded pH value**
1	Cypria ophthalmica	3.0 (Lowndes, 1952)
2	Cypridopsis vidua	4.0 (Lowndes, 1952)
2	Cypricercus obliquus	4.0 (Lowndes, 1952)
4	Candona candida	5.0 (Fryer, 1980)
5	Cyclocypris ovum	5.38 (Fryer & Forshaw, 1979)
6	Herpetocypris chevreuxi	6.5 (Hollwedel & Scharf, 1988)
7	Cypricercus fuscatus	7.0 (Lowndes, 1952)
8	Candona rostrata	7.5 (Janz, 1983)

Comparing these previously found field data with the data obtained from the experimental work, in terms of rank, there is no similarity in the data sets. Indeed, the two species which appear to show the greatest resilience to the harshest environmental conditions in these experiments appear to be those previously never recorded below pH 7.0 !

At this stage it is useful to consider the ranking order of these nine species in the field in the Lake District. Is this order similar to that found by experiment, similar to the previous data, or dissimilar to both ?

Cypria ophthalmica is a very tolerant species in the natural environment, often reaching its greatest densities in very eutrophic ponds rich in Ca $^{2+}$ (Fryer, 1955; Pierre, 1973), and has been found between pH 3.0-11.1, and Ca $^{2+}$ 0.6-271 ppm (Lowndes, 1952; Hiller, 1972; Janz, 1983). Its chemical range in the Lake District was: pH 5.0 (Floutern Tarn) - 8.0 (Browns Tarn), and Ca $^{2+}$ 1.16 (Floutern Tarn) - 48 ppm (Skelsmergh Tarn).

Cypridopsis vidua has been previously recorded between pH 4.0-11.1, and Ca $^{2+}$ 22-110 ppm (Lowndes, 1952; Hiller, 1972; Benzie, 1989). In the Lake District its range was: pH 6.2 (Barrow Plantation Tarn A, Low Water, Buttermere, Manesty Park Tarn) - 7.8 (Tewet Tarn, Skelsmergh Tarn), Ca $^{2+}$ 2.4 (Buttermere) - 48 ppm (Skelsmergh Tarn).

Herpetocypris chevreuxi has been previously recorded between pH 6.5-8.5 (Hollwedel & Scharf, 1988). The only site at which this species was found was Barrow Plantation Tarn D of pH 6.5, Ca $^{2+}$ 6.76 ppm.

Cyclocypris ovum has previously been shown to exhibit a marked antipathy towards acidic sites (Fryer & Forshaw, 1979; Janz, 1983). Its chemical range in the literature is pH 5.38-11.1, Ca $^{2+}$ 14-144ppm. (Lowndes, 1952; Hiller, 1972; Fryer & Forshaw, 1979). In the Lake District, its limits were: pH 4.6 (Parkgate Tarn) - 7.8 (Skelsmergh Tarn), Ca $^{2+}$ 1.8 (Lily Tarn) - 48 ppm (Skelsmergh Tarn).

Candona candida has been recorded between pH 5.0-10.1, Ca $^{2+}$ 14-147 ppm, Mg $^{2+}$ 41 ppm (Lowndes, 1931, 1952; Fryer, 1955, 1980; Hiller, 1972; Hollwedel & Scharf, 1988). Fryer (1980) states that only C. candida and Cyclocypris laevis may be found in tarns with a pH of less than 5. Its Lake District range was: pH 6.2 (Barrow Plantation Tarn A, Manesty Park Tarn, Little Langdale Tarn) - 8.0 (Browns Tarn), Ca $^{2+}$ 2.28 (Wast Water) - 48 ppm (Skelsmergh Tarn).

Candona rostrata has been found in almost saline conditions, being capable of surviving salinities up to 5,000 ppm Na^+ Cl^- (Yassini, 1969). pH ranges varied from include 7.5-8.4, Ca $^{2+}$ 22-34 ppm (Janz, 1983; Benzie, 1989). In the Lake District, its limits were: pH 5.9 (Rosley Thorns Pool) - 7.2 (Boo Tarn), Ca $^{2+}$ 2.0 (Burnmoor Tarn) - 7.68 ppm (Overwater).

Cypricercus fuscatus has previously been recorded at pH 7.0-9.5, Ca $^{2+}$ 21-145 ppm (Lowndes, 1952; Hiller, 1972), a truly freshwater species (Neale, 1964). Its Lake District range was: pH 6.5 (Thirlmere) - 7.2 (Tosh Tarn), Ca $^{2+}$ 3.04 (Thirlmere) - 17.8 ppm (Rather Heath Tarn).

Cypricercus obliquus seems to have a wide pH tolerance of 4.0-9.2 according to Lowndes (1952), being found in Cold Hiendley Reservoir in Huddersfield (Fryer, 1955) which owes its very rich assemblage of Crustacea to the gypsum beds which underlie the surrounding land, giving rise to a high salt content in the water (pH 7.0-7.5, Ca $^{2+}$ 75 ppm, Mg $^{2+}$ 41 ppm. In the Lake District, its chemical range was: pH 6.2 (Barrow

Plantation Tarn A, Devoke Water) - 7.5 (Knipe Tarn), Ca $^{2+}$ 2.44 (Devoke Water) - 11.4 ppm (Knittleton Tarn B).

There are no previous chemical data for Candona siliquosa; its chemical range in the Lake District was: pH 6.0 (White Moss Tarn) - 7.4 (Mockerkin Tarn), Ca $^{2+}$ 5.76 (Bassenthwaite Lake) - 12.54 ppm (Mockerkin Tarn).

The lowest pH in which any species was found in this study is listed below, and the species ranked.

Table 10.72 - Species pH lower limits in the Lake District

Rank	**Species**	**Minimum pH level**
1	C.ovum	4.6
2	C.ophthalmica	5.0
3	C.rostrata	5.9
4	C.siliquosa	6.0
5	C.candida	6.2
5	C.vidua	6.2
5	C.obliquus	6.2
8	C.fuscatus	6.5
8	H.chevreuxi	6.5

In this case, the order of survival with respect to pH shows some similarity to the experimental data, but not to the previously recorded data. Here, three out of the first four ranked species, C. ophthalmica, C. rostrata and C. siliquosa are the same as in the experimental data. The ranking order below those species is also quite similar in both tables, close similarities between C. candida, C. vidua, and H. chevreuxi. Only for two species, C. ovum and C. fuscatus are there major discrepancies between the data sets. Although C. fuscatus is only recorded at a minimum pH of 6.5 in the Lake District, this is likely to be due more to the limitation of suitable sites for the species than restriction due to intolerance of acidity. The largest populations of this species are most often found in woodland pools which have a leaf-litter substrate (Henderson, 1990) and in the New Forest, these sites are often quite acidic, having a pH of around 4.5 (Henderson, pers. comm), and contain no other species of ostracod. Few such woodland pools can be found in the Lake District. If these data are added to those from the Lake District, then C. fuscatus would be ranked as one of the most acid-tolerant species in the fieldwork rankings, correlating well with the experimental work. The results for C. ovum are difficult to justify, as it was the species which occurred in a site (Parkgate Tarn) with a lower pH than any other ostracod species was found at.

Overall, it appears that the absence of species in sites within the Lake District is not determined by acute toxicity through the combination of acidity and the subsequent increase in toxic metal cations, as otherwise the species used in the experimental work would have died out at similar thresholds to the levels found in the Lake District. This suggests that species distribution is at least partly controlled by factors other than pH and metal ion concentrations. Factors that have been shown here to be important include substrate, as shown for C. fuscatus, and possibly other cations and anions. The results documented in this chapter demonstrate the limited value of studying the effects of the acute toxicity of Al^{3+} and acidity upon the survival of mature ostracods.

It appears that ostracod distribution is probably limited and hence subsequently determined by the ability of different species to breed successfully in specific physico-chemical environments, and not the survival tolerance of the adults. This observation has been previously recorded for both fish and invertebrates. Brown (1982), found that Brown Trout (Salmo trutta) could maintain growth independent of pH or calcium down to a pH of 4.4, conditions which are in a range lethal to the eggs of the species. Acidic pH was shown to increase mortality, inhibit development and reduce growth in larvae of the bivalves Mercenaria mercenaria and Crassostrea virginica (Calabrese & Davis, 1966). Bamber (1987, 1990) found that pH levels below those found naturally are intolerable to the young carpet-shell clam Venerupis decussata, and the spat of the mussel Mytilus edulis, and whilst larger individuals are more tolerant of subnormal pH, exposed populations would die out through lack of recruitment. Hence, there may be tolerance ranges for successful reproduction, a water chemistry which may allow the survival of an adult ostracod may inhibit the reproductive success of the species. This mechanism would allow adult survival in the toxicity tests, but would lead to the failure of egg hatching in the same environment.

There is a need for more detailed studies on life cycles, ontogeny, and particularly on the development of ostracod eggs and hatching mortality in specific physico-chemical environments. While the adults of many ostracod species have been shown to be tolerant to acidity and high aluminium concentrations, the ultimate test of significant effect is whether animals would survive to produce viable offspring.

CHAPTER 11 - DISCUSSION.

11.1

Before the distribution of the Lake District Ostracoda is discussed, some aspects of the methodology used in this study will be considered.

1) Were both the number and range of sites appropriate to the project aims and sufficient to reach conclusions ?

The main intention of this project was to relate individual species distribution and community structure to water quality with respect to permanent stillwaters. The total number of sites studied was 91, comprising 75 from the main data set, and 16 from the test data set. The widest possible range of sites was sampled, from large lakes including Windermere (sites 2 & 3) and Ullswater (site 54), to small enriched farmyard ponds, such as Clay Pond (site 22) and Cat Crag Tarn (site T15), to tiny acidic bogpools such as Haystacks Tarn A (site 52) and Black Pool (site 73). This gave as broad a representation as possible of permanent still waters in the Lake District, which was essential to satisfy the aims of the project.

Conclusions were able to be successfully reached on considering the data base that was available by this sampling regime. Obviously, if other types of site, such as streams and rivers, or temporary pools were sampled, then a wider range of Ostracoda would have been collected.

2) Was the sampling methodology suitable and what, if any,

bias did it introduce ?

The sampling methodology proved to be suitable for the main aims of this study. Ideally, quarterly, or even monthly sampling of each site would have been conducted, but the time required to conduct such sampling and analyse the samples would have entailed a considerable reduction in the number of sites included in the survey. As a result of this compromise, some species may have been missed, especially if they were solely spring forms, and this is shown in Chapter 7. However, it should be noted that if this was so in more than a few isolated cases, then empty carapaces or valves of these species would have almost certainly been collected, and this was not the case.

At some sites, there may have been species living just off the marginal zone at perhaps 1 to 3 metres depth that were different to the fauna collected in the shallower marginal water. However, if this was so, then sediment movement in this often unstable zone would have allowed the carapaces to drift into the margins and be collected.

3) How successful was the sorting method ?

The main problem encountered with sorting of the samples arose when small (A-4 and earlier) juveniles were removed from the preservation medium and placed on micropalaeontological microscope slides. These instars, especially those originating from waters of low total dissolved ion content, were especially prone to decalcification. This was a major problem when attempting to identify the developmental stages of some species, especially the genus *Candona*, as accurate valve measurements were impossible. All other aspects of the sorting and picking methods were considered successful.

4) Is a marginal site at a large lake any different from that at a small tarn ?

In Chapter five it was shown that the marginal distribution and abundance of several species was clearly influenced by the size of the site. Three species, *Cypria ophthalmica*, *Cyclocypris ovum* and *Candona reducta* displayed a tendency to occur in small waterbodies, and total density per site increased with decreasing site size. *Cyclocypris serena* showed the opposite response in that it displayed a distinct preference for larger sites.

11.2

The distribution of the Lake District Ostracoda will now be considered.

32 species of Ostracoda were recorded from the Lake District in this study. 31 were previously known British species, whilst one, *Potamocypris sp. A* is previously undescribed. If these data are added to the 6 species previously recorded in the study area but not in this study (see Chapter 2), a total of 38 species is reached, 36 of which were sampled from permanent still waters. Two previously recorded species, *Eucypris pigra* and *Psychrodromus robertsoni* are recorded only in running water (Henderson, 1990).

The important factors controlling both community structure and individual species abundance include pH, calcium and magnesium ion concentration, lake size, substrate and fish presence.

Within Great Britain, several other species are known from permanent still waters (Henderson, 1990). These include; *Limnocythere inopinata* (Baird, 1843), *Ilyocypris gibba* (Ramdohr, 1808), *Ilyocypris monstrifica* (Norman, 1862), *Candona hyalina* (Brady & Robertson, 1870), *Candona insculpta* (Muller, 1900), *Candona protzi* (Hartwig, 1898), *Candona stagnalis* (Sars, 1890), *Potamocypris dianae* (Fox, 1963), *Potamocypris similis* (Muller, 1912), *Potamocypris variegata* (Brady & Norman, 1889), *Cypridopsis obesa* (Brady & Robertson, 1869), *Plesiocypridopsis newtoni* (Brady & Robertson, 1870) and *Isocypris beauchampi* (Paris, 1919). Adding these to the 36 species recorded from the study area yields a potential total of 49 species from permanent still waters in the Lake District.

The most common species recorded in this survey are those which are often the most numerous in comparable studies in Europe. These are, *Cypria ophthalmica*, *Candona candida* and *Cypridopsis vidua*. *C. ophthalmica* especially, has often been recorded as dominating in a study area (Lowndes, 1931; Kohler & Arlt, 1984; Fryer, 1985; Scharf, 1988). A species rarely important in comparable surveys that was often dominant at sites in the Lake District was *Metacypris cordata*.

11.3

Five species of Ostracoda dominate in 71% (44/62) of the sites in the Lake District. A brief discussion will now follow on the ecology of these species.

Cypria ophthalmica is one of the most common species in Great Britain and Europe (Henderson, 1990), and is the most abundant species in the Lake District, dominating especially in small non-acidic tarns and silted-up farmyard ponds. Previous workers have shown that this species often dominates in a study area (Lowndes, 1931; Fryer, 1985; Scharf, 1988) and is one of the few species that can tolerate acidity (Hiller, 1972; Fryer & Forshaw, 1979; Janz, 1983), being recorded in a pH as low as 3.0 (Lowndes, 1952). This correlates to an extent with the findings of this study, as *C. ophthalmica* was recorded at pH 5.0 in Floutern Tarn, the second highest acidity in which an ostracod was recorded in the Lake District.

Cypridopsis vidua appears to dominate, especially in the summer months, in alkaline sites of size classes C and D where there is extensive marginal macrophyte growth on a bed of fine sand or gravel. This species has previously been shown to favour the presence of macrophytes, swimming between the individual leaf fronds (De Deckker, 1979; Fryer & Forshaw, 1979; Danielopol *et al*, 1985; Fryer, 1985; Carbonel *et al*, 1988; Scharf, 1988) and to dominate in sites with a rocky substrate (Scharf, 1988), as well as being a noted summer form (Hoft, 1943; Fox, 1965).

Prior to this study, Loughrigg Tarn was the only site in

England where living specimens of Metacypris cordata had been found (Horne, 1988). Surprisingly, it has been shown to rank as 3 in this survey, occurring in 9 sites, often in great densities. The literature data base for this species is poor, although Hiller (1972) indicates it shows a preference for rich waterbodies, never being found below pH 6.9. This corresponds to its distribution in the Lake District, where M. cordata regularly occurs in tarns rich in calcium and magnesium that have boggy marginal regions.

The male dominance in the winter period is difficult to explain for M. cordata. It is possible that the adult female dies in autumn as part of the reproductive strategy of brood care and the remains could be eaten by the early instars in the brood chamber before they emerge (Horne, pers. comm.). However, why the males go on surviving is still rather problematic, as their existence is now unnecessary.

Candona candida is an important species in the Lake District, occurring in 44 sites, preferring large, non-acidic waters, often of size class A, a phenomenon previously noted (Robertson, 1880; Lowndes, 1931; Fryer, 1955; 1985; Fox, 1965). Although this species has been previously recorded in acidic sites (Fryer & Forshaw, 1979), it was never found below pH 6.2 (Barrow Plantation Tarn A and Manesty Park Tarn) in this study. Analysis of the proportions of adults to juveniles in the samples suggests adults are present in the winter period, whilst juveniles predominate in the summer, corresponding closely to the life history suggested by Hiller (1972) and Scharf (1988).

Cyclocypris ovum appears to show a slight preference for smaller waterbodies, but this distribution is extremely patchy and difficult to predict. Its tolerance to acidity is also unclear. Previous reports give pH 5.38 as the greatest acidity in which the species was collected (Lowndes, 1952; Hiller, 1972; Fryer & Forshaw, 1979; Janz, 1983), whilst in the Lake District it occurred in Park-gate Tarn, a site with a pH of 4.6.

Five species, Candona lactea, Cypricercus affinis, Eucypris pigra, Psychrodromus robertsoni and Cytherissa lacustris that were previously recorded from the Lake District (Horne, Horne, and Horne, 1990) were not collected in this survey. Of these, both E. pigra and P. robertsoni are species found only in lentic (streams and rivers) sites (Henderson, 1990), and were hence unlikely to be found by this survey which did not include running-water sites in its plan. Only one specimen of C. lacustris has been recorded from the Lake District at a depth of 60 metres in Windermere (Holmes, 1937), but both C. lactea and C. affinis have been recently collected by Horne (1988) in lotic sites. C.affinis was recorded at Middle Fairbank Tarn (a site not included in this survey) in October 1986, so it is possible that the life cycle of this species prevented it from being sampled in this survey. Candona lactea, however, was collected from Brotherswater (site 31 in this survey) in August, 1987, and its absence from the summer collection from that site cannot be accounted for.

There are several genera and species groups that are absent from the Lake District data set. These include those related to other types of habitat unsampled in this survey, such as temporary pools and lentic habitats. Temporary pool species include members of the genus *Eucypris* which are especially numerous in such habitats (Henderson, 1990). Stream and river (lentic) species, such as the genus *Psychrodromus*, *Eucypris pigra* and some species of the genus *Potamocypris* are also absent.

Rich water species, such as those with heavily calcified valves were noticable by their rarity in the Lake District, especially members of the genera *Ilyocypris* and *Limnocythere*. Only two sites contained *Ilyocypris*. A single specimen of *I. bradyii* was recorded from Barrow Plantation Tarn A (site 23), whilst *I. decipiens* was the dominant species in the summer sampling period in Browns Tarn (site 69). The latter site noticeably had the greatest pH and alkalinity (see Appendices) of all the waterbodies sampled. The absence of this genus in the Lake District is therefore probably a function of low alkalinity and calcium levels when compared to lakes rich in the genus. I have found large densities of *I. decipiens* and *I. gibba* in the calcium rich gravel pits of the Darenth Valley in Kent, and in Hatchet Pond in the New Forest, Hampshire.

Another permanent water species recorded from Hatchet Pond that is absent in the Lake District is *Isocypris beauchampi*, which is considered a warm water form (Henderson, 1990).

From these observations, it may be deduced that the Lake

District is not particularly species-rich. If one considers that 75 marginal and 6 deep-water sites were sampled, a diversity of 32 species is quite low. In addition, each site is relatively low in species abundance, the maximum recorded being 11 from Loughrigg Tarn (site 36). This figure is exceeded in many waterbodies in the New Forest (P. Henderson, pers. comm.)

The poor species richness of the Lake District is emphasized when data from other publications are analysed. Scharf (1988) recorded 30 species from 23 permanent waterbodies in the "Hordter Rheinaue" nature reserve in Germany, 21 of which were British species and 12 of which were recorded in the Lake District. The genus especially recorded here but noticeably under-represented in the Lake District was *Ilyocypris*. Hollwedel & Scharf (1988) recorded 25 species from 14 sites on the German islands of Mellum and Memmert, 14 of which were recorded in the Lake District. Species present here but absent in the Lake District included members of the genera *Potamocypris* and *Cypridopsis*. Janz (1983) recorded 23 species from 23 sites in Hamburg, Germany, 13 of which corresponded to those found in the Lake District. Species present here and rare or absent in this study again included members of the genera *Ilyocypris* and *Cypridopsis*.

Martens & Dumont (1984) recorded 29 species from one site, Lake Donk in Belgium, during several sampling periods between 1964-1984. This site is especially rich in diverse biotopes and had 17 species corresponding to those of the Lake District.

species present here but missing in the Lakes again included members of the genera Ilyocypris and Potamocypris.

Therefore, to summarise, the poor species richness both overall in the Lake District and per site are due to three main factors:

a) Lack of temporary pools and lentic sites in study plan.
b) All Lake District waters have relatively low alkalinities and low quantities of dissolved cations.
c) Low temperature.

However, there may be other explanations for species absence from a site.

Chapter 9 showed that the size of an ostracod influenced the rate of fish predation upon it. Increasing ostracod size was correlated with an increased rate of predation. The influence of potential predation was seen in the field data, large swimming species and large densities of smaller swimming species never being present in sites containing fish.Imperfect dispersal could prevent a suitable ostracod species from arriving in a habitat, or delay its introduction until a later stage in colonisation when competitive difficulties with the other species make colonisation impossible (Talling, 1951). At this stage it can be seen that the age of a lake or tarn is important, especially with respect to the younger waterbodies. Sites of the same age, and subsequent macrophytic succession may possess a similar ostracod fauna, if they have relatively similar physico-chemical parameters, factors which will also change with age. Hence, some species may inhabit older waterbodies as it is difficult for new species to enter and successfully outcompete them, a situation shown with the Copepoda (Carl, 1940). Consequently, other species will be found in younger sites, as they are unable to withstand the intense competition in the older lakes and tarns which will be less in a poorly established site.

With reference to dispersal, ostracods may be transferred to other sites by both active and passive mechanisms. They have been shown to attach themselves to the legs of flying water beetles (Sharpe, 1918) and amphibians (Seidel, 1989), giving the potential of transportation to another site. The eggs of many species are resistant to desiccation (Kesling, 1951), and have been raised from dried mud of over 10 years in age (Talling, 1951). A group of animals that exhibit this feature will have the potential for their eggs to be transported in dust, or via mud carried on the feet of animals which may walk in the water, to other sites.

11.4

We can now consider the ecological importance of the Ostracoda in the Lake District.

In the marginal zones of the lakes and tarns, ostracods vary in their ecological importance. Obviously, in acidic waters, their contribution to the energy flux through the system is non-existent, and on the exposed rocky shores on the margins of the bigger lakes, especially those in size class A, their contribution must be negligible. However, in small, ion-enriched pools such as Clay Pond (site 22), the Barrow Plantation Tarns (sites 23-26), Parsonby Tarn (site 71), Manesty Park Tarn (site 72), Skelsmergh Tarn (site 74) and Boo Tarn (site 75), ostracod density is sufficiently high to warrant their consideration as very important contributors to the nutrient cycling of these waterbodies as detritivorous organisms.

11.5

How predictable are ostracod communities ?

The data set, when tested in Chapter 6, showed that ostracod community structure could be predicted with a fair degree of accuracy, especially with respect to species number and overall density per site. Several species had clearly defined habitats, such as Metacypris cordata, Cypridopsis vidua, Cyclocypris serena, Candona fabaeformis and Candona reducta, as described in Chapter 5. However, some species were seemingly random in their distribution, especially Cyclocypris ovum.

This raises the question of how the Lake District data may be applied, especially with reference to potential indicator species for use in palaeolimnology. Any of the above five species, with clearly defined habitats could be used in environmental interpretation, but in addition the community structure as a whole must be examined.

The investigation currently suggests that substrate type is an extremely important factor in controlling ostracod distribution, and that in the absence of biotic pressures some species are tolerant to changes in water chemistry. This suggests that there may be a problem in using individual species as indicators of a particular water quality, especially if the results are to be used in palaeolimnological interpretation. The advantage of using diatoms in studies reconstructing the pH of a lake is that most species are pelagic, and hence the influence of substrate type in affecting individual species presence and community dynamics is lessened. The species composition at a site is therefore more of a direct representation of pH than that which may be inferred by organisms such as ostracods which have been shown to be influenced by substrate form. We are more likely to see a shift in the overall community dynamics of Ostracoda in response to water quality change, than to see a change in individual species presence or absence. However, this does not mean that the Ostracoda have little use in water quality determination in palaeolimnological studies. The community structure may represent substrate form, size, altitude and the successional stage in which a lake or tarn is in, as well as giving us a generalised indication of the acidity of the site.

FUTURE WORK

This study has shown that two themes especially should be studied further to enhance our understanding of ostracod ecology.

1) **The exact influence of substrate on species distribution.**

2) **The influence of water chemistry on reproductive success, with reference to the development of eggs and hatching mortality in specific physico-chemical environments.**

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BIBLIOGRAPHY

Abe, K. (1983). Population structure of Keijella bisanensis (Okubo) (Ostracoda, Crustacea) - An inquiry into how far the population structure will be preserved in the fossil record. J.Fac.Sci.Tokyo Univ., **Tokyo**, **20**, 443-488.

Abe, K. (1990). What the sex ratio tells us : a case from marine ostracods. In : Whatley, R. & Maybury, C. (Eds). Ostracoda and Global Events. 175-185. Chapman & Hall.

Alhonen, P. (1970). The paleolimnology of four lakes in southwestern Finland. Annals Acad. Sci. Fenn. A. III **105**, 1-39.

Battarbee, R.W. (1986). Diatom analysis. In : Berglund, B.E. (Ed). Handbook of Holocene Palaeoecology. 527-570. John Wiley and sons, New York.

Bamber, R.N. (1987). The effects of acidic sea-water on young carpet-shell clams Venerupis decussata (L.) (Mollusca:Veneracea). J. Exp. Mar. Biol. Ecol., **108**, 241-260.

Bamber, R.N. (1990). The effects of acidic seawater on three species of lamellibranch mollusc. J. Exp. Mar. Biol. Ecol., **143**, 181-191.

Baum, G.R. (1982). General debate. In : Proceedings - The 1982 Stockholm Conference on Acidification of the Environment. 89-101. Swedish Ministry of Agriculture, Stockholm.

Begon, M. & Mortimer, M. (1981). Population Ecology. A Unified Study of Animals and Plants. Blackwell Scientific Publications.

Benson, R.H. (1981). Form, function and structure of ostracode shells. Ann. Rev. Earth Planet. Sci, **9**, 59-80.

Benzie, J.A.H. (1989). The distribution and habitat preference of ostracods (Crustacea: Ostracoda) in a coastal sand-dune lake, Loch of Strathbeg, north-east Scotland. Freshwater Biology, **22**, 309-321.

Brady, G.S. (1868a). Notes on the Crustacean fauna of the English Lakes. Intellectual Observer, **12**, 416-424.

Brady, G.S. (1868b). A monograph of the Recent British Ostracoda. Trans. Linn. Soc. Lond., **26**, 353-495.

Brady, G.S. & Norman, A.M. (1889). A monograph of the marine and freshwater Ostracoda of the North Atlantic and of Northwestern Europe. Section 1. Podocopida. *Scient. Trans. R.Dubl.Soc.*, *series 2* (**4**), 63-270.

Brown, D.J.A. (1982). Influence of calcium on the survival of eggs and fry of the Brown Trout (*Salmo Trutta*) at pH 4.5. *Bull. Environm. Contam. Toxicol*. **28**, 664-668.

Calabrese, A. & Davis, H.C. (1966). The pH tolerance of embryos and larvae of *Mercenaria* and *Crassostrea virginica*. *Biol. Bull. (Woods Hole, Mass)*, **131**, 427-436.

Campbell, C.E. (1991). Prey selectivities of threespine sticklebacks (*Gasterosteus aculeatus*) and phantom midge larvae (*Chaoborus sp*) in Newfoundland lakes. *Freshwater Biology*, **25**, 155-167.

Carbonel, P., Colin, J-P., Danielopol, D.L., Löffler, H. & Neustrueva, I. (1988). Palaeoecology of limnic ostracodes: A review of some major topics. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **62**, 413-461.

Carbonel, P. & Farmer, M. (1990). The chemical composition of the carapace of *Cytherissa*. In : Danielopol, D.P., Carbonel, P. & Colin, J-P. (Eds). *Cytherissa - The Drosophila of Paleolimnology*. *Bulletin de l'institut de Géologie du Bassin d'Aquitaine*. 261-266.

Carl, G.C. (1940). The distribution of cladocera and free-living copepoda in British Columbia. *Ecol. Monogr.*, **10**, 55-110.

Carrick, T.R. and Sutcliffe, D.W. (1982). *Concentrations of major ions in lakes and tarns of the English Lake District, 1953-1978.* Freshwat. Biol. Ass. Occl. Pub, 16.

Charles, D.F. (1990). Effects of acidic deposition on North American lakes: palaeolimnological evidence from diatoms and chrysophytes. *Phil. Trans. R. Soc. Lond. B* **327**, 177-186.

Chivas, A.R., De Deckker, P. & Shelley, J.M.G. (1986). Magnesium content of non-marine ostracod shells: a new paleosalinometer and paleothermometer. *Palaeogeography, Palaeoclimatology, Palaeoecology,*, **54**, 43-61.

Cronberg, G. (1990). Recent acidification and changes in the subfossil chrysophyte flora of lakes in Sweden, Norway and Scotland. *Phil. Trans. R. Soc. Lond. B* **327**, 289-293.

Danielopol, D.L. (1980). Sur la biologie de quelques ostracodes Candoninae épigés et hypogés d'Europe. Bull. Mus. Natl. Hist. Nat. Paris (Zool., Biol. Ecol. Anim.), **2**, 471-506.

Danielopol, D.L., Geiger, W., Tolderer-Farmer, H., Orellona, C. & Terrat, H.W. (1985). Ostracoda of Mondsee - their spatial and temporal changes during the last 50 years. In : Danielopol, D.L., Schmidt, R. & Schultze, E. (Eds). Contributions to the paleolimnology of the Trumer Lakes (Salzburg) and the lakes Mondsee, Attersee and Traunsee (Upper Austria). 99-121. Limnologisches Institut, Osterreichische Akademie der Wissenschaften, Mondsee.

Danielopol, D.L., Olteanu, R., Löffler, H. & Carbonel, P. (1990). Present and past geographical ecological distribution of Cytherissa (Ostracoda, Cythereidae). In : Danielopol, D.P., Carbonel, P. & Colin, J-P. (Eds). Cytherissa - The Drosophila of Paleolimnology. Bulletin de l'institut de Géologie du Bassin d'Aquitaine. 97-118.

Davies, R.B. (1987). Palaeolimnological diatom studies of acidification of lakes by acid rain: An application of quaternary science. Quat. Sci. Rev, **6**, 147-163.

Davies, R.B. and Berge, F. (1980). Atmospheric deposition in Norway during the last 300 years as recorded in SNSF lake sediments. II. Diatom stratigraphy and inferred pH. In : Drablos, D. & Tollan, A. (Eds). Ecological Impact of Acid Precipitation. 270-271. SNSF Project, Oslo, Norway.

De Deckker, P. (1979). The middle Pleistocene ostracod fauna of the West Runton freshwater bed, Norfolk. Palaeontology, **22**, 293-316.

De Deckker, P. (1983). The Limnological and Climatic Environment of Modern Halobiont Ostracodes in Australia, a Basis for Paleoenvironmental Reconstruction. In : Maddocks, R.L. (Ed). Applications of Ostracoda. Proc. 8th Int. Symp. on Ostracoda. Univ. Houston, Texas. 250-254.

De Deckker, P. & Forester, R.M. (1988). The Use of Ostracods to Reconstruct Palaeoenvironmental Records. In: De Deckker, P., Colin, J-P., & Peypouquet, J-P. (Eds). Ostracoda in the Earth Sciences. 175-199. Elsevier, Amsterdam-Oxford-New York-Tokyo.

Echols, D.J., Price, L.G. & Rafle, M.A. (1975). Variations in fresh-water ostracode populations from lakes in St. Louis County, Missouri. Bull. Am. Paleont., **65** (282), 167-172.

Elner, R.W. & Hughes, R.N. (1978). Energy Maximisation in the diet of the Shore Crab Carcinus maenas (L.). J. Anim. Ecol. **47**, 103-116.

Elofson, O. (1941). Zur Kenntnis der marinen Ostracoden Schwedens. Uppsala Univ. Zool. Bidr., **19**, 215-534.

Ferguson, E.J. (1944).Studies on the seasonal life history of three species of freshwater ostracoda. Amer. Mid. Nat, **32**(3), 713-717.

Fisher, R.A. (1930). The Genetical Theory of Natural Selection. Clarendon Press, Oxford.

Fox, H.M. (1964). On the larval stages of cyprids and Siphlocandona (Crustacea, Ostracoda). Proc. Zool. Soc. Lond., **142**, 165-176.

Fox, H.M. (1965). The ostracods of Lake Maggiore. Mem. Ist. Ital. Idrobiol., **19**, 81-89.

Fox, H.M. (1967). More new and interesting cyprids (Crustacea, Ostracoda) in Britain. J. Nat. Hist., **4**, 549-559.

Fryer, G. (1955). A faunistic and ecological survey of the freshwater crustacea of the Huddersfield District of West Yorkshire. The Naturalist, **1955**, 101-126.

Fryer, G. (1980). Acidity and species diversity in freshwater crustacean faunas. Freshwater Biology, **10**, 41-45.

Fryer, G. (1985). Crustacean diversity in relation to the size of waterbodies, some facts and problems. Freshwater Biology, **15**, 347-361.

Fryer, G. & Forshaw, O. (1979). The freshwater crustacea of the island of Rhum (Inner Hebrides) - a faunistic and ecological survey. Biol. J. Linn. Soc, **11**, 333-367.

Gauthier, H. (1928). Ostracods et cladoceres de l'Afrique du Nord (remote). Bull. Soc. Hist. nat. Afr. n., **19**, 10-19.

Geiger, W. (1990). Field and Laboratory studies on the life cycle of Cytherissa lacustris (Sars) (Crustacea, Ostracoda) with special emphasis on the role of temperature. In : Danielopol, D.P., Carbonel, P. & Colin, J-P. (Eds). Cytherissa - The Drosophila of Paleolimnology. Bulletin de l'institut de Géologie du Bassin d'Aquitaine. 191-208.

Gibson, R.M. (1980). Optimal prey-size selection by three spined sticklebacks (Gasterosteus aculeatus): A test of the apparent size hypothesis. Zeitscrift fur Tierpsychologie, **52**, 291-307.

Grahn, O.H., Hultberg, H. & Landner, L. (1974). Oligotrophication - a self-accelerating process in lakes subjected to excessive supply of acid substances. Ambio, **3**, 93-94.

Green, R.H. & Vascotto, G.L. (1978). A method for the analysis of environmental factors controlling patterns of species composition in aquatic communities. Wat. Res., **12**, 583-590.

Hamilton, W.D. (1967). Extraordinary Sex Ratios. Science, **155**, 477-488.

Hamilton, W.D. (1982). Pathogens as causes of genetic diversity in their host populations. In: Anderson, R.M., & R.M. May, R.M. (Eds). Population Biology of Infectious Diseases. Dahlem Conference Volume. Springer-Verlag, New York.

Hartnoll, R.G. (1982). Growth. In : Abele, L.G. (Ed). The Biology of Crustacea. 2. Embryology, Morphology and Genetics. 111-196. Academic Press, New York.

Heip, C. (1976). The life cycle of Cyprideis torosa (Crustacea, Ostracoda). Oecologia (Berlin), **24**, 229-245.

Henderson, P.A. (1989). On the structure of the inshore fish community of England and Wales. J. Mar. Biol. Ass. (U.K.), **69**, 145-163.

Henderson, P.A. (1990). Freshwater Ostracods. Synopses of the British Fauna, **42**. Universal Book Services, Oegstgeest, Netherlands.

Hiller, V.D. (1972). Contributions to the knowledge about the biology and ecology of freshwater ostracods from the neighbourhood of Hamburg. Arch. Hydrobiol. / Suppl, **40**(4), 400-497.

Hoft, C.C. (1943). Seasonal changes in the freshwater ostracod fauna of temporary ponds. Ecology, **24**(1), 111-118.

Hollwedel, W. & Scharf, B.W. (1988). Sübwassercladoceran und -ostracoden (Crustacea) auf den niedersächsischen Nordseeinseln Mellum und Memmert. Drosera, **88**(1/2), 341-369.

Holmes, P.F. (1937). Pseudocandona elongata, a new species of ostracod. Ann.Mag.nat.Hist. (Series 10), **19**, 422-430.

Honigstein, A. (1986). Ultrastructure of ostracods as a stratigraphical tool for the subdivision of the Senonian sequence in Israel. J. Micropal, **5**, 53-65.

Horne, D.J. (1980). Ostracoda from the Severn Estuary and Bristol Channel. Unpub. PhD thesis. Bristol University.

Horne, D.J. (1983). Life-cycles of Podocopid Ostracoda - a review (with reference to marine and brackish-water species). In : Maddocks, R.F. (Ed). Applications of Ostracoda. 581-590. Univ. Houston. Geosciences.

Horne, D.J. (1988). Recent freshwater ostracoda from the Lake District. Brit. Micropalaentol. Soc. Field guide 7.

Horne, D.J. Horne, D.M. & Horne, J.E.M. (1990). New records of ostracods from the Lake District. Trans. Nat. Hist. Soc. Northumb. **55**(2), 147-148.

Horne, J.E.M. & Horne, D.M. (1985). Lake District Waters. An index and bibliography of scientific work. Freshwat. Biol. Ass. Occl. Pub. 24.

Hotelling, H. (1933). Analysis of a complex of statistical variables into principal components. J. Ed. Psych., **24**, 417-441.

Hultberg, H. (1983). Effects of acid depositions on aquatic ecosystems. In : Ott, H. & Stangl, H. (Eds). Acid Deposition: A Challenge for Europe. 167-185. Commission of the European Communities.

Hustedt, F. (1937-9). Systematische und ökologische untersuchungen uber die diatomeenflora von Java, Bali und Sumatra. Arch. Hydrobiol. / suppl. 15 and 16.

Hynes, H.B.N. (1950). The food of fresh-water sticklebacks Gasterosteus aculeatus and Pygosteus pungitinus with a review of methods used in studies of the food of fishes. J. Anim. Ecol., **19**, 36-58.

Ibanez, F. (1973). Méthode d'analyse mathématique des événements en écologie planctonique. Optimisations méthodologiques; étude expérimental en continu à petite échelle de l'hétérogénéité du plancton cotier. Bulletin de l'Institute Océanographique, **72**, 96p.

Ivlev, V.S. (1961). Ecology of the Feeding of Fishes. Yale University Press.

Janz, V.H. (1983). Die Ostracoden (Crustacea) des Schönbuchs bei Tübingen. Jh. Ges. Naturkde. Wurtt. **138**, 245-259.

Kamiya, T. (1988). The meaning of sex-ratios obtained from fossil Ostracoda. Senckenberg. leth., **68** (5/6), 337-345.

Kempf, E.K. & Scharf, B.W. (1981). Lebende und fossile Muschelkrebse (Crustacea, Ostracoda) vom Laacher See. Mit. Pollichia, **68**, 205-236.

Kerfoot, W.C. (1975). The divergence of adjacent populations. Ecology, **56**, 1298-1313.

Kesling, R.V. (1951). The morphology of ostracod moult stages. Biol. Monogr, **21**, 1-324.

King, C.A.M. (1976). Geomorphology of the British Isles: Northern England. Methuen and Co. Ltd, London.

Klie, W. (1938). Krebstiere oder Crustacea. III. Ostracoda, Muschelkrebse. Die Tierwelt, Deutschlands, 34. 230pp.

Klugh, A.B. (1927). The ecology, food relations and culture of freshwater Entomostraca. Trans. R. Canadian Institute., **16**, 15-99.

Kohler, S. & Arlt, G. (1984). The distribution of ostracods in an inlet of the Darss-Zingst Bodden chain. Limnologica, **15**(2), 415-419.

Kornicker, L.S. & Sohn, I.G. (1971). Viability of Ostracode eggs egested by fish and effect of digestive fluids on ostracode shells - Ecological and paleoecologic implications. In : Oertli, H.J. (Ed). Paléoécologie Ostracodes. Bull. Centre Rech. Pau - SNPA, **5** Suppl., 125-135.

Latifa, G.A. (1987). Effect of temperature on the development of embryonic and postembryonic stages of Heterocypris incongruens (Ramdohr, 1808) (Ostracoda). Crustaceana, **52** (1), 95-100.

Lawton, J.H. (1974). Switching in Invertebrate Predators. In : Usher, M.B. & Williamson, M.H. (Eds). Ecological Stability. 141-158. Chapman and Hall, London.

Lazarro, X. (1987). A review of planktiverous fishes: Their evolution, feeding behaviours, selectivities and impacts. Hydrobiologia, **146**, 97-167.

Leivestad, H., Hendrey, G., Muniz, I.P. & Snekvik, E. (1976). Effects of acid precipitation on aquatic organisms. In : Braekke, F, (Ed). Impact of acid precipitation on forest and freshwater ecosystems in Norway. SNSF Project, 87-111.

Liperovskaya, E.S. (1948). On the Feeding of Freshwater ostracods. Zool. Zh, **27**, 125-156.

Lowndes, A.G. (1931). Some freshwater Entomostraca of the Birmingham District. Ann. Mag. nat. Hist, **10**(8), 561-577.

Lowndes, A.G. (1935). The Sperms of Freshwater Ostracods. Proc. Zool. Soc. London., 35-48.

Lowndes, A.G. (1952). Hydrogen ion concentration and the distribution of freshwater Entomostraca. Ann. Mag. nat. Hist, **5**, 58-65.

MacArthur, R.H. & Pianka, E.R. (1966). On optimal use of a patchy environment. American Naturalist, **100**, 603-609.

Mallwitz, J. (1981). Untersuchungen zur Ökologie litoraler Ostracoden im Schmal- und Lüttauersee (Schleswig-Holstein Kreis Herzogtum Laurenburg). Unpub. Msc Thesis. University of Hamburg.

Martens, K. (1985). Effects of temperature and salinity on postembryonic growth in Mytilocypris henricae (Chapman) (Crustacea; Ostracoda). J. Crust. Biol., **5** (2), 258-272.

Martens, K. & Dumont, H.J. (1984). The ostracod fauna (Crustacea, Ostracoda) of Lake Donk (Flanders): A comparison between two surveys 20 years apart. Biol. Jb. Dodonaea., **52**, 95-111.

Martens, K. & Meisch, C. (1985). Description of the male Potamocypris villosa (Jurine, 1820) (Crustacea, Ostracoda). Hydrobiologia, **127**, 9-15.

Martens, K., De Deckker, P. & Marples, T.G. (1985). Life History of Mytilocypris henricae (Chapman) (Crustacea, Ostracoda) in Lake Bathurst, New South Wales. Aust. J. Mar. Freshw. Res., **36**, 807-819.

McClay, C.L. (1978). Comparative observations on the ecology of four species of ostracods living in a temporary freshwater puddle. Can. J. Zool, **56**, 663-675.

McGregor, D.L. & Kesling, R.V. (1969). Copulatory adaptations in ostracods. Part 1 - Hemipenes of Candona. Contr. Mus. Paleont. Univ. Mich., **22**, 169-191.

Meisch, C. (1985). Revision of the recent West European species of the genus Potamocypris. Part 2. Species with long swimming setae on the second antennae. Travaux Scientifiques du Musee Nationale D'Histoire Naturelle de Luxembourg, **6**, 1-95.

Meisch, C. (1990). Ostracodes et écologie de deux étangs de gravières d'Alsace et du Luxembourg (Crustacea, Ostracoda). Bull. Soc. Nat. Luxembourg. **90**. 183-190.

Merilainen, J. (1967). The diatom flora and the hydrogen ion concentration of water. Ann. Bot. Fen, **4**, 51-58.

Milner, N.J. & Varallo, P.V. (1990). Effects of acidification on fish and fisheries in Wales. In : Edwards, R.W., Gee, A.S. & Stoner, J.H. (Eds). Acid Waters in Wales. 121-144. Kluwer, Dordrecht.

Moss, B. (1980). Ecology of Fresh Waters. Blackwell Scientific Press.

Muniz, I.P. (1981). Acidification - Effects on aquatic organisms. In : Fazzolare, R.A. & Smith, C.B. (Eds). Third International Conference on Energy use Management. 101-123. Berlin (West).

Muniz, I.P. (1983). The effects of acidification on Norwegian freshwater ecosystems. In : Ecological Effects of Acid Deposition. 299-322. National Swedish Environment Protection Board.

Muniz, I.P. & Leivestad, H. (1980). Toxic effects of aluminium on the brown trout, Salmo trutta L. Proc. Int. Conf. Ecol. Impact Acid Precip, 320-321.

Murdoch, W.W. (1969). Switching in general predators : experiments on predator specificity and stability of prey populations. Ecological Monographs. **39**, 335-354.

Neale, J.W. (1964). Some factors influencing the distribution of recent British Ostracoda. Publ. Staz. Zool. Napoli. / Suppl. **33**, 247-307.

Niell, S.R. & Cullen, J.M. (1974). Experiments on whether schooling by their prey affects the hunting behaviour of cephalopods and fish predators. J. Zool, London. **172**, 549-569.

Nilssen, J.P. & Sandoy, S. (1990). Recent lake acidification and cladoceran dynamics: surface sediment and core analysis from lakes in Norway, Scotland and Sweden. Phil. Trans. R. Soc. Lond. B **327**, 299-309.

Nygaard, G. (1956). Ancient and recent flora of diatoms and chrysophyceae in Lake Gribso. Studies on the humic acid Lake Gribso. Folia. Limnologica. Scandinavica., **8**, 32-94.

Paces, T. (1983). The pH and concentrations of sulphate, nitrate and aluminium in the run off from representative catchments in the Elbe River basin. In : Ecological Effects of Acid Deposition. 161-173. National Swedish Environment Protection Board.

Parker, R.E. (1979). Introductory Statistics for Biology. Edward Arnold.

Pastorok, R.A. (1980). Selection of prey by Chaoborus larvae: A review and new evidence for behaviourial flexibility. In: Kerfoot, W.C. (Ed). Evolution and Ecology of Zooplankton Communities. 538-554. Special Symposium Vol. 3, American Society of Limnology and Oceanography. University Press of New England, Hanover, New Hampshire, U.S.A.

Pierre, D. (1973). Etude écologique comparée des populations d'ostracodes dans deux étangs de pisiculture en haute Belgique. Hydrobiologia, **43**(3-4), 273-283.

Pitblado, J.R., Keller, W. & Conroy, N.I. (1980). A classification and description of some Northeastern Ontario lakes influenced by acid precipitation. J. Great. Lakes. Res., **6**(3), 247-257.

Ranta, E. (1979). Population biology of Darwinula stevensoni (Crustacea, Ostracoda) in an oligotrophic lake. Annales Zoologici Fennici, **16**, 28-35.

Renberg, I. & Hellberg, T. (1982). The pH history of lakes in Southwestern Sweden, as calculated from the subfossil diatom flora of the sediments. Ambio, **11**, 30-33.

Renberg, I. et al. (1990). Recent acidification and biological changes in Lilla Öresjön, southwest Sweden, and the relation to atmospheric pollution and land-use history. Phil. Trans. R. Soc. Lond. B **327**, 391-396.

Robertson, D. (1880). The fauna of Scotland, with special reference to Clydesdale and the Western Districts. Fresh and brackish water Ostracoda. Proc. Natur. Hist. Soc. Glasgow, **4**, 1-35.

Sars, G.O. (1925). An account of the Crustacea of Norway. 9, Ostracoda. Bergen museum, Bergen. 277p.

Scharf, B.W. (1988). Living ostracods from the nature reserve, "Hordter Rheinaue" (Germany). In : Hanai, T., Ikeya, N. & Ishizaki, K. (Eds). Evolutionary Biology of Ostracoda. 501-517. Elsevier Science Publishing, Amsterdam, Netherlands.

Schreiber, E. (1922). Beiträge zur Kenntnis der Morphologie, Entwicklung und Lebensweise der Süßwasser-Ostracoden. Zool. Jb. (Anat. Ontog.), **43**(4), 485-538.

Scourfield, D.J. (1943). The Entomostraca of the bottom deposits of Windermere. Proc.Linn.Soc.Lond., Session **154**, Part **3**, 253-258.

Seidel, B. (1989). Phoresis of Cyclocypris ovum (Jurine) (Ostracoda, Podocopida, Cyprididae) on Bombina variegata (L.) (Anura, Amphibia) and Triturus vulgaris (L.) (Urodela, Amphibia). Crustaceana., **57**, 171-176.

Sharpe, R.W. (1918). Ostracoda. In : Ward, H.B. & Whipple, G.C. (Eds). Freshwater Biology. 790-827. New York.

Smith, R.H. & Sibly, R.M. (1985). Behaviourial ecology and population dynamics: Towards a synthesis. In : Sibly, R.M. & Smith, R.H. (Eds). Behaviourial Ecology: The ecological consequences of adaptive behaviour. 577-591. Blackwell, Oxford.

Smol, J.P. et al. (1984). Mallomonadacean microfossils provide evidence of recent acidification. Nature, **307**, 628-630.

Smyly, W.J.P. (1968). Observations on the planktonic and profundal Crustacea of the lakes of the English Lake District. J.Anim.Ecol., **37**, 693-708.

Smyly, W.J.P. (1973). Decrease in abundance of the freshwater ostracod Cypria ophthalmica (Jurine) (Crustacea, Ostracoda) in a small lake. Naturalist, Hull., **925**, 65-69.

Snell, T.W. & King, C.E. (1979). Lifespan and Fecundity patterns in rotifers: The Cost of Reproduction. Evolution, **31**, 882-890.

Stokoe, R. (1983). Aquatic Macrophytes in the Tarns and Lakes of Cumbria. Freshwat. Biol. Ass. Occl. Pub. 18.

Sutcliffe, D.W. & Carrick, T.R. (1988). Alkalinity and pH of tarns and streams in the English Lake District (Cumbria). Freshwater Biology. **19**, 179-189.

Szczechura, J. (1971). Seasonal Changes in a reared Freshwater species, Cyprinotus (Heterocypris) incongruens (Ostracoda), and their importance in the interpretation of variability in fossil Ostracodes. In : Oertli, H.J. (Ed). Paléoécologie Ostracodes. Bull. Centre Rech. Pau - SNPA, **5** Suppl., 191-205.

Talling, J.F. (1951). The element of chance in pond populations. *The Naturalist.*, **1955**, 157-171.

Thaler, B. (1977). *Die Benthischen Crustaceen des Piburger Sees (Ötztal, Tirol)*. Unpubl. Theses., Univ. Innsbruck (Austria).

Theisen, B. (1966). The Life History of Ostracods from a Danish Brackish Water Locality. *Meddelelser frå Danmarks Fiskeri- og Havundersøgelser*, **4**, 215-270.

Tressler, W.L. (1939). *Onychocythere*, a new genus of marine ostracod from Florida, with a description of one species. *J. Washington Acad. Sci*, **29(8)**, 336-339.

Turnpenny, A.W.H., Dempsey, C.H., Davis, M.H. & Fleming, J.M. (1988). Factors limiting fish populations in the Loch Fleet system, an acidic drainage system in south-west Scotland. *J. Fish. Biol.* **32**, 101-118.

Turpen, J.B. & Angell, R.W. (1971). Aspects of moulting and calcification in the ostracod *Heterocypris*. *Biol. Bull,* **140**, 331-338.

Uiblein, F. & Winkler, H. (1988). Der Nahnrungserwerb der Mondsee - Zahrte. *Sitzber. Osterr. Akad.Wiss., mathem.-naturw*, **Kl.Abt. 1**, **196**, 311-322.

Van Morkhoven, F.P.C.M. (1962). *Post-Palaeozoic Ostracoda. Their Morphology, Taxonomy, and Economic Use*. *1*, Elsevier Publishing Company, Amsterdam, London, New York.

Vinyard, G. (1979). An ostracod (*Cypridopsis vidua*) can reduce predation from fish by resisting digestion. *American Midland Naturalist*. **102(1)**, 188-190.

Wagenleitner, H. (1990). Morphology and Evolution of *Cypria cavernae* n. sp. (Ostracoda, Crustacea). *Bull. Soc. Nat. Luxemb.*, **90**, 199-226.

Welch, E.B. & Chamberlain, W.H. (1981). Initial detection of acid lakes in Washington State. *Rep. U.S. Dept. Interior,* 1-30.

Whatley, R.C. (1983). An Ostracod to Catch a Trout. *Br. Micropalaeontol*, **20**, 2.

Whatley, R.C. & Stephens, J.M. (1977). Precocious sexual dimorphism in fossil and recent Ostracoda. In : Löffler, H. & Danielopol, D. (Eds)., *Aspects of Ecology and Zoogeography of Recent and Fossil Ostracoda*, 69-91. Dr. W. Junk b.v. Publishers, The Hague.

Wootton, R.J. (1976). The Biology of Sticklebacks. Academic Press, London.

Yassini, I. (1969). Ecologie des associations d'ostracodes du Bassin d'Arcachon et du littoral Atlantique. Bulletin de l'Institut de geologie du bassin d'Aquitaine., 7, 288p.

14.1 - KEY TO THE OSTRACODA FOUND IN THE ENGLISH LAKE DISTRICT

The following key incorporates the 31 identified species of ostracod found in this survey, together with previously recorded species of the English Lake District.

All British Ostracods in freshwater belong to:

Phylum - Arthropoda

Class - Crustacea

Subclass - Ostracoda

Order - Podocopida

Sub-order - Podocopina

KEY TO THE OSTRACODA OF THE ENGLISH LAKE DISTRICT

A * indicates those species collected by this survey of the Lake District.

1a. The first and third limbs are formed for walking, giving three pairs of walking legs......

Superfamily Cytheroidea......3

1b. Less than three pairs of walking legs......2

2a. The second and third thoracic limbs form walking legs, and the furca is absent......

Superfamily Darwinuloidea......5

2b. The second thoracic limb forms a walking limb, the third is modified for cleaning. The furca is present, but in some groups in the form of a pair of slender setae.....

Superfamily Cypridoidea......6

3. **Superfamily Cytheroidea.**

3a. The antennule has six segments and the carapace is inflated in dorsal view......

Family - Limnocytheridae

Subfamily - Metacyprinidae

Genus - Metacypris

Species - Metacypris cordata *

3b. The antennule has five segments and the carapace is laterally compressed......4

4a. The three terminal bristles on the antennule are not bifurcated. The valves are heavily calcified.

Family - Cytherideidae

Subfamily - Cytherideinae

Genus - Cytherissa

Species - Cytherissa lacustris

4b. One of the terminal bristles on the antennule is bifurcated. The valves are thin and fragile.

Family - Limnocytheridae

Subfamily - Limnocytherinae

Genus - Limnocythere

Species - Limnocythere inopinata

5. Superfamily - Darwinuloidea

Family - Darwinulidae

Subfamily - Darwinulinae

Genus - Darwinula

Species - Darwinula stevensoni *

6. Superfamily - Cypridoidea

6a. The valves are strongly calcified, possess a pitted surface, and have an almost horizontal dorsal edge. On lateral view, each valve is bisected by two vertical folds called sulci......

Family Ilyocyprididae......9

6b. The valves are usually arched and lack heavy pitting and vertical folds......7

7a. The furca is well developed and terminates in two or three claws......8

7<u>b</u>. The furca is reduced to one slender setae embodied in a small bulbous base......

Family Cypridopsidae......10

8<u>a</u>. The fourth segment of the cleaning limb is clearly visible and possesses three setae......

Family Candonidae......12

8<u>b</u>. The fourth segment of the cleaning limb is minute......

Family Cyprididae......30

9. Family - Ilyocyprididae

Subfamily - Ilyocypridinae

Genus - Ilyocypris

9<u>a</u>. The swimming setae of the antenna are of differing length, but the longest just exceeds the tip of the terminal claws......

Species - <u>Ilyocypris decipiens</u> *

9<u>b</u>. The swimming setae do not even reach the base of the claws......

Species - <u>Ilyocypris bradyii</u> *

10. Family - Cypridopsidae

Subfamily - Cypridopsinae

10a. The terminal segment of the maxillary palp is distally enlarged and bears long spines......

Genus - Potamocypris......11

10b. The terminal segment of the maxillary palp is rectangular and bears simple setae......

Genus - Cypridopsis

Species - Cypridopsis vidua *

11a. The swimming setae of the second antennae are reduced, never extending beyond the base of the terminal claws......

Species - Potamocypris pallida

11b. The swimming setae of the second antennae are well developed, reaching at least to the tips of the terminal claws......

Species - Potamocypris villosa *

12. Family - Candonidae

12a. The antennae lack swimming setae......

Subfamily - Candoninae......13

12b. The antennae possess swimming setae......

Subfamily - Cyclocypridinae......25

13. Subfamily - Candoninae

13a. The valve surface possesses small protuberances and a reticulate pattern......

Genus - Paracandona

Species - Paracandona euplectella *

13b. The valve surface is smooth, no protuberances or reticulate patterning......14

14a. The furca possesses a dorsal seta......15

14b. The dorsal seta on the furca is absent......
Genus - Candonopsis.

Species - Candonopsis kingsleii *

15a. The third segment of the cleaning limb has two setae......

Genus - Cryptocandona......16

15b. The third segment of the cleaning limb has one setae......

Genus - Candona......17

16. Genus - Cryptocandona

16a. The third segment of the cleaning limb is subdivided......

Species - Cryptocandona reducta *

16b. The third segment of the cleaning limb is not divided......

Species - **Cryptocandona vavrai** *

17. Genus - Candona

17a. The third segment of the cleaning limb is not divided......18

17b. The third segment of the cleaning limb is subdivided......19

18a. The setal group on the inner edge of the mandibular palp has four members......

Species - **Candona lactea**

18b. This setal group has five members......

Species - **Candona candida** *

19a. The seta in the middle of the distal edge of the third segment of the mandibular palp is plumose......

Species - **Candona neglecta** *

19b. This seta is non-plumose......20

20a. The setal group on the inner edge of the mandibular palp has three members......21

20b. This setal group has four or members......22

21a. The carapace is slim on dorsal view, length being greater than three times the width......

Species - Candona fabaeformis *

21b. The carapace is fatter, and is drawn into a beak at the anterior end. The length is less than three times the width......

Species - Candona rostrata *

22a. The setal group on the inner edge of the mandibular palp has four setae......23

22b. This group has five setae......24

23a. The valve length is less than 0.95 mm, and the genital lobes of the female are rounded in outline......

Species - Candona albicans *

23b. The valve length is greater than 1.00 mm, and the genital lobes of the female are extremely long and pointed in outline......

Species - Candona siliquosa *

24a. The shortest claw on the third segment of the antennae considerably surpasses the tip of segment four. The carapace surface is smooth.....

Species - Candona pratensis *

24b. This claw does not exceed the tip of segment four. The carapace surface is reticulate......

Species - Candona compressa *

25. Subfamily - Cyclocypridinae

25a. On dorsal view, the carapace is laterally compressed. There is on seta on the third segment of the cleaning limb......

Genus - Cypria......26

25b. On dorsal view, the carapace is rounded in outline. There are two setae on the third segment of the cleaning limb......

Genus - Cyclocypris......27

26. Genus - Cypria

26a. The valves are less than 0.8 mm in length, and possess reticulate patterning......

Species - Cypria ophthalmica *

26b. The valves are greater than 0.8 mm in length, and lack reticulate patterning......

Species - Cypria exsculpta *

27. Genus - Cyclocypris

27a. The largest terminal claw of the furca is one third the length of the ramus......

Species - Cyclocypris globosa *

27b. This claw is half he length of the ramus......28

28a. Viewed dorsally, the left valve overlaps the right valve at both the anterior and posterior ends......

Species - Cyclocypris laevis *

28b. Viewed dorsally, the right valve overlaps the left valve at both the anterior and posterior ends......29

29a. The valve length is less than 0.5 mm. The smallest setae on segment four of the cleaning limb is a characteristic S - shape......

Species - Cyclocypris ovum *

29b. The valve length is greater than 0.5 mm. The smallest setae on segment four of the cleaning limb is straight......

Species - Cyclocypris serena *

30. Family - Cyprididae

30a. The furca terminates in two claws......31

30b. The furca terminates in three claws......

Subfamily - Notodromatinae

Genus - Notodromas

Species - Notodromas monacha *

31*a*. The dorsal setae of the furca is almost the same length as the shorter of the two terminal claws of the furca......

Subfamily - Cyprinotinae

Genus - Cyprinotus

Species - *Cyprinotus incongruens* *

31*b*. This setae is at maximum, half the length of the shorter of the two terminal claws of the furca......32

32*a*. The greatest height of the carapace is in front of the mid-line......

Subfamily - Eucypridinae......33

32*b*. The carapace is elongated......

Subfamily - Herpetocyprinidae......37

33*a*. The furcal plate is present......

Genus - Cypricercus

33*b*. The furcal plate is absent......

Genus - Eucypris

34. Genus - Cypricercus

34*a*. Viewed from either the anterior or the posterior, the right valve is set above the left valve......

Species - *Cypricercus obliquus* *

34b. The valves are parallel to one another......35

35a. Each valve has a characteristic chocolate coloured band running dorso-ventrally. The triebel loop has a characteristic shape......

Species - Cypricercus fuscatus *

35b. The chocolate coloured band is absent. The triebel loop has a characteristic shape......

Species - Cypricercus affinis

36. Genus - Eucypris

36a. Larger than 2.0 mm. The adults are rounded in outline and the anterior tips of the valves possess 'warty' nodes......

Species - Eucypris virens *

36b. Smaller than 2.0 mm. The adults are more elongate than E. virens, and the 'warty' nodes are absent......

Species - Eucypris pigra

37. Subfamily - Herpetocypridinae

37a. The dorsal setae of the furca is thin......

Genus - Herpetocypris......38

37__b__. The dorsal setae of the furca is thickened with a broad base......

Genus - Psychodromas

Species - __Psychodromas robertsoni__

38. Genus - Herpetocypris

38__a__. The swimming setae on the antennae extend past the tips of the terminal claws......

Species - __Herpetocypris chevreuxi__ *

38__b__. The swimming setae on the antennae do not extend past the tips of the terminal claws......

Species - __Herpetocypris reptans__ *

APPENDIX 14.3

All values for [Ca], [Mg], [Na], [K] and Alkalinity are given in μel^{-1}.

SITE - 1
NAME - ESTHWAITE WATER
GRID REF. - 362954
SAMPLING DATES : 1.1 - 1/2/89
1.2 - 30/8/89
FAUNA :

	1.11	1.21	1.12	1.22	1.13	1.23
Cypria ophthalmica	0	0	7	22	8	3
Cyclocypris laevis	2	45	3	10	0	0
Candona albicans	0	1	0	0	0	0
Candona candida	0	0	1	0	2	3
Darwinula stevensoni	0	7	0	0	0	0
Herpetocypris reptans	0	0	0	0	0	1
Cypridopsis vidua	0	50	0	0	0	1
Metacypris cordata	0	13	0	0	0	0
Tot/species	1	5	3	2	2	4
Tot/no.	2	116	11	32	10	8
Tot/overall species	8					

LAKE SIZE - 1.00×10^6 m^2
SIZE CLASS - A
ALTITUDE - 65m

MAX DEPTH - 15.5m
F.B.A CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.1 (69)
Mg - 122 (98)
Na - 247 (99)

Ca - 525 (99)
K - 25 (99)
Alk - 385 (90)

SITE DESCRIPTION

This site is 2 km in length and is set in gentle green hills of young slates and grits. It is one of the most biologically rich lakes in the Lake District containing rainbow trout, brown trout, roach, perch, rudd, pike, eels and a few sea trout.

SAMPLE DESCRIPTION

A) Margin sample

Taken from the east side of the lake.
Pebbles/Macrophyte/Leaves.

B) Benthic samples

1.12/1.22 - 4 Jenkin cores from a depth of 12m at the north point of the site.

Organic silt.

1.13/1.23 - 4 Jenkin cores from a depth of 4m at the north point of the site.

Organic silt.

SITE - 2
NAME - WINDERMERE (SOUTH BASIN)
GRID REF. - 390935
SAMPLING DATES : 2.1 - 1/2/89
2.2 - 28/8/89

FAUNA :

	2.11	2.21	2.22	2.23	2.24
<u>Cypria ophthalmica</u>	0	1	5	36	0
<u>Cyclocypris laevis</u>	1	0	0	0	0
<u>Cyclocypris ovum</u>	0	1	0	0	0
<u>Cyclocypris serena</u>	0	0	0	0	13
<u>Candona candida</u>	0	25	4	8	1
<u>Candona neglecta</u>	0	0	6	3	0
<u>Herpetocypris reptans</u>	0	8	0	0	2
<u>Cypridopsis vidua</u>	0	7	0	0	3
Tot/species	1	5	3	3	4
Tot/no.	1	42	15	47	19
Tot/overall species	8				

LAKE SIZE - 6.72 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 39m

MAX DEPTH - 42m
F.B.A CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.1 (91)
Mg - 92 (129)
Na - 219 (129)

Ca - 355 (129)
K - 17 (129)
Alk - 236 (95)

SITE DESCRIPTION

This lake is the largest in the Lake District and contains pike, perch, trout, char and tench. Its main tributaries are the Rivers Rothay and Brathay, flowing into the north end, Trout Beck entering the north basin about half-way down its eastern side (SD 395996), and Cunsey Beck, bringing water from Esthwaite (site 1) into the south basin (SD 384936). The outflow, at the extreme southern end of the south basin (SD 380870). The south basin is more productive and has a higher total ion concentration than the north basin.

SAMPLE DESCRIPTION

A) <u>Margin sample</u>

Taken from the southern tip of the lake at the river exit, there being extensive growth of reedmace and <u>Elodea</u>.

Gravel/Sand/Macrophyte.

B) Benthic samples

2.22 - 4 Jenkin cores from a depth of 42m, the deepest part of the southern basin. Organic silt/faecal pellets.

2.23 - 4 Jenkin cores from a depth of 11m in a bay just north of 'Rawlinson Nab'. Organic silt/faecal pellets.

2.24 - 4 Jenkin cores from a depth of 3m into the bay into which Cunsey Beck flows. Rich in *Elodea*.

Macrophyte/Organic silt.

SITE - 3
NAME - WINDERMERE (NORTH BASIN)
GRID REF. - 395985
SAMPLING DATES : 3.1 - 1/2/89
3.2 - 28/8/89

FAUNA :

	3.11	3.21	3.12	3.22	3.13	3.23	3.14	3.24	3.15
Cypria ophthalmica	1	0	27	12	90	41	1	0	5
Cyclocypris ovum	0	0	0	0	15	5	0	0	5
Cyclocypris serena	80	49	0	0	0	0	0	0	0
Candona candida	85	1	0	14	0	0	0	0	0
Candona neglecta	0	0	61	7	3	6	0	0	4
Candona rostrata	0	0	0	0	4	0	0	0	0
Herpetocypris reptans	0	1	0	0	0	0	0	0	0
Cypridopsis vidua	3	31	0	3	0	1	1	6	0
Cypricercus fuscatus	0	0	0	0	0	0	0	0	2
Tot/species	4	4	2	4	4	4	2	1	4
Tot/no.	169	82	88	36	112	53	2	6	16
Tot/overall species	9								

LAKE SIZE - 8.05 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 39m

MAX DEPTH - 64m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.0 (90)
Mg - 81 (128)
Na - 202 (128)
Ca - 314 (128)
K - 14 (128)
Alk - 204 (94)

SITE DESCRIPTION

See notes for site no. 2.

SAMPLE DESCRIPTION

A) Margin sample

Taken from the north point of the site.
Gravel/Sand/Macrophyte.

B) Benthic samples

3.12/3.22 - 4 Jenkin cores from a depth of 64m, next to the F.B.A. buoy, the deepest part of the north basin.
Organic silt/Faecal pellets.

3.13/3.23 - 4 Jenkin cores from a depth of 15m, in Pull Wyke Bay (buoy 6 from the RH/S margin).
Organic silt.

3.14/3.24 - 4 Jenkin cores from a depth of 3m from the delta with the River Rothay. Sand/Macrophyte.

3.15 - 4 Jenkin cores from a depth of 10m, in Pull Wyke Bay (buoy 10 from the RH/S margin).

Organic silt.

3.16 - 4 Jenkin cores from a depth of 2m, in Bee Bay.

Organic silt.

SITE - 4
NAME - CONISTON WATER
GRID REF. - 305949
SAMPLING DATES : 4.1 - 22/8/89
4.2 - 1/2/90

FAUNA :

	4.1	4.2
Candona candida	0	1
Candona siliquosa	0	1
Cypria ophthalmica	2	2
Cyclocypris laevis	8	0
Cyclocypris serena	51	0
Cyclocypris ovum	0	1
Candona pratensis	1	0
Candona vavrai	1	2
Tot/species	5	5
Tot/no.	63	7
Tot/overall species	8	

LAKE SIZE - 4.91×10^6 m^2
SIZE CLASS - A
ALTITUDE - 44m

MAX DEPTH - 56m
F.B.A CLASS - 3
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.9 (30)
Mg - 87 (43)
Na - 216 (43)

Ca - 311 (41)
K - 18 (43)
Alk - 183 (39)

SITE DESCRIPTION

A natural, long and narrow valley lake, with rocky/boulder margins, consisting of a single basin with shallow areas at both the head and foot of the lake. The three largest inflows all drain the Coniston fells. Two enter the site below the village and were once heavily contaminated by clay and copper when the mines upstream were in production, especially in the 19th Century. Only small streams drain the decorative woodlands on the eastern shore. The nutrient status of the lake is oligotrophic-mesotrophic. Fish present include char, brown trout, pike, perch and eels.

SAMPLE DESCRIPTION

A) Margin sample

Taken from the north-west tip of the lake (GR. 313976). In the winter sample the same area was sampled, although the water level was higher, making access to the exact region very difficult.

Gravel/Sand/Macrophyte ('reedgrass')

SITE - 5
NAME - KILLINGTON RESERVOIR
GRID REF. - 590910
SAMPLING DATES : 5.1 - 20/8/89
5.2 - 28/1/90

FAUNA :

	5.1	5.2
	0	0
Tot/species	0	0
Tot/no.	0	0
Tot/overall species	0	

LAKE SIZE - 6.60 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 214m

MAX DEPTH - 3m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.7 (5)
Mg - 151 (7)
Na - 791 (7)
Ca - 595 (7)
K - 21 (7)
Alk - 459 (3)

SITE DESCRIPTION

A reservoir artificially constructed for the purpose of drinking water. Uniform pebble margins prevail around the site.

SAMPLE DESCRIPTION

A) Margin sample

Taken from the eastern tip of the site (GR. 598913), next to the entrance of a beck near the dam wall.
Gravel/Sand.

SITE - 6
NAME - BLELHAM TARN
GRID REF. - 365004
SAMPLING DATES : 6.1 - 1/2/89
6.2 - 30/8/89

FAUNA :

	6.11	6.21	6.12	6.22	6.13	6.23
Metacypris cordata	1	5	0	0	2	4
Cypria ophthalmica	6	49	135	2	0	0
Cyclocypris laevis	2	2	0	0	6	0
Candona candida	8	29	2	0	0	25
Herpetocypris reptans	2	5	0	0	0	0
Cypridopsis vidua	0	11	0	0	0	0
Tot/species	5	6	2	1	2	2
Tot/no.	19	101	137	2	8	29
Tot/overall species	6					

LAKE SIZE - 1.00 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 42m

MAX DEPTH - 14.5m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.0 (66)
Mg - 136 (93)
Na - 222 (94)
Ca - 540 (94)
K - 26 (94)
Alk - 403 (80)

SITE DESCRIPTION

This lake lies near the north end of the Blelham-Esthwaite-Cunsey glacial valley, a loop of the Windermere glacial basin. Sphagnum bog encroaches on the N-W side of the tarn, and the site has three inflows, Fishpond Beck, Ford Wood Beck and Wray Beck. It contains pike, perch and eels.

SAMPLE DESCRIPTION

A) Margin sample

Taken near the boathouse halfway along the west margin. Organic silt/Macrophyte ('reedmace').

B) Benthic samples

6.12/6.22 - 4 Jenkin cores from a depth of 14m from the middle of the tarn opposite the boathouse.

Organic silt/Faecal pellets.

6.13/6.23 - 4 Jenkin cores from a depth of 2m from the opposite margin of the site to the boathouse, against a bed of reedmace and bullrushes.

Organic silt/leaves.

SITE - 7
NAME - TARN-HOWS TARN
GRID REF. - 330000
SAMPLING DATES : 7.1 - 2/2/89
7.2 - 22/8/89

FAUNA :

	7.1	7.2
Cyclocypris ovum	5	1
Candona candida	9	0
Candona siliquosa	14	3
Herpetocypris reptans	8	1
Potamocypris villosa	11	1
Cypridopsis vidua	3	0
Tot/species	6	4
Tot/no.	50	6
Tot/overall species	6	

LAKE SIZE - 1.44 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 188m

MAX DEPTH - 9m
F.B.A CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.9 (8)
Mg - 108 (10)
Na - 211 (10)

Ca - 288 (10)
K - 12 (9)
Alk - 238 (6)

SITE DESCRIPTION

A large, artificially constructed tarn set in grassland with extensive coniferous tree growth around the lake edge. It contains pike, perch, roach and rudd.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at the southern tip of the tarn (grid ref. 329998), near the car park close to a small inflowing spring. No macrophytic growth present. The substrate was fine silty mud overlying a firm gravel base.

Organic silt/Gravel.

SITE - 8
NAME - POAKA BECK RESERVOIR
GRID REF. - 245785
SAMPLING DATES : 8.1 - 29/8/89
8.2 - 1/2/90

FAUNA :

	8.1	8.2
Cypridopsis vidua	18	0
Tot/species	1	0
Tot/no.	18	0
Tot/overall species	1	

LAKE SIZE - 9.00 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 153m

MAX DEPTH - ?
F.B.A CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.5 (3)
Mg - 336 (4)
Na - 307 (4)

Ca - 647 (4)
K - 29 (4)
Alk - 571 (3)

SITE DESCRIPTION

A heavily dammed, artificially constructed reservoir, owned by N-W Water. The margins consist mainly of fine gravel and pebble sized material.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken near the dam wall, and consisted of fine gravel and sand, over which *Elodea* was growing.

Gravel/Sand/Macrophyte.

SITE - 9
NAME - PENNINGTON RESERVOIR
GRID REF. - 256790
SAMPLING DATES : 9.1 - 29/8/89
9.2 - 1/2/90

FAUNA :

	9.1	9.2
Cypria ophthalmica	63	0
Cyclocypris serena	2	1
Herpetocypris reptans	18	0
Cypridopsis vidua	28	0
Tot/species	4	1
Tot/no.	111	1
Tot/overall species	4	

LAKE SIZE - 1.10 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 122m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.4 (3)
Mg - 335 (4)
Na - 324 (4)

Ca - 719 (4)
K - 28 (4)
Alk - 647 (3)

SITE DESCRIPTION

An artificially constructed reservoir which is heavily dammed. The margins consist of mainly fine gravel and sand.

SAMPLE DESCRIPTION

A) Margin sample

Low water levels in the summer period allowed a large expanse of the margins to be left open in the south-east corner of the site, exposing a region of silty mud near an inflowing stream. In the winter the water levels were higher, but it was possible to sample in the same area.

Organic silt/Clay.

SITE - 10
NAME - BIGLAND TARN
GRID REF. - 355829
SAMPLING DATES : 10.1 - 31/1/89
10.2 - 20/9/89

FAUNA :

	10.1	10.2
Cypria ophthalmica	0	2
Cyclocypris globosa	1	0
Cyclocypris ovum	1	4
Candona candida	0	11
Herpetocypris reptans	0	9
Cypridopsis vidua	4	296
Tot/species	3	5
Tot/no.	6	322
Tot/overall species	6	

LAKE SIZE - 5.30 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 168m

MAX DEPTH - 9m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.4 (4)
Mg - 163 (5)
Na - 262 (5)

Ca - 564 (5)
K - 19 (4)
Alk - 572 (2)

SITE DESCRIPTION

This is a glacial tarn which has been converted into a managed coarse fishery containing pike, perch and roach, surrounded by high quality grassland, being susceptible to agricultural run-off due to the outlying land. A coniferous plantation exists on one side. The tarn is circular and has very flat margins.

SAMPLE DESCRIPTION

The samples were taken at the northern tip of the lake (grid ref. 355831) near the car park. The substrate was reedmace amongst a fine silt and sand sediment, together with dead reedmace and _Elodea sp_.

Organic silt/Macrophyte/Sand.

SITE - 11
NAME - WITHERSLACK HALL POND
GRID REF. - 435864
SAMPLING DATES : 11.1 - 30/1/89
11.2 - 29/8/89
FAUNA :

	11.1	11.2
Cypria ophthalmica	7	7
Cyclocypris laevis	53	45
Candona candida	25	8
Cyprinotus incongruens	1	0
Cypridopsis vidua	1	2
Tot/species	5	4
Tot/no.	94	62
Tot/overall species	5	

LAKE SIZE - 2.6 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 61m

MAX DEPTH - 5m
F.B.A. CLASS - 5
BEDROCK - Carboniferous series

CHEMISTRY

pH - 7.8 (5)
Mg - 537 (7)
Na - 307 (7)

Ca - 2284 (7)
K - 23 (6)
Alk - 2468 (4)

SITE DESCRIPTION

A rich eutrophic 'estate-type' water, very rich in dissolved ions. The site is set in decidious woodland with some mixed conifers and small immature oak and sycamore trees growing around the lake margin.

SAMPLE DESCRIPTION

The sample was taken half-way along the east margin of the lake against the road. The sample was taken from underneath overhanging trees and was rich in decaying leaves and silt.

Organic silt/Leaves.

SITE - 12
NAME - RATHER-HEATH TARN
GRID REF. - 484958
SAMPLING DATES : 12.1 - 20/8/89
12.2 - 30/1/90

FAUNA :

	12.1	12.2
Cypria ophthalmica	1	29
Cypria exsculpta	1	0
Cyclocypris ovum	4	10
Candona candida	1	5
Candonopsis kingsleii	2	79
Cypridopsis vidua	1	2
Candona compressa	0	8
Candona fabaeformis	0	61
Cypricercus fuscatus	0	3
Tot/species	6	8
Tot/no.	10	197
Tot/overall species	9	

LAKE SIZE - 2.12 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 114m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.1 (5)
Mg - 189 (6)
Na - 240 (6)

Ca - 890 (6)
K - 22 (6)
Alk - 897 (4)

SITE DESCRIPTION

A heavily utilised coarse fishery, dammed at one end and lying between two thickly wooded knolls.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at the east tip of the lake over the dam wall, underneath overhanging trees and adjacent to reedmace growth.

Organic silt/Leaves.

SITE - 14
NAME - YEW TREE TARN
GRID REF. - 323004
SAMPLING DATES : 14.1 - 2/2/89
14.2 - 21/8/89

FAUNA :

	14.1	14.2
Candona candida	108	0
Cypria ophthalmica	0	1
Tot/species	1	1
Tot/no.	108	1
Tot/overall species	2	

LAKE SIZE - 3.80 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 107m

MAX DEPTH - 2m
F.B.A. CLASS - 3
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.5 (7)
Mg - 75 (8)
Na - 216 (8)

Ca - 213 (8)
K - 11 (7)
Alk - 191 (6)

SITE DESCRIPTION

A small, shallow, artificial tarn, being dammed at one end, being set in a flat alluvial valley, interspersed with groups of pines among rocky knolls and is surrounded by Yew, larch and spruce trees. A shallow channel leaching spring water flows across the tarn. This site appears to be regularly drained and refilled.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from half way along the eastern margin of the tarn in very shallow water (5cm). The winter sample was taken here from amongst filamentous algae, which was absent in the summer, when the sample was taken from a muddy/gravel lake bed.

Organic silt/Gravel. (+ Algae in winter)

SITE - 15
NAME - SKEGGLES WATER
GRID REF. - 479003
SAMPLING DATES : 15.1 - 27/8/89
15.2 - 30/1/90

FAUNA :

	15.1	15.2
<u>Cypria exsculpta</u>	1	0
<u>Cyclocypris laevis</u>	13	64
<u>Cyclocypris ovum</u>	8	17
<u>Candona candida</u>	7	15
<u>Cypridopsis vidua</u>	0	1
Tot/species	4	4
Tot/no.	29	97
Tot/overall species	5	

LAKE SIZE - 4.70 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 320m

MAX DEPTH - 3m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.5 (6)
Mg - 161 (7)
Na - 150 (7)

Ca - 358 (7)
K - 11 (7)
Alk - 308 (6)

SITE DESCRIPTION

An upland site with a catchment of virtually nil. The margins are rich in reedmace, heather and grass all around the site. The outlet of this site is Skeggleswater Dyke, and it contains perch and pike.

SAMPLE DESCRIPTION

A) <u>Margin sample</u>

The sample was taken from the east end of the lake, where the margin ground was grassy, marshy and boggy, amongst reedmace.

Organic silt/Macrophyte/Bog.

SITE - 16
NAME - KNITTLETON TARN A
GRID REF. - 255860
SAMPLING DATES : 16.1 - 4/2/89
16.2 - 22/8/89

FAUNA :

	16.1	16.2
Metacypris cordata	100	70
Cypria exsculpta	19	8
Cyclocypris laevis	3	0
Cyclocypris ovum	40	31
Candona candida	0	29
Paracandona euplectella	1	0
Herpetocypris reptans	0	16
Cypridopsis vidua	0	7
Potamocypris villosa	10	215
Tot/species	6	7
Tot/no.	173	376
Tot/overall species	9	

LAKE SIZE - 1.68 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 65m

MAX DEPTH - 3m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.1 (3)
Mg - 145 (4)
Na - 360 (4)

Ca - 581 (4)
K - 10 (3)
Alk - 585 (2)

SITE DESCRIPTION

This tarn is situated on open mooorland. There are no trees in the catchment area, and the region immediately surounding the tarn is marshy and reeded with similar small, marshy puddles surrounding the main tarn.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at the south-east end of the marshy area.

Organic silt/Macrophyte/Bog.

SITE - 17
NAME - MOSS-SIDE TARN
GRID REF. - 483957
SAMPLING DATES : 17.1 - 20/8/89
17.2 - 30/1/90

FAUNA :

	17.1	17.2
Cypria ophthalmica	26	49
Cyclocypris ovum	16	115
Candona candida	40	30
Notodromas monacha	10	0
Herpetocypris reptans	2	1
Cypridopsis vidua	8	1
Candonopsis kingsleii	0	3
Candona fabaeformis	0	35
Tot/species	6	7
Tot/no.	102	234
Tot/overall species	8	

LAKE SIZE - 7.60 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 100m

MAX DEPTH - 2m
F.B.A. CLASS - 5
BEDROCK - Carboniferous series

CHEMISTRY

pH - 7.0 (3)
Mg - 312 (5)
Na - 244 (5)

Ca - 1634 (5)
K - 26 (5)
Alk - 2140 (3)

SITE DESCRIPTION

A small tarn situated on rich agricultural farmland with boggy, marshy margins with a small amount of reedmace around its rim.

SAMPLE DESCRIPTION

A) Margin sample

A large quantity of deep, rich organic silt, from the boggy margins.

Organic silt/Bog.

SITE - 18
NAME - HOLEHIRD TARN
GRID REF. - 408008
SAMPLING DATES : 18.1 - 31/1/89
18.2 - 20/8/89

FAUNA :

	18.1	18.2
Cypria ophthalmica	1	103
Cyclocypris ovum	8	9
Candona candida	5	40
Cypridopsis vidua	1	4
Tot/species	4	4
Tot/no.	15	156
Tot/overall species	4	

LAKE SIZE - 9.30 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 110m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.4 (7)
Mg - 167 (10)
Na - 451 (10)

Ca - 968 (10)
K - 73 (9)
Alk - 875 (8)

SITE DESCRIPTION

This tarn is an ornamental pool set in grassland, and is a coarse fishery. A few decidious trees surround the tarn, there also being extensive growth of lily pads.

SAMPLE DESCRIPTION

The sample was taken half-way along the eastern side of the lake amongst reedgrowth. Dense layers of rich sediment.

Organic silt/Leaves.

SITE - 19
NAME - HIGH ARNSIDE TARN
GRID REF. - 331011
SAMPLING DATES : 19.1 - 2/2/89
19.2 - 22/8/89

FAUNA :

	19.1	19.2
Cypria ophthalmica	2	0
Cypria exsculpta	0	3
Cyclocypris laevis	0	1
Cyclocypris ovum	1	3
Candona candida	7	14
Cypricercus obliquus	0	19
Herpetocypris reptans	0	1
Cypridopsis vidua	0	26
Tot/species	3	7
Tot/no.	10	66
Tot/overall species	8	

LAKE SIZE - 8.40 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 168m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 7.3 (4)
Mg - 127 (6)
Na - 228 (6)
Ca - 340 (6)
K - 10 (5)
Alk - 359 (4)

SITE DESCRIPTION

This site is an artificially constructed trout fishery (which also contains perch) low set on grassland with a small amount of decidious woodland on the eastern margin. The site is dammed at one end.

SAMPLE DESCRIPTION

A) Margin sample

On both occasions the samples were taken half-way along the western margin amongst dense macrophyte growth, including *Potamogeton sp*, *Elodea canadensis*, reedmace and lilies.

Organic silt/Macrophyte.

SITE - 20
NAME - GRIZEDALE TARN
GRID REF. - 341944
SAMPLING DATES : 20.1 - 31/1/89
20.2 - 22/8/89

FAUNA :

	20.1	20.2
Cypria ophthalmica	1	0
Cyclocypris ovum	4	1
Candona candida	6	68
Candona rostrata	0	61
Paracandona euplectella	0	31
Cypridopsis vidua	0	24
Tot/species	3	5
Tot/no.	11	185
Tot/overall species	6	

LAKE SIZE - 4.60 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 240m

MAX DEPTH - ?
F.B.A. CLASS - 2
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.6 (3)
Mg - 73 (4)
Na - 273 (4)

Ca - 258 (4)
K - 10 (3)
Alk - 80 (2)

SITE DESCRIPTION

This shallow, circular tarn is set in the Grizedale Forest. It is a peculiar site in although it is a peat-moss tarn and appears to possess 'black' water typical of acidic sites, yet it has a reasonable nutrient profile. The site is set in dense coniferous woodland, mainly lodge-pole pine, and spruce. The tarn is surrounded by Sphagnum bog, cotton-grass and other acidic type flora. Reedmace occurs all around the lake margins and lily growth is extensive in summer. It is fed from the marshes among the outcrops of bleached Bannisdale slate.

SAMPLE DESCRIPTION

A) Margin sample

The samples were taken from the reedmace and Sphagnum in the monospecific marginal habitats.

Macrophyte/Peat-Moss.

SITE - 21
NAME - KNITTLETON TARN B
GRID REF. - 255864
SAMPLING DATES : 21.1 - 4/2/89
22.2 - 22/8/89

FAUNA :

	21.1	22.2
Cypria ophthalmica	88	166
Cypria exsculpta	2	0
Cyclocypris ovum	76	120
Candona candida	0	5
Cypricercus obliquus	0	3
Cypridopsis vidua	2	8
Tot/species	4	5
Tot/no.	168	302
Tot/overall species	6	

LAKE SIZE - 5.10 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 137m

MAX DEPTH - 3m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.2 (2)
Mg - 143 (3)
Na - 389 (3)

Ca - 570 (3)
K - 14 (2)
Alk - 586 (1)

SITE DESCRIPTION

A small tarn. No trres surround the catchment, which is mainly grassland. In the winter there was abundant growth of Potamogeton sp, but not in the summer - a function of floral seasonality.

SAMPLE DESCRIPTION

A) Margin sample

In the winter, the sample was taken from the living macrophyte and associated soft sediment, whilst the summer summer sample was taken from the decayed macrophyte.

Macrophyte/Organic silt.

SITE - 22
NAME - CLAY POND
GRID REF. - 373009
SAMPLING DATES : 22.1 - 31/1/89
22.2 - 21/8/89

FAUNA :

	22.1	22.2
Cypria ophthalmica	803	46
Cyclocypris globosa	3	0
Cyclocypris ovum	28	0
Candona candida	2	6
Candona reducta	11	0
Cypridopsis vidua	3	0
Tot/species	6	2
Tot/no.	850	52
Tot/overall species	6	

LAKE SIZE - 5.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 48m

MAX DEPTH - 0.5m
F.B.A. CLASS - (4)
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.2 (2)
Mg - 160 (2)
Na - 370 (2)

Ca - 575 (3)
K - 21 (1)
Alk - 457 (2)

SITE DESCRIPTION

A tiny artificial farmyard pool, dammed at one end by a stone wall, set amongst grassland and susceptible to agricultural run-off. A small stream flows in at the end of the northern end of the pool. It has extensive reed growth around the margins and periphytic growth within the pool, which is heavily silted, there being over 1m of soft organic sediment, as opposed to just a few cm of water.

SAMPLE DESCRIPTION

A) Margin sample
Very fine, rich organic sediment.
Organic silt/Macrophyte

SITE - 23
NAME - BARROW PLANTATION TARN A
GRID REF. - 422949
SAMPLING DATES : 23.1 - 20/8/89
23.2 - 30/1/89

FAUNA :

	23.1	23.2
Ilyocypris bradyii	1	0
Cypria ophthalmica	2	5
Cypria exsculpta	180	62
Cyclocypris ovum	849	37
Candona candida	64	13
Paracandona euplectella	1	0
Cypridopsis vidua	5	2
Cypricercus obliquus	0	5
Candona siliquosa	0	1
Tot/species	7	7
Tot/no.	1102	125
Tot/overall species	9	

LAKE SIZE - 5.00×10^2 m^2
SIZE CLASS - E
ALTITUDE - 160m

MAX DEPTH - 0.5m
F.B.A. CLASS - (4)
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.2 (3)
Mg - 222 (2)
Na - 412 (2)
Ca - 330 (2)
K - 5 (2)
Alk - 260 (E)

SITE DESCRIPTION

One of the many small, shallow tarns in the Barrow Plantation, which is interconnected to ther others by boggy ground and sluggish streams. This pool is very small, only a few cm in places, and heavily enriched with macrophytes, in a predominately bracken catchment.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken in a region typical for the tarn, amongst macrophytic growth in the margin. No emergent stone surface is present in this tarn.

Organic silt/Macrophyte.

SITE - 24
NAME - BARROW PLANTATION TARN B
GRID REF. - 422949
SAMPLING DATES : 24.1 - 20/8/89
24.2 - 30/1/90

FAUNA :

	24.1	24.2
Cypria ophthalmica	28	3
Cyclocypris ovum	56	36
Candona candida	2	2
Notodromas monacha	8	0
Cypridopsis vidua	59	18
Cypricercus obliquus	0	12
Potamocypris villosa	0	1
Tot/species	5	6
Tot/no.	153	72
Tot/overall species	7	

LAKE SIZE - 5.00 x 10^3 m^2
SIZE CLASS - E
ALTITUDE - 160m

MAX DEPTH - 3m
F.B.A. CLASS - (4)
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.7 (3)
Mg - 179 (2)
Na - 378 (2)

Ca - 330 (2)
K - 7 (2)
Alk - 274 (E)

SITE DESCRIPTION

This tiny pool is deeper than site no. 23 and different in appearance. There is little macrophyte growth, apart from sporadic lily growth. Here, there is a lot of emergent stone present.

SAMPLE DESCRIPTION

A) Margin sample

This was taken from a region typical of the site, amongst soft organic sediment. The region surrounding the lilies could not be sampled as they were situated in the middle of the tarn in deeper water.

Organic silt/Gravel.

SITE - 25
NAME - BARROW PLANTATION TARN D
GRID REF - 422949
SAMPLING DATES : 25.1 - 20/8/89
25.2 - 30/1/90

FAUNA :

	25.1	25.2
Cypria exsculpta	3	0
Cyclocypris ovum	17	6
Paracandona eupletella	12	18
Cypricercus obliquus	16	2
Herpetocypris chevreuxi	43	12
Cypridopsis vidua	2	0
Candona candida	0	2
Tot/species	6	5
Tot/no.	93	40
Tot/overall species	7	

LAKE SIZE - 7.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 160m

MAX DEPTH - 1.5m
F.B.A. CLASS - (4)
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.5 (3)
Mg - 156 (2)
Na - 258 (2)

Ca - 338 (2)
K - 7 (2)
Alk - 264 (E)

SITE DESCRIPTION

This site is really a series of boggy, marshy puddles surrounded by reedmace and reedgrass. No periphytic macrophytes nor emergent stone occur.

SAMPLE DESCRIPTION

Taken from the largest of the boggy puddles, deep layers of rich silt.

Organic silt/Bog.

SITE - 26
NAME - BARROW PLANTATION TARN Q
GRID REF. - 422949
SAMPLING DATES : 26.1 - 20/8/89
26.2 - 30/1/90

FAUNA :

	26.1	26.2
Cypria exsculpta	1	1
Cyclocypris ovum	89	27
Candona candida	6	6
Paracandona euplectella	1	3
Cypridopsis vidua	7	16
Cypria ophthalmica	0	4
Tot/species	5	6
Tot/no.	104	57
Tot/overall species	6	

LAKE SIZE - 5.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 160m

MAX DEPTH - 2m
F.B.A. CLASS - (4)
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.8 (3)
Mg - 144 (2)
Na - 279 (2)
Ca - 396 (2)
K - 11 (2)
Alk - 336 (E)

SITE DESCRIPTION

This is also known as the 'quarry tarn', having a large amount of exposed stone.

SAMPLE DESCRIPTION

A) Margin sample

Taken from underneath an overhanging tree, rich silt sediment.

Organic silt/Leaves.

SITE - 27
NAME - HAWESWATER
GRID REF. - 479140
SAMPLING DATES : 27.1 - 25/8/89
27.2 - 29/1/90

FAUNA :

	27.1	27.2
<u>Cyclocypris laevis</u>	5	0
<u>Cyclocypris serena</u>	3	0
<u>Candona candida</u>	28	0
<u>Cypria ophthalmica</u>	1	0
Tot/species	4	0
Tot/no.	37	0
Tot/overall species	4	

LAKE SIZE - 3.91 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 240m

MAX DEPTH - 57m
F.B.A. CLASS - 3
BEDROCK - Borrowdale volcanics

<u>CHEMISTRY</u>

pH - 6.8 (21)
Mg - 73 (33)
Na - 145 (33)
Ca - 245 (33)
K - 11 (33)
Alk - 169 (31)

<u>SITE DESCRIPTION</u>

Originally, this site was a smaller natural lake, but the surrounding area was flooded to create a large reservoir, which has boulder/rock margins. It contains Schelly, trout, perch and char.

<u>SAMPLE DESCRIPTION</u>

A) <u>Margin sample</u>

The sample site was at the southern point of the lake (grid ref. 477115) where an inflowing river enters. In the summer, the sample was taken from amongst soft clay and shales under a few cm of water, which was overlain by a fine layer of organic silt. In the winter, however, due to increased water levels, the sample could only be taken from flooded grassland.

Organic silt/Clay.

SITE - 28
NAME - WAST WATER
GRID REF. - 153055
SAMPLING DATES : 28.1 - 29/8/89
28.2 - 1/2/90

FAUNA :

	28.1	28.2
Cyclocypris globosa	0	1
Cyclocypris ovum	0	1
Candona candida	0	10
Candona vavrai	0	3
Tot/species	0	4
Tot/no.	0	15
Tot/overall species	4	

LAKE SIZE - 2.91 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 61m
MAX DEPTH - 76m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.7 (31)
Mg - 114 (43)
Na - 169 (43)
Ca - 114 (43)
K - 10 (43)
Alk - 51 (42)

SITE DESCRIPTION

This is the deepest English lake being surrounded by high plunging screes and stark skylines of rugged volcanic rock, and is also very unproductive. The local Borrowdale volcanic rocks provide little by the way of mineral addition to nutrients and there is a slow rate of annual sediment accumulation. There are three major inflows to the lake and many minor ones. All the marginal regions of this site are composed of boulders and large rocks. It contains brown trout, char, minnows and sticklebacks.

SAMPLE DESCRIPTION

A) Margin sample

Due to the difficulty in finding a suitable sampling site, two different areas were sampled at this site, one in each seasonal sampling period. In the summer, a small, macrophyte-free sandy region at the south-west margin of the lake adjacent to the inflow of the River Irt was sampled (grid ref. 147040). In the winter, the sample position was changed due to the location of a small amount of periphytic growth and fine sand at the south-east tip of the lake.

Macrophyte/Organic silt/Sand.

SITE - 29
NAME - THIRLMERE
GRID REF. - 315160
SAMPLING DATES : 29.1 - 3/2/89
29.2 - 21/8/89

FAUNA :

	29.1	29.2
Cypricercus fuscatus	1	0
Potamocypris villosa	1	0
Tot/species	2	0
Tot/no.	2	0
Tot/overall species	2	

LAKE SIZE - 3.26 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 179m

MAX DEPTH - 46m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.5 (27)
Mg - 43 (39)
Na - 157 (38)
Ca - 152 (39)
K - 9 (38)
Alk - 57 (38)

SITE DESCRIPTION

This is a vast natural mere, used as a reservoir for drinking water. There is extensive growth of coniferous trees around all sides of the lake. This site is again typical of all the large waterbodies in the Lake District, possessing large rocky, boulderous margins. It contains pike, perch, trout and char.

SAMPLE DESCRIPTION

A) Margin sample

The two samples were taken at the same position half-way along the eastern margin of the mere (grid ref. 157318) but sample conditions varied with the season. In winter, the mere was in flood, and the sample was taken on rocky suubstrate over a flooded grassland area, whereas the water level was very low in the summer, and fine sand and gravel was encountered.

Sand/Gravel.

SITE - 30
NAME - GRASMERE
GRID REF. - 330065
SAMPLING DATES : 30.1 - 31/1/89
30.2 - 21/8/89

FAUNA :

	30.1	30.2
Cypria exsculpta	2	0
Cyclocypris ovum	1	0
Tot/species	2	0
Tot/no.	2	0
Tot/overall species	2	0

LAKE SIZE - 6.45 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 62m
MAX DEPTH - 21.5m
F.B.A. CLASS - 3
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.8 (96)
Mg - 56 (127)
Na - 184 (128)
Ca - 237 (127)
K - 10 (127)
Alk - 141 (94)

SITE DESCRIPTION

A large, naturally formed lake with gravel and pebble sized material making up the marginal zone. It contains pike, perch and trout.

SAMPLE DESCRIPTION

A) Margin sample

The area sampled was at the northern end of the lake (grid ref 333068) west of the inflowing River Rothay next to a boat yard where there was extensive reedmace growth and soft sediment.

Organic silt/Macrophyte.

SITE - 31
NAME - BROTHERSWATER
GRID REF. - 401125
SAMPLING DATES : 31.1 - 25/8/89
31.2 - 29/1/90

FAUNA :

	31.11	31.21	31.12	31.13
Cypria ophthalmica	7	0	2	19
Cypria exsculpta	3	1	0	2
Cyclocypris ovum	301	3	0	0
Cyclocypris serena	82	0	0	0
Candona candida	97	2	0	9
Herpetocypris reptans	5	0	0	0
Potamocypris villosa	8	0	0	0
Candona neglecta	0	0	2	0
Tot/species	7	3	2	3
Tot/no.	503	6	4	30
Tot/overall species	8			

LAKE SIZE - 1.90 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 174m

MAX DEPTH - 18m
F.B.A. CLASS - 3
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.7 (27)
Mg - 65 (34)
Na - 187 (33)

Ca - 273 (33)
K - 8 (36)
Alk - 182 (32)

SITE DESCRIPTION

Brotherswater is a small, moderately productive lake situated on the Borrowdale Volcanics. It has predominately rocky margins and contains trout and perch.

SAMPLE DESCRIPTION

A) Margin sample

Taken from the south-west tip of the lake, amongst heavy reedmace and Elodea growth.

Organic silt/Macrophyte.

B) Benthic samples

3.12 - 4 Jenkin cores from a depth of 19m, approximately in the lake centre.

Organic silt/Faecal pellets.

3.13 - 4 Jenkin cores from a depth of 11m, approximately 50m

from the margins at the south-east tip of the site.
Organic silt/Faecal pellets.

SITE - 32
NAME - DEVOKE WATER
GRID REF. - 163972
SAMPLING DATES : 32.1 - 4/2/89
32.2 - 29/8/89

FAUNA :

	32.1	32.2
Cyclocypris ovum	6	9
Candona vavrai	4	2
Cypricercus obliquus	0	1
Tot/species	2	3
Tot/no.	10	12
Tot/overall species	3	

LAKE SIZE - 2.80×10^5 m^2
SIZE CLASS - B
ALTITUDE - 233m
MAX DEPTH - 14m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.2 (171)
Mg - 86 (172)
Na - 227 (172)
Ca - 122 (172)
K - 11 (171)
Alk - 2 (168)

SITE DESCRIPTION

This is the largest natural 'tarn' in the Lake District, and is dammed by a low glacial moraine at the south-west tip. It is a large rocky-basin exposed water that lies at the northern end of a granite intrusion into the surrounding andesite, turning it dark and producing biotite and hornblende. No trees surround the catchment area, the site being surrounded by broad heather moors. It contains trout.

SAMPLE DESCRIPTION

The sample was taken from the eastern side of the lake (at grid ref. 162969), opposite a boathouse, where a small grassy margined region with reedgrass existed.

Gravel/Macrophyte/Organic silt.

SITE - 33
NAME - SEATHWAITE TARN
GRID REF. - 253988
SAMPLING DATES : 33.1 - 30/8/89
FAUNA :

	33.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 2.67 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 366m

MAX DEPTH - 26m
F.B.A. CLASS - 1
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 5.1 (171)
Mg - 56 (172)
Na - 155 (172)
Ca - 59 (172)
K - 9 (172)
Alk - -10 (172)

SITE DESCRIPTION

This tarn lies in a high valley, part of the way down a double headed valley, 1,400 ft below the summit ridge. It is a large rock and boulder margined man-made reservoir used for the supply of drinking water, and is dammed at one end, there being a small island. It contains trout.

SAMPLE DESCRIPTION

A) Margin sample

A site was found with extreme difficulty at the southern tip of the tarn (grid ref. 250985) where a small amount of fine gravel was present, over semi-flooded grassland.

Gravel/Sand.

SITE - 34
NAME - LEVERSWATER
GRID REF. - 279993
SAMPLING DATES : 34.1 - 2/9/89
FAUNA :

	34.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 1.50 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 411m
MAX DEPTH -38m
F.B.A. CLASS -1
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH	4.7 (45)	Ca	44 (67)
Mg	58 (67)	K	9 (67)
Na	139 (67)	Alk	-14 (55)

SITE DESCRIPTION

A large rock-basin circular reservoir, which has been carved and dammed by glacial action from hard volcanic rock the margins of which comprised entirely of large rocks, boulders and pebbles.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at the eastern side of the site (grid ref. 278995), amongst sand and moss. No aquatic macrophyte growth nor organic sediment was found anywhere at this site.

Sand/Gravel.

SITE - 35
NAME - BURNMOOR TARN
GRID REF. - 184044
SAMPLING DATES : 35.1 - 3/9/89
35.2 - 1/2/90

FAUNA :

	35.1	35.2
Cyclocypris ovum	3	0
Candona rostrata	3	4
Candona vavrai	0	1
Tot/species	2	2
Tot/no.	6	5
Tot/overall species	3	

LAKE SIZE - 2.40 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 254m

MAX DEPTH - 13m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.3 (16)
Mg - 67 (18)
Na - 195 (18)
Ca - 100 (18)
K - 9 (18)
Alk - 49 (17)

SITE DESCRIPTION

One of the largest of the upland tarns, situated on Eskdale Fell. The margins consist mainly of pebble sized material and gravel and the catchment is composed of poor grassland and some heather which had never been limed. Most of the drainage is from the low hills to the north and south-west. The lake is oligotrophic but does not have a very acidic pH, and is part of the F.B.A. 'Acid Waters Monitoring Programme'. This tarn contains perch, pike and trout.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at an area in the north-east region of the tarn (grid ref. 186046) amongst sand and reedgrass.

Sand/Macrophyte.

SITE - 36
NAME - LOUGHRIGG TARN
GRID REF. - 343044
SAMPLING DATES : 36.11 - 31/1/89
36.21-.24 - 21/8/89
36.25-.26 - 25/8/89
36.3 - 31/1/90

FAUNA :

	.11	.21	.22	.32	.23	.33	.24	.34	.25	.26
Cypria ophthalmica	0	2	1	2	0	0	0	0	0	0
Cypria exsculpta	0	45	8	1	0	0	0	0	0	0
Cyclocypris ovum	0	1	2	0	0	0	1	0	0	0
Cyclocypris globosa	0	0	2	0	49	235	0	6	0	0
Candona albicans	2	0	1	0	7	4	0	0	0	0
Candona candida	1	5	20	1	117	25	7	1	0	0
Candona rostrata	1	1	6	2	70	2	0	0	0	0
Paracandona euplectella	0	5	1	0	4	0	2	0	0	0
Cypridopsis vidua	3	25	13	1	28	0	14	2	0	0
Metacypris cordata	9	163	236	17	316	6	47	0	0	0
Candona vavrai	0	0	0	0	0	12	0	0	0	0
Tot/species	5	8	10	6	7	6	5	3	0	0
Tot/no.	16	246	290	24	591	284	71	9	0	0
Tot/overall species	11									

LAKE SIZE - 8.60×10^4 m^2
SIZE CLASS - C
ALTITUDE - 259m

MAX DEPTH - 10m
F.B.A. CLASS - 4
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 7.0 (7)
Mg - 93 (19)
Na - 192 (19)
Ca - 361 (19)
K - 18 (18)
Alk - 300 (14)

SITE DESCRIPTION

This tarn was formed by glacial action, and is surrounded by oak, larch, Scots pine and sycamore, together with rich reed growth. It contains pike, perch and minnows.

SAMPLE DESCRIPTION

A) *Margin samples*

36.11/36.21 - Taken from the south tip, amongst soft sediment, lilies and *Elodea*.

Organic silt/Macrophyte.

36.22/36.32 - Taken from the south-east corner, underneath overhanging trees with very boggy margins.

Organic silt/Leaves/Bog.

36.23/36.33 - Taken half way along the east margin in marshy bogland adjoining the reedmaced-fringed margin of the lake.

Organic silt/Bog/Macrophyte

36.24/36.34 - Taken from the north-east margin amongst a small amount of organic material overlying a gravel base.

Organic silt/Gravel.

B) <u>Benthic samples</u>

36.25 - 4 Jenkin cores taken from a depth of 8m, approximately 50m from the south margin.

Faecal pellets.

36.26 - 4 Jenkin cores taken from a depth of 10m in the centre of the lake.

Faecal pellets.

SITE - 37
NAME - LITTLEWATER TARN
GRID REF. - 509169
SAMPLING DATES : 37.1 - 25/8/89
37.2 - 29/1/90

FAUNA :

	37.1	37.2
Metacypris cordata	1224	165
Cyclocypris ovum	587	193
Candona candida	7	5
Cypria ophthalmica	0	2
Tot/species	3	4
Tot/no.	1818	365
Tot/overall species	4	

LAKE SIZE - 1.50×10^4 m^2
SIZE CLASS - C
ALTITUDE - 259m

MAX DEPTH - 11m
F.B.A. CLASS - 4
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 7.2 (4)
Mg - 314 (5)
Na - 257 (5)

Ca - 1177 (5)
K - 22 (5)
Alk - 1272 (3)

SITE DESCRIPTION

In appearance, this site is remarkably similar to Little Tarn (site 64). It is surrounded by agricultural farmland, small fields and coppice woods, and overhanging trees such as willows and birches, and has rich macrophytic growth (especially reedmace) and boggy, marshy margins. It contains trout, perch and pike.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from the south bank amongst reedmace in marshy margins and extensive rich organic sediment.

Organic silt/Macrophyte/Bog.

SITE - 38
NAME - WATENDLATH TARN
GRID REF. - 275162
SAMPLING DATES : 38.1 - 23/8/89
38.2 - 29/1/90

FAUNA :

	38.1	38.2
Cyclocypris ovum	1	3
Candona candida	0	10
Tot/species	1	2
Tot/no.	1	13
Tot/overall species	2	

LAKE SIZE - 4.00 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 258m

MAX DEPTH - 17m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.4 (13)
Mg - 47 (15)
Na - 162 (15)

Ca - 150 (15)
K - 12 (11)
Alk - 69 (13)

SITE DESCRIPTION

This glacially formed tarn is a deep, circular, heavily managed trout fishery, the margins of which consist predominately of gravel with small amounts of reedgrass growing in the western margins. The water of this tarn is remarkably opaque. It is fed from the south by Bleatarn Gill and its outflow to the north is Watendlath Beck. The fish include both brown and rainbow trout, together with pike and perch.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst the reedgrass growth half-way along the western margin.

Gravel/Macrophyte/Organic silt.

SITE - 39
NAME - BLEA TARN
GRID REF. - 165010
SAMPLING DATES : 39.1 - 29/8/89
FAUNA :

	39.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 3.30 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 213m

MAX DEPTH - ?
F.B.A. CLASS - 2
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 5.9 (122)
Ca - 98 (123)
Na - 221 (123)

Ca - 108 (123)
K - 12 (124)
Alk - -3 (124)

SITE DESCRIPTION

Blea Tarn lies on Eskdale Moor, in glacial moraines among tough granitic outcrops covered in heather. It is a circular, acidic, upland tarn. The margins are very rocky, large boulders being numerous. It only contains perch.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken where reedmace and filamentous algae existed at the southern end of the tarn near an outflowing stream.

Peat-Moss/Macrophyte.

SITE - 40
NAME - PARK-GATE TARN
GRID REF. - 118006
SAMPLING DATES : 40.1 - 4/2/89
40.2 - 29/8/89

FAUNA :

	40.1	40.2
Cyclocypris ovum	1	0
Tot/species	1	0
Tot/no.	1	0
Tot/overall species	1	

LAKE SIZE - 3.40 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 58m

MAX DEPTH - ?
F.B.A. CLASS - 1
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 4.6 (124)
Mg - 159 (126)
Na - 563 (126)
Ca - 128 (126)
K - 22 (125)
Alk - -40 (125)

SITE DESCRIPTION

An acidic tarn set in a coniferous woodland park. The tarn is situated in a valley surrounded by Spruce, Lark, Willow and Ash, and its margins include extensive macrophytic and periphytic growth (lilies and reedmace) and dense beds of boggy Sphagnum.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst the lilies and reedmace on the west side of the tarn, being rich in soft sediment. The substrate sampled entirely consisted of typical acidic 'orange-brown' humic material.

Peat-Moss/Macrophyte.

SITE - 41
NAME - LOW WATER
GRID REF. - 274983
SAMPLING DATES : 41.1 - 2/9/89
FAUNA:

	41.1
Cypridopsis vidua	1
Tot/species	1
Tot/no.	1
Tot/overall species	1

LAKE SIZE - 1.79 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 544m

MAX DEPTH -14m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.2 (11)
Mg - 60 (14)
Na - 171 (14)

Ca - 146 (13)
K - 12 (14)
Alk - 53 (14)

SITE DESCRIPTION

Low Water is situated in a glacial stepped valley that has four steps, the tarn being on the top step, directly under the summit of the highest mountain in the group. It is now set in an amongst disused mines and a quarry. The water is extremely clear and possesses a strange blue hue due to light reflection from the quarry dust littering the lake bottom. The margins consist predominately of large boulders, there being few regions of organic sediment. It is fed by many underground springs, hence possessing very cold water, yet still contains trout.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from a small region containing gravel and soft sediment on the north-east side of the tarn amongst growth of *Callitriche hamulata*, near an inflowing stream. The sediment was a strange form of grey clay, probably high in quarry dust content.

Clay/Gravel/Macrophyte.

SITE - 42
NAME - BROWN COVE TARN
GRID REF. - 343160
SAMPLING DATES : 42.1 - 31/8/89
42.2 - 2/2/90

FAUNA :

	42.1	42.2
Cypria ophthalmica	31	74
Cyclocypris ovum	287	210
Candona candida	10	27
Candona reducta	15	28
Potamocypris villosa	0	1
Tot/species	4	5
Tot/no.	343	340
Tot/overall species	5	

LAKE SIZE - 7.00 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 625m

MAX DEPTH - 3m
F.B.A. CLASS - 3
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.6 (5)
Mg - 66 (7)
Na - 116 (7)

Ca - 157 (7)
K - 6 (7)
Alk - 113 (6)

SITE DESCRIPTION

This small tarn is set in slight glacial moraines near Helvellyn, and has both inflowing and outflowing streams, giving it the appearance of a bay in a river. The margins had a small amount of macrophytes and extensive periphytic growth, especially *Potamogeton*.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst the soft substrate and flora. The winter sample being taken in deep snow with cat-ice in the margins !

Organic silt/Macrophyte.

SITE - 43
NAME - TOSH TARN
GRID REF. - 128053
SAMPLING DATES : 43.1 - 4/2/89
43.2 - 29/8/89

FAUNA :

	43.1	43.2
Cypria ophthalmica	0	2
Cypricercus fuscatus	19	2
Cypricercus obliquus	0	4
Herpetocypris reptans	0	2
Cypridopsis vidua	1	26
Tot/species	2	5
Tot/no.	20	36
Tot/overall species	5	

LAKE SIZE - 9.30 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 84m

MAX DEPTH - ?
F.B.A. CLASS - 3
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 7.2 (3)
Mg - 97 (4)
Na - 299 (4)
Ca - 174 (4)
K - 20 (3)
Alk - 102 (3)

SITE DESCRIPTION

An artificial farmyard tarn set in an agricultural grassland catchment. A few decidious trees, (including Ash) and Hawthorn surround the predominately rocky margins.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken half-way along the southern margin amongst reedgrass growing between the rocks and gravel.

Macrophyte/Leaves/Gravel.

SITE - 44
NAME - DALEHEAD TARN
GRID REF. - 230153
SAMPLING DATES : 44.1 - 4/9/89
FAUNA :

	44.1
Cypria ophthalmica	74
Cyclocypris ovum	3
Tot/species	2
Tot/no.	77
Tot/overall species	2

LAKE SIZE - 3.60 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 503m

MAX DEPTH - ?
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.2 (4)
Mg - 43 (6)
Na - 126 (6)

Ca - 96 (6)
K - 5 (6)
Alk - 62 (6)

SITE DESCRIPTION

This is an acidic upland tarn, just lying on the Borrowdale Volcanics, near to the boundary of the Skiddaw Slates. The water has a typical acidic 'black' hue, being situated in a marshy peat-bog surrounded by reedgrass, there being no rocky areas. It is fed by springs that come from Little Gable whilst the outflow falls into Newlands Beck. This tarn contains no fish.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken in one area from the monospecific site substrate, the resulting acidic 'orange-brown' sediment being very deep.

Peat-Moss/Macrophyte.

SITE - 45
NAME - LILY TARN
GRID REF. - 364040
SAMPLING DATES : 45.1 - 31/1/89
45.2 - 21/8/89

FAUNA :

	45.1	45.2
Metacypris cordata	2	0
Cypria ophthalmica	6	0
Cyclocypris ovum	2	7
Tot/species	3	1
Tot/no.	10	7
Tot/overall species	3	

LAKE SIZE - 1.90 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 200m
MAX DEPTH - 1m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.0 (6)
Mg - 69 (8)
Na - 181 (7)
Ca - 90 (8)
K - 7 (6)
Alk - 31 (7)

SITE DESCRIPTION

This small upland tarn lies behind the rocky summit of Tod Crag and is surrounded entirely by grassland and bracken, there are no nearby trees. The margins are relatively rich in Sphagnum, waterlilies, rushes and water lobelias. It has been stocked with goldfish or carp.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from reedgrass growing on a small amount of soft sediment and gravel.

Organic silt/Gravel/Macrophyte.

SITE - 46
NAME - SINEY TARN
GRID REF. - 163012
SAMPLING DATES : 46.1 - 29/8/89
FAUNA :

	46.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 7.60 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 221m

MAX DEPTH - ?
F.B.A. CLASS - 1
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 4.7 (7)
Mg - 53 (8)
Na - 187 (8)
Ca - 45 (8)
K - 13 (8)
Alk - -13 (8)

SITE DESCRIPTION

An acidic upland tarn formed from glacial debris from Scafell, that is set in a marshy peat/Sphagnum bog, surrounded by reedmace. The water is the typical 'black colour' of acidic sites and sediment is very deep.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst reedmace beds in the soft 'orange-brown' sediment.

Peat-Moss/Macrophyte.

SITE - 47
NAME - BLACKBECK TARN
GRID REF. - 202128
SAMPLING DATES : 47.1 - 5/9/89
FAUNA :

	47.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 9.70 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 472m

MAX DEPTH - 2m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.0 (14)
Mg - 41 (17)
Na - 152 (17)
Ca - 92 (17)
K - 6 (17)
Alk - 26 (17)

SITE DESCRIPTION

This is an acidic upland tarn with a rocky margins (as opposed to the other form of acidic upland site which is essentially a Sphagnum bog). It lies in a hollow near to the edge of Warnscale Crags. This site had long strands of filamentous algae covering the stones, reaching up to the water surface, together with a small amount of Horsetail.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst the horsetail and the algae covering the stones.

Peat-Moss/Macrophyte.

SITE - 48
NAME - INNOMINATE TARN
GRID REF. - 198129
SAMPLING DATES : 48.1 - 5/9/89
FAUNA :

	48.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 5.40 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 533m

MAX DEPTH - 2m
F.B.A. CLASS - 1
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 4.9 (14)
Mg - 38 (16)
Na - 146 (16)

Ca - 55 (16)
K - 7 (16)
Alk - -8 (16)

SITE DESCRIPTION

This upland acidic tarn was a typical peat-moss '*Sphagnum*-type' site, with heavy reed growth around the margins and few rocky areas. It is set among low rocky outcrops and is fed by marshes from the south, east and west.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from amongst the reeds and deep soft sediment, which was the typical 'orange-brown' humic material.

Peat-Moss/Macrophyte.

SITE - 49
NAME - WHITE MOSS TARN
GRID REF. - 345065
SAMPLING DATES : 49.1 - 31/1/89
49.2 - 21/8/89

FAUNA :

	49.1	49.2
Cypria ophthalmica	2	0
Cyclocypris ovum	1	1
Candona siliquosa	1	0
Potamocypris villosa	1	0
Tot/species	4	1
Tot/no.	5	1
Tot/overall species	4	

LAKE SIZE - 9.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 114m
MAX DEPTH - 1m
F.B.A. CLASS - 4
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.0 (3)
Mg - 76 (5)
Na - 264 (5)
Ca - 341 (5)
K - 15 (4)
Alk - 234 (4)

SITE DESCRIPTION

This is a tiny, artificially dug, disused quarry pool, surrounded by decidious trees, mainly Oak and Silver Birch, dammed at the valley end. Only one monospecific habitat existed in this site, the bottom being thickly covered in decaying leaves.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken in leaves, with a small amount of organic silt.

Leaves/Organic silt.

SITE - 50
NAME - HARD TARN
GRID REF. - 346138
SAMPLING DATES : 50.1 - 31/8/89
FAUNA :

	50.1
Candona vavrai	6
Tot/species	1
Tot/no.	6
Tot/overall species	1

LAKE SIZE - 5.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 716m

MAX DEPTH - 1.5m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH	- 5.9 (8)	Ca	- 138 (9)
Mg	- 54 (9)	K	- 12 (9)
Na	- 169 (9)	Alk	- 20 (9)

SITE DESCRIPTION

This tiny opaque, elliptical tarn is set on a ridge and has a shallow basin scooped out of the rock ledge and a stony margin with a soft sediment bottom. The normal outflow is over the short scree into the main groove of Rothwaite Cove. It contains no fish, but newts and beetles exist.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst the soft sediment and small amounts of Callitriche hamulata.

Organic silt/Clay/Macrophyte.

SITE - 51
NAME - HOW TOP TARN
GRID REF. - 342071
SAMPLING DATES : 51.1 - 31/1/89
51.2 - 21/8/89

FAUNA :

	51.1	51.2
Cypria ophthalmica	4	3
Herpetocypris reptans	0	27
Cypridopsis vidua	0	13
Tot/species	1	3
Tot/no.	4	43
Tot/overall species	3	

LAKE SIZE - 5.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 96m

MAX DEPTH - 0.5m
F.B.A. CLASS - (4)
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.5 (2)
Mg - 103 (2)
Na - 436 (2)

Ca - 366 (2)
K - 18 (1)
Alk - 195 (E)

SITE DESCRIPTION

A tiny farmyard pond. In winter, the site was heavily overgrown with periphyton, especially *Potamogeton sp.*, but this was absent in the summer sampling regime, suggesting the seasonality of the species.

SAMPLE DESCRIPTION

A) *Margin sample*

The sample was taken from a fine layer of organic silt overlying gravel (amongst the flora in winter, but not in summer).

Organic silt/Gravel.

SITE - 52
NAME - HAYSTACKS TARN A
GRID REF. - 197130
SAMPLING DATES : 52.1 - 5/9/89
FAUNA :

	52.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 1.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 540m

MAX DEPTH - 2m
F.B.A. CLASS - 1
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 5.1 (1)
Mg - 25 (1)
Na - 75 (1)

Ca - 38 (1)
K - 3 (1)
Alk - -4 (1)

SITE DESCRIPTION

A tiny circular acidic peatbog approximately 50m to the north of Innominate tarn, containing no floral growth nor any stony material.

SAMPLE DESCRIPTION

A) Margin sample

The sample consisted entirely of the typical acidic 'orange-brown' humic substrate.

Peat-moss.

SITE - 53
NAME - HAYSTACKS TARN B
GRID REF. - 195133
SAMPLING DATES : 53.1 - 5/9/89
FAUNA :

	53.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 9.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 590m

MAX DEPTH - ?
F.B.A. CLASS - 1
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 4.8 (14)
Mg - 47 (14)
Na - 175 (14)
Ca - 32 (14)
K - 9 (14)
Alk - -22 (14)

SITE DESCRIPTION

This small, acidic rock-basin tarn is situated on the summit of Haystacks ridge. The tarn has grassy margins with a small amount of exposed rock surface and no macrophyte growth.

SAMPLE DESCRIPTION

The sample was entirely composed of typical acidic 'orange-brown' humic material.

Peat-moss.

SITE - 54
NAME - ULLSWATER
GRID REF. - 420200
SAMPLING DATES : 54.1 - 25/8/89
54.2 - 29/1/90

FAUNA :

	54.1	54.2
Cypria ophthalmica	1	0
Cyclocypris ovum	17	0
Cyclocypris serena	20	0
Candona candida	4	0
Candona siliquosa	1	0
Tot/species	5	0
Tot/no.	43	0
Tot/overall species	5	

LAKE SIZE - 8.94 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 145m

MAX DEPTH - 62.5m
F.B.A. CLASS - 4
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 7.0 (31)
Mg - 82 (44)
Na - 165 (44)

Ca - 289 (44)
K - 12 (44)
Alk - 226 (42)

SITE DESCRIPTION

A huge, rocky waterbody. The lake is over 11 Km in length, and is one of the few lakes to contain the very rare schelly (Coregonus laveratus). Also present are brown trout, char, perch, salmon, sea trout and eels.

SAMPLE DESCRIPTION

A) Margin sample

Although almost all of the marginal zones of this site are composed of rocks and boulders, there is a region near the southern tip of the lake (grid ref. 389165), near the old boat house, where trees overhang the lake and from the pebble bottom. The sample was taken here where there is also extensive growth of reedmace, the roots of which are covered in very thick layers of filamentous algae.
The winter sample suffered from high water levels covering the previous sample area, which resulted in the sample being taken in the same position but from mainly flooded grassland as close to the decaying reed beds as possible.

Organic silt/Pebbles/Macrophyte.

SITE - 55
NAME - BASSENTHWAITE LAKE
SAMPLING DATES : 55.1 - 3/2/89
55.2 - 23/8/89

FAUNA :

	55.1	55.2
Cypria ophthalmica	1	4
Candona candida	24	0
Candona siliquosa	1	0
Cypridopsis vidua	1	3
Tot/species	4	2
Tot/no.	27	7
Tot/overall species	4	

LAKE SIZE - 5.28 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 69m
MAX DEPTH - 21.3m
F.B.A. CLASS - 4
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.9 (24)
Mg - 108 (37)
Na - 247 (37)
Ca - 288 (36)
K - 18 (36)
Alk - 183 (35)

SITE DESCRIPTION

A huge (6.4 Km in length) natural waterbody with very exposed rocky margins. The catchment area consists of a mixture of grassy fields and tidy decidious woodland below the smooth slopes of the Skiddaw slates. It is probably the most fruitful fishery among the larger lakes in the area, containing pike, perch, brown trout, salmon and eels.

SAMPLE DESCRIPTION

A) Margin sample

As with all the other large waterbodies, sampling was difficult due to the dominance of emergent rock in the marginal zone. The sample was taken (grid ref. 201321) from the northern tip of the site, just east of the outflow of the River Derwent. Here reedgrass existed in a thin layer of organic sediment overlying a fairly coarse gravel substrate.

Organic silt/Gravel/Macrophyte.

SITE - 56
NAME - DERWENT WATER
GRID REF. - 259210
SAMPLING DATES : 56.1 - 23/8/89
56.2 - 29/1/90

FAUNA :

	56.1	56.2
Cypria ophthalmica	1	0
Cyclocypris ovum	3	0
Candona candida	1	0
Tot/species	3	0
Tot/no.	5	0
Tot/overall species	3	

LAKE SIZE - 5.35 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 75m

MAX DEPTH - 22m
F.B.A. CLASS - 2
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.7 (28)
Mg - 51 (42)
Na - 216 (42)
Ca - 232 (42)
K - 9 (42)
Alk - 95 (40)

SITE DESCRIPTION

A very large waterbody, the margins of which are predominately rocky with little fine sediment or macrophyte. The site is 5.6 Km in length and is connected to the southern end of Bassenthwaite Lake by the River Derwent. The site has decorative wooded shores and is relatively shallow, the depth being less than 6m in the marginal areas. The deepest area, at 22m is just south of the four small islands in the lake. The fish fauna includes pike, perch, brown trout, eels, vendace and salmon.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken half-way along the eastern margin of the water (grid ref. 270214) in a silty bay near some overhanging trees.

Organic silt/Gravel.

SITE - 57
NAME - CRUMMOCK WATER
GRID REF. - 155190
SAMPLING DATES : 57.1 - 24/8/89
57.2 - 31/1/90

FAUNA :

	57.1	57.2
<u>Cypria ophthalmica</u>	1	0
Tot/species	1	0
Tot/no.	1	0
Tot/overall species	1	

LAKE SIZE - 2.52 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 98m

MAX DEPTH - 44m
F.B.A. CLASS - 2
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.6 (20)
Mg - 70 (30)
Na - 177 (30)
Ca - 121 (30)
K - 9 (30)
Alk - 44 (28)

SITE DESCRIPTION

Again, this site which is set among mountain grasslands and bare fells, appears to have entirely rocky margins, being very difficult to sample. Fish present include brown trout, perch, sea trout, salmon, char and pike.

SAMPLE DESCRIPTION

A) <u>Margin sample</u>

The area sampled was at the northern tip at the entrance of the River Cocker (grid ref. 153208) where a small amount of reedgrass grew over gravel.

Macrophyte/Gravel.

SITE - 58
NAME - ENNERDALE WATER
GRID REF. - 105152
SAMPLING DATES : 58.1 - 24/8/89
58.2 - 31/1/90
FAUNA :

	58.1	58.2
	0	0
Tot/species	0	0
Tot/no.	0	0
Tot/overall species	0	0

LAKE SIZE - 3.00 x 10^6 m^2
SIZE CLASS - A
ALTITUDE - 112m

MAX DEPTH - 42m
F.B.A. CLASS - 2
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.5 (30)
Mg - 70 (42)
Na - 185 (42)
Ca - 104 (42)
K - 10 (42)
Alk - 44 (40)

SITE DESCRIPTION

A large rocky water, set among bare fells and mountain grassland, which was virtually impossible to sample there being no emergent macrophytes nor areas of soft sediment. Fish present include brown trout, char, minnows and sticklebacks.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at the northern end of the water (grid ref. 092160) amongst fine gravel and sand.

Gravel/Sand.

SITE - 59
NAME - LOWESWATER
SAMPLING DATES : 59.1 - 3/2/89
59.2 - 24/8/89

FAUNA :

	59.1	59.2
Cypria ophthalmica	0	2
Candona candida	25	4
Cypridopsis vidua	5	1
Tot/species	2	3
Tot/no.	30	7
Tot/overall species	3	

LAKE SIZE - 6.40 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 121m
MAX DEPTH - 16m
F.B.A. CLASS - 3
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.9 (28)
Mg - 124 (40)
Na - 257 (40)
Ca - 281 (41)
K - 20 (40)
Alk - 171 (40)

SITE DESCRIPTION

A large natural waterbody with a grassland catchment and dedidious trees lining the western margin. The majority of the marginal zones consist of gravel and pebble sized material overlying large rocks. Fish present include pike,perch and trout.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at the south-east tip of the site (grid ref. 131212) to the west of the outflow of Dub Beck. Here there is a small bay where limited reed growth exists with some soft sediment.

Organic silt/Macrophyte/Gravel.

SITE - 60
NAME - BUTTERMERE
GRID REF. - 183157
SAMPLING DATES : 60.1 - 24/8/89
60.2 - 31/1/90

FAUNA :

	60.1	60.2
Cypridopsis vidua	1	0
Tot/species	1	0
Tot/no.	1	0
Tot/overall species	1	

LAKE SIZE - 9.40 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 101m

MAX DEPTH - 28.5m
F.B.A. CLASS - 2
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.2 (29)
Mg - 54 (42)
Na - 156 (42)

Ca - 120 (42)
K - 7 (42)
Alk - 47 (40)

SITE DESCRIPTION

A large, rocky margined site, with little opportunity for effective sampling. Fish present include pike, perch, trout and char.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from a silty bay (grid ref. 191155) at the south margins of the site.

Organic silt/Gravel.

SITE - 61
NAME - OVERWATER
GRID REF. - 252350
SAMPLING DATES : 61.1 - 3/2/89
61.2 - 23/8/89

FAUNA :

	61.1	61.2
Cypria ophthalmica	2	51
Cypria exsculpta	1	7
Cyclocypris laevis	0	1
Cyclocypris ovum	117	51
Cyclocypris serena	10	7
Candona candida	5	1
Candona rostrata	1	0
Herpetocypris reptans	1	3
Cypridopsis vidua	1	15
Tot/species	8	8
Tot/no.	138	136
Tot/overall species	9	

LAKE SIZE - 2.20 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 198m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 7.1 (3)
Mg - 248 (14)
Na - 295 (4)

Ca - 384 (4)
K - 25 (3)
Alk - 404 (2)

SITE DESCRIPTION

A large artificial waterbody, which is the fourth largest natural tarn in the Lake District. It lies in rounded grass hills, the inflow end surrounded by wet car-fen peat moss and reedmace is present here around most of the margins, whilst the outflow end to the north is stony and dammed. Part of the margins of the west margin are surrounded by decidious forest. Fish present include pike and perch.

SAMPLE DESCRIPTION

A) Margin sample

The area sampled was on the north-west forest margin of the tarn (grid ref. 250352) amongst dense reedmace and reedgrass growth in soft sediment and gravel.

Macrophyte/Organic silt/Gravel.

SITE - 62
NAME - ARLECDON TARN
GRID REF. - 096195
SAMPLING DATES : 62.1 - 3/2/89
62.2 - 24/8/89

FAUNA :

	62.1	62.2
Cypria ophthalmica	1	0
Cyclocypris ovum	0	1
Candona candida	21	0
Cypricercus obliquus	0	95
Tot/species	2	2
Tot/no.	22	96
Tot/overall species	4	

LAKE SIZE - 1.64 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 229m
MAX DEPTH - 4m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.9 (5)
Mg - 120 (6)
Na - 266 (6)
Ca - 153 (6)
K - 7 (5)
Alk - 8 (4)

SITE DESCRIPTION

This is an artificially created managed trout fishery which is dammed at one end, has rocky margins and is set amongst a conifer plantation.

SAMPLE DESCRIPTION

A) Margin sample

The samples were taken half-way along the southern margin (grid ref. 096196) amongst soft sediment and macrophyte (*Potamogeton* in summer, decayed in winter).

Macrophyte/Organic silt

SITE - 63
NAME - MOCKERKIN TARN
GRID REF. - 083232
SAMPLING DATES : 63.1 - 3/2/89
63.2 - 24/8/89

FAUNA :

	63.1	63.2
Cypria ophthalmica	3	0
Cypria exsculpta	1	0
Cyclocypris ovum	2	0
Candona candida	6	0
Candona siliquosa	12	0
Cypridopsis vidua	1	0
Tot/species	6	0
Tot/no.	25	0
Tot/overall species	6	

LAKE SIZE - 3.50 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 115m
MAX DEPTH - 3m
F.B.A. CLASS - 4
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 7.4 (2)
Mg - 151 (3)
Na - 433 (3)
Ca - 627 (3)
K - 33 (2)
Alk - 460 (1)

SITE DESCRIPTION

This glacially formed tarn lies on low lying land with no hills nor woodland nearby, being at the foot of the fells. Most of this site is characterised by rocky/gravel margins with a small amount of reedgrowth, and in the summer sample, lily pad growth. It contains trout and perch.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from the western margin at the mouth of a ditch running into the lake where there was a small amount of fine organic sediment and sand.

Organic silt/Sand

SITE - 64
NAME - LITTLE TARN
GRID REF. - 249338
SAMPLING DATES : 64.1 - 3/2/89
64.2 - 23/8/89
FAUNA :

	64.1	64.2
Cypria ophthalmica	188	88
Cypria exsculpta	197	38
Cyclocypris globosa	4	1
Cyclocypris ovum	74	66
Candona candida	12	86
Candona rostrata	22	1
Candona reducta	5	0
Candona vavrai	4	10
Cypricercus obliquus	0	1
Cypridopsis vidua	1	112
Tot/species	9	9
Tot/no.	507	403
Tot/overall species	10	

LAKE SIZE - 1.30 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 198m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.8 (3)
Mg - 243 (4)
Na - 273 (4)

Ca - 330 (4)
K - 30 (3)
Alk - 429 (2)

SITE DESCRIPTION

This site is set in smooth rounded fields and has an artificial farmyard catchment, being set in typical wet carr-fen flora, especially Silver Birch, Alder and Willow. The trees and rushes grow densely round the margins, access being difficult. It is fed by springs and contains pike and perch.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from the southern margin of the tarn which was littered in disused sheets of corrigated iron, the margins taking on a rust coloured tinge. Here there were overhanging trees and reedmace on top of floating peat-bog.

Organic silt/Macrophyte/Bog.

SITE - 65
NAME - TEWET TARN
GRID REF. - 305235
SAMPLING DATES : 65.1 - 3/2/89
65.2 - 23/8/89

FAUNA :

	65.1	65.2
Candona candida	1	1
Potamocypris villosa	1	0
Paracandona euplectella	3	0
Cypridopsis vidua	3	38
Tot/species	4	2
Tot/no.	8	39
Tot/overall species	4	

LAKE SIZE - 1.50 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 198m

MAX DEPTH - 3m
F.B.A. CLASS - 4
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 7.8 (3)
Mg - 85 (4)
Na - 224 (4)

Ca - 261 (4)
K - 24 (3)
Alk - 84 (2)

SITE DESCRIPTION

This tarn is situated on the 'St Johns in the Vale' microgranite. The site is artificial, dammed at one end and the catchment is predominately farmed grassland, no trees present. The margins are almost entirely rocky, there just being small amounts of rushes, reedgrass and Sphagnum present, creating a relatively monospecific habitat within the tarn. It contains trout.

SAMPLE DESCRIPTION

A) Margin sample

The samples were taken half-way along the eastern margin amongst the reedgrass and gravel.

Macrophyte/Gravel.

SITE - 66
NAME - BLEABERRY TARN
GRID REF. - 166155
SAMPLING DATES : 66.1 - 5/9/89
FAUNA :

	66.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 1.15×10^4 m^2
SIZE CLASS - C
ALTITUDE - 503m

MAX DEPTH - 6m
F.B.A. CLASS - 2
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 6.0 (13)
Mg - 63 (16)
Na - 188 (16)
Ca - 65 (16)
K - 9 (16)
Alk - 4 (16)

SITE DESCRIPTION

An acidic mountain pool, having the form of a corrie tarn lying on an immediate step of a mountain, being rocky margined and exposed.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at the northern (unexposed) point where reedmace and periphyton grew over pebbles.

Peat-moss/Macrophyte.

NOTE

The absence of an ostracod fauna at this site must be a function of the poor/acidic water quality as opposed to suitable floral/habitat presence (especially for *C. vidua*).

SITE - 67
NAME - FLOUTERN TARN
GRID REF. - 125171
SAMPLING DATES : 67.1 - 6/9/89
FAUNA :

	67.1
Cypria ophthalmica	1
Tot/species	1
Tot/no.	1
Tot/overall species	1

LAKE SIZE - 1.51 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 381m

MAX DEPTH - 4m
F.B.A. CLASS - 1
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 5.0 (14)
Mg - 68 (16)
Na - 206 (16)
Ca - 58 (16)
K - 8 (16)
Alk - -4 (16)

SITE DESCRIPTION

An elongate, acidic, upland glacially-formed tarn having typical 'black' water and predominately rocky margins. It contains trout.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken on the west side amongst horsetail, and filamentous and encrusting algae on stone.

Peat-moss/Gravel/Macrophyte.

SITE - 68
NAME - HIGH NOOK TARN
GRID REF. - 124199
SAMPLING DATES : 68.1 - 4/9/89
68.2 - 31/1/90

FAUNA :

	68.1	68.2
	0	0
Tot/species	0	0
Tot/no.	0	0
Tot/overall species	0	0

LAKE SIZE - 7.00 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 221m

MAX DEPTH - 2m
F.B.A. CLASS - 1
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 4.9 (8)
Mg - 61 (11)
Na - 169 (11)
Ca - 26 (11)
K - 6 (11)
Alk - -8 (10)

SITE DESCRIPTION

This tarn is set in a smooth hollow between Black Crag and Carling Knott, being held there by morain debris. This artificial site has an arable farm catchment (hence the acidity is strange). The margins are predominately grassland with extensive macrophytic an periphytic growth, including reedmace, horsetail and Potamogeton sp. It contains tiny, thin, dark trout.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst the macrophytes and in the soft sediment near the dam wall.

Peat-Moss/Organic silt/Macrophyte.

NOTE

Ostracod absence must again be a function of water quality as opposed to substrate unsuitability.

SITE - 69
NAME - BROWNS TARN
GRID REF. - 089297
SAMPLING DATES : 69.1 - 24/8/89
69.2 - 31/1/90

FAUNA :

	69.1	69.2
Ilyocypris decipiens	25	0
Cypria ophthalmica	1	0
Candona candida	6	3
Candona albicans	0	2
Tot/species	3	2
Tot/no.	32	5
Tot/overall species	4	

LAKE SIZE - 8.00×10^3 m^2
SIZE CLASS - D
ALTITUDE - 70m

MAX DEPTH - 3m
F.B.A. CLASS - (5)
BEDROCK - Carboniferous
series

CHEMISTRY

pH - 8.0 (2)
Mg - 424 (3)
Na - 505 (3)

Ca - 1498 (3)
K - 28 (3)
Alk - 1392 (1)

SITE DESCRIPTION

Originally, this was a tiny natural tarn, but it has recently been expanded into a managed coarse fishery, giving the appearance of an excavated gravel pit. The margins consist of pebbles and sand, there being no macrophytic growth.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken amongst pebbles and sand underneath an overhanging bush.

Pebbles/Sand.

SITE - 70
NAME - HIGH STOCK BRIDGE POOL
GRID REF. - 245258
SAMPLING DATES : 70.1 - 23/8/89
70.2 - 29/1/90

FAUNA :

	70.1	70.2
Cypria ophthalmica	24	0
Cyclocypris laevis	1	0
Tot/species	2	0
Tot/no.	25	0
Tot/overall species	2	

LAKE SIZE - 3.00 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 75m

MAX DEPTH - 2m
F.B.A. CLASS - (4)
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.0 (2)
Mg - 503 (2)
Na - 972 (2)

Ca - 601 (2)
K - 29 (2)
Alk - 545 (E)

SITE DESCRIPTION

A small, circular artificial pool with a large island centrally situated, resembling a moat, situated on flat farmland. It was surrounded by reedmace and overhanging trees creating a monospecific habitat.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken in fine organic silt (rich in hydrogen sulphide) amongst the reedmace.

Organic silt/Macrophyte.

SITE - 71
NAME - PARSONBY TARN
GRID REF. - 134384
SAMPLING DATES : 71.1 - 23/8/89
71.2 - 31/1/90

FAUNA :

	71.1	71.2
Cypria ophthalmica	783	479
Candona candida	37	91
Cypridopsis vidua	6	1
Candona pratensis	0	4
Eucypris virens	0	4
Cyclocypris ovum	0	13
Tot/species	3	6
Tot/no.	826	592
Tot/overall species	6	

LAKE SIZE - 4.00 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 108m

MAX DEPTH - 2m
F.B.A. CLASS - (5)
BEDROCK - Carboniferous series

CHEMISTRY

pH - 7.5 (2)
Mg - 440 (2)
Na - 895 (2)

Ca - 1414 (2)
K - 38 (2)
Alk - 1250 (E)

SITE DESCRIPTION

A small, shallow pool surrounded by flat farmland. It appears to have a monospecific habitat of deep layers of rich organic sediment, and extensive reedmace and lily growth, leaaving little exposed water in any part of the pool. Corixidae are extremely numerous.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from within the monospecific habitat described above.

Macrophyte/Organic sediment.

SITE - 72
NAME - MANESTY PARK TARN
GRID REF. - 252191
SAMPLING DATES : 72.1 - 23/8/89
72.2 - 29/1/90

FAUNA :

	72.1	72.2
Cypria ophthalmica	889	852
Candona candida	1	0
Cypridopsis vidua	1	0
Cyclocypris ovum	0	1
Tot/species	3	2
Tot/no.	891	853
Tot/overall species	4	

LAKE SIZE - 5.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 75m

MAX DEPTH - 1m
F.B.A. CLASS - (4)
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 6.2 (2)
Mg - 280 (2)
Na - 770 (2)
Ca - 331 (2)
K - 12 (2)
Alk - 295 (E)

SITE DESCRIPTION

A tiny reed-fringed pool situated in the Manesty Forest, recently excavated. The margins were of a mononspecific nature, reedmace, overhanging trees and deep layers of organic sediment.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from a deep layer of decaying leaves and organic sediment, next to reedmace.

Leaves/Organic silt/Macrophyte.

SITE - 73
NAME - BLACK POOL
GRID REF. - 121173
SAMPLING DATES : 73.1 - 6/9/89
FAUNA :

	73.1
	0
Tot/species	0
Tot/no.	0
Tot/overall species	0

LAKE SIZE - 5.00 x 10 m^2
SIZE CLASS - E
ALTITUDE - 420m

MAX DEPTH - 1m
F.B.A. CLASS - (1)
BEDROCK - Skiddaw slates

CHEMISTRY

pH - 4.3 (1)
Mg - 58 (1)
Na - 503 (1)

Ca - 77 (1)
K - 9 (1)
Alk - -55 (1)

SITE DESCRIPTION

A tiny circular 'black water' acidic bog,no macrophyte being present.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from the peaty margins, and yielded a typical acidic 'orange-brown' humic material.

Peat-moss.

SITE - 74
NAME - SKELSMERGH TARN
GRID REF. - 533967
SAMPLING DATES : 74.1 - 28/1/90
74.2 - 23/8/90

FAUNA :

	74.1	74.2
Metacypris cordata	367	1068
Cypria ophthalmica	21	6
Cypria exsculpta	8	0
Cyclocypris ovum	109	48
Candona candida	14	1
Candona reducta	6	0
Herpetocypris reptans	50	5
Cypridopsis vidua	3	21
Tot/species	8	6
Tot/no.	578	1149
Tot/overall species	8	

LAKE SIZE - 8.40 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 109m

MAX DEPTH - ?
F.B.A. CLASS - 5
BEDROCK - Carboniferous series

CHEMISTRY

pH - 7.8 (2)
Mg - 1307 (4)
Na - 160 (4)

Ca - 2396 (4)
K - 11 (4)
Alk - 3817 (2)

SITE DESCRIPTION

Skelsmergh tarn lies in a hollow among the moraines left behind by the glacier that flowed down Long Sleddale. This site is set in very rich arable farmland (due to the richness of the carboniferous bedrock) and is susceptible to agricultural run-off. The tarn is circular, and possesses a monospecific littoral zone in terms of reedmace, lilies, boggy margins and overhanging trees, especially Willow.

SAMPLE DESCRIPTION

A) Margin sample
From the habitat described above.
Leaves/Organic silt/Macrophyte.

SITE - 75
NAME - BOO TARN
SAMPLING DATES : 75.1 - 1/2/90
75.2 - 21/8/90

FAUNA :

	75.1	75.2
Cypria ophthalmica	604	197
Cyclocypris ovum	492	96
Candona candida	24	46
Candona rostrata	1	0
Candona vavrai	4	0
Candona fabaeformis	14	2
Cypridopsis vidua	11	1
Potamocypris sp. A	10	10
Tot/species	8	6
Tot/no.	1160	352
Tot/overall species	8	

LAKE SIZE - 9.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 288m

MAX DEPTH - ?
F.B.A. CLASS - (4)
BEDROCK - Carboniferous series

CHEMISTRY

pH - 7.2 (2)
Mg - 73 (3)
Na - 169 (3)
Ca - 372 (3)
K - 8 (3)
Alk - 302 (1)

SITE DESCRIPTION

This small tarn is heavily encrusted by macrophytic growth, including reedmace and Elodea over a limestone bed.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from amongst the macrophytic growth and soft sediment overlying a firm rock base.

Organic silt/Macrophyte.

APPENDIX 14.4 - Principal Component Data for Water Chemistry Analysis

SITE	PRIN 1	PRIN 2
1. Esthwaite Water	0.48788	-0.17797
2. Windermere (South Basin)	-0.22737	-0.35143
3. Windermere (North Basin)	-0.48188	-0.44545
4. Coniston Water	-0.26157	-0.31399
5. Killington Reservoir	1.71852	1.51724
6. Blelham Tarn	0.53600	-0.25474
7. Tarn-Hows Tarn	-0.49855	-0.46544
8. Poaka Beck Reservoir	1.60878	-0.10764
9. Pennington Reservoir	1.68955	-0.09948
10.Bigland Tarn	0.43548	-0.30656
11.Witherslack Hall Pond	3.96217	-1.03882
12.Rather Heath Tarn	0.99924	-0.46259
13.High Dam Reservoir	-0.51980	-0.38993
14.Yew Tree Tarn	-0.72998	-0.39587
15.Skeggles Water	-0.43540	-0.73974
16.Knittleton Tarn A	0.22953	-0.16030
17.Moss-Side Tarn	2.48200	-0.75341
18.Holehird Tarn	3.73210	1.31280
19.High Arnside Tarn	-0.42257	-0.49417
20.Grizedale Tarn	-0.59329	-0.24976
21.Knittleton Tarn B	0.45036	0.02632
22.Clay Pond	0.77119	0.09737
23.Barrow Plantation Tarn A	0.04142	0.00478
24.Barrow Plantation Tarn B	-0.04879	-0.08388
25.Barrow Plantation Tarn D	-0.40541	-0.45228
26.Barrow Plantation Tarn Q	-0.14448	-0.32677
27.Haweswater	-0.85339	-0.66041
28.Wast Water	-1.04282	-0.53574
29.Thirlmere	-1.12484	-0.58711
30.Grasmere	-0.87087	-0.53532
31.Brotherswater	-0.88009	-0.58511
32.Devoke Water	-0.79177	-0.29923
33.Seathwaite Tarn	-1.39473	0.20088
34.Levers Water	-1.74283	1.35986
35.Burnmoor Tarn	-1.03396	-0.43875
36.Loughrigg Tarn	-0.23491	-0.42144
37.Littlewater Tarn	1.77805	-0.61714
38.Watendlath Tarn	-0.97485	-0.50034
39.Blea Tarn	-0.75782	-0.23823
40.Parkgate Tarn	0.07064	3.46432
41.Low Water	-0.92524	-0.45506
42.Brown Cove Tarn	-1.27004	-0.81415
43.Tosh Tarn	-0.12364	0.04727
44.Dalehead Tarn	-1.44677	-0.72199

45.Lily Tarn	-1.17160	-0.47557
46.Siney Tarn	-1.47373	1.60909
47.Blackbeck Tarn	-1.36456	-0.57349
48.Innominate Tarn	-1.67852	0.61063
49.White Moss Tarn	-0.30219	-0.13337
50.Hard Tarn	-0.97379	-0.39083
51.How Top Tarn	0.34936	0.40642
52.Haystacks Tarn A	-1.95906	-0.16276
53.Haystacks Tarn B	-1.60766	1.08057
54.Ullswater	-0.68083	-0.60256
55.Bassenthwaite Lake	-0.15524	-0.21701
56.Derwent Water	-0.86461	-0.43977
57.Crummock Water	-1.03327	-0.53477
58.Ennerdale Water	-0.99419	-0.47331
59.Loweswater	-0.00479	-0.15018
60.Buttermere	-1.22801	-0.59696
61.Overwater	0.80953	-0.05622
62.Arlecdon Tarn	-0.72238	-0.34320
63.Mockerkin Tarn	1.47472	0.54772
64.Little Tarn	0.89361	0.01038
65.Tewet Tarn	-0.04701	-0.14866
66.Bleaberry Tarn	-1.17790	-0.39490
67.Floutern Tarn	-1.33844	0.54822
68.High Nook Tarn	-1.63523	0.66042
69.Browns Tarn	3.33876	0.12261
70.High Stock Bridge Pool	3.54767	2.10496
71.Parsonby Tarn	4.60311	1.66361
72.Manesty Park Tarn	1.33738	1.30671
73.Black Pool	-1.62956	5.59772
74.Skelsmergh Tarn	5.64343	-2.42129
75.Boo Tarn	-0.77025	-0.70479

APPENDIX 14.5A - Pearson Correlation Coefficients.

Key to Species

1 - *Cypria ophthalmica*
2 - *Cyclocypris ovum*
3 - *Metacypris cordata*
4 - *Candona candida*
5 - *Cypridopsis vidua*
6 - *Cypria exsculpta*
7 - *Cyclocypris serena*
8 - *Potamocypris villosa*
9 - *Cyclocypris laevis*
10 - *Herpetocypris reptans*
11 - *Cypricercus obliquus*
12 - *Candona fabaeformis*
13 - *Candona reducta*
14 - *Candona rostrata*
15 - *Candonopsis kingsleii*
16 - *Paracandona euplectella*
17 - *Candona vavrai*
18 - *Herpetocypris chevreuxi*

[1,2] 0.0829	[1,3] -0.0567	[1,4] 0.2537	[1,5] -0.0313
[1,6] 0.0224	[1,7] -0.0725	[1,8] -0.0334	[1,9] -0.0727
[1,10] -0.0780	[1,11] -0.0579	[1,12] -0.0289	[1,13] 0.0452
[1,14] -0.0109	[[1,15] -0.0286	[1,16] -0.0697	[1,17] 0.0026
[1,18] -0.0409	[2,3] 0.4185	[2,4] 0.3210	[2,5] 0.0332
[2,6] 0.4652	[2,7] 0.0279	[2,8] 0.0057	[2,9] -0.0854
[2,10] 0.0076	[2,11] -0.0257	[2,12] -0.0143	[2,13] 0.2382
[2,14] -0.0251	[2,15] -0.0397	[2,16] -0.0357	[2,17] 0.0411
[2,18] -0.0346	[3,4] -0.0437	[3,5] -0.0214	[3,6] -0.0221
[3,7] -0.0513	[3,8] 0.0509	[3,9] -0.0464	[3,10] 0.5213
[3,11] -0.0440	[3,12] -0.0367	[3,13] 0.0209	[3,14] -0.0279
[3,15] -0.0280	[3,16] -0.0372	[3,17] -0.0528	[3,18] -0.0267
[4,5] 0.0696	[4,6] 0.3860	[4,7] 0.3315	[4,8] 0.0407
[4,9] 0.0023	[4,10] -0.0346	[4,11] -0.0104	[4,12] 0.0435
[4,13] 0.0502	[4,14] 0.3048	[4,15] -0.0551	[4,16] 0.1021
[4,17] 0.0735	[4,18] -0.0812	[5,6] 0.1962	[5,7] -0.0015
[5,8] -0.0275	[5,9] -0.0209	[5,10] 0.1434	[5,11] -0.0210
[5,12] -0.0410	[5,13] 0.0108	[5,14] 0.1264	[5,15] -0.0375

[5,16] -0.0035	[5,17] 0.1160	[5,18] -0.0428	[6,7] -0.0409
[6,8] -0.0287	[6,9] -0.0457	[6,10] -0.0440	[6,11] 0.0210
[6,12] -0.0303	[6,13] 0.0275	[6,14] 0.2214	[6,15] -0.0211
[6,16] -0.0011	[6,17] 0.2285	[6,18] -0.0137	[7,8] -0.0171
[7,9] -0.0380	[7,10] 0.0024	[7,11] -0.0520	[7,12] -0.0434
[7,13] -0.0566	[7,14] -0.0467	[7,15] -0.0331	[7,16] -0.0549
[7,17] -0.0268	[7,18] -0.0315	[8,9] -0.0047	[8,10] 0.2061
[8,11] -0.0293	[8,12] -0.0254	[8,13] -0.0265	[8,14] -0.0293
[8,15] -0.0193	[8,16] 0.0145	[8,17] -0.0371	[8,18] -0.0184
[9,10] -0.0677	[9,11] -0.0490	[9,12] -0.0435	[9,13] -0.0567
[9,14] -0.0497	[9,15] -0.0331	[9,16] -0.0536	[9,17] -0.0566
[9,18] -0.0316	[10,11] -0.0629	[10,12] -0.0279	[10,13] 0.0083
[10,14] -0.0658	[10,15] -0.0417	[10,16] -0.0630	
[10,17] -0.0856	[10,18] -0.0426	[11,12] -0.0372	
[11,13] -0.0465	[11,14] -0.0356	[11,15] -0.0283	
[11,16] 0.0822	[11,17] -0.0430	[11,18] 0.1570	
[12,13] -0.0405	[12,14] -0.0359	[12,15] 0.8863	
[12,16] -0.0393	[12,17] -0.0454	[12,18] -0.0226	
[13,14] -0.0103	[13,15] -0.0308	[13,16] -0.0512	
[13,17] 0.5844	[13,18] -0.0294	[14,15] -0.0273	
[14,16] 0.6530	[14,17] 0.1009	[14,18] -0.0261	
[15,16] -0.0299	[15,17] -0.0346	[15,18] -0.0172	
[16,17] -0.0574	[16,18] 0.6700	[17,18] -0.0330	

APPENDIX 14.5B - Testing the Equations derived from the Lake District data set.

A) Cypria ophthalmica

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	0	0	0.000
2. WINDERMERE (S.BASIN)	1	0	0.004
3. WINDERMERE (N.BASIN)	1	0	0.005
4. CONISTON WATER	2	0	0.003
5. KILLINGTON RESERVOIR	0	0	0.000
6. BLELHAM TARN	28	33	0.000
7. TARN-HOWS TARN	0	26	0.000
8. POAKA BECK RESERVOIR	0	35	0.001
9. PENNINGTON RESERVOIR	32	31	0.000
10. BIGLAND TARN	1	45	0.001
11. WITHERSLACK HALL POND	7	58	0.001
12. RATHER HEATH TARN	15	61	0.001
13. HIGH DAM RESERVOIR	1	45	0.001
14. YEW TREE TARN	1	51	0.001
15. SKEGGLES WATER	0	47	0.001
16. KNITTLETON TARN A	14	66	0.001
17. MOSS-SIDE TARN	38	80	0.001
18. HOLEHIRD TARN	52	77	0.000
19. HIGH ARNSIDE TARN	1	79	0.003*
20. GRIZEDALE TARN	1	90	0.005*
21. KNITTLETON TARN B	127	88	0.001
22. CLAY POND	425	131	0.131****
23. BARROW PLANTATION A	4	131	0.024*
24. BARROW PLANTATION B	16	131	0.020*
25. BARROW PLANTATION D	0	124	0.021*
26. BARROW PLANTATION Q	2	131	0.025*
27. HAWESWATER	1	0	0.002
28. WAST WATER	0	0	0.000
29. THIRLMERE	0	0	0.000
30. GRASMERE	0	0	0.000
31. BROTHERSWATER	4	21	0.000
32. DEVOKE WATER	0	14	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	0	17	0.001
36. LOUGHRIGG TARN	2	36	0.000
37. LITTLEWATER TARN	1	68	0.002
38. WATENDLATH TARN	0	50	0.001
39. BLEA TARN	0	65	0.002
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	0	0	0.000
42. BROWN COVE TARN	53	82	0.000
43. TOSH TARN	1	77	0.003*
44. DALEHEAD TARN	37	94	0.002

45. LILY TARN	3	106	0.010*
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	76	0.003*
48. INNOMINATE TARN	0	0	0.000
49. WHITE MOSS TARN	1	120	0.017*
50. HARD TARN	0	0	0.000
51. HOW TOP TARN	4	131	0.024*
52. HAYSTACKS TARN A	0	0	0.000
53. HAYSTACKS TARN B	0	0	0.000
54. ULLSWATER	1	0	0.000
55. BASSENTHWAITE LAKE	3	0	0.001
56. DERWENT WATER	1	0	0.000
57. CRUMMOCK WATER	1	0	0.000
58. ENNERDALE WATER	0	0	0.000
59. LOWESWATER	1	0	0.000
60. BUTTERMERE	0	0	0.000
61. OVERWATER	2	18	0.000
62. ARLECDON TARN	1	24	0.001
63. MOCKERKIN TARN	2	52	0.001
64. LITTLE TARN	138	71	0.002
65. TEWET TARN	0	68	0.002
66. BLEABERRY TARN	0	73	0.003*
67. FLOUTERN TARN	1	0	0.000
68. HIGH NOOK TARN	0	0	0.000
69. BROWNS TARN	1	80	0.003*
70. HIGH STOCK BRIDGE POOL	12	97	0.006*
71. PARSONBY TARN	631	92	0.207*****
72. MANESTY PARK TARN	871	131	0.827*****
73. BLACK POOL	0	0	0.000
74. SKELSMERGH TARN	14	79	0.002
75. BOO TARN	400	120	0.096****

B) Metacypris cordata

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	7	6	0.000
2. WINDERMERE (S.BASIN)	0	0	0.000
3. WINDERMERE (N.BASIN)	0	0	0.000
4. CONISTON WATER	0	0	0.000
5. KILLINGTON RESERVOIR	0	0	0.000
6. BLELHAM TARN	3	14	0.001
7. TARN-HOWS TARN	0	0	0.000
8. POAKA BECK RESERVOIR	0	136	0.022*
9. PENNINGTON RESERVOIR	0	130	0.015*
10. BIGLAND TARN	0	29	0.002
11. WITHERSLACK HALL POND	0	141	0.288**
12. RATHER HEATH TARN	0	23	0.001
13. HIGH DAM RESERVOIR	1	20	0.001
14. YEW TREE TARN	0	0	0.000
15. SKEGGLES WATER	0	0	0.000
16. KNITTLETON TARN A	85	16	0.003
17. MOSS-SIDE TARN	0	49	0.011
18. HOLEHIRD TARN	0	2	0.000
19. HIGH ARNSIDE TARN	0	22	0.001
20. GRIZEDALE TARN	0	0	0.000
21. KNITTLETON TARN B	0	16	0.001
22. CLAY POND	0	27	0.001
23. BARROW PLANTATION A	0	0	0.000
24. BARROW PLANTATION B	0	0	0.000
25. BARROW PLANTATION D	0	0	0.000
26. BARROW PLANTATION Q	0	0	0.000
27. HAWESWATER	0	0	0.000
28. WAST WATER	0	0	0.000
29. THIRLMERE	0	0	0.000
30. GRASMERE	0	0	0.000
31. BROTHERSWATER	0	0	0.000
32. DEVOKE WATER	0	0	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	0	0	0.000
36. LOUGHRIGG TARN	127	0	0.013*
37. LITTLEWATER TARN	795	83	0.467*****
38. WATENDLATH TARN	0	0	0.000
39. BLEA TARN	0	0	0.000
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	0	0	0.000
42. BROWN COVE TARN	0	0	0.000
43. TOSH TARN	0	15	0.001
44. DALEHEAD TARN	0	0	0.000
45. LILY TARN	1	0	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	0	0.000

48.	INNOMINATE TARN	0	0	0.000
49.	WHITE MOSS TARN	0	0	0.000
50.	HARD TARN	0	0	0.000
51.	HOW TOP TARN	0	0	0.000
52.	HAYSTACKS TARN A	0	0	0.000
53.	HAYSTACKS TARN B	0	0	0.000
54.	ULLSWATER	0	0	0.000
55.	BASSENTHWAITE LAKE	0	0	0.000
56.	DERWENT WATER	0	0	0.000
57.	CRUMMOCK WATER	0	0	0.000
58.	ENNERDALE WATER	0	0	0.000
59.	LOWESWATER	0	0	0.000
60.	BUTTERMERE	0	0	0.000
61.	OVERWATER	0	98	0.014*
62.	ARLECDON TARN	0	0	0.000
63.	MOCKERKIN TARN	0	17	0.001
64.	LITTLE TARN	0	0	0.000
65.	TEWET TARN	0	1	0.000
66.	BLEABERRY TARN	0	0	0.000
67.	FLOUTERN TARN	0	0	0.000
68.	HIGH NOOK TARN	0	0	0.000
69.	BROWNS TARN	0	131	0.028*
70.	HIGH STOCK BRIDGE POOL	0	0	0.000
71.	PARSONBY TARN	0	148	0.027*
72.	MANESTY PARK TARN	0	0	0.000
73.	BLACK POOL	0	0	0.000
74.	SKELSMERGH TARN	718	640	0.014
75.	BOO TARN	0	0	0.000

C) Cyclocypris ovum

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	0	3	0.000
2. WINDERMERE (S.BASIN)	1	0	0.001
3. WINDERMERE (N.BASIN)	0	0	0.000
4. CONISTON WATER	1	0	0.001
5. KILLINGTON RESERVOIR	0	15	0.001
6. BLELHAM TARN	0	30	0.001
7. TARN-HOWS TARN	3	28	0.001
8. POAKA BECK RESERVOIR	0	24	0.001
9. PENNINGTON RESERVOIR	0	23	0.001
10. BIGLAND TARN	3	31	0.001
11. WITHERSLACK HALL POND	0	32	0.003
12. RATHER HEATH TARN	7	45	0.002
13. HIGH DAM RESERVOIR	43	38	0.000
14. YEW TREE TARN	0	49	0.004*
15. SKEGGLES WATER	13	47	0.002
16. KNITTLETON TARN A	36	48	0.000
17. MOSS-SIDE TARN	66	59	0.000
18. HOLEHIRD TARN	9	50	0.003
19. HIGH ARNSIDE TARN	2	53	0.005*
20. GRIZEDALE TARN	3	71	0.009*
21. KNITTLETON TARN B	98	60	0.002
22. CLAY POND	14	85	0.018*
23. BARROW PLANTATION A	443	102	0.753*****
24. BARROW PLANTATION B	46	94	0.008*
25. BARROW PLANTATION D	12	93	0.025*
26. BARROW PLANTATION Q	58	92	0.004
27. HAWESWATER	0	0	0.000
28. WAST WATER	1	0	0.000
29. THIRLMERE	0	0	0.000
30. GRASMERE	1	13	0.001
31. BROTHERSWATER	152	28	0.017**
32. DEVOKE WATER	8	32	0.002
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	2	32	0.002
36. LOUGHRIGG TARN	1	32	0.002
37. LITTLEWATER TARN	390	48	0.150*****
38. WATENDLATH TARN	2	50	0.005*
39. BLEA TARN	0	0	0.000
40. PARKGATE TARN	1	0	0.001
41. LOW WATER	0	63	0.013*
42. BROWN COVE TARN	249	66	0.057***
43. TOSH TARN	0	53	0.004*
44. DALEHEAD TARN	2	80	0.026*
45. LILY TARN	5	0	0.001
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	0	0.000

48.	INNOMINATE TARN	0	0	0.000
49.	WHITE MOSS TARN	1	0	0.001
50.	HARD TARN	0	0	0.000
51.	HOW TOP TARN	0	97	0.040**
52.	HAYSTACKS TARN A	0	0	0.000
53.	HAYSTACKS TARN B	0	0	0.000
54.	ULLSWATER	9	0	0.003
55.	BASSENTHWAITE LAKE	0	0	0.000
56.	DERWENT WATER	2	0	0.001
57.	CRUMMOCK WATER	0	0	0.000
58.	ENNERDALE WATER	0	0	0.000
59.	LOWESWATER	0	12	0.001
60.	BUTTERMERE	0	19	0.001
61.	OVERWATER	83	20	0.005*
62.	ARLECDON TARN	1	27	0.001
63.	MOCKERKIN TARN	1	36	0.002
64.	LITTLE TARN	70	56	0.000
65.	TEWET TARN	0	38	0.007
66.	BLEABERRY TARN	0	0	0.000
67.	FLOUTERN TARN	0	0	0.000
68.	HIGH NOOK TARN	0	0	0.000
69.	BROWNS TARN	0	42	0.013*
70.	HIGH STOCK BRIDGE POOL	0	0	0.000
71.	PARSONBY TARN	7	58	0.008*
72.	MANESTY PARK TARN	1	102	0.066**
73.	BLACK POOL	0	0	0.000
74.	SKELSMERGH TARN	79	45	0.005
75.	BOO TARN	294	79	0.132****

D) Candona candida

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	0	11	0.004*
2. WINDERMERE (S.BASIN)	13	10	0.000
3. WINDERMERE (N.BASIN)	43	10	0.039***
4. CONISTON WATER	1	10	0.002
5. KILLINGTON RESERVOIR	0	13	0.007*
6. BLELHAM TARN	19	12	0.001
7. TARN-HOWS TARN	5	10	0.001
8. POAKA BECK RESERVOIR	0	11	0.010*
9. PENNINGTON RESERVOIR	0	12	0.008*
10. BIGLAND TARN	6	10	0.001
11. WITHERSLACK HALL POND	17	22	0.002
12. RATHER HEATH TARN	3	14	0.005*
13. HIGH DAM RESERVOIR	8	9	0.000
14. YEW TREE TARN	54	11	0.083****
15. SKEGGLES WATER	11	12	0.000
16. KNITTLETON TARN A	15	12	0.000
17. MOSS-SIDE TARN	35	21	0.003
18. HOLEHIRD TARN	23	14	0.002
19. HIGH ARNSIDE TARN	11	9	0.000
20. GRIZEDALE TARN	37	11	0.024**
21. KNITTLETON TARN B	3	11	0.002
22. CLAY POND	4	11	0.002
23. BARROW PLANTATION A	39	13	0.082***
24. BARROW PLANTATION B	2	11	0.003
25. BARROW PLANTATION D	1	12	0.005*
26. BARROW PLANTATION Q	6	11	0.001
27. HAWESWATER	14	10	0.000
28. WAST WATER	5	9	0.001
29. THIRLMERE	0	11	0.005*
30. GRASMERE	0	10	0.003*
31. BROTHERSWATER	50	11	0.045****
32. DEVOKE WATER	0	11	0.005*
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	0	11	0.007*
36. LOUGHRIGG TARN	11	11	0.000
37. LITTLEWATER TARN	6	16	0.003
38. WATENDLATH TARN	5	11	0.002
39. BLEA TARN	0	0	0.000
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	0	12	0.013*
42. BROWN COVE TARN	19	10	0.002
43. TOSH TARN	0	8	0.003
44. DALEHEAD TARN	0	11	0.006*
45. LILY TARN	0	0	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	0	0.000

48. INNOMINATE TARN	0	0	0.000
49. WHITE MOSS TARN	0	0	0.000
50. HARD TARN	0	0	0.000
51. HOW TOP TARN	0	12	0.008*
52. HAYSTACKS TARN A	0	0	0.000
53. HAYSTACKS TARN B	0	0	0.000
54. ULLSWATER	2	9	0.002
55. BASSENTHWAITE LAKE	12	10	0.000
56. DERWENT WATER	1	10	0.002
57. CRUMMOCK WATER	0	10	0.004*
58. ENNERDALE WATER	0	10	0.004*
59. LOWESWATER	15	10	0.001
60. BUTTERMERE	0	11	0.007*
61. OVERWATER	3	10	0.002
62. ARLECDON TARN	11	9	0.000
63. MOCKERKIN TARN	3	10	0.002
64. LITTLE TARN	49	11	0.038****
65. TEWET TARN	1	6	0.003
66. BLEABERRY TARN	0	0	0.000
67. FLOUTERN TARN	0	0	0.000
68. HIGH NOOK TARN	0	0	0.000
69. BROWNS TARN	5	15	0.004
70. HIGH STOCK BRIDGE POOL	0	0	0.000
71. PARSONBY TARN	64	17	0.276*****
72. MANESTY PARK TARN	1	13	0.007*
73. BLACK POOL	0	0	0.000
74. SKELSMERGH TARN	8	23	0.004
75. BOO TARN	35	10	0.036***

E) Cypridopsis vidua

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	25	10	0.007*
2. WINDERMERE (S.BASIN)	4	10	0.001
3. WINDERMERE (N.BASIN)	17	9	0.002
4. CONISTON WATER	0	8	0.002
5. KILLINGTON RESERVOIR	0	7	0.001
6. BLELHAM TARN	6	9	0.000
7. TARN-HOWS TARN	2	9	0.001
8. POAKA BECK RESERVOIR	9	12	0.000
9. PENNINGTON RESERVOIR	14	11	0.000
10. BIGLAND TARN	150	11	0.805*****
11. WITHERSLACK HALL POND	2	14	0.010*
12. RATHER HEATH TARN	2	9	0.002
13. HIGH DAM RESERVOIR	13	9	0.000
14. YEW TREE TARN	0	6	0.001
15. SKEGGLES WATER	1	6	0.001
16. KNITTLETON TARN A	4	10	0.001
17. MOSS-SIDE TARN	5	9	0.000
18. HOLEHIRD TARN	3	11	0.003
19. HIGH ARNSIDE TARN	13	11	0.000
20. GRIZEDALE TARN	12	7	0.001
21. KNITTLETON TARN B	5	10	0.001
22. CLAY POND	2	10	0.002
23. BARROW PLANTATION A	4	4	0.000
24. BARROW PLANTATION B	39	7	0.020***
25. BARROW PLANTATION D	1	6	0.001
26. BARROW PLANTATION Q	12	8	0.000
27. HAWESWATER	0	8	0.001
28. WAST WATER	0	7	0.001
29. THIRLMERE	0	6	0.001
30. GRASMERE	0	8	0.001
31. BROTHERSWATER	0	7	0.001
32. DEVOKE WATER	0	4	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	0	5	0.001
36. LOUGHRIGG TARN	7	9	0.000
37. LITTLEWATER TARN	0	10	0.003*
38. WATENDLATH TARN	0	5	0.001
39. BLEA TARN	0	2	0.000
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	1	4	0.000
42. BROWN COVE TARN	0	7	0.001
43. TOSH TARN	14	10	0.000
44. DALEHEAD TARN	0	4	0.000
45. LILY TARN	0	3	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	3	0.000

48. INNOMINATE TARN	0	0	0.000
49. WHITE MOSS TARN	0	3	0.000
50. HARD TARN	0	2	0.000
51. HOW TOP TARN	7	6	0.000
52. HAYSTACKS TARN A	0	0	0.000
53. HAYSTACKS TARN B	0	0	0.000
54. ULLSWATER	0	9	0.002
55. BASSENTHWAITE LAKE	2	9	0.001
56. DERWENT WATER	0	7	0.001
57. CRUMMOCK WATER	0	7	0.001
58. ENNERDALE WATER	0	6	0.001
59. LOWESWATER	3	9	0.001
60. BUTTERMERE	1	4	0.000
61. OVERWATER	8	10	0.000
62. ARLECDON TARN	0	9	0.002
63. MOCKERKIN TARN	1	11	0.005*
64. LITTLE TARN	57	8	0.052****
65. TEWET TARN	21	14	0.004
66. BLEABERRY TARN	0	3	0.000
67. FLOUTERN TARN	0	0	0.000
68. HIGH NOOK TARN	0	0	0.000
69. BROWNS TARN	0	15	0.020*
70. HIGH STOCK BRIDGE POOL	0	3	0.000
71. PARSONBY TARN	4	12	0.003
72. MANESTY PARK TARN	1	4	0.000
73. BLACK POOL	0	0	0.000
74. SKELSMERGH TARN	12	14	0.000
75. BOO TARN	6	10	0.001

F) Cyclocypris serena

Site	**Observed**	**Predicted**	**Cook's D**
1. ESTHWAITE WATER	0	2	0.001
2. WINDERMERE (S.BASIN)	0	16	0.355****
3. WINDERMERE (N.BASIN)	65	19	5.150*****
4. CONISTON WATER	26	12	0.005
5. KILLINGTON RESERVOIR	0	2	0.001
6. BLELHAM TARN	0	0	0.000
7. TARN-HOWS TARN	0	0	0.000
8. POAKA BECK RESERVOIR	0	0	0.000
9. PENNINGTON RESERVOIR	2	0	0.001
10. BIGLAND TARN	0	0	0.000
11. WITHERSLACK HALL POND	0	0	0.000
12. RATHER HEATH TARN	0	0	0.000
13. HIGH DAM RESERVOIR	0	0	0.000
14. YEW TREE TARN	0	0	0.000
15. SKEGGLES WATER	0	0	0.000
16. KNITTLETON TARN A	0	0	0.000
17. MOSS-SIDE TARN	0	0	0.000
18. HOLEHIRD TARN	0	0	0.000
19. HIGH ARNSIDE TARN	0	0	0.000
20. GRIZEDALE TARN	0	0	0.000
21. KNITTLETON TARN B	0	0	0.000
22. CLAY POND	0	0	0.000
23. BARROW PLANTATION A	0	0	0.000
24. BARROW PLANTATION B	0	0	0.000
25. BARROW PLANTATION D	0	0	0.000
26. BARROW PLANTATION Q	0	0	0.000
27. HAWESWATER	2	9	0.003
28. WAST WATER	0	6	0.003
29. THIRLMERE	0	7	0.003
30. GRASMERE	0	2	0.002
31. BROTHERSWATER	41	1	0.182*****
32. DEVOKE WATER	0	1	0.000
33. SEATHWAITE TARN	0	1	0.000
34. LEVERSWATER	0	1	0.000
35. BURNMOOR TARN	0	1	0.000
36. LOUGHRIGG TARN	0	0	0.000
37. LITTLEWATER TARN	0	0	0.000
38. WATENDLATH TARN	0	0	0.000
39. BLEA TARN	0	0	0.000
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	0	0	0.000
42. BROWN COVE TARN	0	0	0.000
43. TOSH TARN	0	0	0.000
44. DALEHEAD TARN	0	0	0.000
45. LILY TARN	0	0	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	0	0.000

48.	INNOMINATE TARN	0	0	0.000
49.	WHITE MOSS TARN	0	0	0.000
50.	HARD TARN	0	0	0.000
51.	HOW TOP TARN	0	0	0.000
52.	HAYSTACKS TARN A	0	0	0.000
53.	HAYSTACKS TARN B	0	0	0.000
54.	ULLSWATER	10	21	0.004
55.	BASSENTHWAITE LAKE	0	12	0.113***
56.	DERWENT WATER	0	13	0.125***
57.	CRUMMOCK WATER	0	6	0.005*
58.	ENNERDALE WATER	0	7	0.005*
59.	LOWESWATER	0	2	0.001
60.	BUTTERMERE	0	2	0.001
61.	OVERWATER	9	1	0.008*
62.	ARLECDON TARN	0	1	0.001
63.	MOCKERKIN TARN	0	0	0.000
64.	LITTLE TARN	0	0	0.000
65.	TEWET TARN	0	0	0.000
66.	BLEABERRY TARN	0	0	0.000
67.	FLOUTERN TARN	0	0	0.000
68.	HIGH NOOK TARN	0	0	0.000
69.	BROWNS TARN	0	0	0.000
70.	HIGH STOCK BRIDGE POOL	0	0	0.000
71.	PARSONBY TARN	0	0	0.000
72.	MANESTY PARK TARN	0	0	0.000
73.	BLACK POOL	0	0	0.000
74.	SKELSMERGH TARN	0	0	0.000
75.	BOO TARN	0	0	0.000

G) Herpetocypris reptans

Site	**Observed**	**Predicted**	**Cook's D**
1. ESTHWAITE WATER	0	0	0.000
2. WINDERMERE (S.BASIN)	4	0	0.002
3. WINDERMERE (N.BASIN)	1	0	0.000
4. CONISTON WATER	0	1	0.000
5. KILLINGTON RESERVOIR	0	0	0.000
6. BLELHAM TARN	4	1	0.002
7. TARN-HOWS TARN	5	2	0.003
8. POAKA BECK RESERVOIR	0	5	0.018**
9. PENNINGTON RESERVOIR	9	5	0.002
10. BIGLAND TARN	5	1	0.004
11. WITHERSLACK HALL POND	0	3	0.003
12. RATHER HEATH TARN	0	1	0.000
13. HIGH DAM RESERVOIR	0	1	0.000
14. YEW TREE TARN	0	2	0.001
15. SKEGGLES WATER	0	0	0.000
16. KNITTLETON TARN A	8	1	0.005*
17. MOSS-SIDE TARN	2	2	0.000
18. HOLEHIRD TARN	0	0	0.000
19. HIGH ARNSIDE TARN	1	1	0.000
20. GRIZEDALE TARN	0	0	0.000
21. KNITTLETON TARN B	0	0	0.000
22. CLAY POND	0	1	0.000
23. BARROW PLANTATION A	0	0	0.000
24. BARROW PLANTATION B	0	3	0.002
25. BARROW PLANTATION D	0	3	0.002
26. BARROW PLANTATION Q	0	2	0.001
27. HAWESWATER	0	0	0.000
28. WAST WATER	0	1	0.000
29. THIRLMERE	0	1	0.000
30. GRASMERE	0	0	0.000
31. BROTHERSWATER	3	1	0.003
32. DEVOKE WATER	0	0	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	0	0	0.000
36. LOUGHRIGG TARN	0	0	0.000
37. LITTLEWATER TARN	0	0	0.000
38. WATENDLATH TARN	0	0	0.000
39. BLEA TARN	0	0	0.000
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	0	0	0.000
42. BROWN COVE TARN	0	0	0.000
43. TOSH TARN	1	1	0.000
44. DALEHEAD TARN	0	0	0.000
45. LILY TARN	0	0	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	0	0.000

48. INNOMINATE TARN	0	0	0.000
49. WHITE MOSS TARN	0	0	0.000
50. HARD TARN	0	0	0.000
51. HOW TOP TARN	14	2	0.149*****
52. HAYSTACKS TARN A	0	0	0.000
53. HAYSTACKS TARN B	0	0	0.000
54. ULLSWATER	0	0	0.000
55. BASSENTHWAITE LAKE	0	1	0.000
56. DERWENT WATER	0	0	0.000
57. CRUMMOCK WATER	0	2	0.001
58. ENNERDALE WATER	0	2	0.001
59. LOWESWATER	0	2	0.001
60. BUTTERMERE	0	0	0.000
61. OVERWATER	2	4	0.002
62. ARLECDON TARN	0	0	0.000
63. MOCKERKIN TARN	0	0	0.000
64. LITTLE TARN	0	6	0.009*
65. TEWET TARN	0	0	0.000
66. BLEABERRY TARN	0	0	0.000
67. FLOUTERN TARN	0	0	0.000
68. HIGH NOOK TARN	0	0	0.000
69. BROWNS TARN	0	3	0.002
70. HIGH STOCK BRIDGE POOL	0	0	0.000
71. PARSONBY TARN	0	5	0.005*
72. MANESTY PARK TARN	0	0	0.000
73. BLACK POOL	0	0	0.000
74. SKELSMERGH TARN	28	25	0.003
75. BOO TARN	0	0	0.000

H) Candona fabaeformis

Site	**Observed**	**Predicted**	**Cook's D**
1. ESTHWAITE WATER	0	3	0.008
2. WINDERMERE (S.BASIN)	0	0	0.000
3. WINDERMERE (N.BASIN)	0	0	0.000
4. CONISTON WATER	0	0	0.000
5. KILLINGTON RESERVOIR	0	0	0.000
6. BLELHAM TARN	0	3	0.008
7. TARN-HOWS TARN	0	0	0.000
8. POAKA BECK RESERVOIR	0	0	0.000
9. PENNINGTON RESERVOIR	0	0	0.000
10. BIGLAND TARN	0	0	0.000
11. WITHERSLACK HALL POND	0	0	0.000
12. RATHER HEATH TARN	31	8	0.430****
13. HIGH DAM RESERVOIR	0	0	0.000
14. YEW TREE TARN	0	0	0.000
15. SKEGGLES WATER	0	0	0.000
16. KNITTLETON TARN A	0	4	0.010
17. MOSS-SIDE TARN	18	18	0.001
18. HOLEHIRD TARN	0	0	0.000
19. HIGH ARNSIDE TARN	0	0	0.000
20. GRIZEDALE TARN	0	0	0.000
21. KNITTLETON TARN B	0	4	0.010
22. CLAY POND	0	4	0.010
23. BARROW PLANTATION A	0	0	0.000
24. BARROW PLANTATION B	0	0	0.000
25. BARROW PLANTATION D	0	0	0.000
26. BARROW PLANTATION Q	0	0	0.000
27. HAWESWATER	0	0	0.000
28. WAST WATER	0	0	0.000
29. THIRLMERE	0	0	0.000
30. GRASMERE	0	0	0.000
31. BROTHERSWATER	0	0	0.000
32. DEVOKE WATER	0	0	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	0	0	0.000
36. LOUGHRIGG TARN	0	0	0.000
37. LITTLEWATER TARN	0	12	0.293**
38. WATENDLATH TARN	0	0	0.000
39. BLEA TARN	0	0	0.000
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	0	0	0.000
42. BROWN COVE TARN	0	0	0.000
43. TOSH TARN	0	0	0.000
44. DALEHEAD TARN	0	0	0.000
45. LILY TARN	0	0	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	0	0.000

48.	INNOMINATE TARN	0	0	0.000
49.	WHITE MOSS TARN	0	0	0.000
50.	HARD TARN	0	0	0.000
51.	HOW TOP TARN	0	0	0.000
52.	HAYSTACKS TARN A	0	0	0.000
53.	HAYSTACKS TARN B	0	0	0.000
54.	ULLSWATER	0	0	0.000
55.	BASSENTHWAITE LAKE	0	0	0.000
56.	DERWENT WATER	0	0	0.000
57.	CRUMMOCK WATER	0	0	0.000
58.	ENNERDALE WATER	0	0	0.000
59.	LOWESWATER	0	0	0.000
60.	BUTTERMERE	0	0	0.000
61.	OVERWATER	0	1	0.002
62.	ARLECDON TARN	0	0	0.000
63.	MOCKERKIN TARN	0	0	0.000
64.	LITTLE TARN	0	0	0.000
65.	TEWET TARN	0	0	0.000
66.	BLEABERRY TARN	0	0	0.000
67.	FLOUTERN TARN	0	0	0.000
68.	HIGH NOOK TARN	0	0	0.000
69.	BROWNS TARN	0	0	0.000
70.	HIGH STOCK BRIDGE POOL	0	0	0.000
71.	PARSONBY TARN	0	0	0.000
72.	MANESTY PARK TARN	0	0	0.000
73.	BLACK POOL	0	0	0.000
74.	SKELSMERGH TARN	0	0	0.000
75.	BOO TARN	7	1	0.054*

J) Candona reducta

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	0	0	0.000
2. WINDERMERE (S.BASIN)	0	0	0.000
3. WINDERMERE (N.BASIN)	0	0	0.000
4. CONISTON WATER	0	0	0.000
5. KILLINGTON RESERVOIR	0	0	0.000
6. BLELHAM TARN	0	0	0.000
7. TARN-HOWS TARN	0	0	0.000
8. POAKA BECK RESERVOIR	0	0	0.000
9. PENNINGTON RESERVOIR	0	0	0.000
10. BIGLAND TARN	0	4	0.005*
11. WITHERSLACK HALL POND	0	0	0.000
12. RATHER HEATH TARN	0	1	0.003
13. HIGH DAM RESERVOIR	20	4	0.035**
14. YEW TREE TARN	0	0	0.000
15. SKEGGLES WATER	0	0	0.000
16. KNITTLETON TARN A	0	2	0.004
17. MOSS-SIDE TARN	0	0	0.000
18. HOLEHIRD TARN	0	1	0.001
19. HIGH ARNSIDE TARN	0	2	0.004
20. GRIZEDALE TARN	0	4	0.005*
21. KNITTLETON TARN B	0	1	0.001
22. CLAY POND	6	0	0.048**
23. BARROW PLANTATION A	0	0	0.000
24. BARROW PLANTATION B	0	0	0.000
25. BARROW PLANTATION D	0	0	0.000
26. BARROW PLANTATION Q	0	0	0.000
27. HAWESWATER	0	0	0.000
28. WAST WATER	0	0	0.000
29. THIRLMERE	0	0	0.000
30. GRASMERE	0	0	0.000
31. BROTHERSWATER	0	0	0.000
32. DEVOKE WATER	0	0	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	0	0	0.000
36. LOUGHRIGG TARN	0	0	0.000
37. LITTLEWATER TARN	0	6	0.045**
38. WATENDLATH TARN	0	0	0.000
39. BLEA TARN	0	0	0.000
40. PARKGATE TARN	0	0	0.000
41. LOW WATER	0	0	0.000
42. BROWN COVE TARN	22	17	0.004
43. TOSH TARN	0	0	0.000
44. DALEHEAD TARN	0	0	0.000
45. LILY TARN	0	0	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	0	0.000

48. INNOMINATE TARN	0	0	0.000
49. WHITE MOSS TARN	0	0	0.000
50. HARD TARN	0	0	0.000
51. HOW TOP TARN	0	0	0.000
52. HAYSTACKS TARN A	0	0	0.000
53. HAYSTACKS TARN B	0	0	0.000
54. ULLSWATER	0	0	0.000
55. BASSENTHWAITE LAKE	0	0	0.000
56. DERWENT WATER	0	0	0.000
57. CRUMMOCK WATER	0	0	0.000
58. ENNERDALE WATER	0	0	0.000
59. LOWESWATER	0	0	0.000
60. BUTTERMERE	0	0	0.000
61. OVERWATER	0	0	0.000
62. ARLECDON TARN	0	0	0.000
63. MOCKERKIN TARN	0	2	0.004
64. LITTLE TARN	3	4	0.000
65. TEWET TARN	0	4	0.005*
66. BLEABERRY TARN	0	0	0.000
67. FLOUTERN TARN	0	0	0.000
68. HIGH NOOK TARN	0	0	0.000
69. BROWNS TARN	0	0	0.000
70. HIGH STOCK BRIDGE POOL	0	0	0.000
71. PARSONBY TARN	0	0	0.000
72. MANESTY PARK TARN	0	0	0.000
73. BLACK POOL	0	0	0.000
74. SKELSMERGH TARN	3	1	0.002
75. BOO TARN	0	5	0.008*

U) Diversity

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	5	5	0.000
2. WINDERMERE (S.BASIN)	6	6	0.000
3. WINDERMERE (N.BASIN)	5	5	0.000
4. CONISTON WATER	8	5	0.016**
5. KILLINGTON RESERVOIR	0	4	0.018**
6. BLELHAM TARN	6	5	0.001
7. TARN-HOWS TARN	6	5	0.001
8. POAKA BECK RESERVOIR	1	6	0.059***
9. PENNINGTON RESERVOIR	4	6	0.003
10. BIGLAND TARN	6	6	0.000
11. WITHERSLACK HALL POND	5	7	0.003
12. RATHER HEATH TARN	9	5	0.019**
13. HIGH DAM RESERVOIR	7	5	0.004
14. YEW TREE TARN	2	4	0.007*
15. SKEGGLES WATER	5	4	0.003
16. KNITTLETON TARN A	9	5	0.018**
17. MOSS-SIDE TARN	8	5	0.011**
18. HOLEHIRD TARN	4	6	0.004
19. HIGH ARNSIDE TARN	8	7	0.003
20. GRIZEDALE TARN	6	4	0.004
21. KNITTLETON TARN B	6	6	0.000
22. CLAY POND	6	6	0.000
23. BARROW PLANTATION A	9	3	0.044***
24. BARROW PLANTATION B	7	5	0.004
25. BARROW PLANTATION D	7	4	0.009*
26. BARROW PLANTATION Q	6	5	0.002
27. HAWESWATER	4	4	0.000
28. WAST WATER	4	5	0.001
29. THIRLMERE	2	3	0.002
30. GRASMERE	2	5	0.014**
31. BROTHERSWATER	7	4	0.006*
32. DEVOKE WATER	3	3	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	3	3	0.000
36. LOUGHRIGG TARN	10	5	0.033***
37. LITTLEWATER TARN	4	5	0.002
38. WATENDLATH TARN	2	3	0.002
39. BLEA TARN	0	2	0.012**
40. PARKGATE TARN	1	1	0.000
41. LOW WATER	1	2	0.001
42. BROWN COVE TARN	5	3	0.003
43. TOSH TARN	5	5	0.000
44. DALEHEAD TARN	2	2	0.000
45. LILY TARN	3	3	0.000
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	2	0.014**

48.	INNOMINATE TARN	0	0	0.000
49.	WHITE MOSS TARN	4	3	0.002
50.	HARD TARN	1	1	0.000
51.	HOW TOP TARN	3	4	0.003
52.	HAYSTACKS TARN A	0	0	0.000
53.	HAYSTACKS TARN B	0	0	0.000
54.	ULLSWATER	5	5	0.000
55.	BASSENTHWAITE LAKE	4	5	0.002
56.	DERWENT WATER	3	5	0.004
57.	CRUMMOCK WATER	1	4	0.017**
58.	ENNERDALE WATER	0	4	0.025**
59.	LOWESWATER	3	5	0.004
60.	BUTTERMERE	1	3	0.003
61.	OVERWATER	9	5	0.022**
62.	ARLECDON TARN	4	5	0.001
63.	MOCKERKIN TARN	6	6	0.000
64.	LITTLE TARN	10	5	0.030**
65.	TEWET TARN	4	7	0.027**
66.	BLEABERRY TARN	0	2	0.023**
67.	FLOUTERN TARN	1	0	0.002
68.	HIGH NOOK TARN	0	0	0.000
69.	BROWNS TARN	4	7	0.033**
70.	HIGH STOCK BRIDGE POOL	2	3	0.004
71.	PARSONBY TARN	6	6	0.000
72.	MANESTY PARK TARN	4	4	0.000
73.	BLACK POOL	0	0	0.000
74.	SKELSMERGH TARN	8	7	0.003
75.	BOO TARN	8	6	0.005

V) Ostracod Abundance

Site	Observed	Predicted	Cook's D
1. ESTHWAITE WATER	59	65	0.000
2. WINDERMERE (S.BASIN)	22	6	0.000
3. WINDERMERE (N.BASIN)	126	0	0.009*
4. CONISTON WATER	35	0	0.001
5. KILLINGTON RESERVOIR	0	65	0.001
6. BLELHAM TARN	60	118	0.000
7. TARN-HOWS TARN	28	89	0.001
8. POAKA BECK RESERVOIR	9	251	0.016**
9. PENNINGTON RESERVOIR	56	240	0.009*
10. BIGLAND TARN	164	170	0.000
11. WITHERSLACK HALL POND	78	393	0.067***
12. RATHER HEATH TARN	104	185	0.001
13. HIGH DAM RESERVOIR	100	123	0.000
14. YEW TREE TARN	55	79	0.000
15. SKEGGLES WATER	63	117	0.000
16. KNITTLETON TARN A	275	169	0.002*
17. MOSS-SIDE TARN	168	265	0.002*
18. HOLEHIRD TARN	86	211	0.004*
19. HIGH ARNSIDE TARN	38	188	0.007*
20. GRIZEDALE TARN	98	132	0.000
21. KNITTLETON TARN B	235	201	0.000
22. CLAY POND	451	263	0.019**
23. BARROW PLANTATION A	614	233	0.044****
24. BARROW PLANTATION B	113	241	0.006*
25. BARROW PLANTATION D	67	210	0.006*
26. BARROW PLANTATION Q	81	230	0.009*
27. HAWESWATER	19	0	0.000
28. WAST WATER	8	0	0.000
29. THIRLMERE	1	0	0.002
30. GRASMERE	2	23	0.000
31. BROTHERSWATER	255	50	0.006**
32. DEVOKE WATER	11	21	0.000
33. SEATHWAITE TARN	0	0	0.000
34. LEVERSWATER	0	0	0.000
35. BURNMOOR TARN	6	21	0.000
36. LOUGHRIGG TARN	157	100	0.001
37. LITTLEWATER TARN	1092	262	0.145*****
38. WATENDLATH TARN	7	58	0.000
39. BLEA TARN	0	58	0.001
40. PARKGATE TARN	1	9	0.000
41. LOW WATER	1	71	0.001
42. BROWN COVE TARN	342	119	0.009**
43. TOSH TARN	28	164	0.005*
44. DALEHEAD TARN	77	49	0.000
45. LILY TARN	9	114	0.002
46. SINEY TARN	0	0	0.000
47. BLACKBECK TARN	0	62	0.001

48. INNOMINATE TARN	0	5	0.000
49. WHITE MOSS TARN	3	135	0.005*
50. HARD TARN	6	131	0.006*
51. HOW TOP TARN	24	192	0.010*
52. HAYSTACKS TARN A	0	0	0.000
53. HAYSTACKS TARN B	0	0	0.000
54. ULLSWATER	22	0	0.000
55. BASSENTHWAITE LAKE	17	8	0.000
56. DERWENT WATER	3	0	0.000
57. CRUMMOCK WATER	1	0	0.000
58. ENNERDALE WATER	0	0	0.000
59. LOWESWATER	19	64	0.000
60. BUTTERMERE	1	0	0.000
61. OVERWATER	137	162	0.000
62. ARLECDON TARN	59	93	0.000
63. MOCKERKIN TARN	13	174	0.006*
64. LITTLE TARN	455	206	0.008**
65. TEWET TARN	24	183	0.015*
66. BLEABERRY TARN	0	70	0.001
67. FLOUTERN TARN	1	6	0.000
68. HIGH NOOK TARN	0	4	0.000
69. BROWNS TARN	19	380	0.076***
70. HIGH STOCK BRIDGE POOL	13	321	0.085***
71. PARSONBY TARN	709	373	0.053***
72. MANESTY PARK TARN	872	262	0.126*****
73. BLACK POOL	0	8	0.000
74. SKELSMERGH TARN	864	810	0.006
75. BOO TARN	756	205	0.177*****

APPENDIX 14.6 - TEST SITES

All values for [Ca], [Mg], [Na], [K] and Alkalinity are given in μel^{-1}.

SITE - T1
NAME - EASEDALE TARN
GRID REF. - 308087
SAMPLING DATE : T1 - 23/8/90
FAUNA :

	T1
	NONE
Tot/species	NONE
Tot/no.	NONE

LAKE SIZE - 1.06×10^5 m^2
SIZE CLASS - B
ALTITUDE - 287m

MAX DEPTH - 21m
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 5.7 (24)
Mg - 37 (27)
Na - 143 (28)

Ca - 94 (28)
K - 6 (28)
Alk - 8 (24)

SITE DESCRIPTION

This site is a typical corrie tarn lying in a corrie valley, which lies on the middle step of a mountain between the top of High Rouse and the floor of the Easedale Valley. It has a large catchment, four inlet streams and numerous bogs feed it. It contains trout, perch and eels.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from reedgrass growing amongst gravel on the rocky margins, there being a very small amount of organic sediment present.

Macrophyte/Gravel/Organic silt.

SITE - T2
NAME - RYDAL WATER
GRID REF. - 359064
SAMPLING DATE : T2 - 23/8/90
FAUNA :

	T2
Cypria ophthalmica	4
Cyclocypris ovum	3
Cyclocypris serena	1
Candona candida	1
Tot/species	4
Tot/no.	9

LAKE SIZE - 3.70 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 61m

MAX DEPTH - 19m
F.B.A. CLASS - 3
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.8 (77)
Mg - 60 (90)
Na - 193 (90)
Ca - 241 (90)
K - 12 (90)
Alk - 154 (56)

SITE DESCRIPTION

This large lake situated near Grasmere contains trout, perch and pike.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from a small layer of soft, organic detritus overlying a bed of rock, amongst reedgrass and lily pads.

SITE - T3
NAME - LILY MERE
GRID REF. - 604915
SAMPLING DATE : T3 - 20/8/90
FAUNA :

	T3
Cypria ophthalmica	2
Cyclocypris ovum	2
Candona candida	8
Herpetocypris reptans	40
Cypridopsis vidua	1
Tot/species	5
Tot/no.	53

LAKE SIZE - 1.46 x 10^5 m^2
SIZE CLASS - B
ALTITUDE - 214m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.1 (3)
Mg - 116 (4)
Na - 334 (4)

Ca - 311 (4)
K - 14 (4)
Alk - 201 (2)

SITE DESCRIPTION

This is a large, rocky barren site typical of the Lake District.

SAMPLE DESCRIPTION

A) Margin sample

The area sampled was a small bay on the west margin containing soft sediment over pebbles amongst lily pads and reedgrass.

SITE - T4
NAME - CHAPEL HILL RESERVOIR
GRID REF. - 106978
SAMPLING DATE : 22/8/90
FAUNA :

	T4
	0
Tot/species	0
Tot/no.	0

LAKE SIZE - 1.20×10^4 m^2
SIZE CLASS - C
ALTITUDE - 152m

MAX DEPTH - ?
F.B.A. CLASS - 1
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 4.8 (83)
Mg - 171 (85)
Na - 643 (85)

Ca - 132 (85)
K - 22 (85)
Alk - -17 (84)

SITE DESCRIPTION

This site is surrounded by extensive conifer plantations.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from peat-moss lying over gravel amongst a dense bed of lilies. An interesting point of note is that the gravel and sediment were of a red colour, probably due to iron which may have been precipitated out of solution by the acidic conditions.

SITE - T5
NAME - WOODHOW TARN
GRID REF. - 136043
SAMPLING DATE : 22/8/90
FAUNA :

	T5
Cypria ophthalmica	12
Cypridopsis vidua	65
Potamocypris villosa	2
Tot/species	3
Tot/no.	79

LAKE SIZE - 1.22 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 55m

MAX DEPTH - ?
F.B.A. CLASS - 2
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 6.9 (5)
Mg - 90 (6)
Na - 266 (6)
Ca - 148 (6)
K - 57 (6)
Alk - 84 (5)

SITE DESCRIPTION

This tarn is situated at the foot of the first rock barrier that holds Wast Water. It is a 'farmyard pond' surrounded by Ash and has extensive macrophytic and periphytic growth, including lilies, Elodea and Potamogeton. It contains pike and perch.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken at a typical region from the monospecific margins, and was rich organic sediment amongst floral growth.

Organic silt/Macrophyte.

SITE - T6
NAME - LITTLE LANGDALE TARN
GRID REF. - 308032
SAMPLING DATE : 21/8/90
FAUNA :

	T6
Cypria ophthalmica	1
Cyclocypris ovum	4
Candona candida	3
Tot/species	3
Tot/no.	8

LAKE SIZE - 7.30 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 104m

MAX DEPTH - ?
F.B.A. CLASS - 2
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 6.2 (16)
Mg - 63 (20)
Na - 191 (20)
Ca - 155 (20)
K - 9 (20)
Alk - 61 (17)

SITE DESCRIPTION

This is a glacial valley tarn that is surrounded by marshes and reeds. It contains trout, pike and perch.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from a marshy region, and consisted of a small amount of fine organic silt and clay.

Organic silt/Clay.

SITE - T7
NAME - ESKDALE GREEN TARN
GRID REF. - 145001
SAMPLING DATE : 22/8/90
FAUNA :

	T7
Cypria ophthalmica	2
Cyclocypris ovum	1
Candona candida	7
Cypricercus obliquus	4
Cypridopsis vidua	52
Tot/species	5
Tot/no.	66

LAKE SIZE - 5.00 x 10^4 m^2
SIZE CLASS - C
ALTITUDE - 45m

MAX DEPTH - ?
F.B.A. CLASS - 3
BEDROCK - Igneous intrusion

CHEMISTRY

pH - 7.0 (5)
Mg - 125 (5)
Na - 435 (5)
Ca - 273 (5)
K - 28 (5)
Alk - 121 (4)

SITE DESCRIPTION

This is a shallow 'estate-type' lake, rich in aquatic macrophytes and periphytes including lilies and *Potamogeton*.

SAMPLE DESCRIPTION

A) *Margin sample*

The sample was taken underneath an overhanging tree in macrophyte-rich surroundings, the substrate being rich in organic silt and leaves.

Leaves/Organic silt/Macrophyte.

SITE - T8
NAME - KNIPE TARN
GRID REF. - 427944
SAMPLING DATE : 21/8/90
FAUNA :

	T8
Cypria ophthalmica	4
Cypria exsculpta	32
Candona candida	11
Cypricercus obliquus	1
Cypridopsis vidua	9
Tot/species	5
Tot/no.	57

LAKE SIZE - 2.14×10^4 m^2
SIZE CLASS - C
ALTITUDE - 145m
MAX DEPTH - 4m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.5 (4)
Mg - 170 (5)
Na - 264 (5)
Ca - 487 (5)
K - 14 (5)
Alk - 422 (3)

SITE DESCRIPTION

This is a private reservoir, dammed at one end which is surrounded by overhanging trees and is rich in reedmace, Bog Bean and *Elodea*.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken in a typical region and was rich in organic substrate and leaves.

Organic silt/Macrophyte/Leaves.

SITE - T9
NAME - LOW BIRKER TARN
GRID REF. - 190995
SAMPLING DATE : 23/8/90
FAUNA :

	T9
	0
Tot/species	0
Tot/no.	0

LAKE SIZE - 9.00 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 244m

MAX DEPTH - 2m
F.B.A. CLASS - 1
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 4.5 (6)
Mg - 57 (6)
Na - 191 (6)
Ca - 67 (6)
K - 8 (6)
Alk - -36 (5)

SITE DESCRIPTION

This site is held in under Tarn Crag by a low rock wall of Borrowdale volcanic ash. It is fed by springs that enter from the north through a boggy area, and a small outlet runs into the nearby stream. It is surrounded by rock, heather and bracken, being 'peaty' and contains a few small trout.

SAMPLE DESCRIPTION

A) Margin sample

The substrate was typical acidic 'peat-moss'.
Peat-Moss.

SITE - T10
NAME - LONG MOSS TARN
GRID REF. - 292936
SAMPLING DATE : 21/8/90
FAUNA :

	T10
Cypria ophthalmica	9
Cypria exsculpta	9
Cyclocypris ovum	64
Tot/species	3
Tot/no.	82

LAKE SIZE - 8.50 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 130m

MAX DEPTH - 2m
F.B.A. CLASS - 3
BEDROCK - Silurian slates

CHEMISTRY

pH - 6.6 (2)
Mg - 107 (3)
Na - 233 (3)

Ca - 214 (3)
K - 12 (3)
Alk - 122 (2)

SITE DESCRIPTION

The site was a short thin pool set amongst a dense bracken forest.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from the Sphagnum and lilies that are both numerous in the site. The substrate consisted of organic silt and 'peat-moss', although the site is not particularly acidic.

Macrophyte/Organic silt/Peat-moss.

SITE - T11
NAME - BORWICK FOLD TARN
GRID REF. - 443969
SAMPLING DATE : 20/8/90
FAUNA :

	T11
Cypria ophthalmica	31
Cypria exsculpta	2
Candona candida	245
Herpetocypris reptans	50
Cypridopsis vidua	1
Tot/species	5
Tot/no.	329

LAKE SIZE - 6.80×10^3 m^2
SIZE CLASS - D
ALTITUDE - 195m

MAX DEPTH - 4m
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.3 (3)
Mg - 318 (4)
Na - 228 (4)

Ca - 804 (4)
K - 12 (4)
Alk - 995 (3)

SITE DESCRIPTION

This site is set in arable fields, having an almost entirely grassland catchment. It contains trout, and is almost completely covered in aquatic flora, including reedmace and Potamogeton.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from amongst the macrophytes where soft organic detritus lie over the bare bedrock.

Macrophyte/Organic silt.

SITE - T12
NAME - CLEABARROW TARN
GRID REF. - 424938
SAMPLING DATES : 20/8/90
FAUNA :

	T12
Cypria ophthalmica	6
Cypridopsis vidua	257
Tot/species	2
Tot/no.	263

LAKE SIZE - 5.60 x 10^3 m^2
SIZE CLASS - D
ALTITUDE - 170m

MAX DEPTH - ?
F.B.A. CLASS - 4
BEDROCK - Silurian slates

CHEMISTRY

pH - 7.2 (2)
Mg - 213 (3)
Na - 295 (3)

Ca - 680 (3)
K - 24 (3)
Alk - 679 (2)

SITE DESCRIPTION

This is a small coarse fishery situated near an island in the middle of the tarn.

SAMPLE DESCRIPTION

A) Margin sample

The sample was taken from the marginal reedmace growth. Here, a small amount of organic sediment lied over a firm mud and clay base.

Organic silt/Clay/Macrophyte.

SITE - T13
NAME - LAUNCHY TARN
GRID REF. - 232147
SAMPLING DATE : 4/9/89
FAUNA :

	T13
	0
Tot/species	0
Tot/no.	0

LAKE SIZE - 8.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 553m

MAX DEPTH - 1m
F.B.A. CLASS - 1
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 4.5 (12)
Mg - 43 (14)
Na - 124 (14)
Ca - 32 (14)
K - 8 (14)
Alk - -25 (13)

SITE DESCRIPTION

This is a 'peat-moss' tarn that is set in heather and contains no fish.

SAMPLE DESCRIPTION

A) Margin sample

The substrate was typical acidic 'peat-moss' detritus.
Peat-moss.

SITE - T14
NAME - ROSLEY THORNS POOL
GRID REF. - 291937
SAMPLING DATE : 21/8/90
FAUNA :

	T14
Cypria ophthalmica	1
Cyclocypris ovum	143
Candona rostrata	13
Tot/species	3
Tot/no.	157

LAKE SIZE - 9.00 x 10^2 m^2
SIZE CLASS - E
ALTITUDE - 150m

MAX DEPTH - 1m
F.B.A. CLASS - (3)
BEDROCK - Silurian slates

CHEMISTRY

pH - 5.9 (1)
Mg - 115 (1)
Na - 225 (1)
Ca - 166 (1)
K - 5 (1)
Alk - N/A

SITE DESCRIPTION

A small pool containing sparse growth of *Potamogeton*, and reedgrass.

SAMPLE DESCRIPTION

A) *Margin sample*

The substrate consisted of organic silt and peat-moss, and was taken from amongst the macrophyte.

Organic silt/Macrophyte/Peat-moss.

SITE - T15
NAME - CAT CRAG TARN
GRID REF. - 424938
SAMPLING DATE : 21/8/90
FAUNA :

	T15
Cypria ophthalmica	683
Cyclocypris ovum	117
Candona candida	584
Cypridopsis vidua	12
Tot/species	4
Tot/no.	1396

LAKE SIZE - 10 m^2
SIZE CLASS - E
ALTITUDE - 204m

MAX DEPTH - 0.1m
F.B.A. CLASS - (4)
BEDROCK - Silurian Slates

CHEMISTRY

pH - 6.5 (1)
Mg - 259 (1)
Na - 604 (1)

Ca - 938 (1)
K - 90 (1)
Alk - N/A

SITE DESCRIPTION

This site is literally a muddy pool for farm animals to drink. It certainly contains no fish. It is set amongst dense *Sphagnum* in an arable field.

SAMPLE DESCRIPTION

A) Margin sample

The sample through the *Sphagnum* yielded a dense volume of rich organic detritus.

Organic silt/Macrophyte.

SITE - T16
NAME - BURNMOOR POOL
GRID REF. - 186043
SAMPLING DATE : 3/9/89
FAUNA :

	T16
	NONE
Tot/species	NONE
Tot/no.	NONE

LAKE SIZE - 20 m^2
SIZE CLASS - E
ALTITUDE - 285m

MAX DEPTH - 1m
F.B.A. CLASS - (2)
BEDROCK - Borrowdale volcanics

CHEMISTRY

pH - 5.6 (1)
Mg - 58 (1)
Na - 174 (1)
Ca - 92 (1)
K - 11 (1)
Alk - N/A

SITE DESCRIPTION
This is a tiny acidic 'peat-moss' pool.

SAMPLE DESCRIPTION
A) Margin sample
The substrate was typical acidic 'peat-moss'.
Peat-moss.

APPENDIX 14.7 - ONTOGENY & LIFE CYCLE DATA

1. Herpetocypris reptans

A) Summer samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.75 * 0.30	2	1
0.85 * 0.40	2	2
0.90 * 0.45	2, 9, 61	2, 2, 1
0.95 * 0.45	2	1
1.00 * 0.50	9	1
1.10 * 0.50	9	3
1.15 * 0.50	17	1
1.30 * 0.60	9	2
1.70 * 0.80	9	2
2.30 * 1.10	9	2
2.40 * 1.10	9, 43	1, 1
2.50 * 1.15	9, 61, 74	1, 1, 2
2.60 * 1.20	6, 9, 61	1, 1, 1
2.70 * 1.2	6	1

B) Winter samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.90 * 0.45	74	1
1.00 * 0.50	74	2
1.25 * 0.60	74	1
1.30 * 0.60	74	4
1.70 * 0.80	74	1
2.30 * 1.10	61, 74	1,1
2.40 * 1.10	74	3
2.40 * 1.15	74	1
2.50 * 1.15	74	4
2.50 * 1.20	74	6
2.55 * 1.20	74	4
2.60 * 1.20	74	11
2.65 * 1.2	74	1
2.70 * 1.2	74	4

2. Herpetocypris chevreuxi

A) Summer samples

Size L x H / mm	**Sites (no.)**	**Quantity**
1.30 * 0.55	25	1
1.40 * 0.60	25	1
1.75 * 0.70	25	1
1.90 * 0.80	25	5
1.95 * 0.80	25	1
2.10 * 0.90	25	13
2.15 * 0.90	25	3
2.15 * 0.95	25	2
2.20 * 0.90	25	1
2.20 * 0.95	25	2

B) Winter samples

Size L x H / mm	**Sites (no.)**	**Quantity**
2.05 * 0.85	25	1
2.10 * 0.90	25	2
2.15 * 0.90	25	3
2.15 * 0.95	25	1
2.20 * 0.90	25	2
2.20 * 0.95	25	2
2.30 * 0.95	25	1

3. Metacypris cordata

A) Summer samples - Males

Size L x H / mm	**Sites (no.)**	**Quantity**
0.50 * 0.30	37, 74, 36	44, 15, 3
0.50 * 0.35	1, 16, 37, 74, 36	2, 12, 41, 67, 131

B) Winter samples - Males

Size L x H / mm	**Sites (no.)**	**Quantity**
0.50 * 0.30	74	16
0.50 * 0.35	16, 37, 74, 36	5, 5, 17, 6

C) Summer samples - Females

Size L x H / mm	**Sites (no.)**	**Quantity**
0.55 * 0.35	1, 16, 37, 74, 36	1, 8, 31, 33, 100
0.60 * 0.40	13, 16, 37, 74, 36	1, 1, 18, 12, 32

D) Winter samples - Females

Size L x H / mm	**Sites (no.)**	**Quantity**
0.55 * 0.35	37, 74	3, 18
0.60 * 0.40	74	1

E) Summer samples - juveniles

Size L x H / mm	**Sites (no.)**	**Quantity**
0.40 * 0.25	16, 37, 74, 36	17, 36, 13, 83
0.45 * 0.25	37, 74, 36	21, 31, 104
0.45 * 0.30	1, 6, 16, 37, 74, 36	7, 5, 32, 309, 171, 212

F) Winter samples - juveniles

Size L x H / mm	**Sites (no.)**	**Quantity**
0.40 * 0.25	16, 37, 74, 36	34, 40, 17, 7
0.45 * 0.25	16, 37, 74	1, 12, 1
0.45 * 0.30	16, 45, 37, 74, 36	60, 2, 105, 297, 19

4. Candonopsis kingsleii

A) Summer samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.90 * 0.40	12	1

B) Winter samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.80 * 0.35	12	7
0.80 * 0.40	12	5
0.85 * 0.40	12	5
0.90 * 0.40	12, 17	21, 1
0.90 * 0.45	12, 17	16, 1
1.00 * 0.50	12	3
1.00 * 0.55	12,	1
1.10 * 0.55	12	3
1.20 * 0.60	12	2

5. Candona candida

A) Summer samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.30	6, 11, 13, 15, 17, 18, 19, 20, 27, 31, 36, 64, 2	16, 2, 3, 4, 3, 19, 6, 51, 5, 23, 26, 12, 1
0.60 * 0.35	6	1
0.65 * 0.30	2, 11, 17, 19, 20, 22, 31, 36, 54, 56, 61, 64, 6	3, 1, 6, 3, 6, 2, 9, 10, 1, 1, 1, 9, 1
0.65 * 0.35	2, 6, 36, 75	6, 5, 4, 2
0.70 * 0.35	1, 2, 3, 6, 13, 15, 17, 18, 27, 31, 36, 64, 71, 74, 75	2, 6, 1, 10, 1, 3, 6, 8, 1, 13, 8, 30, 1, 1, 2
0.70 * 0.40	2	1
0.75 * 0.35	6, 17, 19, 22, 31, 54, 64, 65, 75	6, 3, 4, 1, 13, 1, 4, 1, 3
0.75 * 0.40	6, 71	1, 1
0.80 * 0.40	17, 75	4, 2
0.85 * 0.45	2	2
0.90 * 0.45	27	3
0.90 * 0.50	59	3
0.95 * 0.50	75	2
0.95 * 0.55	2, 27, 31, 36, 59	3, 6, 2, 1, 1
1.00 * 0.55	2	2
1.05 * 0.60	69, 72	1, 1
1.10 * 0.60	13, 26, 27, 36, 42, 54, 64, 69, 71, 75	1, 4, 2, 1, 8, 2, 3, 3, 9, 11
1.15 * 0.60	27, 64, 71	1, 1, 2
1.15 * 0.65	64, 69, 75	1, 1, 1
1.20 * 0.65	36, 42, 75	1, 1, 3
1.25 * 0.65	42	1

B) Winter samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.30	14, 26, 59, 62	7, 1, 4, 3
0.65 * 0.30	26, 59, 62	1, 1, 1
0.70 * 0.35	38, 59	2, 8
0.80 * 0.40	15, 18, 37	2, 1, 1
0.85 * 0.40	14	4
0.85 * 0.45	11, 14, 62	1, 1, 3
0.90 * 0.45	3, 11, 14, 26, 28, 38	1, 2, 6, 1, 2, 1
0.90 * 0.50	3, 50, 59, 62, 71	1, 1, 3, 3, 1
0.95 * 0.50	4, 25, 26, 37, 55, 62	1, 2, 1, 1, 1, 1
0.95 * 0.55	62	2
1.00 * 0.55	59	1
1.05 * 0.55	20	1
1.05 * 0.60	1, 11, 14, 17, 38, 55, 63, 71	1, 1, 12, 9, 1, 3, 1, 9
1.05 * 0.65	11	3
1.10 * 0.60	1, 2, 12, 13, 14, 15, 17, 18, 19, 20, 23, 24, 26, 28, 31, 36, 37, 38, 42, 55, 59, 62, 63, 64, 65, 69, 71, 74, 75	2, 21, 3, 2, 30, 9, 15, 1, 3, 4, 5, 1, 1, 5, 1, 1, 2, 4, 12, 16, 5, 4, 2, 5, 1, 2, 12, 9, 13
1.10 * 0.65	11, 71	7, 3
1.15 * 0.60	3, 19, 23, 25, 31, 36, 42, 59, 71, 75	12, 2, 2, 1, 1, 2, 4, 1, 19, 2
1.15 * 0.65	3, 62, 71, 75	19, 1, 5, 2
1.20 * 0.65	3, 6, 11, 12, 13, 14, 15, 17, 18, 19, 22, 23, 26, 28, 37, 38, 42, 59, 61, 62, 69, 71, 74, 75	18, 6, 4, 1, 1, 12, 2, 6, 2, 2, 1, 6, 1, 2, 1, 2, 6, 1, 1, 3, 1, 10, 5, 1
1.25 * 0.65	42, 71	5, 3

1.25 * 0.70	6	7

6. Candona albicans

A) Summer samples

Size L x H / mm	Sites (no.)	Quantity
0.55 * 0.30	36	1
0.65 * 0.35	1, 36	1, 1
0.70 * 0.40	36	1
0.80 * 0.45	36	1

B) Winter samples

Size L x H / mm	Sites (no.)	Quantity
0.70 * 0.40	69	1
0.75 * 0.40	36	1
0.80 * 0.45	36	1
0.90 * 0.50	69	1

7. Candona fabaeformis

A) Summer samples - juveniles

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.30	75	1
0.90 * 0.40	75	1

B) Winter samples - juveniles

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.30	17	2
0.70 * 0.35	12, 17	2, 8
0.80 * 0.40	12	10
0.85 * 0.40	12	4
0.90 * 0.40	12, 17, 75	8, 5, 1
0.90 * 0.45	12	9
1.00 * 0.45	12, 17, 75	2, 6, 2

C) Winter samples - adult males

Size L x H / mm	**Sites (no.)**	**Quantity**
1.20 * 0.65	12	3
1.20 * 0.70	12	3
1.30 * 0.70	12	4

D) Winter samples - adult females

Size L x H / mm	**Sites (no.)**	**Quantity**
1.10 * 0.45	12, 17, 75	1, 2, 6
1.20 * 0.50	12	2

8. Candona neglecta

A) Summer samples - juveniles

Size L x H / mm	Sites (no.)	Quantity
0.90 * 0.45	3	1
1.10 * 0.55	3	1

B) Summer samples - adult males

Size L x H / mm	Sites (no.)	Quantity
1.35 * 0.70	2, 3	1, 3
1.40 * 0.75	2, 3	6, 2

C) Summer samples - adult females

Size L x H / mm	Sites (no.)	Quantity
1.20 * 0.60	3	1

D) Winter samples - juveniles

Size L x H / mm	Sites (no.)	Quantity
0.80 * 0.40	3	3
0.90 * 0.45	3	1
1.10 * 0.55	3	6

E) Winter samples - adult males

Size L x H / mm	Sites (no.)	Quantity
1.35 * 0.70	3	20
1.40 * 0.75	3	7
1.45 * 0.80	3	1

F) Winter samples - adult females

Size L x H / mm	**Sites (no.)**	**Quantity**
1.20 * 0.60	3	5
1.25 * 0.65	3	4

9. Candona rostrata

A) Summer samples - juveniles

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.35	20, 36	3, 9
0.70 * 0.35	20	1
0.70 * 0.40	20	1
0.75 * 0.40	20, 36	2, 1
0.80 * 0.45	20, 36	2, 2
0.85 * 0.50	20	2
0.90 * 0.50	20	2
0.90 * 0.55	20, 35	5, 1

B) Summer samples - adult males

Size L x H / mm	**Sites (no.)**	**Quantity**
1.10 * 0.70	20, 35	1, 1
1.15 * 0.70	20	2

C) Summer samples - adult females

Size L x H / mm	**Sites (no.)**	**Quantity**
1.10 * 0.70	35	1

D) Winter samples - juveniles

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.35	61, 64,	1, 2
0.70 * 0.40	36, 75	1, 1
0.75 * 0.40	36, 64	1, 1
0.80 * 0.45	36	1
0.85 * 0.50	64	5
0.90 * 0.55	35, 64	1, 3

E) Winter samples - adult males

Size L x H / mm	**Sites (no.)**	**Quantity**
1.10 * 0.70	35	1

F) Winter samples - adult females

Size L x H / mm	**Sites (no.)**	**Quantity**
1.00 * 0.65	35	1
1.10 * 0.70	35	1

10. Candona siliquosa

A) Summer samples

Size L x H / mm	**Sites (no.)**	**Quantity**
1.10 * 0.55	54	1

B) Winter samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.70 * 0.35	7, 63,	2, 1
0.80 * 0.40	63	2
0.85 * 0.40	4, 63	1, 1
0.90 * 0.45	7, 63	1, 2
1.00 * 0.45	7, 63	1, 1
1.10 * 0.50	7	1
1.15 * 0.55	7, 55, 63	1, 1, 2
1.20 * 0.55	7, 23, 63	2, 1, 3
1.25 * 0.60	7	1
1.30 * 0.60	7	1

11. Candona reducta

A) Summer samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.25	13	1
0.60 * 0.30	13	3
0.65 * 0.30	13	7
0.85 * 0.40	42	3
0.90 * 0.45	42	1
0.95 * 0.45	42	2
1.00 * 0.50	42	4
1.05 * 0.50	42	3
1.10 * 0.55	42	2

B) Winter samples

Size L x H / mm	**Sites (no.)**	**Quantity**
0.60 * 0.30	13, 42	1, 1
0.80 * 0.40	64, 74	1, 2
0.85 * 0.40	74	1
0.90 * 0.45	13, 42	2, 2
0.95 * 0.45	13, 22, 42	1, 2, 2
1.00 * 0.45	22, 42	1, 2
1.00 * 0.50	13, 42	2, 5
1.05 * 0.50	42	5
1.10 * 0.55	42	4

12. Candona vavrai

A) Summer samples

Size L x H / mm	Sites (no.)	Quantity
0.60 * 0.30	13, 64	2, 7
0.65 * 0.30	13, 50	1, 1
0.80 * 0.40	50	2
0.85 * 0.40	32	1
0.95 * 0.45	4	1

B) Winter samples

Size L x H / mm	Sites (no.)	Quantity
0.60 * 0.30	13	1
0.75 * 0.35	13	3
0.80 * 0.40	13, 28	2, 1
0.85 * 0.40	13, 64	2, 1
0.95 * 0.45	4, 13, 28, 32, 64, 75	1, 10, 2, 1, 2, 2
1.00 * 0.50	4, 13	1, 3

APPENDIX 14.9 - PREDATION

A) Feeding fish with 50 *C. fuscatus* :

1 - Fish One

PREY EATEN / No.	PREY EATEN / %	AFTER TIME / x
10	20	20 secs
20	40	65 secs
28	56	10 mins
29	58	15 mins
30	60	20 mins
31	62	25 mins
33	66	30 mins
35	70	35 mins
36	72	40 mins
37	74	45 mins
37	74	50 mins
37	74	55 mins
38	76	60 mins
38	76	75 mins
40	80	90 mins
41	82	105 mins
42	84	120 mins

2 - Fish Two

PREY EATEN / No.	PREY EATEN / %	AFTER TIME / x
10	20	50 secs
14	28	5 mins
14	28	10 mins
16	32	15 mins
22	44	20 mins
24	48	25 mins
28	56	30 mins
29	58	35 mins
30	60	40 mins
34	68	45 mins
39	78	50 mins
39	78	55 mins
40	80	60 mins
41	82	75 mins
43	86	90 mins
44	88	105 mins
45	90	120 mins

3 - Fish Three

PREY EATEN / No.	PREY EATEN / %	AFTER TIME / x
5	10	1 min
10	20	3 mins
11	22	5 mins
11	22	10 mins
13	26	15 mins
13	26	20 mins
17	34	25 mins
18	36	30 mins
19	38	35 mins
19	38	40 mins
19	38	45 mins
20	40	50 mins
21	42	55 mins
24	48	60 mins
28	56	75 mins
28	56	90 mins
28	56	105 mins
33	66	120 mins

B) Feeding fish with 50 C. ophthalmica :

1 - Fish One

PREY EATEN / No.	PREY EATEN / %	AFTER TIME / x
2	4	5 mins
4	8	10 mins
4	8	15 mins
4	8	20 mins
4	8	25 mins
5	10	30 mins
5	10	35 mins
5	10	40 mins
6	12	45 mins
9	18	50 mins
9	18	55 mins
9	18	60 mins
10	20	75 mins
10	20	90 mins
11	22	105 mins
11	22	120 mins

2 - Fish Two

PREY EATEN / No.	PREY EATEN / %	AFTER TIME / x
3	6	5 mins
5	10	10 mins
5	10	15 mins
5	10	20 mins
7	14	25 mins
8	16	30 mins
10	20	35 mins
10	20	40 mins
10	20	45 mins
10	20	50 mins
13	26	55 mins
13	26	60 mins
15	30	75 mins
16	32	90 mins
16	32	105 mins
17	34	120 mins

C) Feeding fish with 50 E. virens :

1 - Fish one

PREY EATEN / No.	PREY EATEN / %	AFTER TIME / x
2	4	1 min
5	10	2 mins
9	18	5 mins
12	24	10 mins
15	30	15 mins
18	36	20 mins
19	38	25 mins
22	44	30 mins
24	48	35 mins
24	48	40 mins
24	48	45 mins
24	48	50 mins
25	50	55 mins
26	52	60 mins
28	56	75 mins
28	56	90 mins
30	60	105 mins
31	62	120 mins

2 - Fish two

PREY EATEN / No.	PREY EATEN / %	AFTER TIME / x
4	8	1 min
7	14	2 mins
9	18	5 mins
14	28	10 mins
17	34	15 mins
19	38	20 mins
25	50	25 mins
26	52	30 mins
31	62	35 mins
32	64	40 mins
32	64	45 mins
34	68	50 mins
37	74	55 mins
40	80	60 mins
40	80	75 mins
40	80	90 mins
41	82	105 mins
41	82	120 mins

A) Feeding fish with 50 C. fuscatus / 17 C. ophthalmica
(ratio of 3:1)

1 - Fish previously fed on C. fuscatus

C.f/No	C.f/%	C.o/No	C.o/%	Tot/No	Tot/%	Time/m
10	20	2	12	12	18	1
16	32	8	47	24	36	2
19	38	11	65	30	45	3
20	40	11	65	31	46	5
21	42	11	65	32	48	10
23	46	11	65	34	51	15
23	46	11	65	34	51	20
25	50	11	65	36	54	25
26	52	11	65	37	55	30
29	58	11	65	40	60	35
34	68	11	65	45	67	40
39	78	11	65	50	75	45
41	82	11	65	52	78	50
42	84	12	71	54	81	55
43	86	12	71	55	82	60
47	94	12	71	59	88	75
50	100	12	71	62	93	79
50	100	12	71	62	93	105
50	100	12	71	62	93	120

2 - Fish previously fed on C. ophthalmica

C.f/No	C.f/%	C.o/No	C.o/%	Tot/No	Tot/%	Time/m
3	6	0	0	3	4	5
7	14	1	6	8	12	10
15	30	5	29	20	30	15
22	44	7	41	29	43	20
23	46	7	41	30	45	25
25	50	9	53	34	51	30
27	54	9	53	36	54	35
31	62	10	59	41	62	40
32	64	10	59	42	63	45
33	66	11	65	44	66	50
33	66	11	65	44	66	55
33	66	11	65	44	66	60
33	66	11	65	44	66	75
35	70	11	65	46	66	90
35	70	11	65	46	66	105
36	72	11	65	47	70	120

B) Feeding fish with 50 <u>C. fuscatus</u> / 50 <u>C. ophthalmica</u>.
(ratio of 1:1)

1 - Fish previously fed on <u>C. fuscatus</u>

<u>C.f</u>/No	<u>C.f</u>/%	<u>C.o</u>/No	<u>C.o</u>/%	Tot/No	Tot/%	Time/m
2	4	4	8	6	6	2
4	8	6	12	10	10	3
5	10	8	16	13	13	5
6	12	10	20	16	16	10
6	12	11	22	17	17	15
7	14	11	22	18	18	20
11	22	12	24	23	23	25
13	26	12	24	25	25	30
13	26	13	26	26	26	35
16	32	13	26	26	26	40
17	34	17	34	34	34	45
19	38	19	38	38	38	50
19	38	19	38	38	38	55
20	40	21	42	41	41	60
20	40	22	44	42	42	75
22	44	24	48	46	46	90
26	52	26	52	52	52	105
29	58	27	54	56	56	120

2 - Fish previously fed on C. ophthalmica

C.f/No	C.f/%	C.o/No	C.o/%	Tot/No	Tot/%	Time/m
3	6	3	6	6	6	1
4	8	5	10	9	9	2
6	12	10	20	16	16	5
8	16	11	22	19	19	10
8	16	11	22	19	19	15
10	20	12	24	22	22	20
11	22	14	28	25	25	25
13	26	17	34	30	30	30
13	26	19	38	32	32	35
15	30	22	44	37	37	40
18	36	23	46	41	41	45
19	38	23	46	42	42	50
20	40	26	46	46	46	55
22	44	28	56	50	50	60
22	44	29	58	51	51	75
24	48	29	58	53	53	90
25	50	31	62	56	56	105
26	52	33	66	59	59	120

C) Feeding fish with 50 _C. fuscatus_ / 150 _C. ophthalmica_
(ratio of 1:3)

1 - Fish previously fed on _C. fuscatus_

C.f/No	C.f/%	C.o/No	C.o/%	Tot/No	Tot/%	Time/m
1	2	6	4	7	4	1
3	6	19	13	22	11	5
8	16	29	19	37	19	10
9	18	31	21	40	20	15
9	18	35	23	44	22	20
10	20	36	24	46	23	25
11	22	38	25	49	25	30
12	24	39	26	51	26	35
13	26	40	27	53	27	40
13	26	41	27	54	27	45
16	32	45	30	61	31	50
18	36	49	33	67	34	55
22	44	50	33	72	36	60
24	48	53	35	77	39	75
24	48	53	35	77	39	90
25	50	55	37	80	40	105
25	50	56	37	81	41	120

2 - Fish previously fed on C. ophthalmica

C.f/No	C.f/%	C.o/No	C.o/%	Tot/No	Tot/%	Time/m
3	6	4	3	7	4	1
4	8	4	3	8	4	2
5	10	7	5	12	6	5
7	14	10	7	17	9	10
10	20	14	9	24	12	15
10	20	17	11	27	14	20
12	24	20	13	32	16	25
13	26	21	14	34	17	30
16	32	25	17	41	21	35
17	34	26	17	43	22	40
19	38	30	20	49	25	45
20	40	30	20	50	25	50
22	44	36	24	58	29	55
22	44	39	26	61	31	60
22	44	44	29	66	33	75
23	46	47	31	70	35	90
23	46	48	32	71	36	105
23	46	48	32	71	36	120

Ostracod pair.	**Fish one**	**Fish two**	**Fish three**
C. fuscatus / *C. ophthalm*	70 % (7) / 30 % (3) X^2=1.6 (P>0.1)	60 % (6) / 40 % (4) X^2=0.4 (P>0.5)	60 % (6) / 40 % (4) X^2=0.4 (P>0.5)
C. fuscatus / *E. virens*	50 % (5) / 50 % (5) X^2=0 (P>0.9)	20 % (2) / 80 % (8) X^2=3.6 (P>0.05)	10 % (1) / 90 % (9) X^2=6.4 (P>0.01)
C. ophthalm / *E. virens*	30 % (3) / 70 % (7) X^2=1.6 (P>0.1)	30 % (3) / 70 % (7) X^2=1.6 (P>0.1)	20 % (2) / 80 % (8) X^2=3.6 (P>0.05)

APPENDIX 14.10 - TOXICITY DATA

Table 10.61a - Ostracod % survival with reference to calcium

Conc/ ppm	C.optht	C.ovum	C.vidua	C.obliq	H.chev	C.incon
0.01	90	75	70	70	90	50
0.1	95	100	70	70	60	45
1.0	90	90	95	65	65	35
2.0	100	90	85	65	90	75
4.0	90	90	90	90	95	90
6.0	75	90	85	85	100	90
8.0	90	90	75	80	90	90
10.0	90	75	90	100	90	70
16.0	90	95	90	95	80	70
20.0	90	75	90	95	100	55
30.0	90	70	80	90	95	95
35.0	85	95	80	80	90	60
40.0	80	85	80	95	90	80
50.0	90	85	75	95	90	65
70.0	100	95	90	75	90	95
80.0	95	100	85	80	100	85
100	100	95	90	80	95	85
500	100	75	70	90	80	70
1000	100	90	80	95	85	70
5000	100	100	95	90	75	65

KEY

C.optht - C. ophthalmica,
C.obliq - C. obliquus,
H.chev - H. chevreuxi,
C.incon - C. incongruens.

Table 10.61b - Ostracod % survival with reference to magnesium

Conc/ppm	C.ophth	C.ovum	C.vidua	H.chev	C.incon
0.01	95	80	85	90	65
0.1	90	65	90	95	70
0.5	85	75	95	85	60
1.0	95	70	80	100	80
5.0	100	95	90	95	85
10.0	95	80	90	100	75
25.0	100	95	80	95	65
50.0	90	85	100	90	95
100	75	100	100	95	75
250	95	90	90	100	65
500	100	80	90	100	75
1000	100	100	100	95	80

Table 10.61c - Ostracod % survival with reference to sodium

Conc/ppm	C.ophth	C.ovum	C.vidua	H.chev	C.incon
0.01	85	90	80	90	80
0.1	75	80	95	100	65
0.5	85	75	95	95	55
1.0	95	100	100	90	90
5.0	80	75	85	80	85
10.0	100	85	75	95	90
25.0	95	95	85	100	65
50.0	100	100	85	90	65
100	85	100	90	80	100
250	100	95	90	75	95
500	95	100	100	80	85
1000	95	90	95	90	80

Table 10.61d - Ostracod % survival with reference to aluminium

Conc/ ppm	C.ophth	C.ovum	C.vidua	C.obliq	H.chev	C.incon
0.01	95	100	75	95	100	55
0.1	100	95	100	85	90	65
0.5	95	90	70	85	85	75
1.0	100	90	80	90	100	60
5.0	95	95	95	65	90	50
10.0	95	40	65	40	75	20
25.0	85	35	70	40	85	10
50.0	90	20	90	25	100	15
100	90	25	80	20	80	15
500	95	15	80	25	95	30
1000	85	20	75	20	85	25

1. Table 10.62a - CYPRIA OPHTHALMICA - % SURVIVAL

A) Calcium = 100 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	20	10	20	0	0
4.0	90	100	80	80	70
5.0	90	90	100	60	60
6.0	100	90	70	100	80
7.0	90	80	90	70	80

B) Calcium = 10.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	0	0	0	10	0
4.0	90	80	60	80	60
5.0	100	90	100	80	80
6.0	70	100	90	60	70
7.0	80	90	80	70	60

C) Calcium = 1.00 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	0	0	0	0	0
4.0	80	100	100	70	60
5.0	80	100	50	60	70
6.0	100	90	80	90	90
7.0	100	100	80	90	80

D) <u>Calcium = 0.10 ppm</u>

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	70	80	70	80	60
5.0	90	100	70	70	80
6.0	80	90	90	100	90
7.0	80	80	90	100	90

2. Table 10.62b - CYPRIDOPSIS VIDUA - % SURVIVAL

A) Calcium = 100.0 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	80	70	70	80	0
5.0	90	70	60	80	100
6.0	80	70	90	60	80
7.0	80	90	80	100	90

B) Calcium = 10.0 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	70	60	40	100	20
5.0	70	90	60	80	70
6.0	90	100	80	60	80
7.0	80	100	90	80	90

C) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	60	80	80	50	10
5.0	80	100	100	80	60
6.0	100	80	70	90	80
7.0	90	80	60	70	80

D) Calcium = 0.01 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	80	60	80	40	20
5.0	90	60	40	60	70
6.0	70	80	60	60	70
7.0	70	90	80	70	80

3. Table 10.62c - HERPETOCYPRIS CHEVREUXI - % SURVIVAL

A) Calcium = 100.0 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	70	90	70	50	0
5.0	90	70	100	60	50
6.0	100	100	100	100	70
7.0	90	70	100	90	60

B) Calcium = 10.0 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	90	100	100	60	40
5.0	80	70	50	100	70
6.0	80	60	70	90	60
7.0	80	80	80	90	60

C) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	100	100	50	60	0
5.0	80	100	100	70	50
6.0	100	90	90	70	70
7.0	100	90	90	100	70

D) Calcium = 0.01 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	100	70	80	10	0
5.0	90	50	70	100	70
6.0	80	80	100	90	80
7.0	90	80	90	80	70

4. Table 10.62d - CYCLOCYPRIS OVUM - % SURVIVAL

A) Calcium = 100.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	0	0	0	0	0
4.0	90	70	80	30	20
5.0	80	100	70	40	30
6.0	60	80	90	30	40
7.0	80	80	90	60	30

B) Calcium = 10.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	0	0	0	20	0
4.0	70	80	90	10	10
5.0	70	80	80	40	30
6.0	90	80	80	40	30
7.0	90	80	60	30	30

C) Calcium = 1.00 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	0	0	0	0	0
4.0	80	90	100	10	20
5.0	80	80	90	20	40
6.0	90	70	80	30	30
7.0	100	100	80	50	10

D) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	100	80	90	10	10
5.0	100	80	60	30	20
6.0	90	70	80	40	50
7.0	60	80	60	50	30

5. **Table 10.62e - <u>CANDONA CANDIDA</u> - % SURVIVAL**

A) <u>Calcium = 100.0 ppm</u>

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	80	60	70	60	40
5.0	90	80	60	80	80
6.0	100	60	60	70	80
7.0	90	80	60	70	80

B) <u>Calcium = 10.0 ppm</u>

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	70	80	90	80	50
5.0	100	60	80	70	70
6.0	80	90	60	70	80
7.0	70	100	80	70	80

C) <u>Calcium = 1.00 ppm</u>

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	70	70	90	50	30
5.0	80	80	70	70	50
6.0	80	40	70	50	60
7.0	70	100	60	90	50

D) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	80	100	80	60	0
5.0	70	80	90	80	90
6.0	70	100	80	70	70
7.0	80	80	70	100	70

6. Table 10.62f - CANDONA ROSTRATA - % SURVIVAL

A) Calcium = 100.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	70	40	50	60	40
4.0	70	60	100	70	60
5.0	80	70	80	80	70
6.0	90	70	70	60	90
7.0	90	80	60	50	9

B) Calcium = 10.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	80	60	60	100	50
4.0	90	90	70	80	80
5.0	100	70	80	70	90
6.0	100	70	80	70	100
7.0	80	80	60	70	60

C) Calcium = 1.00 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	80	100	60	0	0
4.0	80	90	70	70	60
5.0	90	80	100	60	60
6.0	100	70	80	70	90
7.0	100	60	80	70	70

D) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	60	80	60	0	0
4.0	80	80	60	40	80
5.0	70	100	80	40	90
6.0	80	80	100	80	50
7.0	70	100	80	70	80

7. Table 10.62g - CYPRICERCUS FUSCATUS - % SURVIVAL

A) Calcium = 100.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	100	90	80	80	100
4.0	90	100	80	70	80
5.0	70	70	80	80	80
6.0	90	90	70	90	80
7.0	80	70	70	80	80

B) Calcium = 10.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	70	60	40	80	90
4.0	100	60	60	100	80
5.0	90	80	80	80	70
6.0	100	70	60	70	80
7.0	100	80	70	60	80

C) Calcium = 1.00 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	90	40	60	0	0
4.0	100	60	60	80	80
5.0	100	60	60	70	70
6.0	90	100	70	80	80
7.0	90	100	70	80	80

D) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	40	60	100	0	0
4.0	90	80	70	40	80
5.0	80	90	80	90	60
6.0	70	60	70	90	80
7.0	80	80	70	90	80

8. **Table 10.62h - CANDONA SILIQUOSA - % SURVIVAL**

A) Calcium = 100.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	70	40	50	50	60
4.0	70	50	70	80	60
5.0	80	100	70	100	90
6.0	90	70	80	90	90
7.0	80	70	80	90	90

B) Calcium = 10.0 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	70	90	100	100	80
4.0	100	70	70	80	50
5.0	80	70	60	70	60
6.0	100	90	60	50	70
7.0	100	90	60	60	90

C) Calcium = 1.00 ppm

pH\Al	0.01	0.10	1.00	10.0	100.0
3.0	70	100	60	0	0
4.0	70	100	70	100	90
5.0	70	80	60	80	70
6.0	90	90	90	80	80
7.0	70	100	60	90	70

D) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	60	100	0	0	0
4.0	70	70	70	90	100
5.0	70	100	100	60	80
6.0	90	90	100	70	70
7.0	80	90	100	90	80

9. Table 10.62j - CYPRICERCUS OBLIQUUS - % SURVIVAL

A) Calcium = 100.0 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	80	90	70	20	0
5.0	70	80	90	50	20
6.0	90	70	80	30	20
7.0	90	90	70	40	0

B) Calcium = 10.0 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	90	80	70	30	20
5.0	60	90	80	50	10
6.0	80	100	60	30	20
7.0	70	70	100	60	10

C) Calcium = 1.00 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	90	80	90	10	30
5.0	80	80	100	20	10
6.0	70	90	80	30	20
7.0	70	80	70	30	20

D) Calcium = 0.10 ppm

pH\Al	**0.01**	**0.10**	**1.00**	**10.0**	**100.0**
3.0	0	0	0	0	0
4.0	80	90	60	30	60
5.0	70	70	60	10	20
6.0	100	100	100	30	20
7.0	90	100	80	50	30

ANALYSIS OF VARIANCE PROCEDURE

a. *Cypria ophthalmica*

[Al] / ppm	mean survival	S.D. survival
0.01	7.05	3.50
0.10	7.35	3.72
1.00	6.60	3.41
10.0	6.30	3.47
100.0	5.90	3.19

[Ca] / ppm	mean survival	S.D. survival
0.10	6.64	3.53
1.00	6.68	3.67
10.0	6.36	3.46
100.0	6.88	3.23

pH	mean survival	S.D. survival
3.0	0.25	0.64
4.0	7.80	1.32
5.0	8.10	1.59
6.0	8.65	1.18
7.0	8.40	1.04

b. <u>*Cypridopsis vidua*</u>

[Al] / ppm	mean survival	S.D. survival
0.01	6.40	3.41
0.10	6.40	3.51
1.00	5.70	3.29
10.0	5.80	3.33
100.0	5.00	3.80

[Ca] / ppm	mean survival	S.D. survival
0.10	5.32	3.13
1.00	6.00	3.57
10.0	6.04	3.58
100.0	6.08	3.63

pH	mean survival	S.D. survival
3.0	0.00	0.00
4.0	5.75	2.75
5.0	7.55	1.63
6.0	7.75	1.25
7.0	8.25	1.02

c. <u>Herpetocypris chevreuxi</u>

[Al] / ppm	mean survival	S.D. survival
0.01	7.10	3.74
0.10	6.50	3.61
1.00	6.70	3.77
10.0	6.10	3.45
100.0	4.10	3.21

[Ca] / ppm	mean survival	S.D. survival
0.10	5.92	3.84
1.00	6.24	4.06
10.0	6.04	2.47
100.0	6.12	3.84

pH	mean survival	S.D. survival
3.0	0.00	0.00
4.0	6.20	3.58
5.0	7.50	1.78
6.0	8.40	1.39
7.0	8.30	1.22

d. *Cyclocypris ovum*

[Al] / ppm	mean survival	S.D. survival
0.01	6.65	3.60
0.10	6.50	3.43
1.00	6.40	3.45
10.0	2.60	1.88
100.0	2.15	1.50

[Ca] / ppm	mean survival	S.D. survival
0.10	4.76	3.53
1.00	5.00	3.85
10.0	4.68	3.44
100.0	5.00	3.42

pH	mean survival	S.D. survival
3.0	0.00	0.00
4.0	5.70	3.63
5.0	6.10	2.69
6.0	6.25	2.36
7.0	6.25	2.63

e. Candona candida

[Al] / ppm	mean survival	S.D. survival
0.01	6.40	3.41
0.10	6.30	3.59
1.00	5.85	3.17
10.0	5.70	3.14
100.0	4.90	3.28

[Ca] / ppm	mean survival	S.D. survival
0.10	6.08	3.63
1.00	5.32	3.15
10.0	6.12	3.32
100.0	5.80	3.21

pH	mean survival	S.D. survival
3.0	0.00	0.00
4.0	6.55	2.32
5.0	7.65	1.18
6.0	7.20	1.51
7.0	7.75	1.37

f. <u>Candona rostrata</u>

[Al] / ppm	mean survival	S.D. survival
0.01	8.30	1.17
0.10	7.65	1.53
1.00	7.40	1.47
10.0	6.05	2.48
100.0	6.55	2.78

[Ca] / ppm	mean survival	S.D. survival
0.10	6.84	2.61
1.00	7.16	2.54
10.0	7.76	1.42
100.0	7.00	1.58

pH	mean survival	S.D. survival
3.0	5.25	3.14
4.0	7.40	1.39
5.0	7.80	1.51
6.0	8.00	1.41
7.0	7.50	1.36

g. <u>*Cypricercus fuscatus*</u>

[Al] / ppm	mean survival	S.D. survival
0.01	8.60	1.50
0.10	7.50	1.67
1.00	7.00	1.21
10.0	7.05	2.72
100.0	7.15	2.56

[Ca] / ppm	mean survival	S.D. survival
0.10	6.92	2.55
1.00	7.08	2.62
10.0	7.64	1.52
100.0	8.20	0.96

pH	mean survival	S.D. survival
3.0	5.90	3.58
4.0	7.80	1.64
5.0	7.70	1.08
6.0	7.95	1.19
7.0	7.95	1.00

h. *Candona siliquosa*

[Al] / ppm	mean survival	S.D. survival
0.01	7.90	1.21
0.10	8.30	0.66
1.00	7.05	1.64
10.0	7.25	2.61
100.0	6.90	2.69

[Ca] / ppm	mean survival	S.D. survival
0.10	7.32	3.05
1.00	7.36	2.56
10.0	7.68	1.86
100.0	7.48	1.64

pH	mean survival	S.D. survival
3.0	5.50	3.71
4.0	7.65	1.56
5.0	7.75	1.41
6.0	8.20	1.32
7.0	8.20	1.32

j. <u>*Cypricercus obliquus*</u>

[Al] / ppm	mean survival	S.D. survival
0.01	6.40	3.42
0.10	6.80	3.61
1.00	6.30	3.47
10.0	2.60	1.84
100.0	1.55	1.47

[Ca] / ppm	mean survival	S.D. survival
0.10	5.00	3.72
1.00	4.60	3.66
10.0	4.72	3.57
100.0	4.60	3.69

pH	mean survival	S.D. survival
3.0	0.00	0.00
4.0	5.85	3.10
5.0	5.60	3.03
6.0	6.10	3.21
7.0	6.10	3.01

EXPLANATION OF PLATE 1

SCANNING ELECTRON MICROGRAPHS OF VALVES OF LAKE DISTRICT OSTRACODA. ALL SCALE BARS = 100 μm.

Figure 1. Candona candida (Müller, 1785).
Female, left valve. Tarn Hows Tarn, 2-2-89.

Figure 2. Candona reducta (Alm, 1914).
Female, right valve. Brown Cove Tarn, 2-2-90.

Figure 3. Candona fabaeformis (Fischer, 1854).
Female, left valve. Rather Heath Tarn, 30-1-90.

Figure 4. Candona fabaeformis (Fischer, 1854).
Male, right valve. Rather Heath Tarn, 30-1-90.

Figure 5. Candona vavrai (Kaufman, 1900).
Female, left valve. Wast Water, 1-2-90.

Figure 6. Candonopsis kingsleii (Brady & Robertson, 1870).
Female, left valve. Rather Heath Tarn, 30-1-90.

Figure 7. Candona rostrata (Brady & Norman, 1889).
Female, left valve. Grizedale Tarn, 22-8-89.

Figure 8. Candona compressa (Koch, 1838).
Female, left valve. Rather Heath Tarn. 30-1-90.

Figure 9. Candona siliquosa (Brady, 1910).
Female, right valve. Tarn Hows Tarn, 2-2-89.

Figure 10. Candona neglecta (Sars, 1887).
Female, left valve. Windermere (North Basin), 1-2-89.

Figure 11. Candona albicans (Brady, 1864).
Female, left valve. Brown's Tarn. 31-1-90.

Figure 12. Candona pratensis (Hartwig, 1901).
Female, left valve. Parsonby Tarn, 31-1-90.

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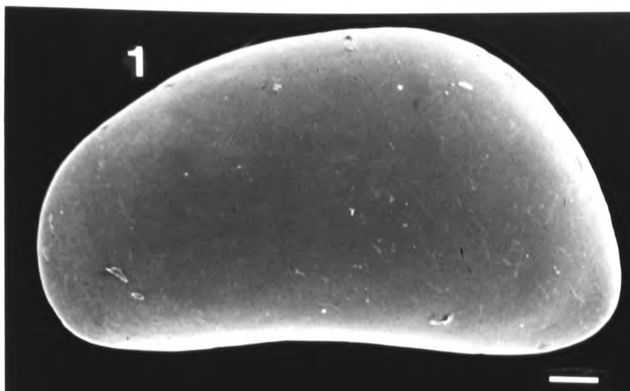

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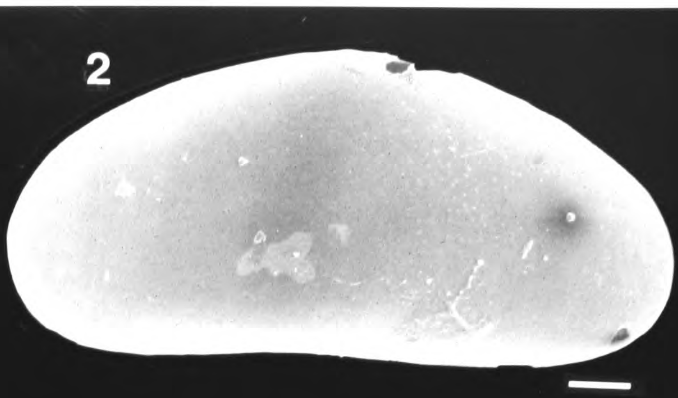

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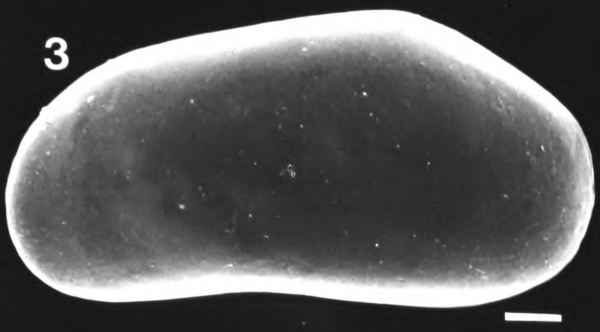

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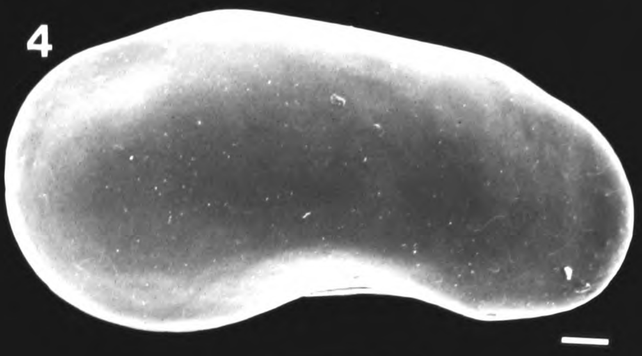

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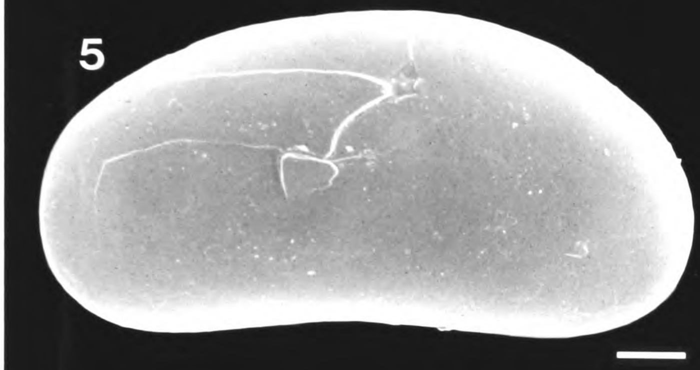

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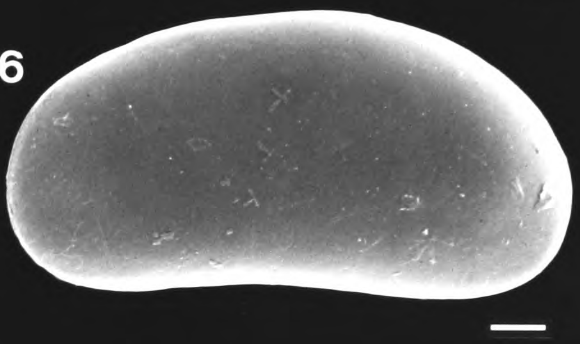

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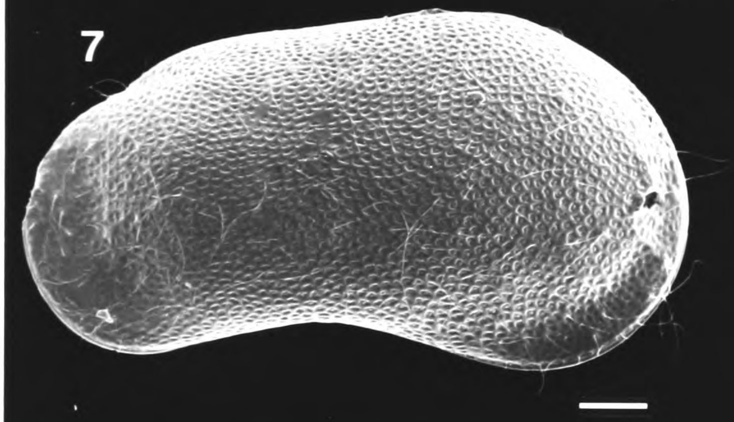

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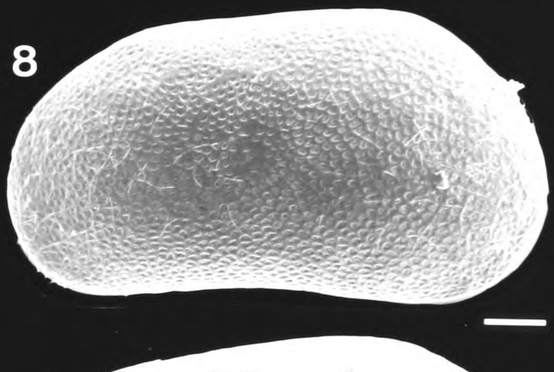

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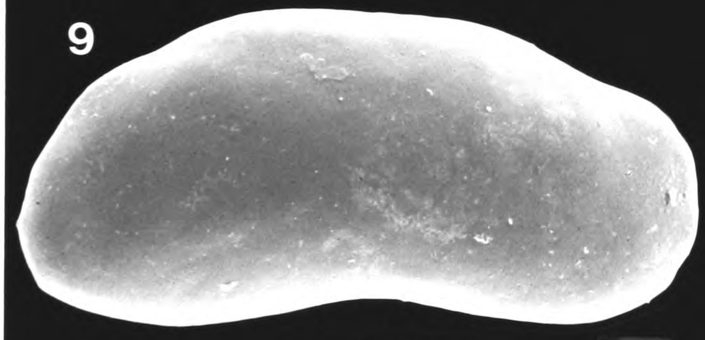

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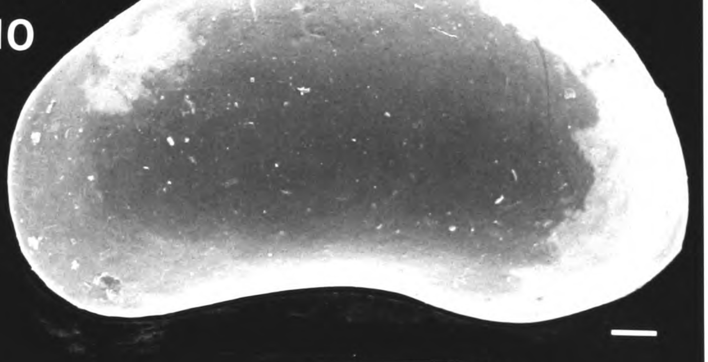

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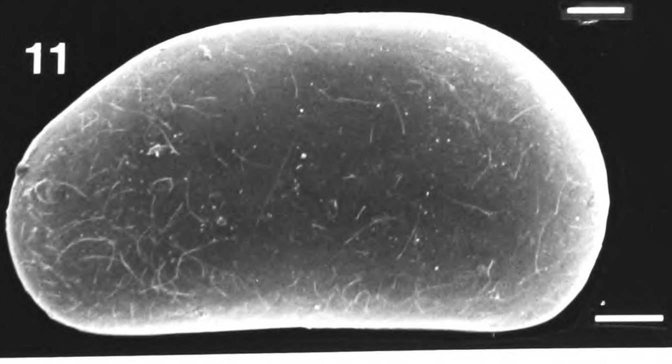

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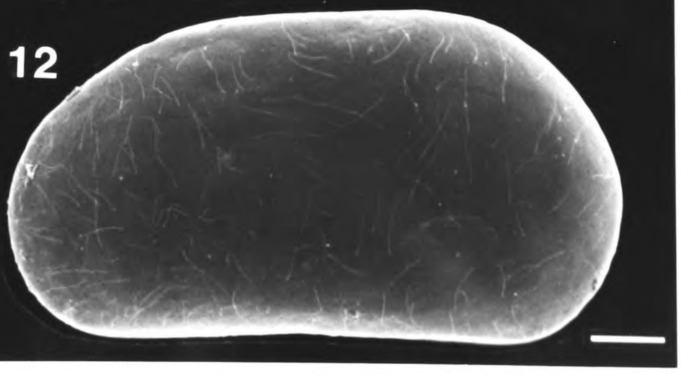

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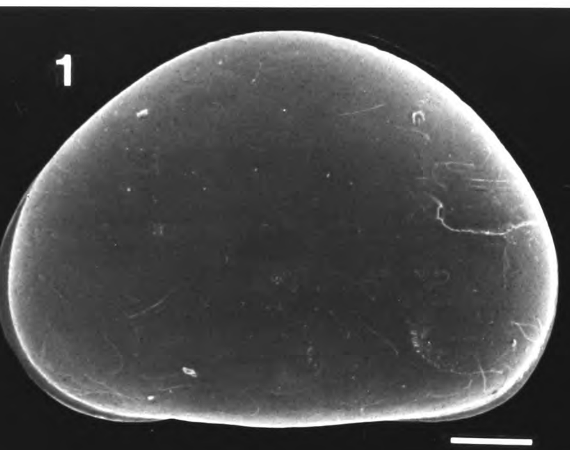

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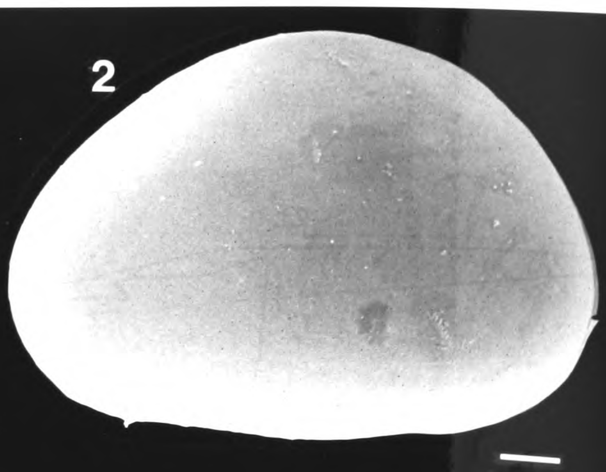

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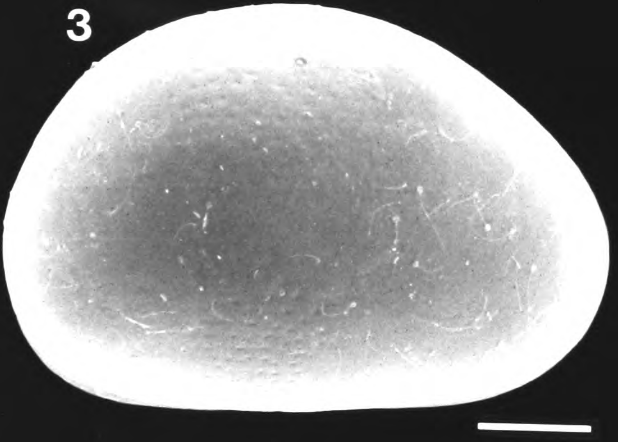

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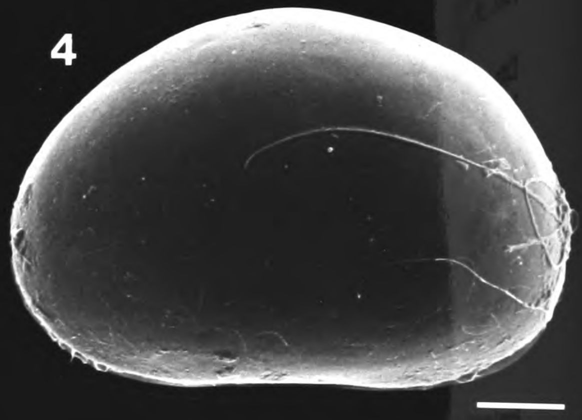

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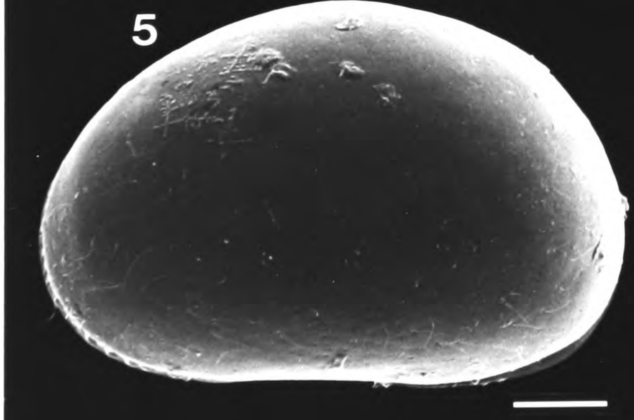

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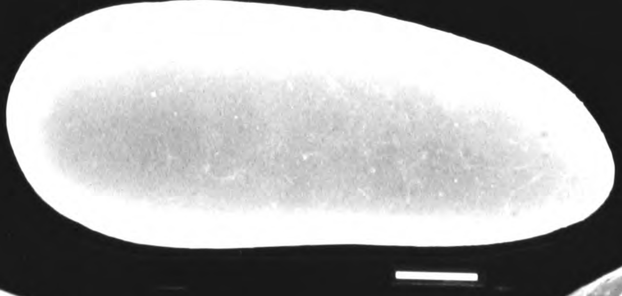

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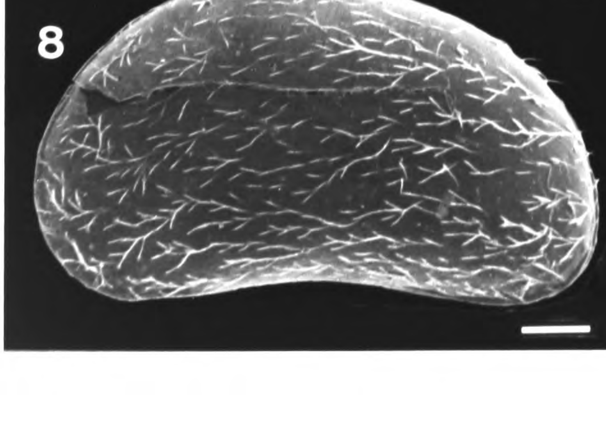

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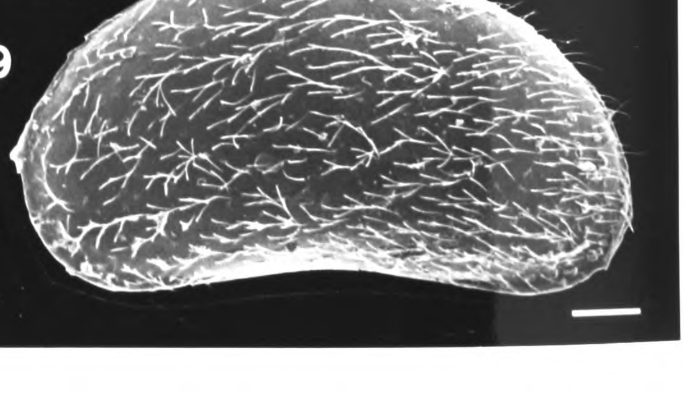

EXPLANATION OF PLATE 2

SCANNING ELECTRON MICROGRAPHS OF VALVES OF LAKE DISTRICT OSTRACODA. ALL SCALE BARS = 100 μm.

Figure 1. Cypria ophthalmica (Jurine, 1820).
Female, left valve. Holehird Tarn, 20-8-89.

Figure 2. Cypria exsculpta (Fischer, 1855).
Female, left valve. Barrow Plantation Tarn A, 20-8-89.

Figure 3. Cyclocypris ovum (Jurine, 1820).
Female, right valve. Knittleton Tarn A, 4-2-89.

Figure 4. Cyclocypris serena (Koch, 1837).
Female, left valve. Windermere (North Basin), 1-2-89.

Figure 5. Cyclocypris laevis (Müller, 1776).
Female, left valve. Haweswater, 25-8-89.

Figure 6. Cyclocypris globosa (Sars, 1863).
Female, left valve. Loughrigg Tarn, 31-1-90.

Figure 7. Darwinula stevensoni (Brady & Robertson, 1870).
Female, right valve. Esthwaite Water, 30-8-89.

Figure 8. Potamocypris villosa (Jurine, 1820).
Female, left valve. Tarn Hows Tarn. 2-2-89.

Figure 9. Potamocypris sp. A (?).
Female, left valve. Boo Tarn, 21-8-90.

EXPLANATION OF PLATE 3

SCANNING ELECTRON MICROGRAPHS OF VALVES OF LAKE DISTRICT OSTRACODA. ALL SCALE BARS = 100 μm.

Figure 1. Metacypris cordata (Brady & Norman, 1870).
Female, left valve. Skelsmergh Tarn, 28-1-90.

Figure 2. Metacypris cordata (Brady & Norman, 1870).
Male, right valve. Skelsmergh Tarn, 28-1-90.

Figure 3. Eucypris virens (Jurine, 1820).
Female, left valve. Parsonby Tarn, 31-1-90.

Figure 4. Paracandona euplectella (Brady & Norman, 1889).
Female, left valve. Loughrigg Tarn, 21-8-89.

Figure 5. Cypricercus obliquus (Brady, 1868).
Female, right valve. Arlecdon Tarn, 24-8-89.

Figure 6. Cypricercus fuscatus (Jurine, 1820).
Female, right valve. Tosh Tarn, 4-2-90.

Figure 7. Herpetocypris reptans (Baird, 1835).
Female, left valve. Skelsmerghh Tarn, 28-1-90.

Figure 8. Herpetocypris chevreuxi (Sars, 1896).
Male, left valve. Barrow Plantation Tarn D, 30-1-90.

Figure 9. Ilyocypris decipiens (Masi, 1906).
Female, right valve. Brown's Tarn, 24-8-89.

Figure 10. Cypridopsis vidua (Müller, 1776).
Female, left valve. Esthwaite Water, 30-8-89.

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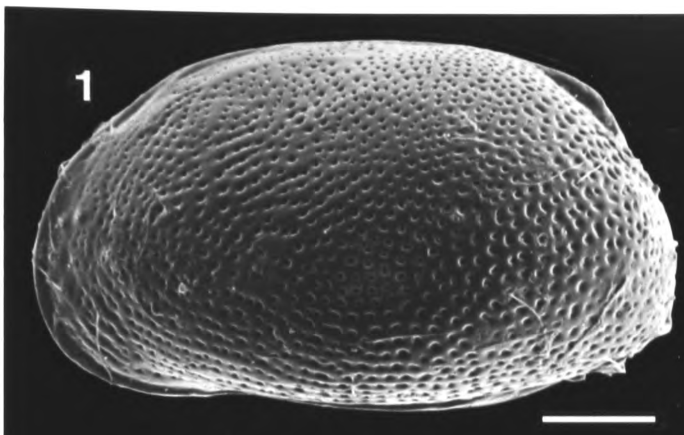

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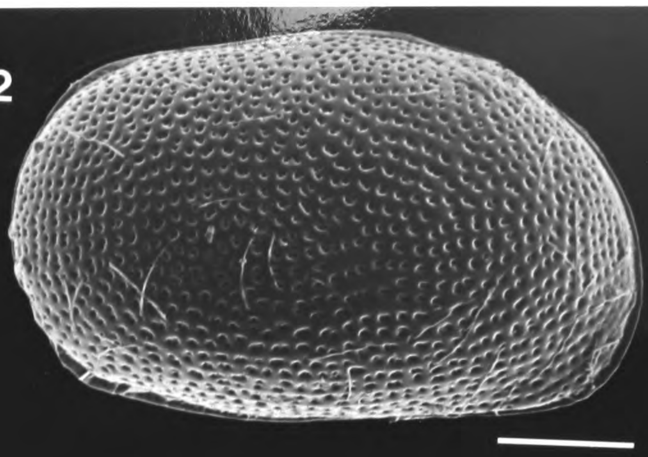

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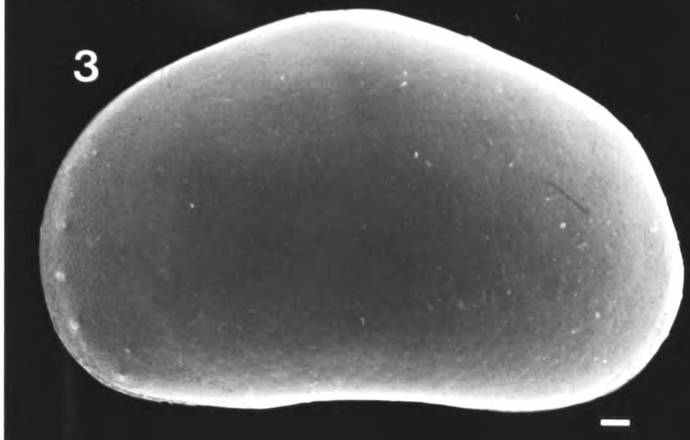

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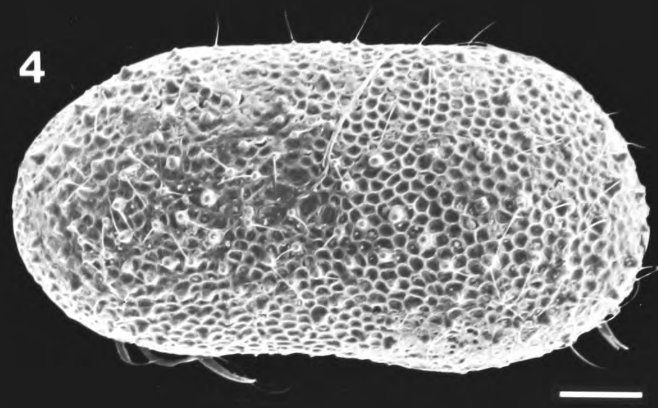

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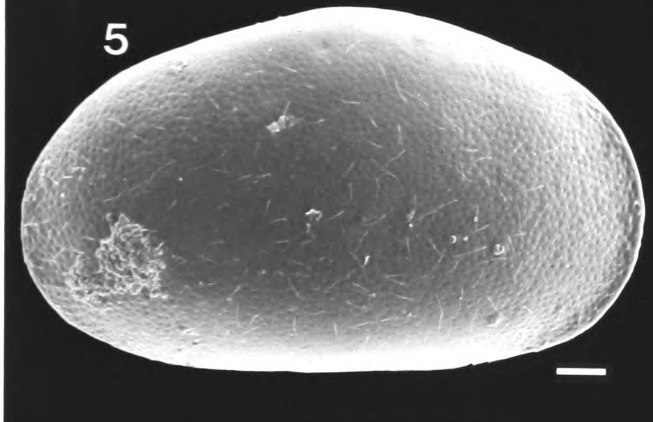

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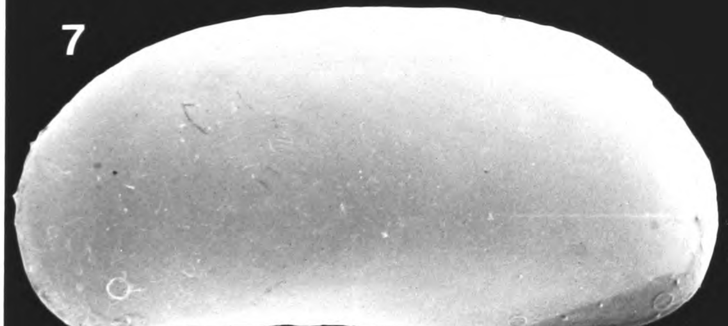

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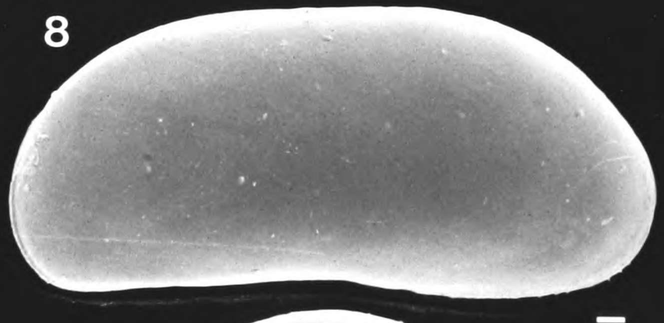

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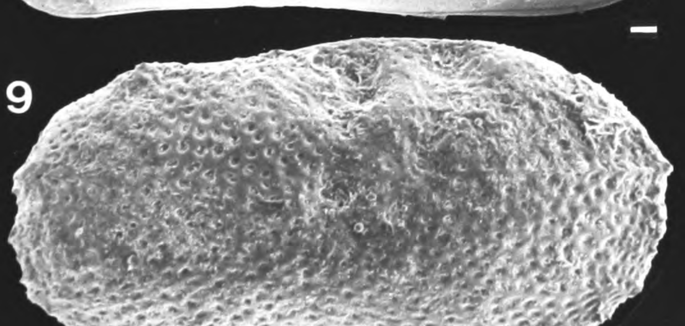

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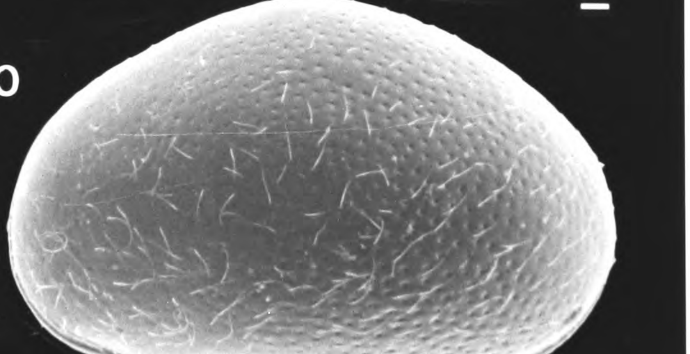

PLATE 4

Brown Cove Tarn (site 42) in summer (top) and winter (bottom).

PLATE 5

i) Innominate Tarn (site 48).

ii) Haystacks Tarn B (site 53).

PLATE 6

i) Hard Tarn (site 50).

ii) Blelham Tarn (site 6).

A representative collection of ostracod species from this thesis has been deposited in the British Museum (Natural History), London. Catalogue numbers are given below.

BM (NH) 1993. 479-488.	*Cypria ophthalmica* (Jurine, 1820). Pennington Reservoir 29:8:89
BM (NH) 1993. 489-498.	*Cypria exsculpta* (Fischer, 1855). Barrow Plantation Tarn A 20:8:89
BM (NH) 1993. 499-508.	*Cyclocypris ovum* (Jurine, 1820). Moss-side Tarn 30:1:90
BM (NH) 1993. 509-518.	*Cyclocypris laevis* (Muller, 1785). Esthwaite Water 30:8:89
BM (NH) 1993. 519-528.	*Cyclocypris serena* (Koch, 1837). Windermere (North Basin) 28:8:89
BM (NH) 1993. 529-538.	*Cyclocypris globosa* (Sars, 1863). Loughrigg Tarn 21:8:89
BM (NH) 1993. 539-548.	*Candona candida* Muller, 1785. Yew Tree Tarn 2:2:89
BM (NH) 1993. 549.	*Candona albicans* (Brady, 1864). Browns Tarn 31:1:90
BM (NH) 1993. 550-551.	*Candona pratensis* Hartwig, 1901. Parsonby Tarn 31:1:90
BM (NH) 1993. 552-553.	*Candona compressa* (Koch, 1838). Rather Heath Tarn 30:1:90
BM (NH) 1993. 554-556.	*Candona neglecta* Sars, 1887. Windermere (North Basin) 1:2:89
BM (NH) 1993. 557-566.	*Candona fabaeformis* Fischer, 1854 Rather Heath Tarn 30:1:90
BM (NH) 1993. 567-570.	*Candona rostrata* Brady & Norman, 1889 Grizedale Tarn 22:8:89
BM (NH) 1993. 571-575.	*Candona siliquosa* Brady, 1910 Mockerkin Tarn 3:2:89
BM (NH) 1993. 576-585.	*Paracandona euplectella* (Brady & Norman, 1889) Barrow Plantation Tarn D 30:1:90
BM (NH) 1993. 586-591.	*Cryptocandona vavrai* Kaufman, 1900 High Dam Reservoir 30:1:89
BM (NH) 1993. 592-601.	*Cryptocandona reducta* Alm, 1914 Brown Cove Tarn 31:8:89 / 2:2:90
BM (NH) 1993. 602-611.	*Candonopsis kingsleii* (Brady & Robertson, 1870) Rather Heath Tarn 30:1:90
BM (NH) 1993. 612-621.	*Ilyocypris decipiens* Masi, 1906 Browns Tarn 24:8:89
BM (NH) 1993. 622-623.	*Eucypris virens* (Jurine, 1820) Parsonby Tarn 31:1:90
BM (NH) 1993. 624-633.	*Cypricercus fuscatus* (Jurine, 1820) Tosh Tarn 4:2:89
BM (NH) 1993. 634-643.	*Cypricercus obliquus* (Brady, 1868) Arlecdon Tarn 24:8:89
BM (NH) 1993. 644-653.	*Herpetocypris reptans* (Baird, 1835) Skelsmergh Tarn 28:1:90
BM (NH) 1993. 654-663.	*Herpetocypris chevreuxi* (Sars, 1896) Barrow Plantation Tarn D 30:1:90
BM (NH) 1993. 664-673.	*Cypridopsis vidua* (Muller, 1776) Esthwaite Water 30:8:89
BM (NH) 1993. 674-683.	*Potamocypris villosa* (Jurine, 1820) Tarn-Hows Tarn 2:2:89
BM (NH) 1993. 684-689.	*Potamocypris sp* Boo Tarn 1:2:90 / 28:8:90
BM (NH) 1993. 690-691.	*Darwinula stevensoni* (Brady & Robertson, 1870) Esthwaite Water 30:8:89
BM (NH) 1993. 692-701.	*Metacypris cordata* (Brady & Robertson, 1870) Loughrigg Tarn 21:8:89