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THE ECOLOGY OF BENTHIC MACRO-INVERTEBRATES IN EARTHEN TROUT PONDS AT HOWIETOUN, CENTRAL SCOTLAND

A thesis presented for the degree of
Doctor of Philosophy to the University of Stirling

by

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5/87

To my wife and children

Declaration

I hereby declare that this thesis has been composed by myself and is the result of my own investigations. It has neither been accepted, nor is being submitted for any other degree. All sources of information have been duly acknowledged.

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Abstract

An investigation into the ecology of benthic macro-invertebrates in earthen ponds subjected to intensive trout (Salmo trutta L.) culture practices at Howietoun, Central Scotland, was conducted between May 1984 and January 1986. Soil and water quality, seasonal changes in benthos, its role in the trout diet and the interaction between fish and benthos were studied.

Pond benthos mainly comprised 6 major groups including Oligochaeta (10 species), Chironomidae (18 species), Mollusca and Hirudinea (2 species each) and an asellid and a sialid species. Oligochaeta formed 78 to 90% of benthic fauna, dominated by Tubifex tubifex, Limnodrilus hoffmeisteri, L. udekemianus and Psammoryctides barbatus, with an average population density of 68,400 - 191,200 worms m^{-2}, and exhibited peaks in summer and late autumn corresponding to two major breeding periods. The principal species of Chironomidae were Chironomus spp., Procladius spp. and Prodiamesa olivacea, with a population density of 5,400 to 14,900 ind. m^{-2} and forming 7 to 13% of the total benthos with peaks in spring and autumn.

Dry biomass of total benthos varied from 24-59 g m^{-2} in the cultured ponds with oligochaetes accounting for 14-49 g m^{-2} and chironomids 4-7 g m^{-2}. The mean annual dry weight production of total benthos varied from 130-215 g m^{-2} in the cultured ponds, with oligochaete production of 94-160 g m^{-2} and chironomid production of 20.6-33.5 g m^{-2}.

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In an unstocked control pond the total production was 55 g m^{-2}, 35 g m^{-2} of which was accounted for by oligochaetes and 8.06 g m^{-2} by chironomids. Analyses of gut contents of the farmed trout showed that 12% of the diet by volume consisted of natural food, mainly benthos. Fish selectively fed on chironomid larvae, Mollusca, Asellus aquaticus and Sialis lutaria. Fish took maximum natural food in the morning and evening.

Experimental enclosures to exclude fish from selected areas of the ponds demonstrated that number of species increased outside the enclosures but, except for chironomids, population density, biomass and production generally increased inside the enclosure. The possibility of explaining this result in terms of differential predation is discussed.

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1.1 Pond Fish Culture Intensification and Benthic Fauna

Aquaculture has received increased attention during the past few years in almost all parts of the world to minimize the pressure on land resources and to meet the critical protein deficit in the human diet. Fish production by aquaculture can make a unique contribution to nutrition due to its high productivity and because the aquatic crops are primarily protein rather than sources of starchy staple foods (Bardach et al., 1972).

The farming of fish has been generally practised in ponds. In fish culture, a pond is a section of fairly shallow water used for controlled farming of fish and laid out in such a way that it may be easily and completely drained (Huet, 1979). In recent years, growing interest in intensive fish culture has been observed in many countries in the temperate region, particularly in the United Kingdom and the United States of America. Fish culture in earth ponds has been widely used as a means of intensive aquaculture. One of the great advantages of pond fish culture is that the fish can make use of natural food from their environment in addition to that supplied as artificial pelleted rations.

In an effort to obtain rapid fish growth and large production in intensive fish farming, large quantities of food and nutrients are commonly introduced into commercial fish ponds. Uneaten portions of these food materials, in addition to algal decay, faeces, skin debris (scales and slime) as well as soluble metabolic wastes from the fish accumulate in the bottom sediments (Colby et al., 1972; Beveridge et al., 1982; Penczak et al., 1982; Skogheim et al., 1982), where they are decomposed by microbial processes (Ram et al., 1981). The addition of bioelements from the wasted food and organic materials may bring about changes in the water and soil chemistry. These can have several effects within a freshwater 'pond ecosystem', among which are changes in abundance and diversity of different aquatic flora and fauna. A hypothetical 'pond ecosystem' subject to intensive aquaculture practices is shown in Fig. 1.

It is demonstrated that a large portion of the food applied settles to the pond bottom. Metabolites are accumulated on the pond bottom mainly as the faecal materials. Dissolved nutrients are released in the water column from the uneaten food and excretory products of the fish and enhance the growth of a large population of algae, periphyton and photosynthetic bacteria. A part of this is eaten by zooplankton and other herbivores but a large part is sedimented to the pond bottom as the 'food rain'. Moreover, the nutrients accumulated in the bottom sediments favour the growth of epipelic algae in shallow areas. All of these sedimenting and benthic algae are either eaten by benthic animals or are decomposed by bacteria along with detritus to release nutrients in the overlying water. The detritus with increased numbers of bacteria provide the source of energy for the detritivores. The benthic animals maintain a complex relationship among themselves and a part of them are ultimately eaten by the fish and some of the insect larvae develop and escape

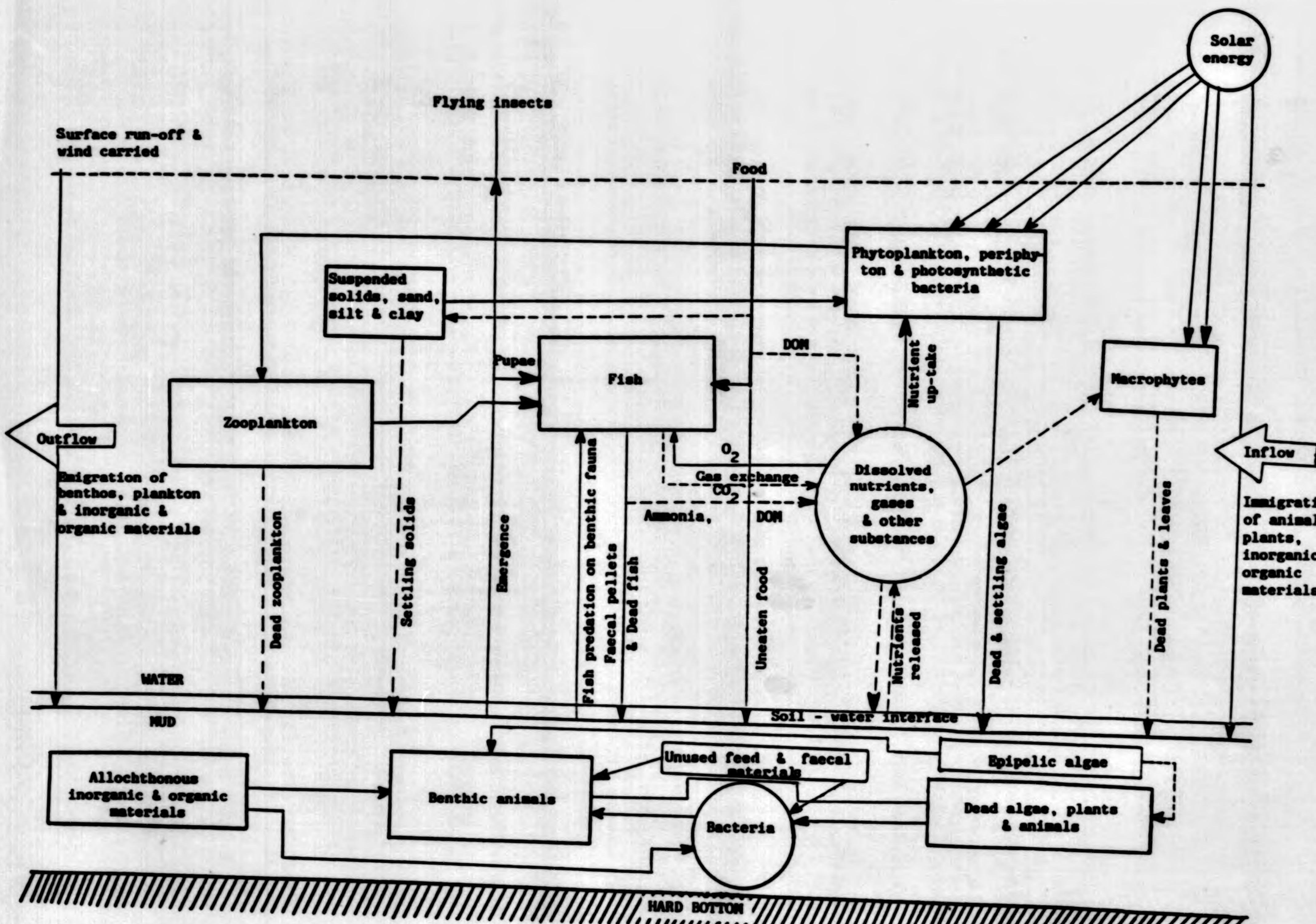

Fig. 1 Schematic earthen Pond Ecosystem subject to intensive aquaculture (bold lines indicate more important transfer of materials; broken lines indicate secondary routes)

as flying adults to provide a new generation of aquatic larvae. Thus, the wasted food materials are eventually converted into a source of living protein for the fish.

The benthos, as being defined as, 'that assemblage of animals living in or on the sediments and dependent upon the decomposition cycle for most if not all of its basic food supply' (Brinkhurst, 1974), form a major component of any aquatic ecosystem. The benthic fauna constitute an important food item for many fishes including trout and carps and thus play an important role in aquatic food chains (Petr, 1968). They are of fundamental importance to the economy of aquatic environments as they take part in the nutrient release from the bottom sediments into the overlying waters so as to enrich the waterbodies. In any pond ecosystem subjected to intensive fish culture practices, none but the benthic animals are affected in so very many different ways. Although the knowledge of the nature and extent of these effects is still very inadequate, it is presumed that the unused food and faecal materials are creating an environment that is far from their natural environmental conditions. Besides, through the influence exerted by the dense stock of fish as a component of the biocenosis, the benthos is liable to heavy predation. Whereas the role of bottom fauna as the main food of brown trout in natural lochs, streams and reservoirs is well documented, information on the role of natural food in the diet of farmed brown trout is lacking. Some preliminary work on carps and tilapias showed a considerable role of natural food in the diet of these fish, in spite of the supply of artificial and/or supplementary feeds (Szumiec, 1969; Spataru et al., 1980, 1982). Yashouv (1966) stated that the goal of rational pond management is to fully utilize the existing ecological niches in the pond in addition to supplementary feed to produce fish to its optimum carrying capacity. Therefore, the dietary contribution of natural foods especially bottom fauna in relation to intensive trout culture in earthen ponds has been investigated.

1.2 Benthic Macro-invertebrates and Environmental Parameters

In comparison with the work done on the bottom fauna of other freshwater bodies (streams, rivers, lochs and reservoirs), little has been reported on the benthic fauna of freshwater ponds. Knowledge concerning species composition, abundance and seasonal variation of bottom fauna and the various factors responsible for their growth, survival and dominance in a pond benthic community is scarce and fragmentary. There have been few continuous round the year studies, which are necessary for an understanding of seasonal cycles. In this respect, research done by Srivastava (1956, 1959) in India, Lubyanov (1956) in the Ukranian steppe in U.S.S.R., Vaas-van Oven (1957) in Indonesia, Kajak (1963, 1964) in Poland, Lellák (1964) in Czechoslovakia, Macan (1964, 1965, 1966) in the moorland fish ponds in U.K. and Dineen (1953) in Minnesota, U.S.A., could be regarded as the pioneering attempts to study benthic organisms in freshwater fish ponds.

In most studies dealing with macrobenthos, the universal dominance of some benthic groups has been recorded. In all lentic water bodies, Chironomidae and Oligochaeta are quantitatively important and in some circumstances Mollusca and Crustacea make a major contribution to production. A general characteristic of the faunal components of the three climatic groups of lakes has been suggested by Morgan _et al_ (1980). According to them, the arctic-alpine lakes are characterized by a paucity of Mollusca and presence of Amphipoda, Sialidae and Ephemeroptera (may flies) and Trichoptera (caddis flies) in the region with summer temperatures above 14°C. In stratified eutrophic temperate lakes with a mean depth less than 15 m, chironomids predominate in the profundal zone. In the profundal zone of deeper lakes, Oligochaeta (in most European lakes) or Amphipoda (in the Great Lakes of North America) predominate. In warm temperate lakes in the U.S.S.R., Chironomidae and/or Mollusca predominate. Most tropical lakes are dominated by Chironomidae but in Lakes Chad and Léré, in the 'sahel' zone of Africa and also in Laguna Lake in the Philippines, Mollusca are quantitatively the most important group.

Smith _et al_ (1981) studied the littoral and profundal substrata and zoobenthos of the largest five lochs (Lomond, Awe, Ness, Morar and Shiel) of Scotland. The most important constituents of fauna of all five lochs were Oligochaetae, Ephemeroptera, Plecoptera, Coleoptera, Trichoptera and Diptera. The profundal zone communities were dominated by Oligochaeta (mainly Tubificidae), sphaeriid molluscs and various species of chironomid larvae.

In the temperate pond-type lake Warniak, Poland, Kajak and Dusoge (1973) recorded chironomid larvae as the dominant fauna in the benthic community. Apart from Chironomidae, Trichoptera, Ephemeroptera and Oligochaeta were also of significance. Similar observations were made by Wojcik-Migala (1979), who studied benthos in some experimental ponds at Zabieniec in Poland. In tropical Indian fish ponds, the three universal dominant bottom fauna/groups are chironomids, oligochaetes and molluscs while leeches are the least significant (Mandal & Moitra, 1975a; Raman et al., 1975). Similar faunal groups have been recorded by Ali et al (1978) in Bangladesh fish ponds. Benson et al (1980) recorded may flies and chironomids as two dominant groups out of nine principal taxa of macrobenthos in a pond in north-central Texas.

The reflection of lake morphometry and its complexity on the nature of benthos has been observed by different authors (e.g. Berg, 1938; Rawson, 1952; Slack, 1965; Johnson & Brinkhurst, 1971). Rawson (1952), while studying the bottom fauna of Great Slave Lake in Canada, concluded that lake basin morphometry is important for productivity, because it affects temperature, thermal and chemical stratification and dilution and circulation of nutrients. Welch (1952) pointed out that the number of different benthic species usually diminished, often rapidly, with increasing depth beyond the littoral zone. The shallower sublittoral zone consistently showed the greatest 'standing crop' of benthos in terms of weight as well as number. Michael (1968) studied the limnology of a tropical fish pond in in India. He distinguished between two zones with differences in faunal composition: the littoral zone was dominated by mollusca, whereas oligochaetes were predominant in the profundal zone.

Mean depth, as the best indicator of lake morphometry, has been suggested as an important factor in lake productivity (Ryder _et al_., 1974). Several other reports have emphasized the depth of a water body as an important factor and stated that shallower lakes support high rates of benthos production (Johnson, 1974; Zytkowiez, 1976). Johnson (1974) also suggested that surface area might be important since in larger lakes the profundal zone is less enriched by the littoral zone or from allochthonous sources.

Water level fluctuation may also affect benthic production. Hynes (1961) recorded big reductions in numbers and variety of invertebrates living in the littoral zone due to the reduction in water level. Hunt and Jones (1972a) mentioned that the effects are twofold: firstly, the fauna may be affected directly when organisms are left stranded by the descending level of water and they die off through dessication; secondly, the change in the mean water level and increased fluctuations will not only alter the physical nature of the bottom, but also result in the loss of macro-vegetation. Many species are, therefore, deprived of their habitat and may be replaced either by new species or by increased numbers of those existing species which are favoured by the new conditions. In common carp ponds in Israel, Zur (1979) observed no correlation between the appearance of chironomid larvae and the depth of the water column. Benson et al (1980) found that the fluctuations in water level affected the littoral zone and reduce the benthic production. In the flow-through systems of intensive fish culture ponds, water level is always maintained at a certain level throughout the year, so water level fluctuation is not a factor. Nevertheless, the increased sedimentation resulting in greater nutrient availability (Kilambi et al., 1976), in intensive fish culture may cause an increase in bottom mud layer and a decrease in water column which may have some influence on the benthic production.

Since the pioneering studies of Ekman (1915, 1917) and Borner (1917) various authors published accounts of benthic fauna and their relationship to various types of substratum. The complex chemistry of the sediment-water interface has been the subject of only a few detailed studies (Brinkhurst, 1974). Several studies (Lindegaard, 1971; Mackey, 1976 a & b, 1977) have identified the nature of substratum as an important factor limiting the distribution of chironomid larvae. Rawson (1930) and Ford (1962) reported that chironomid larvae in general are confined to the surface layers of soft sediments, but some species may penetrate more deeply (Berg, 1938). Wene (1940) showed a preference of chironomids for finer sediment than sands. Definite substrate preferences were exhibited by chironomid larvae, Nilodorum brevibucca Freeman in the absence of competition for food (McLachlan, 1969). Larvae of Glyptotendipes paripes were associated with large particles, suitable for case building, but of low nutritional value (McLachlan, 1976). McLachlan and Cantrell (1976) and Hodkinson and Williams (1980) believed that the depth of sediment may be limiting to population density in some instances. In addition, substratum affected the rate of migration and settlement of larvae. Nutall (1972) showed a decrease in species diversity with an increase in sand deposition. Nutall and Bielby (1972) observed an increase in diversities in Tubificidae, Naididae and Chironomidae with increased siltation by clay. Hamill et al (1979), working in a large river, found that the production of benthic snails was highest in intermediate substrate particle sizes. Similar suggestions have been made by Mecom (1972), Martien and Benke (1977), and Neves (1979). Ruggiero and Merchant (1979) observed that the distribution of benthic macro-invertebrates was more closely related to substrate than to water quality in the Patuxent River, Maryland. For lacustrine benthos, the production of benthic fauna seems to rely more heavily on organic matter content than particle composition (Johnson, 1974; Zytkowicz, 1976; Jonasson, 1978). Similarly, Culp et al (1983), after a field experiment in a stream in British Columbia, concluded that the differential colonization of substratum demonstrated for many invertebrate faunal taxa was likely to be related to differences in organic sedimentation.

A comprehensive idea of the bottom soil edaphic factors along with benthos has been claimed to be of great importance (Tadajewski, 1966; Mandal & Moitra, 1975b). Some studies on the bottom soils of ponds have been carried out (Nees, 1946; Banerjea, 1967; Boyd, 1976; Boyd & Cuenco, 1980; Boyd & Musig, 1981; Ram et al., 1982;

Shilo & Raman , 1982), but these have not been related to benthic faunal studies. Therefore, the composition of the substrate along with its nutrients content and their relation with pond benthos has been considered in this study.

Many production ecologists have found that secondary production increases with an increase in temperature (Laville, 1971; McNaught & Fenlon, 1972; Edmondson, 1974; Pederson et al., 1976; Iversson & Jesson, 1977; Finlay, 1978; Neves, 1979; Selin & Hokkari, 1982). Pidgaiko et al (1972) held the view that temperature variation could have either a positive or negative effect on secondary production, depending on the geographical location and morphometry of a waterbody. Sitaramiah (1966), while studying the ecology of a freshwater fish pond in India, observed that the abundance of bottom fauna was directly related to the temperature. A similar observation was also made by Michael (1968). The general positive effect of temperature on benthic production is a result of the reproductive biology of benthos. A number of authors suggested that growth rates increase with increased temperature (Johnson, 1974; Jonasson, 1978; Sutcliffe et al., 1981). The other effects are the decrease in egg development time, the rise in the rate of population increase and the increase in feeding rates (Armitage et al., 1973; Zimmerman & Wissing, 1978; Makarewiez & Likens, 1979). Pinder (1986) suggested that temperature is one of the major factors controlling rates of growth and development in aquatic insects, and the adult body size of a number of insects depends largely on temperature experienced during larval development

(Sweeney & Vannote, 1978). The emergence of Chironomus anthracinus in Lake Esrom was found to be temperature dependent (Jonasson, 1965). Eggs of Chironomus plumosus hatched in 1.5 to 2 days at temperatures between 22°C and 25°C (Tubb & Dorris, 1965); Hilsenhoff (1966), in another study, found it took 3, 6.5 and 14 days to hatch at temperatures of 24°C, 16°C and 9°C, respectively, and that eggs of this species failed to hatch below 8°C.

Aston (1973a) observed a decrease in egg production in Oligochaeta with increase in water temperature. Poddubnaya (1980), while studying the life cycles of mass species of tubificids under controlled conditions in the U.S.S.R., found that the temperature influences the time of egg laying, number of cocoons produced and hatching time of oligochaetes.

Seasonal variation in the abundance and diversity of bottom fauna has been observed by many authors (e.g. Sitaramiah, 1966; Kajak & Dusoge, 1975; Mandal & Moitra, 1975a; Ali et al., 1978; Särkka, 1979). Morgan et al (1980) described a general seasonal pattern in the benthic abundance in respect of biomass in different lakes of the world. In arctic-alpine lakes the maximum biomass occurred between November and January inclusive. In stratified temperate lakes the maxima occur mostly in spring (April-May) and autumn (October). In shallow unstratified lakes, additional maxima occur in summer, mainly in July. In tropical Lake Chad, there is clear regular maximum of Oligochaeta and Chironomidae in February, corresponding with the cold season, whereas in Lake George, Uganda, which is in the equatorial region, no seasonal variation in the benthic biomass was observed.

Kajak and Dusoge (1973) in pond type lake Warniak, Poland and Wojcik-Migala (1965) in Polish fish ponds observed similar population dynamics as mentioned by Morgan et al (1980) for the temperate lakes. The volume of benthic fauna in tropical fish ponds in India (Michael, 1968, Mandal & Moitra 1975a) was found to be highest in winter-spring (November-April) and lowest in summer to autumn (April-October).

Since the benthos live in areas that are oxygen poor, the availability of oxygen is thought to be critical. Jónasson (1978) suggests that sufficient oxygen is important to benthos production because food cannot be metabolized efficiently at low oxygen levels. Similar observations have been made by Dermott et al (1977) and Rosenberg (1977). Martien and Benke (1977) reported that pond benthos seem to require 1 mg l^{-1} of dissolved oxygen in order to maintain positive production. Many species of chironomid larvae are tolerant of poorly oxygenated conditions (Pinder, 1986) and such tolerance is related to the possession of haemoglobin. Jonasson and Kristiansen (1967) and Konstantinov (1971) observed that the various species increased the length of time spent pumping water through their tubes when oxygen levels decline. Growth of Chironomus anthracinus in Lake Esrom is known to be inhibited when oxygen levels fall to less than 4% saturation in summer (Jónasson & Kristiansen, 1967). Moore (1979) found that the chironomid densities in part of the Great Slave Lake were found to be negatively correlated with oxygen concentration, but this was probably indicative of a positive correlation with the organic content of sediments. Aston (1973a) suggests that egg production in freshwater oligochaetes is constant with decreasing oxygen concentration until some critical low level is reached. Poddubnaya and Arkhipova (1977) found that a simultaneous drop in water temperature to 0.3-1.0°C and in dissolved oxygen content to 0.5-2.0 mg l^{-1} stops the process of reproduction in oligochaetes (Tubificidae).

Several other studies have demonstrated that biota differ greatly with changes in physico-chemical conditions in aquatic systems (Curry, 1965; Olive & Dambach, 1973). Hilsenhoff and Narf (1968) attempted to correlate the species of Chironomidae and other benthos with an assortment of chemical and physical data collected from fourteen Wisconsin Lakes in the U.S.A. They found no real statistical correlations beyond those attributable to chance alone.

Egglishaw and Morgan (1965) showed that the benthic fauna of Scottish streams is severely limited in areas with a total cation concentration less than 400 m equiv. l^{-1}. In another study, Egglishaw (1968) observed a significant positive relationship between total invertebrate biomass and calcium concentration. Armitage et al (1974) found similar results in Teesdale in England. The significance of pH for molluscs and crustaceans has been discussed by several workers found that the chironomid densities in part of the Great Slave Lake were found to be negatively correlated with oxygen concentration, but this was probably indicative of a positive correlation with the organic content of sediments. Aston (1973a) suggests that egg production in freshwater oligochaetes is constant with decreasing oxygen concentration until some critical low level is reached. Poddubnaya and Arkhipova (1977) found that a simultaneous drop in water temperature to 0.3-1.0°C and in dissolved oxygen content to 0.5-2.0 mg l^{-1} stops the process of reproduction in oligochaetes (Tubificidae).

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(Macan, 1950; Maitland, 1966; Williams, 1970; Sutcliffe & Carrick, 1973). A very close relationship between the pH regime of stream water and the benthic fauna was observed in the mountain streams of the Lake District (Sutcliffe & Carrick, 1973). They mentioned that calcium concentration is less important than pH - carbonate concentrations in limiting the qualitative distribution of benthic invertebrates. Brooker and Morris (1980) found that Sphaerium, Gammarus and Asellus were restricted to sites with mean calcium concentrations greater than 8 mg l^{-1}. Pinder (1986) noted that many aquatic animals experience difficulties with calcium regulation at pH less than 5.5, whereas below pH 5.0 problems also arise in relation to sodium regulation (Havas, 1981). Many species of Chironomidae are tolerant of a wide range of pH, from 6.0 to 9.0 (Roback, 1974), but outside this range decreasing pH results in the occurrence of fewer species (Driver, 1977; Raddum & Saether, 1981; Simpson, 1983). Mathias (1983) investigated the faunistic structure of five small brooks in Germany with different degrees of acidification. The number of species decreased and the composition of the benthic community changed for the benefit of few species with high physico-chemical tolerance, in the acid waters. He concluded that high hydrogen-ion concentration operates directly to restrict benthic invertebrates. In most of the above works, the relationship between one or two factors of water quality and the abundance of benthic fauna has been considered. A thorough investigation of the relationship between most of the important chemical qualities of water and benthic fauna is, therefore, considered necessary to predict the ecological relationship of benthos with their chemical environment. Although the responses of the benthic fauna of lakes to eutrophication are well known and sometimes form the basis of lake classification, the effects of organic pollution due to fish farming in ponds on the benthic community have been least investigated. Jumppanen (1976) reported that the number of benthic species was much lower in the polluted biotope, but a few more tolerant species remaining were usually abundant, because of weaker competition and lack of predators. Aston (1973b), while reviewing the tubificids and water quality, mentioned that an increase in number of worms and a reduction in the number of species of Oligochaeta has been recorded in waters receiving organic pollution. Saether (1979) mentioned that the change from a chironomid dominated to an oligochaete dominated community often is one of the first signs of eutrophication. He also classified the species of Chironomidae on the basis of their tolerance and thus classified the trophic status of lakes. The influence of pollution on the population density and production of Chironomidae in running waters was discussed by Losos (1984). He observed pollution to operate selectively on chironomid larvae, causing more or less essential changes of species composition and gradually the elimination of clean water forms. A high increase in abundance, biomass and production were reflected in the chironomid communities colonizing the mud of organically polluted streams.

Many authors have suggested that the rates of production in freshwater benthos are positively correlated with food availability (Ladle et al., 1972; Martien & Benke, 1977; Jónasson, 1978; Benke & Wallace, 1980). Epibenthic and sedimenting planktonic algae, detritus and bacteria form the main food items of benthic animals (Morgan et al., 1980). Brinkhurst (1974) suggests that fine balances between the precise biochemical nature of food, its rates of settlement, the nature and vigor of the microflora and the differing abilities of the competing species to utilize these, are more likely to determine the quality and relative quantity of the benthos. Slack (1965) suggested that the availability of food might explain the anomolous appearance of Sergentia coracina in the oligotrophic north end of Loch Lomond and the presence of Tanytarsus signatus in the eutrophic south.

The rate of benthos production has been found to be positively related to rates of primary production (Johnson, 1974; Dermott et al., 1977). For the zoobenthos, sedimented diatoms are a nutrient-rich food and easily digestible, that is, "the cream on the detritus cake" (Jónasson, 1964, 1965, 1972; Kajak & Warda, 1968; Morton, 1969; cited by Jónasson, 1978). Decaying organic matter is generally considered to be of low nutritive value compared with living cells. Its importance within the food chain is probably higher as a substratum for bacterial growth, rather than as food in itself (Morgan et al., 1980). The role of bacteria is still not well known but they presumably form the main food supply for many benthic species. According to the review by Kuznetsov (1970), bacteria form about

5% of the organic matter in the bottom mud.

A distinct preference for algae as opposed to detritus has been shown by several chironomids, where their proportion in the gut has been found to be higher than in the surface layer of the mud (Kajak, 1968). Predatory Chironomidae (mainly Tanypodinae) prefer small chironomid larvae as food but Copepoda, Cladocera, Protozoa, Tubificidae and large algae are found regularly in their guts (Roback, 1969; Kajak & Dusoge, 1970; Konstantinov, 1971).

Tubificidae select small particles as food (Poddubnaya, 1962) and show a clear food preference for certain types of organic materials (Chu & Brinkhurst, 1973). Changes in the biomass and production, other than of Mollusca, correlated well with the course of tripton sedimentation in Lake Mikolajskie, Poland (Kajak et al., 1972). Moore (1980) observed that the increased availability of algae in the Great Slave Lake, Canada, had no direct effect on chironomid communities, whereas the density of oligochaetes was strongly correlated with algal abundance.

In intensive fish ponds, enrichment due to the high concentration of nutrients from uneaten food and metabolic wastes of fish may result in a dense algal production. Simultaneously, a large volume of sedimenting materials settle onto a dense bacterial population. Both of these food sources may accelerate the abundance and production of benthic macro-invertebrates. The importance of organic loading arising from intensive culture of trout on the development of benthos has been investigated in a series of earthen trout ponds which receive increasing enrichment.

1.3 Benthos in the Diet of Farmed Trout

The food and feeding of brown trout (Salmo trutta L.) has been the subject of numerous studies in natural waterbodies (e.g. Frost, 1950; Allen, 1951; Nilsson, 1955; Ball, 1961; Thomas, 1962; Maitland, 1965; Elliott, 1967; Hunt & Jones, 1972b; Pedley & Jones, 1978). Almost all of them agreed that the extent to which trout feed on any food organism depends mainly on its accessibility and representation in the fauna which alone account for the composition of the diet, without involving any discrimination by the fish. The availability of food organisms to fish is affected by their activity and exposure (Pedley & Jones, 1978). A number of authors, notably Allen (1951), Ball (1961), Thomas (1964) and Hunt and Jones (1972b) have classified organisms according to their accessibility; partly explaining why certain species are seldom eaten while others occur frequently in the diet. Pedley and Jones (1978) made a similar classification for the fauna of Llyn Dwythweh, North Wales, as follows: 1) species generally sheltered but accessible to fish prior to or during emergence, e.g. certain Chironomidae, Plecoptera, Sialis lutaria and Caenis moesta, 2) species prermanently sheltered and never readily available to fish, e.g. Oligochaeta, Hirudinea (except Erpobdella octoculata) and some Trichoptera, 3) species which are mobile and exposed on the bottom or plants, e.g. certain

Trichoptera and Chironomidae, Ephemeroptera, Lymnaea peregra, Pisidium sp. and E. octoculata; these species are freely available, any seasonal variation of occurrence in the diet being chiefly related to size. 4) Free swimming weed and mid-water animals, e.g. Gammarus aculeatus, Gammarus pulex, E. lamellatus, and 5) terrestrial organisms, highly accessible to surface feeding fish.

The principle of opportunism has been qualified by some workers (Allen, 1938; Frost, 1939; 1945) who thought that although the composition of the diet broadly reflects the faunal make-up, some selection is exercised by the trout. Ball (1957) found trichopteran larvae to be of major importance in the diet of brown trout, as did Frost and Smyly (1952) and Kennedy and Fitzmaurice (1971). In Llyn Tegid in the U.K. Ball (1961) observed that over the whole year, the most important single species consumed by brown trout was Gammarus pulex, which made up 24 percent by volume of the total food. Hunt and Jones (1972b) observed that the fauna in Llyn Alaw, Anglesey, North Wales, was rich and varied and as trout food it was plentiful, but trout selectively predated only on six invertebrate species (Erpobdella octoculata, Lymnaea peregra, Gammarus pulex, Asellus meridianus Corixidae and chironomidae) and sticklebacks. He suggested that not only the numerical abundance but the size and/or mobility of the food fauna are important for selective predation. Keenleyside (1962), Maitland (1965), Sinha and Jones (1967) and Mann and Orr (1969) stated that aerial food is more common in the diet of trout than of salmon. Pedley and Jones (1978) reported that the major

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Earthworms of terrestrial origin have been found in the diet of brown trout (Campbell, 1963; Crisp _et al_., 1978). Similarly, Aarefjord _et al_ (1973) found that the limnic oligochaetes _Eiseniella teraedra_ (Sav.), _Peloscolex ferox_ (Eisen.), _Stylodrilus heringianus_ (Clap.), _Tubifex tubifex_ (Mull.), _Stylaria lacustris_ (L.) and at least two enchytraeids were found in the trout of Norwegian lakes. In another Norwegian mountain lake, Johnsen (1978) found that the bottom fauna, especially Trichoptera, was important as trout food. Chironomid larvae and pupae occurred frequently in trout stomachs and contributed 20% by weight to the total diet in a eutrophic reservoir in Liecestershire (Brown _et al_., 1980). They suggested that the free living species of chironomids are heavily predated whilst the tube dwelling species are not.

Changes in dietary composition with age and size of brown trout have been observed by Allen (1938). In Lake Windermere, he noticed that as a trout grows it takes bigger food organisms, the larger fish tending to be exclusively piscivorous. A similar observation was made by Frost (1939) in the River Liffey, Ireland, and by Nilsson (1955) in Swedish lakes. Ball (1961) was unable to show any significant change in the diet within the size range 88 to 344 mm, that is, fish aged 0+ to IV+. Hunt and Jones (1972b) thoroughly studied the food of brown trout of different sizes and found differences between different sizes of fish in Llyn Alaw, Anglesey. According to them, Gammarus pulex and Asellus meridianus are important for all sizes of fishes, although its occurrence by number and volume decreases with size of fish; the occurrence of Erpobdella octoculata and Lymnaea increases with fish size between 300 mm to 430 mm; chironomid larvae is important for all sizes of fish but the pupae are preferred only by fish between 300 and 430 mm; corixidae are of little importance to both under and above 430 mm fish; and sticklebacks become increasingly important in the food with the increasing fish size. Thorpe (1974) reported that the adult trout diet includes Asellus, Daphnia, and Chironomidae larvae along with perch fry in Loch Leven, Scotland. Pedley and Jones (1978) reported that the larger trout ate fewer food items and the size and volume of each food item increased with age of fish, in Llyn Dwythch, Wales. Haraldstad and Jonsson (1983) observed that age groups 1-2 fed mainly on littoral zoobenthos and older fish largely fed on chironomids, both larvae and pupae in a Norwegian lake.

Seasonal dietary changes appear to be determined by changes in the availability of the food organisms (Allen, 1938). Brown (1946) showed that the food intake of two-year old brown trout increased gradually with temperature from 4-5°C to about 19°C and fell sharply at higher temperatures. Ball (1961) observed that the mean volume of food in the stomachs varied seasonally, with a maximum in summer about 8 times the winter levels. Since digestion depends on temperature, it proceeds more rapidly at summer temperatures than in winter (Hewitt, 1943), and the summer food intake must be higher than that of winter. Ball, also showed considerable seasonal variation, dividing the year into the main periods: October-April, when trout fed predominantly on bottom living animals, and May-September, when they fed mainly on the surface food. Pyefinch (1960) reported that trout in Loch Tummel, Scotland, fed on chironomids and terrestrial insects during summer and on Asellus and caddis fly during the winter. Tusa (1968) distinguished two different periods as regards to the composition of trout food: the growing season (May-October) when food contains both aquatic and airborne organisms, and the winter season (November-April) when food contains only aquatic organims. Hunt and Jones (1972b) observed that food intake increases to a maximum in July when the average temperature was 19.4°C. Food intake decreased during autumn to a minimum in November and December. Pedley and Jones (1978), Kaeding and Kaya (1978), and Sagar and Eldon (1983) also observed the seasonal variation in quality and quantity of different food items in the trout diet. Adult chironomids were mainly eaten during early summer and swarming ants during late summer (Haraldstad & Jonsson, 1983).

There is no report on the natural feeding of trout under farmed conditions where artificial pelleted food is applied. The natural feeding of trout under such conditions during different seasons of the year has been investigated in earthen pond systems.

Diurnal variation in feeding patterns have not been thoroughly studied.

Some fragmentary works have been carried out so far. Elliott (1967) observed the day and night time food of brown trout in a Dartmoor stream. He observed that the principal day foods were nymphs of Baetis spp. for 0+ trout, terrestrial invertebrates and oligochaetes for 1+ trout, large larvae of Limnephillidae for 2+ trout. At night, the trout were feeding at the early hours of the night during the summer months. It was concluded that the availability of many benthic animals increased at night and that the trout were utilizing this readily available food, either as drift or from the tops of the stones. Chaston (1969) observed that brown trout were most active between dusk and dawn. Analysis of the variation in the weight of stomach contents during 24 hours showed a higher peak in weight at noon in the summer months. In another study, Elliott (1975) observed the daily food consumption of brown trout. He suggested that the daily food consumption is affected by a large number of factors which include the size of the fish, the amount of food eaten in a meal and the rate of gastric evacuation. Neveu (1980), in an artificial stream in France, found that during the light period, Diptera and Ephemeroptera form the bulk of food of brown trout whilst from dusk, Echinogammarus and molluscs become increasingly important. The major feeding was observed to occur in the early hours of the night when the trout feed chiefly on benthic and aerial forms of aquatic invertebrates. A second feeding peak occurred in early morning.

Detailed information of the feeding activities of fish around the clock and the contribution of natural food in the daily diet is necessary for calculation of the quantity of ration and quality of food supplied during different feeding times in a 24 hour period. Observations have been made on diurnal variation in feeding activity and dietary preference of brown trout in earthen ponds.

1.4 Interaction between Fish and Benthos

Fish influence the benthos production in many different and complex ways. In an experiment (Lellák, 1957), the effect of fish on benthos production was determined, not only from the point of view of predation, but by virtue of the activity of the fish in the whole system. It was suggested that fish might adversely affect the zooplankton population and thus allow more phytoplankton to settle on the bottom, in situations where a large fish population confined in a cage allowed the development of a larger benthic population than when the fish were absent. In addition, the faeces of the crowded fish might make organic matter available in a particularly effective form. The fish stock, therefore, affects the benthos in important ways (Lellák, 1966, 1978) - firstly, by preying upon them, and secondly, by affecting the relative abundance of zooplankton which would control the production of phtyoplankton. When fish density is high, predation rate by fish may increase but so may the amount of settled food. The opposite may be expected in a situation where the fish stock is diminished. A similar opinion has been expressed by Hayne and Ball (1956). In an investigation into the effects of fish predation on benthic productivity in two one-acre ponds in southern Michigan, they observed that the average production of bottom fauna fish-food during a growing season amounted to about 17 times the standing crop, when fish were present. In the absence of fish, the apparent production rate of fish food decreased and finally stopped at a higher level of standing crop. In the presence of fish, the standing crop of fish food was depressed and the rate of production increased. The effect of removing fish from a pond and subsequently re-introducing them has been reported by Macan (1966) in a moorland fish pond in the U.K. He observed that the important trout-food organisms were abundant, both before and after the fish were introduced into the pond, and suggested that predation allowed for growth and survival of specimens that would otherwise have perished, perhaps through the operation of territoriality or other modes of intra-specific competition for limited food. Wojcik-Migala (1966) suggested that up to some level of density of fish in ponds, their influence stimulates the quantitative development of the Chironomidae. Wasilewska (1978) showed that the intensification of fish rearing practices had a positive effect on the natural benthic food conditions for the fish. In an intensive carp pond at Zabieniec, Poland, he found that the rate of biomass turnover was in general faster in fish ponds than in the controls, that is to say, the compensation for the benthos eliminated was faster than in the control ponds. In another study, Wasilewska (1978) observed that the introduction of silver carp in carp ponds exerted a favourable influence on the numbers and quality of the bottom fauna and thus provided better feeding conditions for carps in the ponds at Zabieniec, Poland.

It appeared that the presence of silver carp influenced the physico-chemical conditions in the pond and ensured a better environmental (O_2) and feed conditions (diatoms, detritus rich in bacteria) for chironomid larvae. In Polish lakes, Wisniewki (1978) observed tubificids with tails cropped by fish predation. In laboratory investigations, the increase of the body during the regeneration of the parts lost was faster than during normal growth. As a result, predation proved to be a factor stimulating the production of Tubificidae. Besides, there is a greater proportion of invertebrate predators in the benthos biomass when fish grazing is small (Wolny, 1962; Kajak, 1968, 1972) which indicates that fish graze selectively on predatory benthos.

The numbers and biomass of bottom fauna have been reported to decrease due to the direct feeding of fish in the fish ponds (Vass-van Oven, 1957; Assman, 1962; Wojcik-Migala, 1965, 1966). Grygierek and Wolny (1962) reported a distinct decrease in the number of Mollusca in a pond stocked abundantly with fish. Morin (1984), observed an increased abundance of larval Odonata after exclusion of fish in a North Carolina farm pond. Some authors believe that the biomass of benthos might be reduced to about half or a third by fish predation (reviewed by Kajak, 1968; Kajak & Zawisza, 1973). Kajak and Dusoge (1973) have shown that the increasing fish pressure in Lake Warniak in Poland, resulted in a decreasing biomass of bottom fauna so food conditions for benthophagus fish became worse. They also observed that some benthos such as *Asellus aquaticus* and *Sialis lutaria* were preferentially consumed by fish and totally disappeared from the benthos on the examined sites.

The influence of fish on the benthic fauna is very complex. Apart from predation, influence of the fish controls the availability of food to the benthos, depositing their own faecal materials on the territory of benthos and improving and/or disrupting the environmental and living conditions of benthos in the waterbody. Wojcik-Migala (1979), in her studies on the development of benthos communities in carp ponds in Poland, interpreted the reaction of benthic animals to the effect of fish activity through: 1) direct predation resulting in changes in the age structure and biocenotic relationship between the components of benthos, 2) changes in the quantity and quality of food, as well as primary regulation of the inflow of fresh food to the bottom of the pond, 3) the type and degree of water turbidity. Kajak (1977) described the role of fish as a complex phenomenon: decreasing directly the abundance of invertebrate predators and bigger non-predatory forms, the fish thus acting towards increasing biomass and production of benthos. On the other hand, they act in the opposite direction - not only exploiting benthos but also stirring the bottom and thus increasing the availability of benthos for invertebrate predators, by destroying protective accommodations of benthic organisms. Apart from studies by Macan (1966), most of the above studies relating to fish influence are confined to carp ponds. The influence of brown trout (<u>Salmo</u> <u>trutta</u> L.) on their natural food organims in the benthos, particularly under cultured conditions has not yet been reported. This aspect has been investigated experimentally by the use of enclosures.

Although the volume of work done on the benthic fauna is considerable and there is no lack of dietary information on wild brown trout, there is a great scarcity of information on the fish-pond benthos and the role of bottom fauna of fish ponds in the diet of farmed brown trout. Moreover, the consequences of intensive fish culture on the overall ecosystem of the pond and its effects on the pond benthic community has seldom been documented. As a result of the paucity of information in these important areas of pond benthic ecology, a research project, on earthen ponds used for culturing brown trout has been designed with the following objectives:

1) to study the physico-chemical parameters of water and soil quality and their seasonal variation;
2) to study the chemical composition (mainly bioelements) of the sedimenting materials and their inter-relationships with those of pond bottom soil;
3) to study the seasonal variation in the abundance of different benthic macro-invertebrate groups and/or species with observations on their life-history;
4) to study the relationships between environmental parameters and benthic fauna;
5) to assess the biomass and production of benthic fauna in relation to the stocking density and level of enrichment of water in

a series of intensive fish-ponds;

6) to study the dietary contribution of benthic fauna to brown trout given an artificial pelleted diet; and

7) to study the interactions between fish and benthic fauna under culture conditions.

With these aims in mind, the environmental conditions including meteorology, geology and the location of the study site, Howietoun Fish Farm, are presented in Chapter 2. A diagram of the farm layout and a brief description of the history of the fish farm and its management schedule are also included in this chapter. The details of materials including the sampling devices and the different methods adopted in the field and in the laboratory are described separately in Chapter 3. The results of the entire investigation are compiled in a single Chapter 4, although each of the above objectives is recorded separately and the interactive results are shown in the most relevant section. Finally, in Chapter 5, the results are discussed in the light of the present results and existing information.

2 Study Area and Environmental Conditions

2.1 Description of the Study Area

2.1.1 Historical background of Howietoun fish farm

The famous and historic fish farm at Howietoun was established at Sauchieburn, just south of Stirling by Sir James Maitland (Bart.) between 1871 and 1885 to conduct experiments on fish rearing utilizing the excellent water supply of the local burns and springs. The goal which guided Sir James in his great work was to prove by "actual experience that the culture of Salmonidae can be made commercially a success if set about in a business-like manner" (Maitland, 1887). Sir James had been successful in producing 'ova' and 'young fish' for stocking and replenishing of barren or depleted waters at home and abroad. Howietoun has provided most of the trout fisheries of the world with their foundation stock and anglers in New Zealand, Australia, South and Central Africa and Asia as well as British reservoir trout fisheries have appreciated the qualities of stock of Howietoun lineage (Roberts, 1974).

This fish farm was established on 10.12 hectares of land, 4.05 hectares of which are ponds with a holding capacity of 40 tonnes of fish. There are about 40 earth ponds in total, all of varying depths and sizes and are carefully laid out to allow each pond to be serviced by gravity-flow water (Fig. 2). Total drop in elevation from the top ponds to the bottom ponds is 6.39 m and the distance between them is 341 m.

The earth ponds at the fishery part of the farm are a masterpiece

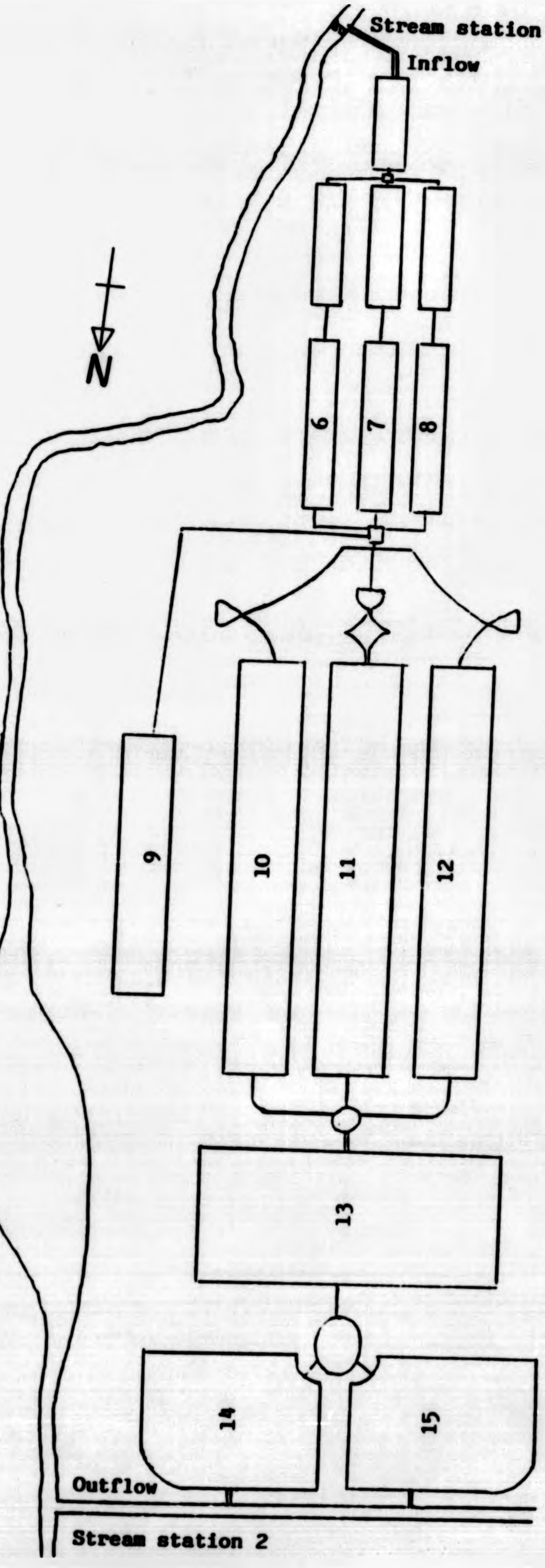

Fig. 2 Plan of Howietoun fish farm ponds and adjacent supply stream (Sauchieburn) (Not to scale)

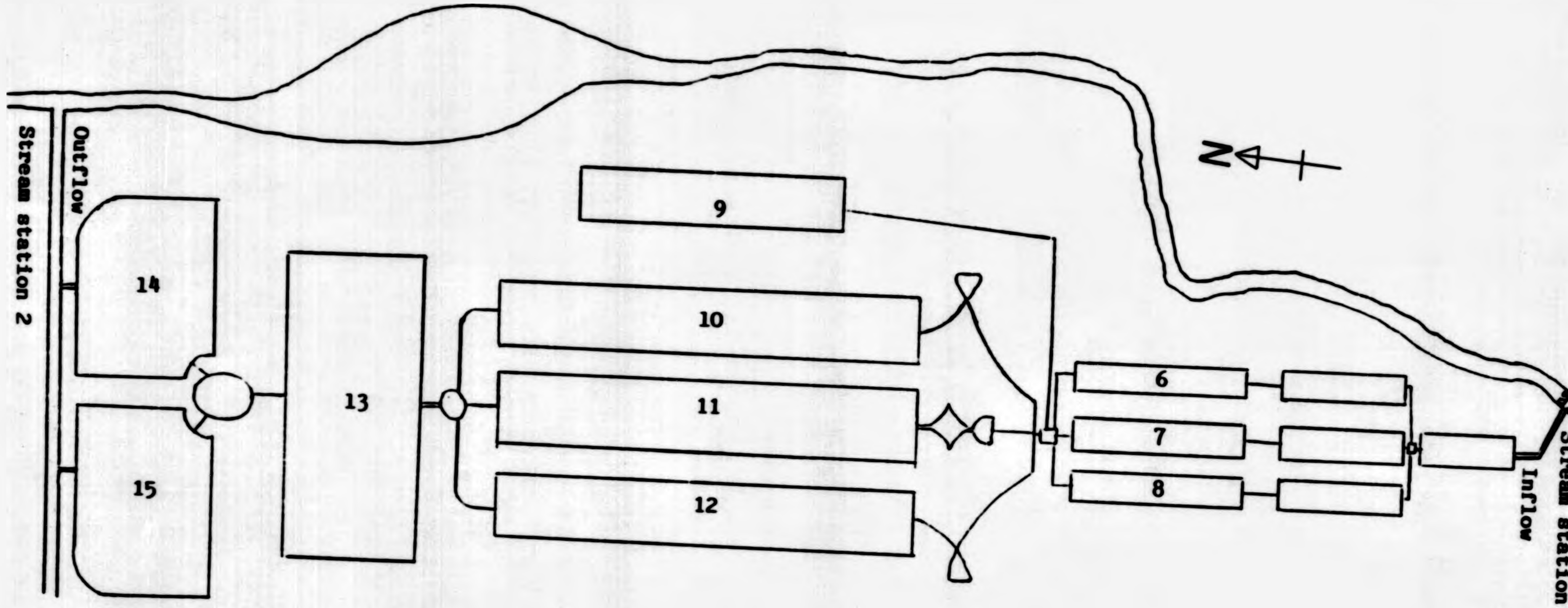

Fig. 2 Plan of Howietoun fish farm ponds and adjacent supply stream (Sauchieburn) (Not to scale)

of planning and design, and it is a credit to the workmanship that all the ponds are still in use today with only minor modification.

The two-storied stone made hatchery is a purpose-built one which has the capacity to take upto 20 million eggs a year. The hatchery sections have facilities for hatching trays and first feeding tanks.

A series of springs, a stream and a guaranteed discharge of 1 million gallons per day from a reservoir are the three sources of water supply. The average daily intake of water is 2 million gallons a day, producing 20 tonnes of fish per year.

After the death of Sir James Maitland, the farm changed hands several times. It was purchased by the University of Stirling in 1979 to supplement its facilities as a centre for aquaculture research and training. This timely takeover by the University and constant untiring effort by the Institute of Aquaculture staff has returned the farm to its production potential and thus has turned Sir James' dream into reality.

2.1.2 Management of the fish farm

Howietoun fish farm has its own management strategy which is based on the knowledge gained from Sir James' period (which he compiled in his book 'The History of Howietoun') and combined with the modern fish culture techniques which the Institute of Aquaculture scientists have standardized through their experience of teaching and research.

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A brief description of the management practices of the ponds which are relevant to this study is given below.

The culture cycle at the farm runs from March to February of the following year. The main species cultured is brown trout Salmo trutta L. During early spring the brown trout, after spending 2 years in the ponds, are netted, graded and transported to various waters for restocking purposes. Fishes are normally caught from the ponds using a seine net but frozen ponds were left undisturbed. Around 200 fish are selected from the current year's production to supplement the existing brood stock, the oldest and largest broodfish being sold for restocking.

The main ongrowing ponds (numbers 10, 11 and 12 (Fig. 2) are drained one after another during April to mid-May, after completion of one culture cycle. The ponds are left empty for 7-15 days. The objective of draining is to remove the excess bottom sediment layers and to repair the inlet and outlet and sides of the ponds if necessary. The drying of the ponds in the spring sunshine eliminates toxic gases such as H_2S, which may have accumulated during the culture period. During this period, the pond sides become almost dry and hard but the bottom remains moist.

The ponds are again filled up and left for 8 to 10 days and then stocked with 8,000 fish of 75 g weight (equivalent to a stocking density of 41,000 per hectare) and fed with pelleted feed at the

Table 1 Morphometric and management parameters of the experimental ponds at Howietoun fish farm

Morphometric & management parameters		Pond 9	Pond 7	Pond 11	Pond 13	Pond 14
Length	(m)	66.25	42.50	103.75	75.0	43.75
Breadth	(m)	12.50	7.50	18.75	31.25	35.0
Average depth	(m)	3.5	1.8	3.0	3.5	3.0
Surface area	(m^2)	828	319	1,945	2,344	1,531
Volume	(m^3)	2,898	430	5,836	8,203	4,594
Residence time	(hr)	-	5.5	73.0	35.9	40.0
Initial stocking density	Actual No.	-	1,000	8,000	500	10,000
	No. ha^{-1}	-	31,350	41,000	2,130	67,000
Fish weight at stocking density	(g)	-	30.0	65.4	>1 Kg	31.7
Annual feed input (May - January)	(Kg)	-	361	2,000	859	2,090

rate of 2.5% body weight per day. The size of the pellet is increased with the increase in size of fish. Feeding is carried out three times a day and feeds are given by hand. If there is heavy rain and the water supply becomes turbid, feed is not usually given. The total quantity of feed given to the different ponds during the study period is shown in Table 1.

The management of pond 14 and 15 is similar to that of ponds 10, 11 and 12. The only difference is that these ponds are stocked with 10,000 smaller sized 50 g fish (at a density of 67,000 per hectare) and fed with pelleted feed at the rate of 2.75% body weight per day. These ponds are also drained during the month of May, after harvesting the previous year's crop.

The management of pond 13 is completely different from all other ponds. This pond is called the 'office pond'. There is a summer house constructed on this pond by the founder of the farm as a retreat. He used to run his administrative work from this house during the summer time. Since the establishment of the farm, this pond is stocked with big fish which are used as brood fish. It is lightly stocked with large fish (>1 kg) and fed with a floating pelleted diet at the rate of 0.8% body weight per day. This pond is surrounded by reeds (Phragmites communis) which harbour many terrestrial insects and flies, some of which may have spent part of their life cycle in mud on the pond bottom.

Pond 13 is usually drained during the autumn (October-November) after the brood fish are transferred to pond 9 prior to stripping the eggs and milt.

The only purpose served by pond 9 is to hold the brood fish during winter months, thus providing a 'bridal chamber' for the Howietoun trout. Apart from its use for the said purpose, for most of the year this pond remains dry. Sometimes pond 9 is used as an isolation and treatment pond for those fish needing minor treatment.

During the period of May to December, 1984, pond 9 was used to simulate a natural waterbody without fish, with no feed and even no water flow which may have brought nutrient enriched water from other ponds. This pond was considered as the control pond during this period. In the following year, the farm could not spare this pond for the experiment.

Though Howietoun is a fairly intensively managed fish farm, eutrophication which results in an algal bloom has never been noticed, except on few occasions. A very thin scum appeared in ponds 11 and 14 during the longest period of sunshine in the summer, but that was also for a very short period. Algal bloom was observed in pond 9 during June-July of 1984. During the months of August to September, a floating aquatic weed (<u>Lemna</u> sp.) lightly covered pond 13 and some were scattered on pond 14. There was no luxuriant growth of any type of aquatic weed except reeds surrounding the edges of pond 13.

In conclusion, Howietoun is an example of a well managed fish farm.

2.2 Environmental condition of the fish farm area

2.2.1 Geology

Howietoun fish farm (56° N; 3°57 W) is situated in Sauchieburn which is very close (about 8.9 km) to the district headquarter of Stirling. Stirling lies in the watergap of the River Forth between Gargunnock and the Touch Hills of carboniferous volcanic lavas on one flank and the Ochill Hills of Devonian volcanic on the other: its site is a text book example of the close dependence of physical landscape on geological stucture (Timms, 1974).

Sauchieburn lies in the carboniferous lava, thus providing Howietoun fish farm with a suitable chemically stable substratum. Being built on carboniferous soil with a water supply mainly from the intrusive igneous rock originating around 'Loch Coulter', the quality of Howietoun water is far better for fish culture than many highland waterbodies. The unique characteristics of Howietoun water are its high and consistent level of total alkalinity and total hardness which are ultimately credited for maintaining buffering conditions in the water and preventing any unusual increase or decrease in pH.

2.2.2 Meterology

Meteorological conditions influence the freshwater ecosystem in a number of ways. Temperature acts as a limiting factor in the distribution of benthic fauna. Solar radiation is the main source of heat which is directly responsible for raising the temperature of the water. Rainfall brings, as surface run-off, the allochthonous materials from the surrounding land masses. It also brings down nitrogen into the water.

As a whole, meteorologically, the Stirling area can be regarded as transitional in a Scottish context, and on average a balance is maintained between the mild west climate characteristic of Western Scotland and the drier, more continental conditions of coastal lowland to the east (Timms, 1974).

Meteorological information during the period of study, which was recorded at the Stirling (sewage works) climatological station, about 8.0 km NNE of Howietoun fish farm and 7.0 metres above mean sea level is presented below.

2.2.2.1 Temperature

Monthly maximum, minimum and the mean air temperatures are shown in Fig. 3. Highest temperatures were in June in 1984 and in July in 1985. The lowest temperatures were recorded in January and November 1985.

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Meteorological conditions influence the freshwater ecosystem in a number of ways. Temperature acts as a limiting factor in the distribution of benthic fauna. Solar radiation is the main source of heat which is directly responsible for raising the temperature of the water. Rainfall brings, as surface run-off, the allochthonous materials from the surrounding land masses. It also brings down nitrogen into the water.

As a whole, meteorologically, the Stirling area can be regarded as transitional in a Scottish context, and on average a balance is maintained between the mild west climate characteristic of Western Scotland and the drier, more continental conditions of coastal lowland to the east (Timms, 1974).

Meteorological information during the period of study, which was recorded at the Stirling (sewage works) climatological station, about 8.0 km NNE of Howietoun fish farm and 7.0 metres above mean sea level is presented below.

2.2.2.1 Temperature

Monthly maximum, minimum and the mean air temperatures are shown in Fig. 3. Highest temperatures were in June in 1984 and in July in 1985. The lowest temperatures were recorded in January and November 1985.

Fig. 3 Air temperature

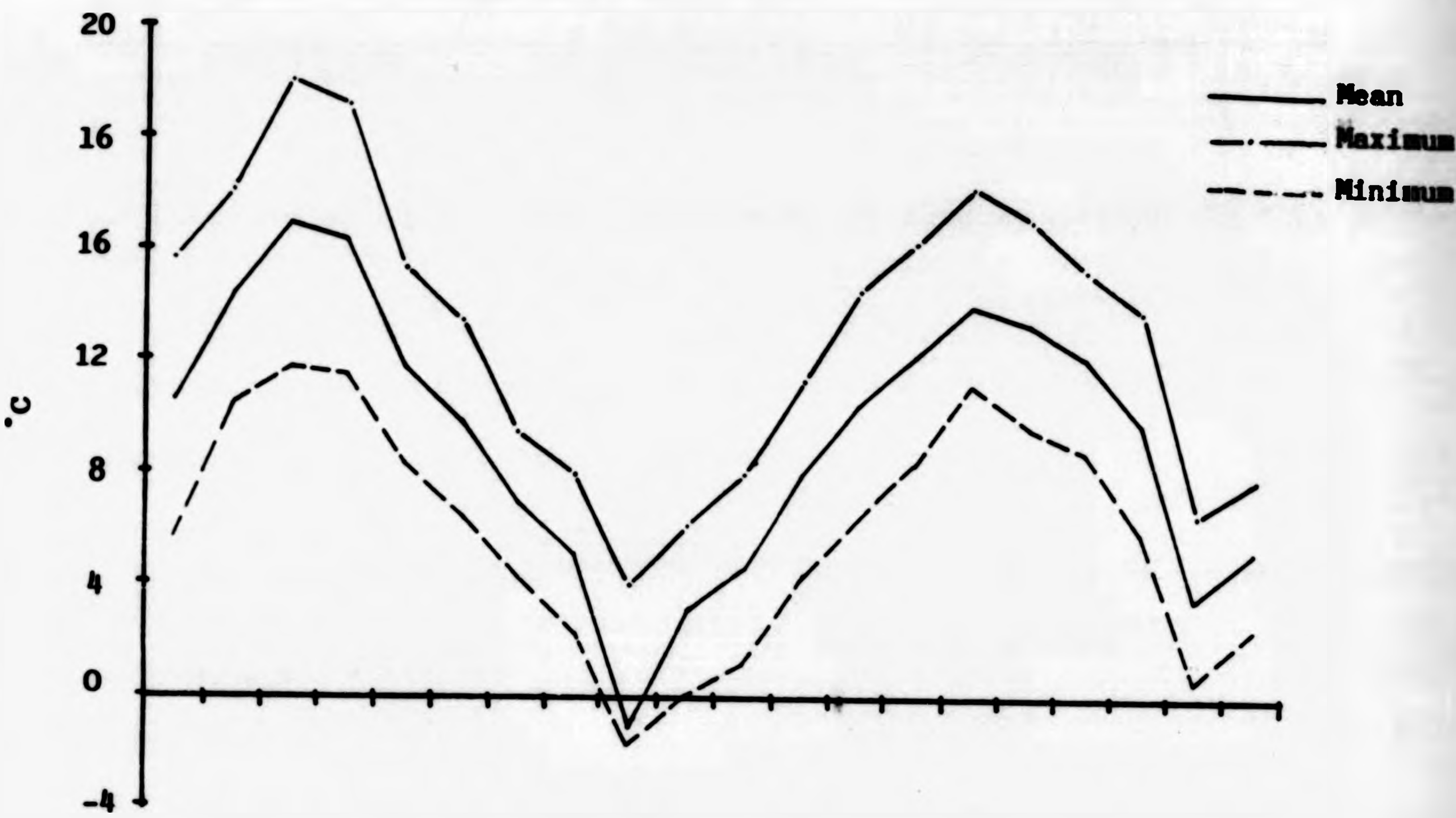
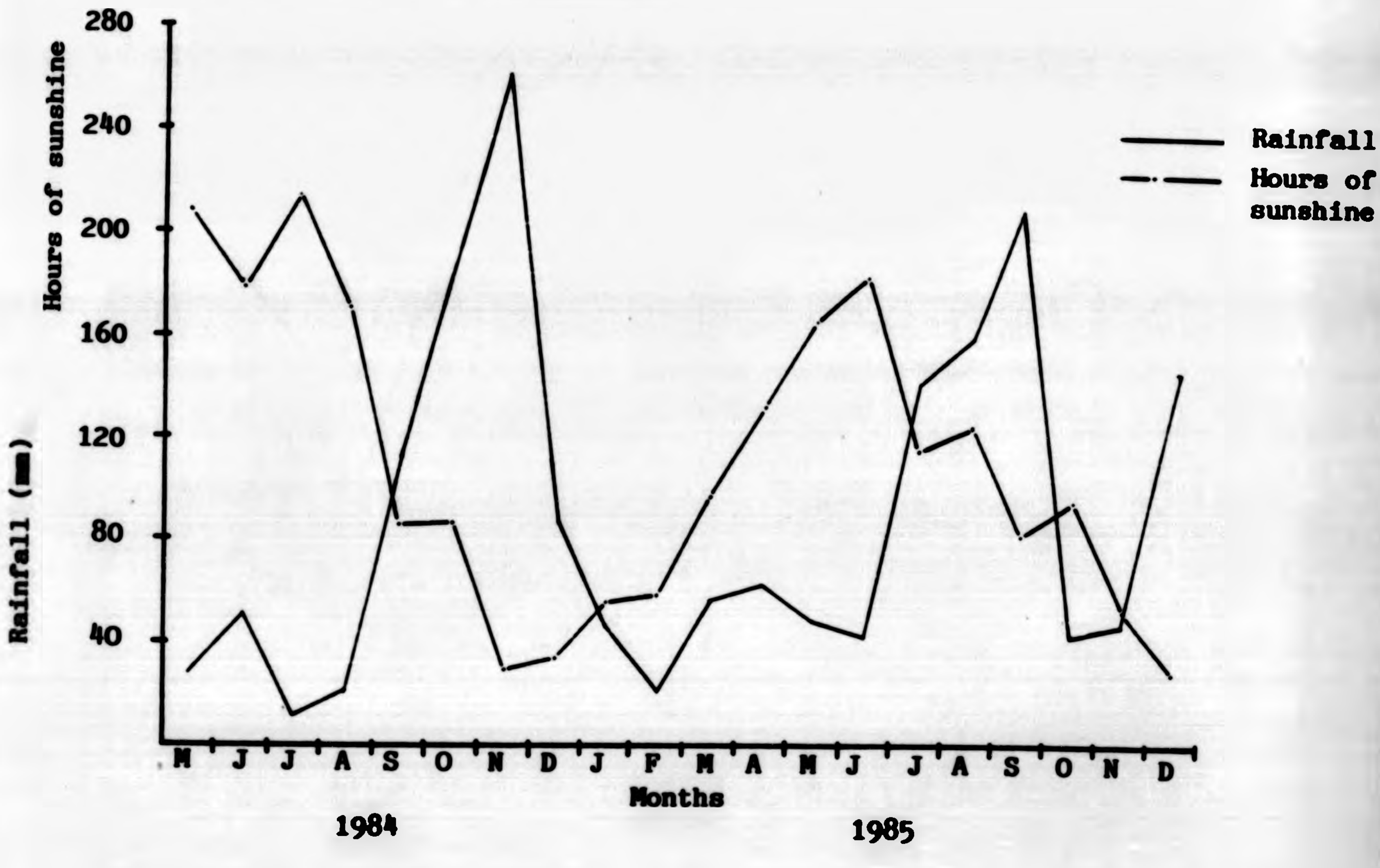


Fig. 4 Rainfall & sunshine



Figs 3-4 Seasonal changes in weather conditions during 1984-85; temperature, rainfall and sunshine

Bearing in mind the relatively northern latitude and inland location, mean annual temperatures are remarkably high over the Stirling area. The thermal advantages of the Stirling region is the result of a combination of factors operating at different seasons. The worst possible winter conditions are made better by both the intrusion of western influences and shelter provided by the Ochills barrier against the incursion of polar and arctic air masses from the north and the east. On the other hand, the enclosed lowlands warm up quickly during summer to produce high maximum temperatures.

2.2.2.2 Rainfall

The total monthly rainfall is shown in Fig. 4. November and September were the wettest months in 1984 and 1985, respectively. In both years spring was the driest season.

2.2.2.3 Hours of sunshine

Fig. 4 shows the total monthly hours of sunshine in the Stirling area. As might be expected, there was a well defined seasonal cycle of incidence with maximum duration in summer months in 1984 and in spring months in 1985. The minimum receipts were recorded in November-December in both years.

Since the Stirling lowlands are a preferred area for fog formation, the development of radiation fcg during winter months restricts the duration of sunshine to some extent.

3 Materials and Methods

3.1 Analyses of water

3.1.1 Choice of parameters for analyses

The objective and the nature of the proposed analyses dictate the sampling programme, sampling procedure and storage method (Stirling, 1985).

Those conservative properties which characterise a waterbody and are usually correlated with productivity, such as total hardness and total alkalinity, were considered for this study. Information on the calcium content of the water was necessary to examine its suitability as a habitat for Mollusca, which was included in this study.

The variable properties such as pH, DO, suspended solids, ammonia, nitrite, nitrate, dissolved organic nitrogen, ortho-phosphate and total phosphorus, which vary according to the extent of intensification of fish farming activities, were analysed during this investigation. All these factors singly or synergystically influence the abundance of benthic animals.

The most important physical factor, temperature, was measured throughout the study period.

3.1.2 Collection and treatment of water samples

Water samples were collected fortnightly throughout the present investigation. On each sampling day, samples of water were collected from the inflow, outflow and ponds 7, 9, 11, 13 and 14 between 10.30

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3.1.2 Collection and treatment of water samples

Water samples were collected fortnightly throughout the present investigation. On each sampling day, samples of water were collected from the inflow, outflow and ponds 7, 9, 11, 13 and 14 between 10.30

- 11.30 am. For studying the diel variation in water quality, samples were collected every 3 hours for 24 hours once in autumn, 1984 and another in summer, 1985.

3.1.3 Sampling methods

Water samples for dissolved oxygen were collected by a Van Dorn sampler (Van Dorn, 1956). For nutrient analyses, depth-integrated water samples were collected using a 2 m length of flexible PVC tubing of 2 cm internal bore, open at both ends (details in Stirling, 1985). Samples from inflow and outflow were collected simply by lowering the bottles into the water.

125 ml glass bottles with ground glass stoppers were used for storing dissolved oxygen samples. Water samples for nutrient analyses were collected in 1 litre plastic bottles with plastic stoppers. All the bottles were washed 3-4 times with the water to be samples before filling with the actual sample.

3.1.4 Sample treatment in the field

For DO analysis, the water samples were treated with 0.5 ml of manganous sulphate and 0.5 ml of Winkler's reagent for every 100 ml of sample volume. The stoppers of the bottles were firmly replaced, taking utmost care to avoid trapping of air. Water samples were then mixed thoroughly by shaking the bottles. Thus, the sample was made ready for laboratory analysis.

For the remaining samples, no treatment was made in the field. They were brought straight to the laboratory for subsequent preservation and analyses.

3.1.5 Laboratory analyses of the samples

On return to the laboratory, approximately 300 ml of the sample was poured into a 500 ml conical flask which was used for pH, total hardness and total alkalinity analyses. pH was measured immediately after returning to the laboratory. 25 ml unfiltered sample was stored for a short period in a refrigerator after adding nitric acid at a rate of 1 ml per 100 ml of sample, which was used for calcium analysis. About 500 ml of the remaining sample from each of the plastic bottles were filtered through a pre-washed, pre-ashed and pre-weighed glassfibre filter paper (Whatman GF/C). The filtered samples were divided into small portions and poured into 100 ml stoppered plastic bottles and preserved in a deep freeze at -15°C for further analyses. Before analyses, the frozen samples were thawed and thoroughly mixed up.

The filter papers used up for filtering the samples were used for total suspended solids estimation.

3.1.6 Equipment and techniques used for water analyses

3.1.6.1 Temperature

Both surface and bottom water temperature were measured using a 'PHOX' thermistor probe. A thermometer was also placed in the inlet of pond 11. Air temperature was recorded using another thermometer. In all cases, the reading was recorded to the nearest 0.5°C.

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3.1.6.2 pH

Measurement of pH was done electrochemically with a 'Philips digital' pH meter fitted with a glass electrode with an accuracy of about $\pm$ 0.01. The electrode was standardized by two buffers at pH 4 and 7.

3.1.6.3 Total hardness

It was measured titrimetrically using standard solution of EDTA (disodium salt of ethylenediamine tetraacetic acid) and Eriochrome Black-T as the end point indicator.

3.1.6.4 Calcium

Calcium was determined by atomic absorption spectrophotometry (Golterman et al., 1978). Both samples and standards were treated with 5% W/V Lanthanum solution by adding 1 ml of Lanthanum per 4 ml of samples and standards. The aborbance was measured at 422.7 nm for calcium.

3.1.6.5 Total alkalinity

This was determined by titrating with standard hydrochloric acid to a pH of 4.5; using BDH '4.5' indicator to indicate the end point. Additionally a pH meter was used to observe the end point at 4.5 (Stirling, 1985).

3.1.6.6 Total suspended solids

A known volume of water sample was passed through a pre-washed, pre-ashed and pre-weighed glassfibre filter paper (Whatman GF/C). The filter paper was then dried at 105°C for 12 hours, cooled and weighed again. The difference in weight was divided by volume of water sample which gave the mg l^{-1} solids.

The filter paper with the dry solids obtained from final weighing as above was ashed in a muffle furnace at 500°C for 12 hours, allowed to cool in a dessicator, and reweighed. The decrease in weight gave the content of particulate organic matter in the corresponding volume of water sample (Stirling, 1985).

3.1.6.7 Total ammonia

This was determined by the phenol-hypochlorite method (Mackereth, 1978; Stirling, 1985). Here, ammonia reacts with phenol and hypochlorite in alkaline solution and gives indophenol blue; sodium nitroprusside is used to intensify blue colours at room temperature. The resulting absorbance was measured spectrophotometrically at 635 nm.

Un-ionised ammonia was calculated using equation:

$$\%\ \text{un-ionised ammonia} = \frac{100}{1 + \text{antilog}\ (pKa - pH)}$$

where pKa = negative logarithm of the ionisation constant which is dependent on temperature.

Trussel (1972) and Emerson et al (1975) were also consulted during calculation of un-ionised ammonia.

3.1.6.8 Nitrite

Nitrite was determined by the method outlined by Strickland and Parsons (1972) and Mackereth et al., (1978). Here, nitrite reacts with sulphanilamide and naphthyl-ethylene diamine to give a red azo-dye. The absorbance was measured spectrophotometrically at 540 nm.

3.1.6.9 Nitrate

It was analysed with an auto-analyser 'Technicon samplers IV'. Nitrate is reduced to nitrite by a cadmium-copper couple and then nitrite is determined in the auto-analyser by the above method.

3.1.6.10 Dissolved organic nitrogen

Organic nitrogen in the filtered water sample was broken down by a potassium persulphate-sulphuric acid digestion to ammonia and the ammonia in the digest was determined by the phenol-hypochlorite method (Adamski, 1976). From this, the total ammonia value was subtracted to give DON.

3.1.6.11 Soluble reactive phosphate

It was measured by the method as outlined by Stirling (1985). The principle of the method is that phosphate reacts with molybdate to form molybdophosphoric acid which is then reduced to the intensely coloured molyledenum blue complex and determined spectrophotometrically at 882 nm.

3.1.6.12 Total phosphorus

By digestion with a mixture of sulphuric acid and potassium persulphate, the phosphorus in the sample was converted to soluble inorganic phosphorus which was then determined by the same method as used for soluble reactive phosphorus.

3.2 Analyses of soil and sediment

3.2.1 Collection and preparation of pond soil

Pond bottom soil was collected at monthly intervals on the date of benthos collection with the same air-lift sampler. Since the pond soil was stirred up during lifting up, the samples along with interstitial water were left to settle in the collecting bucket for an hour. The clear water was then slowly decanted and the pond bottom mud was tranferred to a 500 ml plastic bucket and covered with a lid and brought to the laboratory.

Soil samples were also collected from the immediately drained pond bottom with the help of a trowel at the beginning and end of the culture cycle. These samples were used for particle size determination.

In the laboratory the samples were thoroughly mixed up and a portion of them were left for air drying on aluminium foil at room temperature and the remaining portions were put in an oven for drying.

3.2.2 Collection and preparation of sediment

Freshly produced sediments were collected by using sediment traps which were placed on the bottom of the ponds 11, 13 and 14.

Details of the sediment trap are given by Merican and Phillips (1985). Each trap consisted of 8 equal sized funnels (5.1 cm in diameter), all of which were collected every 15 days and replaced by new ones. These were brought to the laboratory and transferred to 100 ml beakers and placed in an oven at 105°C for measuring dry weight of the sediment.

3.2.3 Physico-chemical analyses of soil and sediment

3.2.3.1 Texture or particle size

Particle size of the dried pond soil was determined on the basis of the 'Wentworth scale'. The essential equipment for analysis is a graded series of standard sieves suited to the intervals of the Wentworth scale. The scale was: Gravel (4,000-2,000 μm), very coarse sand (2,000-1,000 μm), coarse sand (1,000-500 μm), medium sand (500-250 μm), fine sand (250-125 μm), very fine sand (125-62.5 μm), silt (62.5-39 μm), and clay (39 μm) (Wentworth, 1922). Later these scales were narrowed down into 4 major groups, such as gravel, sand, silt and clay so that results of the particle size analyses could be fitted to a triangular graph to know the soil class.

3.2.3.2 Moisture content and loss on ignition

A sub sample of air dried soil was transferred to a pre-weighed beaker, weighed and oven dried at 105°C until it reached a constant weight. The difference in weight was the moisture content. The sample was then ignited in a muffle furnace at 500°C for 12 hours and weighed. The decrease in weight was the organic matter content or loss on ignition.

3.2.3.3 pH

pH of the pond mud was determined from a mixture of pond mud and distilled water in a 1:2.5 (W/V) ratio and stirred at intervals. After one hour the pH of the freshly stirred suspension was measured with a digital pH meter (Smith et al., 1981).

3.2.3.4 Total Carbon and Nitrogen

A sub sample of 1500-2500 μg of dried pond soil and sediment was analysed for total carbon and nitrogen using a Perkin Elmer 240 Elemental Analyser. Results were calculated from the bar graph recordings.

3.2.3.5 Total Phosphorus

Total phosphorus of pond soil and sediment were determined following the method of Strickland and Parsons (1972), as modified at the Institute of Aquaculture. In this method, a weighed soil and sediment sample were first digested with conc. nitric acid and then perchloric acid. Total phosphorus was finally determined following Stirling (1985).

3.3 Methods for Benthic Macro-invertebrates

3.3.1 Choice of sampling device

A large variety of sampling devices have been used to sample benthic invertebrates. In two annotated bibliographies, Elliott and Tullet (1978; 1983) listed most of the literature which describes the samplers. The range of sampler covers the following major categories: net and quadrat samplers; scoops, shovels, and dredges; grabs; corers; suction and air-lift samplers; and electroshocking samplers.

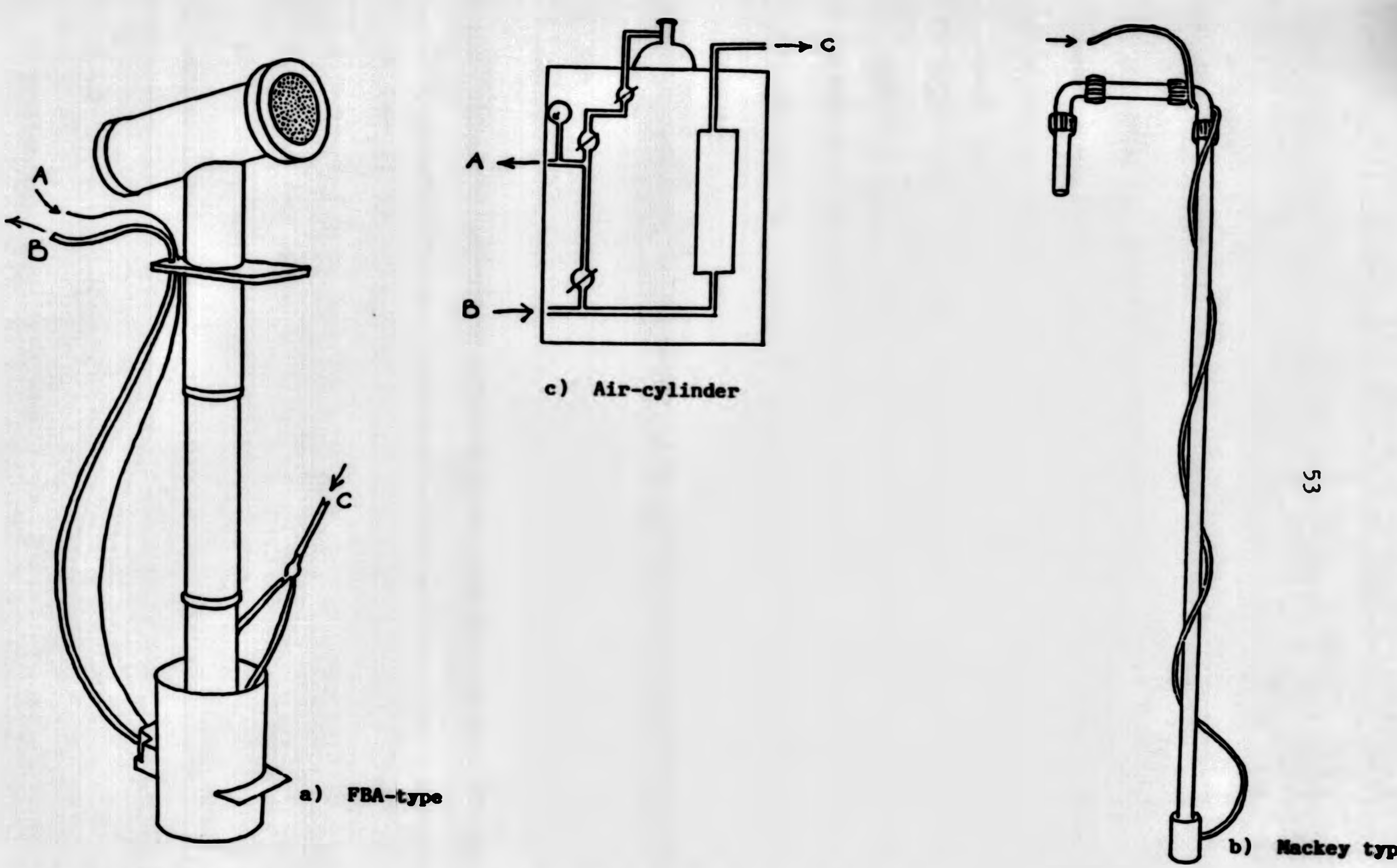
Although the final choice of a sampler depends upon the purpose of the exercise (Holme & McIntyre, 1984), some factors such as the substrate composition, depth of the waterbody, kind of organisms and their distribution pattern should be considered before the selection of a suitable sampling device.

The bottom soil of Howietoun fish farm ponds is composed principally of cobbles, gravels and stones. Several authors (e.g. Hughes, 1975; Elliott *et al.*, 1980; Elliott & Drake, 1981(a); Elliott & Drake, 1981(b)) attempted to compare sampling devices and concluded that most of the devices failed to effectively sample the substrata where stones of more than a few centimeters diameter are the prinicpal components.

An air-lift sampler, as defined by Elliott and Tullet (1978) as 'samplers that use air under pressure to lift substratum and animals from the bottom into a collecting net' was found suitable for the stony substratum of Howietoun fish ponds and was selected for this study.

Among the known air-lift samplers (Croce & Chairabini, 1971; Emig, 1977; Mackey, 1972; Pearson et al., 1973 and Drake & Elliott, 1983), the sampler described by Mackey (1972) used in the River Thames and the FBA (Freshwaters Biological Association) air-lift sampler designed by Drake & Elliott, (1983) were chosen for this study. The FBA sampler has been claimed by the authors as equally efficient for qualitative and quantitative sampling of the benthic fauna from stony substrata. The great disadvantages of this sampler are that only 3-4 samples can be collected with one cylinder of gas; and at least two persons are needed for its operation. The excess of gas use and number of operators needed often limit the use of this sampler. The details of the sampler are shown in Fig. 5a.

Considering the disadvantages of the FBA air-lift sampler, the other sampler based on Mackey (1972) was used for the greater part of this study. Fig. 5b shows the details of this sampler. The



Figs 5(a-b) Diagrams of air-lift samplers used in this study (Not to scale) advantages of this sampler are: it is easy to construct and operate, it is remotely controllable (i.e. operation from a boat is possible); efficient to collect both the mud layer and stones with organisms and about 18-20 samples can be collected by using one cylinder of compressed air. For qualitative sampling this sampler was found to be as efficient as the FBA sampler, but Drake & Elliott (1983) showed that the Mackey sampler overestimates the benthic animals quantitatively. Therefore, an FBA air-lift sampler was used to standardize the Mackey sampler for this study by occasionally sampling on the same day at the same sampling station with both samplers.

A corer was used for obtaining benthic samples from the Sauchieburn stream. Because of the greater differences in the water flow between the inflow to the fish farm and the outflow, traditional devices for stream benthos collection such as the widely used Surber sampler (Surber, 1937), whose efficiency is flow dependent, were not usable. Since the purpose of the study in the very narrow burn was to get an idea of the similarity of the fauna with that of the farm ponds, a corer of 3.8 cm internal diameter was found to be most suitable. The corer was operated by pushing it into the substratum up to 10 cm depth and pulling it out diagonally to prevent any loss of sample.

3.3.2 Pilot survey

A preliminary survey was carried out before and after the draining of each of the ponds except pond 13, as a reconnaisance of the ecosystem. This survey demonstrated important features of the physical and chemical environment and biological communities, type of substrata, bottom contour etc., which were eventually useful in deciding the number of stations and the size and number of sampling units required for a meaningful study.

3.3.3 Number of sampling stations

The pilot survey revealed that each pond has a homogeneous distribution of substrata with fairly flat bottoms and the average depth being almost constant along their longer axis. In the middle of each pond, there is a narrow slightly deeper area surrounding the drain pipe for complete drain-out of the pond.

The water quality, and consequently the benthos, was presumed to gradually change as the water passed from one pond to the next and ultimately became enriched with nutrients as it left the farm and mixed with burn water.

Therefore, a series of ponds, nos. 7, 9, 11, 13 and 14 was selected for this study. Each of the ponds was considered as one station for collection of benthic samples. Pond 9 was considered as a control pond.

Two additional stations in the water supply burn, one at the inflow and another below the outflow of the fish farm, were also included for this investigation. The sampling stations are shown in Fig. 2 .

3.3.4 Size of the sampling units

Several workers (Beall, 1939; Finney, 1946; Taylor, 1953) have suggested that a small unit is more efficient than a larger one (cited from Elliott, 1977a). Elliott (1977a) described the advantages of smaller sampling units over larger units which are :

(1) more small units can be taken for the same amount of labour in dealing with the catch;

(2) as with many small units statistical error is reduced; and

(3) since many smaller units cover a wider range of the habitat than fewer larger units, the catch of smaller units is more representative.

For the present investigation the sample size was 0.196×10^{-2} m^2, the stone size being a limiting factor in choosing this size limit.

3.3.5 Number of sampling units from each sampling station

Since the dispersion of many species of benthic macro-invertebrates is contagious, a large number of samples is needed for an accurate calculation of population density. This is practically not feasible when samples are collected from many stations and at regular intervals of time. The inconvenience of sampling by using air-lift sampler is a further hindrance in collecting a large number of samples. The final choice of number of sampling units for this study was a compromise between statistical requirements and practicability (Elliott, 1977a).

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During the pilot survey 9 replicate corer samples were collected randomly from pond 11 and the number of taxa examined. The number of sampling units was plotted against the number of taxa recorded and three samples per station were found to be the minimum number of sampling units required. No new taxa were recorded with more samples.

Using the formula suggested by Elliott (1977a):

$$n = \frac{S^2}{D^2 \bar{x}^2}$$

where n = number of samples, S^2 = variance, $\bar{x}$ = mean, D = index of dispersion (ratio of standard error and arithmetic mean), for an allowable standard error of 20% of the mean, three sampling units were found adequate for the station pond 11. Similarly, three samples from all the stations have been collected for this investigation.

3.3.6 Collection and preservation of benthic samples

Benthic samples were collected fortnightly from 7 stations. Three replicate samples were collected from each station on each sampling day. Sample collection usually started around 1000h. in the morning and continued until 1600h. The mixture of substrata and water along with benthos was collected in a large bucket in case of the Mackey air-lift sampler and in a large 250 μm mesh nylon bag in case of samples collected by the FBA air-lift sampler.

After collection by the Mackey sampler, the bottom materials were then passed through a 250 μm mesh sieve for a preliminary separation of benthos and larger particles from water, fine detritus and soil particles. After reducing a considerable proportion of the volume by this method, each of the samples, was then transferred to a 500 ml marked plastic bucket with lid. The samples were then preserved by adding 40% formaldehyde solution to give a final concentration of 5% formalin (Wetzel & Lickens, 1979).

3.3.7 Separation of animals

The samples were kept for 48 hours in the laboratory to allow the animals to harden (Maitland & Hudspith, 1974). The samples were then transferred on to a 250 μm mesh sieve and washed in a half filled sink to remove the remainder of the washable detritus and muds. The samples were then put in a 2 l plastic beaker for washing and decantation as suggested by Maitland and Hudspith (1974). This was a simple decantation method based on the differences in specific gravity between the invertebrates and the substrata. Tap water was run into the sample vigorously so that all the materials including invertebrates are thoroughly stirred up; as soon as the heavy substrata had settled down the tap water was decanted through the sieve. The process was continued until all the organisms were separated from the substrata inside beakers. The materials in the beaker were then transferred to a 210 x 210 mm white tray, big and heavy animals were then picked up. The animals along with some detritus which remained on the sieve were washed again in a half filled sink a few more times and then made ready for sorting out.

A 250 μm sieve was considered for this study, because the use of the next smaller readily available sieve in the Wentworth series (125 μm) would have greatly increased the difficulty and time involved in sorting. The smaller the mesh size, the more organisms would be retained, but also more detritus and other substrata retained. A sieve of 250 μm should retain at least the later larval stages of all macro-benthic animals but not all younger stages (Kajak et al., 1968).

3.3.8 Sorting and preservation of animals

The sieved materials were then washed into a large white tray and dispersed. Large amounts of material retained on the sieve, were sorted in portions. The materials were frequently examined under a low power microscope to check whether any animal had been missed. The flotation method using a sugar solution was tried but proved to be messy, tedious, and of no advantage.

The sorted animals were preserved in 70% alcohol in sterile fix-pots. Unlike formalin, alcohol preserved materials were found easy to handle and not hazardous to health.

3.3.9 Enumeration of animals in the samples

The preserved materials were then separated into different groups and counted with the aid of a light source and a low power dissecting microscope (Hamilton, 1971). The larger benthic animals including molluscs, megalopterans, isopods, trichopterans and hirudineans could be counted without any kind of aid.

It was necessary to examine the chironomids and oligochaetes under the microscope to separate them into different sub groups, family or genera (if possible) on the basis of morphological differences. The members of the similar looking groups were counted and given a provisional generic and/or specific status until finally confirmed by mounting and identification. Only complete worms and head ends were counted, tails and fragments of body parts other than the head being discarded to avoid any duplicate recording of one specimen (Brinkhurst & Kennedy, 1965). After enumeration a good proportion of the specimens were mounted for identification.

3.3.10 Identification of benthic macro-invertebrates

3.3.10.1 Oligochaeta

Before slide preparation the worms were transferred from 70% alcohol to 30% and then to water (Brinkhurst, 1971). Polyvinyl lactophenol has been suggested by Brinkhurst (1971) for permanent preparation of the worms, which was used all along for this study. Up to 5 worms were placed on a slide with a few drops of polyvinyl lactophenol and covered with a coverslip. Care was taken to remove excess water from the body by touching on tissue paper before placing on a slide because water along with ethanol makes the mounting difficult. After labelling, the slides were placed on a hot plate within a fume cupboard and set at 50-60°C for 24 hours. The time depends on the size of the specimen. For the larger specimen 48 hours at this temperature was found sufficient. Polyvinyl lactophenol often evaporates during that time leaving an air space on the slide, so care was taken to add more polyvinyl lactophenol whenever necessary.

This method was found extremely suitable and easy for dealing with voluminous ecological materials. It was especially useful when setae, cuticular penis-sheaths and gut contents needed to be studied.

In spite of these advantages, there are some limitations using P.V.L.P. as a mounting reagent. It destroys very soft tissues, particularly of poorly preserved material; it evaporates easily during heating; and, due to the presence of phenol, it is toxic and unpleasant and sometimes may cause headache to the researcher or may cause skinburn and blisters if not handled carefully to avoid contact.

3.3.10.1.1 Microscopic examination

An 'Olympus' compound microscope fitted with a graticule was used for identification. Identification of oligochaetes was done following Brinkhurst (1971). All the identified materials were finally checked by Dr. Mike Ladle of the Freshwater Biological Association.

Not all the specimens collected were referrable to a species, particularly immature tubificids and lumbriculids. Naidids were identified up to species levels using setal pattern and arrangement as characters. Juveniles were counted as a whole and divided in the proportions corresponding to those of the adults. Eggs and recently hatched juveniles were also taken into consideration for detecting breeding cycles of individual species. Some identified adults were maintained in the laboratory in distilled water in petri dishes without food, only providing some pond debris, to determine the egg laying period.

3.3.10.2 Chironomidae

3.3.10.2.1 Microscopic slide preparation and examination

Chironomid larvae were also mounted in polyvinyl lactophenol in a similar way to that described for oligochaetes, only each individual was mounted on a separate slide. The head capsule was separated from the body with the help of a surgical needle and a pair of fine forceps. The body and head capsule of each individual was placed on the same slide under separate coverslips. In case of big larvae such as 4th instar of Chironomus plumosus, the head capsule was removed and macerated into a hot 10% solution of caustic potash (KOH) for 5-10 minutes (Pinder & Reiss, 1983). After heating on the hot plate at 50-60°C for 24-36 hours, the specimen was ready for identification. The larval identification of Chironomidae was performed following Wielderholm (1983). All the specimens were identified at least up to generic level, while a few could be identified upto species level, even without the adult. All the larval identifications were checked by Dr. L. C. V. Pinder of the Freshwater Biological Association.

3.3.10.2.2 Rearing of adults and their identification

For identification of Chironomidae up to specific level, it was desirable to obtain a reared series of imago, larvae and pupal exuviae. The best way of achieving this was by rearing larvae singly, in an individual container (Pinder & Reiss, 1983). In this study, well developed 4th instar larvae, recognizable by their swollen thoracic segments, were reared in 50 ml water in petri dishes. A high level of success was achieved without providing them with any food or artificial aeration. The petri dishes were placed in a dark undisturbed cupboard.

To prevent the newly emerged adult falling back into the water and rapidly decomposing, the containers were checked every 2-3 days. The emerged adults along with pupal exuviae were preserved in 70% alcohol.

3.3.10.2.3 Adults

The adult (male) specimens were then examined under a low power microscope. For detailed examination, the hypopygium was removed by a pair of forceps and surgical needle and placed in hot 10% caustic potash (KOH) for 5 minutes. After washing in distilled water it was returned to 70% alcohol. The complete specimen was dehydrated in 100% alcohol. The antennae, head, wings and legs were serially removed and mounted in polyvinyl lactophenol under many small coverslips on a single slide for each specimen. The hypopygium was mounted horizontally on the same slide. Details of the mounting of the adult midges are described by Pinder (1978). The identification of adult midge was carried out following Pinder (1978).

3.3.10.2.4 Pupal exuviae

The pupal exuviae was mounted in a similar way as done for adults and the identification was made following Langton (1984).

3.3.10.3 Other groups

Molluscs, leeches, isopods, Megaloptera, Trichoptera and others were identified simply by transferring them from 70% alcohol to a clean petri dish containing distilled water, sometimes with the aid of low power microscope and sometimes even without it. A light source fitted with magnifying glass was found very useful in most cases.

The following keys were used during identification of different groups of organisms:

Mollusca - Macan (1977), Ellis (1978);

Hirudinea - Elliott and Mann (1979);

Isopoda - Macan (1968), Quigley (1977);

Megaloptera - Elliott (1977b)

Trichoptera - Macan (1973), Wallace (1980).

The two books Macan (1968) and Quigley (1977) were useful guides to reach the family and generic level identification for many large invertebrates.

3.3.11 Biomass and Production estimation

3.3.11.1 Biomass

Dry weight was obtained after drying animals at 60°C for 24 hours or until a constant weight was reached. In most cases 24 hours were found sufficient to reach a constant weight (Lindegaard & Jónasson, 1979). A Mettler balance was used to take the weight of the samples. Ash free dry weight was considered for molluscs and it was determined after incineration in a muffle furnace for 4 hours at 550°C (Crisp, 1984).

As the sample was preserved in 70% alcohol only for a short period, no correction was made for weight loss due to preservation. Lindegaard & Jónasson (1979) multiplied their dry weight results by 1.67 for chironomid and by 1.43 for other groups of formalin preserved material.

3.3.11.2 Production

There are several methods for the calculation of secondary production, which are, 'removal-summation' (Boyson-Jensen, 1919), 'increment-summation' (Winberg, 1971), 'instantaneous growth rate' (Ricker, 1946; Allen, 1949); 'Allen curve' (Allen, 1951) and Hynes (size-frequency) method (Hynes & Coleman, 1968). Several earlier reviewers (Mann, 1969; Winberg, 1971; Waters, 1977) discussed the advantages and limitations of each of these methods. Almost all of them require direct information or assumptions concerning all or some of the population parameters, such as population density, biomass, growth rate, voltinism and the life span (Bird, 1982), which often limit their use.

The life histories of many benthic animals still require investigation. In particular the degree of voltinism and the rate and causes of mortality in freshwater ecosystems have yet to be established. Nevertheless, the continuous reproduction of many species such as oligochaetae, often causes a great problem in production estimation and has provoked a 'short-cut' method to avoid many of the parameters not always considered for ecological study.

Downing & Rigler (1984), in their recent IBP book on secondary production noted that 'the literature on secondary production contains such a diversity of equations, some correct and some erroneous . . . . the calculations are conceptually difficult'. They suggested 'growth increment summation' as the simplest method both conceptually and mathematically. This method does not need all of the parameters mentioned.

Therefore the 'growth increment summation' method has been used in this study. Production was estimated for each group of benthic macro-invertebrates as a whole, rather than for individual species. It was calculated as the product of mean abundance between successive sampling times and the increment in the mean individual dry weight (or ash-free dry weight for mollusca) during this time interval; and summed for all time intervals over an entire year. The formula for calculating the production is shown in Appendix I..

Negative values in production estimation, whether real of apparent, were not subtracted from the total production (Maitland & Hudspith,1974).

3.4 Food and feeding habits of brown trout

3.4.1 Collection and preservation of fish stomachs

Fish samples for this study were collected monthly starting from May 1984 to January 1986. For investigating the seasonal variation in the stomach contents of trout, a standard sample of 20 to 30 fish was collected on each occasion by seining, or angling using flies. Maitland (1965) considered that a sample of twenty fish was adequate for stomach contents analysis. A sample of even ten salmon parr has been found to give valid results for estimating the food of a population of that species (Carpenter, 1940). All the fish samples were caught between 12.00 noon and 1500 h to avoid any diurnal variation (Ball, 1961). Fish were killed by pithing and immediately taken to the Howietoun fish farm's laboratory (5 minutes driving distance). In the laboratory, each fish was measured for fork length (from tip of fork to the tip of the snout) to the nearest millimetre using a measuring board, and weighed to the nearest 0.1 g by a mettler balance. Excess water was removed by paper towel before taking the weight of the fish.

The alimentary canal was then removed after a median ventral incision was made from the cloaca forward to the gill arches. The stomach, starting from oesophagus to the pyloric sphincter was considered for food analysis (Maitland, 1965). The food items beyond pylorus are usually mostly digested (Ball, 1961) and were not considered for analysis. Food items partly in the stomach and partly in the oesophagus were included in the stomach contents. The stomach was then preserved in 70% ethyl alcohol to await examination.

3.4.2 Analysis of stomach contents

The visual estimation of the degree of fullness of each stomach was made in accordance with the widely used classification established by Ball (1961). The points allocated to each stomach according to the degree of fullness are as follows:

Degree of fullness	Criteria	Points
Empty	Stomach collapsed, no food present	0
¼ full	One fourth of the stomach volume occupied by food	1
½ full	Stomach containing food, generally along most of its length, but the inner surface is longitudinally pleated and wall feels thick and hard	2
¾ full	Stomach nearly filled with food but some space remains and small region of the wall feels thick and hard	3

Degree of fullness	Criteria	Points
Full	Stomach full of food, entire wall feels soft and thin	4
Distended	Stomach overpacked with food. Wall cannot be pinched with forceps and is thin	5

The mean number of points per stomach was determined per month which gave a "stomach fullness index", an arbitrary indication of monthly food intake by fish in general.

The volume of each stomach was then determined both with or without food in the stomach by water displacement in a measuring cylinder. The stomach wall was cleaned up in both cases using a paper towel to remove excess water. Stomach contents were transferred to a clean petri dish containing 70% alcohol and the various organisms were sorted out from the rest of pelleted feed stuff and identified to the lowest convenient taxon and counted with the aid of a low power binocular microscope. At this stage some specimens, especially oligochaetes and chironomid larvae, whether complete or partially digested, were mounted for microscopic examination using polyvinyl lactophenol. All of the aerial and/or terrestrial insects were identified as far as family or genus and no further.

Three methods, numerical, volumetric and occurrence, were chosen as suitable for determining the dietary importance of benthic animals. Hyslop (1980) reviewed the different methods for analysing stomach contents and critically assessed their suitability for determining dietary importance. The best measure for the above purpose refers to a combination of both the number and bulk of the food category (Hyslop, 1980). These two attributes were considered in this investigation.

A brief description of the methods used in this study is given below:

3.4.2.1 Numerical Method

The number of each food item is recorded for all stomachs and the total is expressed as proportion, usually as percentages of the total number of food organisms present in all fish stomachs examined (Crisp et al., 1978). It is a simple and relatively fast method (Hyslop, 1980). For food organisms which were broken by digestion, the heads, legs, wings or any hard part resistant to digestion were counted. This might lead to a minor overestimation, however, the effect could only be slight in comparison with total number of organisms counted (Ball, 1961).

3.4.2.2 Volumetric Method

The total volume of a food category taken by the fish population is usually given as a percentage of the total volume of all stomach contents (Hunt & Jones, 1972b; Pedley & Jones, 1978). Volumetric method gives the most representative measure of bulk and may be applied to all food items (Hyslop, 1980).

For the present study, the total volume of stomach contents and volume of each food item were estimated using different types of measuring cylinders by water displacement method. The difference in the volumes between total stomach contents and the total volume of all natural food items gave the volume of pelleted feed in the stomach. For small organisms like chironomids and oligochaetes, the volume of 10 individuals of equal size were measured together and then average volume was considered for each of the organisms. For measuring the volume of partially digested animals, a new specimen of the same size was replaced from benthic faunal sample by each of the degraded animals. Excess water or alcohol was removed from the item by a blotting paper.

3.4.2.3 Occurrence Method

This is the simplest way of recording the number of stomachs containing one or more individuals of each food category. This number may then be expressed as the percentage of all stomachs (Frost, 1946; 1954; Hunt & Jones, 1972b)or all those containing food (Dineen, 1951; Dunn, 1954; Kennedy & Fitzmaurice, 1971).

Studying the stomach contents by these three methods and the degree of stomach fullness, the following information was obtained for each sampling occasion:

(i) The status of stomach fullness and average monthly fullness index,

(ii) The percentage composition of each food item by number, volume and occurence, and

(iii) the relative importance of the natural and the pelleted diet.

3.4.3 Diel pattern of feeding

For the study of diel patterns of feeding a sample of five fish were caught every 3 hours over a 24 hour period, once in summer and once in autumn during the study period. Fish were caught by angling with flies. For each occasion of 24 hours sampling, the same person caught fish for the whole period with the same rod. Both the weather conditions and physico-chemical characteristics of the water were also determined on each of the sampling days with the same interval of time.

The treatments and analysis of gut contents of fish were done using the methods described earlier.

3.4.4 Index of Selective Feeding or 'Electivity'

In order to gain an idea of the proportion of organisms in the diet relative to the proportion measured in the benthos an index of selective feeding or 'electivity' was calculated using the formula by Ivlev (1961) (cited by Brown et al. (1980):

$$E = \frac{Pd - Pb}{Pd + Pb}$$

where E = electivity index, Pb = proportion of the organism present in the benthos; Pd = proportion of the organism present in the diet.

The numerical assessment of gut contents and collected benthic faunal data provided the required information for measuring electivity in this study.

Positive electivity, or selection for an organism, is expressed by values from +1 to 0 and negative electivity by values from 0 to -1.

3.5 Study of interaction between fish and benthos by means of enclosure experiments

Investigation of the interaction between fish and benthos in the fish ponds was carried out from July to October 1985, aimed at determining the changes in species composition, population density, biomass and production of benthos in fish free areas and in areas accessible to the fish in relation to fish density and feed inputs. For this purpose, three ponds were stocked with three different densities of equal sized fish and a part of the pond bottom was covered by an enclosure which prevented access of fish to the bottom.

3.5.1 The ponds

Ponds 6, 7 and 8 (Fig. 2) of the fish farm were selected for this experiment. These three ponds are all similar in size, depth, basin conformation and bottom type. These ponds receive their water supply from a common source and at the same flow rate. Moreover, these ponds are relatively easier to manipulate because of their smaller size. The surface area of each of the ponds is 0.03 hectare with an average depth of 1.8 m. These ponds are free from aquatic vegetation except some long stems of grasses hanging from the edge of the ponds, some of them touching the waters.

All the ponds were dried up on the same day before introducing the enclosures.

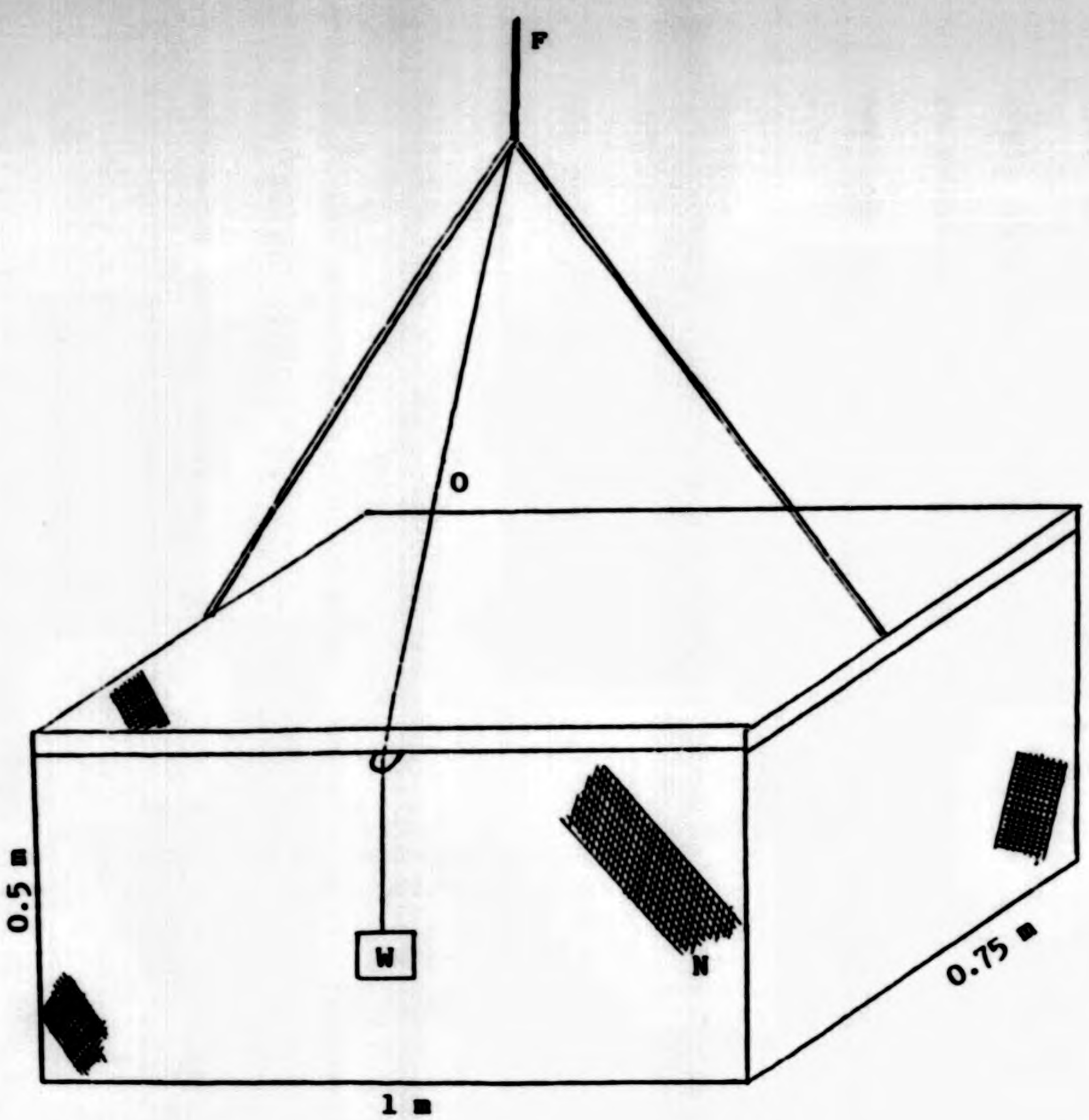
3.5.2 The enclosures

The details of the enclosure are shown in Fig. 6. The rectangular frame was made with angle iron. A separate lid was also made with angle iron and tied to the frame at one end, and the other end being tied to a weight to keep the enclosure shut. The enclosures and the lids were covered with a knotless nylon mesh with a mesh size of 9.5 mm. The mesh was sufficient to keep fish from entering the enclosures, while permitting all other animals at all stages of their life history to pass through the mesh. The mesh was transparent in colour. The four legs of the enclosures protruded upto 20 cm into the mud and weights were tied to the bottom corners to keep the enclosure firm during operation.

3.5.3 The Fish

30 g juvenile brown trout (Salmo trutta L.) were chosen for this experiment. Details of the numbers and biomass of fish stocked in the different ponds are shown in Table 32 in results section.

The fish were kept in circular tanks for 7 days before stocking



F - Rope connected to float
O - Operating line
W - Weight
N - Net mesh

Fig. 6 Illustration of the enclosure (Not to scale) the experimental ponds. The fish were not fed for 24 hours before transfer. The fish were randomly caught by a scoop net, counted and weighed and carried to the ponds in a wide mouthed bucket full of water.

One day after releasing the fish, they were fed with a pelleted diet at the rate of 2.4% body weight per day. Records of feed input were maintained throughout the period. The total feed applied in each pond during this period is also shown in Table 32 in results section.

Benthic samples were collected monthly from these ponds, three samples from outside and three from inside each enclosure with the help of the air-lift sampler, used for the benthic faunal survey, the sampling was carried out from the boat. Care was taken to disturb inside the enclosure as little as possible. At the same time, the long tube of the air-lift sampler was kept moving through the water column so that the fish were frightened to enter the enclosure during sampling.

3.6 Statistical analysis

Statistical analyses were performed using the main computer terminal of the University of Stirling. 'Minitab' statistical package was used for analyses of all ecological materials, which was provided by the University Computer Unit.

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4 Results

4.1 Physical and Chemical Parameters

4.1.1 Water quality

The overall annual means of monthly values of each water quality parameter of all ponds for the whole experimental period are presented in Table 2. In a similar way, all parameters of stream water are summarized in Table 5. Figs 7-21 and 24-35 represent the seasonal variation of each of the parameters of pond water and stream water quality, respectively. A combined graphical representation of the major variable parameters of water in Tables 2 and 5 is shown in Figs 36 and 37. This reveals that, as the water passes through the fish farm, it becomes enriched with nutrients and depleted in dissolved oxygen.

Two-way ANOVAs were carried out to observe the differences between the ponds and months for each of the parameters, the results of which are presented in Table 3. All the parameters were found to vary significantly with months. To evaluate further the differences between the ponds, paired t-tests were used and the results are presented in coded form in Table 2.

An attempt was made using correlation analysis to determine the inter-relationship among all the water parameters studied during the period of investigation, the results of which are tabulated in Table 4.

Table 2 Overall annual mean of monthly values of each water quality parameter for whole experimental period. Superscript letters indicate differences ($P \angle 0.05$) between the ponds on the basis of t-tests on log transformed data (except DO, nitrite and un-ionised ammonia). Values with the same superscript are not significantly different

Chemical parameters of water	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14
Total suspended solids (mg 1^{-1})	7.33 ± 0.63	8.27 ± 0.65	8.36 ± 0.54	8.18 ± 0.49	8.03 ± 0.41
Particulate organic matter (mg 1^{-1})	3.05 ± 0.14^{a}	2.32 ± 0.20^{b}	2.71 ± 0.20^{c}	3.0 ± 0.17^{acd}	3.27 ± 0.17^{d}
Total hardness (mg 1^{-1})	32.69 ± 0.51^{ab}	31.85 ± 0.59^{a}	32.60 ± 0.60^{ab}	32.65 ± 0.51^{ab}	33.45 ± 0.54^{b}
Total alkalinity (meq. 1^{-})	0.39 ± 0.03	0.38 ± 0.02	0.39 ± 0.02	0.39 ± 0.01	0.40 ± 0.02
pH	6.84 ± 0.14	6.76 ± 0.06	6.70 ± 0.02	6.70 ± 0.05	6.78 ± 0.05
Dissolved oxygen (mg 1^{-1})	9.33 ± 0.34^{a}	11.20 ± 0.38^{b}	10.79 ± 0.35^{b}	10.57 ± 0.35^{b}	10.35 ± 0.32^{b}
Total ammonia (μg 1^{-1})	55.0 ± 8.0^{a}	108.0 ± 14.0^{b}	186.0 ± 16.0^{c}	206.0 ± 19.0^{cd}	250.0 ± 23.0^{d}

continued . . .

Table 2 continued

Chemical parameters of water	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14
Un-ionised ammonia ($\mu g\ l^{-1}$)	0.15 ± 0.04^{a}	0.12 ± 0.01^{a}	0.23 ± 0.03^{b}	0.33 ± 0.05^{bc}	0.45 ± 0.08^{c}
Nitrite-nitrogen ($\mu g\ l^{-1}$)	4.0 ± 0.55^{a}	6.0 ± 0.48^{b}	7.0 ± 0.60^{c}	9.0 ± 0.68^{cd}	10.0 ± 0.79^{d}
Nitrate-nitrogen ($\mu g\ l^{-1}$)	270.50 ± 46.51^{a}	417.0 ± 51.28^{b}	458.40 ± 44.16^{b}	503.30 ± 42.25^{bc}	593.25 ± 49.28^{c}
Dissolved organic nitrogen ($\mu g\ l^{-1}$)	213.63 ± 26.54^{a}	254.45 ± 21.32^{b}	297.55 ± 19.46^{bc}	309.2 ± 22.20^{cd}	353.25 ± 23.30^{d}
Total phosphorus ($\mu g\ l^{-1}$)	21.0 ± 1.03^{a}	30.70 ± 2.06^{b}	40.60 ± 3.03^{c}	51.0 ± 3.91^{d}	60.0 ± 4.78^{d}
Ortho-phosphate ($\mu g\ l^{-1}$)	11.88 ± 1.03^{a}	16.5 ± 1.96^{b}	22.0 ± 2.32^{bc}	26.7 ± 2.24^{cd}	33.55 ± 2.72^{d}
Calcium ($mg\ l^{-1}$)	7.25 ± 0.53	8.20 ± 0.27	8.35 ± 0.30	8.25 ± 0.24	8.35 ± 0.32

Table 3 F-values and their associated levels of significance for two-way ANOVAs on chemical parameters of waters of all cultured ponds (7, 11, 13 & 14) (N.S. non-significant; $P<0.05$,*; $P<0.01$,**)

Chemical parameters of waters	Types of transformation needed	Sources of Variation			
		Between ponds (F)		Between times (F)	
Total suspended solids	log	1.049	N.S.	8.580	**
Particulate organic matter	log	60.730	**	36.290	**
Total hardness	log	15.691	**	29.471	**
Total alkalinity	log	1.380	N.S.	30.429	**
pH	log	2.690	N.S.	3.390	*
Dissolved oxygen	-	59.442	**	204.374	**
Total ammonia	log	62.390	**	8.580	**
Un-ionised ammonia	log	16.389	**	4.909	**
Nitrate	log	67.833	**	53.420	**
Nitrite	-	95.169	**	51.109	**
Dissolved organic nitrogen	log	29.0	**	19.730	**
Total phosphorous	log	128.154	**	36.080	**
Ortho-phosphate	log	75.390	**	29.421	**
Calcium	log	3.520	*	101.750	**

Table 4 Matrix of Pearson's product moment correlation of all physical and chemical parameters of pond waters (7, 11, 13 & 14) ($P<0.05$,*; $P<0.01$, **)

	Total solids	Organic matter	Total hardness	Total alkalinity	pH	Dissolved oxygen	Total ammonia	Nitrate	Nitrite	Un-ionised ammonia	Dissolved organic nitrogen	Total phosphorus	Ortho-phosphate	Calcium
Organic matter	-0.187													
Total hardness	0.164	-0.243*												
Total alkalinity	0.161	-0.239*	0.743**											
pH	0.087	-0.059	-0.014	-0.039										
Dissolved oxygen	-0.004	-0.729**	0.609**	0.488**	-0.008									
Total ammonia	0.376**	0.178	0.332**	0.276**	-0.318**	-0.072								
Nitrate	-0.087	-0.387**	0.641**	0.441**	0.093	0.657**	0.055							
Nitrtie	0.413**	-0.025	0.262**	0.070	0.028	0.047	0.479**	0.090						
Un-ionised ammonia	0.147	0.461**	-0.137	-0.128	-0.269**	-0.489**	0.646**	-0.287**	0.139					
Dis. organic nitrogen	0.138	0.529**	-0.100	-0.274**	0.091	-0.495**	0.191	-0.272**	0.448**	0.296**				
Total phosphorus	-0.043	0.566**	0.093	0.022	-0.348**	-0.331**	0.451**	-0.065	0.106	0.587**	0.367**			
Ortho-phosphate	0.107	0.342**	0.597**	0.441**	0.201	0.025	0.542**	0.257**	0.216*	0.371**	0.290**	0.698**		
Calcium	0.326**	-0.679**	0.613**	0.617**	0.001	0.762**	0.149	0.607**	0.230*	-0.403**	-0.410**	-0.261**	0.088	
Temperature	-0.066	0.689**	-0.578**	-0.477*	0.045	-0.846**	-0.021	-0.650**	-0.227*	0.502**	0.337**	0.350**	0.020	-0.782**

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Temperature	-0.066	0.689**	-0.578**	-0.477*	0.045	-0.846**	-0.021	-0.650**	-0.227*	0.502**	0.337**	0.350**	0.020	-0.782**

4.1.1.1 Pond water

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The average surface and bottom temperatures of the pond water recorded during the period of investigation were $9.62 \pm 1.0^\circ C$ and $9.27 \pm 0.95^\circ C$ respectively. The difference between the surface and bottom water temperature never exceeded $0.5^\circ C$ except during mid December to first week of March 1985 when the surface water was frozen but the bottom water always remained between 3°-$4^\circ C$. Conditions were different in 1986 when severe winter weather arrived very late to freeze the surface water and farming management continued even until the end of January.

Temperature differences between the ponds were never noticed, neither was thermal stratification in any of the ponds.

The seasonal variation of water temperature is shown in Fig. 7, which seemed to follow closely that of the air. June and July were the warmest months in 1984 and 1985, respectively.

Figs 22 and 23 indicate the diurnal fluctuations in water temperatures, which were recorded once in October 1984 and once in July in the following year. During autumn, the temperature remained close to $10.0^\circ C$ throughout a 24 hour period. On the contrary, a distinct diurnal fluctuation was observed in the same pond in summer, when temperature gradually increased from $11.5^\circ C$ in the early morning to $15^\circ C$ in the afternoon (2 pm) and then started to fall again

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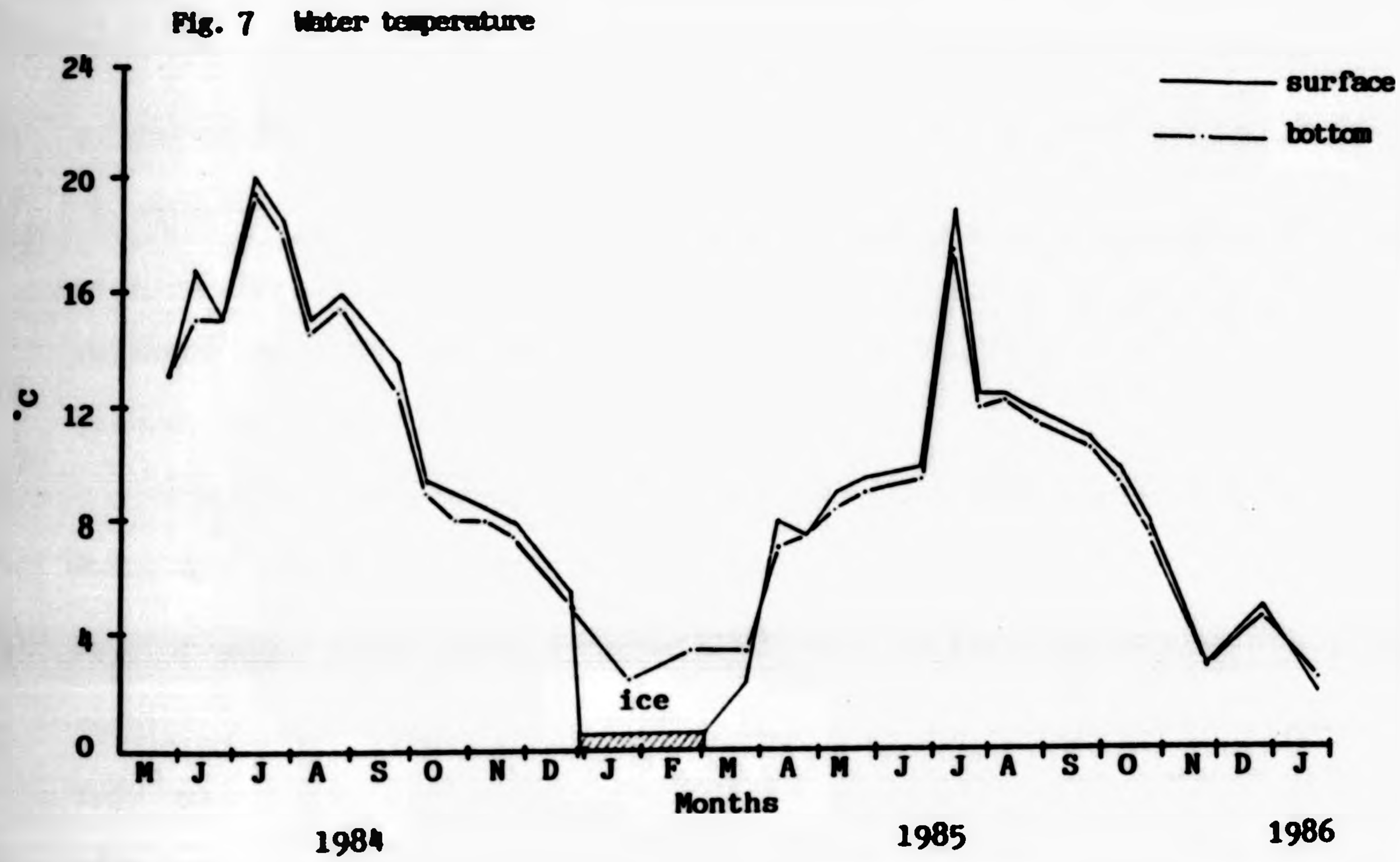


Fig. 7 Seasonal changes in water temperature in Howietoun fish ponds

throughout the night.

4.1.1.1.2 Total suspended solids

From Fig. 8, it is evident that there was a marked seasonal variation in the total suspended solids concentration in the ponds, with peaks in November, 1984 and September, 1985, with a relatively smaller peak in May. Although a two-way ANOVA showed highly significant variation between the months, there was no significant difference between the ponds (Table 3).

4.1.1.1.3 Particulate organic matter

Fig. 9 shows that the highest peaks were observed during May to August in both years. Organic matter content in water increased from pond 7 to pond 14 and the differences between the ponds were highly significant ($P < 0.01$, Table 3).

From the correlation matrix in Table 4, it is clear that particulate organic matter had a high positive correlation with temperature, total phosphorus and dissolved organic nitrogen and a high negative correlation with dissolved oxygen.

4.1.1.1.4 Total hardness

Among the conservative properties of water, total hardness was the only one that showed a highly significant difference between the ponds (Table 3). Total hardness was lower during summer months

Fig. 8 Total suspended solids

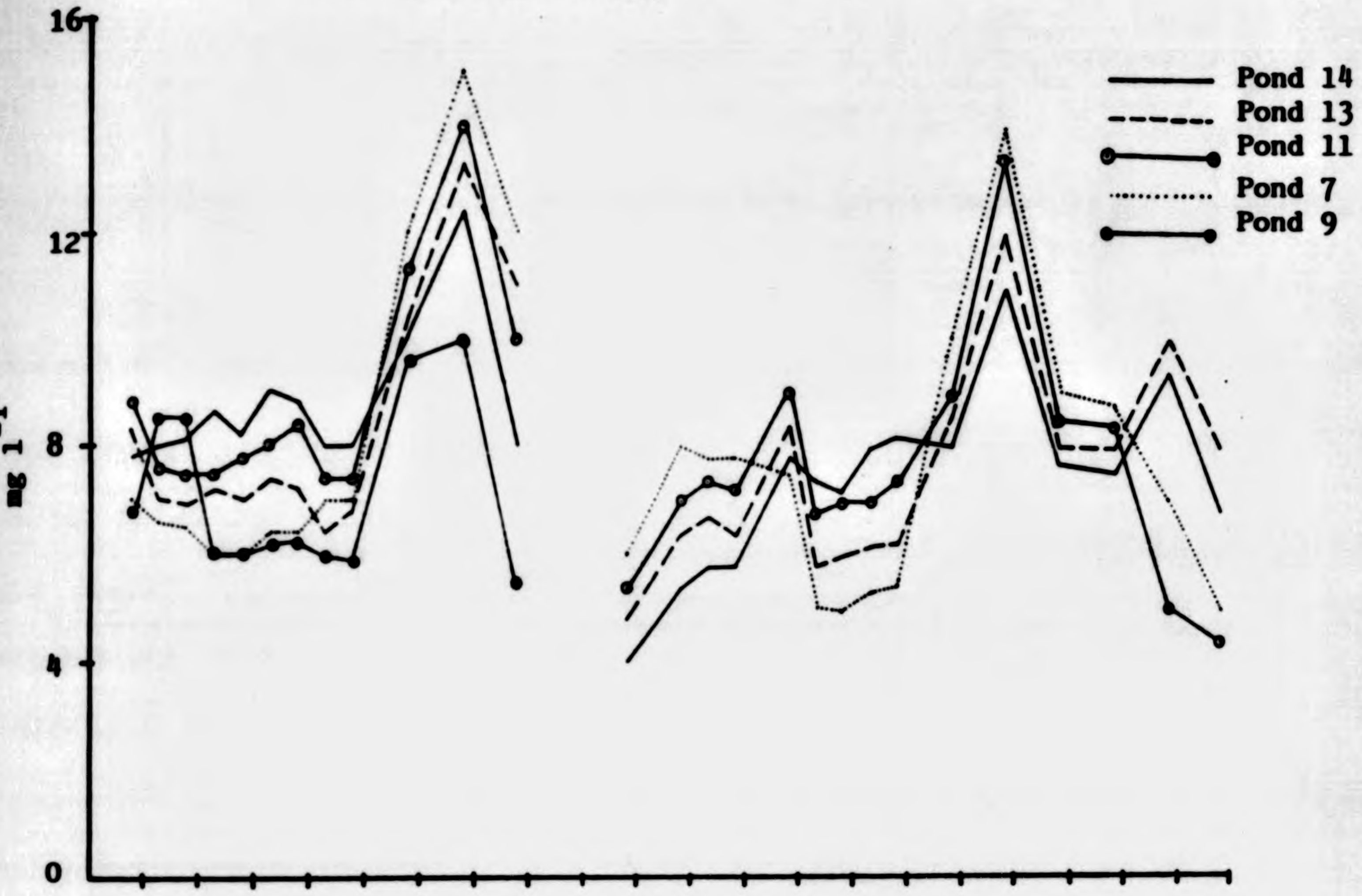
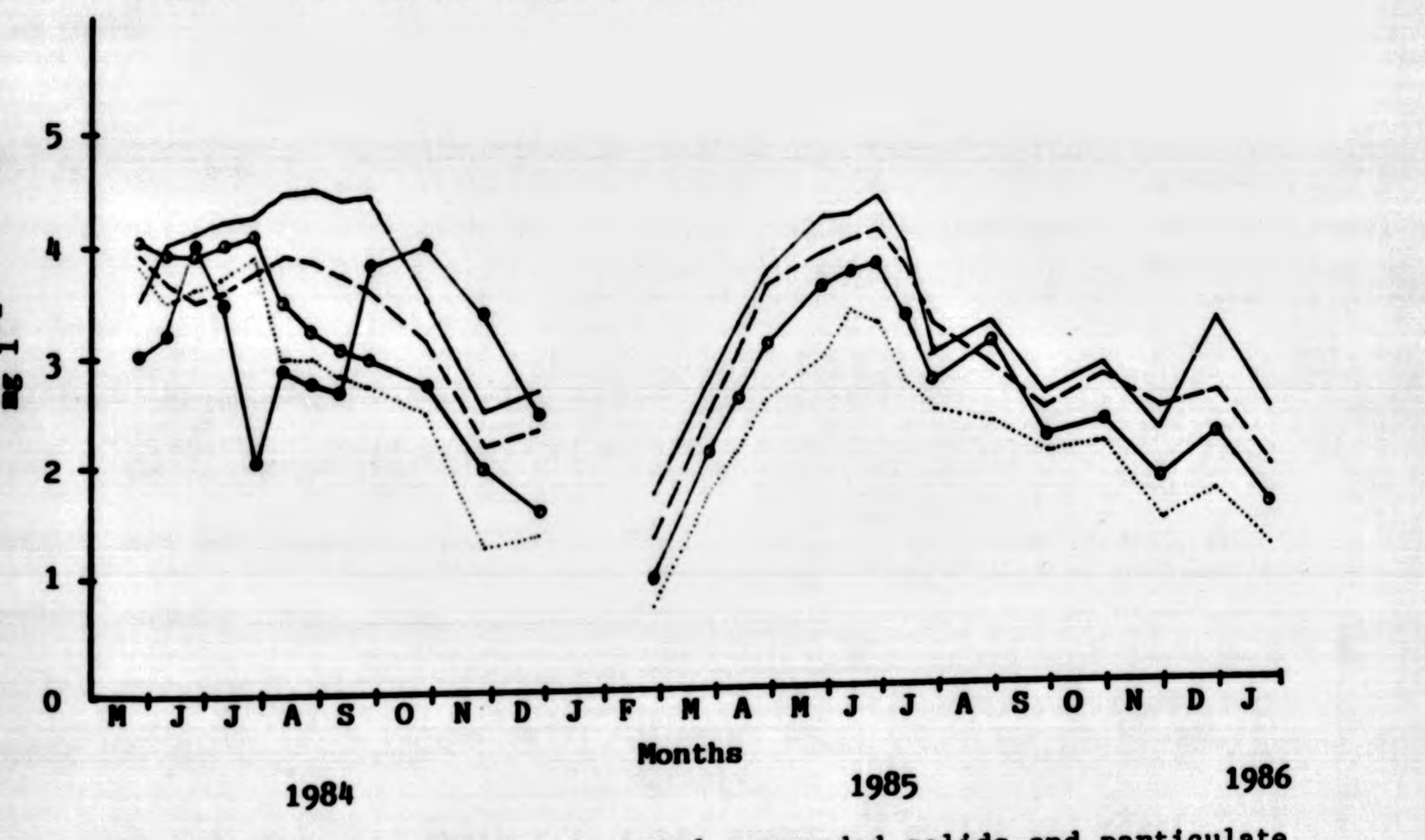


Fig. 9 Particulate organic matter



Figs 8-9 Seasonal changes in total suspended solids and particulate matter in Howietoun fish ponds

than at other seasons (Fig. 10) of the year. It had a positive correlation with calcium and total alkalinity (Table 4).

4.1.1.1.5 Calcium

This shows a similar seasonal trend to total hardness (Fig. 11) having decreased in summer and increased in autumn to winter. Though the overall variation in calcium between ponds and the months was significant (Table 3), differences in the annual means between individual ponds could not be detected.

4.1.1.1.6 Total alkalinity

This followed a similar seasonal pattern to that of total hardness (Fig. 12) being also lower during summer months. Differences between the ponds were not significant.

4.1.1.1.7 pH

Throughout the period of study, the pH of pond water was found to be near neutral (Table 2). The range of pH in the farm was 6.50 to 7.15 except an unusual increase upto 8.15 in pond 9 in July, 1984. The seasonal pattern (Fig. 13) showed a decrease during winter months and an increase during summer. An increasing trend during summer months from pond 7 to pond 14 was noticeable, but during winter the trend was reversed. The overall variation in pH between ponds was not significant.

Fig. 10 Total hardness

Fig. 11 Calcium

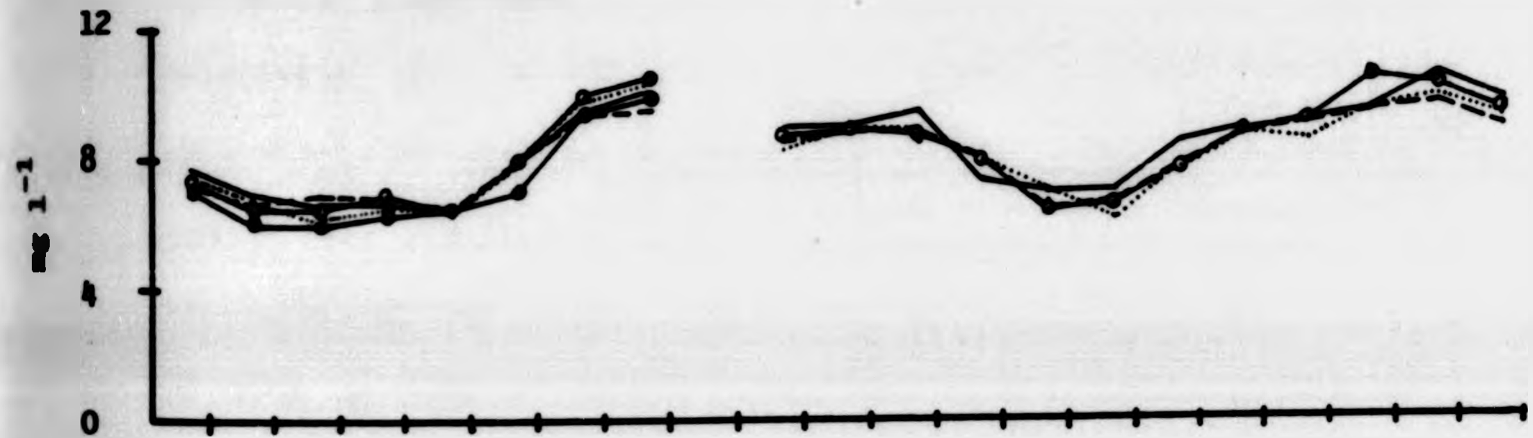
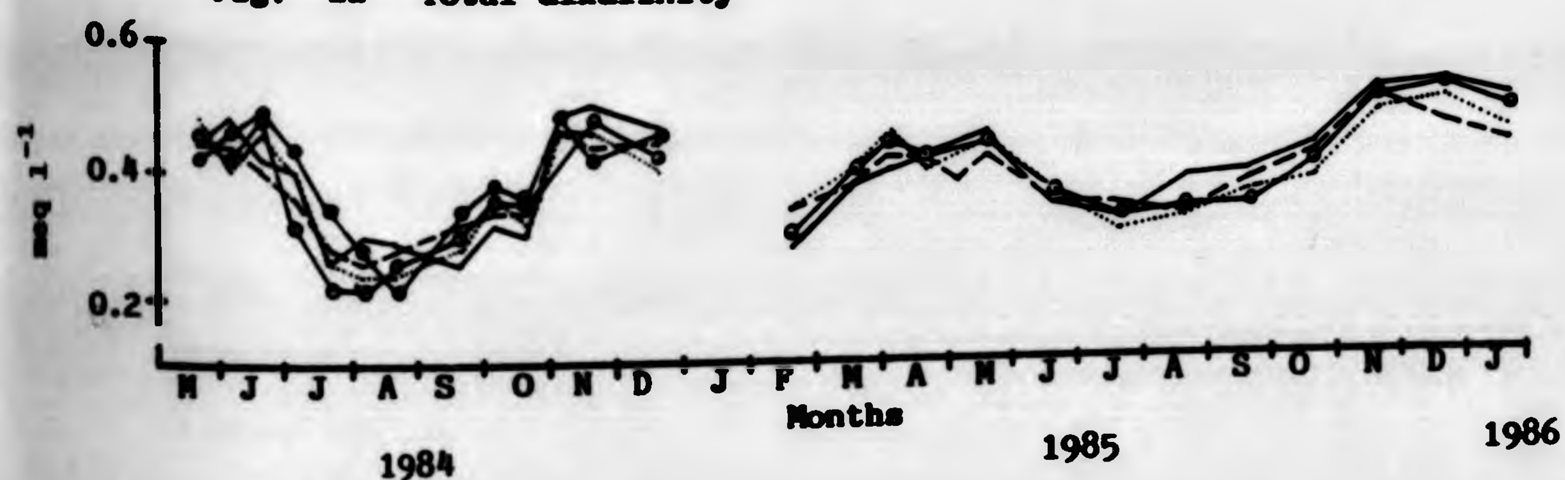


Fig. 12 Total alkalinity



Figs 10-12 Seasonal changes in total hardness, calcium and total alkalinity in Howietoun fish ponds (coding for ponds shown in Fig. 8)

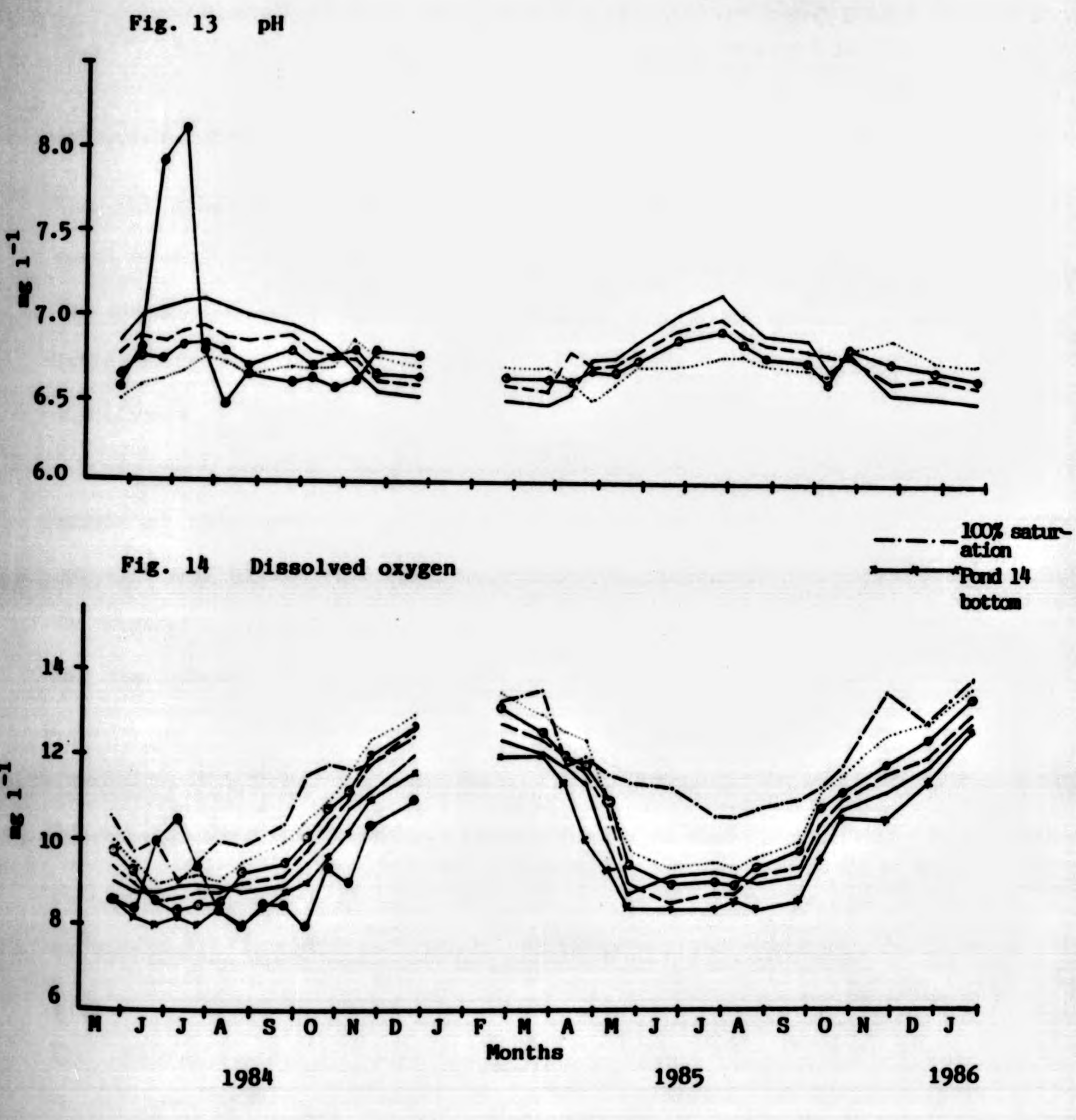
Diel fluctuation in pH level was distinguishable from Figs 22 and 23. pH values increased during the day and decreased during the night. The diurnal pattern of pH followed that of dissolved oxygen, as would be expected if both parameters reflected the balance between photosynthesis and community respiration.

4.1.1.1.8 Dissolved oxygen

Dissolved oxygen concentration (measured at mid-morning) was always relatively high in all the ponds. It showed a maximum variation of 0.8 mg l^{-1} between surface and bottom water during summer months and a very little difference in the rest of the year. Oxygen concentration was higher during winter, reaching a saturation level of 100% on some occasions, and lower in summer but never reached below 80% in any pond.

Oxygen gradually decreased from pond 7 to pond 14 throughout the year except during June and July, when a slight increase in surface oxygen was noticed in pond 14 which even exceeded ponds 11 and 13 (Fig. 14). Overall variation between ponds was highly significant according to two-way ANOVA (Table 3), but on the basis of paired t-tests the only significant difference was between pond 7 and 9 (Table 2).

There was a clear diurnal variation in dissolved oxygen concentration in both the seasons (Figs 22 and 23). The maximum dissolved oxygen was recorded in the afternoon and the minimum was before dawn.



Figs 13-14 Seasonal changes in pH and dissolved oxygen in Howietoun fish ponds (coding for ponds shown in Fig. 8)

The daily fluctuation of dissolved oxygen was 10.20 to 11.20 mg l^{-1} in summer.

4.1.1.1.9 Total ammonia

Fig. 15 shows a similar seasonal pattern of total ammonia in all ponds except pond 9, with peaks in spring and autumn in both years. The concentration of ammonia increased from pond 7 to pond 14, and Table 3 shows that the variation between the ponds was highly significant.

Values of diel changes in ammonia lay in the range of 317 to 350 $\mu g\ l^{-1}$ and 88 to 119 $\mu g\ l^{-1}$ in autumn and summer, respectively. The highest concentration of total ammonia was recorded in the evening and the lowest in the late night and early morning (Figs 22 and 23).

4.1.1.1.10 Un-ionised ammonia

Un-ionised ammonia never exceeded 1.6 $\mu g\ l^{-1}$ in any of the ponds. An increasing trend from pond 7 to pond 14 was detected (Fig. 16) and the difference between the ponds was highly significant (Table 3). Paired t-tests between ponds revealed that there was no significant difference between pond 9 and 7 but these were significantly different from the others (Table 2).

Fig. 15 Total ammonia

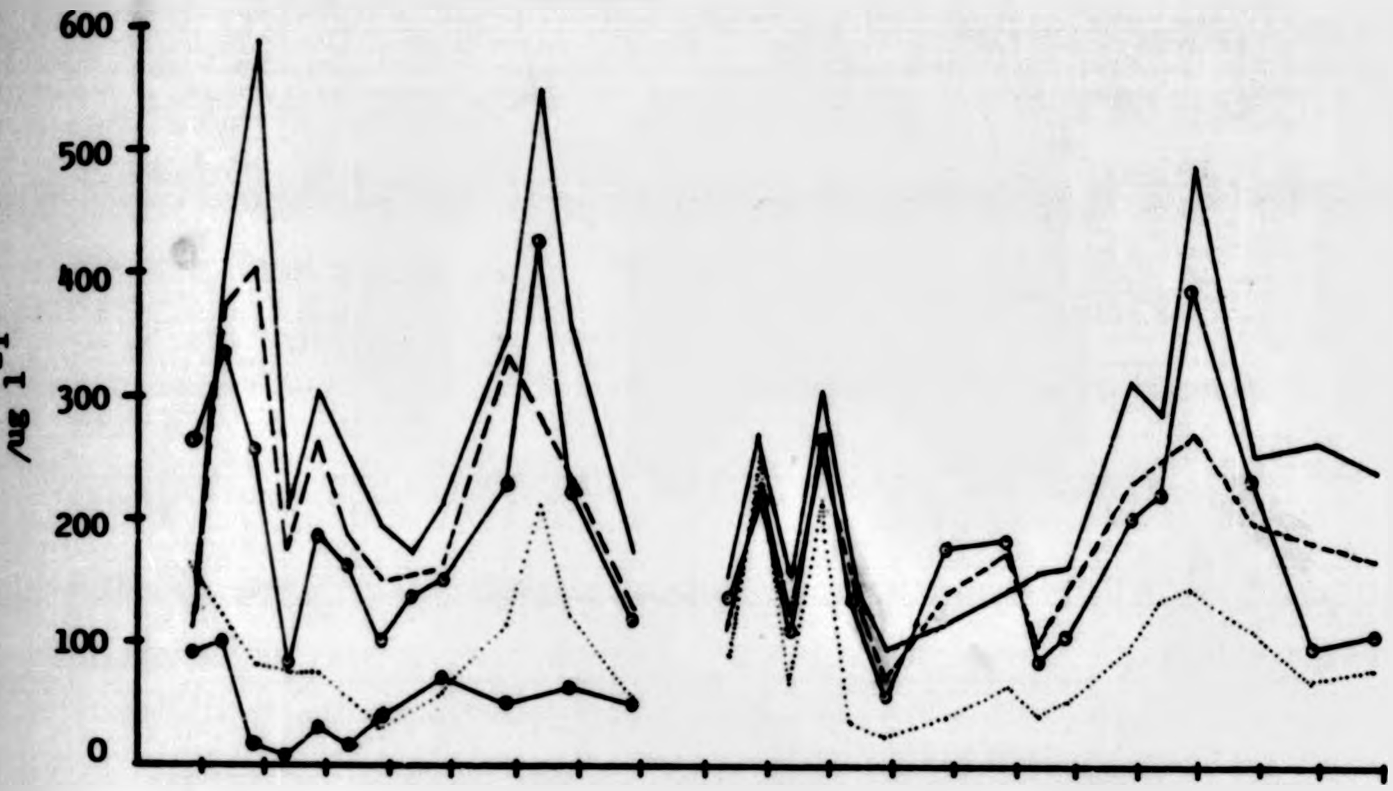
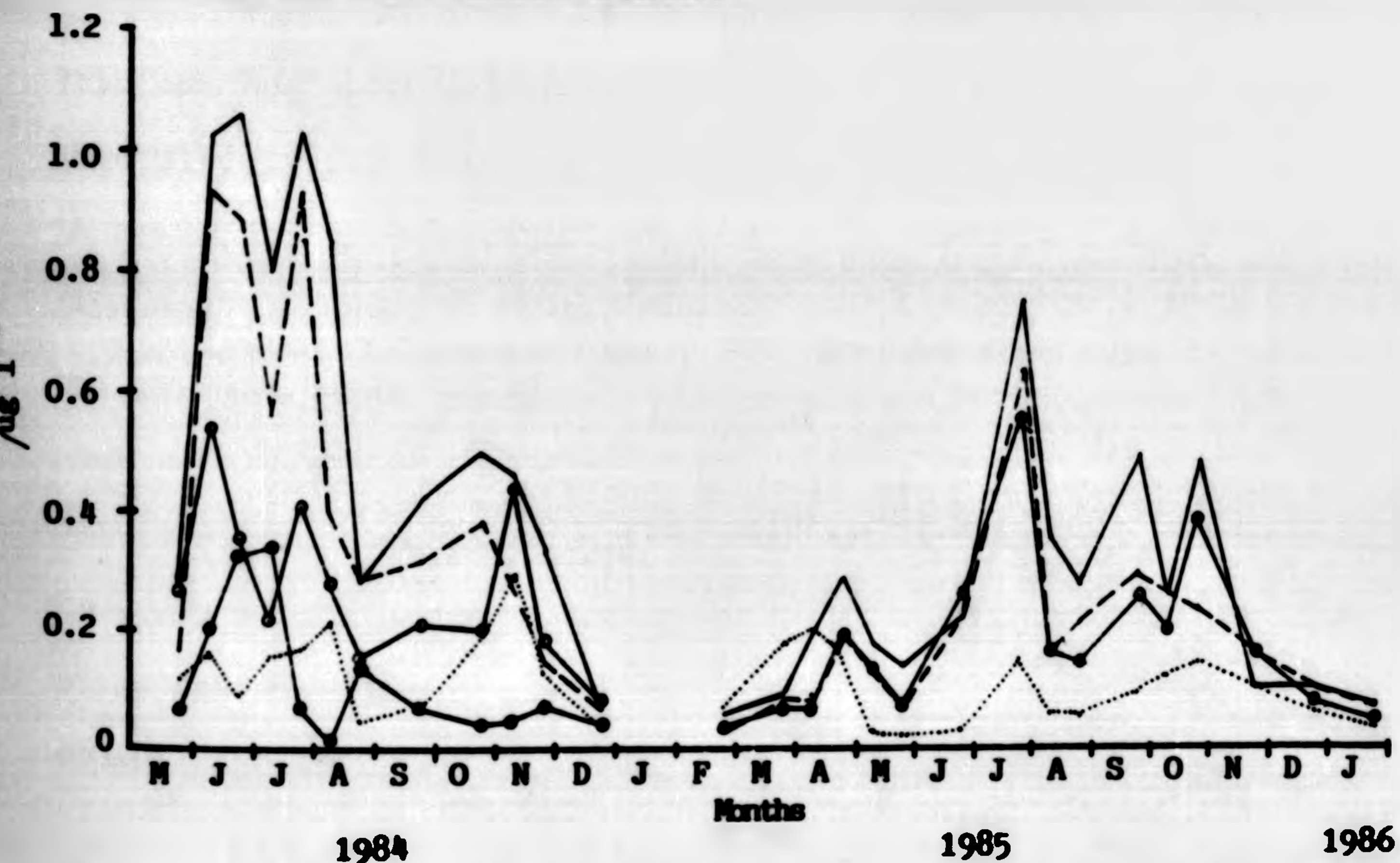


Fig. 16 Un-ionised ammonia



Figs 15-16 Seasonal changes in total ammonia and un-ionised ammonia in Howietoun fish ponds (coding for ponds shown in Fig. 8)

4.1.1.1.11 Nitrite

Nitrite showed two peaks in 1985, one in March to April and the other in September to November, compared with a single peak in September to November in 1984 (Fig. 17). As the water progressed through the farm, nitrite concentration increased from pond 7 to pond 14 and the difference between the ponds was highly significant (Table 3).

Diurnal concentration of nitrite showed a day time decrease and a night time increase in both summer and autumn (Figs 22 and 23).

4.1.1.1.12 Nitrate

This was the most dominant nutrient over all the nitrogenous and phosphatic nutrients measured in the ponds with a high concentration in winter and a low during summer (Fig. 18). Nitrate concentration increased from pond 7 to pond 14 and control pond 9 was well below the cultured ponds (Table 2). Two-way ANOVA demonstrated that the ponds were significantly different (Table 3).

Similarly to nitrite, nitrate was found to show a night time increase and a day time decrease over a 24 hour period in both summer and autumn (Figs 22 and 23).

4.1.1.1.13 Dissolved organic nitrogen

Even though the concentration registered did not present a clear

Fig. 17 Nitrite

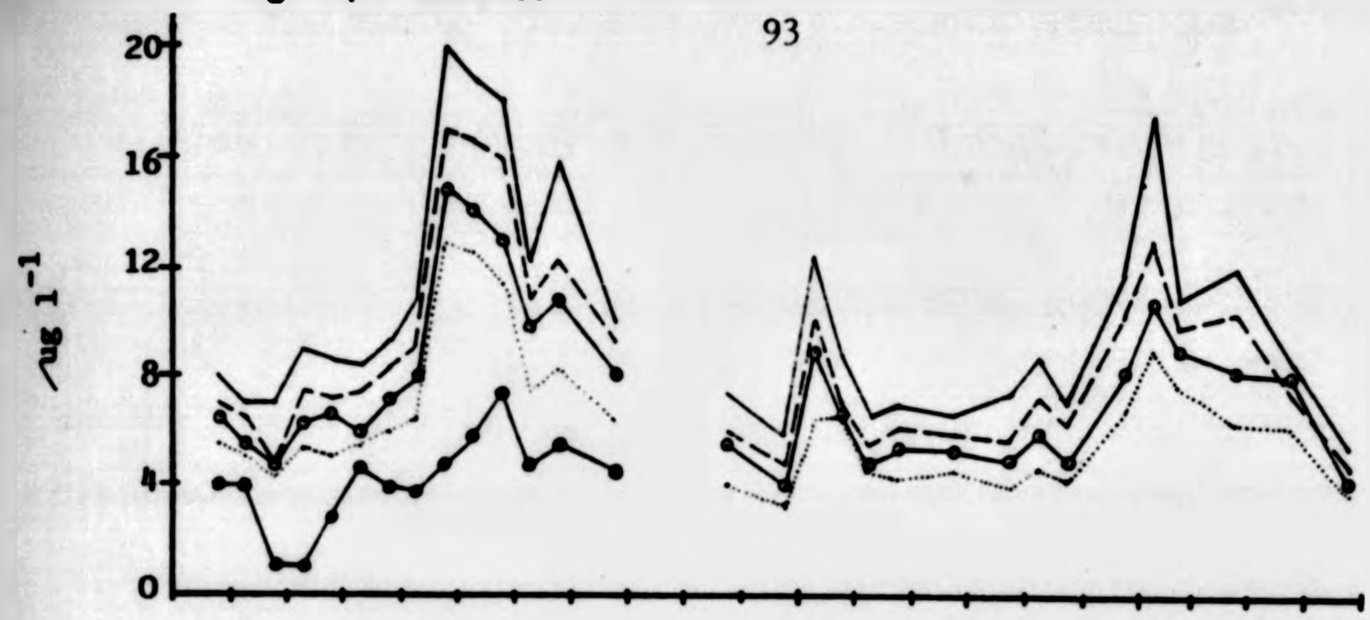


Fig. 18 Nitrate

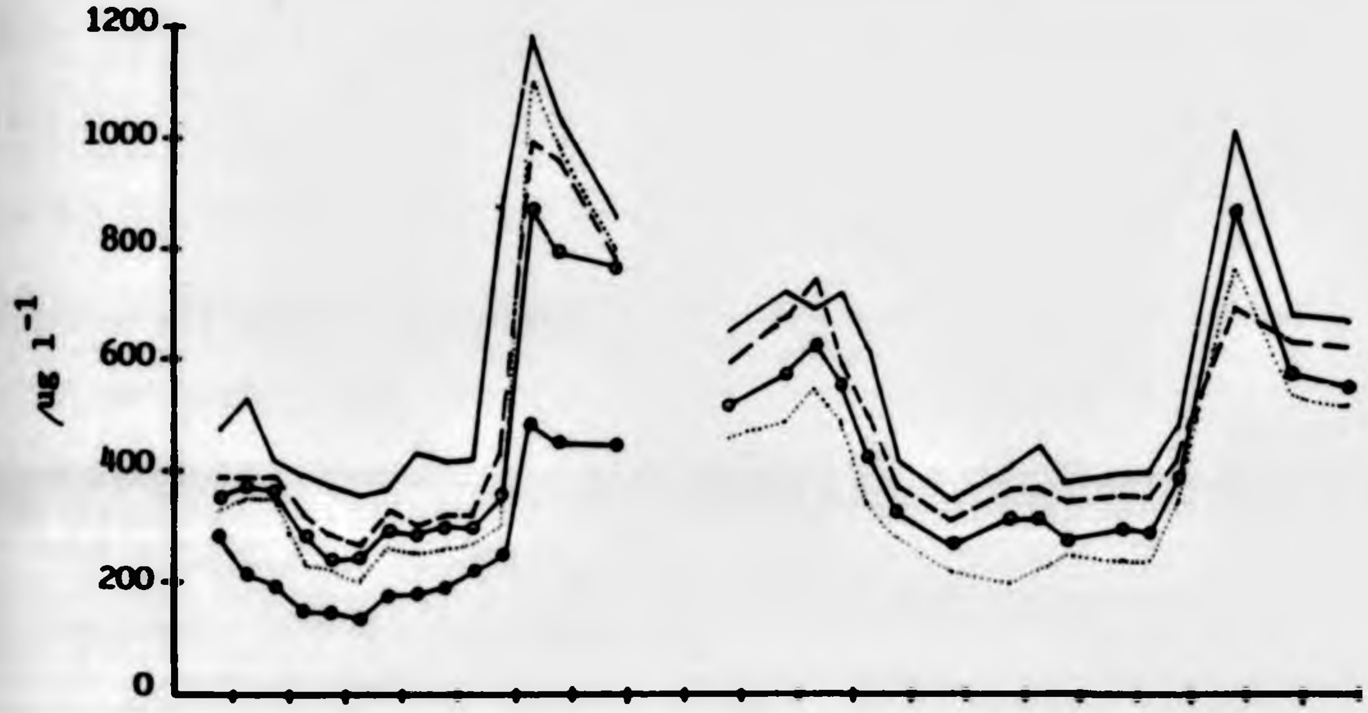
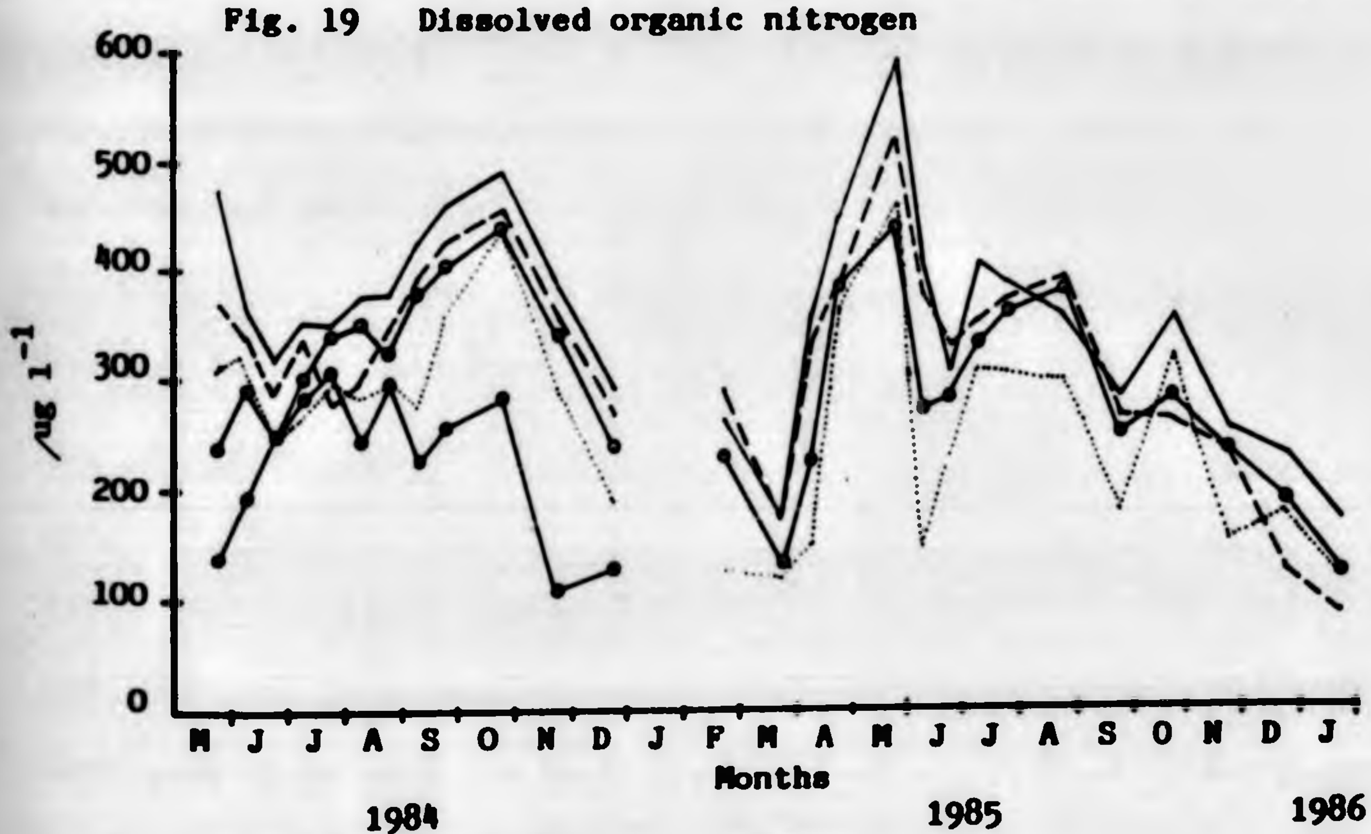
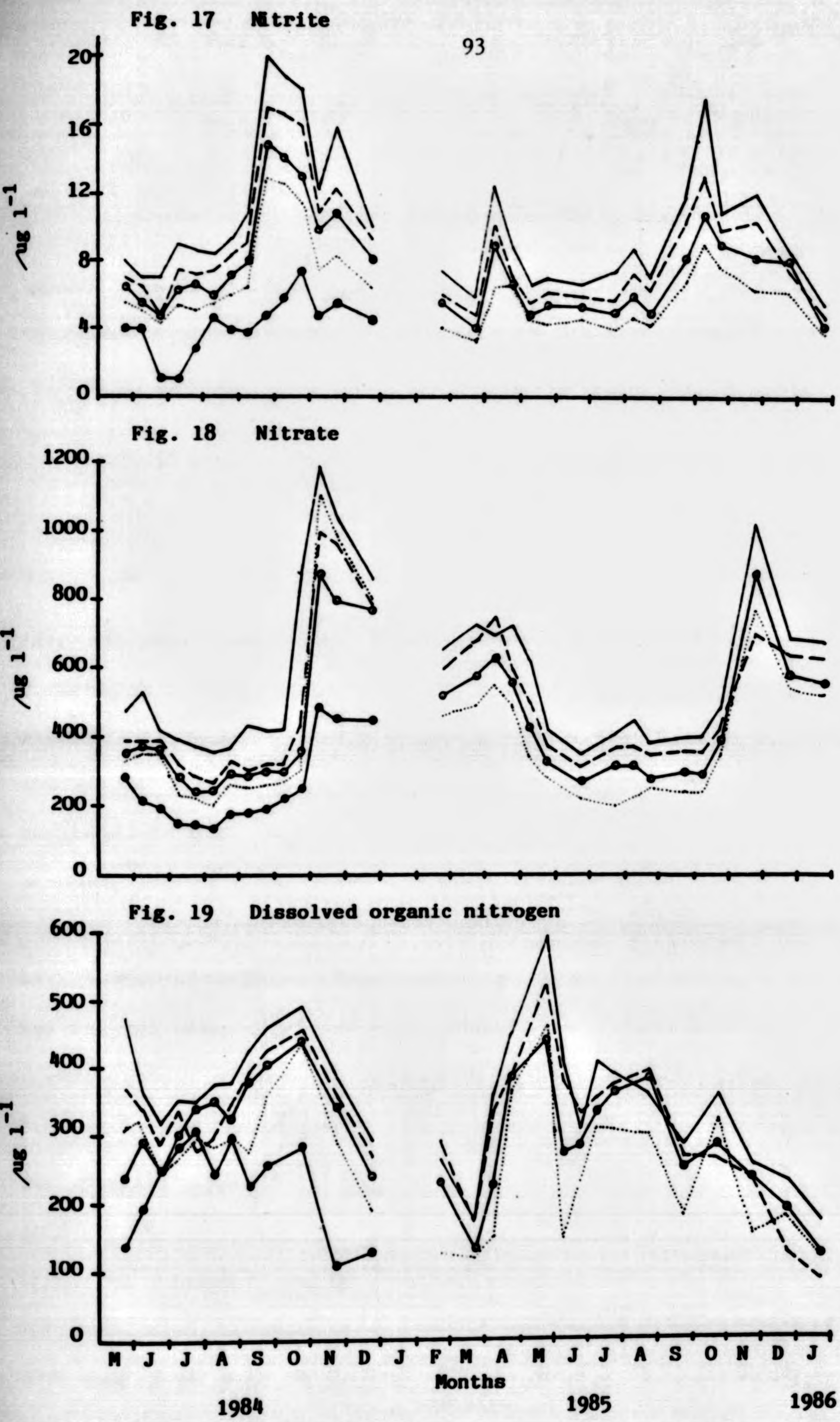


Fig. 19 Dissolved organic nitrogen



Figs 17-19 Seasonal changes in nitrite, nitrate and dissolved organic nitrogen in Howietoun fish ponds (coding for ponds shown in Fig. 8)



Figs 17-19 Seasonal changes in nitrite, nitrate and dissolved organic nitrogen in Howietoun fish ponds (coding for ponds shown in Fig. 8)

seasonal trend, it could be deduced from Fig. 19 that an increased concentration occurred in spring and early summer in 1985. In 1984 on the other hand, a high concentration was observed in autumn. Dissolved organic nitrogen had a decreasing trend in the winter.

Analysis of variance on log transformed data exhibited a highly significant difference between the ponds (Table 3).

4.1.1.1.14 Total phosphorus

Like all other nutrients, total phosphorus increased through pond 7 to pond 14 and the differences between the ponds was highly significant (Tables 2 and 3). An increased concentration in spring and autumn was prominent but an unusual summer increase was also noticeable in 1985 (Fig. 20). Such a seasonal trend was less distinct in 1984.

In the diurnal study, a relatively higher level of total phosphorus was detected after midnight (Figs 22 and 23).

4.1.1.1.15 Ortho-phosphate

Two distinct maxima, one in spring (March to May) and another in autumn (October to November) were observed for ortho-phosphate (Fig. 21). The seasonal trends were similar in all the cultured ponds and differed from pond 9. An increased concentration was found from pond 7 to pond 14, and the differences between the ponds was highly significant as revealed by two-way ANOVA (Table 3).

Fig. 20 Total phosphorus

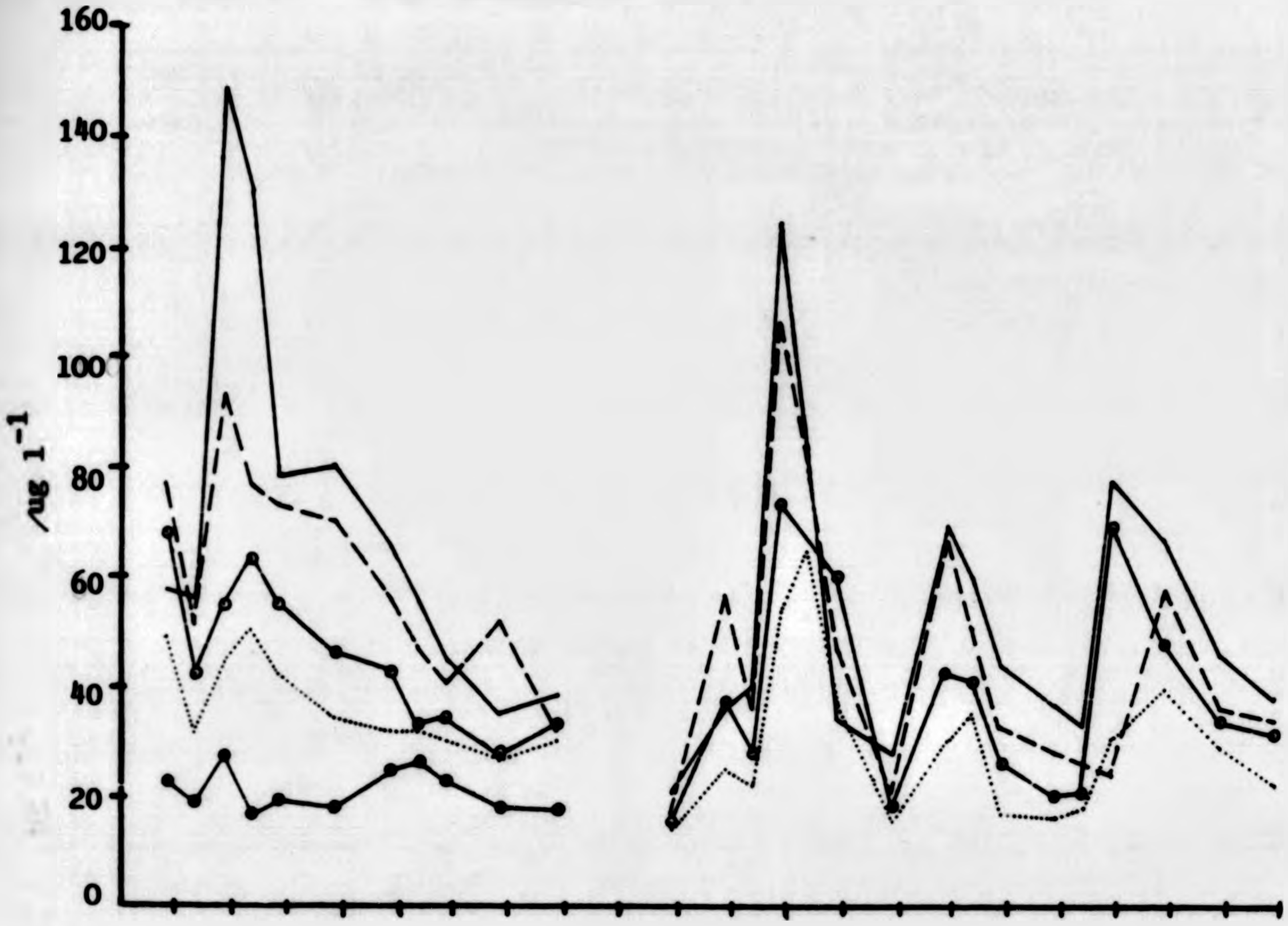
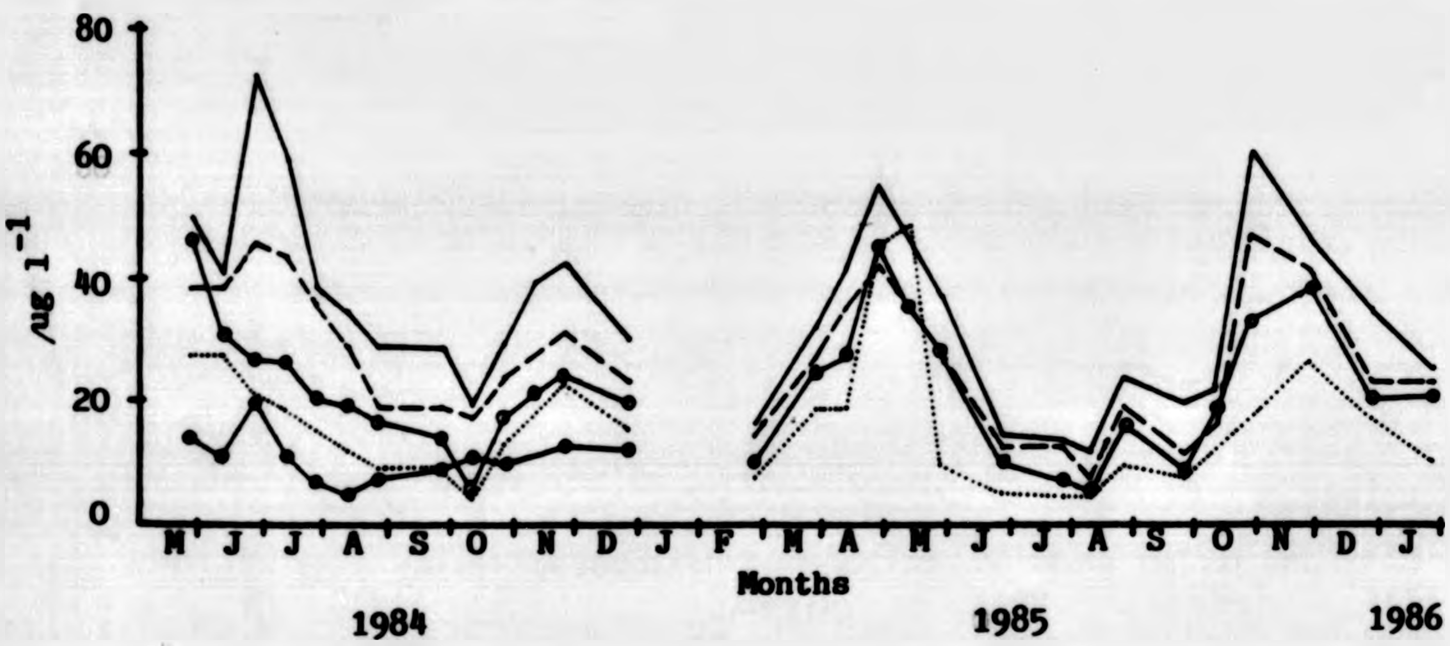


Fig. 21 Ortho-phosphate



Figs 20-21 Seasonal changes in total phosphorus and ortho-phosphate in Howietoun ponds(coding for ponds shown in Fig. 8)

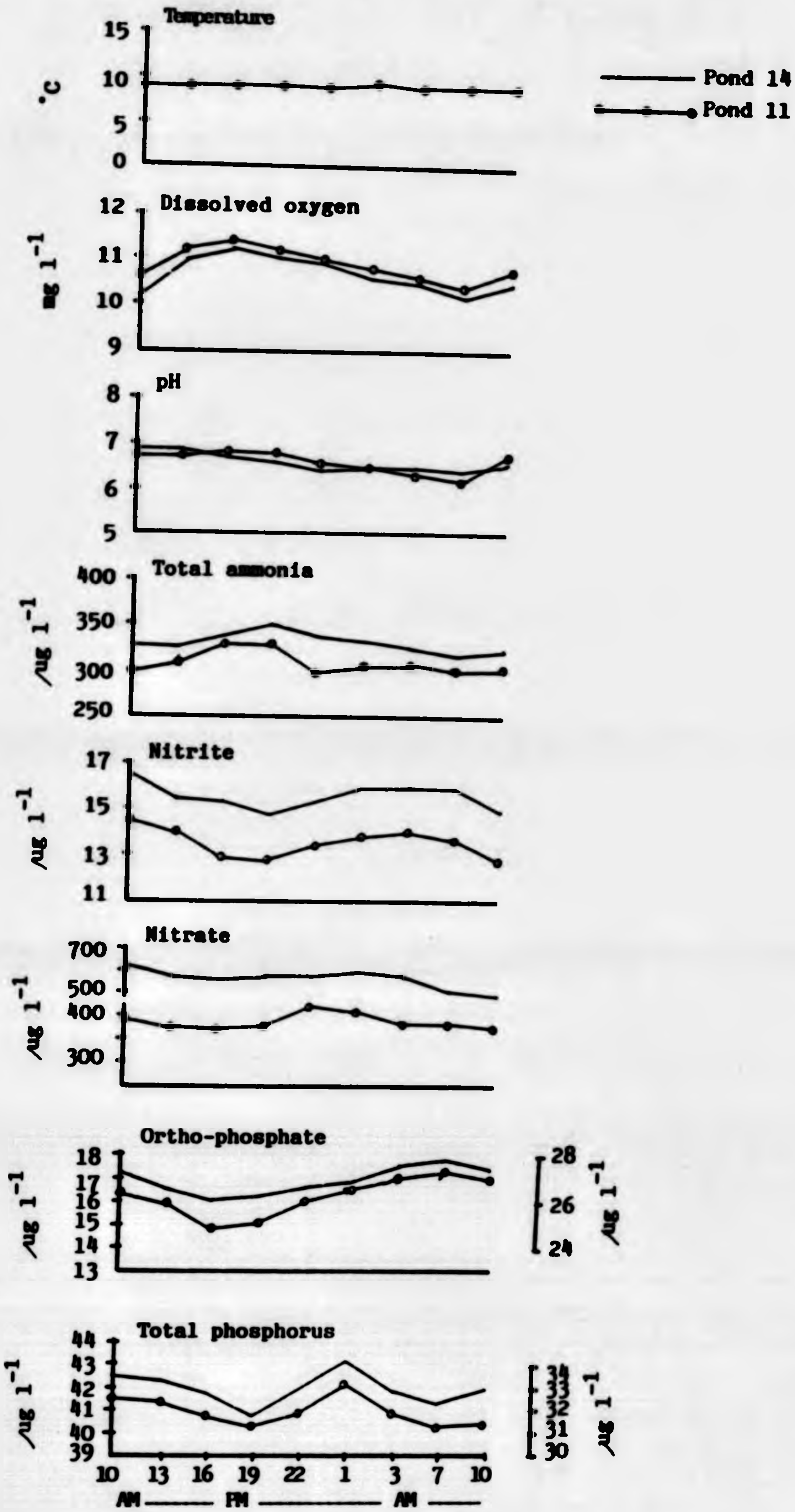


Fig. 22 Diurnal variation in physico-chemical characteristics of pond water in autumn (18-19 October, 1984)

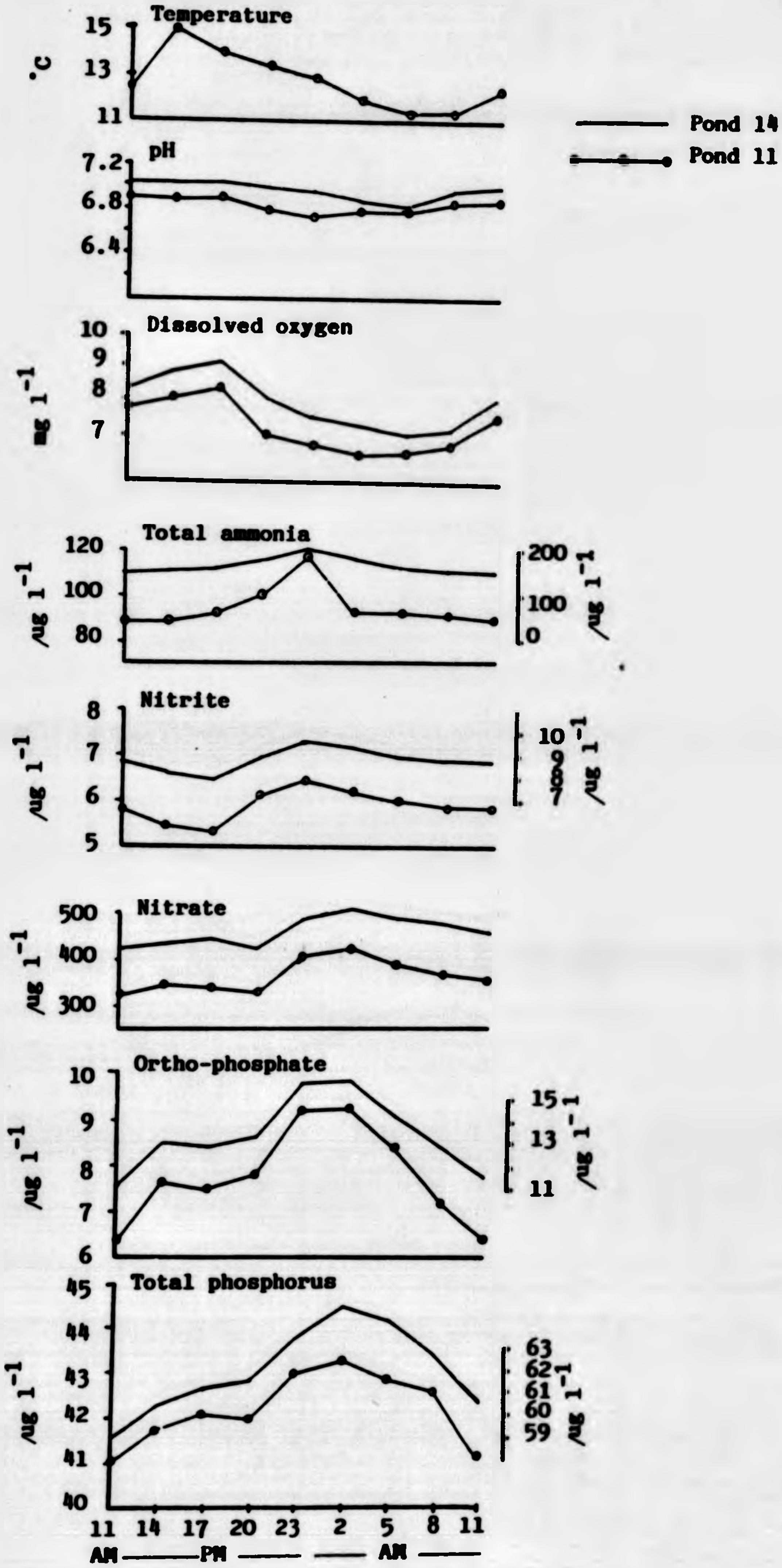


Fig. 23 Diurnal variation in physico-chemical characteristics of pond water in summer (19-20 July, 1985)

A night time increase and a day time decrease was found during the diurnal study (Figs 22 and 23).

4.1.1.2 Stream water

4.1.1.2.1 Total suspended solids

This shows a summer decrease and an autumn increase in both the stations (Fig. 24). The highest concentrations were recorded in November and September in 1984 and 1985, respectively. There was no significant difference between the stations when compared by a t-test (Table 5).

4.1.1.2.2 Particulate organic matter

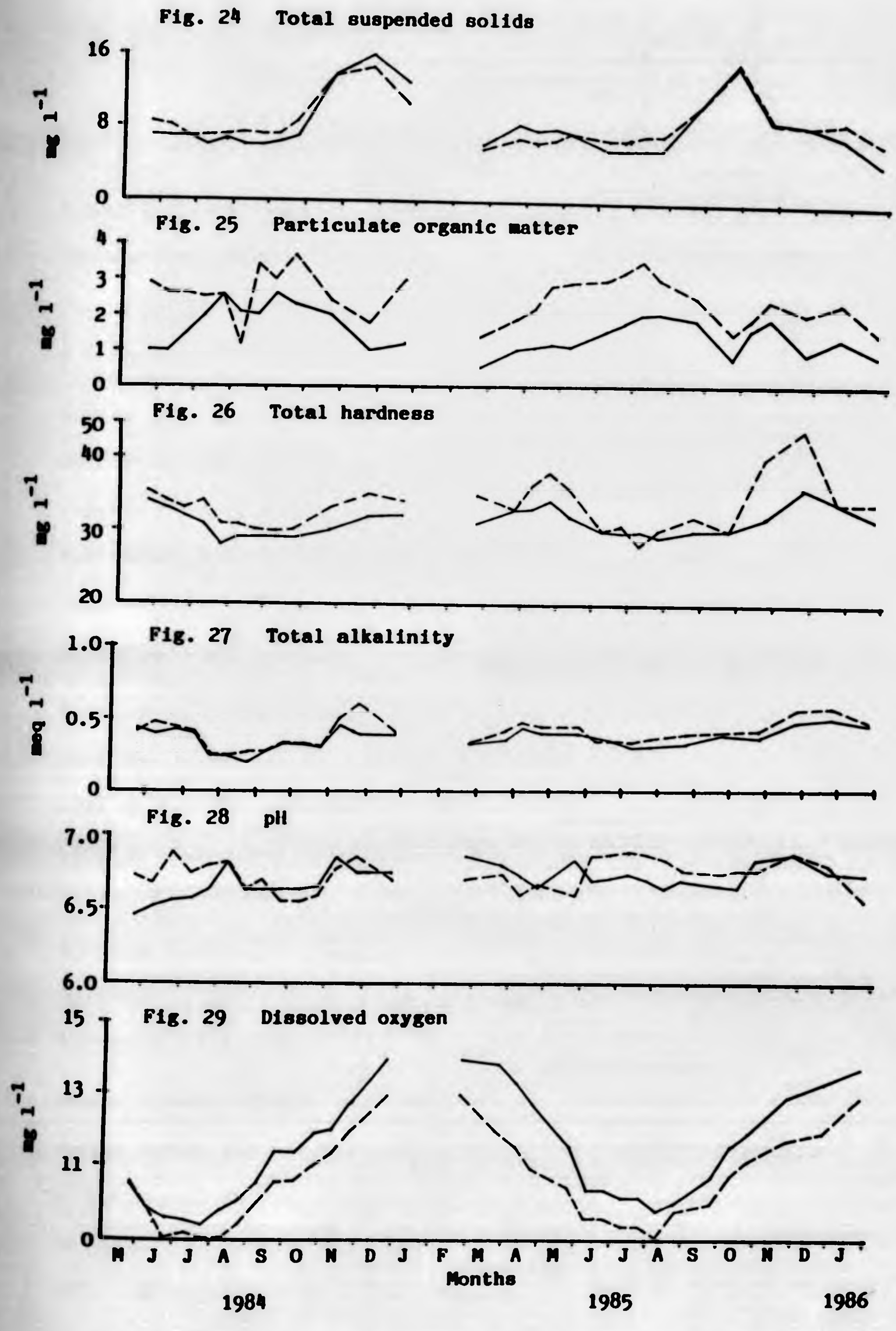
The seasonal trend in organic matter concentration was not distinct, but an autumn and summer increase in both the stations could be detected in 1984 and 1985 respectively (Fig. 25). Organic matter content was significantly higher at the outflow station 2 (Table 5).

4.1.1.2.3 Total hardness

Total hardness was higher in spring and late autumn, showing the highest concentration in November in both stations in both years (Fig. 26). A distinct summer decline was noticeable, paired t-test on log transformed data showed that stream station 2 had significantly higher ($P < 0.05$) concentration of total hardness.

Table 5 Overall annual mean of monthly values of stream water parameters and their level of significant (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**) difference between the stations as compared by t-tests on log transformed data

Chemical parameters of water	Mean ± Standard Error ($\bar{x} \pm$ S.E.) Stream St. 1 (Inflow)	Mean ± Standard Error ($\bar{x} \pm$ S.E.) Stream St. 2 (Outlfow)	Level of Significance
Total suspended solids (mg l^{-1})	8.78 ± 0.75	9.03 ± 0.63	N.S.
Particulate organic matter (mg l^{-1})	1.43 ± 0.13	2.44 ± 0.14	**
Total hardness (mg l^{-1})	31.50 ± 0.44	33.88 ± 0.80	*
Total alkalinity (meq. l^{-1})	0.37 ± 0.02	0.41 ± 0.02	N.S.
pH	6.70 ± 0.02	6.75 ± 0.02	N.S.
Dissolved oxygen (mg l^{-1})	11.70 ± 0.36	10.75 ± 0.31	*
Total ammonia (μg l^{-1})	65.0 ± 7.0	169.0 ± 19.0	**
Un-ionised ammonia (μg l^{-1})	0.06 ± 0.007	0.36 ± 0.09	**
Nitrate-nitrogen (μg l^{-1})	276.0 ± 17.0	439.0 ± 35.0	**
Nitrite-nitrogen (μg l^{-1})	4.86 ± 0.27	8.37 ± 0.69	**
Dissolved organic nitrogen (μg l^{-1})	181.60 ± 14.28	292.65 ± 23.70	**
Total phosphorus (μg l^{-1})	20.70 ± 1.29	39.10 ± 2.69	**
Ortho-phosphate (μg l^{-1})	8.65 ± 0.58	20.85 ± 1.29	**
Calcium (mg l^{-1})	8.05 ± 0.25	8.45 ± 0.30	N.S.



Figs 24-29 Seasonal changes in total suspended solids, particulate organic matter, total hardness, total alkalinity, pH and dissolved oxygen in stream water (continuous line = intake station 1; broken line = outflow station 2)

4.1.1.2.4 Calcium

Calcium ranged between 6.0 to 10.0 and 6.0 to 11.0 mg l^{-1} at stations 1 and 2, respectively. There was no significant difference between the stations (Table 5).

4.1.1.2.5 Total alkalinity

Similar to total hardness, this also presents a summer decrease and an increase in winter and spring months (Fig. 27). Although, station 2 apparently showed higher concentration, no significant difference could be established between the stations (Table 5).

4.1.1.2.6 pH

Hydrogen-ion concentration did not vary widely at any of the stations over the entire study period, and ranged between 6.46 to 6.89 and 6.56 to 6.90 in stations 1 and 2 respectively. Though the seasonal trend was not clear, an autumn decrease was observed in both stations and in both years (Fig. 28). No significant difference could be detected between the stations.

4.1.1.2.7 Dissolved oxygen

Stream waters always contained a high concentration of dissolved oxygen which was $>$100% saturation throughout the year except on a few occasions in summer months. A summer decline was observed in both the years, but it never fell below 95% saturation (Fig. 29). A significantly higher concentration of dissolved oxygen at inflow station 1 was observed (Table 5).

4.1.1.2.8 Total ammonia

This shows a great fluctuation within the stations. Fig. 30 presented a summer decrease and spring and autumn increase in both the stations in 1985. In 1984, the seasonal trend was not distinct at station 2, whereas station 1 showed a similar trend to that of 1985. Total ammonia differed significantly between the stations, having a higher concentration at station 2 than station 1 (Table 5).

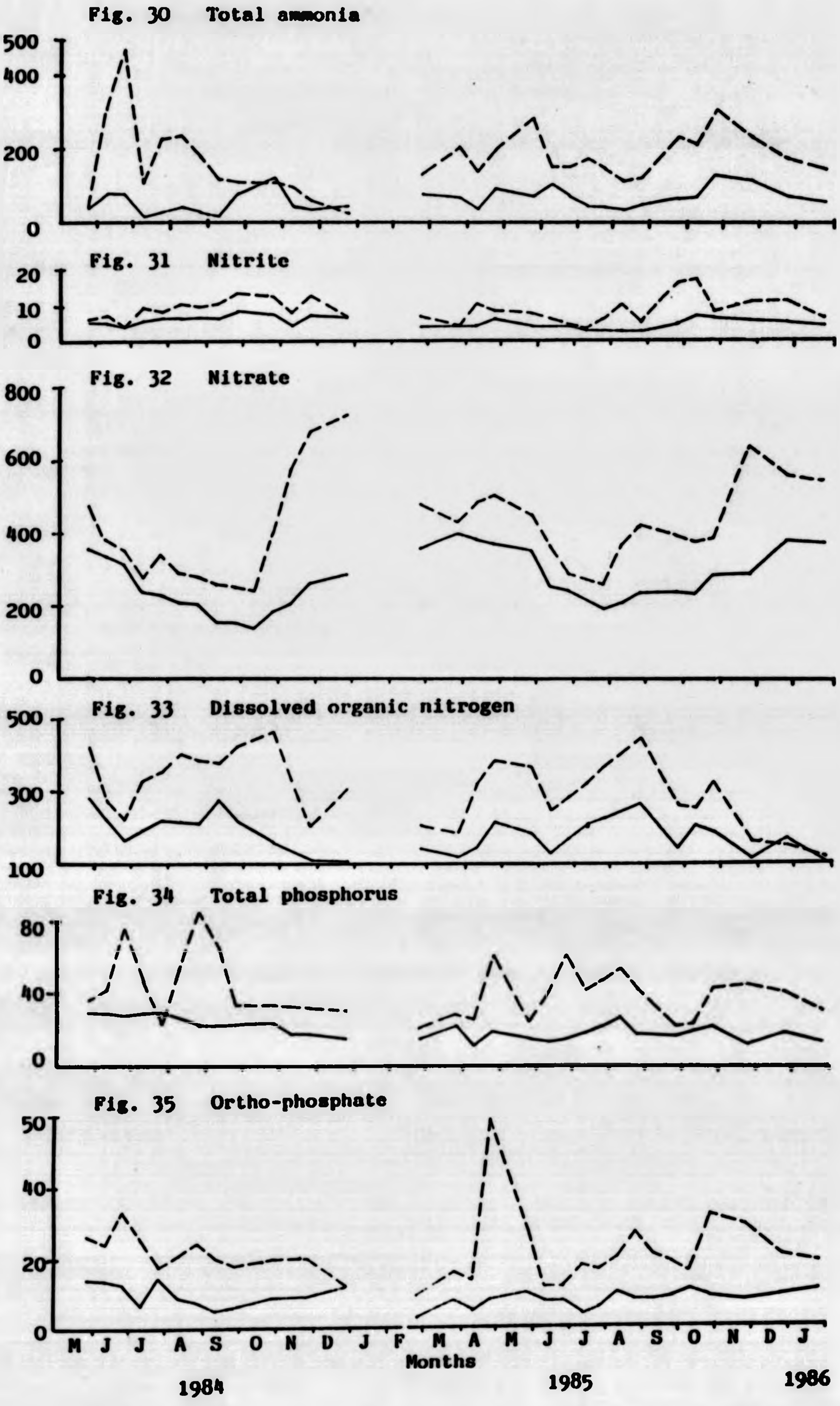
The level of un-ionised ammonia was lower at station 1, with a range of 0.02 to 0.17 $\mu g\ l^{-1}$, than at station 2 (0.03 to 2.59 $\mu g\ l^{-1}$). This difference was significant (Table 5).

4.1.1.2.9 Nitrite

Nitrite did not fluctuate greatly at station 1 and maintained a consistent low level throughout the period of the study. Station 2, on the other hand, showed seasonal variation with an autumn increase after a summer decline (Fig. 31). It was significantly higher at station 2 than station 1.

4.1.1.2.10 Nitrate

Nitrate levels were higher in spring and autumn at both stations and lower in summer (Fig. 32). Station 2 had a significantly higher mean value than station 1 (Table 5).



Figs 30-35 Seasonal changes in total ammonia, nitrite, nitrate, dissolved organic nitrogen, total phosphorus and ortho-phosphate in stream water (continuous line = intake station 1; broken line = outflow station 2)

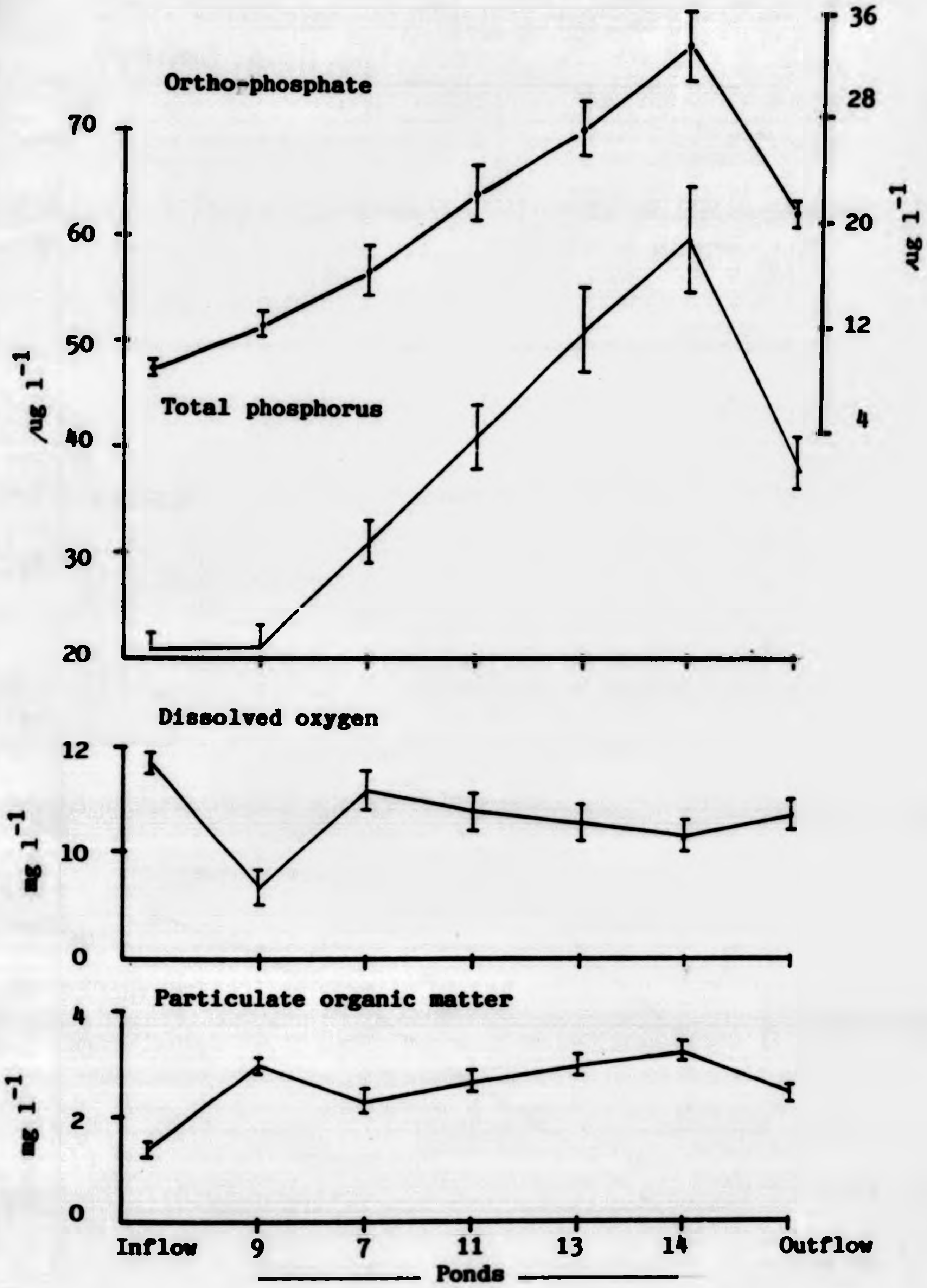


Fig. 36 Annual means of particulate organic matter, dissolved oxygen, total phosphorus and ortho-phosphate in pond and stream stations. Vertical bars indicate standard errors

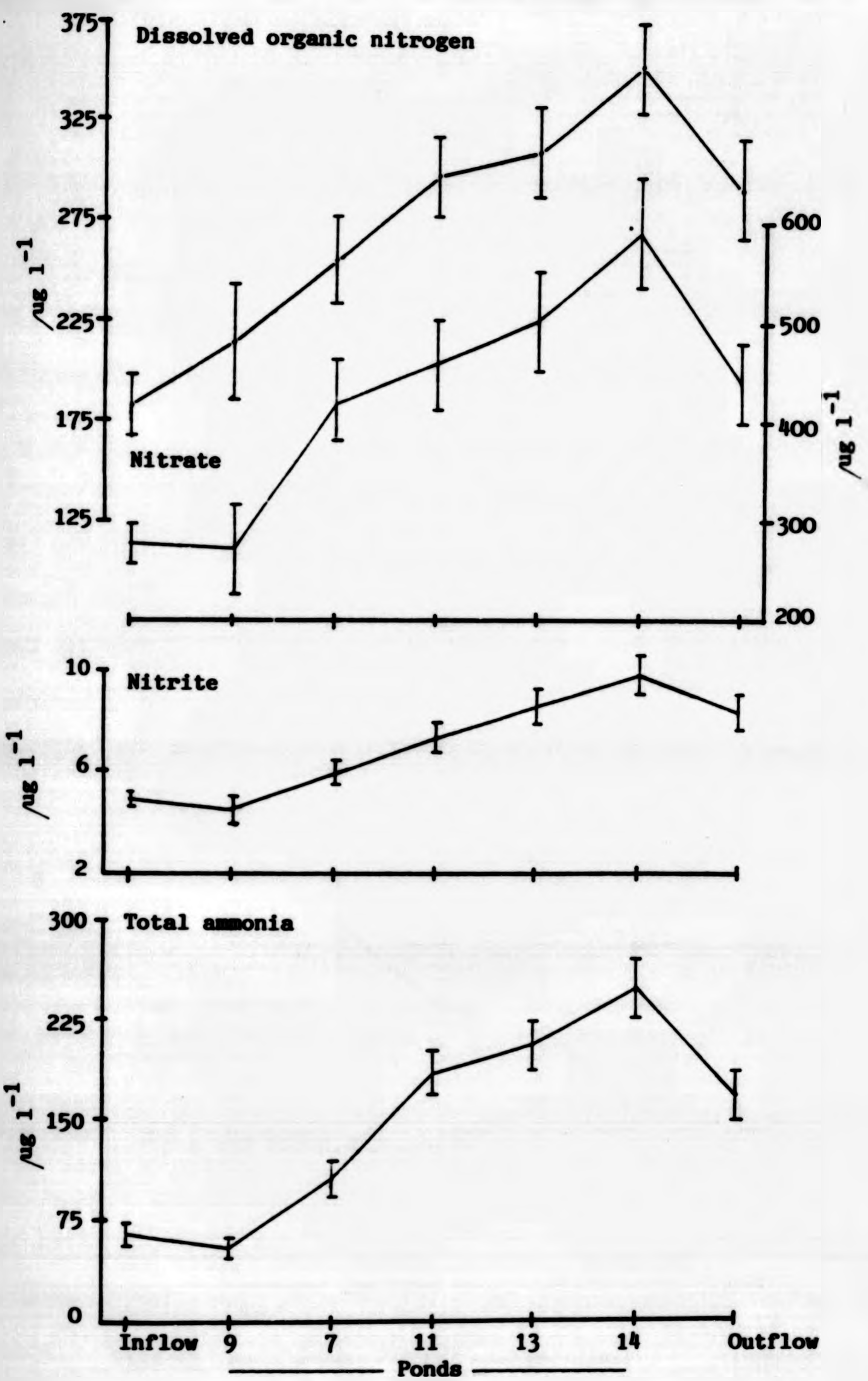


Fig. 37 Total ammonia, nitrite, nitrate and dissolved organic nitrogen in pond and stream stations. Vertical bars indicate standard errors

4.1.1.2.11 Dissolved organic nitrogen

Fig. 33 shows that a seasonal trend was not clearly established in both stations, a summer increase and a winter decrease was noticed. The difference between the stations was significant, showing a higher concentration at station 2 than station 1 (Table 5).

4.1.1.2.12 Total phosphorus

No distinct seasonal pattern could be detected, but some summer months showed higher concentrations (Fig. 34) between stations. The difference was highly significant, demonstrating higher total phosphorus at station 2 (Table 5).

4.1.1.2.13 Ortho-phosphate

This shows an irregular seasonal trend having the highest concentration in July, 1984 and in April, 1985 at station 1 and 2 respectively (Fig. 35). Ortho-phosphate was significantly higher in station 2 than station 1 as revealed by a t-test (Table 5).

4.1.2 Soil quality

The overall annual mean of monthly values of different soil parameters of all ponds are presented in Table 7. Coded results of paired t-tests between each pair of ponds are also indicated in the same table. Results of two-way ANOVAs of different soil parameters of cultured ponds (7, 11, 13 and 14) are summarized in Table 8.

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An attempt was made to evaluate the relationship between the nutrient content in the pond soils and those of the material collected by sediment traps, the results of which are presented in Table 10.

Stream soil parameters were tested by t-tests and their results along with means of monthly values are presented in Table 11.

4.1.2.1 Pond soils

4.1.2.1.1 Particle size distribution

The percentage composition of different sizes of particles and their corresponding size grades are shown in Table 6. The major components of pond soils were gravel and sand of different sizes. Among the cultured ponds, pond 11 contained the highest percentage of gravel, but pond 9 had an even higher percentage. Bottom soil of pond 7 had the greatest proportion of sand.

Most silt and clay was present in pond 14, while pond 9 had the least. According to standard soil classification diagram of Buchanan (1984) all 5 pond soils would be classified as 'silty gravelly sand'.

4.1.2.1.2 pH

Fig. 38 shows that pond soil pH varied within a narrow range of 5.0 to 6.0 in all ponds, except an increase of up to 6.40 in pond 13 and upto 6.30 in pond 9 in October to December in 1984. Though there was a significant monthly variation in pH level, summer having

Table 6 Particle size distribution in the bottom soils of all ponds and stream stations : Percentage composition and corresponding size grades

Wentworth Grades	Range of Diameter (mm)	Stream Station 1	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14	Stream Station 2
Gravel	$>$2,000	27.0	31.0	23.0	28.0	22.0	22.0	35.0
Very coarse sand	1,000-2,000	32.5	31.54	22.85	27.61	21.87	17.58	35.14
Coarse sand	500-1,000	16.0	18.46	18.86	14.73	21.87	26.11	16.72
Medium sand	250-500	6.77	7.76	13.18	9.24	12.78	10.48	9.82
Fine sand	125-250	5.52	6.24	13.11	11.42	10.48	8.68	2.32
Very fine sand	63-125	4.90	2.49	3.84	5.45	5.52	5.23	0.35
Silt and clay	$<$63	7.30	2.51	5.16	3.55	5.48	9.92	0.65

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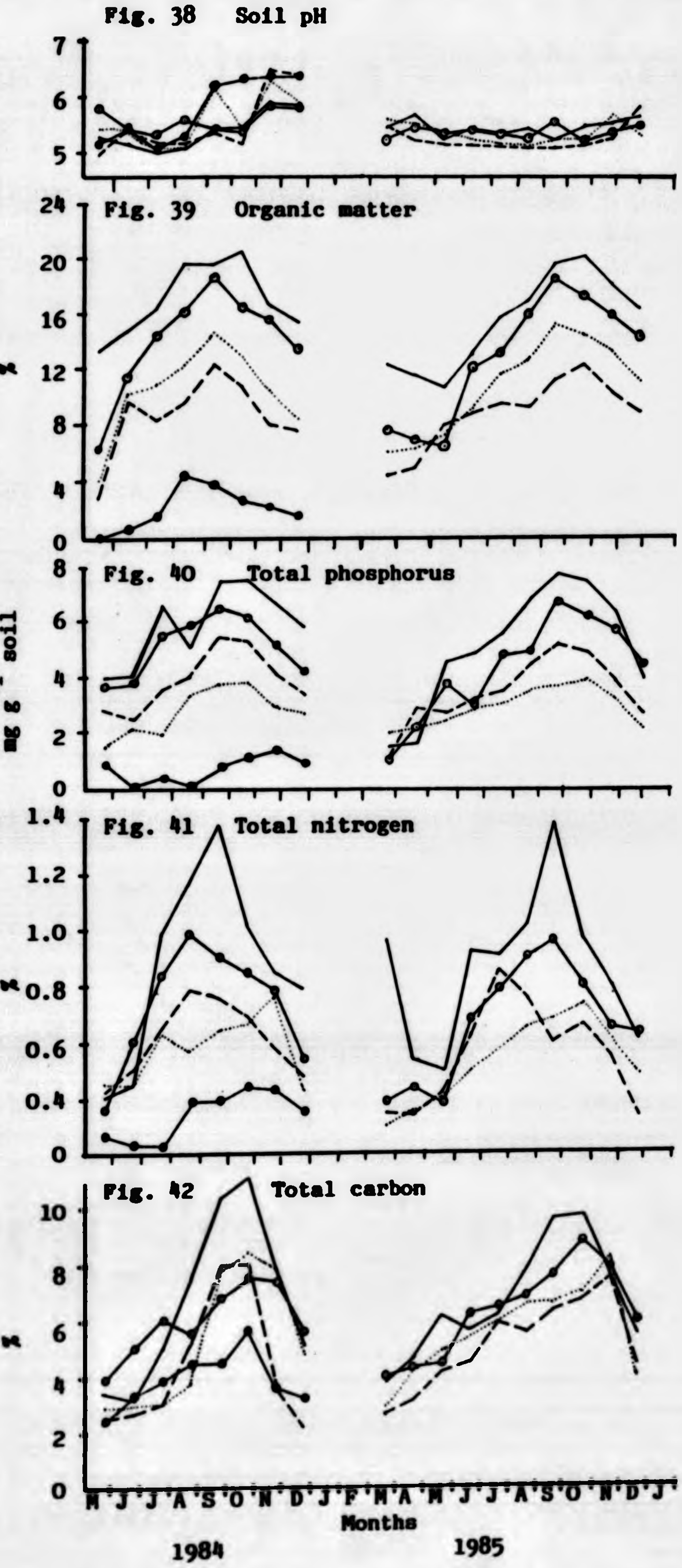
Gravel	$>2,000$	27.0	31.0	23.0	28.0	22.0	22.0	35.0
Very coarse sand	1,000-2,000	32.5	31.54	22.85	27.61	21.87	17.58	35.14
Coarse sand	500-1,000	16.0	18.46	18.86	14.73	21.87	26.11	16.72
Medium sand	250-500	6.77	7.76	13.18	9.24	12.78	10.48	9.82
Fine sand	125-250	5.52	6.24	13.11	11.42	10.48	8.68	2.32
Very fine sand	63-125	4.90	2.49	3.84	5.45	5.52	5.23	0.35
Silt and clay	<63	7.30	2.51	5.16	3.55	5.48	9.92	0.65



Figs 38-42 Seasonal changes in pH, organic matter content, total phosphorus, total nitrogen and total carbon in the Howietoun fish ponds (coding for ponds shown in Fig. 8)

Table 7 Overall annual mean of monthly values and standard errors of each soil parameter in the ponds during May 1984 to December 1985. Superscript letters indicate the significant differences ($P < 0.05$) between the ponds on the basis of paired t-tests on log transformed data. Values with the same superscript are not significantly different

Soil parameters	Pond 9	Pond 7	Pond 13	Pond 11	Pond 14
pH	5.72 ± 0.21	5.41 ± 0.08	5.42 ± 0.11	5.43 ± 0.04	5.40 ± 0.06
Organic matter (% dry wt.)	6.19 ± 0.55^{a}	14.65 ± 0.77^{b}	12.75 ± 0.60^{b}	17.48 ± 0.97^{c}	20.34 ± 0.73^{d}
Total phosphorus ($mg\ g^{-1}$ dry soil)	2.68 ± 0.17^{a}	4.89 ± 0.18^{b}	5.71 ± 0.28^{c}	6.71 ± 0.37^{cd}	7.49 ± 0.44^{d}
Total nitrogen (% dry wt.)	0.35 ± 0.03^{a}	0.55 ± 0.03^{b}	0.57 ± 0.04^{bc}	0.69 ± 0.05^{cd}	0.87 ± 0.09^{d}
Total carbon (% dry wt.)	3.89 ± 0.36^{a}	5.42 ± 0.46^{ac}	4.80 ± 0.46^{a}	6.16 ± 0.33^{bc}	6.68 ± 0.57^{c}
C/N ratio	11.57 ± 1.06^{a}	9.88 ± 0.57^{ab}	8.48 ± 0.68^{bcd}	9.26 ± 0.40^{bc}	7.92 ± 0.48^{d}
N/P ratio	1.3 ± 0.01	1.1 ± 0.005	1.0 ± 0.005	1.0 ± 0.005	1.2 ± 0.01

comparatively lower pH, there was no significant variation between the ponds (Table 8).

4.1.2.1.3 Organic matter

Fig. 39 shows that the organic matter content in the pond mud was always higher in the cultured ponds than in the control pond 9. Organic matter gradually increased throughout the summer to a peak during autumn. It increased from pond 7 to pond 14, pond to pond differences being highly significant (Table 8).

A significant positive correlation was observed between organic matter content in the soil and sedimenting materials (Table 10).

4.1.2.1.4 Total phosphorus

Total phosphorus showed similar seasonal trends to that of organic matter (Fig. 40). Pond 14 contained the highest total phosphorus in the soil and pond 9 the least. Cultured ponds were significantly different as revealed by two-way ANOVA (Table 8). When the ponds were compared, all of them were different from each other except ponds 11 and 14 (Table 7).

Bottom soil total phosphorus of ponds 13 and 14 were found to be positively correlated with that of sedimenting materials (Table 10).

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4.1.2.1.3 Organic matter

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Bottom soil total phosphorus of ponds 13 and 14 were found to be positively correlated with that of sedimenting materials (Table 10).

Table 8 F-values and their associated levels of significance for two-way ANOVAs on pond (7, 11, 13 & 14) soil parameters (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**)

Soil parameters	Type of transformation needed	Sources of Variation			
		Between Ponds	(F)	Between Months	(F)
pH	log	0.427	N.S.	6.033	**
Organic matter	log	97.16	**	23.08	**
Total phosphorus	log	40.17	**	14.40	**
Total nitrogen	log	26.0	**	11.94	**
Total carbon	log	16.53	**	15.82	**
C/N ratio	log	4.59	**	4.17	**
N/P ratio	-	1.87	N.S.	1.69	N.S.

Table 8 F-values and their associated levels of significance for two-way ANOVAs on pond (7, 11, 13 & 14) soil parameters (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**)

Soil parameters	Type of transformation needed	Sources of Variation			
		Between Ponds	(F)	Between Months	(F)
pH	log	0.427	N.S.	6.033	**
Organic matter	log	97.16	**	23.08	**
Total phosphorus	log	40.17	**	14.40	**
Total nitrogen	log	26.0	**	11.94	**
Total carbon	log	16.53	**	15.82	**
C/N ratio	log	4.59	**	4.17	**
N/P ratio	-	1.87	N.S.	1.69	N.S.

4.1.2.1.5 Total nitrogen

Fig. 41 shows that each of the ponds had its own pattern of seasonal changes, showing higher values in autumn except pond 13, which showed an earlier peak in summer. Pond 9 was well below the other ponds. The differences between the ponds was highly significant (Table 8).

Total nitrogen in the pond soil was positively correlated with that of sedimenting materials in the fish ponds (Table 10).

4.1.2.1.6 Total carbon

Table 7 and Fig. 42 show the mean total carbon in different ponds and the seasonal trend respectively. Similar to other bio-elements (P and N) total carbon also reached a peak during the autumn months. F-values indicated a highly significant difference between the ponds (Table 8). Paired t-tests showed that ponds 9, 7 and 13 were not significantly different and so were the ponds 7, 11 and 14 (Table 7).

4.1.2.1.7 C/N and N/P ratio

Carbon:Nitrogen ratio decreased from pond 7 to pond 14 and pond 9 had the highest value (Table 7). Ponds were significantly different on the basis of C/N ratio (Table 8).

The nitrogen:phosphorus ratio was not significantly different between

Table 9 Mean of monthly values and results of two-way ANOVAs on log transformed data of different parameters of sedimenting materials collected from three cultured ponds (11, 13 & 14) (N.S. non-significant; $P \angle 0.05$, *; $P \angle 0.01$, **)

Sediment parameters	Pond 11	Pond 13	Pond 14	Sources of Variation			
				Between Ponds	(F)	Between Months	(F)
Rate of sedimentation ($g\ m^{-2}\ day^{-1}$ dry wt.)	119.88 ± 15.90	35.48 ± 6.12	112.54 ± 17.13	70.86	**	9.47	**
Organic matter (% dry wt.)	19.03 ± 1.11	16.34 ± 0.70	19.63 ± 1.70	7.08	**	7.77	**
Total phosphorus ($mg\ g^{-1}$ dry wt.)	10.56 ± 0.48	6.99 ± 0.47	10.94 ± 0.53	15.68	**	8.47	**
Total nitrogen (% dry wt.)	0.85 ± 0.04	0.72 ± 0.09	0.93 ± 0.09	8.32	**	8.64	**
Total carbon (% dry wt.)	7.57 ± 0.26	7.13 ± 0.46	8.34 ± 0.52	4.30	*	4.63	*
C/N ratio	9.06 ± 0.56	10.67 ± 1.15	9.30 ± 0.84	2.06	N.S.	6.08	*
N/P ratio	0.80 ± 0.02	0.79 ± 0.08	0.85 ± 0.07	0.542	N.S.	2.49	N.S.

the ponds (Table 8) and it remained around 1.0 in all the ponds.

4.1.2.1.8 Sedimenting materials

The mean of monthly values of rate of sedimentation and nutrient content in the sedimenting materials and results of ANOVAs are summarized in Table 9.

The rate of sedimentation varied from pond to pond and month to month. The highest sedimentation rate was observed in pond 11 and the lowest in pond 13, the differences between the ponds being highly significant (Table 9).

Organic matter content in the sedimenting materials was higher in pond 14 and lower in pond 13, the differences between the ponds being highly significant (Table 9).

Similar to organic matter content, total phosphorus, total nitrogen and total carbon were also higher in concentration in pond 14 and lower in pond 13 and between ponds differences were significant (Table 9).

4.1.2.2 Stream soil

4.1.2.2.1 Particle size distribution

Table 6 shows that stream stations differed greatly on the basis of particle size distribution. There was more silt and clay in the ponds (Table 8) and it remained around 1.0 in all the ponds.

4.1.2.1.8 Sedimenting materials

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4.1.2.2 Stream soil

4.1.2.2.1 Particle size distribution

Table 6 shows that stream stations differed greatly on the basis of particle size distribution. There was more silt and clay in

Table 10 Results of correlation coefficients between nutrient contents in the pond soils and those of sedimenting materials (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**) as performed on log transformed data

Variables	Pond 11	Pond 13	Pond 14
Organic matter	0.785 *	0.721 N.S.	0.619 N.S.
Total phosphorus	0.442 N.S.	0.839 *	0.936 **
Total nitrogen	0.946 **	0.845 *	0.929 **
Total carbon	0.744 N.S.	0.602 N.S.	0.980 **

Table 11 Overall annual mean of monthly values of stream soil parameters and the level of significant difference ($P < 0.05$,*; $P < 0.01$,**) between the stations as compared by t-tests on log transformed data

Soil parameters	$\bar{x} \pm$ S.E. Stream station 1	Stream station 2	Level of significance
pH	5.29 ± 0.08	6.07 ± 0.08	**
Organic matter	6.31 ± 0.17	3.30 ± 0.35	**
Total phosphorus	2.73 ± 0.07	2.07 ± 0.08	**
Total nitrogen	0.32 ± 0.02	0.20 ± 0.01	**
Total carbon	3.04 ± 0.18	1.74 ± 0.09	**

station 1 than in station 2, whereas the latter contained larger amounts of gravels and sands than the former. According to the standard soil classification diagram, stream station 1 was 'silty gravelly sand' and station 2 was 'gravelly sand'.

4.1.2.2.2 pH

Stream soil pH ranged from 4.60 to 5.60 and 5.70 to 6.90 in station 1 and 2 respectively. t-test showed a highly significant difference between the stations (Table 11).

4.1.2.2.3 Nutrient contents in stream soils

Table 11 shows that organic matter, total phosphorus, total nitrogen and total carbon were significantly higher in stream station 1 than station 2.

4.2 The Benthic Macro-invertebrates

As listed in Table 12, 14 groups of different benthic macro-invertebrates, consisting of 41 genera, were recorded from Howietoun fish farm ponds and adjacent stream (Sauchieburn) stations during 20 May 1984 to 23 January 1986. Apart from some rarely occurring individuals, the total benthic macro-invertebrates mainly consisted of six major groups of animals, which were found to occur consistently throughout the year, some of them appearing in very large numbers. Therefore, the term 'benthic macro-invertebrates' (or conveniently 'benthos') was used to describe all organisms under these six groups.

Table 12 Species list of benthic macro-invertebrates from Howietoun fish farm ponds and adjacent steam stations. (+) indicates presence and (-) indicates absence of a species.

Species	Stream st. 1	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14	Stream st. 2
OLIGOCHAETAE							
Tubificidae							
Tubifex tubifex (Muller)	+	+	+	+	+	+	+
Limnodrilus hoffmeisteri (Claparede)	+	+	+	+	+	+	+
L. udekemianus (Claparede)	+	+	+	+	+	+	+
Psammoryctides barbatus (Grube)	+	+	+	+	+	+	+
T. ignotus (Stole)	-	+	+	+	+	+	+
Aulodrilus pluriseta (Piguet)	+	-	-	-	+	+	-
Lumbriculidae							
Lumbriculus variegatus (Muller)	+	+	+	+	+	+	+
Naididae							
Ophidonais serpentina (Muller)	+	-	-	-	+	+	+
Stylaria lacustris (L.)	+	-	-	-	+	+	-
Nais variabilis (Piguet)	-	-	-	-	+	+	-
CHIRONOMIDAE							
Chironominae							
Chironomus anthracinus (Zetterstedt)	*	+	+	+	+	+	*
C. plumosus (L.)	+	+	+	+	+	+	+
C. venustus (Staeger)	*	+	+	+	+	+	*
Clodoploma sp. Kieffer)	-	-	+	+	+	+	-
Glyptotendipes pallens (Meigen)	-	+	+	+	+	+	-
Micropsectra lindrothi (Goetghebuer)	+	-	+	+	+	+	-
M. atrofasciata (Kieffer)	+	-	+	+	+	+	-

* either or both these species present

Table 12 continued

Species	Stream st. 1	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14	Stream st. 2
Microtendipes chloris (Meigen)	-	+	+	+	+	-	-
Paratendipes sp. (Kieffer)	+	-	+	+	+	-	-
Polypedilum sp. (Kieffer)	+	+	+	+	+	+	-
Tanytarsus lestagei (Goetghebuer)	-	+	+	+	+	+	+
T. pallidicornis (Walker)	-	+	+	+	+	+	+
Tanypodinae							
Ablabesmyia monilis (L.)	-	+	+	+	+	+	-
Guttipelopia sp. (Fittkau)	-	-	+	+	+	-	+
Macropelopia sp. (Thienemann)	+	-	+	-	-	-	+
Tanypus sp. (Meigen)	-	-	-	-	+	-	-
Procladius choreus (Meigen)	+	+	+	+	+	+	+
Diamesinae							
Diamesa sp. (Meigen)	-	-	-	-	-	-	+
Orthocladinae							
Tvetenia verralli (Edw.)	-	-	-	-	-	-	-
Prodiamesinae							
Prodiamesa olivacea (Meigen)	+	+	+	+	+	+	+
SIMULIDAE							
Simulium sp.	+	-	-	-	-	-	+
CHAOBORIDAE							
Chaoborus flavicans (Meigen)	-	+	-	-	-	-	+
HYDROPSYCHIDAE							
Hydropsche sp.	+	-	-	-	-	-	+
LIMNEPHILIDAE							
Stenophylax lateralis (Stephens)	-	-	-	+	-	-	-

Table 12 continued

Species	Stream st. 1	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14	Stream st. 2
Drussus annulatus (Stephens)	-	-	-	-	-	-	+
Limnius sp.	-	-	-	-	-	-	+
BAETIDAE							
Baetis rhodoni (Pietet)	+	-	-	-	-	-	+
CORIXIDAE							
Corixa sp.	-	+	-	-	-	-	-
SIALIDAE							
Sialis lutaria (L.)	+	+	+	+	+	+	+
TIPULIDAE							
Dicranota sp.	+	-	-	-	-	-	-
ASELLIDAE							
Asellus aquaticus (L.)	+	+	+	+	+	+	+
GAMMARIDAE							
Gammarus pulex (L.)	+	-	-	-	-	-	-
MOLLUSCA							
GASTROPODA							
Lymnaeidae							
Lymnaea peregra (Muller)	+	+	+	+	+	+	-
Planoirbidae							
Planorbis vortex (L.)	-	-	-	+	+	+	+
BIVALVIA							
Sphaeriidae							
Sphaerium corneum (L.)	+	+	+	+	+	+	+

Table 12 continued

Species	Stream st. 1	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14	Stream st. 2
Drussus annulatus (Stephens)	-	-	-	-	-	-	+
Limnius sp.	-	-	-	-	-	-	+
BAETIDAE							
Baetis rhodoni (Pictet)	+	-	-	-	-	-	+
CORIXIDAE							
Corixa sp.	-	+	-	-	-	-	-
SIALIDAE							
Sialis lutaria (L.)	+	+	+	+	+	+	+
TIPULIDAE							
Dicranota sp.	+	-	-	-	-	-	-
ASELLIDAE							
Asellus aquaticus (L.)	+	+	+	+	+	+	+
GAMMARIDAE							
Gammarus pulex (L.)	+	-	-	-	-	-	-
MOLLUSCA							
GASTROPODA							
Lymnaeidae							
Lymnaea peregra (Muller)	+	+	+	+	+	+	-
Planorbidae							
Planorbis vortex (L.)	-	-	-	+	+	+	+
BIVALVIA							
Sphaeriidae							
Sphaerium corneum (L.)	+	+	+	+	+	+	+

Table 12 continued

Species	Stream st. 1	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14	Stream st. 2
HIRUDINEA							
Glossiphoniidae							
Glossiphonia complanata (L.)	-	-	-	-	+	+	+
Helobdella stagnalis	+	+	+	+	+	+	+
Erpobdellidae							
Erpobdella octoculata (L.)	+	+	+	+	+	+	+

Both the groups and the dominant species in each of the groups were compared and contrasted between stations and between times, using different statistical analyses, such as paired t-test, two-way ANOVA and the Student-Newman-Keuls multiple range test (SNK). All these statistical tests were performed on original data (number of animals in replicate samples). Whenever necessary, data were log transformed in order to homogenise variances before carrying out any of the above statistical tests.

Temporal patterns of the benthic animal groups or of individual species were shown by graphical representation, for which data were converted into numbers per m^2.

Fig. 43 shows a summary picture of the mean annual population density of major groups of benthic animals from different sampling stations.

4.2.1 Pond Benthic Fauna

As mentioned above, six major groups, viz., Oligochaeta, Chironomidae, Mollusca, Hirudinea, Asellidae and Sialidae comprised the total benthic macro-invertebrates in Howietoun fish farm ponds. The relative contribution of each of these groups in the total monthly population are presented in Fig. 46 (a-e).

Fig. 44 shows the two seasonal peaks of total benthic fauna in different ponds, one in summer (June to August) and another in autumn (October to November) in both years.

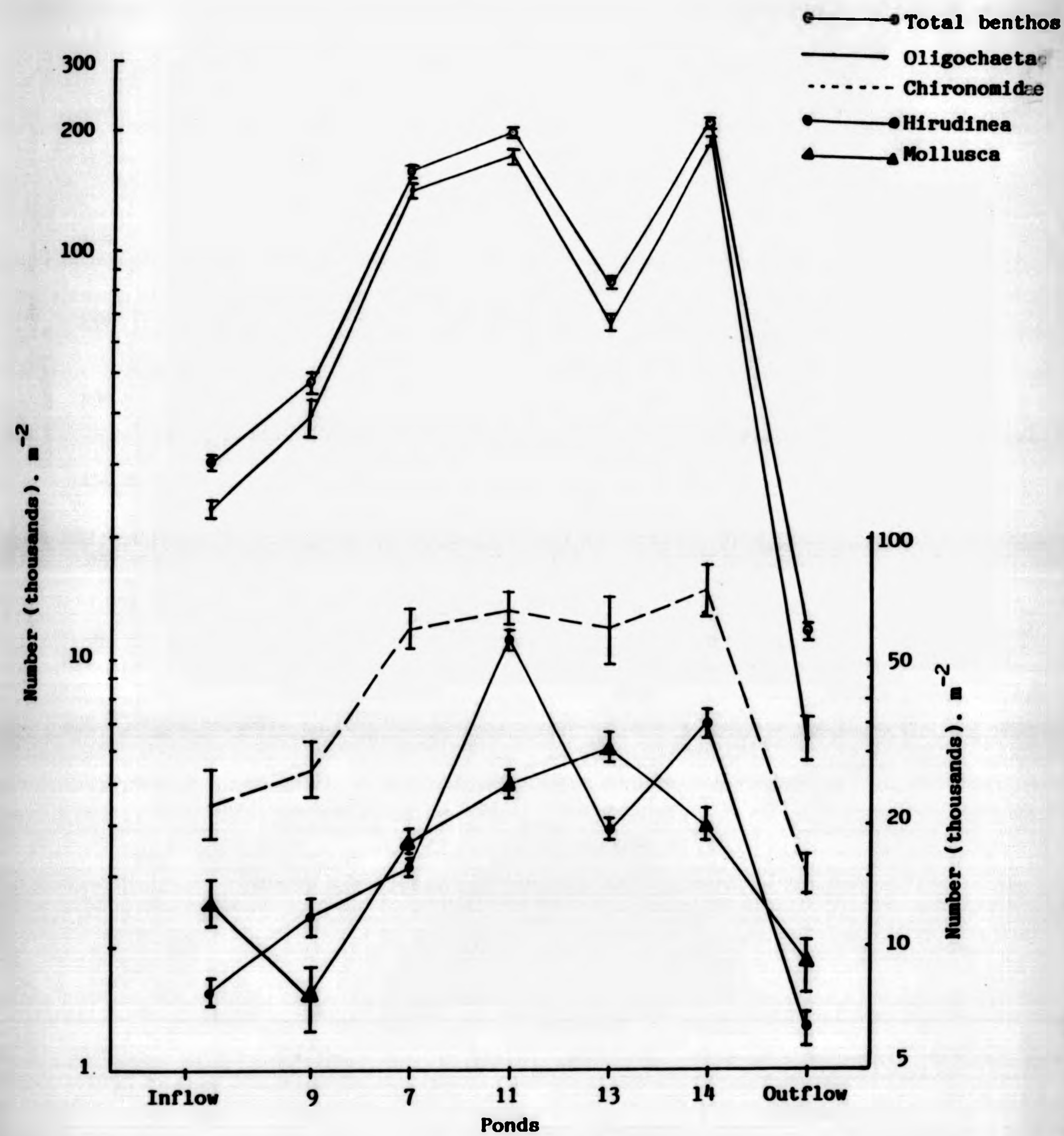

Fig. 43 Summary of the mean annual population density of major groups of benthos in different sampling stations (vertical bars represent ± standard errors)

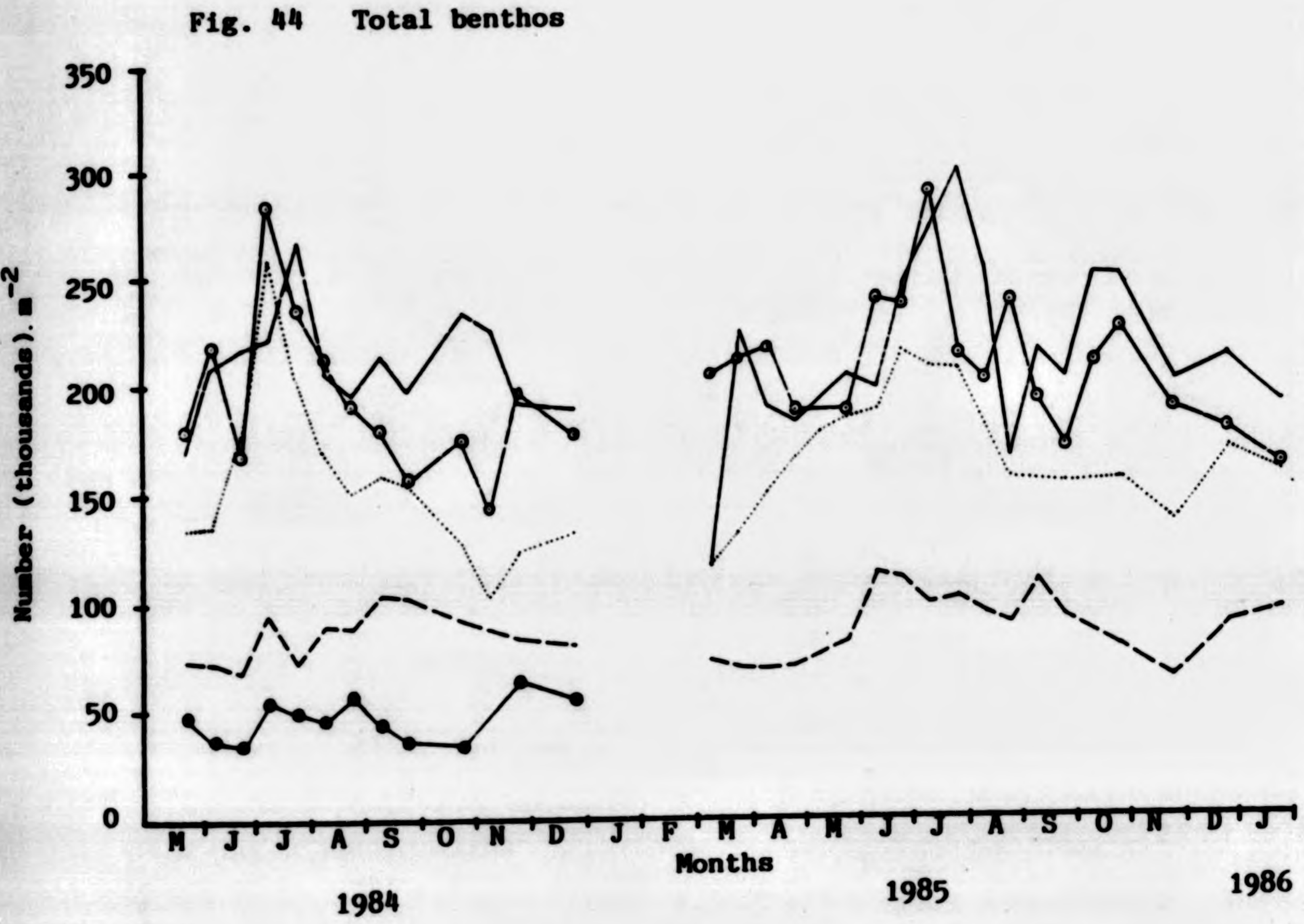

Fig. 44 Seasonal changes in total benthic macro-invertebrates in Howietoun fish ponds (coding for ponds shown in Fig. 8)

Table 13 Correlation Matrix of soil and water parameters and benthic animal groups from all cultured ponds (P<0.05,*; P<0.01,**)

Benthic animal groups	Water Parameters											Soil
	Temp.	Total Hardness	Calcium	Total Alkalinity	Particulate Organic Matter	DO	Nitrate	Nitrite	Un-ionised Ammonia	Dissolved Organic Nitrogen	Phosphate Phosphorus	Organic Matter
Oligochaeta	0.212*	-0.204*	-0.127	-0.066	0.129	-0.210*	-0.072	-0.091	-0.121	0.088	-0.034	0.557**
Chironomidae	-0.110	-0.099	0.003	-0.197*	-0.027	-0.058	-0.204*	0.329**	0.054	0.055	-0.147	0.386
<u>Chironomus</u> sp.	-0.168	0.064	0.187	0.002	-0.124	-0.023	-0.010	0.437**	+0.036	-0.012	-0.048	0.473*
Mollusca	0.458**	-0.320**	-0.490**	-0.276**	0.438**	-0.599**	-0.386**	-0.056	0.299**	0.315**	0.002	-0.149
Hirudinea	0.074	-0.072	-0.136	-0.172	0.092	-0.090	0.099	0.030	0.030	0.209*	0.059	0.290
Asellidae	0.107	-0.164	-0.162	-0.158	0.174	-0.264**	-0.146	-0.010	-0.097	0.143	-0.083	0.024
Sialidae	0.598**	-0.635**	-0.548**	-0.507**	0.442**	-0.689**	-0.594**	-0.120	0.390**	0.269**	-0.226*	0.262
Total benthic macro-invertebrates	0.217*	-0.224*	-0.150	-0.117	0.132	-0.225*	-0.111	-0.055	0.120	0.098	-0.058	0.605**

A two-way ANOVA was used to compare the data between ponds and between times, which revealed highly significant variance ratios ($P < 0.01$) for both sources of variation.

Between pond differences were further compared by using a SNK test, which revealed that all the ponds were significantly different. Ponds 11 and 14 were significantly higher and the control pond 9 was lower than the other ponds.

A series of correlation coefficients were computed between different parameters of soil and water and benthic faunal groups. A correlation matrix table was prepared with only those parameters which had a positive significant or negative relation with at least one of the groups of benthic fauna (Table 13). The pond benthic fauna as a whole showed a significant positive correlation with water temperature and soil organic matter and a negative correlation with total hardness and dissolved oxygen.

4.2.2 Stream Benthic Fauna

In addition to the already mentioned six major groups, stream stations occasionally harboured many other forms of temporary or permanent bottom living animals, some of which were only recorded once or twice (Table 12).

The density of stream benthos was always lower than those of pond benthos.

A two-way ANOVA was used to compare the data between ponds and between times, which revealed highly significant variance ratios ($P < 0.01$) for both sources of variation.

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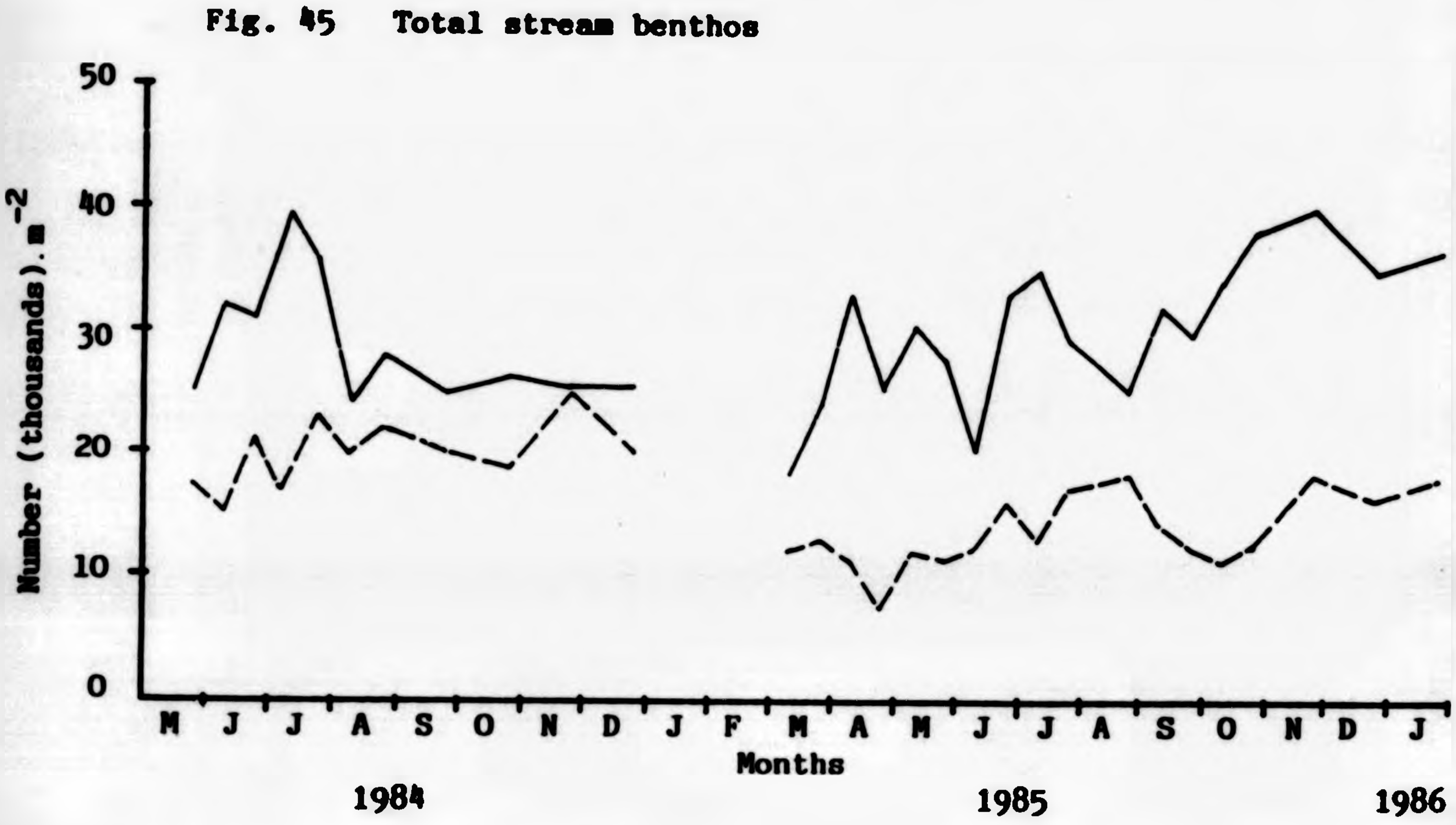

Fig. 45 Seasonal changes in total benthic macro-invertebrates in stream stations (solid line for stream station 1 and broken line for stream station 2)

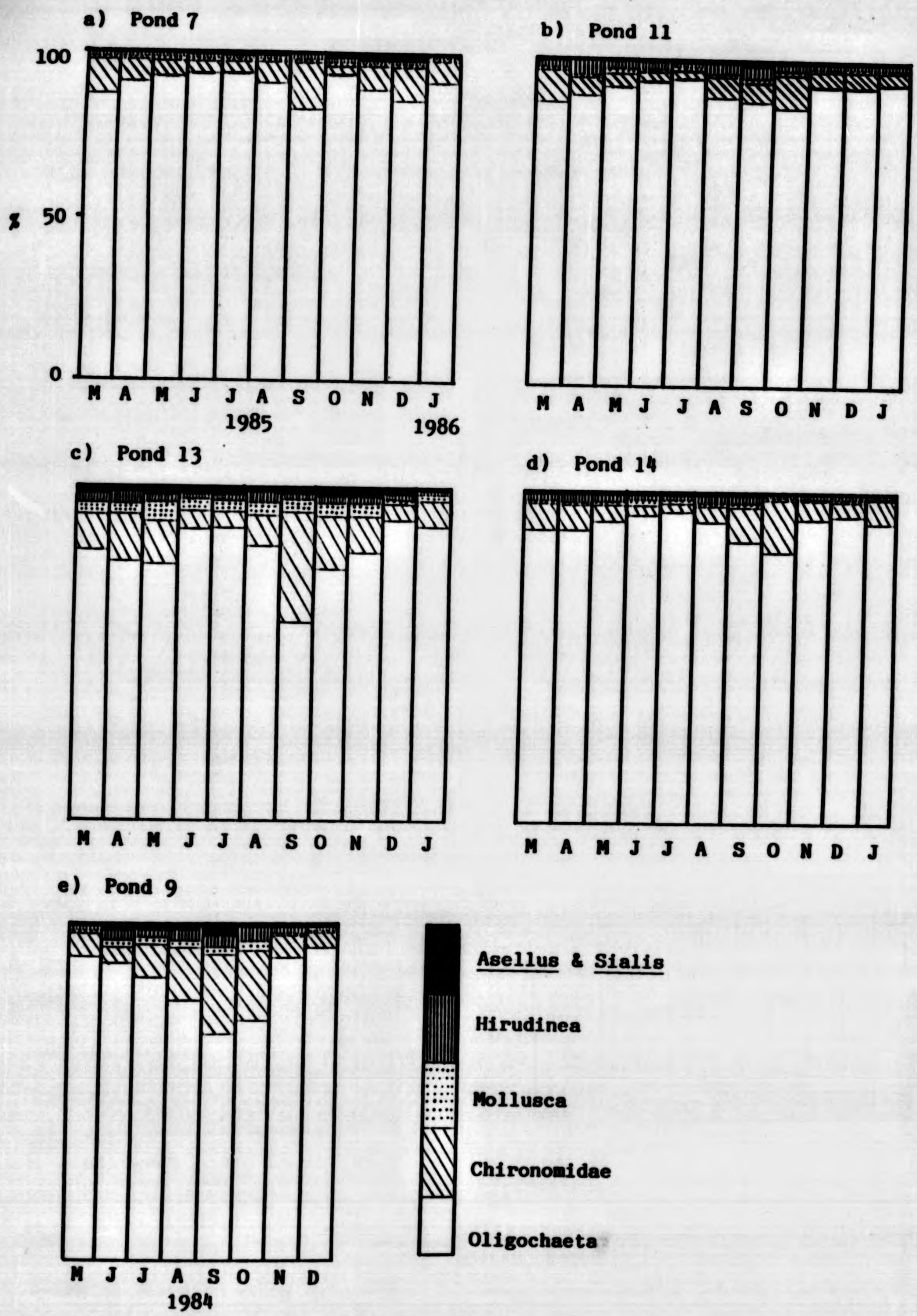

Fig. 46 (a-e) Relative abundance of major components of benthic fauna in Howietoun fish ponds

Fig. 45 shows no distinct seasonal trends as such, but a high population density was noticed in summer in station 1 in both years, and the highest number was recorded in late autumn in 1985. No seasonal trends could be established in station 2.

The numbers of total benthos was always higher in stream station 1 than in station 2. This difference between the stream stations was significant on the basis of a paired t-test ($P < 0.01$).

4.2.1.1 Oligochaeta

Fig. 43 shows that Oligochaeta was the most dominant group among the total benthic macro-invertebrates in the fish ponds, which on average made up 78-90%. Although the family Tubificidae was the major contributor to the Oligochaeta population, altogether three families of Oligochaeta were recorded from Howietoun fish farm ponds. One species of the second family Lumbriculidae was consistently available in all the ponds, whereas none of the three species of Naididae recorded in the ponds was consistently present. All the species of Tubificidae except Aulodrilus pluriseta were encountered throughout the year. Table 14 presents the average population density of different species of Oligochaeta recorded from all the ponds.

Seasonal and interpond variation in the population density of total Oligochaeta are exhibited in Fig. 47. There appeared two peaks, one in summer and the other in late autumn. Apart from seasonal variation, a variation between ponds, with lower densities in ponds

Fig. 47 Total Oligochaeta

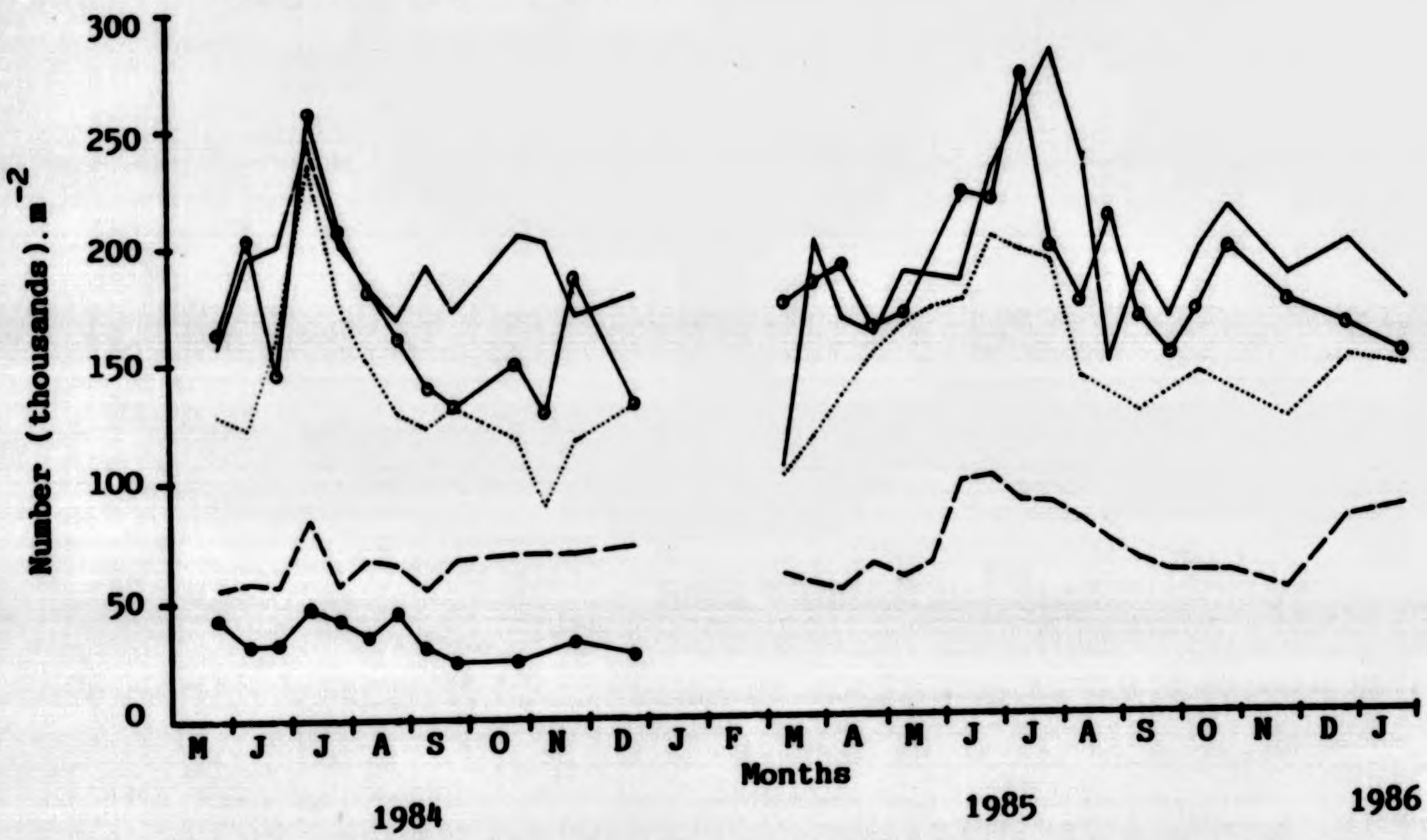

Fig.47 Seasonal changes in population density of total oligochaeta in Howietoun fish ponds (coding for ponds shown in Fig. 8)

9 and 13, was found. When the results from the cultured ponds were compared by using a two-way ANOVA, both sources of variation were found to be significant ($P<0.01$) (Table 15).

A multiple range test (SNK) was carried out for all dominant species of Oligochaeta a summary of which is given in Table 14. SNK test demonstrated that all the ponds were significantly different ($P<0.05$); pond 13 was the lowest and pond 14 was the highest among cultured ponds; and the control pond 9 was significantly lower than all other ponds.

Fig. 46 (a-e) shows the monthly relative abundance of Oligochaeta in the total benthos of pond 7, 11, 13, 14 and 9 respectively. In pond 7, May to August and October were the months of higher relative abundance (Fig. 46a). June, July and November 1985, and January 1986 had the maximum relative abundance in pond 11 (Fig. 46b).

The relative abundance of Oligochaeta was below 90% in pond 13. The maximum percentages were recorded in June and July and again December to January (Fig. 46c).

Pond 14 attained the highest monthly percentage abundance in May to June in both years. A winter maximum from November to January was also observed (Fig 46d).

Only one seasonal peak in relative abundance from November to December

9 and 13, was found. When the results from the cultured ponds were compared by using a two-way ANOVA, both sources of variation were found to be significant ($P<0.01$) (Table 15).

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Only one seasonal peak in relative abundance from November to December

Table 14 Overall annual means of the monthly abundance of oligochaetes per m^2 in each pond at Howietoun. Superscript letters indicate significant differences ($P < 0.05$) between pond means as compared by Student-Newman-Keuls tests. Values with the same superscript are not significantly different

Species	Mean abundance in 000's per m^2 ± S.E. Pond 9	Pond 13	Pond 7	Pond 11	Pond 14
<u>T. tubiflex</u>	14.3 ± 2.0^{a}	18.2 ± 1.3^{a}	34.0 ± 4.0^{a}	41.9 ± 4.0^{c}	54.2 ± 4.7^{d}
<u>L. hoffmeisteri</u>	7.1 ± 1.0^{a}	8.8 ± 0.9^{a}	25.2 ± 2.0^{b}	39.4 ± 2.4^{c}	51.0 ± 3.1^{d}
<u>L. udekemianus</u>	4.9 ± 1.2^{a}	9.9 ± 1.4^{a}	31.1 ± 4.3^{b}	41.0 ± 5.7^{c}	37.6 ± 5.1^{d}
<u>P. barbatus</u>	5.4 ± 4.0^{a}	9.1 ± 1.0^{a}	36.9 ± 5.3^{b}	32.3 ± 4.0^{b}	25.8 ± 3.0^{c}
<u>T. ignotus</u>	4.3 ± 0.7^{a}	5.5 ± 0.4^{a}	7.8 ± 0.5^{b}	8.6 ± 0.5^{b}	6.9 ± 0.5^{c}
<u>L. variegatus</u>	3.9 ± 0.5^{a}	4.5 ± 0.3^{a}	8.7 ± 1.0^{b}	12.4 ± 1.2^{c}	7.7 ± 0.6^{b}
<u>A. pluriseta</u>	-	5.1 ± 0.7	-	-	1.3 ± 0.8
<u>O. serpentina</u>	-	2.5 ± 0.5	-	-	2.1 ± 1.0
<u>N. variabilis</u>	-	2.5 ± 0.7	-	-	4.2 ± 1.2
<u>S. lacustris</u>	-	2.2 ± 1.0	-	-	4.0 ± 0.3
Total Oligochaeta	39.9 ± 4.0^{a}	68.4 ± 3.0^{b}	143.6 ± 6.4^{c}	175.6 ± 6.1^{d}	191.2 ± 6.0^{e}

Table 15 Results of ANOVAs to compare population of oligochaetes per m^2 from all cultured ponds (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**)

Species	Types of transformation needed	Sources of Variation: Between ponds (F)	Between times (F)	Interactions (F)
<u>Tubifex</u> <u>tubifex</u>	log	80.42 **	10.90 **	1.38 *
<u>L</u>. <u>hoffmeisteri</u>	log (x + 1)	330.63 **	6.91 **	1.48 *
<u>L</u>. <u>udekemianus</u>	log (x + 1)	157.63 **	17.38 **	1.09 N.S.
<u>P</u>. <u>barbatus</u>	log (x + 1)	112.08 **	10.69 **	1.08 N.S.
<u>T</u>. <u>ignotus</u>	log (x + 1)	21.12 **	5.69 **	3.23 **
<u>L</u>. <u>variegatus</u>	log (x + 1)	39.86 **	4.68 **	1.30 N.S.
Total Oligochaeta	log	472.75 **	8.11 **	1.53 *

was observed in pond 9 (Fig. 46e).

4.2.1.1.1 Tubificidae

4.2.1.1.1.1 Tubifex tubifex

This was the most abundant species of Oligochaeta in all the ponds except in pond 7 (Table 14); it constituted 24-28% of total Oligochaeta.

Two peaks in the population density, one in spring (March to April) and one in late autumn (October to December) appeared in 1985 and presumably the same pattern occurred in 1984 (Fig. 48). The population remained low but steady throughout the summer.

There was a significant difference in annual mean populations between the cultured ponds as compared by using a two-way ANOVA on log transformed data (Table 15). SNK test led to the conclusion that, except for ponds 9 and 13, all other ponds were significantly different ($P < 0.05$) (Table 15).

The relative abundance of different species of Oligochaeta throughout the year are presented in Fig. 54 (a-e). Similar trends in relative abundance of T. tubifex were observed in all ponds except pond 9, with higher relative abundances during March - April and October - December and lower numbers in June, July and August. In pond 9 higher relative abundances were found in May and November to December

Fig. 48 Tubifex tubifex

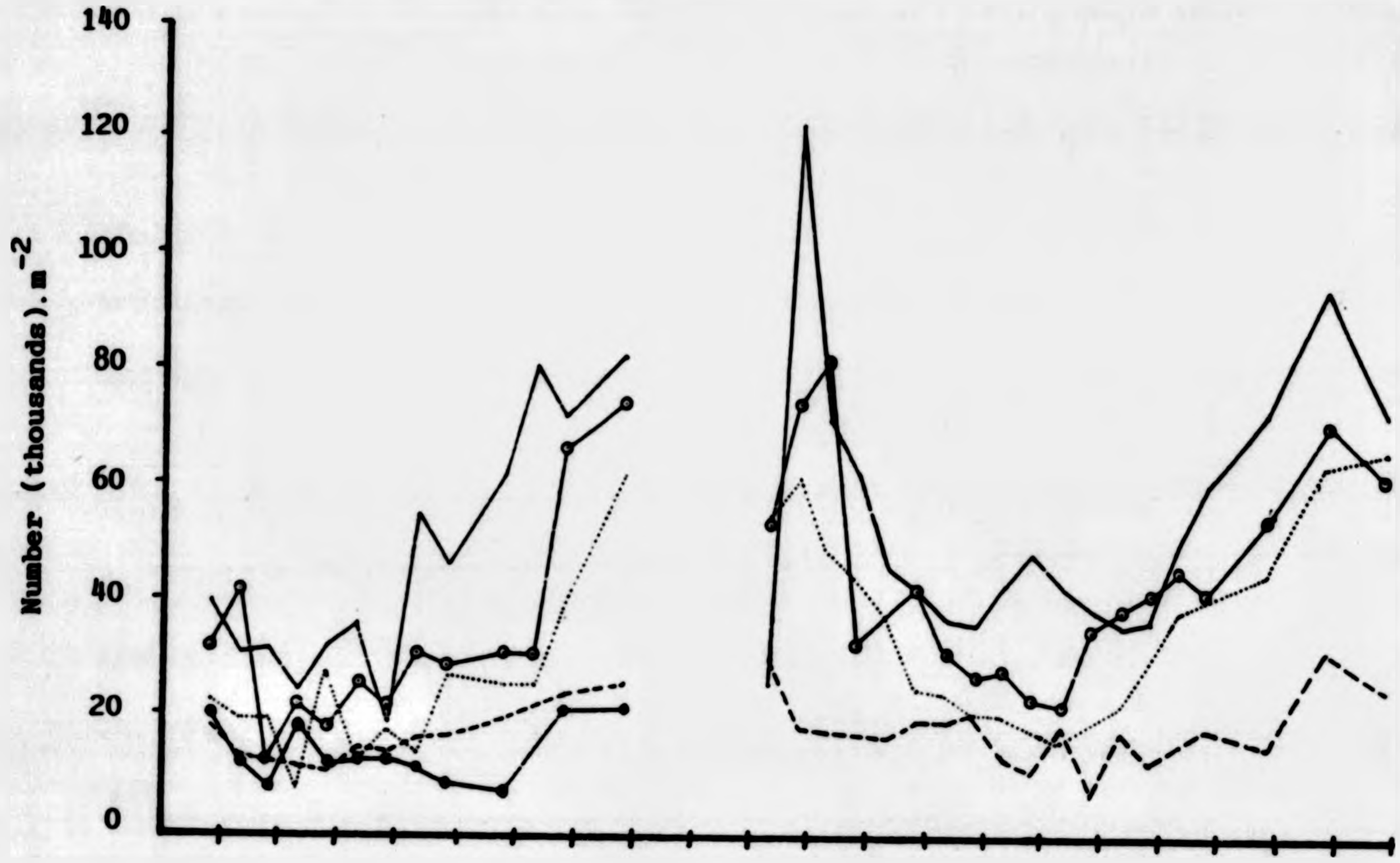
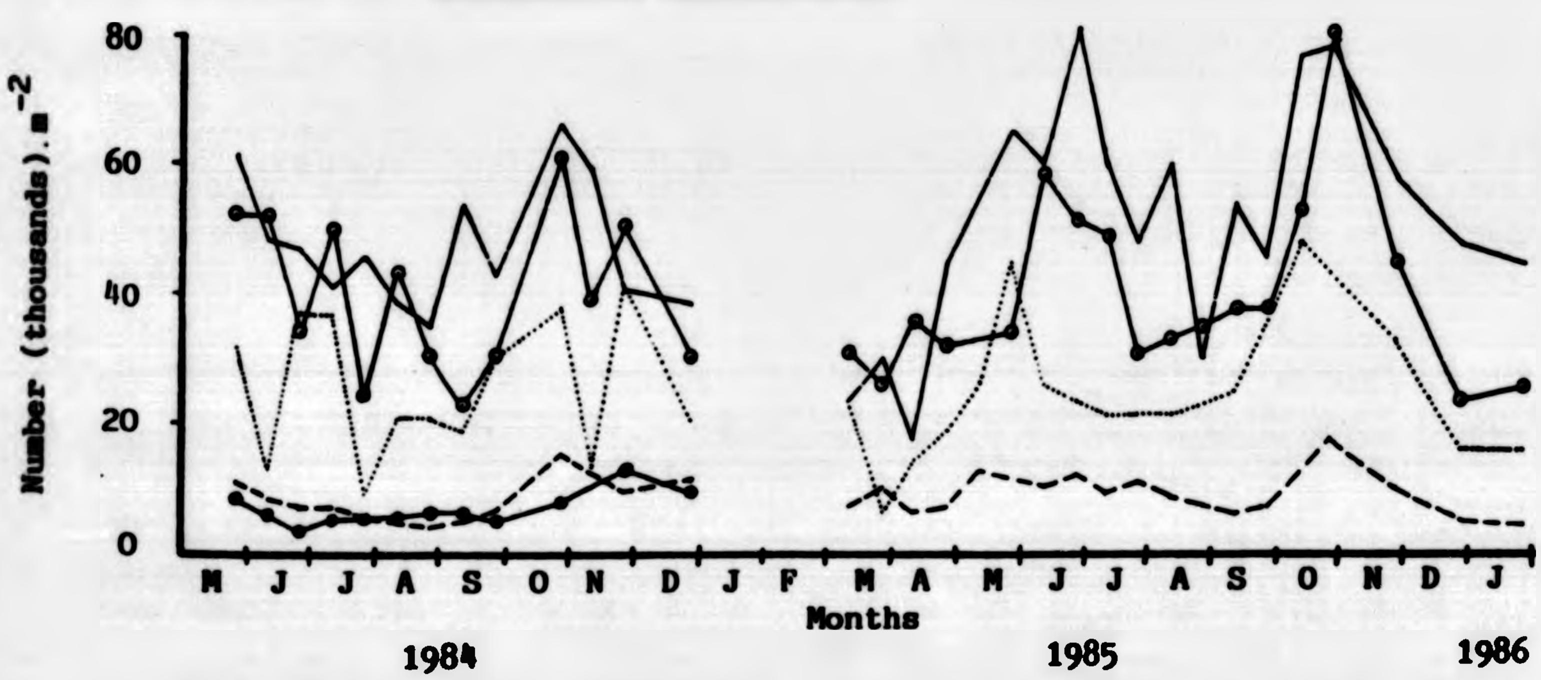


Fig. 49 Limnodrilus hoffmeisteri



Figs 48-49 Seasonal changes in Tubifex tubifex and Limnodrilus hoffmeisteri (coding for ponds shown in Fig. 8)

and lower in October (Fig. 54e).

The maximum relative proportion of mature T. tubifex (bearing cuticular penis sheaths) was recorded in March, when the pond water just started to warm up. A large number of cocoons was observed in the sample during this period. Since no other species were found to be mature (except one or two mature specimens of Limnodrilus hoffmeisteri), the cocoons were presumed to be those of T. tubifex. Some mature specimens with visible spermatophores were collected from the field and kept in a beaker in slowly flowing tap water, in which they laid eggs. After identifying the parents, it was confirmed that T. tubifex had laid cocoons on a massive scale in the fish ponds. A relatively small proportion of young Tubifex sp. also appeared during this period.

The recruitment of juveniles increased rapidly and a maximum number of T. tubifex of about 122,000 ± 15,000 individuals per m^2 (Fig. 48) was attained in pond 14 in late March, indicating that March was the major breeding season of T. tubifex.

4.2.1.1.1.2 Limnodrilus hoffmeisteri

L. hoffmeisteri, as one of the major species, occurred in all ponds throughout both years. It had the second highest population density in pond 14 and, surprisingly in pond 9, consisting of 13-27% of the total Oligochaeta population. Table 15 shows that the numbers of this species were significantly different between the cultured ponds ($P < 0.05$). SNK test revealed that all the ponds were significantly different except ponds 9 and 13 (Table 14).

There was a distinct pattern of temporal changes which was similar to that of T. tubifex. The number of L. hoffmeisteri gradually built up from the second fortnight of April onwards until it reached the greatest abundance during May to June in 1985, although there was a small variation in timing between the ponds (Fig. 49). After remaining static during summer, the population density began to increase at the end of September. This second increase lasted for a short time, which maintained high population density until the end of October 1985 and then decreased. Similar trends were presumed to occur in 1984.

Fig. 54 (a-e) exhibits the relative importance of L. hoffmeisteri in different ponds and months. A similar pattern in the relative abundance of L. hoffmeisteri was observed in both years. May to June and October to November were the two periods of maximum relative abundance.

A massive appearance of adults with a pair of long penes and characteristic chaetae was observed in the samples collected on the 26th April 1985. By 10th of May, the number of cocoons increased rapidly. Because of the similarity in cocoon size, it was almost impossible to separate cocoons of T. tubifex and L. hoffmeisteri in the field. For confirmation of the actual breeding population, a number of mature specimens were maintained under cultured conditions in the laboratory during this period and found to lay eggs.

The recruitment of young juveniles started simultaneously, which increased the population level to a maximum density thereafter. Apart from their incidental presence mature specimens ceased to appear during July and August.

Mature worms again reappeared during mid-September and continued their breeding period until the end of November. The number of mature worms reached the peak in late September, whereas the recruitment of young individuals reached a maximum in mid to late October. Thus, L. hoffmeisteri was found to have two clearly distinguishable breeding periods in Howietoun ponds.

4.2.1.1.1.3 Limnodrilus udekemianus

As one of the abundant species, L. udekemianus on average contributed 12-23% of the total oligochaetes.

A highly significant variation between the cultured ponds was shown by a two-way ANOVA test (Table 15). Similarly to T. tubifex and L. hoffmeisteri, L. udekemianus also showed significant differences between individual ponds, except pond 9 and 13 as confirmed by SNK test (Table 14).

Fig. 50 shows the unimodal peak of L. udekemianus which maintained a high population density from mid-June to August in all the ponds throughout the study period. During the rest of the year, the population density remained lower but steadier.

Relative abundance as shown in Fig. 54(a-e) demonstrated that the maximum abundance in all the ponds was during June to August with the peak in July in both years. Lowest values were obtained from November to December.

In Howietoun ponds L. udekemianus bred from June to August in both years. The mature worms (characterized by the shape and dimension of penis tube and the shape of the chaetae) first appeared in the sample in early June. Their numbers increased in subsequent samples, peaked at the end of July and then declined. Late June to the end of July was the peak period of cocoon deposition. Cocoons of L. udekemianus were easily identifiable from those of other species by their larger size.

A marked recruitment into the population occurred during July to August which helped to raise the population to the highest number in July in both years. Since the majority of the individuals during this greatest abundance were newly recruited young and immatures, it was strongly believed that the period from June to August was the only breeding season of L. udekemianus.

Fig. 50 Limnodrilus udekemianus

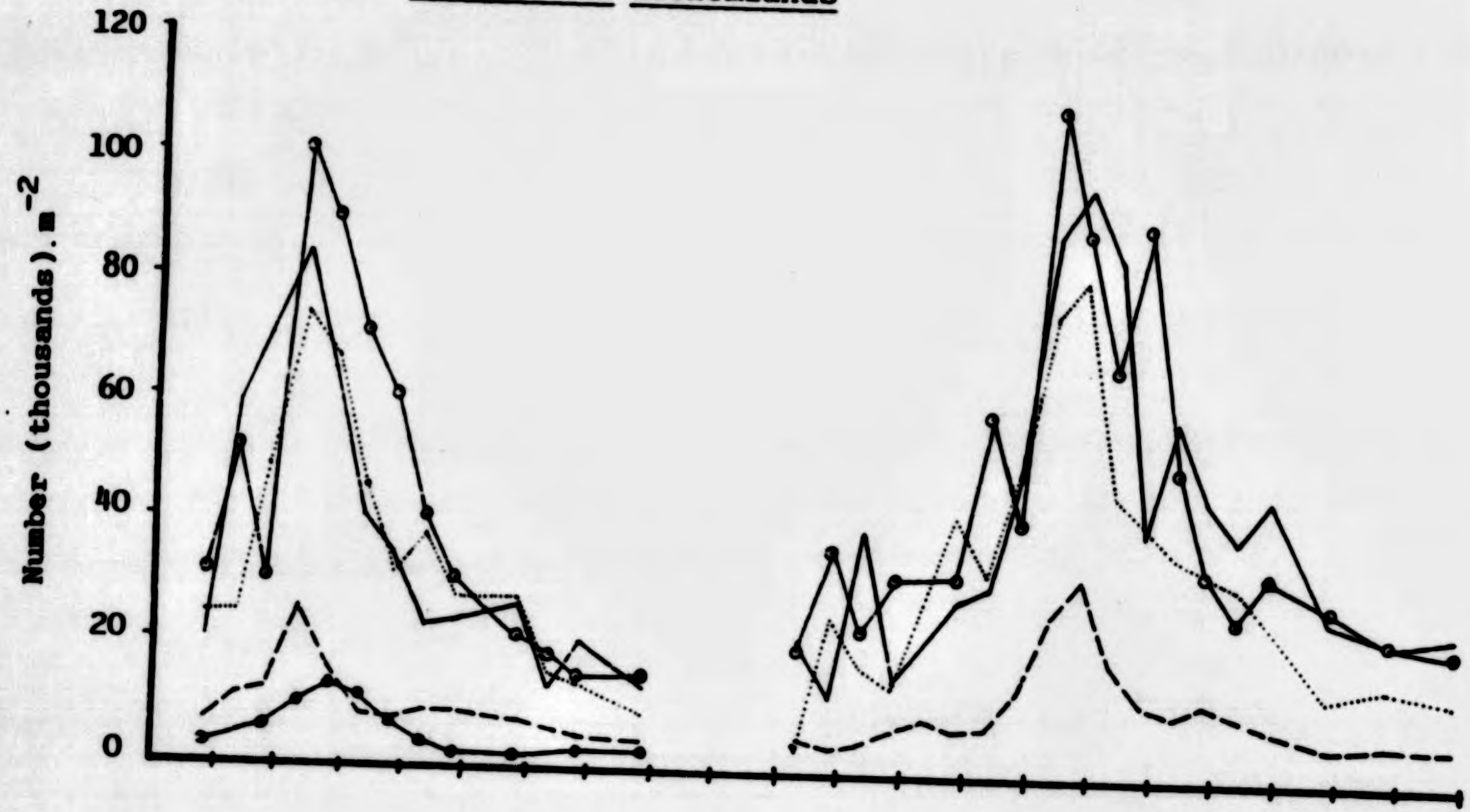
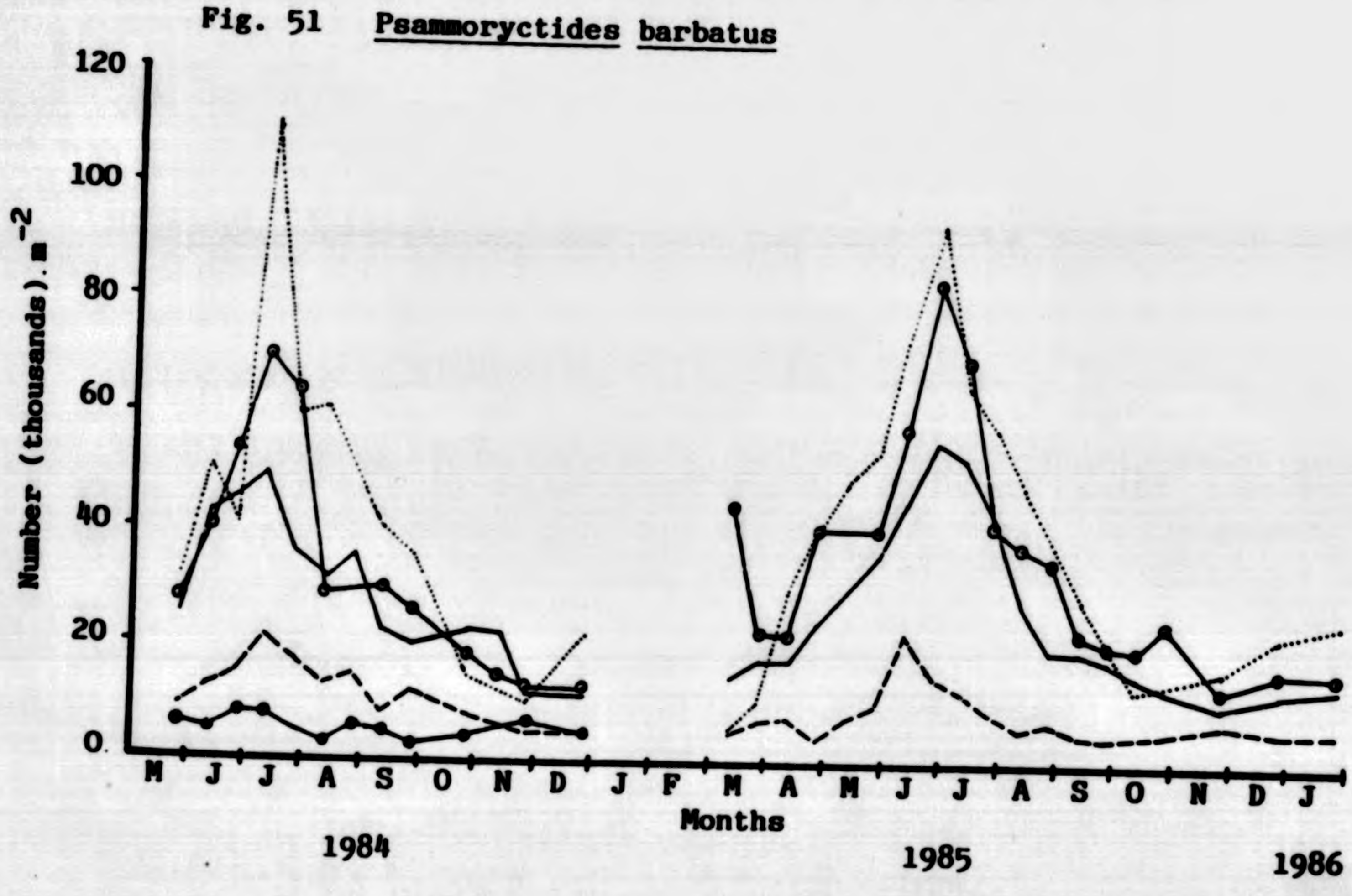


Fig. 51 Psammoryctides barbatus



Figs 50-51 Seasonal changes in Limnodrilus udekemianus and Psammryctides barbatus in Howietoun fish ponds (coding for ponds shown in Fig. 8)

4.2.1.1.1.4 Psammoryctides barbatus

One of the four very prominent species, P. barbatus was recorded from all ponds throughout the study period. It constituted on average 13-26% of the oligochaete population. This species dominated in pond 7, where it showed its highest population density. Table 14 shows the means of monthly numbers per m^2 and the summary results of SNK multiple range tests. The test showed that ponds 7 and 11 were significantly higher than pond 14. Ponds 9 and 13 were significantly different from other ponds, but not between themselves.

The relative abundance showed similar monthly trends in all the ponds in both years (Fig. 54 (a-e)). With little variation between ponds, the maximum relative abundance of P. barbatus was found during May to August with a peak in July 1984, except in pond 14 and 9 where it was in June. Similar trends, with the highest values in June, were observed in 1985.

Unlike many other tubificid worms, both immature and mature stages of P. barbatus were easily recognizable by their characteristic palmate dorsal chaetae. The mature worms, which bear modified penial chaetae, were recorded from April to September with the greatest relative proportion in May, 1985. In 1984, benthic samples collected in May also contained a large number of mature specimens.

Cocoons of P. barbatus were inseparable from those of T. tubifex and L. hoffmeisteri; the peak time of cocoon deposition, therefore, was obscured. Many mature worms laid eggs in laboratory culture during May to June.

As the recruitment started, so the population density per m^2 began to increase, reaching a peak in July 1984 and July 1985 (Fig. 51). Thereafter, the population density began to decline.

4.2.1.1.1.5 Tubifex ignotus

T. ignotus was a less dominant species in the fish ponds, never attaining densities greater than 14,000 $\pm$ 7,000 m^{-2}, which was observed on 19 December 1985 in pond 7. It formed 4-11% of the total population of Oligochaeta.

Fig. 52 shows that the population density declined throughout the summer and early autumn (June to September). The density increased during late autumn, and continued to increase throughout the winter (October to end of April). The population density varied significantly between cultured ponds when tested by two-way ANOVA (Table 15). It was significantly higher in ponds 7 and 11 than the rest of the ponds (Table 14).

T. ignotus was easily identifiable by its thin body and chaetal pattern, while mature specimens could be easily identified from their weakly developed, short cuticular penes sheaths. Mature specimens were very scarce, only one mature worm being recorded in November 1984.

Fig. 52 __Tubifex ignotus__

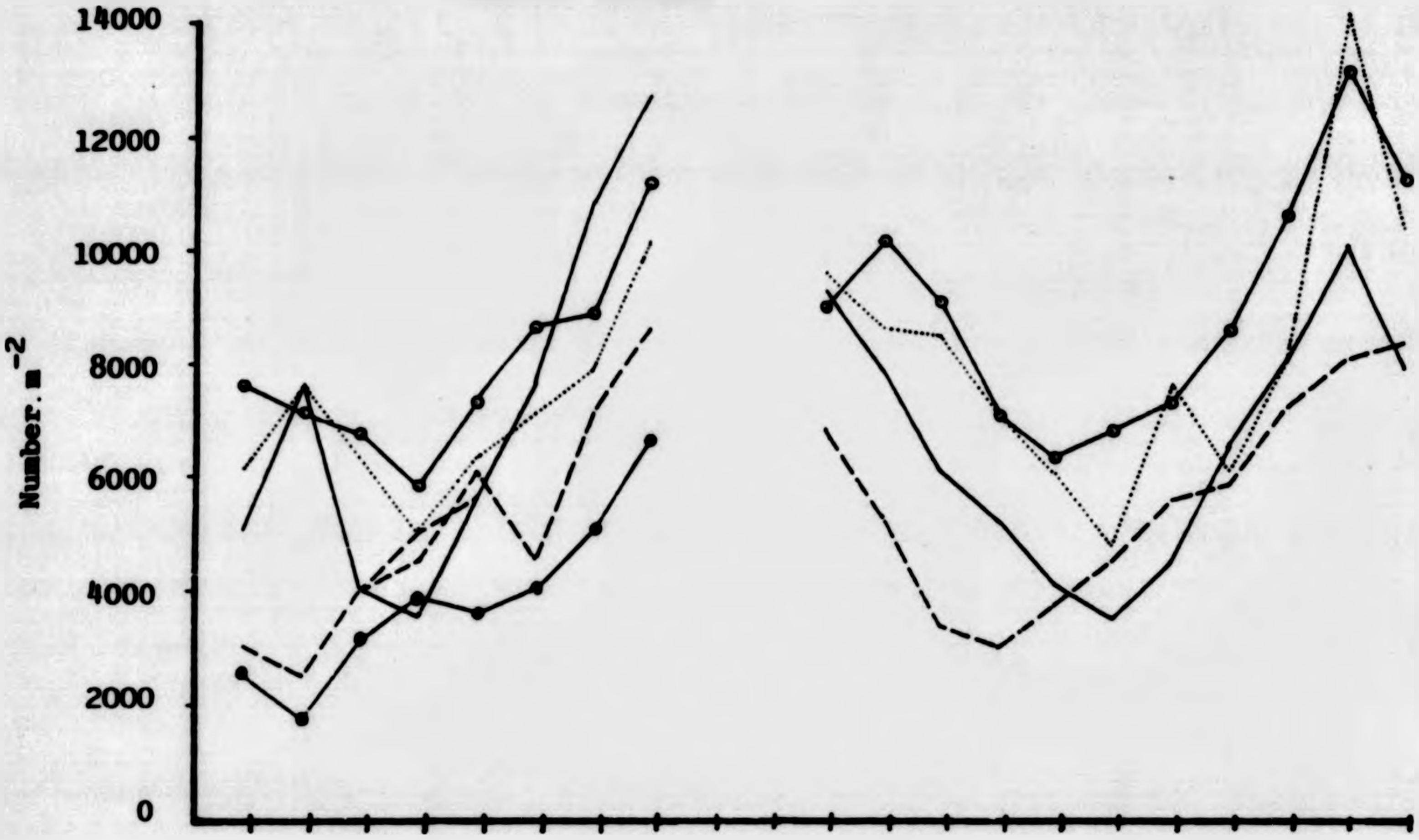
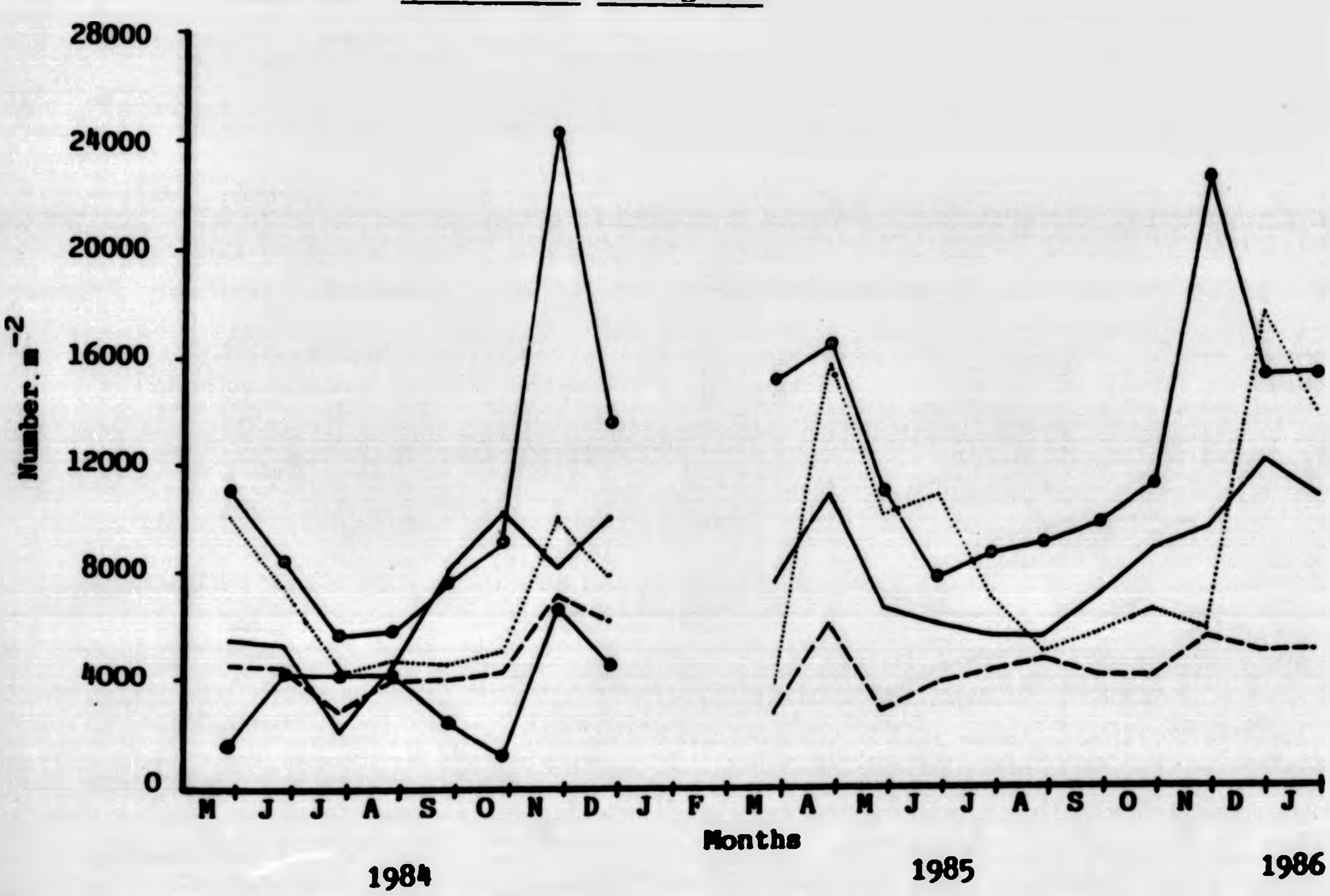


Fig. 53 __Lumbriculus variegatus__



Figs 52-53 Seasonal changes in __Tubifex ignotus__ and __Lumbriculus variegatus__ in Howietoun fish ponds (coding for ponds shown in Fig. 8)

The relatively smaller sized cocoons appeared in the samples during winter months but it was not possible to identify them as belonging to this species.

4.2.1.1.1.6 Aulodrilus pluriseta

A. pluriseta was available throughout the year in pond 13 except in October-November in 1985. The maximum number was recorded in June-July in 1985. In pond 14, it was recorded only in August and September in 1984 and July in 1985. No sexually mature organism was found in this study.

4.2.1.1.2. Lumbriculidae

4.2.1.1.2.1 Lumbriculus variegatus

The only species of Lumbriculidae, L. variegatus, occurred in all ponds throughout the year. It constituted 4-22% of the total oligochaete population in the fish ponds.

A seasonal variation in population density, with an increased number in spring and autumn to winter and decrease in summer, was observed (Fig. 53). The SNK test revealed that, except for ponds 9 and 13, all other ponds were significantly different (Table 14).

Although mature worms of L. variegatus were not recorded, immature specimens of Lumbriculus sp. of varying size, mostly recently fragmented, were found in March to May with a peak in April and

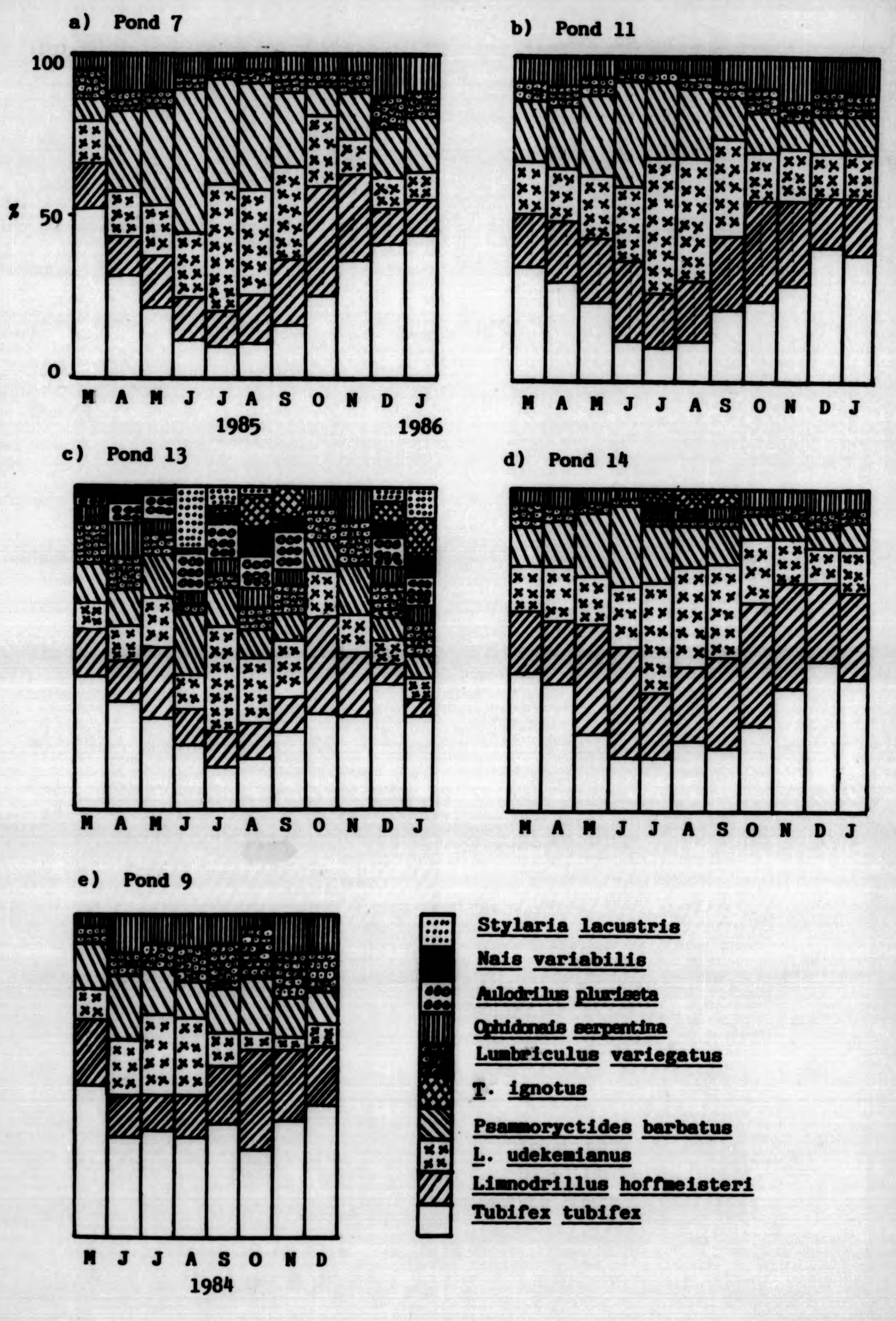


Fig 54 (a-e) Relative abundance of different species of Oligochaetae in Howietoun fish ponds in October to December with peaks in November in pond 11 and 13 and December in ponds 7 and 14 in 1985. Pond 9 reached a peak in November, 1985. Many bigger animals with segmented anterior ends were observed during the study period. The present study revealed that there might be two breeding periods, one in March to May and one in October to December, which might extend throughout the coldest months.

4.2.1.1.3 Naididae

Three species of Naididae, Ophidonais serpentina, Nais variabilis and Stylaria lacustris were very infrequently recorded from ponds 13 and 14 only. Table 14 and Fig. 54 (a-e) show the annual mean numbers per m^2 and the monthly changes in their relative contribution to total oligochaetes. No sexually mature specimen of these species was recorded during the study period.

4.2.2.1 Stream Oligochaeta

Oligochaetae made up about 77% and 71% of total stream benthos in stream station 1 (upstream) and station 2 (downstream), respectively. The different species of Oligochaeta with their annual mean abundances are presented in Table 16. It may be noted that T. ignotus was never found in station 1 but it was present in stream station 2. A. pluriseta, O. serpentina and S. lacustris were only occasionally recorded from station 1 but never occurred in station 2.

All the major species of Oligochaeta were significantly more abundant

Table 16 Annual means of monthly abundance of stream oligochaetes and their level of significant (N.S. non-significant; $P < 0.05$,*; $P < 0.01$ **) difference between stream stations

Species	$\bar{X} \pm$ S.E. Stream station 1	$\bar{X} \pm$ S.E. Stream station 2	Level of Significance
T. tubifex	5,500 ± 350	2,830 ± 270	**
L. hoffmeisteri	4,500 ± 270	2,900 ± 200	**
L. udekemianeus	4,800 ± 350	1,650 ± 160	**
P. barbatus	4,200 ± 400	1,700 ± 200	**
L. variegatus	3,300 ± 450	1,340 ± 130	**
T. ignotus	-	1,250 ± 170	-
A. pluriseta	470 ± 180	-	-
O. serpentina	160 ± 160	180 ± 90	-
S. lacustris	580 ± 400	-	-
Total Oligochaeta	23,600 ± 800	11,800 ± 500	**

at station 1 ($P < 0.01$), when compared by a t-test on log transformed data (Table 16). Fig. 55 shows no marked seasonal changes except their dominance in the winter months.

The comments on the results are restricted to those major species which consistently appeared in large numbers throughout the study period.

4.2.2.1.1 *T. tubifex*

This was the most abundant species in station 1 and second dominant species in station 2. Though Fig. 56 failed to indicate any distinct seasonal trend in any of the stations, the number of worms seemed to be higher during autumn.

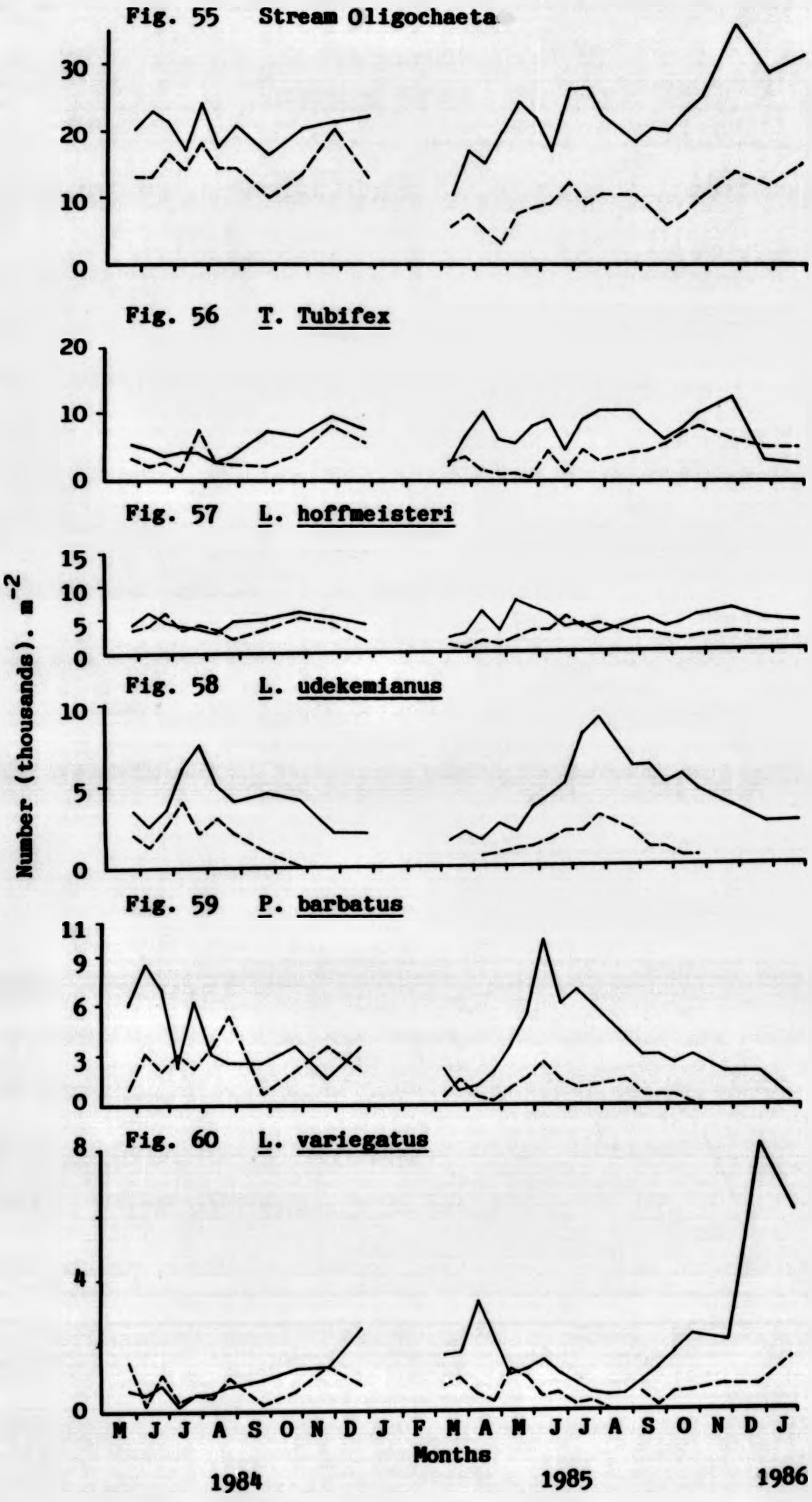
4.2.2.1.2 *L. hoffmeisteri*

This was the most abundant species in station 2 and ranked third in station 1. Fig. 57 does not show any clear seasonal pattern in either of the stations.

Mature specimens of this species were recorded during spring and autumn from the stations. Both cocoons and juveniles were encountered in small numbers in the samples during this period.

4.2.2.1.3 *L. udekemianus*

L. udekemianus occurred throughout the year in station 1, but in



Figs 55-60 Seasonal changes in Oligochaeta T. tubifex, L. hoffmeisteri, L. udekemianus, P. barbatus and L. variegatus in the stream stations (continuous line = intake station 1; broken line = outflow station 2)

station 2 it disappeared in both years after October. A summer peak during July - August was observed at both stations in both years, possibly associated with breeding season (Fig. 58).

Some large mature worms of L. udekemianus along with their cocoons appeared in mud samples during summer months (June to July), only in station 1 in both years.

4.2.2.1.4 P. barbatus

P. barbatus showed a marked temporal variation, having a peak denisty during summer. Although, it consistenly occurred in station 1, it disappeared from station 2 from November, 1985 (Fig. 59).

4.2.2.1.5 L. variegatus

Unlike the pond situation, this species was one of the dominant species, particularly in station 1. It rose upto 17,000 $\pm$ 6,000 m^{-2} in December, 1985. An autumn to winter increase in the population density was observed in both years (Fig. 60).

4.2.1.2 Chironomidae

Regarding the overall population density, Chironomidae occupied a position next in importance to Oligochaeta. in Howietoun fish farm ponds. They comprised 7-13% of the total benthos in the fish ponds.

Fig. 61 Total Chironomidae

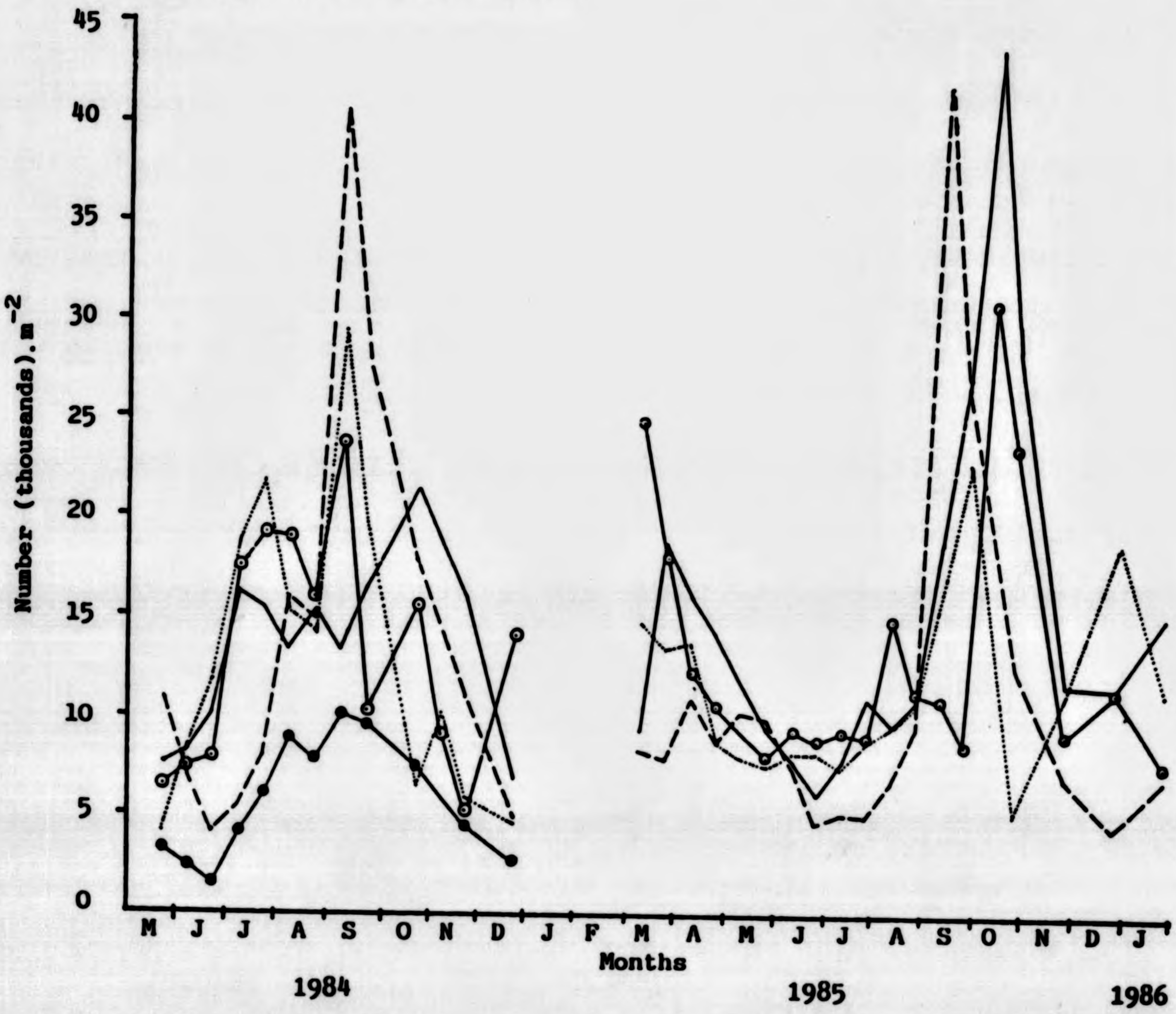


Fig. 61 Seasonal changes in population density of total Chironomidae in Howietoun fish ponds (coding for ponds shown in Fig. 8)

The chironomid population consisted of three subfamilies containing about 18 different species. Of this large number of species, Chironominae alone had 12 species, and the rest of the species are distributed as Tanypodinae with 5 species and Prodiamesinae with one species. Two genera, Tanypus and Macropelopia were recorded only on one occasion. One of the species of Orthocladiinae, Ivetenia verralli was only recorded as an adult from the flying swarm. No aquatic larval form of this species was found in the ponds. Table 12 shows that two species of Chironominae, Microtendipes chloris and Paratendipes sp. and one species of Tanypodinae, Guttipelopia sp. were always absent from pond 14. Five species, viz., Paratendipes sp., Micropsectra sp., Cladopelma sp., Guttipelopia sp. and Prodiamesa olivacea never occurred in pond 9 samples.

Fig. 61 shows two major periods of maximum abundance of Chironomidae, one in March - April and the other in August to October. Numbers remained at a reduced level from late spring throughout the summer.

The population density of Chironomidae including its dominant species were compared and contrasted between the ponds and sampling times using two-way ANOVA and SNK tests, the results are presented in Tables 17 and 18 respectively. Chironomidae as a whole showed highly significant ($P < 0.01$) differences in abundance between the ponds. SNK test demonstrated that pond 14 was higher than all other ponds and pond 9 was the lowest ($P < 0.05$) (Table 18).

Table 17 Matrix for results of ANOVAs for Chironomids of all cultured ponds (7, 11, 13 & 14) ($P < 0.01$, **)

Species	Types of transformation needed	Sources of Variation		
		Between ponds (F)	Between months (F)	Interactions (F)
Chironomus sp.	log (x + 1)	42.80 **	11.02 **	4.38 **
Procladius sp.	log (x + 1)	7.51 **	18.13 **	4.16 **
Total Chironomidae	log	17.13 **	17.74 **	5.52 **

Table 18 Overall annual means of the monthly abundance of chironomids in each pond at Howietoun. Superscript letters indicate significant differences ($P < 0.05$) between the pond means. Values with same superscript are not significantly different

Species	Mean abundance per $m^2 \pm$ S.E.				
	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14
Chironomus sp.	$1,500 \pm 240^a$	$4,100 \pm 670^b$	$5,500 \pm 1,100^b$	$3,200 \pm 700^c$	$8,600 \pm 2,100^d$
Procladius sp.	$1,200 \pm 300^a$	$2,550 \pm 600^b$	$3,200 \pm 600^c$	$5,000 \pm 1,700^c$	$2,400 \pm 400^b$
Prodiamesa sp.	820 ± 240	$1,800 \pm 420$	$1,100 \pm 240$	720 ± 140	690 ± 160
Ablabesmyia	380 ± 200	340 ± 110	520 ± 170	500 ± 130	440 ± 130
Micropsectra sp.	-	$1,080 \pm 210$	830 ± 180	870 ± 200	900 ± 200
Tanytarsus sp.	480 ± 280	300 ± 100	270 ± 100	200 ± 100	500 ± 150
Polypedilum sp.	340 ± 190	470 ± 120	600 ± 180	490 ± 140	380 ± 120
Cladopelma sp.	-	420 ± 120	460 ± 170	160 ± 70	320 ± 140
Glyptotendipes sp.	40 ± 40	250 ± 90	380 ± 140	220 ± 100	570 ± 200
Paratendipes sp.	-	130 ± 60	80 ± 50	100 ± 60	-
Guttipelopia sp.	-	100 ± 60	130 ± 80	160 ± 80	-
Microtendipes sp.	600 ± 200	400 ± 180	250 ± 100	280 ± 170	-
Total Chironomidae	$5,400 \pm 1,000^a$	$12,000 \pm 1,400^b$	$13,300 \pm 1,400^{bc}$	$12,000 \pm 2,300^b$	$14,900 \pm 2,200^c$

Chironomidae demonstrated a significant positive correlation with the nitrite content of the water (Table 13).

Fig. 46 (a-e) shows the relative abundance of Chironomidae in comparison with other groups of benthic macro-invertebrates. All the ponds showed a similar pattern with minimum percentage in June-July and maximum in August-October.

4.2.1.2.1 Chironominae

4.2.1.2.1.1 Chironomus spp.

C. plumosus, C. anthracinus and C. venustus were the three species of Chironomus recorded from Howietoun fish ponds. It was very difficult to separate larvae of these species collected from the field. Often, large sized red larvae have been identified as Chironomus plumosus.

Although analyses of imago and pupal exuviae confirmed the presence of three species, it was decided to consider them as one species group, as this study revealed no obvious ecological differences and the emergence periods were co-incident.

Chironomus spp. was the most dominant of all species of Chironomidae, which alone made up about 28-52% of the total chironomidae.

Fig. 62 indicates the distinct seasonal variation in population density which varied slightly from pond to pond. In general, the

Fig. 62 Chironomus spp

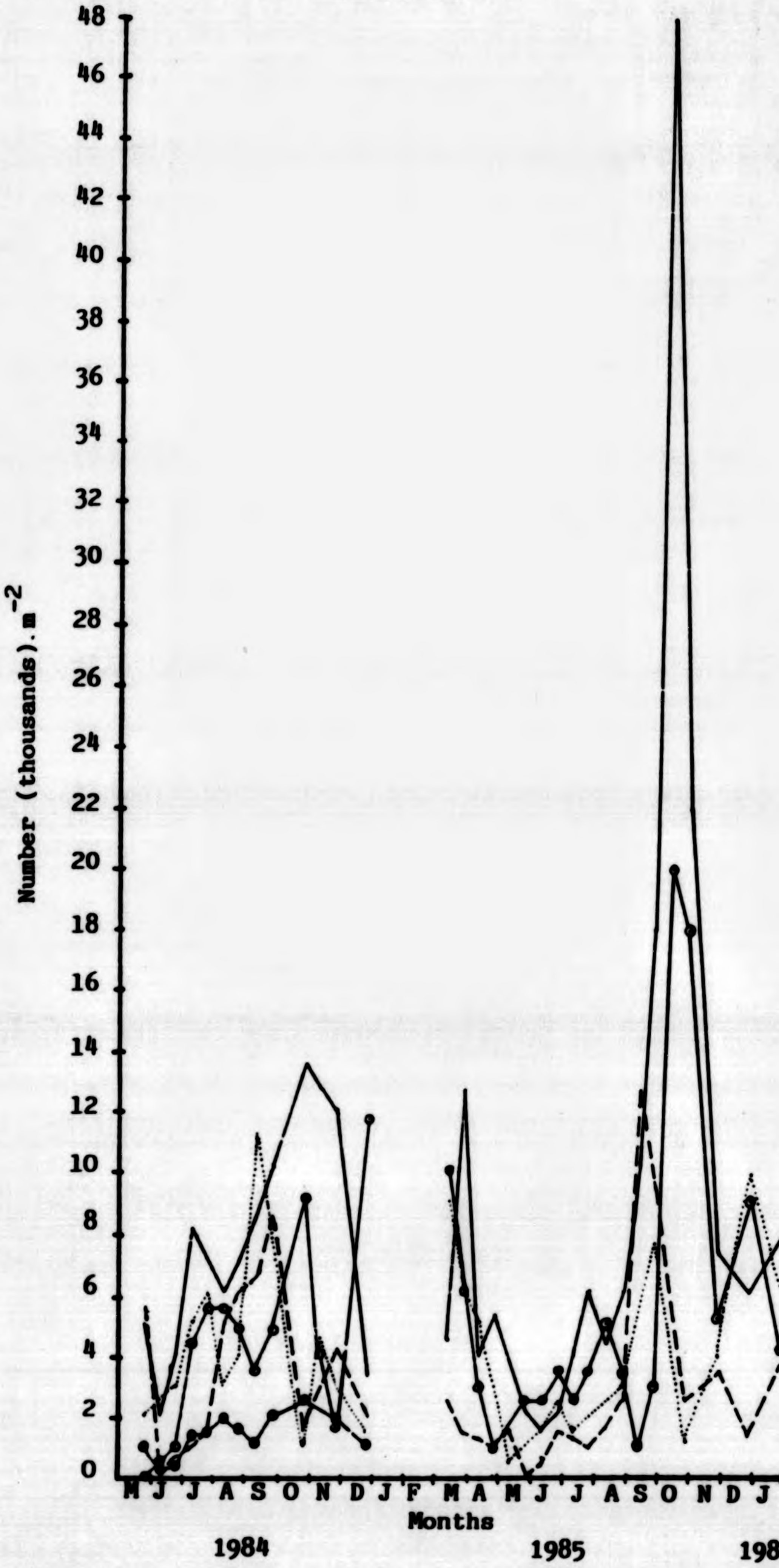


Fig. 62. Seasonal changes in Chironomus spp in Howietoun fish ponds(coding for ponds shown in Fig. 8)

number of Chironomus spp. larvae appeared to increase rapidly after their spring emergence and continued to do so until it reached a peak in August to October and then started declining before a second emergence. The presence of aerial adult populations suggested that a slow process of emergence did go on even in between these two major periods of emergence. During the first emergence period the population even dropped to zero in some ponds.

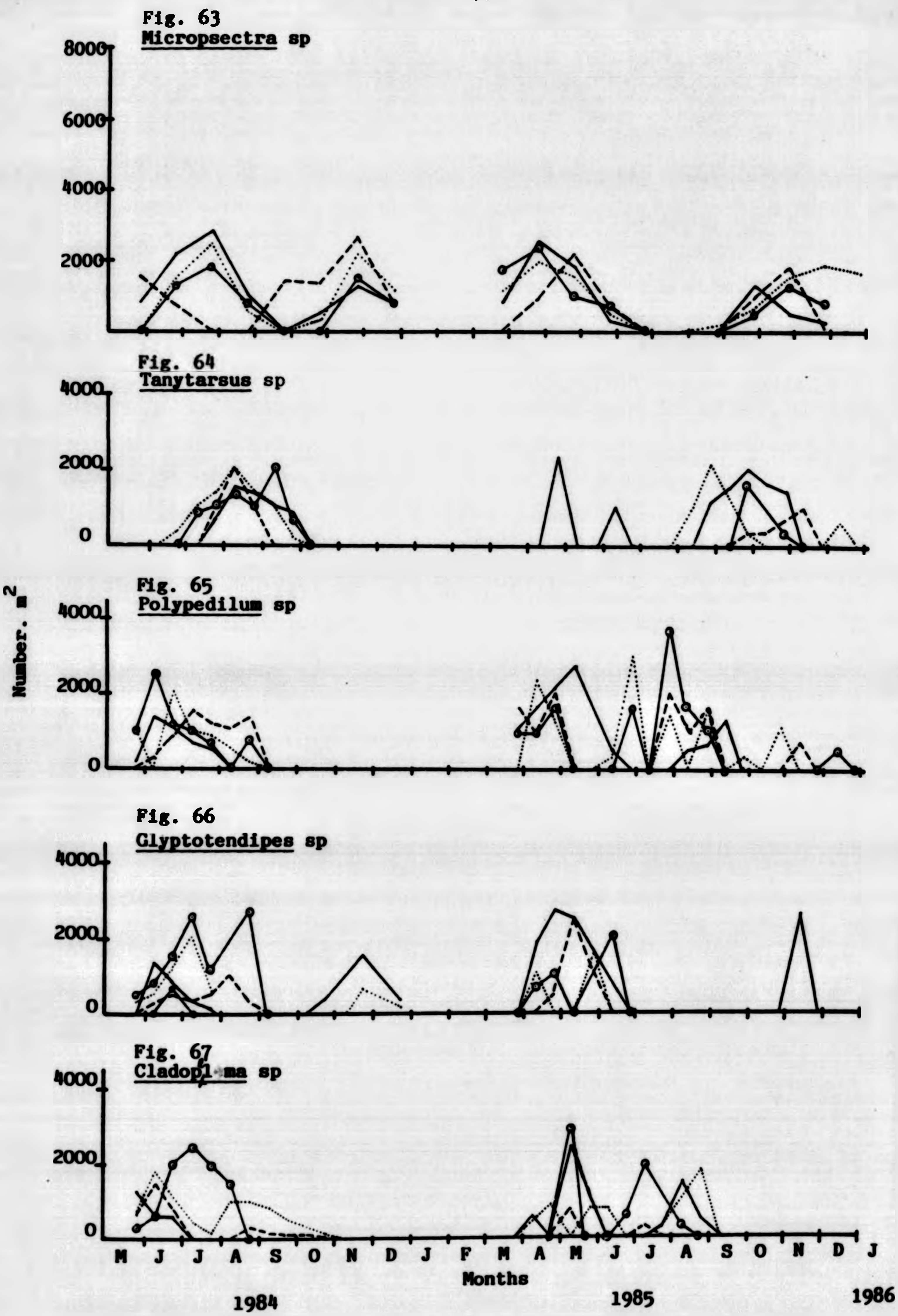
Table 17 shows a significant interpond difference as appeared in two-way ANOVA test. A further analysis using SNK revealed that all the ponds were significantly different ($P < 0.05$), in which pond 14 was the highest and 9 was the lowest in the population density of Chironomus spp. (Table 18).

An attempt made to correlate Chironomus spp. with parameters of soil and water indicated that nitrite in the water and organic matter content of soil were positively related (Table 13).

4.2.1.2.1.2 Micropsectra spp.

M. lindrothi and M. atrofasciata were the two species of the long tube forming tribe Tanytarsini. Because of inseparable larval forms, the larvae was considered as Micropsectra spp.

Fig. 63 exhibits two well defined peak periods of abundance of this species group in April and November. Interpond variation in the build up of peaks over 2 to 3 weeks was noticeable.



Figs 63-67 Seasonal changes in Micropsectra sp., Tanytarsus sp., Polypedilum sp., Glyptotendipes sp. and Cladompl ma in Howietoun fish ponds (coding for ponds shown in Fig. 8)

A long flying period from July to September was observed, when no organisms were collected from the bottom of the pond. Another emergence period was observed at the end of autumn and beginning of winter. Except in pond 7, no traces of an overwintering population in any of the ponds was found. An almost identical seasonal trend was observed in 1984.

4.2.1.2.1.3 Tanytarsus spp.

It was almost impossible to distinguish Tanytarsus spp. at their larval stage unless pupal exuviae and/or imagines were found from the field collection and reared. From the reared imagines and pupal exuviae the larvae were found to belong either to T. lestagei or T. pallidicornis, so they were treated as one group for subsequent analyses.

Tanytarsus spp. larvae first appeared in July in both years and maintained a higher level until September and then started to decline (Fig. 64). The larvae virtually disappeared from the population by the end of September in 1984 and end of October, 1985. Though the presence of organisms was noticed on two occasions in pond 14 in spring, a well established spring generation was not confirmed. There was no trace of an overwintering population in any of the ponds during this study.

4.2.1.2.1.4 Polypedilum sp.

Study of larval morphology indicated the presence of one species in the fish ponds. Due to the non-availability of adult specimens or pupal exuviae, specific identification was not possible.

Fig. 65 shows that Polypedilum sp. developed two generations, one in early spring and another in summer. The period of emergence was from April to May after the first peak and August onwards after the second. No larvae were observed after the second emergence in 1984, but in 1985, a very small proportion of 4th instar larvae was recorded after the second emergence, indicating a protracted second generation in some ponds.

4.2.1.2.1.5 Glyptotendipes pallens

Larvae of this species appeared in the May samples in 1984 in ponds 7 and 11. By the end of June, it appeared in all ponds and reached peaks during June to August in different ponds (Fig. 66).

Emergence started in July and by mid-September, the number of larvae declined to zero. It again reappeared in ponds 7 and 14 during November to December and October to December, respectively.

In 1985, larvae appeared in April and the generation continued until the end of June. All either emerged or disappeared thereafter. After a long absence, the larvae again reappeared in November and again disappeared. No conclusive generation numbers could be established for this species.

4.2.1.2.1.6 Cladopelma sp.

Except in pond 9, the larvae of Cladopelma sp. were recorded from all ponds at least for part of, if not throughout, the year (Fig. 67). There was no overwintering population in either of the years.

The generation started in May and continued until October in both years. There was a decline during the middle of this period in most ponds in both years. The contribution of this species to the total chironomid population is very low (Fig. 71 a-e).

4.2.1.2.1.7 Paratendipes sp.

Larvae of Paratendipes sp. appeared in June, 1985 in ponds 7, 11 and 13. It maintained a small population for 2 to 3 months and then disappeared. Neither pupal exuviae nor imagines were available for specific identification. Paratendipes sp. was never recorded in pond 14.

4.2.1.2.1.8 Microtendipes chloris

Larval Microtendipes sp. was only available in pond 9 in 1984. In the following year it was recorded in April in ponds 7, 11 and 13. None was present in pond 14. It continued to appear in the samples until June and then disappeared. Disappearance of the larvae co-incided with emergence of imagines and presence of pupal exuviae which suggested the emergence period of this species.

Larvae again reappeared in October, maintained a low density and then started to disappear within a month or two except in pond 11, where it passed through an overwintering 2nd instar stage after a partial emergence.

There are possibly two separate generations of this species in Howietoun fish ponds.

4.2.1.2.2 Tanypodinae

4.2.1.2.2.1 Procladius spp.

The second dominant species of Chironomidae was Procladius choreus, which occurred in all ponds in both years. Analyses of the 4th instar larvae of Procladius sp. and pupal exuviae collected from the outlet of the ponds indicated the presence of two species in the fish ponds; the second one could not be identified because of failure to obtain adults of the second species.

The peak emergence periods, which were characterized by a decline in numbers of larvae, presence of pupal exuviae and adult flight, occurred once in mid-April to mid-June and again in mid-October to mid-December in both years. A marked increase in number was observed in August to mid-October (Fig. 68).

Table 17 shows that the cultured ponds were significantly different when compared by two-way ANOVA. The SNK test confirmed that while there was no significant difference between ponds 11 and 13 and

Fig. 68 Procladius spp

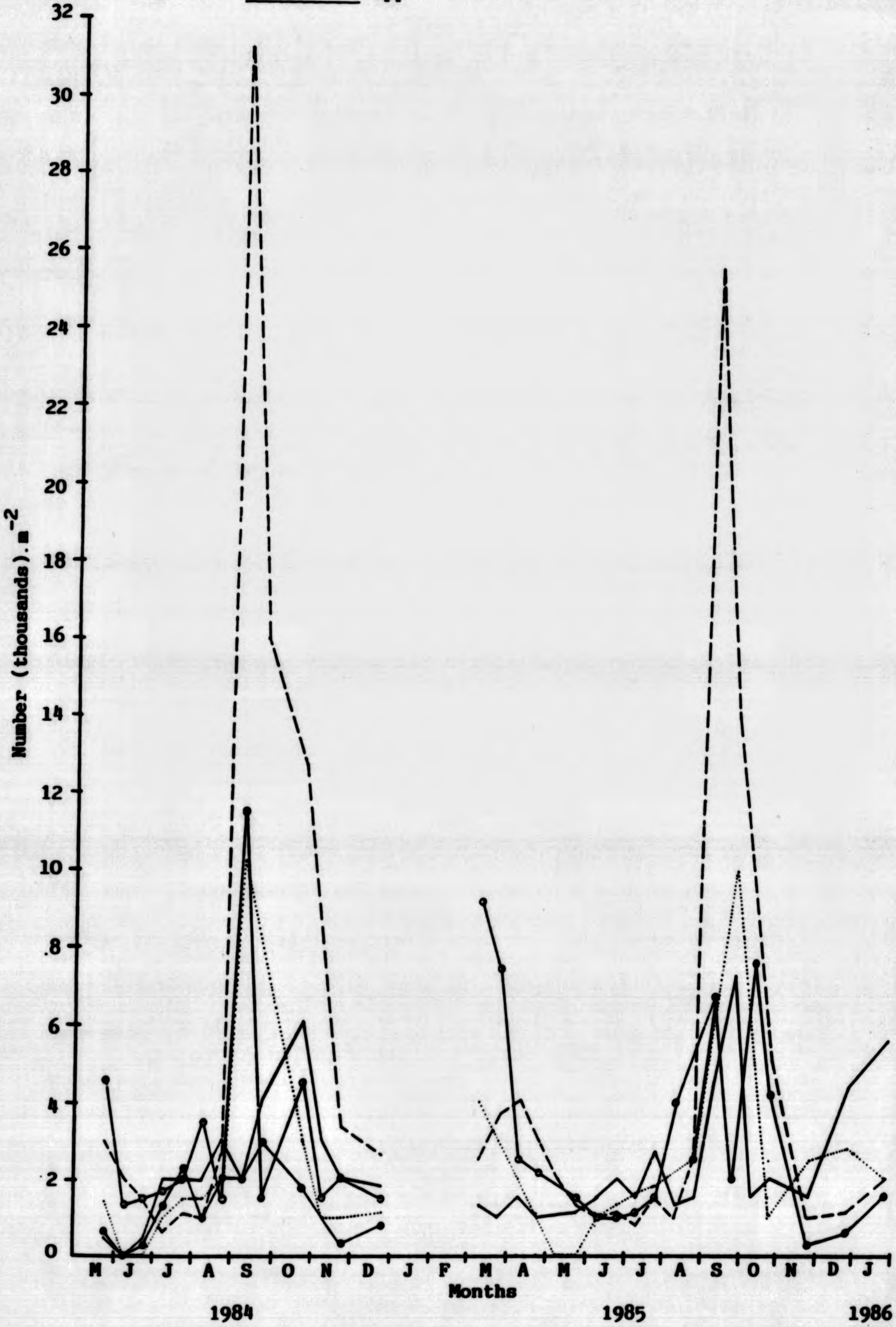


Fig. 68 Seasonal changes in Procladius spp in Howietoun fish ponds (coding for ponds shown in Fig. 8)

7 and 14, the remaining comparisons were significant (Table 18).

4.2.1.2.2.2 Ablabesmyia monilis

This was the second important species of the predatory chironomid group Tanypodinae recorded from all the ponds. It occurred in high densities during early spring and summer in 1985 in all the ponds except control pond 9, where the maximum number was recorded in mid-September, 1984 (Fig. 69).

The rapid decline in number in May indicates the first emergence period. The population again built up in July to August and declined for a second time. During these two emergence periods, large numbers of males were swarming in and around the fish farm. Apart from the isolated occurrence of one or two larvae, no trace of an over-wintering population was noticed.

4.2.1.2.2.3 Guttipelopia sp.

Larvae of Guttipelopia sp. appeared in June, July and November in pond 7 and June to July in pond 13. Larvae were completely absent from pond 14 in both years. Larvae of Guttipelopia sp. were always present in their 2nd and 3rd instars.

4.2.1.2.3 Prodiamesinae

4.2.1.2.3.1 Prodiamesa olivacea

P. olivacea is one of the most common species which occurred in

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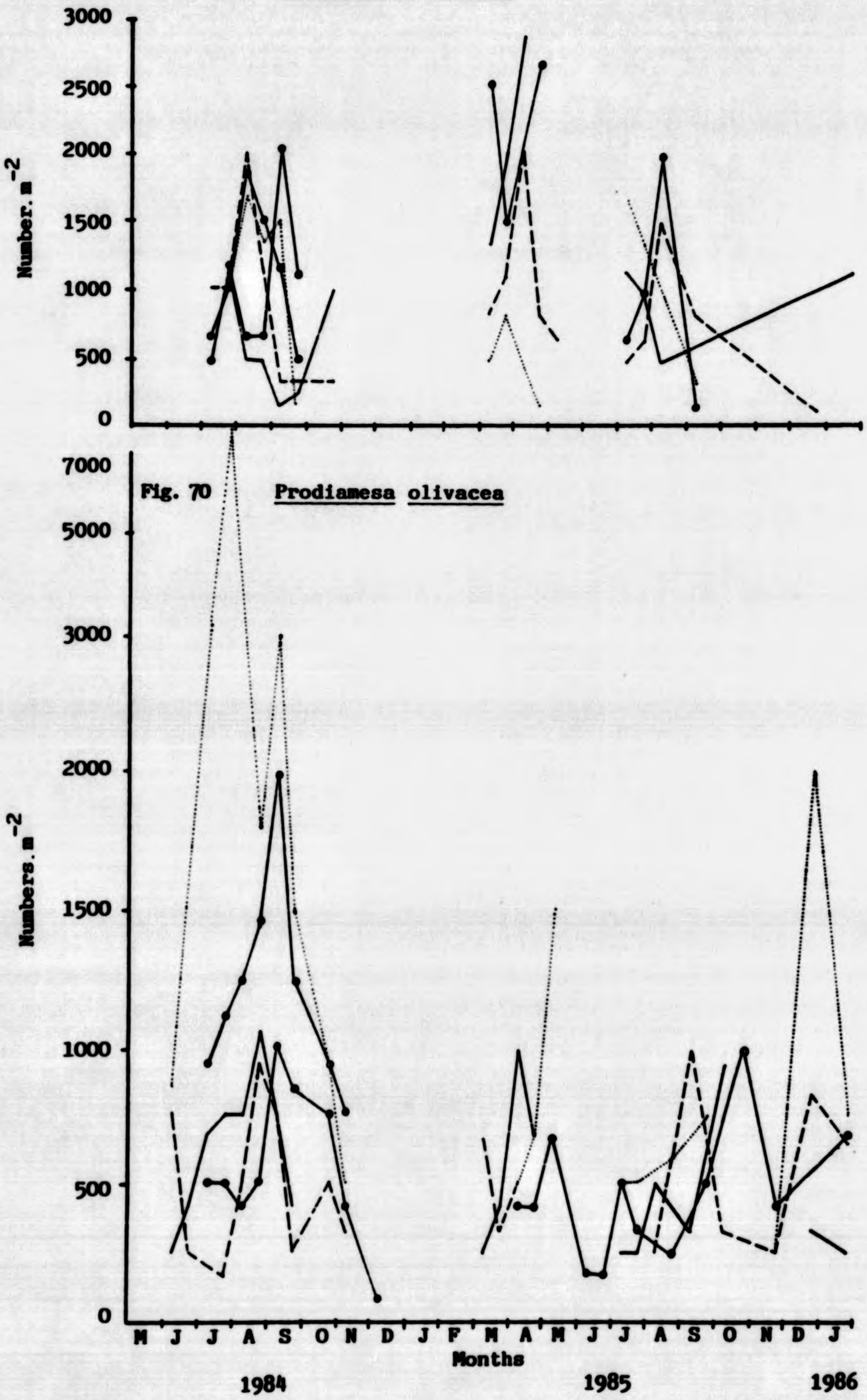
Fig. 69 Ablabesmyia monilis



Figs 69-70 Seasonal changes in Ablabesmyia monilis and Prodiamesa olivacea in Howietoun fish ponds (coding for ponds shown in Fig. 8)

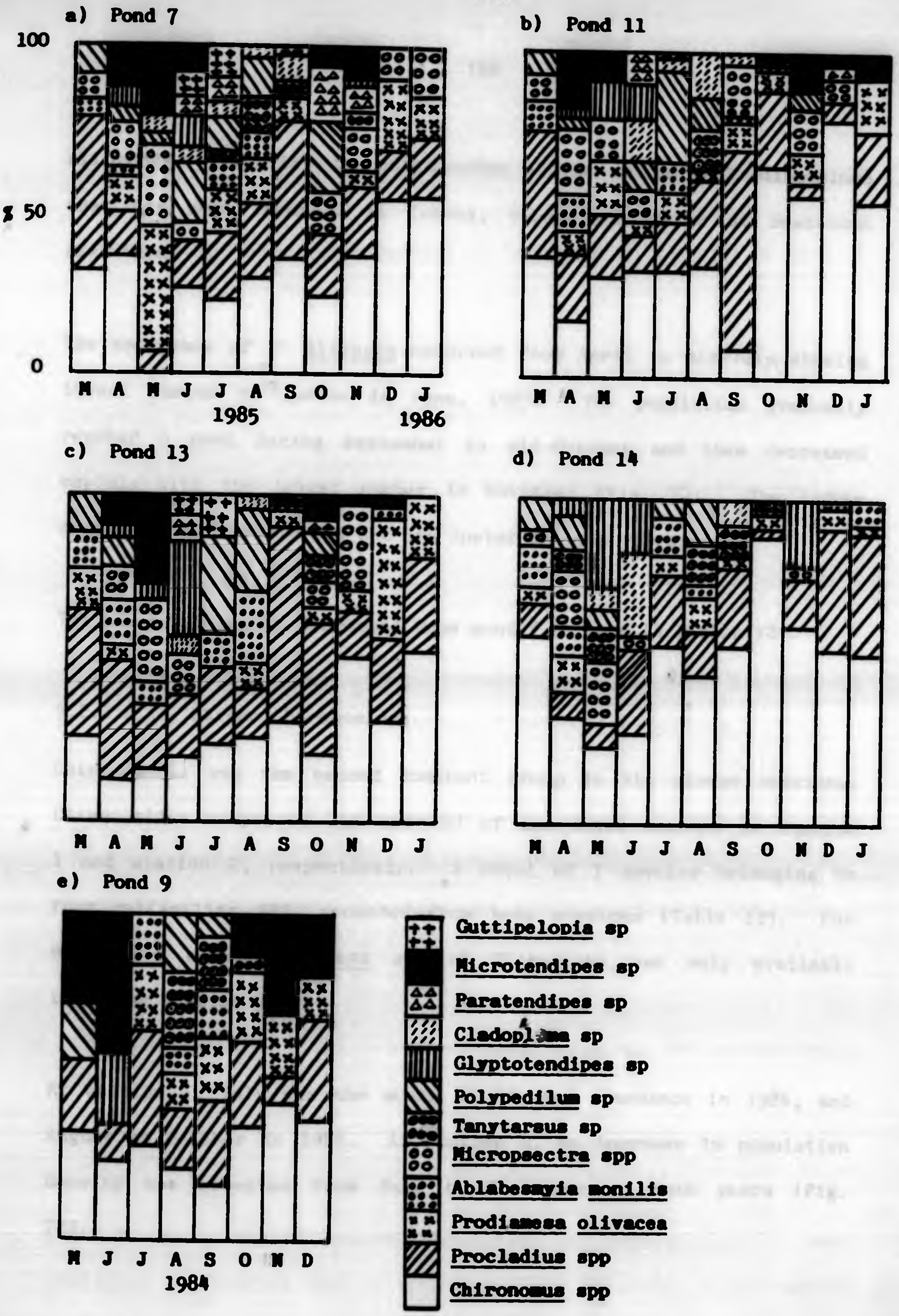


Fig. 71 (a-e) Relative abundance of different species of chironomidae in Howietoun fish ponds all ponds. This is the only species of the subfamily Prodiamesinae that has been recorded as larvae, pupae and adults at Howietoun fish farm.

The emergence of P. olivacea occurred from April to mid-July, showing lowest number of larvae in June, 1985. The population gradually reached a peak during September to mid-October and then decreased rapidly with the lowest number in November (Fig. 70). The larvae overwintered in their 2nd and 3rd instar in both years.

The number of larvae decreased from pond 7 to pond 14 (Table 18).

4.2.2.2 Stream Chironomidae

Chironomidae was the second dominant group in the stream stations. Chironomidae comprised 15% and 18% of the total benthos in station 1 and station 2, respectively. A total of 7 species belonging to four subfamilies was recorded from both stations (Table 12). One rheophilic species, Diamesa sp. of Diamesinae, was only available in stream station 2.

At station 1, July was the month of highest abundance in 1984, and August to October in 1985. At station 2, an increase in population density was observed from July to September in both years (Fig. 72).

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The abundance of Chironomidae including its major species from stream station 1 and station 2 was compared by using paired t-tests, the results of which are presented in Table 19.

The population density of Chironomidae at station 1 was significantly higher than at station 2.

An account of the major species of Chironomidae which were regularly available in both stations is given below.

4.2.2.2.1 Chironomus sp.

This was found in the highest density and comprised 30% and 40% of the total Chironomidae at stations 1 and 2, respectively.

Fig. 73 shows two different generations; spring and autumn at both stations, during which the population density was higher. Two emergence periods, one in early spring and another in late autumn, were noted.

t-test indicated that the number of Chironomus sp. was not significantly different in station 1 than station 2 (Table 19).

4.2.2.2.2 Procladius sp.

Fig. 74 shows marked seasonal variation of this genus at both stations. A spring and a summer-autumnal increase in population

Table 19 Annual means of monthly abundance of stream chironomids and their level of significance (N.S. non-significant; $P < 0.05$,*; $P < 0.01$ **) difference between stream stations

Species	$\bar{X} \pm$ S.E. Stream station 1	Stream station 2	Level of Significance
Chironomus sp.	1,350 ± 160	1,200 ± 180	N.S.
Procladius sp.	830 ± 120	690 ± 140	N.S.
Prodiamesa sp.	1,370 ± 570	650 ± 100	N.S.
Micropsectra sp.	590 ± 150	-	-
Polypedilum sp.	170 ± 70	-	-
Tanytarsus sp.	-	140 ± 70	-
Paratendipes sp.	140 ± 80	-	-
Macropelopia sp.	20 ± 20	90 ± 60	-
Guttipelopia sp.	-	100 ± 60	-
Diamesa sp.	-	140 ± 80	-
Total Chironomidae	4,500 ± 700	3,000 ± 330	**

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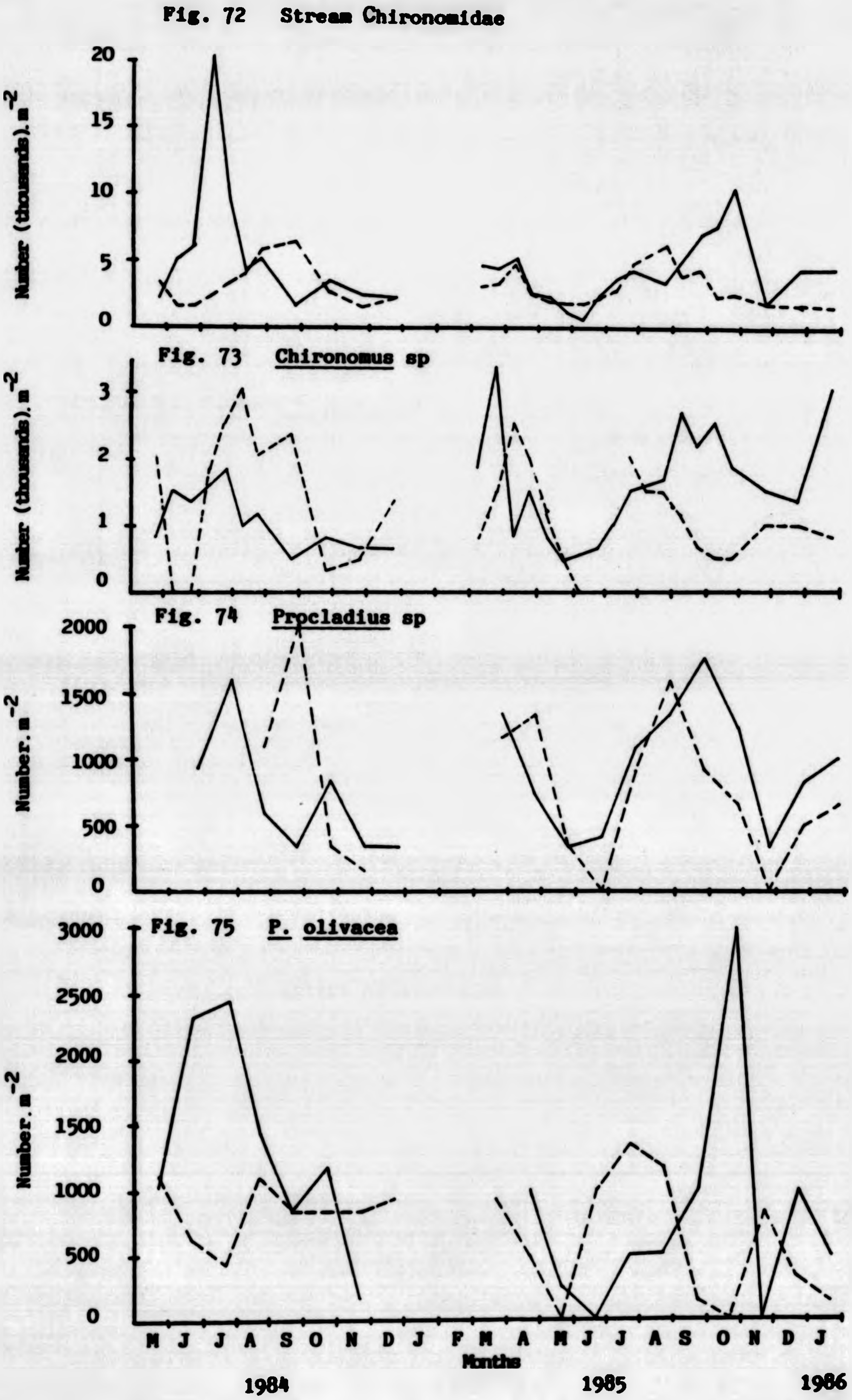
Micropsectra sp.	590 ± 150	-	-
Polypedilum sp.	170 ± 70	-	-
Tanytarsus sp.	-	140 ± 70	-
Paratendipes sp.	140 ± 80	-	-
Macropelopia sp.	20 ± 20	90 ± 60	-
Guttipelopia sp.	-	100 ± 60	-
Diamesa sp.	-	140 ± 80	-
Total Chironomidae	4,500 ± 700	3,000 ± 330	**



Figs 72-75 Seasonal changes in Chironomidae, Chironomus sp., Procladius sp. and P. olivacea in the stream stations (continuous line = intakestation 1; broken line = outflow station 2)

density were clearly visible. May to June and October to November were the two periods of major emergence from both stations.

There was no significant difference between the steam stations (Table 19).

4.2.2.2.3 Prodiamesa olivacea

This was the only species of the subfamily Prodiamesinae which was available in stream stations. Sometimes, the number of this species was exceedingly high, even higher than all other species together.

The seasonal pattern of Prodiamesa olivacea differed between the two stream stations, an increase at one station being accompanied by a decrease at the other (Fig. 75).

When the number of Prodiamesa olivacea was compared between the stations, it was found that there was no significant difference.

4.2.1.3 Mollusca

There were two species of Mollusca inhabiting the Howietoun ponds. Apart from Sphaerium corneum and Lymnaea peregra, dead floating shells of Planorbis sp. were also observed but no live animal was found during the two year study period. Numerically, Mollusca made up about 0.9-3.6% of the total benthic macro-invertebrates.

Fig. 76 indicates that the mollusc population was higher during the growing season (spring to summer). The density of molluscs was the lowest in pond 9 and the highest in pond 13. There was a significant variation between the cultured ponds and between sampling times (Table 20 b). SNK test showed that ponds were significantly different except ponds 7 and 14 (Table 20 a). Table 13 shows that total Mollusca is positively correlated with temperature, particulate organic matter, dissolved organic nitrogen and un-ionised ammonia and negatively correlated with total hardness, calcium, total alkalinity, dissolved oxygen and nitrate.

The relative contribution of molluscs in the total benthic fauna is shown in Fig. 46 (a-e).

4.2.1.3.1 Bivalvia

4.2.1.3.1.1 Sphaerium corneum

This was the dominant mollusc species in all the ponds except pond 14.

Two seasonal peaks, one during March to May another during August to October, can be deduced from Fig. 77.

Two-way ANOVA showed that the cultured ponds were significantly different ($P < 0.01$). A further test by using SNK showed that pond 9 was significantly lower than all other ponds (Table 20 a).

Fig. 76 Total Mollusca

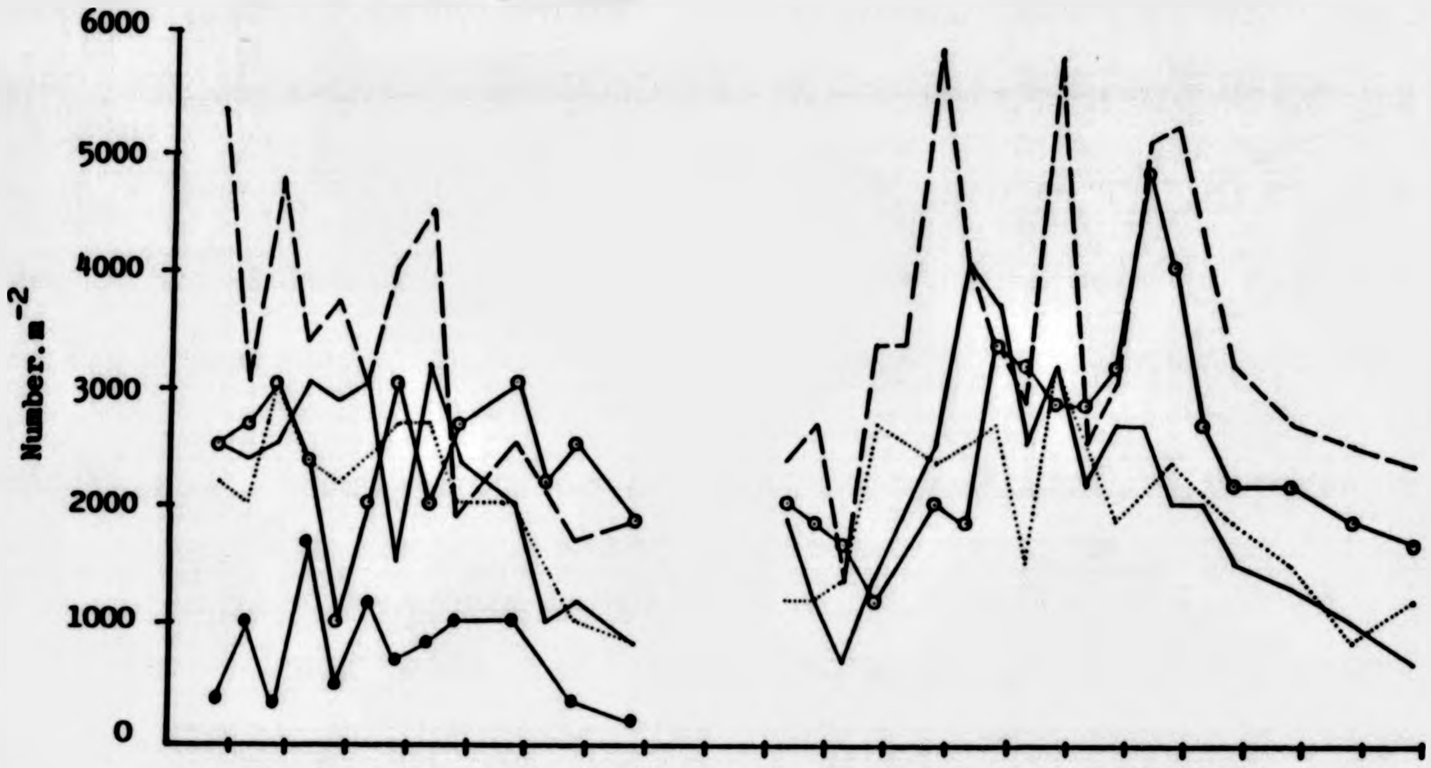


Fig. 77 Sphaerium corneum

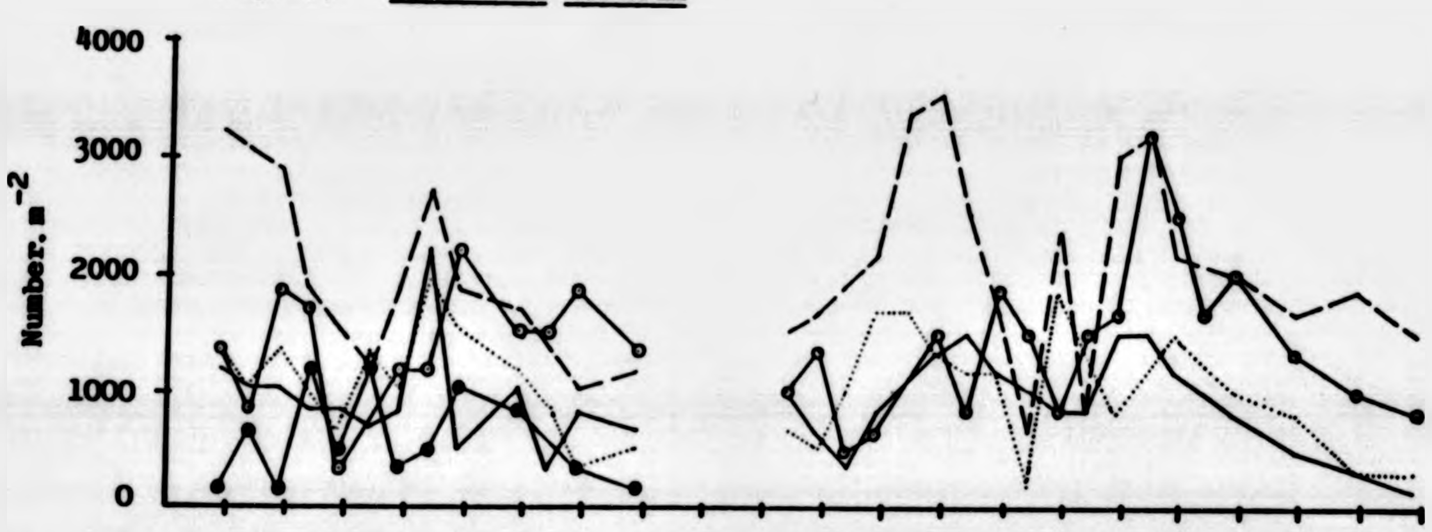
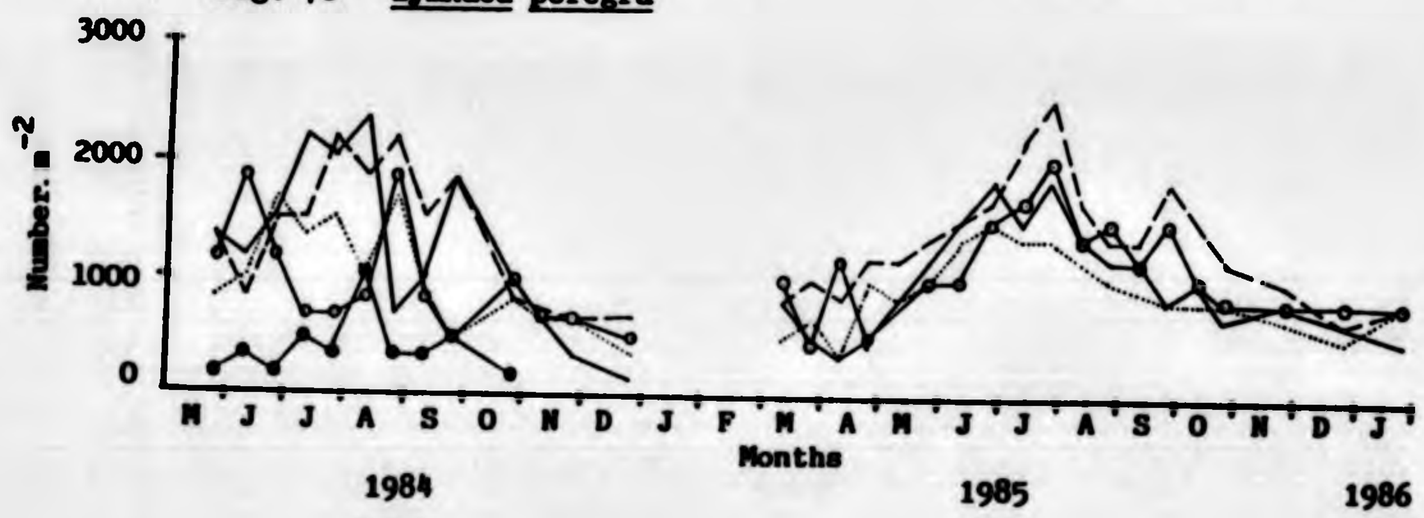


Fig. 78 Lymnaea peregra



Figs 76-78 Seasonal changes in total Mollusca, Sphaerium corneum and Lymnaea peregra in Howietoun fish ponds (coding for ponds shown in Fig. 8)

Table 20 Mollusca at Howietoun

(a) Means of the monthly number per m^2 from all ponds. Superscript letters indicate the significant differences ($P < 0.05$) between the ponds. Values with the same superscript are not significantly different

Species	Pond 9	Pond 7	$\bar{X} \pm$ S.E. Pond 11	Pond 13	Pond 14
S. corneum	400 ± 90^{a}	940 ± 90^{b}	$1{,}400 \pm 140^{c}$	$1{,}900 \pm 170^{c}$	850 ± 80^{b}
L. peregra	360 ± 80^{a}	840 ± 90^{b}	$1{,}070 \pm 90^{bc}$	$1{,}240 \pm 120^{c}$	$1{,}080 \pm 140^{bc}$
Total Mollusca	760 ± 138^{a}	$1{,}800 \pm 150^{b}$	$2{,}500 \pm 200^{c}$	$3{,}100 \pm 240^{d}$	$1{,}900 \pm 200^{b}$

(b) F-values and associated levels of significance for ANOVAs on cultured ponds' data (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**)

Species	Sources of Variation Between ponds (F)	Between times (F)	Interactions (F)
S. corneum	17.06**	3.27**	-
L. peregra	5.17**	5.15**	-
Total Mollusca	14.39**	3.11**	0.68 N.S.

(c) Means of the monthly number per m^2 from stream data and results of t-tests

Species	$\bar{X} \pm$ S.E. Stream station 1	Stream station 2	Level of significance
S. corneum	900 ± 100	900 ± 140	N.S.
L. peregra	600 ± 90	0	-
Total Mollusca	$1{,}300 \pm 160$	900 ± 140	**

5 Discussion

There were two peaks of recruitment of young individuals in 1985. In the first instance, young bivalves with an average size of 2.9 $\pm$ 0.54 mm shell length formed 36% of the total number of bivalves collected from all ponds in March. This figure gradually increaed and reached 56% in May in the same year. Breeding continued slowly throughout the summer. Heavy mortalities occurred during July in both years.

During the second recruitment time, smaller sized individuals increasingly occurred in the samples during September to October. A size range of 2.24 $\pm$ 0.16 mm comprised 55% of the total bivalves. A large 10.4 $\pm$ 0.42 mm size class with two annuli was recorded during early spring, possibly constituting the breeding population, and a similar size class of 10.0 $\pm$ 1.2 mm also with two annuli was found in October. After each of the breeding periods, these large size individuals disappeared from the population. It seemed that the animals bred in their second year of life and then died.

4.2.1.3.2 Gastropoda

4.2.1.3.2.1 Lymnaea peregra

L. peregra, the only gastropod available in the fish ponds, comprised 56% of the average mollusc population in pond 14 but was less abundant than Sphaerium in all other ponds. In general, L. peregra attained maximum density in summer months in both years (Fig. 78).

A significant variance ratio was observed between the cultured ponds (Table 20 b), but SNK test showed that only ponds 9 and 13 were significantly different from the rest of the ponds (Table 20 a).

Except for very few large molluscs with a shell length of 13.5 $\pm$ 1.0 mm, the majority of the spring population could be divided into two size classes, 9.50 $\pm$ 0.81 and 5.70 $\pm$ 0.43 mm. During early June the larger size partially disappeared from the population and small animals with an average shell size 2.15 $\pm$ 0.55 mm appeared in the samples. The maximum recruitment of young individuals was observed during July in 1985 and June to August in 1984.

A relatively small proportion of small individuals entered into the population during September in both years. All these young, with very few of the earlier generation, entered into the overwintering population. It could be postulated that there was only one protracted breeding season in its second year.

4.2.2.3 Stream Mollusca

The molluscan population in the upstream (station 1) consisted of the same two species as in pond populations. Surprisingly, there was only one species S. corneum in downstream (station 2). Fig. 79 shows little seasonal pattern except in 1985, when both total molluscs and S. corneum were found to show spring and autumn maxima. A much higher population density was observed at station 2 in December, 1984.

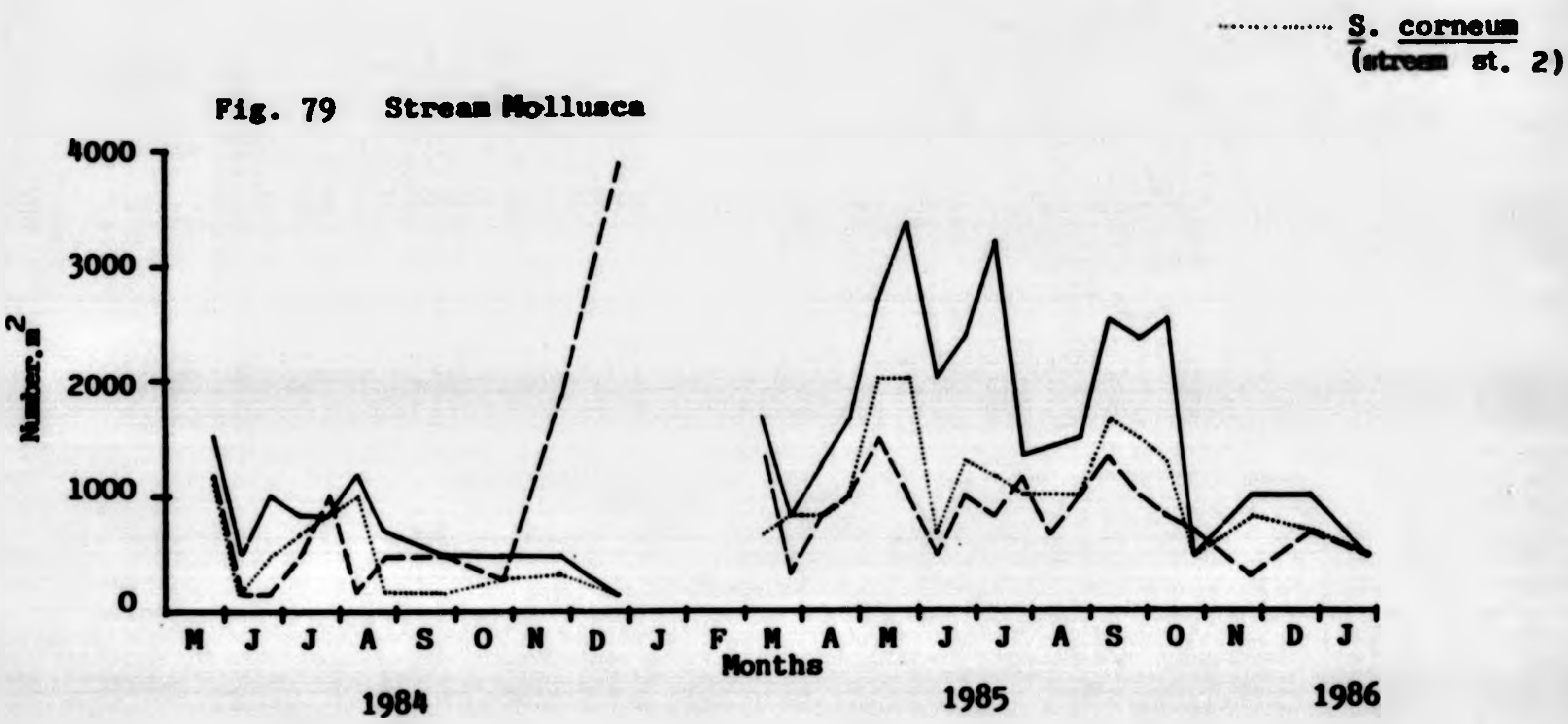


Fig. 79 Seasonal changes in Mollusca and S. corneum in the stream stations (continuous line = intake station 1; broken line = outflow station 2)

t-tests on log transformed data showed that the total mollusc population at station 1 was significantly higher than at station 2, but the populations of S. corneum were not significantly different (Fig. 20 c).

4.2.1.4 Hirudinea

Three species of leeches occurred in Howietoun ponds. Helobdella stagnalis and Erpobdella octoculata occurred throughout the year, while Glossiphonia complanata appeared rarely in the samples.

Leeches comprised only 1.0-3.1% of the total benthic macro-invertebrate population.

Fig. 80 shows two periods of maximum abundance, viz., March to early June and August to September 1985. The population density varied from pond to pond, the highest number was recorded in pond 11 and the lowest in pond 9. Both two-way ANOVA and SNK tests showed these differences to be significant (Table 21 a, b).

The relative abundances of leeches in the total benthos are given in Fig. 46 (a-e).

4.2.1.4.1 Helobdella stagnalis

Fig. 81 shows that the population density was lower during June and July in most of the ponds and was higher during spring and autumn.

Table 21 Hirudinea at Howietoun

(a) Means of monthly number per m^2 from all ponds. Superscript letters indicate significant ($P < 0.05$) differences as tested by Student-Newman-Keuls test. Values with the same superscript are not significantly different

Species	Pond 9	Pond 7	$\bar{X} \pm$ S.E. Pond 11	Pond 13	Pond 14
H. stagnalis	670 ± 100^a	940 ± 90^a	$5,400 \pm 826^c$	750 ± 80^a	$1,900 \pm 100^b$
E. octoculata	530 ± 100^a	650 ± 50^b	900 ± 60^c	$1,200 \pm 90^d$	$1,500 \pm 100^e$
Total Hirudinea	$1,200 \pm 130^a$	$1,600 \pm 100^b$	$6,300 \pm 850^e$	$1,940 \pm 120^c$	$3,500 \pm 250^d$

(b) F-values and their associated levels of significance for ANOVAs on log transformed data from all cultured ponds (N.S. non-significant; $P < 0.05$,*; $< P$ 0.01,**)

Species	Sources of Variation: Between ponds (F)	Between times (F)	Interactions
H. stagnalis	48.27**	2.92**	-
E. octoculata	75.90**	13.95**	-
Total Hirudinea	80.53**	6.80**	1.53*

(c) Mean values of monthly number per m^2 from stream stations and results of t-tests on log (x + 1) transformed data (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**)

Species	$\bar{X} \pm$ S.E. Stream station 1	Stream station 2	Level of significance
H. stagnalis	440 ± 56	160 ± 40	**
E. octoculata	330 ± 40	470 ± 50	N.S.
Total Hirudinea	780 ± 60	630 ± 60	*

The mean number of *H. stagnalis* in ponds 11 and 14 were significantly greater than in the other ponds (Table 21 a).

H. stagnalis was found to breed two times per year. It first bred during March to May with a peak of 30% very young size (0.1 to 0.5 mg, wet weight) in April. The older large leeches (6.0 mg, wet weight) disappeared from the population in May.

Brooding leeches with tansparent cocoons fastened to the ventral surface of the body started appearing in August. During this time 50% of animals were $>$7 mg in weight. The appearance of young individuals began in September and continued until November. In September, young individuals (0.1 to 0.6 mg) accounted for only 17% of the total, but by the end of November, young individuals with size range 0.6 to 1.5 mg comprised 56% of the total *H. stagnalis* population. Both spring and autumn generations entered into the overwintering population, forming two major size classes.

4.2.1.4.2 *Erpobdella octoculata*

This species of leech increased their mean population density from pond 7 to pond 14 with the lowest numbers in pond 9. Table 21 a shows the population densities in different ponds to be significantly different (SNK).

Fig. 82 shows the temporal pattern of population density in which the maximum level was observed in early spring and late summer,

Fig. 80 Hirudinea

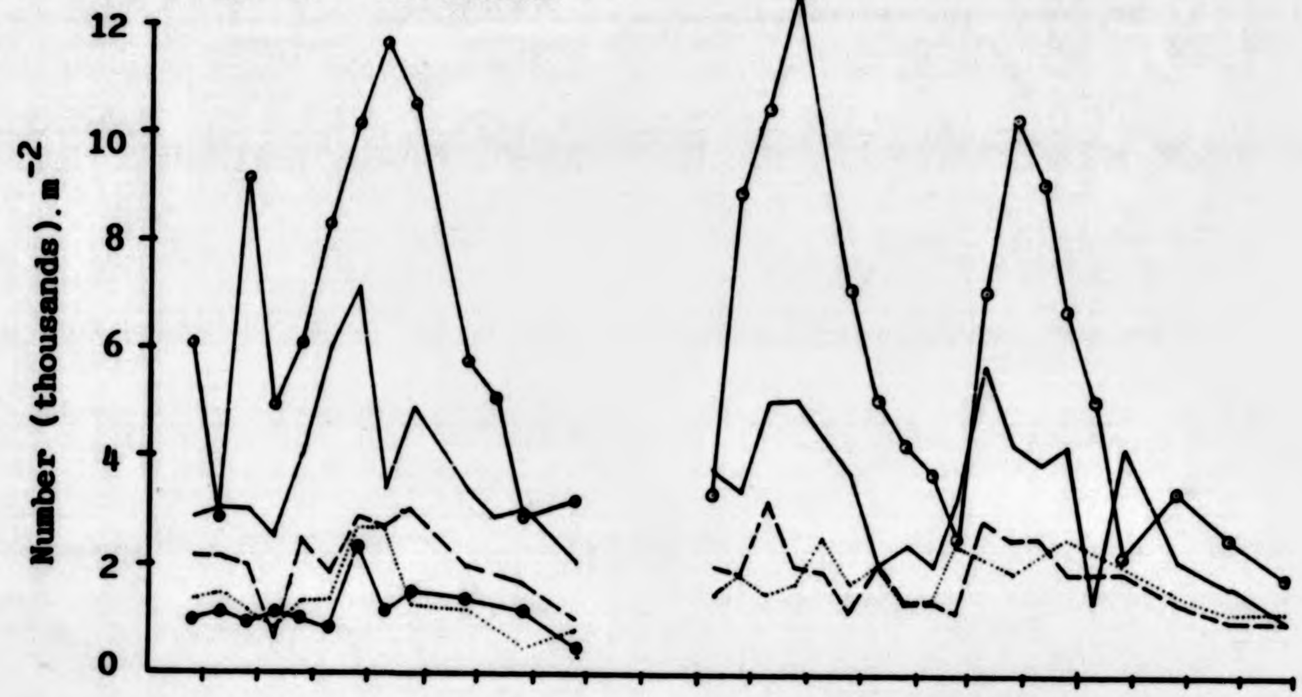


Fig. 81 Helobdella stagnalis

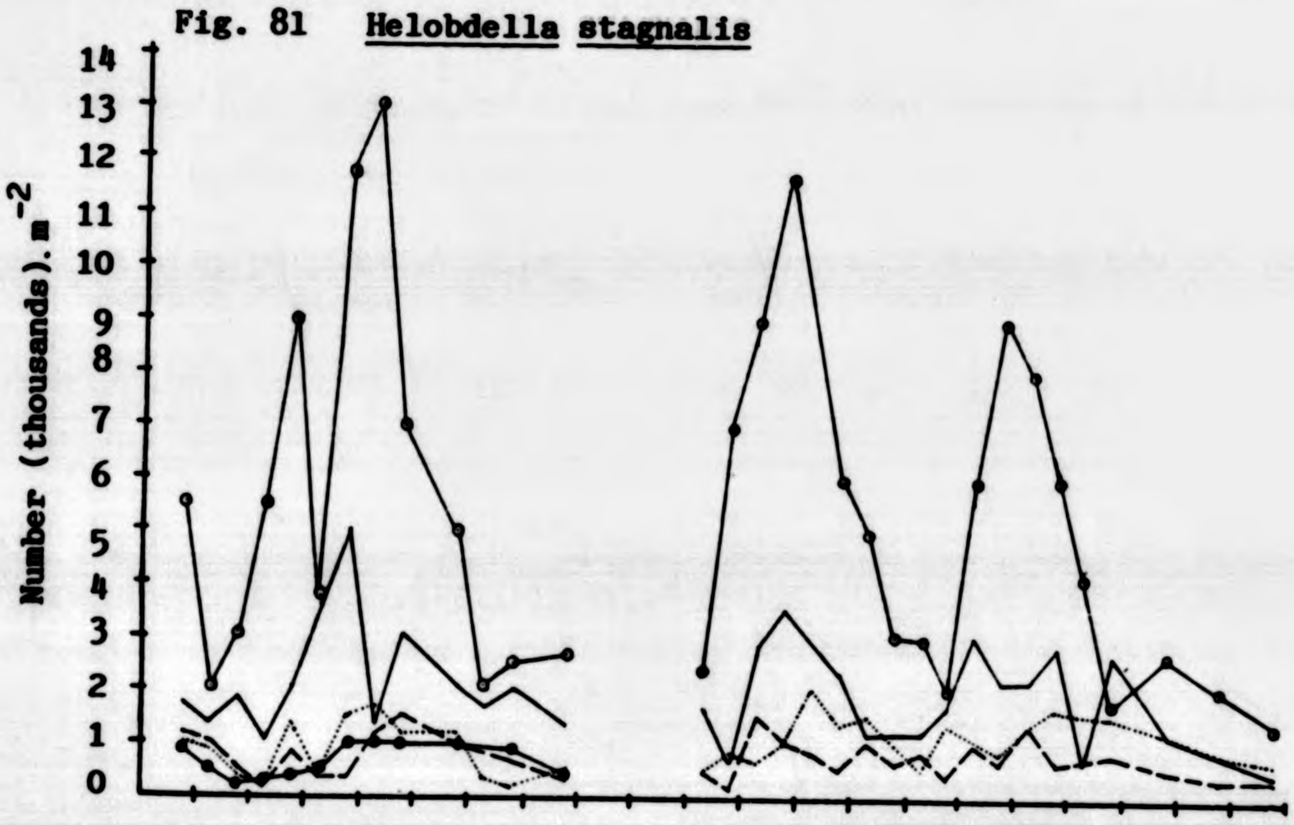
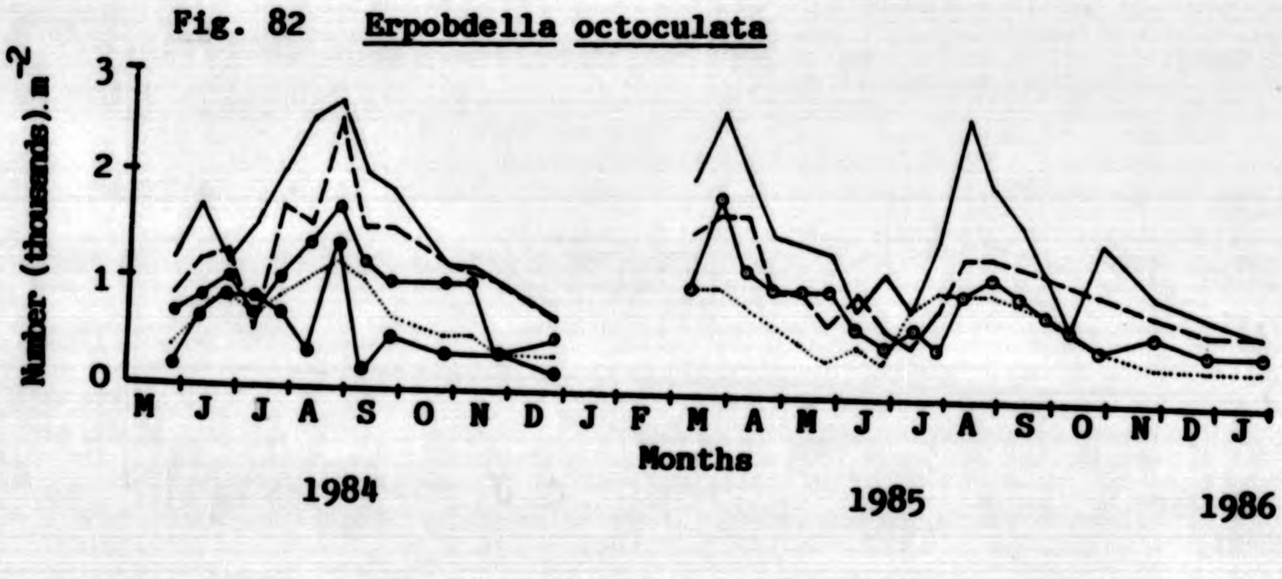


Fig. 82 Erpobdella octoculata



Figs 80-82 Seasonal changes in Hirudinea, Helobdella stagnalis and Erpobdella octoculata in Howietoun fish ponds (coding for ponds shown in Fig.8)

while relatively lower numbers were maintained in June and July and the winter months.

The life-cycle of E. octoculata took one year in Howietoun ponds. The first generation of young individuals appeared in March. The percentage of young individuals increased from 33% in March to 62% in May 1985, whereas larger individuals declined from 33% to 8% during the same period. Throughout the summer both first generation and the survivors of the overwintering population increased their size.

Recruitment of young individuals extended over the period August to October, but with the main pulse in August (66% of the maximum population). Older animals gradually disappeared from the population. Until October 73% of the total population was between 2.3 to 8.1 mg in size. A maximum individual weight of 200.10 mg and a minimum of 0.8 mg was recorded from ponds 14 and 13, respectively.

4.2.2.4 Stream Hirudinea

Similar to pond populations, stream leeches were also represented by two species. Both H. stagnalis and E. octoculata were available at station 1 throughout the year. In stream 2, on the other hand, only E. octoculata was regularly available, while H. stagnalis was infrequently recorded.

Figs 83 and 84 do not indicate any distinct seasonal patterns of while relatively lower numbers were maintained in June and July and the winter months.

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Fig. 83 Stream Hirudinea

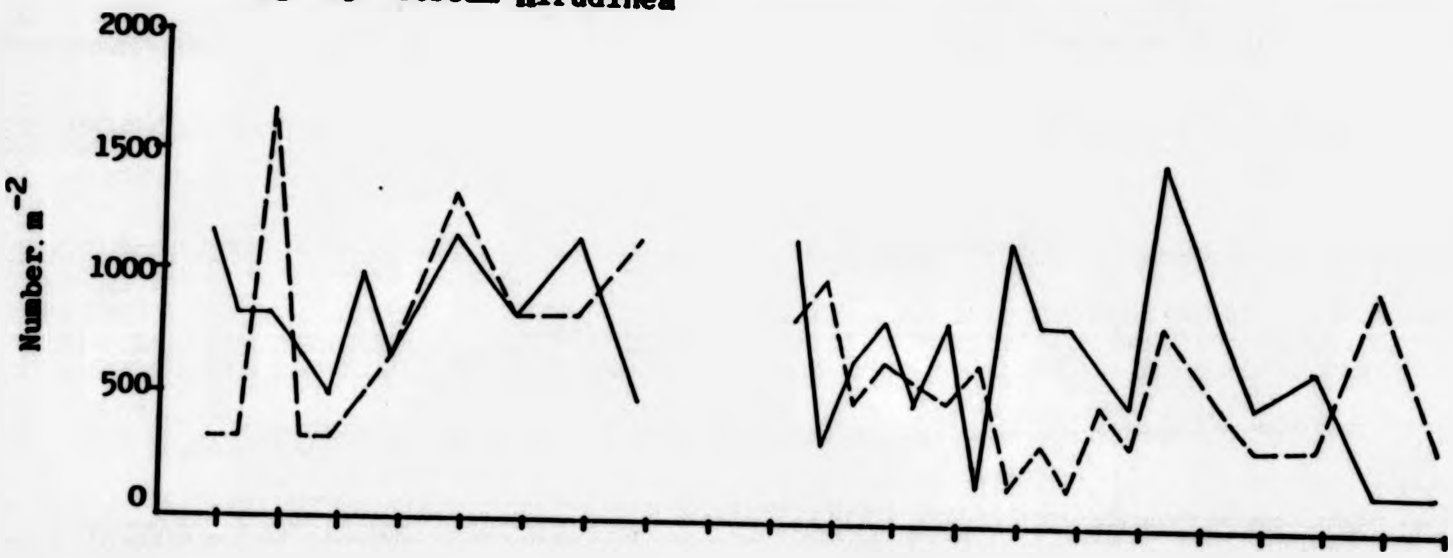
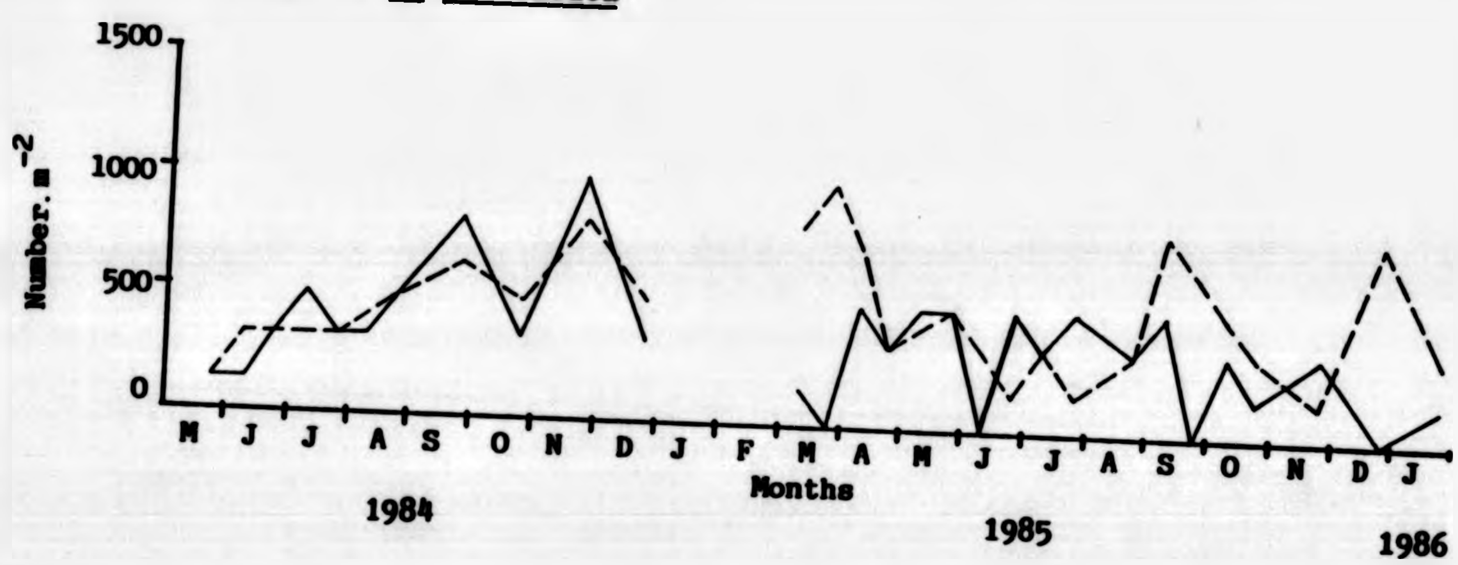


Fig. 84 E. octoculata



Figs 83-84 Seasonal changes in Hirudinea and E. octoculata in the stream stations (continuous line = intake station 1; broken line = outflow station 2)

either Hirudinea or E. octoculata.

Both total leeches and H. stagnalis were significantly higher in station 1 than in station 2 (Table 21 c) but E. octoculata was not significantly different between upstream and downstream stations.

4.2.1.5 Asellidae

4.2.1.5.1 Asellus aquaticus

This was the only species of Asellidae recorded from Howietoun ponds. It was available throughout the year in all the ponds, forming on average 0.3-1.0% of the total benthic fauna.

Table 22 b shows that the number of A. aquaticus were significantly different between the cultured ponds as derived from a two-way ANOVA on log transformed data. Ponds 11 and 13 contained significantly higher numbers of Asellus sp. than ponds 9, 7 and 14 (SNK test).

Fig. 85 failed to show any clear cut seasonal trend in any of the ponds.

A. aquaticus had two breeding cycles, which were evident from the presence of couples, gravid females and young individuals in the samples.

At the beginning of March 1985, nearly 66% of the population formed 'couples' when a male carried his mating partner under his venter.

Table 22 (a) Means of the monthly number per m^2 of A. aquatican and S. lutaria from all the ponds. Superscript letters indicate significant differences ($P < 0.05$) between the ponds. Values with same superscript are not significantly different

	$\bar{X} \pm$ S.E.				
	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14
Asellus aquaticus	440 ± 70^a	530 ± 50^a	780 ± 60^b	880 ± 90^b	580 ± 60^a
Sialis lutaria	380 ± 70^a	890 ± 90^b	870 ± 80^b	$1,020 \pm 100^b$	$1,000 \pm 70^b$

(b) F-values and related level of significance for ANOVAs on log (x + 1) transformed data from all the cultured ponds (N.S. non-significant; $P < 0.05$,*; $P < 0.01$,**)

	Sources of Variation		
	Between ponds (F)	Between times (F)	Interactions (F)
Asellus aquaticus	3.97**	2.0 **	0.59 N.S.
Sialis lutaria	0.50 N.S.	3.50**	0.38 N.S.

Fig. 85 **Asellus aquaticus**

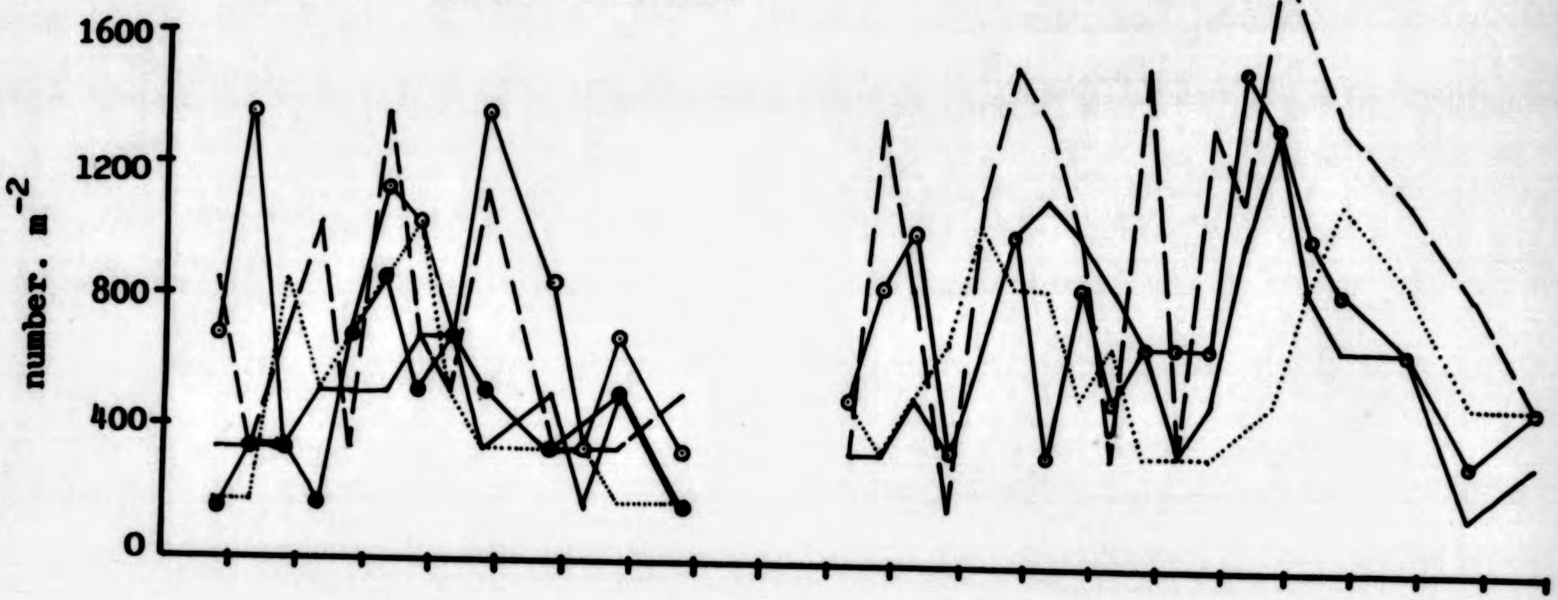
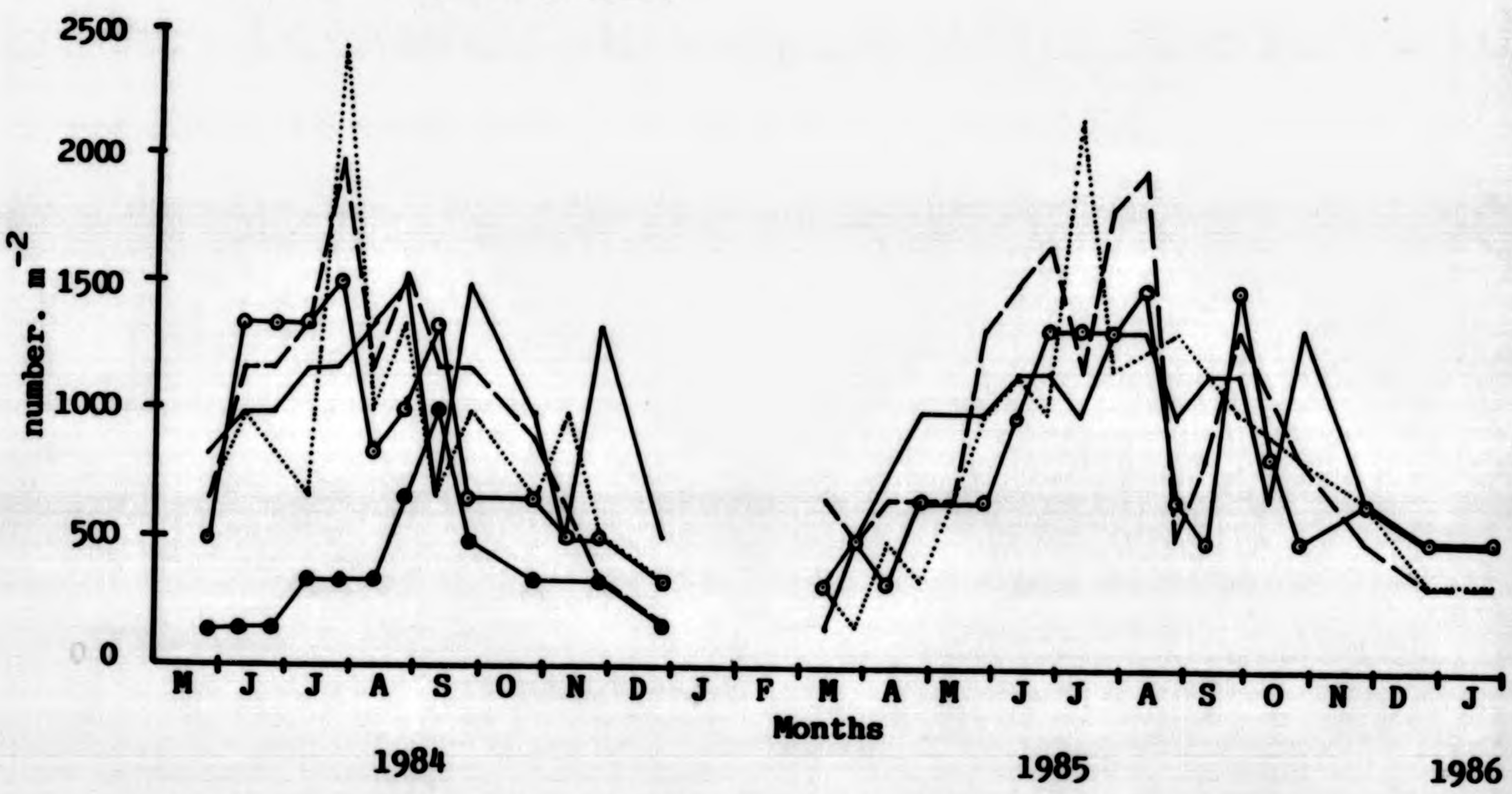


Fig. 86 **Sialis lutaria**



Figs 85-86 Seasonal changes in _Asellus aquaticus_ and _Sialis lutaria_ in Howietoun fish ponds (coding for ponds shown in Fig. 8)

The size of the male was almost always bigger (9.6 $\pm$ 0.27 mm) than the female (6.8 $\pm$ 0.23 mm). Ovigerous (gravid) females first appeared on 20th March 1985, carrying eggs in the brood-pouch and preparing for hatching their eggs by leaving the male partners. By the end of April, the majority of the individuals consisted of ovigerous females. At this time, a few very small individuals (2 mm in length). appeared in the samples. After their first appearance on 26th of April, the number of juveniles gradually increased and continued until the end of July with a maximum abundance in May to June, 1985. The older generation gradually disappeared from the population and a size-class of 6.0 mm in length was found during this period.

A second breeding period, with the appearance of a small number of gravid females, began at the beginning of August. Though breeding continued until October, young individuals reached a peak in September. The last gravid female was collected on 10th October, 1985. These juveniles, along with ones born in spring, entered into the over-wintering population.

4.2.1.6 Sialidae

4.2.1.6.1 Sialis lutaria

The nymph of alderfly S. lutaria was found in all the fish ponds throughout the period of study. Although an increase in summer months was noticeable, the overall seasonal pattern was not distinct (Fig. 86).

The size of the male was almost always bigger (9.6 ± 0.27 mm) than the female (6.8 ± 0.23 mm). Ovigerous (gravid) females first appeared on 20th March 1985, carrying eggs in the brood-pouch and preparing for hatching their eggs by leaving the male partners. By the end of April, the majority of the individuals consisted of ovigerous females. At this time, a few very small individuals (2 mm in length). appeared in the samples. After their first appearance on 26th of April, the number of juveniles gradually increased and continued until the end of July with a maximum abundance in May to June, 1985. The older generation gradually disappeared from the population and a size-class of 6.0 mm in length was found during this period.

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4.2.1.6 Sialidae

4.2.1.6.1 <u>Sialis lutaria</u>

The nymph of alderfly <u>S</u>. <u>lutaria</u> was found in all the fish ponds throughout the period of study. Although an increase in summer months was noticeable, the overall seasonal pattern was not distinct (Fig. 86).

Two-way ANOVA revealed that there was no significant difference between the ponds (Table 22 b). Control pond 9 was significantly lower than all other ponds, which were not significantly different from each other (SNK test) (Table 22 a). The correlation matrix in Table 13 shows that there was a significant positive correlation of S. lutaria with temperature and particulate organic matter.

Life-cycle information was not complete enough to be presented here. A very small size group (5 mm) formed about 40% of the population during July to August. Two alderfly were also caught from the banks of a pond in July which indicated a possible emergence period.

4.2.3 Biomass and production estimation

4.2.3.1 Total benthic fauna

Fig. 87 shows that the total benthic biomass varied seasonally with spring and autumn-winter maxima and a summer maximum in 1985. Similar trends were not distinct in 1984.

Biomasses of all benthic animal groups in different ponds were compared by SNK and their results are presented in Table 23. Biomass of total benthos in ponds 9 and 13 was significantly lower than other ponds.

Details of production estimation including changes in number and mean weight are shown in Appendices II-VII. The results of production are summarized in Table 24.

Table 23 Overall annual mean dry biomass of different groups of benthic macro-invertebrates from all ponds. Superscript letters indicate significant differences ($P < 0.05$) between the ponds as compared by SNK tests. Values with the same letter are non-significant.

Benthic Group	$\bar{B} \pm$ S.E. (g dry wt. m^{-2})				
	Pond 9	Pond 7	Pond 11	Pond 13	Pond 14
Oligochaeta	11.64 ± 1.36^{a}	48.51 ± 4.68^{c}	46.74 ± 3.29^{c}	13.59 ± 2.42^{a}	34.31 ± 3.78^{b}
Chironomidae	0.98 ± 0.23^{a}	3.86 ± 0.69^{bc}	5.28 ± 0.88^{bc}	3.75 ± 0.62^{b}	7.10 ± 1.37^{c}
Mollusca	0.38 ± 0.07^{a}	0.87 ± 0.09^{b}	1.18 ± 0.10^{c}	1.54 ± 0.12^{d}	1.09 ± 0.09^{bc}
Hirudinea	0.57 ± 0.09^{a}	0.86 ± 0.18^{b}	2.52 ± 0.28^{c}	0.94 ± 0.11^{b}	1.73 ± 0.21^{c}
Asellidae	0.56 ± 0.11^{a}	0.67 ± 0.09^{a}	1.03 ± 0.11^{b}	1.06 ± 0.12^{b}	0.77 ± 0.08^{a}
Sialidae	0.91 ± 0.16^{a}	2.08 ± 0.23^{b}	2.39 ± 0.20^{b}	2.69 ± 0.32^{b}	2.51 ± 0.22^{b}
Total benthic macro-invertebrates	15.03 ± 1.53^{a}	56.85 ± 5.20^{bc}	59.14 ± 3.63^{c}	23.56 ± 2.53^{a}	47.51 ± 4.55^{b}

Fig. 87 Biomass of total benthos

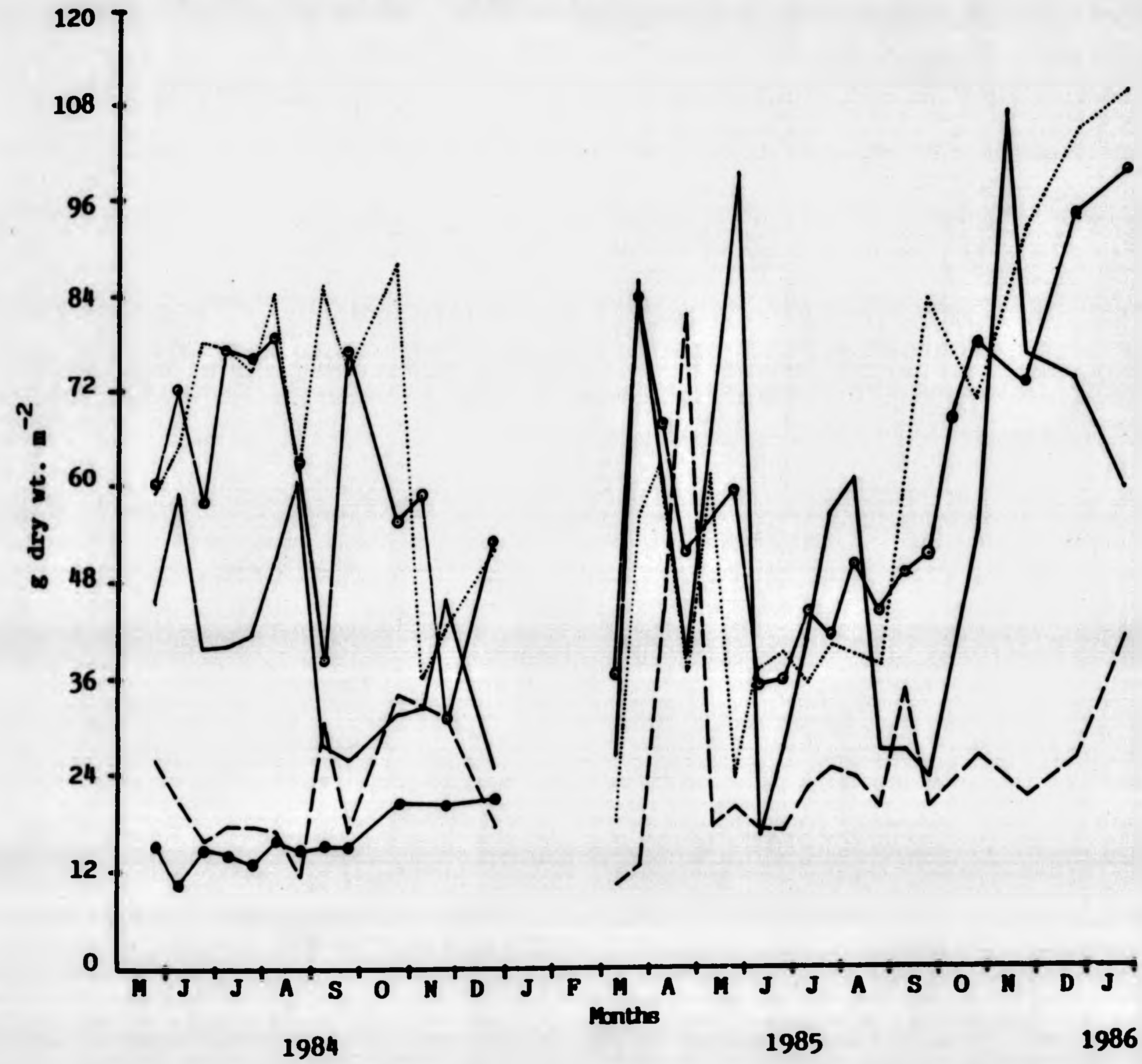


Fig. 87 Seasonal changes in the biomass of total benthos in Howietoun fish ponds (coding for ponds shown in Fig. 8)

Table 24 Annual dry weight production of different groups of benthic macro-invertebrates for all ponds. (All values are expressed in g $m.^{-2}$ yr^{-1} on the basis of dry wt. except mollusca, which is expressed in ash free dry weight basis)

Benthic group	Pond 9 1984	Pond 9 1985	Pond 7 1984	Pond 7 1985	Pond 11 1984	Pond 11 1985	Pond 13 1984	Pond 13 1985	Pond 14 1984	Pond 14 1985
	Production (g $m.^{-2}$ yr^{-1})									
Oligochaetae	35.28	-	131.50	187.64	167.34	150.77	75.45	112.0	104.61	190.18
Chironomidae	8.06	-	29.39	20.57	31.04	24.46	20.84	20.36	34.20	32.71
Mollusca	2.0	-	10.79	1.75	5.90	2.68	4.17	2.27	6.66	3.70
Hirudinea	2.64	-	3.36	2.07	12.08	9.69	3.20	1.70	11.90	4.78
Asellidae	4.80	-	0.84	3.07	2.19	5.27	1.35	6.88	1.94	4.57
Sialidae	2.13	-	8.43	7.78	11.81	5.78	6.68	6.80	10.22	5.89
Total production (without Mollusca)	52.91	-	173.52	221.13	224.46	195.97	107.52	108.28	162.87	238.13
Total production (with Mollusca)	54.91	-	184.31	222.88	230.36	198.65	111.69	149.0	169.53	241.83
Average annual production	54.91		203.60		214.51		130.35		205.68	

A high level of benthic production was observed in all ponds except in control pond 9. Each of stocking ponds 7, 11 and 14 had an annual production which was almost four times greater than that of the control pond. Production in brood pond 13 was always lower than the other cultured ponds.

Production of benthic organisms was higher in 1985 in all ponds except in pond 11.

4.2.3.1.1 Oligochaetae

Oligochaetae was the main contributor to the biomass and production of total benthos in all ponds. On average, the contribution of oligochaetes to the total benthic biomass was 58-85% in different ponds (Table 23), while corresponding contribution to total production was 64-74% (Table 24).

Seasonal changes in the biomass of Oligochaetae in all the ponds are shown in Fig. 88.

SNK tests showed that dry biomass of Oligochaetae was significantly higher in ponds 7 and 11 followed by pond 14. Lowest biomass was recorded from the control pond 9 and pond 13 was the lowest of the cultured ponds.

Although Oligochaetae production was higher in all cultured ponds, ponds 7 and 11 had the highest production. Brood fish pond 13 and

Fig. 88 Oligochaete biomass

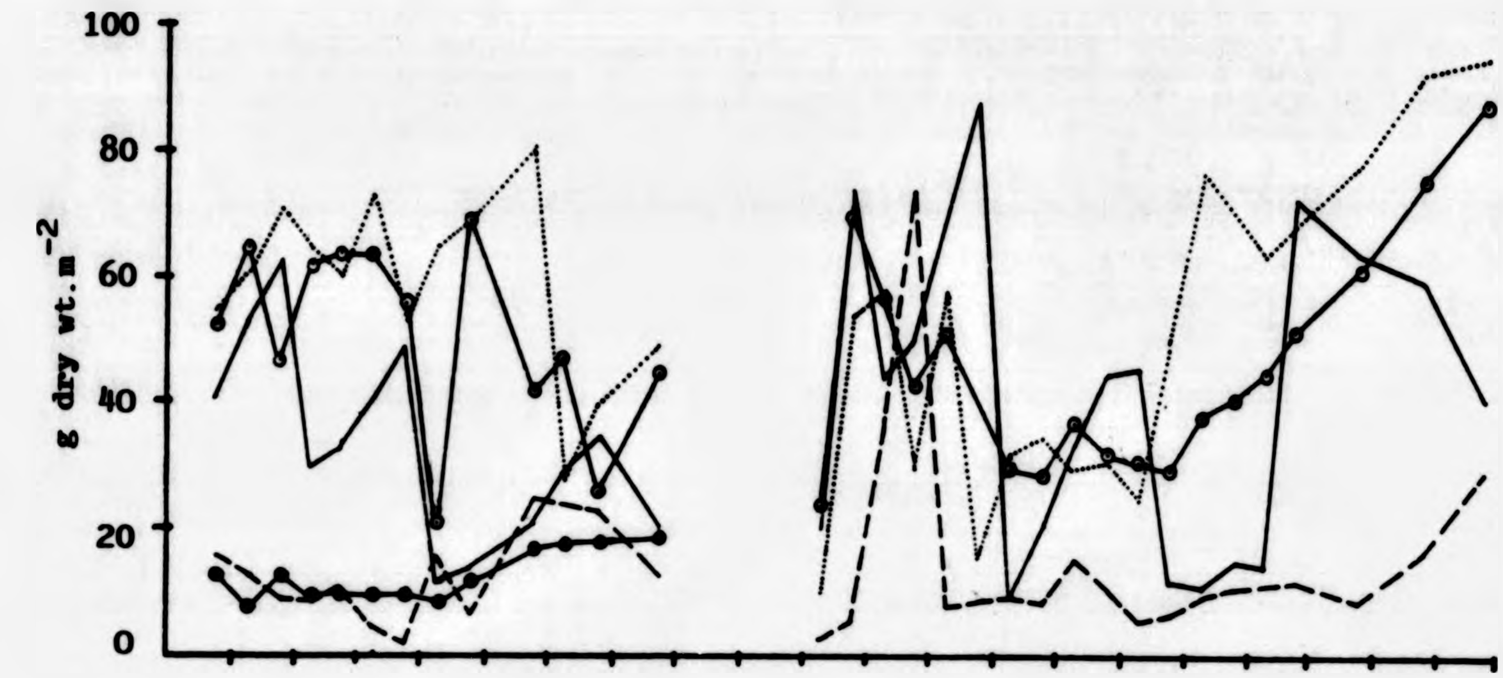
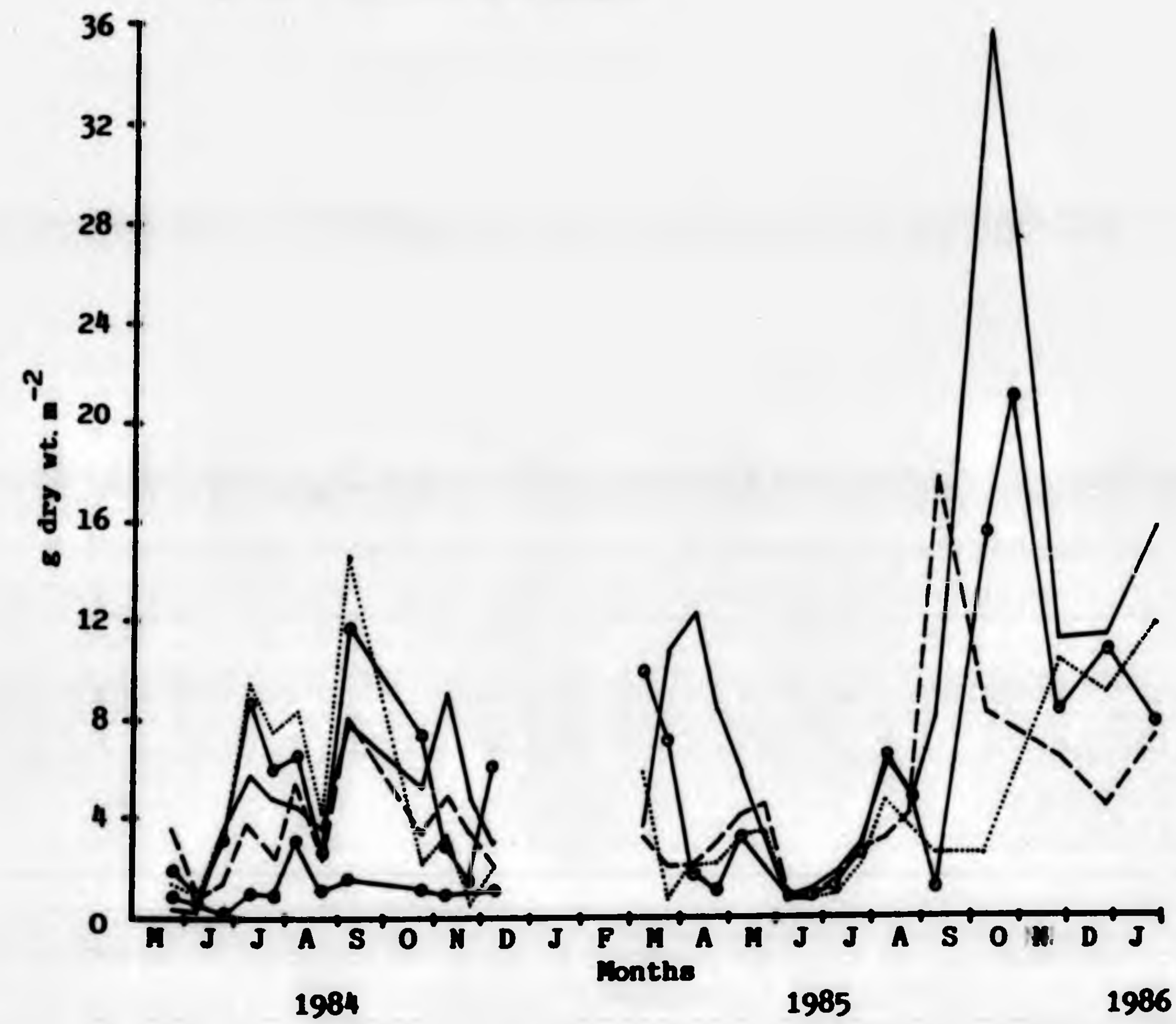


Fig. 89 Chironomid biomass



Figs 88-89 Seasonal changes in the biomass of Oligochaeta and Chironomidae in Howietoun fish ponds (coding for ponds shown in Fig. 8)

control pond 9 were always lower in Oligochaetae production (Table 24).

4.2.3.1.2 Chironomidae

Similarly to Oligochaetae, two periods of maximum biomass were observed among chironomidae in 1985 (Fig. 89).

Chironomid biomass was significantly higher in pond 14, and pond 9 held the lowest position (Table 23). Chironomidae made up about 15-16% of the total production in the ponds. Total production was higher in pond 14 than other ponds (Table 24).

4.2.3.1.3 Mollusca

Seasonal trends in the ash-free-dry biomass of mollusca is shown in Fig. 90.

Except ponds 7 and 14, and 11 and 14, all the ponds were significantly different (Table 23). Molluscs biomass was maximum in pond 13 and minimum in pond 9.

The contribution of molluscs to total production was not more than 3.6% in any of the cultured ponds. Average annual production was higher in pond 7 and lower in pond 13. There was a marked difference between 1984 and 1985 with much higher production being observed in 1984 (Table 24).

Fig. 90 Molluscs biomass

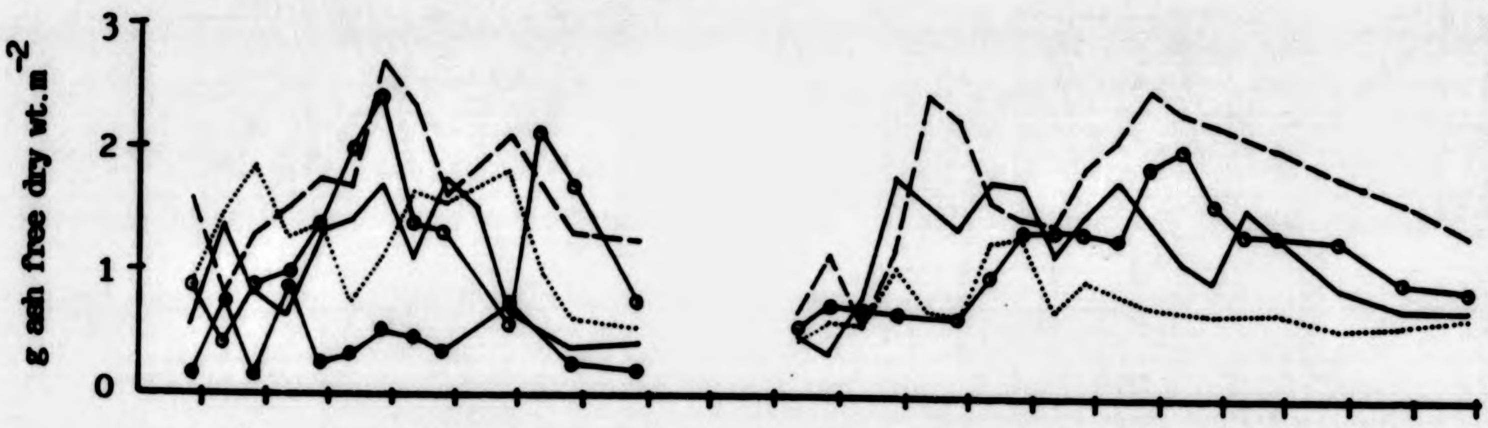
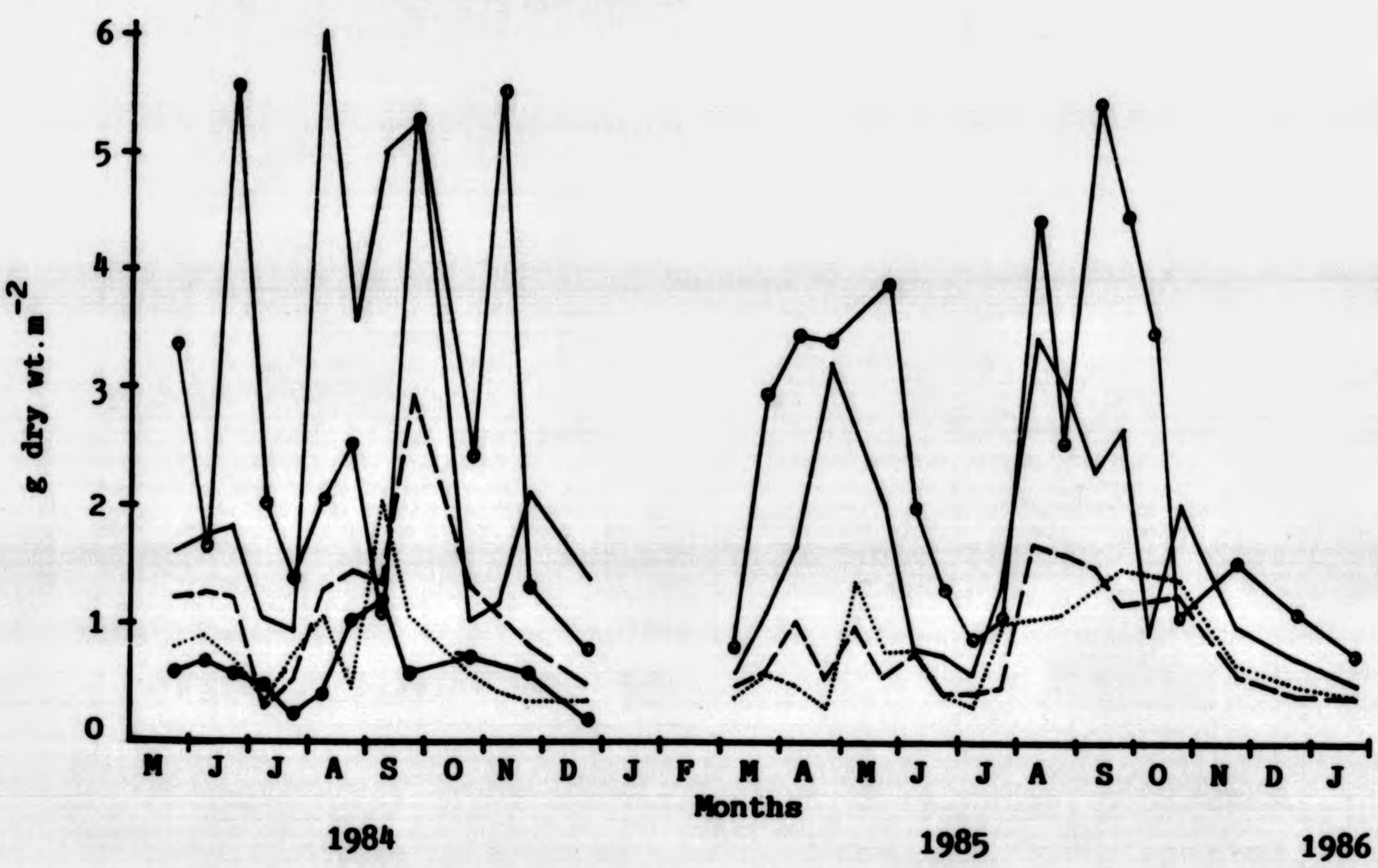


Fig. 91 Hirudinea biomass



Figs 90-91 Seasonal changes in the biomass of Mollusca and Hirudinea in Howietoun fish ponds (coding for ponds shown in Fig. 8)

4.2.3.1.4 Hirudinea

Two peaks were observed in the seasonal dynamics of leech biomass in all ponds (Fig. 91).

Leech biomass was significantly higher in pond 11 and lower in ponds 7 and 13. The lowest average biomass was recorded in pond 9 (Table 23).

The production of leech populations in different ponds was different (Table 24). Pond 11 had the highest production of leeches which contributed 5% to the total benthic production. Leech production was higher in 1984 than 1985.

4.2.3.1.5 Asellidae

The temporal pattern of asellid biomass revealed two maxima, one in spring and another in autumn, with lower values in summer and winter (Fig. 92).

Ponds 11 and 13 had a significantly higher biomass of *A. aquaticus* (Table 23).

A relatively higher production in pond 13 and lower in pond 7 was observed. Surprisingly, control pond 9 had the highest production of asellids (Table 24).

Fig. 92 Asellid biomass

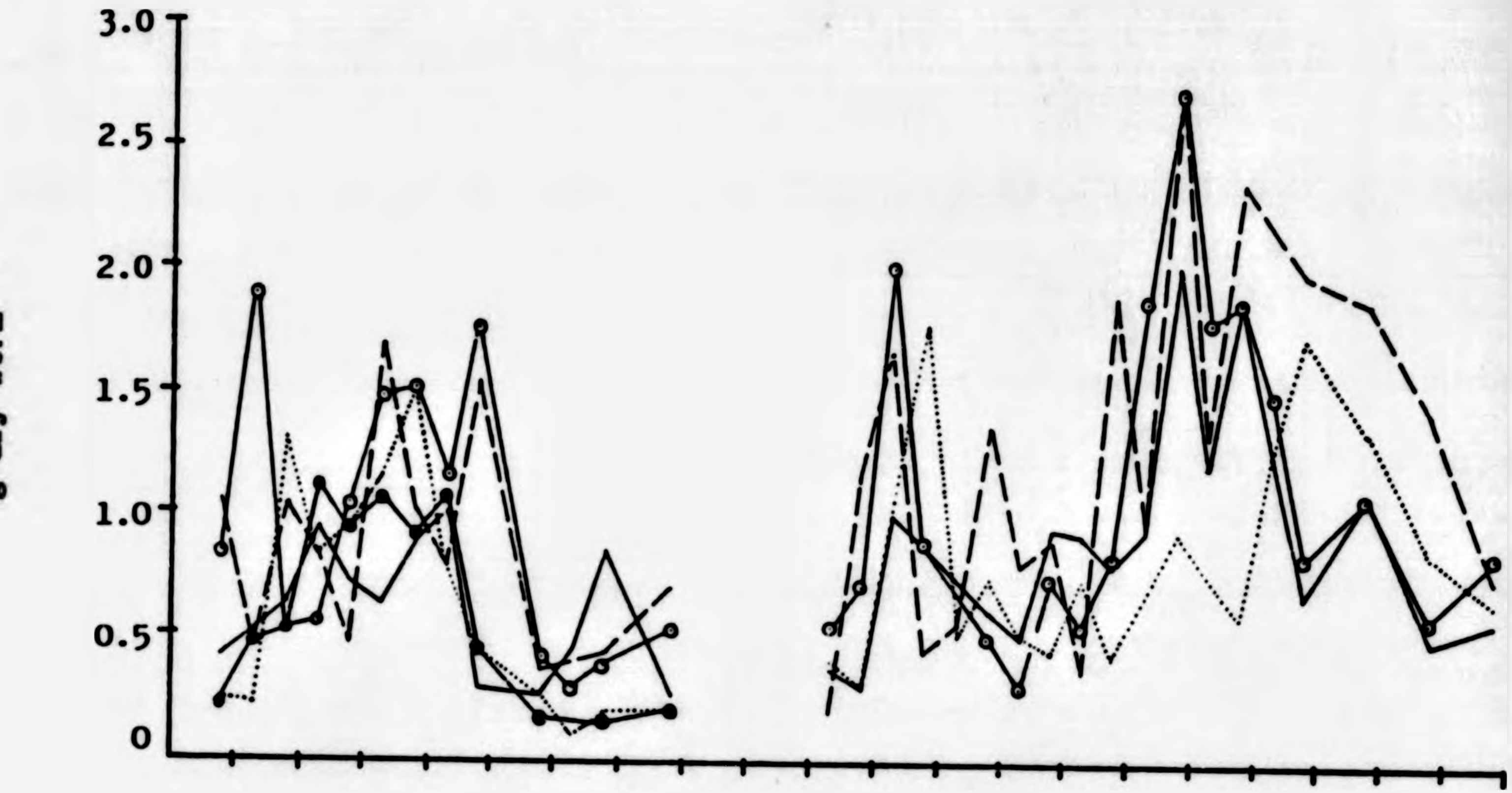
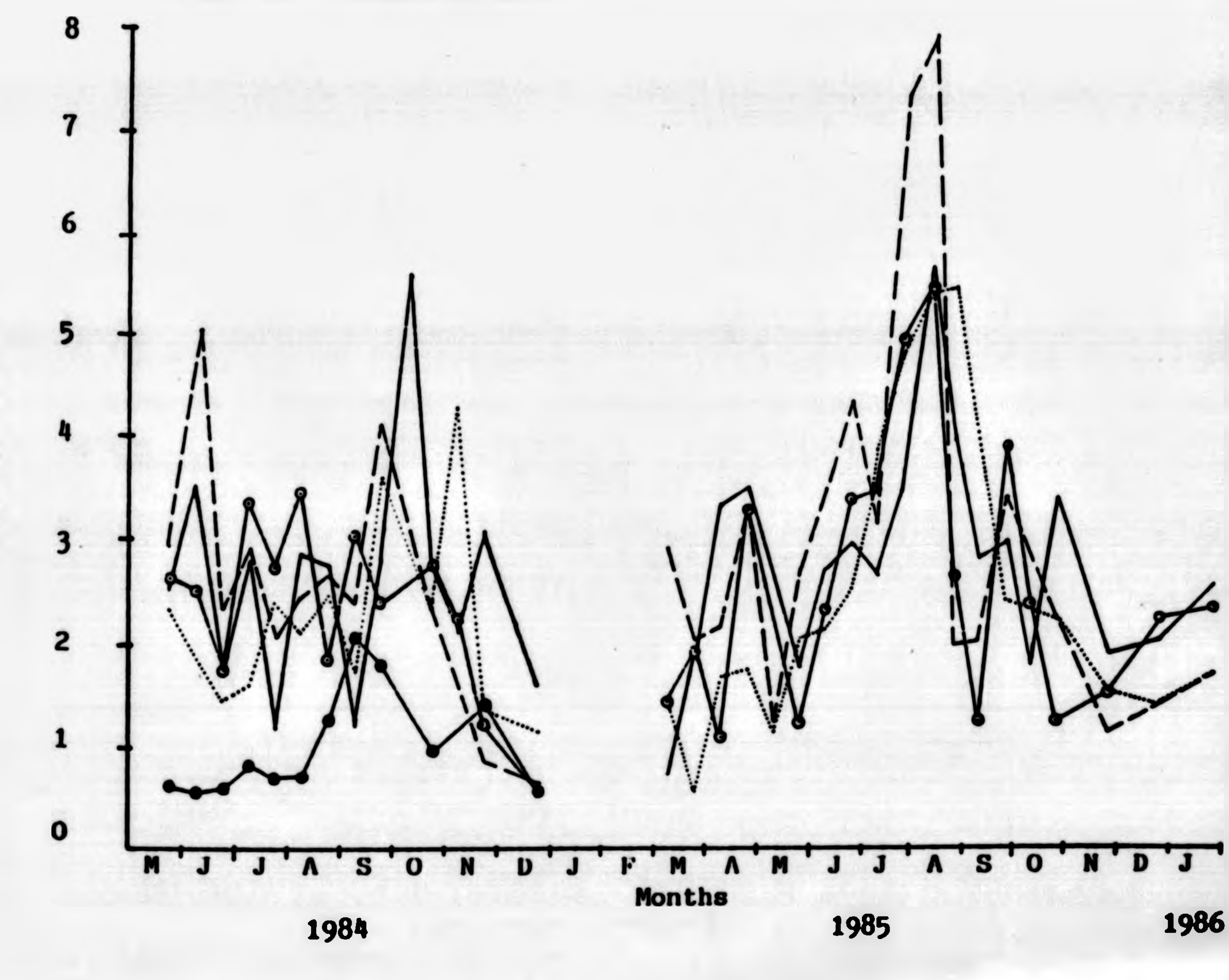


Fig. 93 Sialid biomass



Figs 92-93 Seasonal changes in the biomass of <u>Asellus aquaticus</u> and <u>Sialis lutaria</u> in Howietoun fish ponds (coding for ponds shown in Fig. 8)

4.2.3.1.6 Sialidae

Fig. 93 shows the seasonal trends in dry biomass of the alderfly nymph, Sialis lutaria. Apart from drops in biomass in May and September onwards, it maintained a higher biomass level throughout the growing season (spring and summer) in 1985. Conversely, an autumnal increase in biomass was noticeable in 1984.

Dry biomass of S. lutaria was not significantly different in cultured ponds according to SNK tests (Table 23). Pond 9 was lower than all other ponds.

Although, siallid production was relatively lower in pond 13, it was more or less similar in all cultured ponds. Lowest production of S. lutaria was recorded in pond 9 (Table 24).

4.3 Benthos in the Diet of Brown Trout

A total of 384 stomachs was analysed to understand the contribution of natural food organisms, especially benthic animals, in the diet of farmed brown trout. In spite of regular supply of commercial pelleted feed, the trout, an essentially carnivorous fish, consumed a wide range of natural food items of both aquatic and terrestrial origin.

Table 25 shows the list of the natural food organisms which were recorded from the stomach contents analyses. All six major groups of benthic macro-invertebrates were found to have been taken by

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Table 25 List of food organisms recorded from the stomach contents of brown trout (*Salmo trutta* L.)

Taxon	Stage		Species	Stage
ANNELIDA				
Oligochaetae		:	*Tubifex tubifex* *Limnodrilus hoffmeisteri* *L. udekemianus* *Psammoryctides barbatus* *Lumbriculus variegatus*	
Hirudinea		:	*Helobdella stagnalis* *Erpobdella octoculata*	
MOLLUSCA				
Bivalvia		:	*Sphaerium corneum*	
Gastropoda		:	*Lymnaea peregra*	
ARTHROPODA				
Crustacea				
Malacostraca				
Asellidae		:	*Asellus aquaticus*	
Insecta				
Megaloptera				
Sialidae		:	*Sialis lutaria*	N,A
Trichoptera	A			
Ephemeroptera				
Baetidae		:	*Baetis rhodani*	N
Ecdyonuridae		:	*Ecdyonurus venosus* (Fabricius)	N
Plecoptera	A			
Hymenoptera				
Ichneumonidae	A			
Coleoptera	A			
Diptera				
Chironomidae	L,P,A	:	*Chironomus* sp. *Glyptotendipes* sp. *Microtendipes* sp. *Polypedilum* sp. *Micropsectra* sp. *Tanytarsus* sp. *Procladius* sp. *Ablabesmyia* sp. *Prodimesa* sp.	
Simuliidae	A			
Empididae	A			
Dolichopodidae		:	*Dolichopus* sp.	A
Syrphidae	A			
Muscidae	A			
Arachnida	A			

A = adult, L = larvae, P= pupae, N = nymph the fish. A substantial proportion of the natural diet was formed by adults and larval stages of many terrestrial insects, beetles and even spiders. All those animals which are not usually part of the pond community were treated as 'terrestrial invertebrates'.

4.3.1 Composition of the diet

Table 26 shows the actual and percentage composition of the diet, assessed by the number, volume and occurrence methods. Although these three methods provided relatively close picture and show clearly the most important items in the diet, they need special comments on their precision for measuring stomach contents. The numerical method underestimated the importance of the larger animals such as Sialis lutaria and overestimated the smaller animals such as chironomid larvae and pupae. The number method did not account for the pelleted feed in the diet. Similarly, the occurrence method exaggerated the relative importance of smaller animals by only their presence in many stomachs, even in small numbers. This method was, however, successful in indicating the most important item in the general diet. The volumetric method was found to be the best expression of the relative nutritive importance of each food category and the results obtained by this method have been regarded as a standard one.

Stomach contents of the fish collected from pond 11 and 14 showed similar patterns in the relative abundance of different groups of animals in the diet.

Table 26 Composition of the natural food in the stomachs of brown trout in Howietoun fish farm ponds

Food organisms	Pond 11 (210 fish)				Pond 14 (195 fish)			
	Mean no. per stomach	% No. per stomach	% Volume	% Occurrence	Mean no. per stomach	% No. per stomach	% Volume	% Occurrence
Chironomidae larvae	5.12	49.80	33.90	74.87	5.49	45.41	32.40	72.97
Chironomidae pupae	1.58	15.37	10.49	41.21	2.66	22.0	15.74	50.27
Mollusca	1.05	10.21	13.92	36.18	1.20	9.92	14.30	34.59
Oligochaetae	0.89	8.66	5.89	25.13	0.76	6.29	4.50	35.14
Hirudinea	0.17	1.65	13.70	4.02	0.18	1.49	12.37	10.27
Sialidae	0.24	2.33	7.83	15.58	0.24	1.99	7.18	15.68
Asellidae	0.68	6.61	11.32	33.67	0.76	6.29	11.25	27.57
Terrestrial invertebrates	0.41	3.99	2.73	20.60	0.34	2.81	1.98	19.46
Plant parts and algae	0.14	1.36	0.22	24.62	0.46	3.80	0.27	21.62
Totals	10.28	100	100		12.09	100	100	

Chironomid larvae and pupae comprised first and second dominant components among the natural foods. Mollusca was found to be the third most important group in the diet. Although Oligochaetae was the most dominant group in the fish ponds, their contribution as fish food was not as much as expected. Despite their occurrence in relatively small numbers, the volumetric contributions of leeches, Asellus aquaticus and Sialis lutaria were higher.

In order to get an idea of the selective predation on different groups of animals exerted by fish, an index of selective feeding or 'electivity' was determined as presented in Table 27. The calculation of an electivity index for chironomid pupae and terrestrial invertebrates was not possible, because estimates of their abundance were difficult and were not considered for this study.

Table 27 revealed that brown trout in Howietoun fish ponds exerted a strong positive selectivity for all groups of benthic animal except Oligochaetae and leeches.

4.3.2 Seasonal changes in the diet

Tables 28 and 29 show the seasonal changes in the different components of diet, both natural and artificial in ponds 11 and 14 respectively. Commercial pelleted diet (Ewos-Baker) provided about 88% of the total food of the fish. The remaining portion of stomach contents was formed from the natural food, mainly benthos.

Table 27 **Electivity Index for different groups of organisms found in the benthos and in the stomach contents of fish**

Benthic groups	Pond 11 % No. in benthos	Pond 11 % No. in stomach	Pond 11 Electivity Index	Pond 14 % No. in benthos	Pond 14 % No. in stomach	Pond 14 Electivity Index
Chironomidae larvae	6.67	49.80	+0.76	6.97	45.41	+0.73
Oligochaetae	88.11	8.66	-0.82	89.75	6.29	-0.87
Mollusca	1.25	10.21	+0.78	0.91	9.92	+0.83
Hirudinea	3.14	1.65	-0.31	1.64	1.49	-0.05
Asellidae	0.39	6.61	+0.89	0.27	6.29	+0.92
Sialidae	0.41	2.33	+0.70	0.44	1.99	+0.64

Table 28 Percentage composition of food items in the stomach contents of brown trout from Pond 11 according to number (N), volume (V) and occurrence (O) methods

n refers to numbers of fish sampled per month

Food items	May (n = 10) 1984			Jun (n = 10)			Jul (n = 10)			Aug (n = 10)			Sep (n = 10)		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	54.5	11.43	100	40.48	4.72	70	56.50	4.0	90	60.86	3.41	50	19.05	0.42	80
Chironomid pupae	6.8	2.86	50	2.38	0.28	20	10.22	0.72	70	13.04	0.73	20	2.39	0.05	10
Mollusca	9.1	1.90	50	53.57	7.60	30	12.80	3.37	30	15.24	4.02	30	11.90	0.52	50
Oligochaeta	11.4	2.38	30	2.38	0.28	10	2.50	0.38	20	2.17	0.012	10	-	-	-
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sialis lutaria	-	-	-	-	-	-	2.48	2.71	20	-	-	-	7.14	7.81	30
Asellus aquaticus	6.8	1.14	70	-	-	-	2.70	0.20	20	2.17	0.12	10	30.95	6.77	30
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-	2.39	0.05	10
Terrestrial invertebrates	11.4	2.38	50	1.19	0.14	10	5.10	0.33	40	6.52	0.37	30	4.76	0.10	10
Plant parts and algae	-	-	-	-	-	-	7.70	0.03	30	-	-	-	4.76	0.01	10
Stone particles	-	-	-	-	-	-	-	-	-	-	-	-	16.67	0.04	10
Pelleted diet	-	77.90	100	-	86.96	90	-	88.0	100	-	91.22	70	-	84.23	100

Table 28 continued

Food items	Oct (n = 10) 1984			Dec (n = 15)			Feb (n = 10) 1985			Mar (n = 10)			Apr (n = 10)		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	23.80	0.63	50	56.63	3.36	67	26.92	1.52	40	34.50	2.0	80	47.66	1.63	100
Chironomid pupae	35.71	0.95	20	-	-	-	-	-	-	8.25	0.75	60	6.54	0.22	30
Mollusca	11.90	6.31	40	7.23	0.86	40	11.54	12.9	30	17.42	1.5	40	19.63	0.96	50
Oligochaeta	-	-	-	19.28	1.14	47	30.77	0.17	40	15.20	0.50	40	3.74	0.013	40
Hirudinea	-	-	-	-	-	-	-	-	-	3.30	7.02	20	19.63	3.58	40
<u>Sialis lutaria</u>	9.53	1.26	40	4.82	1.14	27	11.54	3.26	20	6.98	1.5	30	10.28	1.76	60
<u>Asellus aquaticus</u>	9.53	1.26	30	6.0	1.14	27	7.69	0.43	20	15.30	1.20	50	38.32	2.65	60
Trichoptera	-	-	-	-	-	-	-	-	-	1.70	0.20	30	1.87	0.13	20
Terrestrial invertebrates	4.76	0.126	10	-	-	-	7.69	0.43	10	2.50	0.25	20	1.87	0.64	20
Plant parts and algae	-			3.61	0.02	20	3.85	0.43	60	1.25	0.05	40	4.67	0.016	50
Stone particles	4.6	0.012	20	2.41	0.12	27		-	-	-	-	-	-	-	-
Pelleted diet	-	89.45	80	-	92.22	73	-	80.86	60	-	85.0	80	-	88.98	100

Table 28 continued

Food items	May (n = 10) 1985			Jun (n = 10)			Jul (n = 10)			Aug (n = 15)			Sep (n = 10)		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	43.3	4.59	80	42.0	4.77	80	58.74	5.42	100	38.46	5	60	36.36	1.38	80
Chironomid pupae	18.0	1.94	100	38.20	4.16	90	11.19	1.03	70	46.15	6	80	29.09	1.10	60
Mollusca	12.20	2.65	60	12.50	2.70	80	7.69	1.42	20	4.62	1.2	13	7.27	5.52	40
Oligochaeta	8.30	0.88	50	2.10	0.21	20	1.40	0.13	10	6.15	0.8	27	3.64	0.14	20
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<u>Sialis lutaria</u>	-	-	-	-	-	-	1.40	0.32	10	-	-	-	5.45	1.034	30
<u>Asellus aquaticus</u>	8.20	2.21	70	-	-	-	2.80	3.23	30	-	-	-	5.45	0.41	30
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	10.0	0.71	40	2.40	0.31	30	4.90	0.45	50	4.62	0.6	20	3.64	0.14	20
Plant parts and algae	3.30	0.04	40	2.28	0.03	30	9.09	0.08	60	-	-	-	5.45	0.02	20
Stone particles	-	-	-				3.50	0.07	30	-	-	-	3.64	0.014	20
Pelleted diet	-	87.0	100	-	88.0	80	-	87.85	90	-	86.4	80	-	90.24	90

Table 28 continued

Food items	Oct (n = 15) 1985			Nov (n = 10)			Dec (n = 15)			Jan (n = 10) 1986		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	79.40	2.34	80	62.50	4.37	70	58.51	3.14	67	33.33	2.12	40
Chironomid pupae	-	-	-	10.0	0.70	40	-	-	-	-	-	-
Mollusca	-	-	-	3.50	0.46	30	7.45	0.8	40	3.70	0.47	10
Oligochaetae	12.02	0.35	33	16.0	1.11	60	21.28	1.14	60	22.22	1.41	50
Hirudinae	1.28	0.05	13	-	-	-	-	-	-	-	-	-
<u>Sialis</u> <u>lutaria</u>	1.72	0.25	13	1.33	0.46	10	-	-	-	-	-	-
<u>Asellus</u> <u>aquaticus</u>	1.72	0.05	20	4.0	2.79	30	4.26	0.17	20	5.56	2.12	10
Trichoptera	-	-	-	-	-	-	-	-	-	16.67	0.70	50
Terrestrial invertebrates	-	-	-	-	-	-	-	-	-	-	-	-
Plant parts and algae	1.28	0.003	20	2.0	0.01	20	3.19	0.02	20	9.30	0.06	50
Stone particles	2.56	0.005	27	0.66	0.09	10	5.32	0.03	47	9.30	0.12	30
Pelleted diet	-	92.36	100	-	90.0	90	-	93.95	87	-	93	90

Table 29 Percentage composition of food items in the stomach contents of brown trout from Pond 14 according to number (N), volume (V) and occurence (O) methods

n refers to numbers of fish sampled per month

Food items	Jun (n=10) 1984			Jul (n = 10)			Aug (n = 10)			Sep (n = 10)			Oct (n = 10)		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	31.75	3.63	80	48.39	6.25	70	36.86	0.22	70	23.33	0.67	50	15.79	0.39	30
Chironomid pupae	46.05	5.27	80	29.68	3.83	60	49.12	0.28	60	20.0	0.57	40	39.47	0.98	20
Mollusca	6.35	0.90	40	3.87	1.0	30	3.50	0.04	20	13.33	7.62	30	21.05	4.56	40
Oligochaeta	3.17	0.036	20	6.45	0.83	50	3.50	0.002	10	-	-	-	-	-	-
Hirudinea	3.17	0.073	20	-	-	-	-	-	-	-	-	-	-	-	-
<u>Sialis lutaria</u>	1.58	0.90	10	0.65	0.42	10	-	-	-	6.66	0.95	20	5.26	1.30	20
<u>Asellus aquaticus</u>	-	-	-	1.29	0.67	20	-	-	-	33.33	2.38	40	10.53	1.30	40
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	7.93	0.90	30	3.23	0.42	20	7.02	3.83	20	4.33	0.19	10	2.63	0.006	10
Plant parts and algae	-	-	-	3.87	0.05	20	-	-	-	-	-	-	2.63	0.006	10
Stone particles	-	-	-	2.58	0.03	20	-	-	-	-	-	-	2.63	0.006	10
Pelleted diet	-	88.25	90	-	86.5	90	-	87.0	70	-	87.62	90	-	91.45	80

Table 29 continued

Food items	Dec (n = 15)			Mar (n = 10) 1985			Apr (n = 10)			May (n = 10)			Jun (n = 10)		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	46.30	2.78	60	30.0	2.70	80	29.22	2.11	100	25.86	1.67	80	35.71	4.17	80
Chironomid pupae	-	-	-	12.50	1.09	70	20.78	1.50	80	31.03	2.0	80	42.86	5.0	90
Mollusca	7.4	0.88	27	15.0	2.70	50	9.74	1.41	90	10.34	1.33	90	4.29	0.5	30
Oligochaeta	24.07	1.44	60	12.20	1.09	50	1.30	0.09	20	3.45	0.22	40	5.71	0.67	20
Hirudinea	-	-	-	4.50	5.93	30	9.74	0.70	90	-	-	-	2.86	0.07	20
Sialis lutaria	3.70	1.11	13	4.70	2.08	20	5.19	1.88	80	-	-	-	2.86	1.67	20
Asellus aquaticus	5.56	0.67	20	17.20	1.56	40	22.73	3.29	100	21.55	2.78	100	-	-	-
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	-	-	-	2.75	0.21	30	1.30	0.09	20	4.31	0.28	50	5.71	0.07	30
Plant parts and algae	9.26	0.06	13	1.50	0.02	30	-	-	-	3.45	0.02	40	-	-	-
Stone particles	3.70	0.22	13	0.75	0.10	10	-	-	-	-	-	-	-	-	-
Pelleted diet	-	92.84	87	-	82.5	100	-	88.92	100	-	91.7	90	-	87.67	100

Table 29 continued

Food items	Jul (n = 15) 1985			Aug (n = 15)			Sep (n = 10)			Oct (n = 15)			Nov (n = 10)		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	29.8	3.78	67	43.0	6.15	73	26.32	1.25	80	90.20	4.76	60	55.55	4.28	70
Chironomid pupae	44.7	5.67	67	38.71	5.54	80	21.05	1.0	60	5.23	0.28	13	11.70	0.90	50
Mollusca	-	-	-	4.3	1.23	27	7.89	0.75	30	-	-	-	5.26	0.81	40
Oligochaeta	8.77	1.11	40	4.3	0.62	20	-	-	-	1.31	0.07	13	19.88	1.53	70
Hirudinea	-	-	-	-	-	-	-	-	-	0.65	0.07	7	1.17	2.16	20
Sialis lutaria	1.75	1.11	13	-	-	-	10.53	2.5	40	-	-	-	-	-	-
Asellus aquaticus	4.39	2.22	27	-	-	-	15.79	1.5	50	0.65	0.07	13	2.34	0.72	30
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	2.63	3.33	20	4.3	0.62	27	7.89	0.38	30	0.65	0.05	13	-	-	-
Plant parts and algae	7.89	0.1	47	5.38	0.08	20	10.53	0.05	40	0.65	0.004	13	2.34	0.02	40
Stone particles	-	-	-	-	-	-	-	-	-	0.65	0.07	13	1.75	0.27	20
Pelleted diet	-	83.28	60	-	85.77	80	-	92.58	90	-	94.63	93	-	89.30	80

Table 29 continued

Food items	Dec (n = 15)			Jan (n = 10) 1986		
	% N	% V	% O	% N	% V	% O
Chironomid larvae	47.62	3.33	73	23.50	0.99	60
Chironomid pupae	-	-	-	-	-	-
Mollusca	7.14	1.0	33	7.0	5.92	20
Oligochaeta	29.76	2.08	80	43.50	1.83	50
Hirudinea	-	-	-	-	-	-
<u>Sialis lutaria</u>	2.38	0.67	13	1.50	0.12	10
<u>Asellus aquaticus</u>	2.38	0.83	13	3.0	0.20	10
Trichoptera	-	-	-	-	-	-
Terrestrial invertebrates	-	-	-	-	-	-
Plant parts and algae	7.14	0.05	27	11.90	0.05	60
Stone particles	3.57	0.25	20	5.95	0.25	30
Pelleted diet	-	91.78	67	-	91.11	100

Fig. 94 shows the seasonal changes in the mean monthly fullness index and percentage of natural food estimated by the volume method for both ponds. The fullness index indicated that the intake of food increased to a maximum in July when the temperature of water was 15°C. A gradual decrease in food intake was observed from autumn to winter and reached the lowest level when there was an ice cover on the ponds. The situation was different in January, 1986, when the water temperature was higher and the fullness index rapidly increased in this month.

The seasonal pattern of the quantity of natural food taken by fish showed similar trends in both ponds (Fig. 94). Volume of animal food intake was higher during summer and lower during autumn and winter, showing a close link with the mean fullness index. An exception to this, was a very high increase in the percentage volume of natural food in overwintering fish population in February 1985, but the fullness index, during this period declined to its lowest level.

A considerable seasonal variation in the natural food selection by trout was found in the cultured ponds 11 and 14 (Tables 28 and 29). Two separate periods in the year, from November to February and from March to October could be distinguished according to the nature of the food organisms. From November to February, the fish predominantly feed on benthic animals, and from March to October on chironomid pupae, terrestrial insects and beetles along with

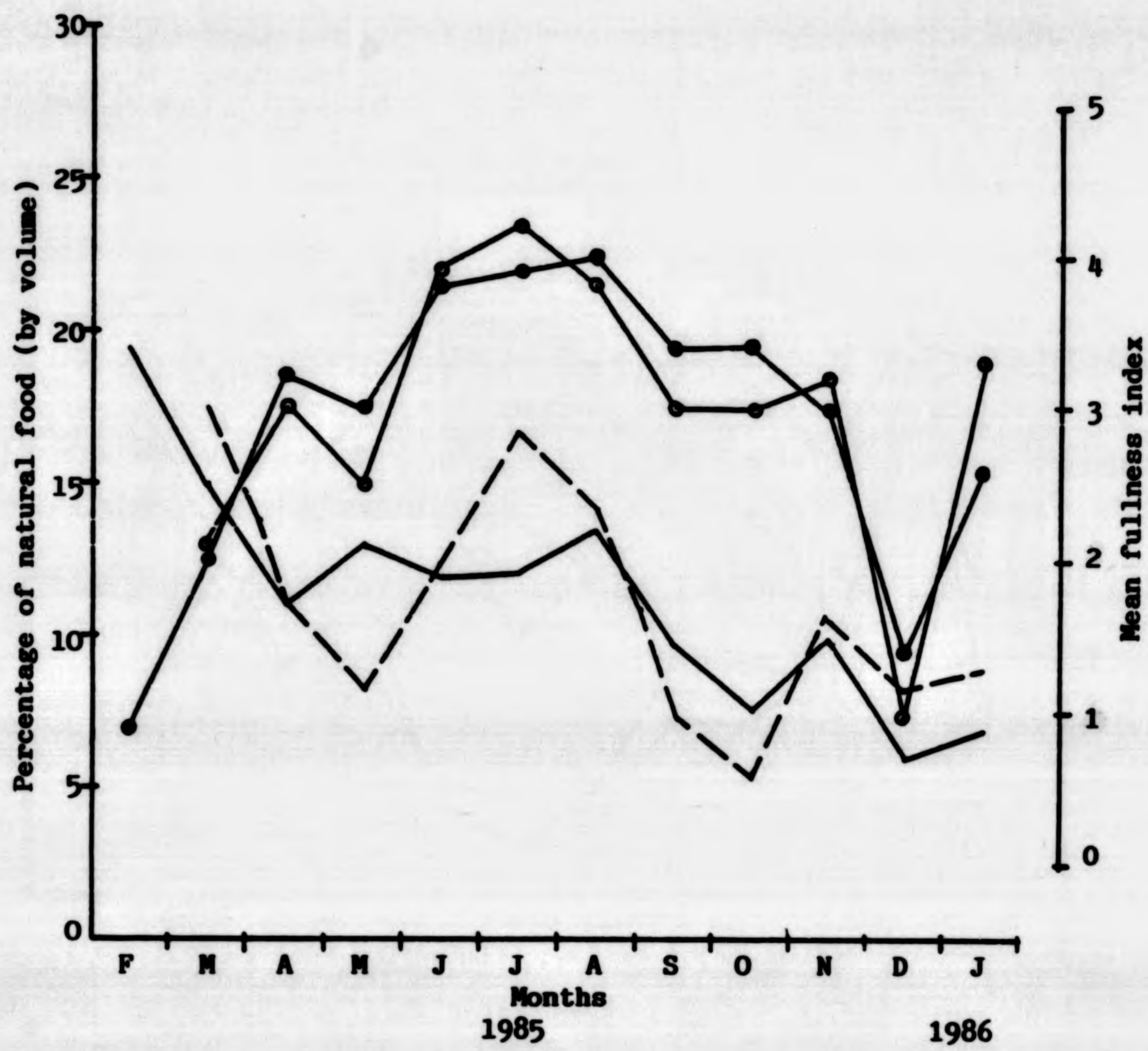


Fig. 94 Natural feeding of brown trout, Salmo trutta L., in Howietoun ponds. Monthly variation in percentage of natural food and mean fullness index. ——— percentage of natural food in the stomach of fish from pond 11; -------- percentage of natural food from pond 14; ●———● mean fullness index from pond 11 and ●———● mean fullness index from pond 14

benthos. During winter months, benthic filamentous algae and small stone particles also appeared in the stomach contents which might have been taken while the fish were feeding on other items.

4.3.2.1 Notes on some important food items

Chironomid larvae were the most important component of natural fish food in Howietoun fish farm ponds, consistently occurring in the fish stomachs throughout the year. As in the case of the benthic community, each of the chironomid larvae showed its own maximum in the stomach contents in different months of the year. Among 18 species of midge larvae known to occur in the benthos, only 9 species were recorded from the fish guts (Table 25). Conversely, chironomid pupae were only available during periods of emergence. The occurrence of the pupae in the stomach ceased completely during winter months.

Both Sphaerium corneum and Lymnaea peregra were found in the gut contents, but the former was more frequent than the latter. With few exceptions, molluscs were taken by fish throughout the year and formed an important food item.

Table 25 shows that 5 species of Oligochaetae were identified from the stomach contents. Worms were recorded in the fish food throughout the year, although not in large numbers. Higher numbers of worms were recorded during winter months.

Leeches were not regularly recorded from the stomach contents, the larger leech Erpobdella octoculata was present in the fish guts for limited periods only.

Sialis lutaria and Asellus aquaticus were the two larger members of the pond benthos. Although these animals did not persistently occur in the fish stomachs, they formed a considerable proportion of the natural diet whenever present.

4.3.3 Diurnal feeding rhythms

Diel changes in the dietary components of the farmed trout were studied once in summer (19-20 July, 1985) and once in autumn (18-19 October, 1984). An index of fullness was recorded irrespective of the size of the stomach of the fish. Fig. 95 shows the mean index of fullness at each time of sampling and the volume of natural food expressed as a percentage of total food volume.

Indexes of fullness in both summer and autumn were found to be associated with feeding rhythms, which increased immediately after supplying pelleted feeds. Fish were generally fed once in the early morning and once in the afternoon except during wet weather. This was the case during the autumn sampling, when fish were fed only in the morning, there was a gradual decline in the fullness index which reached a minimum the following morning before their next feed. An increase in fullness index in early evening and morning was observed during the summer sampling.

The relative proportion of natural food, mainly benthos, reached a maximum in the early morning in both seasons. A smaller maximum also developed in the early evening during autumn and in the afternoon during summer. The average daily percentage volume of natural food were 9% and 12% in autumn and summer respectively.

Tables 30 and 31 show the diurnal variation in dietary composition during autumn and summer respectively. Though there was a marked quantitative variation between food taken by day and that by night there was little qualitative variation. Brief comments on the day and night foods are made below.

4.3.3.1 The day food

Three important food items, viz., chironomid larvae, Sialis lutaria and Asellus aquaticus were consistently available in all the samples collected from 10 am to 7 pm in autumn (Table 30). Chironomid pupae were available in the diet in the morning and in the afternoon, as they emerged. Mollusca occurred until 1 pm. Terrestrial invertebrates were found in the morning diet and they appeared again at 4 pm mainly as adult insects.

Chironomid larvae constituted the main natural food in summer, which increased through morning to afternoon. Pupal chironomidae only occurred from 2 pm onwards and reached a maximum at around early evening. Molluscs, Sialis and aerial insects were found in the afternoon diets in summer (Table 31).

Table 30 Diel feeding of brown trout at Howietoun fish farm on 18-19 October 1984, according to number (N), volume (V) and occurrence (O) methods

Food items	0700 - 1000			1000 - 1300			1300 - 1600			1600 - 1900			1900 - 2200		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	12.12	0.33	60	33.33	0.49	40	47.37	2.37	100	50	3.0	100	14.29	0.29	20
Chironomid pupae	45.45	1.22	40	-	-	-	26.32	1.32	80	-	-	-	28.57	0.57	20
Mollusca	12.12	6.50	60	16.67	4.9	40	-	-	-	-	-	-	-	-	-
Oligochaeta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<u>Sialis lutaria</u>	3.03	0.81	20	16.67	1.23	20	5.26	1.32	40	11.11	3.33	100	-	-	-
<u>Asellus aquaticus</u>	6.06	0.65	40	33.33	1.96	40	5.26	1.05	40	16.67	40	100	-	-	-
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	6.03	0.024	40	-	-	-	10.53	0.53	40	22.22	1.33	100	57.14	1.14	20
Plant parts and algae	9.09	0.16	60	-	-	-	5.26	0.03	40	-	-	-	-	-	-
Stone particles	6.06	0.16	40	-	-	-	-	-	-	-	-	-	-	-	-
Pelleted diet	-	90.14	80	-	90.54	60	-	93.40	100	-	88.33	100	-	98	80

Table 30 continued

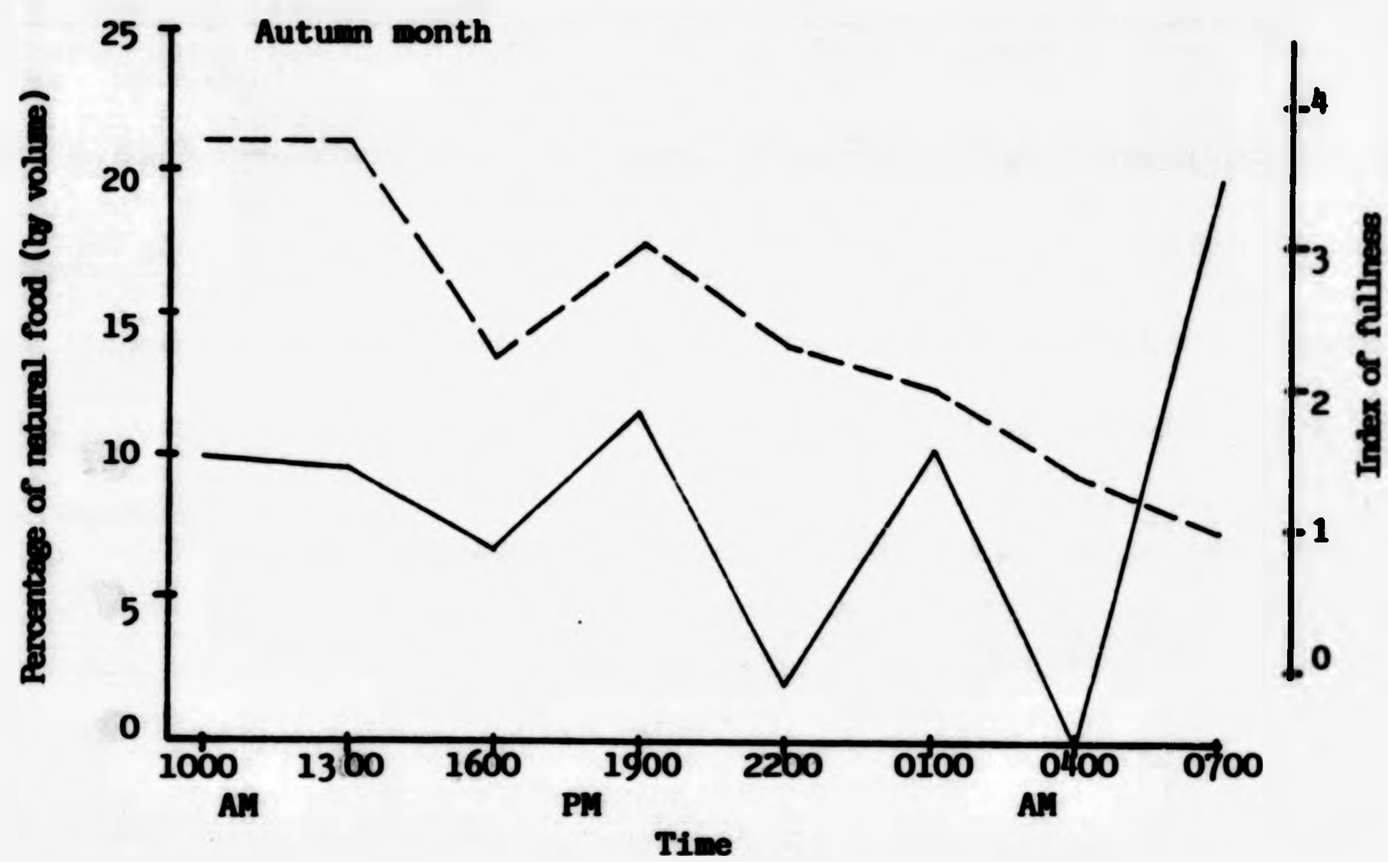
Food items	2200 - 0100			0100 - 0400			0400 - 0700		
	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	25	1.0	60	-	-	-	57.89	11	80
Chironomid pupae	25	1.0	60	-	-	-	-	-	-
Mollusca	8.33	6.67	20	-	-	-	5.26	2	20
Oligochaeta	-	-	-	-	-	-	5.26	1	20
Hirudinae	-	-	-	-	-	-	-	-	-
<u>Sialis</u> <u>lutaria</u>	8.33	1.67	20	-	-	-	-	-	-
<u>Asellus</u> <u>aquaticus</u>	-	-	-	-	-	-	-	-	-
Trichoptera	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	-	-	-	-	-	-	10.53	2	20
Plant parts and algae	25	0.01	40	-	-	-	15.79	3	40
Stone particles	8.33	0.03	20	-	-	-	5.26	1	20
Pelleted diet	-	89.53	80	-	100	40	-	80	20

Table 31 Diel feeding of brown trout at Howietoun fish farm on 19-20 July 1985, according to number (N), volume (V) and occurrence (O) methods

Food items	0800 - 1100			1100 - 1400			1400 - 1700			1700 - 2000			2000 - 2300		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	78.26	8.57	60	65.38	7.39	80	75.93	8.2	100	63.22	5.5	80	75.76	3.68	60
Chironomid pupae	-	-	-	15.38	1.74	20	9.26	1.0	60	31.03	2.7	80	6.06	0.29	20
Mollusca	-	-	-	3.85	0.87	20	3.70	0.8	40	-	-	-	6.06	0.59	20
Oligochaeta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	-	-	-	-	-	-	1.85	0.2	20	-	-	-	-	-	-
<u>Sialis lutaria</u>	-	-	-	-	-	-	-	-	-	1.15	0.5	20	-	-	-
<u>Asellus aquaticus</u>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	-	-	-	-	-	-	3.70	0.4	40	2.30	0.2	40	-	-	-
Plant parts and algae	21.74	0.23	60	15.38	0.17	60	5.56	0.6	60	2.30	0.02	40	12.12	0.06	80
Stone particles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pelleted diet	-	91.20	80	-	88.67	100	-	89.34	80	-	91.08	100	-	95.38	100

Table 31 continued

Food items	2300 - 0200			0200 -0500			0500 - 0800			0800 - 1100		
	% N	% V	% O	% N	% V	% O	% N	% V	% O	% N	% V	% O
Chironomid larvae	60	9.55	60	80.20	28.73	60	42.3	4.23	80	86.36	6.9	80
Chironomid pupae	11.43	1.82	20	13.20	4.73	40	-	-	-	-	-	-
Mollusca	8.57	2.73	20	1.02	0.73	20	-	-	-	-	-	-
Oligochaeta	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-
<u>Sialis lutaria</u>	-	-	-	0.50	0.36	20	7.69	1.54	40	-	-	-
<u>Asellus aquaticus</u>	-	-	-	-	-	-	-	-	-	4.5	0.36	40
Trichoptera	-	-	-	-	-	-	-	-	-	-	-	-
Terrestrial invertebrates	11.43	1.82	60	3.05	1.09	60	30.76	3.08	40	-	-	-
Plant parts and algae	8.57	0.14	60	0.50	0.02	20	3.85	0.04	20	9.0	0.07	80
Stone particles	-	-	-	1.5	0.05	20	15.38	1.54	20	-	-	-
Pelleted diet	-	83.95	40	-	64.30	60	-	90.96	60	-	92.65	100



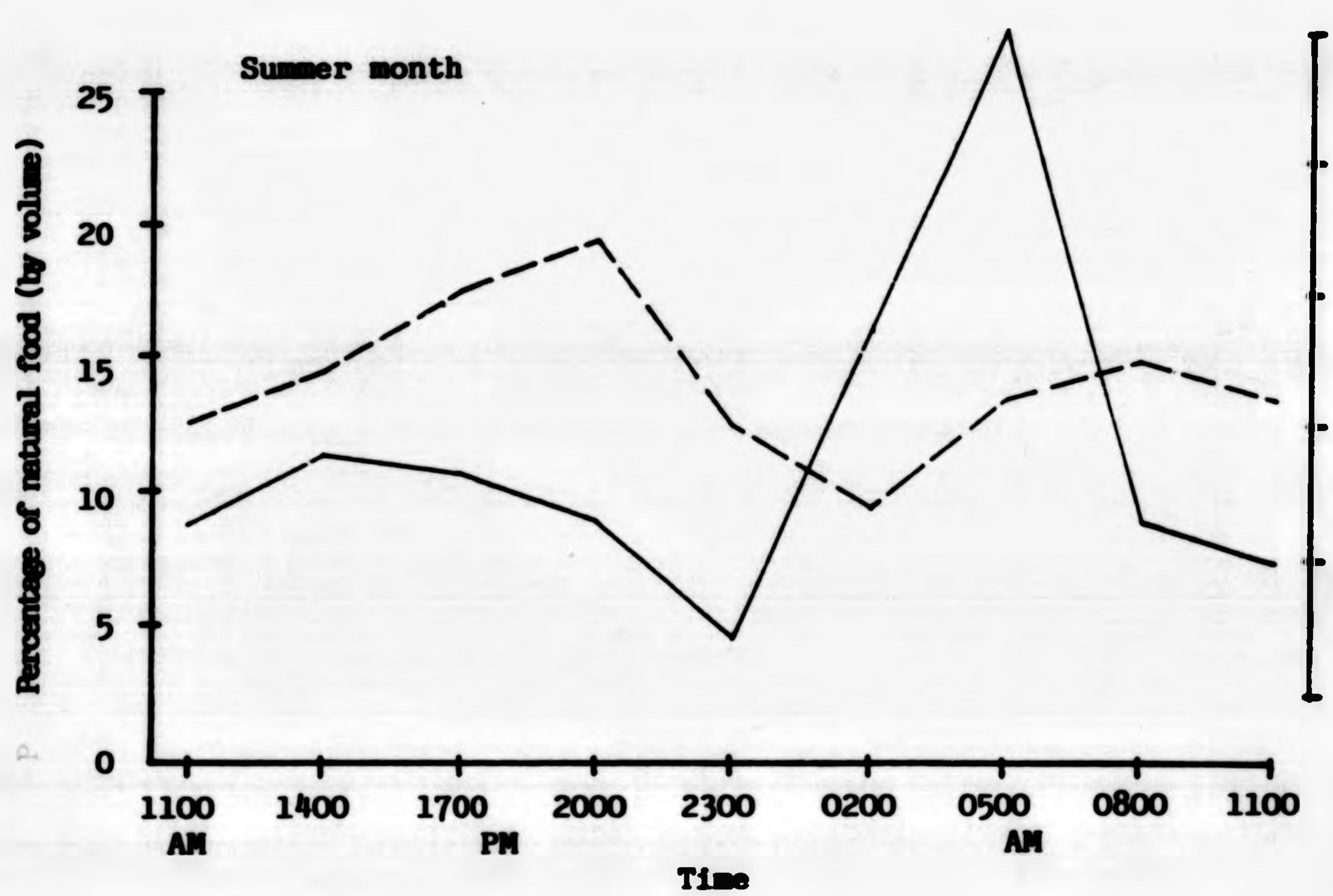


Fig. 95 Diurnal changes in percentage (by volume) of natural food (continuous lines) and fullness index (broken lines) for brown trout in Howietoun ponds sampled in summer and autumn

Plant parts and algae were recorded in both periods of diel sampling.

4.3.3.2 The night food

The autumn night food was dominated mainly by chironomid larvae and by pupae to a lower extent. Fish picked up molluscs and Sialis during midway throughout the night. No aerial insects were found in the fish stomachs after 10 pm. As the weather got worse late at night, fish ceased to take any single invertebrate (Table 30). Presence of benthic filamentous algae and pebbles indicates their complete benthic feeding nature in autumn night.

Unlike the autumn season, brown trout in cultured ponds during the summer ate higher amounts of natural food at night than by day. This result, however, may have been affected by the better weather experienced during the summer sample. The natural foods gradually increased in the diet after midnight and reached a peak of about 36% by volume at around 5 am (Fig. 95). Thus brown trout at Howietoun fish ponds appeared to be making good use of abundant benthos at night, when there was no supply of pelleted feeds.

Larval as well as pupal Chironomidae and Mollusca comprised the main summer night food for brown trout (Table 31). Terrestrial organisms also formed a considerable proportion throughout the night.

It may therefore be concluded that brown trout in Howietoun fish farm ponds are utilizing natural food throughout the day and night, during good weather conditions.

4.4 Study of Interaction between Fish and Benthos by means of Enclosure experiments

Three ponds, provided with enclosures to prevent access to the bottom, were stocked with different densities of fish. Details of the treatments and result of fish growth, total production and food conversion rates are presented in Table 32. Benthos from inside and outside the enclosures were analysed for species composition, population density, biomass and production. Summary results of the above parameters are presented in Table 33.

The population density and biomass of different groups of benthic animals from all experimental ponds were compared statistically by two-way ANOVAs, the results of the tests being shown in Table 34.

Fish reduced the abundance of total benthos outside the enclosure as compared with the inside (Fig. 96). The population density was significantly different between the ponds and between outside and inside the enclosures at both high and low densities of fish (Table 34). From an analysis of the differences in the abundance of different groups of benthic fauna (Table 34) it was evident that Oligochaetae, Chironomidae and Mollusca were significantly different between inside and outside the enclosures. Fig. 98 shows that unlike other groups, the abundance of Chironomidae was always higher outside

Table 32 Stocking density, feed input and growth of fish in the experimental ponds during 14 July to 11 November 1985

Pond No.	Initial fish stock Number	Initial fish stock Biomass Total (kg)	Initial fish stock Biomass Individual (g)	Final fish stock Number	Final fish stock Biomass Total (kg)	Final fish stock Biomass Individual (g)	Increase in weight Total (kg)	Increase in weight Individual (g)	Increase in weight Daily %Instantaneous Growth Rate	Total weight of food input (kg)	F.C.R.
6	556	16.5	29.7	473	54.5	115.2	38.0	85.5	1.22	48.9	1.29
7	999	26.5	26.5	980	83.77	85.5	57.3	59.0	0.97	85.5	1.49
8	1,458	48.5	33.3	1,404	166.40	118.5	117.9	85.2	1.04	168.2	1.43

Table 33 Comparison of population parameters: population density ($\bar{X} \pm$ S.E.), dry biomass ($\bar{B}$), mean individual dry body weight (Wi) and dry weight production (P) from July-October of the different groups of benthic fauna between inside and outside enclosures in different experimental period

Benthic animal groups	Population parameters	Pond 6 Inside enclosures	Pond 6 Outside enclosures	Pond 7 Inside enclosures	Pond 7 Outside enclosures	Pond 8 Inside enclosures	Pond 8 Outside enclosures
	$\bar{X} \pm$ S.E. (000's.m^{-2})	373.4 ± 53.0	221.2 ± 17.4	274.0 ± 29.0	134.1 ± 5.7	373.6 ± 34.9	204.0 ± 42.6
	$\bar{B}$ (g m^{-2})	499 ± 97	95 ±17	449 ± 66	61 ±12	530 ± 71	88 ±26
Oligochaeta	Wi (mg ind. wt.)	1.34	0.43	1.64	0.46	1.42	0.43
	P (g m^{-2})	201.0	108.0	216.0	84.0	181.0	117.0
	P/B	0.40	1.14	0.48	1.38	0.34	1.33
	$\bar{X} \pm$ S.E.	4,670 ± 1,460	10,200 ± 2,070	8,300 ± 1,270	12,700 ± 3,740	12,240± 1,750	23,100± 5,040
	$\bar{B}$	3.42 ± 2.64	6.56 ± 3.36	4.10 ± 1.79	5.19 ±1.85	13.13± 2.12	21.81 ± 3.62
Chironomidae	Wi	0.73	0.64	0.49	0.41	1.07	0.95
	P	6.53	7.73	5.44	8.09	5.18	13.33
	P/B	1.90	1.18	1.33	1.56	0.39	0.61
	$\bar{X} \pm$ S.E.	2,160 ± 80	2,000 ± 80	2,200 ± 70	1,900 ± 170	2,040 ± 120	1,580 ± 110
	$\bar{B}$ (g ash free dry wt.m^{-2})	1.43 ± 0.12	1.31 ± 0.15	1.52 ± 0.09	0.34 ± 0.02	1.47 ± 0.13	1.04 ± 0.20
Mollusca	Wi	0.66	0.66	0.69	0.18	0.72	0.66
	P	0.37	0.32	0.29	0.18	0.39	0.54
	P/B	0.26	0.24	0.19	0.53	0.27	0.52
	$\bar{X} \pm$ S.E.	1,900 ± 380	1,740 ± 220	1,870 ± 150	1,870 ± 120	2,000 ± 320	1,660 ± 280
	$\bar{B}$	1.18 ± 0.27	1.06 ± 0.19	1.12 ± 0.12	1.11 ± 0.15	1.23 ± 0.25	1.02 ± 0.23
Hirudinea	Wi	0.62	0.61	0.60	0.59	0.62	0.62
	P	0.14	0.18	0.15	0.22	0.18	0.21
	P/B	0.12	0.17	0.13	0.20	0.15	0.21
	$\bar{X} \pm$ S.E.	1,070 ± 110	850 ± 70	1,020 ± 210	720 ± 190	1,020 ± 70	640 ± 140
	$\bar{B}$	1.88 ± 0.27	1.46 ± 0.24	0.96 ± 0.05	0.72 ± 0.08	1.56 ± 0.31	0.98 ± 0.47
Asellidae	Wi	1.76	1.71	0.94	0.99	1.53	1.54
	P	0.76	0.72	0.21	0.25	0.57	0.29
	P/B	0.40	0.49	0.22	0.35	0.37	0.30
	$\bar{X} \pm$ S.E.	1,280 ± 150	1,200 ± 110	1,230 ± 100	980 ± 150	940 ± 180	810 ± 110
	B	2.89 ± 0.24	2.64 ± 0.20	1.88 ± 0.39	1.50 ± 0.44	2.67 ± 0.39	1.85 ± 0.42
Sialidae	Wi	2.27	2.17	1.52	1.53	2.85	2.28
	P	1.11	0.91	0.23	0.28	0.58	0.23
	P/B	0.38	0.34	0.12	0.19	0.22	0.12
	$\bar{X} \pm$ S.E. (000's.m^{-2})	384.5 ± 32.2	2372 ± 11.8	288.4 ± 19.5	152.3 ± 4.9	391.8 ± 26.5	231.8 ± 22.8
Total benthic fauna	$\bar{B}$	509 ± 96	108 ± 18	458 ± 66	72 ± 12	550 ± 73	115 ± 28
	P	210	118	222	93	188	132

Table 34 Results of ANOVAs and their associated levels of significance ($P < 0.05$,*; $P < 0.01$,**) from the comparison between experimental ponds and outside and inside the enclosure using log transformed data

Benthic group	Parameters	Sources of Variation		
		Between ponds	Between inside & outside enclosure	Interactions
Oligochaeta	Number	15.61**	98.36**	0.87
	Biomass	0.60	76.93**	0.34
Chironomidae	Number	16.47**	19.32**	1.68
	Biomass	9.66**	3.21	0.35
Mollusca	Number	4.20*	12.08**	1.18
	Biomass	3.72*	23.99**	5.62*
Hirudinea	Number	0.11	0.41	0.23
	Biomass	0.09	0.22	0.17
Asellidae	Number	0.73	6.89*	0.41
	Biomass	3.34	2.44	1.75
Sialidae	Number	3.58*	1.84	0.20
	Biomass	0.86	0.07	1.31
Total benthos	Number	17.16**	94.60**	0.70
	Biomass	1.02	93.40**	0.25

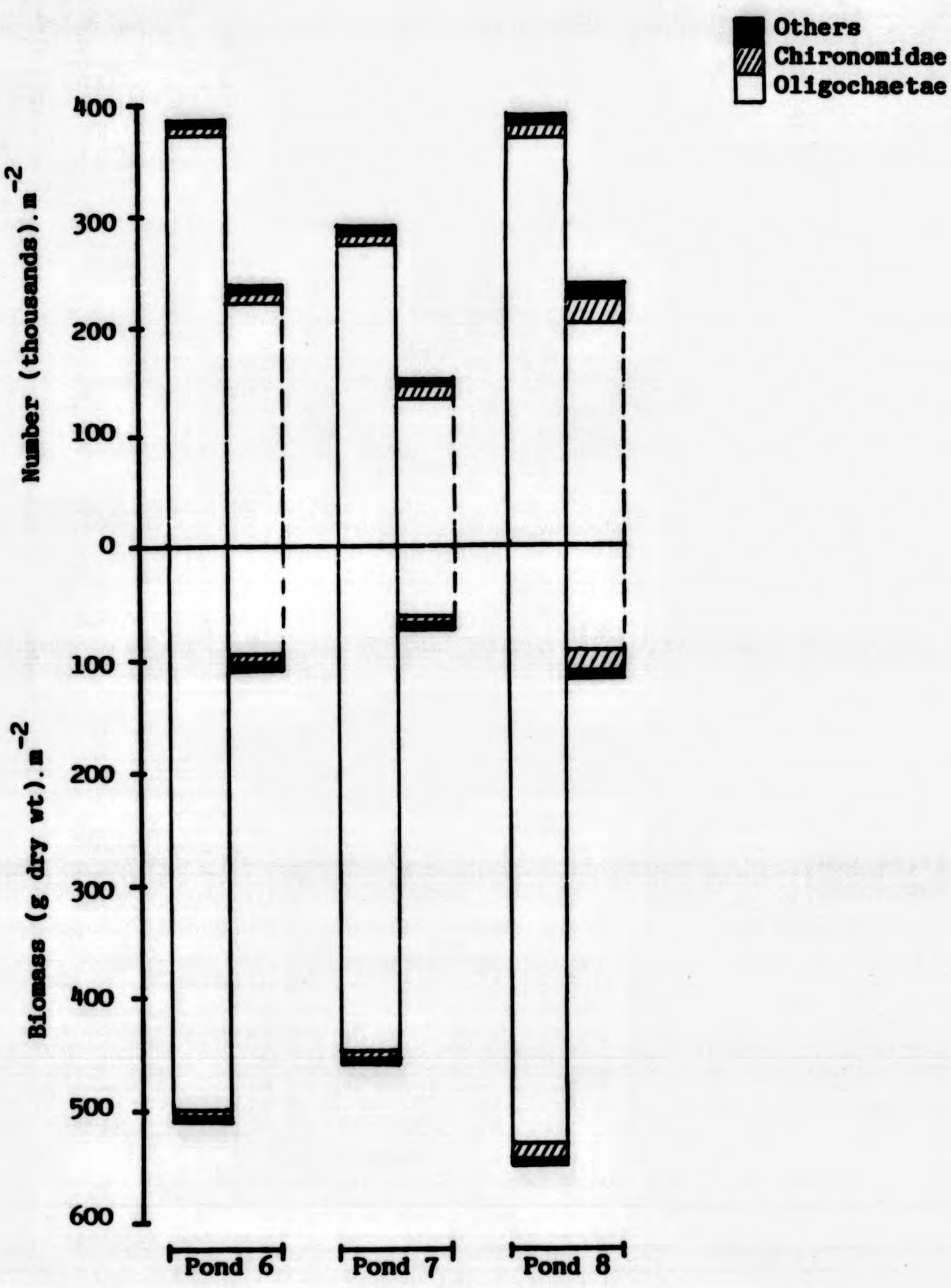


Fig. 96 Comparison of abundance and biomass of benthic animal groups between the inside (solid boxes) and the outside (open boxes) of the enclosures in the experimental ponds

the enclosures than inside. Between ponds variation for the above groups was also significant. Asellus aquaticus varied significantly inside and outside the enclosures, and Sialis lutaria was significantly different between the ponds (Table 34).

Fig. 97 illustrates the species composition of Oligochaeta inside and outside the enclosures. The Oligochaeta fauna exhibited a similar compositional pattern in all the ponds throughout the four month study period. Only four species occurred inside the enclosures, and also dominated the outside population. Three large species, Limnodrilus udekemianus, L. hoffmeisteri and Tubifex tubifex were more abundant inside the enclosures, while Psammoryctides barbatus was less abundant.

Comparison of larval chironomid genera indicated that there were fewer species inside than outside. Fig. 98 shows that the abundance of non-predatory Chironomidae, mostly of 2nd and 3rd instars, was higher on the outside. Predatory larvae, mainly Procladius and Ablabesmyia spp. were also present outside but in small numbers of smaller larval instars. On the contrary, large size larvae of these predatory Chironomidae were abundant inside the enclosures. The relatively smaller proportion of non-predatory Chironomidae inside the enclosure consisted mainly of Chironomus sp.

All the species of Mollusca, Hirudinea, Asellidae and Sialidae were present both on the inside and outside in all experimental ponds, and there

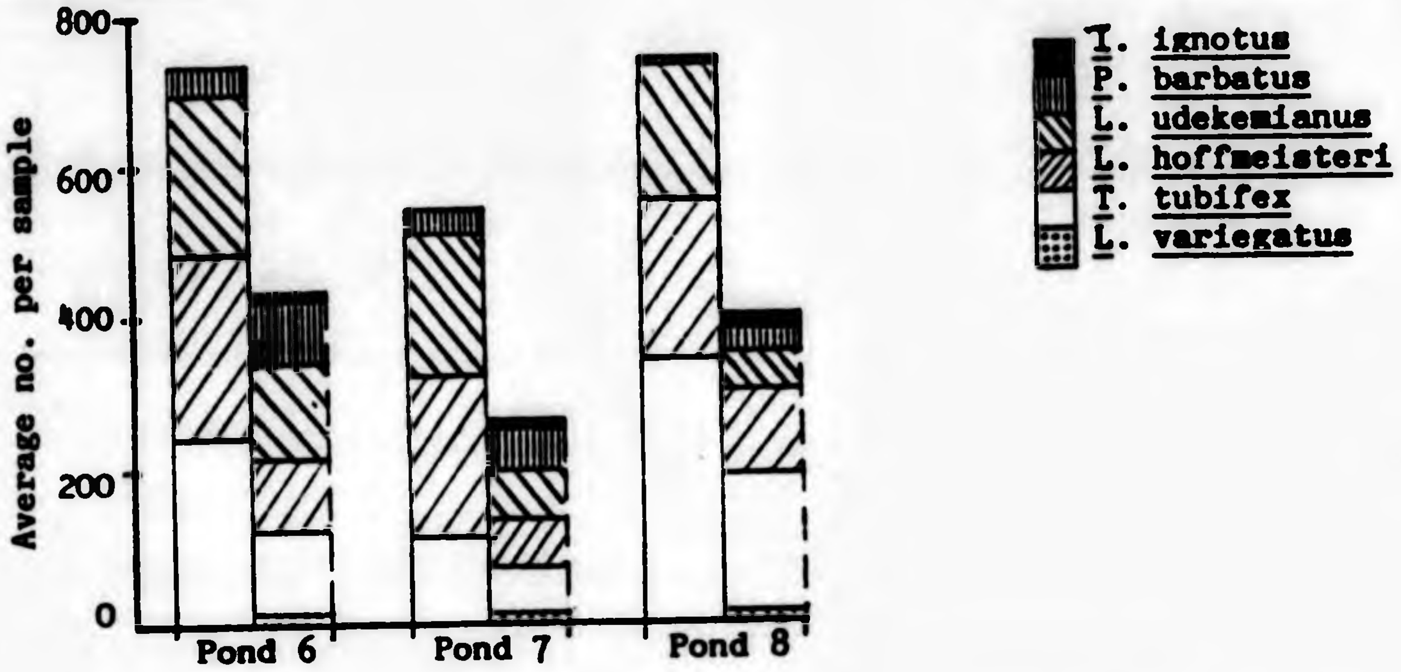


Fig. 97 Relative abundance of Oligochaeta species on inside (solid boxes) and outside (open boxes) the enclosures

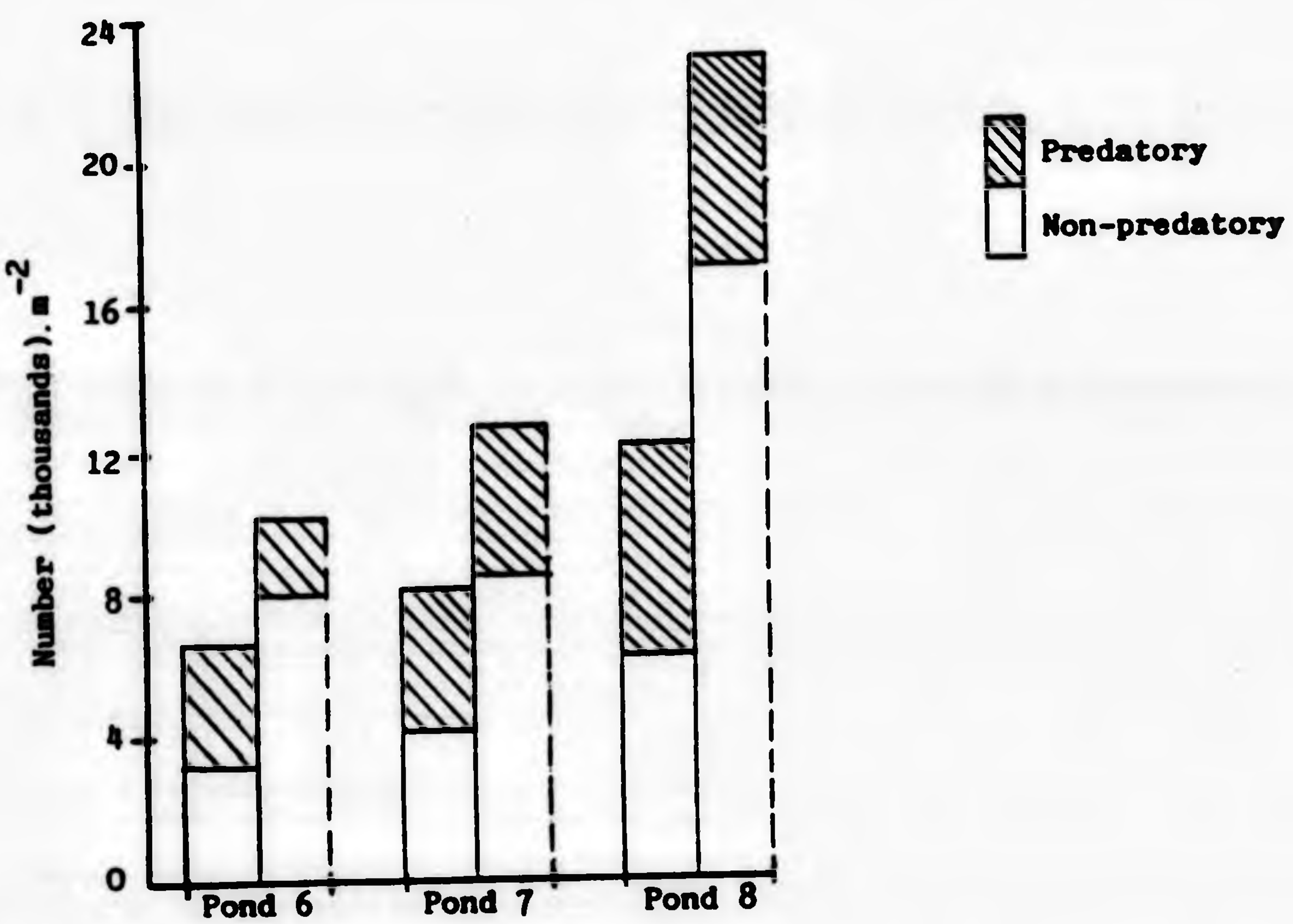


Fig. 98 Relative abundance of predatory and non-predatory chironomidae on inside (solid boxes) and outside (open boxes) the enclosures

was no distinct difference in size.

Regarding the effect of excluding fish from the benthos, there was a significant increase of 4-6 times in the biomass of total benthos inside the enclosures (Fig. 96 and Table 33). This was due mainly to Oligochaetae, the principal component of the benthos, which increased not only in numbers but also in mean weight on the inside (by 3-4x). Differences in biomass between the ponds, however, were not significant. Chironomidae, on the contrary, showed significant differences in biomass between the ponds but not between inside and outside the enclosures, although, the mean individual weight of chironomidae was higher inside the enclosures (Table 33). Mollusca was the only group which showed a significant difference in biomass, both between the ponds and between inside and outside the enclosures, as well as a significant interaction effect ($P < 0.05$).

Fish apparently exerted an influence on the production of benthic animals in the experimental ponds. Table 33 shows that production (as determined by 'growth increment summation' method) of Oligochaetae and total benthos was higher inside the enclosures. In contrast, Chironomidae demonstrated a higher production outside the enclosures, which increased with the stocking density of fish from pond 6 to 8 (Table 33).

Table 33 showing the P/B ratios between inside and outside the enclosures, revealed that these coefficients for major groups of benthos, such as Oligochaeta, Chironomidae, Mollusca, Hirudinea were higher outside than inside the enclosures. An exception to this was observed in pond 6, where Chironomidae and Mollusca were found to have higher P/B ratios inside.

Table 32 demonstrates that the mean individual weight increment of trout during the experimental period was comparatively higher in ponds 6 and 8, but less difference between treatments is apparent in instantaneous growth rates.

5.1 Environmental Parameters

The maintenance of a healthy aquatic environment and production of sufficient fish food organisms used to be considered as the two factors of primary importance in successful pond culture operations. This concept has been partially changed in recent years with the introduction of intensive aquaculture operations, where large amounts of high quality protein-rich pelleted feeds are applied to the fish ponds. The intensification of fish culture in fish ponds may lead to deleterious changes in water quality as a result of the accumulation of fish metabolites, faeces and non-ingested food. The intensification of cage culture operations in freshwater has already become a growing concern in many countries, stimulated by the evidence that cage farming can cause eutrophication (Kilambi et al., 1976; Korzeniewski & Salata, 1982; Beveridge, 1984). A similar situation may arise in fish ponds where, besides the fish, other co-inhabitants equally experience beneficial or harmful effects of intensification. Moreover, due to the high stocking density, the fish themselves exert a greater influence on the whole ecosystem. Intensification of trout culture in Howietoun fish ponds and its effect on the physico-chemical environment are discussed in relation to the ecology of the benthos.

5.1.1 Physico-chemical Parameters of Water Quality

The literature suggests that no natural factor is as important as temperature because, while pH and nutrients appear to be tolerated by an organism over a wide range, a change in temperature of a single°Celsius can be significant.

Macan (1961, 1963) pointed out that in a number of ways temperature can effect the growth and life-cycle and limit the distribution range of freshwater animals. A similar suggestion was also made by Maitland (1978), who linked up the breeding biology of many insects with the day-length and/or temperature of their surroundings. Morgan and Waddell (1961) found the number of species of chironomid emerging from various sites of Scottish lochs was directly proportional to water temperature.

Like many other fish ponds, Howietoun ponds are shallow, have a small surface area and thermal stratification has never occurred. In addition to its shallowness, a slow flow through the ponds and the turbulence created by fish due to the high stocking density may be responsible for preventing the formation of the thermal stratification. The shallowness may not be the only factor to check thermal stratification. Parks _et al_ (1975) found that thermal stratification developed even in very shallow ponds on calm sunny days and a close similarity in the seasonal pattern of air temperature and the temperature of the epilimnion was observed (Parks _et al_., 1975).

At Howietoun, the absence of diurnal variations during the cooler autumn days but their presence during summer agrees with the limited published information from temperate regions (Martin, 1972; Young, 1975a).

The three main sources of suspended solids in fish ponds are likely to be soil particles derived from surface run off during rainfall, fragmentation of feeds and faeces and planktonic organisms. Clark et al (1985) considered that fragmentation of faeces was the principal source of suspended solids in the Shearwater fish farming system in Cumbria, U.K. According to him, production rate of suspended soilds varies considerably with the design of the system and efficiency of faeces removal.

At Howietoun the peak period of total suspended solids was observed in autumn which coincides with the rainfall during this period. A considerable proportion of solids are produced when feeds are applied and the feeds and faeces are fragmented by the swimming activity of fishes (Clark et al., 1985). Boyd (1982) indicated that waters from fish ponds would vary in their solids concentration depending upon the degree of mineralization, amount of suspended clay and plankton.

Measurement of particulate organic matter has been more widely used in fish culture (Boyd, 1982). Organic matter is present as living plankton, suspended particles of decaying organic matter (detritus) and dissolved organic matter in the fish ponds. The maximum amount of organic matter was recorded during May to August, which might be due to the higher production of phytoplankton during this period, as observed by Dey (1984). The increase in the amount of particulate organic matter from pond 7 to 14 was also consistent with the increase in phytoplankton abundance as the water passed through the farm, as suggested by Dey (1984).

The conservative properties of water, such as total hardness, total alkalinity and calcium, are not much influenced by the intensification of fish farming. Total hardness is usually related to total alkalinity and the cations of hardness are generally derived from the dissolution of calcium and/or magnesium carbonate. These compounds with dissolved carbon dioxide in water form an equilibrium system which is of primary importance in the ecology of the environment. Having played the central role in the pH - carbon dioxide system in freshwaters, calcium influences the supply of photosynthetically available carbon. Calcium content of water is the major factor in deciding the distribution of Mollusca (Boycott, 1936; Dussart, 1976). Since the Howietoun pond water contained a low level of calcium typical of soft water aquatic ecosystems, many of the calciphile Mollusca which need a calcium concentration >20 mg l^{-1} may not be able to settle there and grow.

The seasonal trend of these conservative properties of water showed a summer decrease which might be associated with the uptake of calcium directly by the molluscan population during the growing season, or may be due to the precipitation of $CaCO_3$ because of the equilibrium CO_2 taken up by the primary producers.

The observation of a positive correlation between calcium and total alkalinity is in good agreement with similar findings in Alabama ponds by Arce and Boyd (1980).

Hydrogen-ion concentration (pH) is considered to be an important characteristic of water to the aquaculturist. Waters which are poorly buffered may exhibit a drastic fluctuation in pH (Maitland, 1978) which may imbalance the physiological adjustment of many organisms living in the aquatic ecosystem. There is a closer link between photosynthetic activity and pH in freshwater (King, 1970; Sreenivasan, 1970, 1976; Bales et al., 1980; Rimon & Shilo, 1982). The increase in day time pH observed during summer months was probably due to the photosynthetic up take of free CO_2 by the phytoplankton population at this time, as reported by Rimon & Shilo (1982). Variation in photosynthetic activity and community respiration explain the diurnal variation in pH of pond water, with an increase during day time and a decrease at night, as observed at Howietoun and reported by George (1961), Michael (1964), Rimon and Shilo (1982) and Boyd (1982).

Dissolved oxygen is one of the primary factors in natural waters as a regulator of metabolic processes of plants and animals, and as an indicator of water condition. Hutchinson (1957) has aptly remarked that a series of oxygen determinations along with the turbidity and colour of the water could provide more information about the nature of the water than any other chemical parameter.

When fish culture is intensified through artificial feeding, problems with dissolved oxygen increase in frequency and severity (Boyd, 1982). In many intensive culture systems, dissolved oxygen becomes so critical a factor that the success or failure of the fish farming often depends upon the ability of the farmer to cope with the problems of low dissolved oxygen (Boyd, 1982).

Generally, in ponds with a high standing crop and receiving artificial feed, the metabolic wastes provide nutrients to encourage the growth of plankton. Phytoplankton plays a dominant role in the dissolved oxygen dynamics of fish ponds. The seasonal trend of dissolved oxygen is under the influence of factors such as temperature and rate of photosynthesis (Dey, 1984). The summer decline in dissolved oxygen in Howietoun fish ponds may be due to high temperature and resulting higher rates of decomposition and respiration of aquatic organisms. A decrease in oxygen concentration was observed as the water passes through the farm, which is in accord with Warrer-Hansen and Wood-Petersen (1976) and Bergheim _et al_ (1982) in Danish and Norwegian fish ponds, respectively. Clark _et al_ (1985) found that the effluent from fish farms has oxygen consuming properties.

Fluctuations in diurnal dissolved oxygen concentration were recorded with a maximum value in the afternoon and minimum before dawn. Such a diel fluctuation was reported by Nasar (1977), Reddy (1981) and Boyd (1982). All of them suggested that photosynthetic production increased the day time dissolved oxygen, and respiration was responsible for the night time decrease. Schroeder (1975) suggested three main factors responsible for night time oxygen decline: BOD of water, fish respiration and diffusion of oxygen to atmosphere. To this list should be added respiration by phytoplankton and benthos.

Low oxygen content of water has great influence on the abundance and diversity of benthic invertebrates. Jonasson (1984) pointed out that when oxygen is present in limited amounts, it retarded growth, increased the longevity, and lowered the production of zoobenthos.

As a constituent of protein, nitrogen occupies a highly important place in aquatic ecosystems. Forms of nitrogen in water include: nitrogen gas, nitrate, nitrite, ammonium, ammonia and various forms of organic nitrogen (Boyd, 1982). In natural water bodies combined nitrogen may be obtained from the air, either through nitrogen fixing bacteria (Demoll, 1931) or through fixation of atmospheric nitrogen by blue-green algae (Singh, 1961; Prowse, 1964). Whereas in intensive fish ponds, nitrogenous nutrients are added from the feeds and excretory products of fish in addition to the natural resources. Some authors found that nitrogen fixation rates are usually higher in eutrophic waters than in oligotrophic ones (Rusness & Burris, 1970; Horne & Fogg, 1970).

Among the various forms of nitrogenous nutrients, ammonia, nitrite and nitrate are most important to aquaculturists. Ammonia is a principal nitrogenous excretory product of the fish kept on an intensive feeding regime of high nitrogen containing feeds (Guerin-Ancey, 1976; Kausik, 1980). It is also produced by the bacterial ammonification process of the organic nitrogenous matter in the water column under aerobic conditions and anaerobically in the sediment (Clark et al., 1985). The concentration of total ammonia in this study was very high but the proportion of un-ionised ammonia, which is toxic to fish at high pH levels (Smart, 1975; Alabaster & Lloyd, 1980), was always found lower than the dangerous level of 0.2 mg NH_3/l (un-ionised). This was probably due to the coincidence of a decrease in pH and temperature during the increase in total ammonia.

Nitrite is an intermediate product in the process of nitrification of ammonia to nitrate (Stirling, 1985). In excess amounts, nitrite is toxic to fish, although the sources of excessive nitrite in fish ponds have not been definitely identified (Boyd, 1982). Hollerman and Boyd (1980) noted that nitrite originates from the reduction of nitrate by bacteria in anaerobic mud or water. However, a common opinion is that an imbalance in the nitrification reaction results to the accumulation of nitrite. Regardless of the source, nitrite was always available in considerable quantity in Howietoun fish ponds, but it never reached the lethal level of 0.5 mg l^{-1} as suggested by Crawford and Allen (1972).

Nitrate was the most dominant nitrogenous nutrient in the fish ponds. It is a final product of nitrification and major phtyoplankton nutrient (Stirling, 1985). Nitrate is not toxic to fish.

All these nitrogenous compounds were found to vary significantly between the ponds with higher concentration towards the outflow. Similar results were reported by Bergheim et al (1982, 1984) in Norwegian fish farm ponds. These nutrients were found to be lower during summer, which may be due to the maximum biosynthetic activity during this period. During the period of intensification of production a major part of the nitrogenous nutrients are assimilated by the phytoplankton which die off and sediment to the bottom. Since the release of these nutrients from the bottom is not very rapid, this may account for the fact that the concentration in the water was lower during this period (Trojanowski et al., 1985). The summer decline of dissolved organic nitrogen may also be due to the algal die off and delay in regeneration.

A day time decrease and a night time increase of nitrite and nitrate and an opposite pattern for ammonia were observed in this study. This may probably be due to day time feeding of a pelleted diet, which eventually increases the excretion of ammonia, and bacterial denitrification which goes on through the night, increasing the concentration of nitrite and nitrate. Kausik (1980) found that the rate of ammonia excretion increases immediately after each meal; the maximum rate occurred at different intervals, depending on the amount of nitrogen as well as on the time lapse after a particular feeding regime was initiated. Salmonid nitrogen excretion was measured by Burrows (1964), Brett and Zala (1975) and Richly and Marina (1977), who showed a post-prandial increase in ammonia excretion, the peak values being observed at different times (4 hours in sockeye salmon, 6 hours in trout and 11 hours in coho salmon) after feeding.

Ecologically, phosphorus is considered as the most critical single element in the maintenance of aquatic productivity. Most phosphorus data for freshwaters refer to total phosphorus and soluble inorganic phosphorus (ortho-phosphate), although in more detailed studies, four general fractions have been identified (Hutchinson, 1957). Phosphorus is added to the pelleted fish feed as it is needed for optimum food conversion (Andrew et al., 1973), normal growth and bone development (Ketola, 1975; Lovell, 1978) and the β-oxidation of fatty acids (Sakomoto & Yone, 1980; Takeuchi & Nakazoe, 1981). Fish derive phosphorus mainly from dietary sources, because of the low absorption rate from water (Nose & Arai, 1978). Tacon and De Silva (1982) investigated 38 different artificial feeds and showed that the average total phosphorus content was about 1.47%. From this dietary phosphorus, the phosphorus level in intensive culture systems increases and leads to eutrophication (Phillips et al., 1985). Phosphate is produced by direct excretion through the kidney (Forster & Goldstein, 1969) and also possibly through leaching of faeces and food (Clark et al., 1985) in any culture system.

Similar to other flow-through systems of intensive aquaculture (Bergheim et al., 1982; Boyd, 1982) an increase in both total and reactive phosphorus was observed from pond to pond as the water passed through the farm, which was due to the addition and accumulation of phosphorus from the metabolic wastes, faeces and unused feeds.

The decrease in both reactive and total phosphorus in summer seems to be related to the increase in algal biomass during summer months (Korzenewski & Salata, 1982). Trojanowski et al (1985), while holding a similar view, also stressed that the summer decrease may be associated with less intense release of phosphorus from dead algae deposited on the bottom, since the effective mixing of water prevented the establishment of anaerobic conditions. Both phenomena probably work together in well mixed Howietoun pond water.

A night time increase and a day time decrease was observed in the diurnal study, which may be due to utilization during the day by photoassimilation and accumulation during the night from fish excretion. In this respect, it is not clear whether the fish also play any role through physical disturbance of the bottom sediments to release their locked up phosphorus while the fish are searching for food. Such a phenomenon is evident in carp culture systems as reported by Tatvai and Istvanovies (1986).

A generalization emerged from the study of water quality from the inflow and outflow of the fish farm, which was a general increase in all the nutrients in the outflow (downstream) compared with the inflow (upstream). In contrast, the dissolved oxygen concentration was always higher at station 1 (inflow) than at station 2 (outflow). No obvious difference was observed in other parameters except an increase in total hardness in station 2 for unknown reasons. The supply water at Howietoun passes through a hatchery and smolt rearing tanks upstream before entering the farm. Thus, it contains a certain level of nutrients but always has a high concentration of dissolved oxygen. When this water passes through the farm it becomes enriched with more and more nutrients and loses oxygen, but finally becomes moderately diluted through mixing with by-pass stream water at the outflow. The nutrient concentration at the outflow was, therefore, always higher than the inflow but lower than the last ponds in the series.

Finally, a general conclusion can be made that none of the measured parameters of water quality was found to be extreme for brown trout. Since benthos are considerably more tolerant than trout of limiting environmental conditions, one can assume that there was no direct limiting effect of the environment on most benthic organisms.

5.1.2 Physico-chemical Parameters of the Soil and Sedimenting Materials

Most benthic animals show some degree of preference for certain types of substratum. Despite conflicting results on the relationship between organisms and their substratum Meadows and Campbell (1972) concluded that the optimum habitat is selected by each organism by continually assessing and responding to information received from the environment. The particle size distribution in this study revealed that all the ponds have a 'silty gravelly sand' type of substratum, although some apparent variation between ponds is noted. Pond 7 contained more sand, probably brought from allochthonous sources by the inflow. Higher percentage of silt and clay in pond 14 is probably due to the sedimentation of autochthonous materials in the last pond in a series with a flow-through system.

Pond mud pH is very important, because it influences the solubility of inorganic components of sediments and it exerts an influence on the vital processes of organisms inhabiting them (Trojanowski et al., 1982). In Howietoun fish ponds, soil pH was slightly acidic with a range of 5-6 in all ponds. This acidity may be due to several reasons, such as, leaching during heavy rainfall, inherent acid parent material and most importantly, microbial action on the deposit materials. A similar suggestion has been made by Mandal and Moitra (1975a). Seasonal variation in soil pH of different ponds demonstrated a summer decline. This may be due to the high accumulation of metabolites, faeces and dead algal materials and their slow decomposition which leads to reduced or partially oxidized products such as H_2S, CH_4 and short-chain fatty acids, which may make pond soil acidic and reduce the rate of bacterial action (Banerjea, 1967). An unusually high pH in pond 13 during October to December was probably due to the drying up effect during this period or to the reduced organic accumulation in the sediment of this pond.

The organic matter content of pond soils is closely related to their trophic status. In fact, the greater the amount of organic matter, the higher is the degree of eutrophication (Kufel, 1976). The main source of organic matter in natural waters is dead organisms (mainly plankton) and their metabolites sedimenting to the lake bottom. Trojanowski et al (1985) noted the higher range (6-26%) of organic matter in the soil from the trout culture region of Male Lake, Poland, which he described as due to the sedimentation of trout faeces and non-ingested food. In this study, the organic matter content of the cultured pond soils was always higher than the control pond, which is in agreement with the above findings. The low organic matter content in the soil of pond 13 was probably due to the low stocking density and use of floating pellets which seldom sedimented to the bottom. The organic matter content of the pond soils and that of the sedimenting materials collected in the traps were found to be highly correlated, which confirmed that the bottom soil organic matter is the result of sedimentation of materials derived from fish farming.

The importance of soil phosphorus in freshwaters for increasing primary productivity is well recognized. The accumulation of large quantities of phosphorus due to intensive fish farming is causing concern regarding its environmental impact. Penczak et al (1982) found that the concentration of phosphorus is much higher (1.77 x) in the faeces than in the food of farmed trout, which is reflected in the present study. Both soil and sedimenting materials contain a high percentage of total phosphorus (5.0-11.0 $mg.g^{-1}$), indicating a great amount of faecal deposition on the bottom mud. Soil from cultured ponds always contained higher amounts of phosphorus than that from the control pond, clearly indicating the metabolic source of phosphorus in the cultured ponds. In Polish Lake Letowo, a higher concentration of total phosphorus was observed around the trout culture site (Trojanowski, et al., 1982).

Bottom mud plays an important role in the phosphorus cycle in the hypolimnion (Mortimer, 1941, 1942, 1971; Hayes et al., 1952), the phosphorus in the bottom deposits being released by bacterial action under anaerobic conditions. The effect of bioturbation (processing of sediment by benthic fauna) on phosphorus dynamics has been given increased recognition. Lee (1970) suggested that bioturbation could amplify the release of phosphorus from the sediment. Dissolved phosphorus released across the sediment-water interface was largely attributed to the stirring activities of the macro-fauna (Neame, 1977). Graneli (1979) demonstrated that the release of total phosphorus increased in the presence of *Chironomus plumosus* larvae. Tubificids mediated transfer of ^{32}P from the sediment to overlying water was reported by Davis et al (1975). The release of phosphorus by bioturbation is impeded near the surface, particularly in oxygenated conditions.

Nitrogen in soil is mostly present in organic form as amino-acids, peptides and easily decomposible proteins (Banerjea, 1967). Nitrogen content in the bottom soil is strongly related to the trophic type of lake (Tadajewski, 1966). The greater this content, the higher the degree of eutrophication (Trojanowski et al., 1982).

A high concentration of total nitrogen was found in the cultured pond soils which indicated that wasted feed materials and faeces were the source of nitrogen in the cultured ponds. In intensive fish farming, the artificial feed contains a high amount of protein (35-40%), which leads to a greater accumulation of nitrogen in the bottom soil. A low stocking density and a different type of feed with a lower specific gravity were responsible for lower sedimentation of nitrogen in the bottom soil of pond 13. A positive correlation between the nitrogen content of the soil and that of the material captured in sediment traps confirmed their similar origin in intensive fish ponds.

Organic forms of nitrogen are broken down in the pond soil by bacteria which release inorganic nitrogen into the overlying water. Other than bacterial transformation, the nitrogen dynamics in the soil-water system is modified by the benthic macro-invertebrate community (Krantzberg, 1985). He noted that the net direction of transfer will differ between systems as a function of total organic content, oxygen concentration, Eh, and intensity of bacteria-mediated processes. Ganapati (1949) showed that Chironomus riparius larvae increased the release of free ammonia from the sediment. Anderson (1977) observed a linear correlation between the denitrification of nitrate added to waters overlying sediments and the biomass of colonizing C. plumosus larvae. Chatarpaul et al (1979) demonstrated that oligochaete worms significantly increased the rate of denitrification in the first twelve days of colonization and then stimulated nitrate production in the sediments. Rates of sediment-water exchange of ammonium-N are accelerated by burrowing activities (Chatarpaul et al., 1980).

A greater accumulation of total carbon in the pond soil is more likely in intensive aquaculture because about 31.6-42.6 % carbon is present in the pelleted feed. The bottom soils of the more densely stocked ponds at Howietoun contain higher percentages of total carbon. Similar results were reported by Pennington (1974) and Kajak and Kaibacz (1977), who found more carbon in the sediments of a cage culture site on a lake than at the control site. Change in the organic carbon content of bottom soils close to the trout culture region of a lake were observed by Trojanowski et al (1982). According to them, the main sources of organic carbon comprised the metabolites excreted by trout, residual fish food and dead algae which in certain periods develop in masses. Similar sources of organic carbon may have increased the carbon content of the pond soils in the present study. The algal contribution is evident by the higher carbon content in the pond soil in late summer following the peak algal abundance (Dey, 1984).

Organic matter in the bottom sediments is mineralized with the release of, among others, nitrogen compounds and carbon; these are reflected by the carbon : nitrogen ratio. According to Lityński (1971), the degradation of organic matter with a C:N ratio by weight of $<$ 17 leads to the release of inorganic nitrogen compounds. The C:N ratio was found to be 10 in the cultured ponds at Howietoun which testifies to a satisfactory mineralization rate (Korzenowski, et al., 1979). Compared with most lakes, the shallow depth of Howietoun ponds increases the degree of oxygenation and rate of heating of the sediments, thus stimulating the degradation of organic matter in the ponds and lowering the C:N ratio. However, a similar C:N ratio was reported from the shallow Danish eutrophic Lake Esrom (Kamp-Nielsen, 1975).

Besides their absolute concentrations, the ratio of N:P is likely to influence aquatic productivity, and an average atomic ratio of 15-16 (about 7N:1P by weight) is considered optimal (Redfield, 1958). Significant departures from this ratio have sometimes been taken as evidence of nutrient stress in any aquatic system. N:P ratio of the pond bottom soil has been regarded here as an indicator of the origin of the organic materials of the soil and state of mineralization. In this study the N:P ratio was around 1.0 by weight, which is indicative of very high phosphorus content in the bottom soil. In other words, total phosphorus is not limiting because a large amount would have been supplied in the fish feed.

Stream soil showed higher nutrient concentrations and smaller particle size in station 1 (inflow) than station 2 (outflow), probably because of accumulation and sedimentation behind the dam on the inflow and the washing out of materials from the stream station 2 by the strong outflow from the fish farm.

5.2 Benthic Macro-invertebrate Ecology

The lack of ecological work on the benthos of trout ponds subjected to intensive fish farming practices necessarily limits comparative discussion between similar culture systems.

In spite of the paucity of literature on pond benthos, satisfactory progress has been made in the study of large inland water bodies. Some very detailed studies have been carried out in the major Scottish Lochs (Weerekoon, 1956; Charles et al., 1974; Maitland & Hudspith, 1974; Maitland, 1981). When comparing the findings of the present study with previous work, differences in aims and objectives and in sampling methods and subsequent processing techniques often make it difficult to make a direct comparison between different studies.

Macro-invertebrates for this study were considered to include those organisms retained on a 250 μm seive. Barnes and Mann (1980) defined macrobenthos as those organisms over 1 mm in size, but this definition is not suitable for all benthic studies.

The general composition of the benthic macro-invertebrate community in the Howietoun fish ponds consisted of the six major groups. Oligochaetae, Chironomidae, Mollusca, Hirudinea, Asellidae and Sialidae. The pond benthos thus showed a great general resemblance to that of other European fish ponds and British lochs and reservoirs (e.g. Macan, 1965; Maitland, 1966; Kajak & Dusoge, 1973; Maitland & Hudspith, 1974; Potter & Learner, 1974; Wojcik-Migala, 1979; Smith et al., 1981), although the fauna of more eutrophic water bodies (including the present ponds) show greater abundance but lower diversity (Hynes, 1960; Kondratieff & Simon, 1982; Bazzanti & Seminara, 1985).

The densities of the benthic fauna in the cultured ponds vary from 70,000 to 300,000 ind. m^{-2}, which is far higher than the reported densities from other fish ponds. A comparison of this high abundance can be made with the benthic population density in Loch Fad, a shallow eutrophic loch subjected to intensive cage culture of trout. The average population density of benthic fauna was 156,000 ind. m^{-2} studied during 1980-1981 (Beveridge, personal communication). Dall et al (1984) recorded 65,000 ind. m^{-2} at the sheltered western side and 200,000 ind. m^{-2} on the exposed eastern shore of the eutrophic Lake Esrom. Therefore, the densities recorded at Howietoun are not unusual in eutrophic ecosystems. The adjacent stream, on the other hand, had a much lower number of individuals per m^2 than that of the ponds. Since the stream provides the intake to the fish farm, the stream benthos can easily drift into the fish ponds and find better breeding grounds there. The stream also serves as the source of imago forms of insects such as Chironomidae (Jermolaeva, 1959). This study revealed the resemblance between the pond fauna and those of the stream. A few of the benthic species were found to be confined to only one habitat, probably because of differences in the hydrological regime, they can not settle in opposite habitat. For example, the rheophilus species of Diamesa was only found in the stream.

5.2.1 Oligochaetae

Oligochaeta have been a more or less unknown quantity even to freshwater biologists, despite being very obvious constituents of invertebrate samples from a wide range of freshwater habitats (Brinkhurst & Jamieson, 1971). If little is known of Oligochaeta in general, even less is known of those in fish farm ponds as most research efforts have been directed to large lentic situations. Many lakes have been studied with regard to their oligochaete faunas (e.g. Brinkhurst, 1964, 1970; Jónasson, 1972; Maitland & Hudspith, 1974; Thorhauge, 1975; Milbrink, 1978, 1980; Lang & Lang-Dobler, 1980; Särkkä & Ahq, 1980). Some detailed accounts of stream Oligochaeta have also been published (Brinkhurst & Kennedy, 1965; Wachs, 1967; Ladle, 1971; Dumnicka & Pasternak, 1978; Bird, 1982).

As the major component of benthic macro-invertebrates at Howietoun, oligochaetes formed about 78-90% of the total benthos. The density of oligochaetes often exceeded 100,000 ind. m^{-2} in the cultured ponds. Similar high densities of tubificids in rivers and lakes receiving sewage and other organic effluents are extensively referred to in the literature (King & Ball, 1964; Brinkhurst, 1965, 1966a&b; Brinkhurst & Kennedy, 1965; Hawkes & Davies, 1971; Howmiller & Beeton, 1970, 1971). In heavily polluted waters, population densities of well over a million worms per m^2 are not uncommon (Richardson, 1929; Gaufin & Tarzwell, 1956; Brinkhurst & Kennedy, 1965; Brinkhurst, 1970; Aston, 1973b). In Loch Fad, around 90% of the total population of benthos was Oligochaeta with an average population density of 155,000 worms m^{-2} in areas below floating cages used for trout culture (Beveridge, personal communication), which was in good agreement with the present findings. Lower population densities were observed in the control pond at Howietoun which were similar to the control site in Loch Fad distant from the cages.

Although ten species of Oligochaeta were recorded from the Howietoun ponds, only six of them were available throughout the year. The remaining four occasionally appeared in the benthic samples. A reduction in number of species and increase in the number of worms is a characteristic feature of organically polluted water bodies (Brinkhurst, 1965; Howmiller & Beeton, 1970).

The abundance of total oligochaetes was found to be positively correlated with temperature and soil organic matter, and negatively correlated with total hardness and dissolved oxygen. The biological processes in oligochaetes are controlled by temperature, along with other factors. The maturation time, fecundity, length of life, mobility and mode of reproduction are controlled by environmental conditions (Bird, 1982) among which temperature is the most important. For example, the number of eggs per cocoon increased with temperature in L. hoffmeisteri (Poddubnaya, 1973; Aston, 1973a; Timm, 1974) and decreased in T. tubifex (Poddubnaya, 1974). Many authors observed that low temperature increases the time taken for hatching and the attainment of sexual maturity (Poddubnaya, 1980; Kaster, 1981). Timm (1974) observed that the corresponding time taken by T. tubifex at 1-4°C was 6-10 months and the progeny were 6-9 times less abundant than at room temperature, whilst Poddubnaya (1980) observed that this species attained maturity after two months at 20°C.

Brinkhurst and Jamieson (1971) have pointed out that, where careful analyses have been made, few correlations between the variations of total organic matter and the distribution and abundance of worms have been demonstrated, unlike the positive correlation observed in this study. Jonhnsen and Matheson (1968) observed that the profundal sediments in Hamilton Bay, Lake Ontario, which were rich in organic matter, contained an abundant population of L. hoffmeisteri and T. tubifex. In recent studies, oligochaetes are commonly regarded as 'detritivores' (Hynes, 1970; Cummins, 1975) or 'collector gatherers' (Anderson & Sedell, 1979), and they obtain energy from the organic content of the bottom mud and, thus, soil organic matter is associated with general nutrition of Oligochaeta. Bird (1982) stated that the rate of maturation and fecundity of worms are also influenced by the amount of 'organic matter' in the bottom sediment. Similar suggestions have been made by Ladle (1971) and Kaster (1981).

The finding of a negative correlation between total Oligochaeta and dissolved oxygen may be a reflection of the high rates of loading of organic matter coinciding with high temperature which stimulate not only benthic production but also microbial decomposition at the expense of dissolved oxygen in the ponds. Negative correlations between some species of Oligochaeta and dissolved oxygen are also reported by Dumnicka and Pasternak (1978). Aston (1973b) reported that the respiratory mechanisms of some species of Oligochaeta is adapted to operate at very low oxygen concentrations and they are able to survive for long periods in anaerobic conditions. The respiration rates in relation to dissolved oxygen concentration in four species of tubificids, were studied by Berg et al (1962), Aston (1966) and Palmer (1968) and found that in all four species, the respiration rate is virtually unaffected by dissolved oxygen concentration down to 20% of air saturation. Since the oxygen saturation at Howietoun always exceeded 80%, oxygen availability did not appear to limit oligochaetes.

The population density increased through the course of the farm waters, with significantly higher abundance in ponds 11 and 14 which may be due to the application of high inputs of food materials which may have contributed to the accumulation of greater amounts of wastes and unused feeds on the pond bottom and improved the feeding conditions for the detritivores. The lower population density observed in pond 13 may be due to a different type of management practice with this pond, including low stocking density and low rate of organic loading due to the use of floating pellets and complete drying out of the pond during early winter. The negative effect of winter drying on the benthic fauna of the fish ponds has been well reported (Korotun, 1959; Vlastov, 1959; Borodich, 1962).

The higher abundance of Oligochaeta in stream station 1 than 2 may be due to the higher organic matter content in the substrate and slow flow of water in stream station 1.

There appeared two seasonal peaks of oligochaete population, one in summer and another in autumn in this study. Ali and Lellák (1985) stated that the maximum abundance of benthic Oligochaeta was usually found in early spring and autumn by most authors. The present study agrees with those findings, but instead of a spring maximum, the formation of a delayed summer maximum was probably due to the drying out of the pond during spring. The increase in abundance in summer and autumn may be associated with high temperatures and availability of large amounts of food for these detritivores in the fish ponds during these periods. Food availability may be associated with algal production and subsequent deposition on the pond bottom during summer and autumn. Moore (1980) found strong correlation between the density of oligochaetes and algal production. Parallel findings are also reported by Lang (1978) and Maciorwski et al (1977). Dey (1984), however, recorded only a single peak of phytoplankton abundance in July 1981 at Howietoun.

T. tubifex was the most dominant species of Oligochaeta in all the experimental ponds except in pond 7. It was significantly lower in ponds 13 and 9, probably due to the lower food availability in the bottom sediments of these two ponds. Dumnicka and Pasternak (1978) found a positive correlation between T. tubifex and organic matter content in the sediment in the River Nida.

T. tubifex has received greater attention towards life history studies (Brinkhurst & Kennedy, 1965; Ladle, 1971; Bonomi & Di Cola, 1980; Kaster, 1981). Most of the authors concluded that it was highly fecund and matures quickly. In the present study, two seasonal peaks probably associated with two major recruitments were attained, one in spring (March-April) and the other in autumn (September-December). Many authors also report two major peaks of recruitment but at different times. In Ditton Brook, Brinkhurst and Kennedy (1965) recorded the two main influxes of juveniles in March and May-August. Similar to the present study, two periods of breeding have been reported by Matsumoto and Jammoto (1966) in March-July and September-October. On the contrary, Wachs (1967) recorded the mature T. tubifex mainly in May and June in the River Fulda. Unlike many stream environments, there are reasons to believe that worms mature earlier in fish ponds receiving high organic loading and thus providing more nutrients to the worms than the natural habitat. Similar observations were also made by Poddubnaya (1973), Timm (1973) and Kaster (1981).

Ambient temperature may be an important factor influencing breeding as well as the recruitment of this species. Recently Poddubnaya (1980) pointed out that _T. tubifex_ attained maturity rapidly in two months at 20°C when the population density was 20,000 m^{-2}. Since the population density at Howietoun is almost twice her observed density and the average temperature never reached 20°C, the development rate should be slower.

L. hoffmeisteri was another dominant species of Oligochaeta at Howietoun. The highest abundance was observed in pond 14 which was found to be highly enriched with the farm effluents. Aston (1973b) stated that polluted regions are dominated by _Limnodrilus_ species, particularly _L. hoffmeisteri_. The increased abundance may be related to the highly adaptable life-cycle of this species (Kennedy, 1966a), for this is likely to enable the worms to recover more rapidly than other species after unfavourable conditions (Aston, 1973b). Its high abundance in pond 14 may also be associated with high organic matter content in the soil. Dumnicka and Pasternak (1985) found that _L. hoffmeisteri_ is positively correlated with BOD, NH_4 and organic matter content in the sediment.

Regarding its breeding and life cycle, L. hoffmeisteri has also received increased attention (Brinkhurst & Kennedy, 1965; Kennedy, 1966a; Ladle, 1971; Bird, 1982). Their conclusions vary considerably, especially regarding breeding period and the time taken to reach sexual maturity. Published results for breeding period include: Kennedy (1966a), February-October in Ditton Brook; Wachs (1967) March-June in the River Fulda; Ladle (1971) from November-August in Bere stream; while Carter (1978) found numerous mature worms of L. hoffmeisteri during winter months in Lough Neagh, Northern Ireland, the major recruitment occurring during May-June, a period similar to that reported by Wachs (1967). The present study demonstrates the occurrence of two distinct breeding periods: April-June and September-November.

Timm (1974) and Bonomi and Di Cola (1980) have shown that L. hoffmeisteri could attain maturity after two months, which suggests that several generations are possible in a year. Potter and Learner (1974) reported 4-5 generations per year from Eglwys Nunydd reservoirs, although they have provided no data. Similar to the present study, Bird (1982) recorded 2 generations annually in Bere stream in Southern England.

L. udekemianus was the largest sized worm species in the fish ponds. The numbers of individuals were significantly different in different ponds, and ponds 13 and 9 contained a lower abundance. This species is said to flourish in organically polluted water.

It was found to be most abundant in pond 11. As the water passes through the farm, the size of the worm becomes smaller, the smallest ones being found in pond 14. There might be some relationship between the level of pollution and size of the worm. Pond 7 had the largest size but pond 11 appeared to provide optimum conditions for this species, with large size and higher abundance. The relatively smaller size in pond 14 may be due to the high level of pollution and higher predation pressure, where animals are probably selectively eaten by the fish.

The seasonal abundance in the population density of L. udekemianus showed a unimodal peak from mid-June to August, which may be due to the recruitment of young individuals during this period. This species seemed to have a one year life cycle at Howietoun fish ponds and to produce only one generation in a year. This is in contrast to Kennedy (1966b) and Bird (1982), who recorded a biannual life cycle for L. udekemianus in Ditton Brook and Bere stream. Timm (1962) recorded mature L. udekemianus primarily in June and July in Estonian waterbodies. In another study, Timm (1970) recorded cocoons only from June to August, which is in full accordance with the present study. Ali & Lellák (1985) recorded the presence of L. udekemianus during June to October in Bohemian carp ponds with a higher population density in June which may be associated with the breeding period.

P. barbatus was available in the fish ponds throughout the year.

Unlike the other species of Tubificidae, it gradually decreased in abundance from pond 7 to pond 14, pond 7 being the least enriched of the fish ponds. This is probably due to the 'oligo-mesotrophic' nature of this species (Adreani *et al*., 1984). Ladle and Bird (1984) found that *P. barbatus* was more abundant in silted sands than in gravel and detritus-rich silts. From the field samples and subsequent laboratory cultures, it could be concluded that the breeding period starts in April and continues until September. Cocoons are laid during May-June and the peak period of recruitment was during June-July. This is in full accordance with the findings of Ladle and Bird (1984) from the streams of Southern England. The observations of Brinkhurst and Kennedy (1962) and Timm (1970) are also consistent with the present evidence of summer recruitment. Adreani *et al* (1984) noted that maturation time is density dependent; density reduces the percentage of the population reaching maturity and also the specific fecundity. Timm (1970) found this species maturing at about 4 months old in the aquarium. Poddubnaya (1973) observed that *P. barbatus* takes at least 9-12 months to attain maturity.

T. ignotus was less abundant in the fish ponds. The relative proportions of *T. ignotus* in the Oligochaeta were higher in ponds 9 and 13, opposite to the findings for other species. The population density was higher in ponds 7 and 11 and lower in pond 14. The relatively higher abundance in less polluted areas indicates that this species does not prefer high levels of organic enrichment. This observation parallels the findings of Dumnicka and Pasternak (1985) in the River Nida. They found a positive correlation with dissolved oxygen but a negative correlation with phosphate.

Very little is known about the life history of this species. The relatively thinner body and smaller cocoons are helpful to separate them from the mixed population, although mature specimens were very scarce. The present study showed that this species may have a breeding period in the winter months which extends until the spring. Ladle (1971) observed the similar peak of mature worms from January to March in Bere stream. Bird (1982) reported that T. ignotus is a spring breeding species with peak of maturity occurring during March-June. Brinkhurst and Jamieson (1971) suggest that the lack of information on this species probably results from its relatively infrequent occurrence.

Another intolerant species of Tubificidae, A. pluriseta was only available in pond 13 throughout the year. The presence of this species in pond 13 indicates a low pollution level in the sediment in comparison to other cultured ponds. Its absence from control pond 9 was probably due to the absence of an inflow whereby this species could not be implanted. No sexually mature worm of this species was recorded from the fish ponds. Sexual specimens have been recorded from Lake Windermere in July and September by Brinkhurst (1964).

L. variegatus was the only lumbriculiid available in the fish ponds throughout the year but in small numbers. The number was higher in pond 7 than in pond 14. This might be due to two reasons: firstly, it may be sensitive to pollution and, secondly, it may prefer decaying plant material which is carried into pond 7 from the stream.

A review of early studies by Stephensen (1930) suggested that both sexual and asexual reproduction occur in this species, although asexual fission is the principal reproductive method. This is in good agreement with the findings of the present study. No sexually mature worm was recorded, but many segments with growing anterior ends were found from March to May, with peaks in April and October-December, indicating two periods of asexual reproduction at Howietoun. Bird (1982) also recorded asexual reproduction of L. variegatus in Bere Stream. Although this species has rarely been reported as mature, Cook (1969) suggests that it may be sexually active during June-July in British waterbodies.

None of the naidids was consistently available in the Howietoun fish ponds, the three species, O. serpentina, N. variabilis and S. lacustris, only being very rarely recorded from ponds 13 and 14. Their availability was so small that it is not possible to comment on their ecology.

5.2.2 Chironomidae

The Chironomidae is the most widely distributed and frequently the most abundant group of insects in freshwater environments (Pinder, 1986). Larval Chironomidae have been reported to be important secondary producers in the benthic environment of lakes (Jonasson, 1972; Charles et al., 1974) and to be an important element of invertebrate communities of shallow lakes (Potter & Learner, 1974; Mason, 1977; Lindegaard & Jónasson, 1979; Uutala, 1981). Besides the advancement of various biological and ecological works on Chironomidae in lacustrine environments, some major breakthroughs have been made in the stream and riverine Chironomidae (Lindegaard-Petersen, 1972; Pinder, 1974; Mackey, 1976 and 1977; Pinder, 1980; Pinder, 1983). Despite the enormous literature on various aspects of the ecology of Chironomidae (Fittkau, et al., 1976; Hoffrichter & Reiss, 1981), there is a dearth of information on the biology and ecology of chironomid populations in fish ponds. The principal reason for such deficiencies is probably the difficulty in identification of the various stages coupled with a large number of species frequently encountered within even a small waterbody (Pinder, 1986).

Eighteen species of Chironomidae were recorded in the Howietoun fish ponds, which is clearly a reflection of Pinder's opinion. In spite of the large number of species, their contribution to the total benthos is relatively small in comparison with Oligochaeta, which is probably the characteristic feature of an organically enriched aquatic ecosystem.

The subfamily Chironominae was found to contain two-thirds of all chironomid species, which may be due to the ability of these species to withstand low oxygen content in the benthic environment (Oliver, 1971). Pinder (1986) noted that tolerance of poorly oxygenated conditions in the Chironominae is related to the possession of haemoglobin. Curry (1954) reported that some of the species of Chironominae can withstand prolonged periods of anaerobic conditions in nature. Moore (1979) reported that chironomid populations in part of the Great Slave Lake were found to be negatively correlated with oxygen concentration, which was probably indicative of a positive correlation with the organic content of the sediment.

The chironomid abundance was found to be positively related with nitrite and negatively with total alkalinity and nitrate. The interpretation of these correlations was not possible, because, these may be chance relations rather than indicating any causal relationships.

There was qualitative and quantitative variation of the chironomid species in different ponds, with the highest population density in pond 14 and the lowest in pond 9. Three species of Chironomidae were absent from pond 14 and 5 species from pond 9. The higher abundance in the more productive pond 14 may be due to better feeding conditions. In pond 9, on the other hand, due to the control of flow, no immigration was possible from other ponds or the stream which may isolate the 5 species from settling in pond 9. In this case, imago may lay eggs on the surface of the pond water and larvae may develop, but the nutritional status of the pond may also be a deciding factor for the settling of particular species. The absence of nutrient-rich sediment in pond 9 may limit the number of species in this pond.

Seasonal changes in the population abundance of Chironomidae have been investigated by many workers (e.g. Mundie, 1957; Morgan & Waddell, 1961; Sandber, 1969; Titmus, 1979; Brown & Oldham, 1984). A distinct seasonal variation in total Chironomidae was observed in this study, with peaks in March-April and August-October, although different species appeared and emerged at different times of the year. The lowest densities tended to occur during the late spring to throughout summer. These spring and autumn peaks may be concomittant with diatom maxima during these periods (Jónasson, 1977). The lower chironomid abundance in summer was due, at least in part, to emergence and also possibly to the sedimentation of unpalatable summer phytoplankton (Jonsson, 1985), including blue-green algae which are reported to be a poor nutrient for chironomids compared to diatoms.

The emergence of midges appears to be determined by a variety of factors, of which temperature is a principal one. Pinder (1986) suggested that temperature is one of the major factors controlling rates of growth and development of aquatic insects; in addition to the direct effect on metabolism, temperature is also likely to have an indirect effect through its influence on food quality and quantity (Sweeney & Vanote, 1978). Many authors believe that the emergence of Chironomidae in temperate regions may be controlled primarily by temperature, light or a combination of both (e.g. Palmer, 1955; Wartinbee, 1979).

The Chironomus species group was the major component of the chironomid community, which comprised C. plumosus, C. anthracinus and C. venustus. Very little is known about the ecology of C. venustus, and as no marked difference in ecology could be established between these species, all of them were considered as one species group. Both C. plumosus and C. anthracinus, which are intimately associated with the sediment in the construction of sediment tubes as well as feeding strategies, have been shown to be dependent on sediment composition (Walshe, 1951; McLachlan & Cantrell, 1976; Hodkinson & Williams, 1980). Larvae of Chironomus graze on detritus or are filter-feeders (Pinder & Reiss, 1983).

A most obvious positive correlation of Chironomus spp. population density with soil organic matter content was recorded in this study, which reflected the importance of sedimentary organic matter and detritus in the food of Chironomus spp. Mandal and Moitra (1975b) observed that high organic matter content of pond soil facilitated the growth of Chironomus larvae in tropical fish ponds in India. Lindegaard & Jónasson (1983) noted that C. plumosus often benefit for a short time when the original terrestrial organic matter decomposed.

The population density of Chironomus spp. was higher in pond 14 and lower in pond 9, which may be due to the better feeding and tube building facilities in the former than the latter. Nevertheless, chironomid larvae show specific differences in their resistance to low oxygen concentration (Oliver, 1971) as well as pollution level. The Chironomus spp. recorded from Howietoun ponds could be classified as mesotrophic-eutrophic on the basis of Saether (1979).

Two emergence periods were recorded at Howietoun with a peak population density during August-October which may be due to the increased productivity during this period. Longer emergence periods for all three species were recorded in spring. Similar bivoltine C. plumosus was recorded by Mundie (1957) in Kempton Park reservoirs and Potter and Learner (1974) at Eglwys Nunydd reservoirs. Borutski (1939) observed two generations a year in shallow water and one in deep water. Jonasson (1972), in a detailed study on the dominant profundal species of C. anthracinus in Lake Esrom, concluded that it has a two year life cycle in deep water (17 and 21 m) and an annual one at shallower depths (11 and 14 m). Carter (1976) found an annual life cycle in Lough Neagh and explained that it was due to the higher mean bottom temperature and to the absence of a summer stagnation period. She also suggested that generation time is obviously flexible, being determined by conditions in each lake.

The genus Micropsectra was available in the fish ponds as two species

M. lindrothi and M. atrofasciata. Pinder and Reiss (1983) described their wide range of habitats from thermal springs to temporary ponds. The larvae build long cylindrical sand-tubes. Larval Micropsectra, together with other animals, characterise a biotope known by the name of 'the Micropsectra-Community' (Lindegaard-Petersen, 1972). Two peaks of abundance, one in April and another in November, were recorded during this study. In the Danish low-land stream, Linding A, the larvae showed maximum abundance in March-April and June-July. Two flight periods, from June to September and December onwards were assumed from the absence of larvae in the pond bottom. Lindegaard-Petersen (1972) observed that the period of pupation was from March to October, with a maximum in April and September, which is in accord with the present findings.

Tanytarsus spp. represented by T. lestagei and T. pallidicornis appeared in the samples from July and maintained a higher population until September and then disappeared from the population. Some larvae were found in pond 14 in March which might indicate the presence of a spring generation, but it is not well established. Mundie (1957) reported T. lestagei to be bivoltine with the main emergence occurring in August and September. Most Tanytarsus spp. showed two generations in Lake Esrom (Jonsson, 1985). Potter and Learner (1974) observed the main emergence periods of Tanytarsus spp. to be from May to October in Eglwys Nunydd reservoir.

The larvae of Polypedilum sp. occurring in the fish ponds seemed to be only one species, but identification was not possible due to the non-availability of imago exuviae. Larvae occur in all kinds of still and flowing waters, with the exception of the arctic and high mountains, and prefer sediments as substratum (Pinder & Reiss, 1983). This species developed two generations, in early spring and in summer. The declining periods were possibly due to emergence, from April-May and August onwards. This agrees with Pinder (1983) who observed two generations for P. cultellalum in Tadnoll Brook. Mundie (1957) reported that May, July and September are the main periods of emergence of P. nubeculosum. At Rutland Water, larval population declined in February, May and August (Brown & Oldham, 1984). Similar to the present study, Jonsson (1985) observed 2 generations per year with emergence in early June and in late August.

Glyptotendipes pallens is generally found in mines among macrophytes (Walshe, 1951; Opalinski, 1971) where it filter feeds (Kalungina, 1963), but it is not an obligate mining form. It was available in the fish ponds in both years, first appearing in April/May and it continued until August. The first emergence started from June-July and by mid-September the population had declined to zero. A second generation appeared during October-December. Therefore, there were two generations per year, although not very distinct. Mackey (1976a) recorded that G. pallens inhabited long flimsy tubes covered with large amounts of detritus in the Acorus zone, in the River Thames. Similar to present results, Mackey (1976a) also reported two generations per year with a maximum abundance from May to early July. *G. paripes*, a closely related species widely recorded from British waters, was found to have two generations per year in Kempton Park reservoir (Mundie, 1957) and in Eglwys Nunydd reservoir (Potter & Learner, 1974). In contrast, Charles *et al* (1974), however, considered *G. paripes* to be essentially univoltine in Loch Leven, Kinross.

Starting from May, larvae of *Cladopelma* continued to occur in the bottom samples until October and then disappeared. A partial decline in abundance was observed in the middle of this period, probably due to partial emergence. No trace of an overwintering population was found. If this interpretation is satisfactory, then there might be two short generations in summer. Very little is known about the ecology of this species. Pinder & Reis (1983) noted that larval *Cladopelma* occur in sandy and muddy substrata in lochs and rivers.

The larvae of *Paratendipes* sp. occur in lakes, ponds, small waterbodies, and in flowing streams and rivers (Pinder & Reiss, 1983b), where they build long tubes of sand and detritus (Lenz, 1954). It appeared to have only one summer generation in the Howietoun fish ponds. It only maintained a small population during 2-3 months appearing in June and then disappearing. A similar life history pattern with a higher population abundance was found from May-August in Danish lowland stream Linding A (Lindegaard-Petersen, 1972). Life cycles parallel to the present study were also reported by Lehmann

(1971) and Ward and Cummins (1978). Pinder (1983) reported a similar life history pattern for P. albimanus in Tadnoll Brook.

Larvae of Microtendipes inhabit both standing and running waters on the bottom or in the vegetation (Lindegaard-Petersen, 1972). They build short and rather loose sand tubes; before pupation, the front part is enlarged and both openings are provided with perforated lids (Lenz, 1954).

M. chloris with two generations a year, from April-June and October-November/December with the disappearance of larvae between these generations, were observed in this study. Larvae were found to overwinter as 2nd instar in pond 11. Similar bivoltinism in M. chloris was reported by Potter and Learner (1974) and Brown and Oldham (1984). In contrast, both Macan (1949) and Mundie (1957) recorded M. chloris as a spring species and M. pedelles as a summer species but none of them investigated the larval populations. In a recent study, Jonsson (1985) reported 2 generations per year in Lake Esrom, although he was doubtful about the separation of M. chloris and M. pedelles.

Procladius choreus was the only member of the Tanypodinae to occur in large numbers, being the second most dominant species of Chironomidae in all the fish ponds. Procladius sp. larvae are known to be free living and facultative predators (Kajak & Dusoge, 1970) but in adverse conditions utilize other food items, mainly detritus (Brennan

& McLachlan, 1979). Larval Procladius prefer muddy substrata of standing as well as slowly flowing waterbodies, especially ponds and small lakes (Pinder & Reiss, 1983).

There appeared to be two generations per year, from July-October and December-April. The overwinteing population clearly emerges during April to June. This observation is in agreement with Pinder (1983) regarding the existence and timing of the overwintering generation but contrasts with his finding of 3 generations per year in Tadnoll Brook. This study has similarity with the periods recorded by Mundie (1957) and Potter and Learner (1974), who both considered P. choreus to be bivoltine. Ford (1957) reported two generations a year including one overwintering generation in a chalk stream.

Ablabesmyia monilis was another species of Tanypodinae which occurred in relatively large numbers in all the ponds. Scanty information is available about the ecology of this species except that they are euryoxibiontic and tend to avoid springs and upper part of the streams (Fittkau, 1962). It has two periods of maximum abundance in Howietoun ponds, one in early spring and the other in summer. The periods of emergence were May-June and August onwards. Mackey (1976a) recorded three generations in one station and two generations in another in the Acorus zone in the River Thames.

A relatively smaller number of larvae of Guttipelopia were recorded inconsistently from the fish ponds. It was not possible to reach any conclusion on these data. Larvae of Guttipelopia primarily live in shallower bodies of standing water. Information on its ecology is very scanty.

The subfamily Prodiamesinae was represented by only one species, Prodiamesa olivacea in the fish ponds at Howietoun. Larvae of this species occur in springs, streams, rivers, ponds and the littoral zones of lakes (Pinder & Reiss, 1983). They feed on detritus (Thienemann, 1954), and do not make a tube of any kind and live burrowing freely. They make loosely spun tubes prior to pupation (Kraatz, 1911). The generations of the larvae in this study are not clearly separable but from the periods of abundance and emergence it could be deduced that there were two generations, with an over-wintering population which emerges in late spring to early summer. This life cycle was very similar to that recorded by Pinder (1983) from Tadnoll Brook. Ford (1957) also reported a similar timing for the overwintering population.

5.2.3. Mollusca

Boycott (1936), in a detailed study, observed some of the factors influencing the distribution of freshwater molluscs in Britain, and a number of physical and chemical factors appeared to dominate the ecology of molluscs in standing waters. Hardness, pH, altitude, size of the waterbody, temperature, vegetation and pollution were significant aspects. In a more localized survey in the English

Lake District, Macan (1950) reached similar conclusions.

Mollusc populations at Howietoun are represented by only two species, which may be due to the influence of inherent qualities of soil and water of the farm. The intensification of fish farming and loading of organic materials may also prevent the establishment of species which are found in other Scottish waterbodies.

The abundance of total mollusca at Howietoun was found to be correlated with temperature, particulate organic matter, dissolved organic nitrogen and un-ionised ammonia, and negatively correlated with total hardness, calcium, total alkalinity, dissolved oxygen and nitrate. Not all of these factors necessarily have a biological effect on molluscs, as some of these may have just been chance correlations. The importance of temperature for molluscs is described by Boycott (1936); molluscs are generally active, grow well and breed only in the summer and, within temperate climates, the hotter the better. There are numerous evidences regarding the effects of calcium concentration on the biology of molluscan species (Thomas et al., 1974; Thomas & Lough, 1974; Young, 1975b). Dussart (1979) suggested that cations usually associated with calcium hardness are the major factors rather than calcium itself. Boycott (1936) noted that a calcium concentration of about 20 mg l^{-1} is a critical limit below which a number of species, which may be referred to as 'calciphiles', seldom or never occur. Others can tolerate lower concentrations, but they may be found also where the calcium exceeds this value. The negative correlation with calcium, total hardness and total alkalinity may be due to the utilization of calcium for the shell formation by the recruited population during the growing season.

The population density of Mollusca was higher in pond 13 and lower in pond 9. This may be due to the population of other benthos in those two ponds, thus providing better feeding conditions for Mollusca and may be due to the rooted vegetation around the edge of pond 13. Similar observations of the importance of a fair but not excessive growth of rooted plants are made by Boycott (1936).

Sphaerium corneum is one of the two species that inhabit Howietoun ponds. It inhabits most kinds of freshwater and is the commonest and most widely spread mollusc throughout Britain (Ellis, 1978). It is a useful indicator of good molluscan conditions; it can live in brackish water and occasionally in mountain lakes (e.g. Kinardochy, Perth, 1200 ft.), so that it has a wide range of distribution. It dominated in all the ponds except pond 14, which may be due to the relatively turbid water in pond 14. The lower number recorded from pond 9 may be due to the absence of any slow flow of water which is favoured by this bivalve (Boycott, 1936) and the lack of food may also be another reason. The food of bivalves consists of minute organisms, chiefly microscopic algae, and particles of organic matter and detritus suspended in the water.

Two periods of maximum abundance, in spring and autumn, may be due to the recruitment of young individuals during these periods. Although there were two periods of recruitment for this species at Howietoun, it was not possible to establish with certainty whether there were one or two generations. Avolizi (1976) discussed that the viviparous nature of sphaeriids, which results in relatively large sized young, probably allow the reproductive period to begin early and last into harsh weather conditions. He observed recruitment to continue for eight months of the year.

Lymnaea peregra is the commonest and most abundant species of gastropod, recorded from every vice-county in the British Isles (Macan, 1977a). Although a high calcium concentration is important for most molluscan species, L. peregra can survive in very small concentrations. Macan (1950) recorded L. peregra from the tarns having concentrations of calcium below 3 mg l^{-1} in the English Lake District. Boycott (1936) quoted a record of L. peregra in less than 1 mg l^{-1} calcium, but did not mention the locality. The calcium concentration at Howietoun varies from 6.0 to 10.6 mg l^{-1}, which may be considered a suitable range of calcium concentration for this species.

The population density of L. peregra was higher in pond 14 than the other ponds. This indicates the tolerance and/or preference of this species for organically enriched water. Ökland (1969) holds similar views. Boycott (1936) described that they fed on decayed remains of water plants and especially on algae which they scrape off the leaves of the plants, the mud, stones and other surfaces.

L. peregra has different life cycles in hard and medium waters compared to soft water. In soft water ponds at Howietoun, L. peregra was found to have one breeding season extending from June-August. A similar annual cycle in soft waters was also reported by Dussart (1979). The overwintering population comprises small snails, and there is little overlap between generations, confirming the simple annual life cycle observed by Hunter (1961) in the soft waters of Scotland. In contrast, there is a considerable overlap of generations in hard and medium waters (Dussart, 1979).

5.2.4 Hirudinea

The leech population at Howietoun comprised principally two species, Helodella stagnalis and Erpobdella octoculata, which were recorded from all the ponds throughout the year. Two periods of maximum abundance were from March - early June and August-September, which may be associated with the recruitment of young individuals into the population.

The leech population did not show any significant correlation with any of the physico-chemical variables in this study, which may indicate their wide range of ecological tolerance. Similar observations were made by Maitland (1979) for H. stagnalis in Loch Leven.

H. stagnalis, the dominant of the two leech species at Howietoun, is a widely distributed species in freshwater and the numerically dominant leech in eutrophic waters (Mann, 1955). It is most numerous in hard waters, next to which the size of the waterbody appears to be the most important factor in their ecology. Mann (1955) observed that, in waters of similar hardness, it will prefer the larger waterbody. The significantly higher numbers in ponds 11 and 14 may be due to the larger area of the ponds. Along with other factors, food may contribute to its distribution in the waterbodies. *H. stagnalis* is a sucking leech which is found to feed on chironomid larvae (Hilsenhoff, 1963; Moore, 1966), small annellids (Moore, 1912) and *Asellus aquaticus* (Bennike, 1943; Wilkialis, 1970). The greater numbers of these food organisms in ponds 11 and 14, may have led to greater numbers of this leech in these ponds.

The population density of *H. stagnalis* at Howietoun was maximum in spring and autumn, which may be linked with their breeding season. Two breeding periods, one during March-May and another from August-November were observed in this study. A similar life history was recorded from Eglwys Nunydd reservoir in South Wales by Potter & Learner (1974). Davies and Reynoldson (1976) found a population in Newsome pond, Canada with a short breeding season in spring, after which overwintering adults died. Mann (1957a) also found that overwintering adults in Whiteknights Lake, England, produced a brood and died. Young and Ironmonger (1982) studied the life cycle of H. stagnalis in a hard water, productive lake and an upland soft water, unproductive lake in Britain and found that H. stagnalis in both lakes had two distinct breeding periods, one in spring and one in summer.

Most authors recognized that temperature is the main factor controlling breeding in leeches (Mann, 1957a&b, 1962; Tillman & Barnes, 1972) and that the rising temperature in the spring is the stimulus for reproductive activities is well accepted. The decreasing temperature in autumn may also initiate copulatory behaviour, which needs to be determined.

E. octoculata is one of the most common freshwater leeches and often predominates in soft water (Mann, 1955). As already mentioned in the results, this second species at Howietoun gradually increases from pond 7 to pond 14, with its lowest density in the control pond 9. Thus, the organically enriched cultured ponds are probably preferred by E. octoculata (Mann, 1955; 1964).

Between the two stream stations, E. octoculata was found to be similarly abundant, while H. stagnalis was rarely found in stream station 2. Mann (1955) noted that in running water which is sufficiently fast to scour the bottom, leaving a stony bed, E. octoculata is particularly abundant. A firm substrate may be helpful for movement and cocoon deposition (Mann, 1955).

A number of factors were found to determine the distribution of this leech, which are in order of importance: food, water depth, type of habitat, hardness, pH, temperature, oxygen, siltation, turbidity and salinity (Sawyer, 1974). E. octoculata is carnivorous, devouring its prey whole, having a varied diet but preying mostly on chironomid larvae followed by oligochaetes (Young & Ironmonger, 1979). Other prey items taken were leeches, Asellus, Gammarus, tipulid larvae, Ephemeropteran nymphs, Plecoptera and Odonata.

With respect to water chemistry no obvious correlation could be established in the present study. Although, Mann (1955) reported that E. octoculata is the most numerous leech in soft water and recorded from a wide range of pH from 5.3 (Tucker, 1958) to 9.4 (Mann, 1955) in English waterbodies.

Temperature has been cited as an important factor in the biology of this leech, especially in determining the onset of breeding (Mann, 1957a; Cristea, 1970).

The seasonal variation in the population density showed that the maximum abundance was reached twice one in spring and another in autumn, which coincided with the recruitment of young individuals. The low population density in summer may be due to the high mortality during the first few months of life and during the breeding season (Maltby & Calow, 1986). E. octoculata appears to have a versatile life cycle, with the most extended one being recorded by Thomson

(1977) for populations in the River Hull and in gravel pits, Humberside, England. A one-year life cycle was observed in Howietoun fish ponds. Similar annual life cycles have been recorded in many other organically polluted habitats by workers including Aston and Brown (1975); Dall (1979), Murphy and Learner (1982); Young and Ironmonger (1982). A two-year life cycle of this species is recorded by many authors, particularly in unpolluted waterbodies. Mann (1953) found that the majority of leeches in Foundary Brook, Berkshire lived for two years, breeding each year before death. Elliott (1973) recorded that all individuals bred in their second year of life before dying in Wilfin Brook, Cumbria. Aston and Brown (1975) gave a more conclusive idea about breeding of E. octoculata. They found a two-year life cycle at a relatively unpolluted site in River Trent whereas at four polluted sites it was found to be one year.

5.2.5 Asellus aquaticus

Although 4 species of Asellus are listed as occurring in the British Isles by Maitland (1977), only Asellus aquaticus is available at Howietoun. Some other authors also recorded this species from different Scottish waterbodies (Weerekoon, 1956; Warwick, 1959; Smith et al., 1981). Warwick (1959) noted that both of the common species A. aquaticus and A. meridianus were found in Scotland, but so far they have not been recorded together in any of the Scottish waterbodies. It occurs in localities ranging from small ponds with a substratum of thick mud to large lakes with substratum of stones and boulders (Dunn, 1952; Weerekoon, 1956; Moon, 1957; and Tucker, 1958).

Asellus was found to be correlated with chemical characters of waters such as with calcium, total ions and total dissolved matter. In a study covering 65 localities, Reynoldson (1961) found that in the localities containing 0.63 meq.l^{-1} of calcium and 110 mg l^{-1} of total dissolved matter, Asellus was present and that in localities containing less than 0.25 meq.l^{-1} of calcium and 70 mg l^{-1} of total dissolved matter, Asellus was usually absent. On this basis, Howietoun ponds were a suitable habitat for Asellus in terms of calcium content.

Holdrich and Tolba (1981) suggested that A. aquaticus is particularly prevalent in areas with a fairly high level of organic matter. Similar observations were also made by Hawkes and Davies (1971) and Aston and Milner (1980). Detritus, silt, fine debris and bacteria covering stones and leaves are principal food items for A. aquaticus (Moon, 1957; Marcus & Willoughby, 1978; Rossi & Fano, 1979).

Asellus aquaticus was more abundant in ponds 11 and 13, but no obvious explanation could account for this. No distinct seasonal trend was observed in this study.

Two periods of breeding of A. aquaticus were observed at Howietoun ponds. This observation agrees with previous findings (Steel, 1961; Anderson, 1969; Prus, 1977). Two periods of peak recruitment of juveniles were observed, from May-June and September, which was a delay of one month for the spring brood from that of the River Thames population (Steel, 1961). A substantial difference was observed with the populations of Asellus aquaticus in the Brasside pond in Durham (Fitzpatrick, 1968), where there was a restricted period of reproduction (February-April). Water quality and temperature may have an effect on the developmental rate and survival of A. aquaticus eggs and embryos (Holdrich & Tolba, 1981).

5.2.6 Sialis lutaria

Of the two British species of alderfly, Sialis lutaria (L.) and S. fulginosa Pictet, only S. lutaria was available at Howietoun fish ponds. Elliott (1977b) described that the larvae of this species live in ponds, lakes and sluggish parts of streams and rivers where there is an abundance of silt. Berg and Petersen (1956), Matthey (1971) and McLachlan and McLachlan (1975) observed that it was numerous in the benthos of humic acid lakes and ponds.

The population density of S. lutaria at Howietoun was higher in the cultured ponds than the control pond. This might be due to a higher prey availability for this predatory species in the cultured ponds. Larval Sialis actively feed mainly on chironomid larvae and Oligochaeta (Giani & Laville, 1973; Griffiths, 1973), which were more abundant in the cultured ponds.

A summer increase in the population density, comprising 40% of early larval instars, and the significant positive relationship with temperature in this study indicate that breeding is temperature dependent and the increase in number was because of the recruitment of new born individuals. The flight period of S. lutaria is reported to be from late April to July (Elliott, 1977b). In Howietoun ponds, detailed life history information was not available, but an indication of summer breeding is evident.

5.2.7 Biomass and Production

Similarly to the high population density of benthos in the cultured trout ponds, biomass of the benthos was also high, almost 2-4 times higher than the control pond. The benthic biomass also showed biomodal peaks in spring and in autumn to early winter. Similar spring and autumn maxima have been recorded in many other waterbodies (Wojcik-Migala, 1965; Kajak & Dusoge, 1973, 1975). This decrease in biomass in summer is probably due to trophic conditions (Kajak & Dusoge, 1975). In this study, draining of the ponds at the end of spring may be responsible for low summer biomass, because the standing stock of benthos produced during the spring is partly removed by washing out the pond bottom during the draining phase. The population of benthos can only start to build up again during summer.

In spite of a higher population density in pond 14, biomass was higher in ponds 7 and 11. This might be a negative effect of pollution on biomass which, while stimulating an increase in numbers, inhibited the growth of individuals and thereby reduced their individual mean weight. This is further confirmed by comparing the biomass of the Oligochaeta from different ponds. The result reveals an important finding that the biomass of Oligochaetae decreases from pond 7 to pond 14; this implies that the mean individual weight decreases with an increase in organic pollution.

The total production of benthic macro-invertebrates ranged from 130-215 g dry wt. $m.^{-2}$ yr^{-1} in the cultured ponds and 55 g dry wt. $m.^{-2}$ yr^{-1} in the control pond. Comparison of annual benthic production in Howietoun fish ponds with those of other temperate waterbodies (Table 35) shows that it was much higher in earthen trout ponds subjected to intensive aquaculture than other waterbodies. This might be due to the higher input of wasted feed and excretory material into the ponds, enhancing primary production as well as the general feeding conditions for the detritivores. Fish feeds and faeces may also directly contribute food to the detritivorous oligochaetes. This hypothesis may be justified by the high benthic production in the cultured ponds of which 64-74 % is due to Oligochaeta. Annual production in the unstocked control pond, however, is similar to that in the shallow eutrophic Loch Leven.

Annual variation in the production of total benthos was observed in this study. Similar annual variations have been observed by, among others, Lindegaard and Jonasson (1979). According to them, the annual production in Lake Esrom varied from 36-14 g $m.^{-2}$ yr^{-1}

Table 35 Comparison of annual production (g dry wt. m^{-2} yr^{-1}) of total macro-benthos in different types of limnetic habitat within the temperate zone

Name of the waterbody	Productivity	Source
Livingstone Reservoir, U.S.A.	6.8	McCullough & Jackson (1985)
Wyland Lake, U.S.A.	8.4	Gerking (1962)
Texas Pond, U.S.A.	10.3	Benson _et_ _al_ (1980)
Marian Lake, B.C.	15.2	Hall & Hyatt (1974)
Lake Esrom, Denmark	20.0	Jonasson (1972)
Lake Mikolajskie, Poland	28.3	Kajak & Ryback (1966)
Lake Myvatn, Iceland	28.4 (AFDW)	Lindegaard & Jonasson (1979)
Eglwys Nunydd Reservoir , U.K.	37.0	Potter & Learner (1974)
Lake Taltowisko, Poland	ca. 40.0	Kajak _et_ _al_ (1972)
Loch Leven (Scotland) U.K.	46.5	Maitland & Hudspith (1974)
Howietoun Fish Ponds	130.4 - 214.5	This study
Unstocked Control Pond	54.9	This study

during 1972-1974.

The seasonal changes in the Oligochaetae biomass showed that there were spring and autumn maxima as with total benthos. The reasons have already been mentioned in earlier paragraphs. From the comparison of the biomass and production values of the different waterbodies in temperate regions as shown in Table 36, the dry biomass of Oligochaetae recorded in this study was much higher. Oligochaetae not only dominated in terms of population density but also in terms of biomass and productivity at Howietoun fish ponds. Although the abundance of worms was higher in pond 14, the last pond in the series, the biomass and production was higher in ponds 7 and 11 having an intermediate level of pollution. It has been suggested that the individual mean biomass of the oligochaete species might have decreased with the increase in pollution.

Production data of oligochaetes are very scanty and obtained with different assumptions and methods. From Table 36 the production values of oligochaetes was very high at Howietoun fish ponds. The other published production values for total Oligochaeta are similar to those recorded from the control pond in this study. However, Poddubnaya (1980) found Tubifex, the most productive among tubificids species. Her production values range from 35 g to 2 kg m.$^{-2}$ yr^{-1} (assumed to be wet wt.). The results of the present study were found to be within this range.

Table 36 Comparison of Oligochaeta biomass (g dw. m^{-2}) and production (g dw. m^{-2} yr^{-1}) from different types of waterbodies in the temperate zone.

Name of the waterbody	Biomass	Production	Source
Eglwys Nunydd Reseroir, U.K.	0.26 - 0.58	1.7 - 5.8	Potter & Learner (1974)
Lake Ontario, Canada	-	0.66 - 18.3	Johnson & Brinkhurst (1971)
Lake Balaton, Central Europe	1.7 - 3.7	-	Pony _et_ _al_ (1983)
Chalk stream, U.K.	1.0 - 25.8	10.8 - 79.8	Bird (1982)
Bohemian Carp Pond, Czech.	2.5 - 29.7	-	Ali & Lellak (1985)
U.S.S.R. Sleepe Ponds	84.8[a]	-	Grigelis (1980)
The River Thames, U.K.	86.8[a]	-	Birtwell & Arthur (1980)
Howietoun Fish Ponds	13.6 - 48.5	93.7 - 159.6	This study
Unstocked Control Pond	11.6	45.0	This study

[a] Calculated from wet weight biomass assuming dry matter content of 10%

The total Chironomidae also showed two periods of maximum biomass, which were again in spring and autumn. Among other factors, food availability and emergence may be the most important factors in determining the seasonal variation in the biomass. Low summer biomass may be due to the emergence and availability of nutrient poor food (Jonsson, 1985). Blue-green algae, mainly Oscillatoria agardhii, tend to dominate Howietoun phytoplankton during the summer (Dey, 1984) and are reported to be nutritionally poor for Chironomidae (Johannsson, 1980). Both the biomass and production of Chironomidae were higher in pond 14. This was due to the higher abundance of the dominant species group Chironomus which are large-sized species often favoured by pollution due to their high tolerance and ability to withstand low oxygen concentrations for short periods (Jonsson, 1985). Although information on production from similar intensive culture systems is not available, a comparison of chironomid production from different waterbodies from temperate regions is presented in Table 37. The production of Chironomidae in this study is within the production values recorded from the Scottish Loch Leven. This study, therefore, indicates that, while the production of Oligochaetae is very high, the chironomid production is very much within the range of other waterbodies, although it was much lower than the production recorded in a sewage treatment lagoon, Oregon, as reported by Kimerle and Anderson (1974). An annual variation in chironomid production, as was observed in this study, is not uncommon in production studies. Maitland and Hudspith (1974) while estimating the production of the two dominant larval Chironomidae (Glyptotendipes

Table 37 Comparison of chironomid production (g dry wt. m^{-2} yr^{-1}) from different types of water-bodies in the temperate zone

Name of the waterbody	Productivity	Source
Shallow Lakes, Norfolk, U.K.	ca. 1.1 - 9.2	Mason (1977)
Texas pond, U.S.A.	8.4	Benson et al (1980)
Lake Kasumigaura, Japan	13.0	Iwakuma et al (1984)
Lake Esrom, Denmark	16.0	Jonasson (1972)
Loch Leven (sandy littoral area) Scotland, U.K.	15.0 - 42.0	Maitland & Hudspith (1974)
Loch Leven (mud area) Sotland, U.K.	34.0	Charles et al (1974)
Eglwys Nunydd Reservoir, U.K.	21.0	Potter & Learner (1974)
Lake Beloye, U.S.S.R.	34.70 (wet wt.)	Borutski et al (1971)
Sewage treatment Lagoon, Oregon, U.S.A.	90.0	Kimerle & Anderson (1971)
Howietoun Fish Ponds	20.6 - 33.5	This study
Unstocked Control Pond	8.0	This study

and <u>Stictochironomus</u>) in the sandy littoral area of Loch Leven, gave annual estimates of 40.5 and 1.2 g (dry wt.) m^{-2}, respectively for 1970 and 5.0 and 10.2 g m^{-2} for 1971.

Molluscan biomass was determined as ash free dry weight in order to avoid the bulk of shells. The higher biomass observed in pond 13 may be due to less predation and competition for food and the greater presence of littoral vegetation which is considered to provide a better habitat for mollusca. Boycott (1936) suggested that the aquatic vegetation provided the humus which helps so much to make the bottom of the pond watertight and the locus permanent and offers a safe refuge for the Mollusca during the drying period.

Unlike the biomass, the production of Mollusca was higher in pond 7 and lower in 13 among the cultured ponds, which may be due to the better growth in mildly polluted pond 7.

Two species of Hirudinea provided biomodal peaks of biomass which may be associated with their breeding cycle. Leeches become bigger in size before breeding in spring and autumn, therefore, these may cause the higher biomass during these periods. A leech biomass at Howietoun of 0.86-2.52 g m^{-2} was much higher than that recorded by Mann (1971) in the River Thames, which was 0.58 g wet wt.m^{-2} and just lower than the biomass of the control pond. Elliot (1973), on the contrary, reported a much higher biomass 7.82-20.96 g wet wt. m^{-2} in Wilfin Beck for only one species, <u>E. octoculata</u>. A similar biomass to the present study was recorded by Dall (1979) from Lake Esrom.

Although there was annual variation, the mean annual production of leeches was higher in ponds 11 and 14 than other ponds. The hiding nature of leeches may have saved them from intense fish predation and the large production of prey organisms in these ponds may be the reasons for higher production in ponds 11 and 14. The production of leeches at Howietoun was much higher than that of Eglwys Numydd reservoir (Learner & Potter, 1974) but is almost half and one quarter, respectively, of the production values given by Dall (1979) from Lake Esrom (17.97 g m^{-2} yr^{-1}) and Murphy and Learner (1982) from the River Ely, U.K. (29.4 g m^{-2} yr^{-1}).

Asellid biomass was very low in comparison with other waterbodies. Adcock (1979) reported 7.6 g m^{-2} from Wistow Lake, Liecester, which was 7 times higher than the biomass found in the present study. Similar higher biomasses were recorded from Lake Pajep Mastejaure (8.52 g m^{-2}) and Lake Erken (15.59 g m^{-2}) by Anderson (1969). The only similar low biomass (0.3-1.7 g m^{-2}) was recorded from Powsinski Lake, Poland by Prus (1977).

The annual production of Asellidae in this study was very similar to that of Adcock (1979) from Wistow Lake. But the production values reported by Anderson (1969) was many times higher than the present study. The higher production in pond 9 may be due to a longer drying period which allows creeping vegetation and grasses to grow on the pond bottom which might enhance asellid production. Anderson (1969) reported that A. aquaticus prefers a vegetation rich bottom.

S. lutaria was found to have a similar biomass in all the ponds except pond 9. The biomass was higher during the growing season. Better feeding conditions of this predatory nymph in the culture ponds may be responsible for higher biomass in cultured ponds over the control. The presence of full grown nymphs before pupation during the growing season may have increased biomass.

An annual production of 7.0-9.0 g $m.^{-2}yr^{-1}$ in the cultured ponds may be low for eutrophic ponds. This low production in intensive fish ponds may be due to the higher predation pressure by the densely stocked fish. The large size and active movement on the pond bottom make S. lutaria more vulnerable to predation.

In spite of the enormous information provided by the biomass and production estimation, some sources of errors in the use of the method itself should not be overlooked. Calculation of production on the basis of mean individual weight increment and total number of organisms per m^2, which was employed in this study, may result in the loss of biological information. The most obvious one is the turnover ratio of each species which would have been a better indication for establishing generation time(s). The contribution of individual species to the production of the group is also obscured in this method of production analysis. However, considering the large number of species, limitation of time and labour and purpose of the overall study, the information gained from this method of production estimation is useful.

5.3 Contribution of Benthos in the Diet of Farmed Trout

Fish nutritionists often have entertained the idea that, if a reliable estimate could be made of the nutritional contribution of pond organisms to the fish, a more economical supplemental feed could be used by taking this source of nutrient into account (Lovell, 1977). It must be noted that the amount of food a fish receives from natural pond organisms depend upon the productivity of the pond and, more importantly, the feeding habits of fish. The high production capacity of Howietoun fish ponds under intensive fish culture operations has been discussed already. The proportion of this benthos which is actually utilized by the farmed brown trout, whose feed in natural waterbodies consists mainly of benthic fauna, is of major interest to aquaculturists.

A generalization that emerges from considering the previous works is that the extent to which trout feed on any particular food organism depends mainly on its accessibility and representation in the fauna. These factors alone account for the composition of the diet without involving discrimination by the fish (Frost, 1950; Allen, 1951; Frost & Smyly, 1952; Nillsen, 1955; Ball, 1961; Thomas, 1964).

Stomach content analyses demonstrated that brown trout in the earthen fish ponds fed on natural food organisms, although a pelleted diet routinely supplied to the ponds accounted for most of the food intake. All the major groups of benthic organisms were found to be taken by fish. This is in agreement with Allen (1938), who noted that the nature of food of brown trout is controlled firstly by what is available and secondly, by the behaviour of the fish.

Chironomid larvae and pupae comprised the first and second most dominant components in the diet, respectively. Mollusca was next in importance. Asellus and Sialis were not consistently recorded from the stomach but formed an important component whenever present. Although oligochaetes were the most dominant group in the benthic community, they contributed relatively little to the fish diet. The predominance of some less abundant species, notably Mollusca, in the trout stomachs and the comparative rarity of other species which are abundant in the bottom fauna may indicate that their size, habits and/or mobility are more important than their numerical representation in the fauna. Hunt and Jones (1972b) hold similar views. In contrast, Ball (1961) stated that the relative extent to which different animals are eaten depends mainly upon their numerical representation, although he considers size, habits and mobility are probably also important.

The importance of chironomid larvae in the trout diet has been emphasized by many authors (e.g. Ball, 1961; Hunt & Jones, 1972b;

Johnsen, 1978; Pedley & Jones, 1978; Brown et al., 1980). Heavy feeding on chironomid pupae during emergence was recorded by Brown et al (1980) among others. In spite of their frequent dominance in the bottom fauna, usually only isolated records exist of Oligochaeta in the stomach contents of brown trout (Aarefjord et al., 1973); if recorded at all they are often assumed to be of terrestrial origin (Berg, 1951; Elliott,1967). Some authors believe that oligochaetes are not available to trout because of their hidden life in the bottom sediments (Frost, 1945; Nilsson, 1955; Grimas, 1963). Poddubnaya (1962) was able to demonstrate that the tubificids are important in the diet of bream in Rybinskoe basin. The importance of Oligochaetae may be underestimated in this study. Kennedy (1969) stated that the digestion of tubificids is very rapid and the remains pass quickly through the intestine and only the cuticular fragments remain undigested and can be recognized as such for as long as they remain in the fish.

The importance of Mollusca in the trout diet was reported by Hunt and Jones (1972b) from the Llyn Tegid.

Both Sialis and Asellus were important in the trout diet probably because of their large size and mobility. In Loch Leven, Thorpe (1974) found that the adult trout diet comprised Asellus along with Daphnia, chironomids and perch fry.

Leeches were little utilized as trout diet because their hidden nature and firm attachment to the substratum made it difficult for fish to prey upon them. Hunt and Jones (1972b) also found little importance of leech in the trout in Llyn Tegid.

Terrestrial invertebrates, mainly different types of aerial insects and beetles, formed a considerable proportion of the pond fish diet. This is also reported in much literature dealing with brown trout feeding in natural waterbodies (e.g. Allen, 1938; Ball, 1961; Maitland, 1965; Hunt & Jones, 1972b; Pedly & Jones, 1978). These aerial organisms are carried by wind and fish randomly eat them as they fall on the water (Maitland, 1965). O'Grady (1983) observed that recently planted fish in the natural waterbody favoured food items which are on or near the surface. He also suggested that perhaps fish-farm feeding practices precondition stocked fish to 'look up' for their food.

Plant parts and filamentous algae often occurred in the fish stomachs. This is probably an incidental intake with the food attached to it. Small stone particles were very common in the stomach contents of the Howietoun trout. These may also be taken along with food. Since this happens only to the farm reared trout, it may indicate that some fishes may have difficulty in recognizing invertebrates. This behaviour in farmed trout is also recorded by O'Grady (1983).

Salmonid fishes are generally considered opportunistic and generalized predators, although they are frequently selective feeders (Allan, 1978; Bisson, 1978; Healy, 1979; Godin, 1981). They have got a flexibility in the timing of foraging behaviour which may permit their opportunistic exploitation of prey whenever encountered, as suggested by Curio (1976) for predators in general.

Many workers have developed forage ratio or availability factors to show the relationship between available food supply and dietary composition, with special reference to selection (Ball, 1948; Hynes, 1950; Elliott,1967).

Selectivity index (Electivity) of fish feeding was considered by using the total results for the whole year. This may give a generalized view, ignoring seasonal changes in the diet and fauna. Electivity revealed that chironomid larvae and pupae, molluscs, Asellus and Sialis are being selectively taken up by the trout in the fish ponds. The positive electivity of these species or groups reflected not only their greater importance in the diet but also probably the influence of size and accessibility on their selection. (Pedley & Jones, 1978). Prey characteristics such as prey size, behaviour, habitat, distribution and abundance (Ringler, 1979) and the behaviour, morphology and habitat preference of the fish itself can be a major influence in determining the selectivity. Pyke et al (1977) noted that selectivity varies with hunger level and prey density. In general, the degree of selectiveness by fish decreases as the hunger level increases (Ivlev, 1961), or as the prey density decreases (Ivlev, 1961; Werner & Hall, 1974). The phenomenon of selectivity is, therefore, a function of several factors involving both predator and prey.

In the light of the accessibility classification described by Thomas (1964) and later followed by Hunt and Jones (1972b) and Pedley and Jones (1978), the natural food organisms at Howietoun fish farm may be classified as follows:

(i) species sheltered in silt or under stones and which only become available to the trout immediately before or during emergence, e.g. the majority of the Chironomidae and Sialis lutaria;

(ii) species which are invariably exposed, mobile and available to trout, e.g. Mollusca, Tanypodinae, Asellus aquaticus;

(iii) species sheltered permanently in the substratum which are not readily available to trout, e.g. Oligochaetae, leeches; and

(iv) the terrestrial invertebrates, which are carried to the ponds and easily accessible to fish.

Several authors (Allen, 1938; Ball, 1961; Hunt & Jones, 1972b; Pedley & Jones, 1978) reported considerable seasonal variation in the diet of brown trout in natural waterbodies. Almost all of them agreed that seasonal variation in the diet reflects the seasonal variation in the prey fauna. A considerable seasonal variation was observed regarding natural food organisms in the diet of farmed brown trout. The index of fullness was increased from April to November and the maximum food intake coincided with this period. The highest food intake was recorded in July when the water temperature was 15°C. Similar findings were reported by Hunt & Jones (1972b). Brown (1946) observed that food intake increased gradually with temperature from 4.5°C to 19°C and fell sharply at higher temperatures. Total food intake was higher in summer and lower in autumn and winter. This is in accordance with Ball (1961), who stated that the drop in feeding from October-December was associated with falling temperature and decreasing daylight. The availability of bottom fauna may decline to some extent as the activity may decrease with falling temperature.

During this study, an exceptionally high proportion of natural food was recorded in February. The decrease in fullness index during this period, however, indicated that the overall food intake was low. This was due to the non-availability of pelleted food, and the concentration of fish near the bottom to avoid surface ice and the uppermost layer of cold water, thus making the bottom animals more accessible to them. This is similar to the observation of Humphries (1936), that permanent bottom fauna in the fish diet was more numerous during winter months. Maitland (1965) reported that Oligochaeta were more important to fish during winter months.

As reported elsewhere by Allen (1938), Ball (1961), Tusa (1968), Pedley & Jones (1978), for wild brown trout, farmed brown trout showed two distinct periods as regards the composition of natural food: the first, from March to October, when trout feed on both aquatic and terrestrial organisms; and the second, from November to February when they feed exclusively on aquatic benthic organisms. Johnsen (1978) found that trout preferred surface food as well as bottom food in summer in Lake Dalsvatn in Norway. In late autumn and winter, the supply of surface animals was very small. Arawomo (1981) observed that seasonal changes in the diet of juvenile trout in Loch Leven were related to the availability of the food items.

From the study of stomach contents of fish caught from the same waterbody at different times of the day and night, one can infer that qualitative and quantitative changes in feeding occurred over 24 hours resulting in feeding periodicity. Similar observations were made by, among others, Eggers (1977), Jenkins & Greens (1977) and Godin (1981).

Several authors studying stream dwelling rainbow trout (Salmo gairdneri) (Jenkins, 1969, Bission, 1978), brook trout (Salvelinus fontinalis) (Hoar, 1942; Allan, 1978) and brown trout (Salmo trutta) (Jenkins, 1969; Elliott, 1970, 1973) have reported that fish feed actively during the day and (or) night, depending on season, prey availability and prey type among other factors. Brown trout in farm conditions show a maximum fullness index immediately after feeding with pellets, which indicates that pelleted feeds supply the major proportion of their food. As shown in the results, the volume of natural food was highest in the early morning in both summer and autumn, before pelleted feeds were applied to the ponds. A relatively smaller maximum was also found in the early evening in autumn and in the afternoon in summer. Periods of maximum food intake at dawn and dusk have been observed in the other studies with wild trout (Chaston, 1969; Neveu, 1980).

Chironomid larvae, Sialis and Asellus were the most important natural items during the day time in autumn. Pupae were available in the early morning and evening, which might be associated with emergence (Brown et al., 1980). During day time in summer, chironomid larvae formed the bulk of the natural food and pupae appeared in the afternoon and continued until evening. Aerial insects occurred in the afternoon diet. The presence of aerial insects in the diet may be dependent on weather conditions (Johnsen, 1978).

The night time food in autumn was mainly chironomid larvae and pupae in small numbers. Extremely bad weather at night during the autumn sampling probably inhibited feeding on natural organisms, although some molluscs and Sialis were found in the stomach midway through the night. No food was present in the stomach around 1 to 4 am. This is probably due to the dark windy night with heavy rainfall. The negative effect of bad weather on fish feeding has been reported by Johnsen (1978).

In contrast to the autumn night feeding, trout feeding by night during summer took astonishingly high amounts of natural food and even more than that taken by day. This is in accord with Kalleberg (1958) who observed young salmon to feed at a high intensity during the light nights in the summer. The summer night feeding at Howietoun comprised chironomid larvae, Mollusca and terrestrial invertebrates. Bission (1978) observed snails, turbellarians, simuliid and caddis larvae in the night food.

Changes in the food composition with age and size were observed by many workers (Allen, 1938; Frost, 1939; Nilsson, 1955; Hunt & Jones, 1972b; Pedley & Jones, 1978). Several authors have failed to show any changes (Ball, 1961). Under farm conditions at Howietoun where kinds of available organisms are limited, such changes with age or size of the fish are unlikely. Moreover, due to unavoidable circumstances, a study on different ages or size-groups of fish in the same season was not possible.

It is now known that the Howietoun farmed brown trout are utilizing benthic organisms and other natural food throughout the seasons, in spite of the availability of pelleted diet. But the question is, why are they taking natural food organisms? The answer to this may be diverse, and it is difficult to come to a conclusion.

Firstly, it may be considered that enough pelleted feed is not supplied, so fish remain hungry and feed on natural pond organisms. Secondly, the fish may not be given feed when they are hungry, so they look for an alternative source of food. Thirdly, it may be the subordinate fish who cannot compete with dominant ones for pelleted feed and feed on natural feed rather than fighting with the strong and losing energy. Finally, it may be due to the usual inherent behaviour of trout to feed on natural food organisms, even when pelleted feeds are sufficiently available.

Howietoun fish farm is under the management of a highly trained aquaculturist and earning reputation from home and abroad for its better management. From his long experience, the Manager (personal communication) believes that Howietoun brown trout are fed sufficient artificial food and the timing of feeding is also scientifically decided after many feeding trials under experimental conditions. Thus the feeding routine has been decided considering scientific as well as economic points of view. On this basis, the first two options may not be considered.

It has been demonstrated that the most dominant fish obtain the best feeding stations in terms of energetic profitability (Jenkins, 1969; Fausch, 1984). Salmonids are found to have formed this type of dominance hierarchy both in small laboratory populations and in the wild (Metcalfe, 1986). By the very nature of their preferential access to food resources (Yamagishi, 1962; Fausch, 1984), the dominant fish remain dominant (Bachmann, 1984). Metcalfe (1986) noted that the extent of food deprivation of the subordinate fish depends on the degree of competition, being greatest at high densities (Li & Brockson, 1977) and when the food availability is restricted spatially and temporally (Yamagishi, 1962; Jobling, 1983).

Each pond at Howietoun is stocked with fish of the same age group, if not strictly similar in size and weight. During the culture cycle, a proportion of them may become size dominant, but the stomach analyses of all sizes of randomly caught fish failed to demonstrate any difference in their content of natural food organisms. All sizes of fish caught from the same pond contained natural food organisms in their stomach. Moreover, fish are fed manually by spreading all over the pond, therefore, it is unlikely that the dominance theory applies to this pond fish population.

Lastly, from the study of some behaviour attributes of brown trout, O'Grady (1983) found that there was little difference in the feeding rate and dietary preference of wild trout and farmed trout (held captive for one year under controlled conditions). Godin (1979) believed that the behaviour of salmonid fishes enhances their growth rate, including continuous swimming and foraging during available feeding time, maintenance of a full stomach by feeding at a relatively low hunger threshold and at a rate that balances gastric evacuation rate when they find available prey, and flexible timing of feeding and swimming which may permit opportunisitc exploitation of food resources whenever encountered.

The extent to which natural pond organisms contribute to the fish population can be summarized by the comments made by the fish nutritionist, Lovell (1977), 'it is under this type of culture condition - where the fish depend primarily, but not exclusively, on the nutrients provided in supplemental feeds for growth - that the amount of nutrients provided from pond sources may be of economic benefit'.

The bulletin 'Nutrient Requirements of Warmwater Fish' (Anon., 1983) explains that, for fish which depend heavily on prepared feeds, pond organisms may be an important source of major nutrients (protein, energy) when the standing crop of fish is low or a significant source of micro-nutrients (vitamins) when the standing crop of fish is high.

Pond benthic organisms may enhance the pink colour of the flesh of salmonids in intensive farming conditions (Stirling, personal communication). According to Kennedy and Fitzmaurice (1971), many adult trout in Irish lakes have pink or reddish coloured flesh, although they were white-fleshed on planting. Frost and Brown (1967) indicated that carotene obtained from Crustacea and Gastropoda are responsible for colouring trout musculature. The attractive skin colour (similar to wild trout) and pink musculature of Howietoun brown trout may be an indication that they have been eating substantial amounts of natural food organisms. Nevertheless, this area warrants further investigation.

5.4 Interactions between Fish and Benthos

In the previous sections the increase in abundance of bottom fauna due to intensification of fish culture and their contribution as a natural food to the farmed trout diet has been discussed. This section focusses on the influence of the fish on the benthic community and the response of the benthos to the fish. Wojcik-Migala (1979) suggested that the influence of fish on the organisms constituting their food, is very complicated and requires comprehensive examination. It is usually very difficult to know whether an observed phenomenon is the consequence of fish predation, or else a secondary effect due to environmental changes. Kajak (1977) also suggested that the influence of fish on the benthos seemed to be complex; by diminishing directly the invertebrate predators and bigger non-predatory forms, fishes should increase the rate of production of the benthos; on the other hand, besides strongly exploiting the benthos, fish increase the availability of prey for the surviving invertebrate predators by stirring up the bottom.

A short term experiment using enclosures to keep the fish away from part of the pond bottom and benthos was carried out to investigate this complicated predator-prey relationship. This method of isolating a part of the bottom of a waterbody in order to determine the influence of fish on the benthos has been applied by other workers (see review by Kajak, 1968). Unfortunately, no experimental control using an enclosure without any fish in the pond could be maintained for this experiment, but three stocking densities were tried.

It was assumed that (1) the environments inside and outside the enclosures in each pond were similar with regard to their physical and chemical nature, (2) equal amounts of unused feeds and metabolites accumulated both inside and outside, and (3) the only difference was the accessibility to the fish. Therefore, any change in the benthic fauna between inside and outside would probably be due entirely to the effect of fish. This effect of fish in various studies (e.g. Hayne & Ball, 1956; Lellák, 1957, 1965; Wojcik-Migala, 1965, 1966; Kajak & Dusoge, 1973) has produced many different outcomes. Such a divergence of outcomes with different freshwater communities often complicates the emerging theories on community structure (Zaret, 1980).

In spite of several limitations and complications, some important outcomes of this experiment may be accepted as the basis for further work in similar ecosystems. The results of this experiment are summarized in Fig. 99.

The study revealed that the population density of total benthos was significantly higher inside the enclosure. The lower population density outside may be due to predation by trout. This is supported by Lellák (1957), who noted that the carp stock of the pond Smylov consumed half of the natural population of bottom fauna. In contrast, Allan (1982) found no difference in the population density of bottom fauna between a section of stream from which 70-90% of the trout had been removed and corresponding upstream and downstream sections.

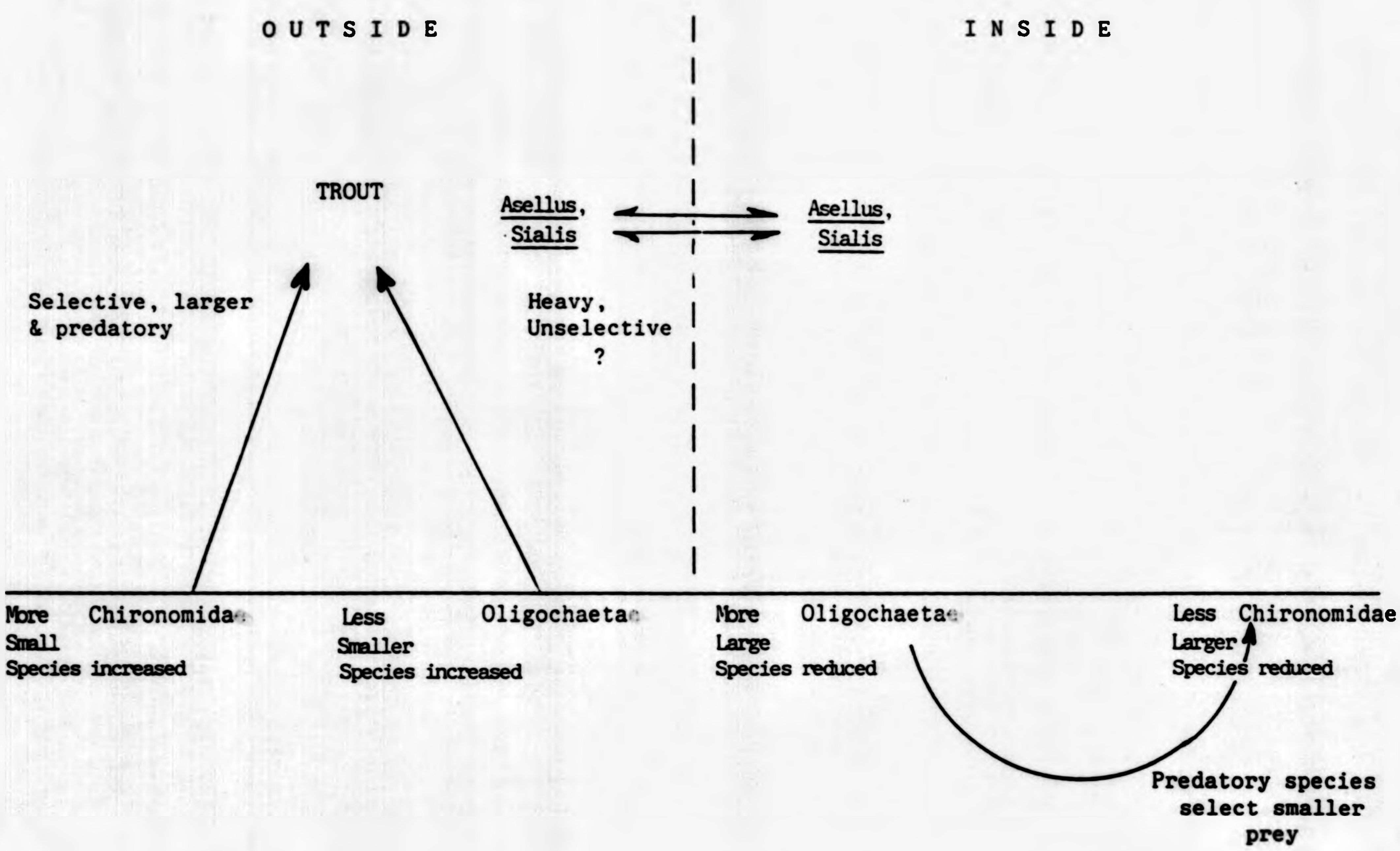


Fig. 99 Simplified model of interaction between fish and benthos as revealed by the enclosure experiment

Of the major groups of benthos the population density of Oligochaetae was higher inside but that of Chironomidae was higher outside the enclosure. The lower number of oligochaetes outside may be due to intense predation, particularly on the larger worms, which affected the size of the breeding population. Fish predation can be specially important during the breeding periods of benthic animals (Kajak & Wiseniewski, 1966, for Tubificidae; Berguland, 1968, for Asellus). The consumption of oligochaetes by trout may have been higher than estimated in the gut content analyses, as explained above. Oligochaetae inside the enclosure multiplied rapidly in the absence of fish predation, which would have continued until they were limited by space, because the question of food limitation is unlikely to have arisen. The chironomid population, on the contrary, may have been greater on the outside because of the selective feeding by trout on the active predatory and large non-predatory chironomids and other invertebrate predators. This hypothesis is supported by the higher number of predatory chironomid larvae inside than outside. Inside the enclosure, the predatory Chironomidae, mainly Procladius sp. may have predated heavily on the smaller instars of non-predatory chironomids, thus keeping their population down. Also the intensity of emergence may have been higher inside, contributing to a lower population density, because of less/or no predation on the large larvae inside the enclosures. Moreover, intensive feeding by trout on the oligochaetes outside the enclosures probably reduces adverse inter-group relationships, particularly the competition for space. This would allow room for tube building and sediment penetrating chironomid larvae which would be protected from the fish (Hersey, 1985). This is further supported by the highest population density of chironomid larvae outside the enclosure in pond 8, which had the highest density of trout and hence should have experienced a higher predation pressure. Nevertheless, the enclosure itself might be a physical barrier to egg-laying by female chironomids which may have led to the presence of fewer chironomids inside the enclosure. The most conspicuous changes due to the influence of fish was recorded in the species composition between outside and inside the enclosures. A shift from larger to smaller sized zoobenthos occurred outside as well as an increase in the number of species of Oligochaetae and Chironomidae. Whereas a shift towards the large sized possibly dominant species of oligochaetes and chironomids was observed inside the enclosures. Size selective predation by fish may be responsible for smaller size-groups outside the enclosure. This phenomenon has been observed by many workers, including Hrbaček *et al* (1961), Hutchinson (1971), Kajak and Dusoge (1973), Nilssen and Pejler (1973), and De Bernardi and Giussani (1975, 1978). Several other studies demonstrated the effect of size selective predation by fish on the benthic fauna. Crowder and Cooper (1982) concluded that predation by yellow perch, *Perca flavescens* in little Minnow Lake, Ontario, significantly altered species composition, shifting size structure towards the smaller invertebrates. Hall *et al* (1970) showed that size selective predation by blue gills, *Lepomis macrochirus* significantly decreased the abundance of larger species and allowed a compensatory increase in smaller species. Similar results for zooplankton were reported by Hrbaček (1958) and Grygierek (1967), who demonstrated that in densely stocked fish ponds the larger forms of Cladocera disappeared and smaller forms developed in their place. A contrasting result was reported by Throp and Bergey (1981), who showed that chironomid head capsule lengths were not significantly different between vertebrate predator exclusion cages and control plots.

Sialis lutaria and Asellus aquaticus may have migrated from outside to inside and vice-versa, so size differences were not apparent. Kajak (1972) pointed out the migratory behaviour of S. lutaria to and from the enclosure in Lake Sniardwy.

The influence of fish on benthic biomass has been reported by, among others, Kajak and Zawisza (1973). According to them, the biomass of benthos may be reduced to about half or a third by fish predation. If the predation is not too strong and the decrease of biomass not too great, predation may stimulate benthic production by maintaining biomass at an optimum level, reducing competition within the benthos, removing invertebrate predators, and favouring young stages of those species with short life cycles (Hayne & Ball, 1956; Wolny, 1962; Kajak, 1972). In this study, the biomass of total benthos was 4-6 times higher inside the enclosures which was due mainly to Oligochaetae and Mollusca.

This increase was the result of higher numbers and larger size groups with a higher mean individual biomass, especially for Oligochaetae. Chironomidae failed to show any significant difference in biomass between inside and outside because there was a balance between higher numbers and smaller size groups outside and smaller numbers and larger sizes inside.

A contrasting result was reported by Wojcik-Migala (1965), when she observed the highest biomass and production in spite of strong elimination. Kajak (1972) observed that, after lowering the benthic biomass significantly, fish move to other feeding places or to other food such as to zooplankton which allows the benthos to recover. In the present case, the supply of artificial feed acts as a buffer, decreasing pressure of fish on the benthos, and allowing for the recovery and development of benthic fauna. Similar conclusions were drawn by Wasilewska (1978) and Wojcik-Migala (1965, 1968).

Hayne and Ball (1956) and Maksimova (1961) have shown that the effect of fish is rather small on the biomass of benthic fauna, but much greater (stimulating) on the production. This study demonstrated a higher production of total benthos inside the enclosure. This is due to the higher population density and higher individual biomass of Oligochaetae which eventually contributes to the increased Oligochaetae as well as total benthos production. Similar results were obtained by Kajak (1972). He reported that fish decreased the total production from 1.9 to 2.1 times in Lake Warniak (Poland). In contrast, Hayne and Ball (1956) and Wojcik-Migala (1970) observed that benthophagus fish such as sunfish and carps increased the production but decreased the biomass of macrobenthos.

A higher P/B ratio outside for oligochaetes was probably due to the disproportionate decrease in biomass (1/4-1/6), while the production only halved in the outside; this might be related to a lower mean weight/size, the population being less senescent and more efficient in transforming detritus.

The above discussion of the effect of the enclosures applied equally to all three stocking densities, but differences were observed. The similar growth rates of fish observed in the lowest and the highest stocking densities indicated that the growth of fish was not limited by the range of stocking densities employed. This also implies that fish at the lowest density did not derive any significant benefit from the assumed greater availability of benthos. Pond 7 showed apparently slower growth, although it was less so when instantaneous growth rate rather than actual weight increases were considered. This slow growth may be partly due to the stocking of relatively smaller fish in pond 7 which may have resulted in a limitation of supply in relation to their higher metabolic requirements.

Nevertheless, the biomass of most benthic groups was relatively lower in pond 7 which may have been due to the long term effect of different management of different ponds, resulting in lower growth of fish.

From the above discussion it may be concluded that the interactions between fish and benthos have decreased the population density, biomass and production and increased the species composition in general. Chironomidae increased in abundance and production but decreased in number of predatory species outside the enclosure.

Apart from the influence of fish, the effect of predatory invertebrates would have been an important factor in regulating the benthic population dynamics. In contrast to fish, predatory invertebrates most extensively utilize the young individuals of oligochaetes and chironomids, thereby reducing the number of non-predatory Chironomidae and juveniles of Oligochaetae (Wasilewska, 1978).

5.5 Suggestions for further work

For the application of the knowledge acquired in this investigation to aquaculture in earthen fish ponds, further research efforts should be carried out in future. The following areas have been identified:

1) A study of the percentage of benthos lost from the ponds through emergence of insects and emigration in the outflow, and gained by immigration from the inflowing stream into the ponds.

2) A study of the rate of organic loading into the pond bottom

and what proportion of this is utilized by benthos and converted to live protein or is otherwise mineralized into the overlying water. In this respect, a quantification of the net loss of artificial feed and an economic evaluation of earthen pond management in comparison with tank based and raceway systems of aquaculture should be undertaken. Apart from the loss of artificial feeds from these more intensive culture systems, a considerable cost may also be involved for the treatment of wastes from the systems.

3) A study of the relative contributions of allochthonous materials from the inflow and autochthonous materials from fish farming into the organic loading and energy flow between different groups of producers and consumers in the ponds leading towards modelling the ecosystem of earthen fish ponds.

4) An evaluation of the bottom fauna from the nutritional point of view such as major and micro-nutrients, especially the role of carotenoids in flesh colouration.

5) A study on the taste, colour and acceptability of fish (by the customer) grown in earthern ponds having a large benthic production, compared with fish produced in tanks and cages.

6) A comparison of the behavioural aspects of pond fish and tank and cage grown fish for implantation for stocking of reservoirs for sport fisheries. The pond grown fish, because of their previous exposure to natural foods, may be better adapted to the more natural habitat of a reservoir; and

7) an optimization of the stocking density in the earthen fish ponds, so as to fully utilize the benthic and other natural food organisms as well as to maintain the environment for their sustained production. Here, growth of fish should be given top priority. To achieve the above objective, ponds may be stocked experimentally with different stocking densities of fish, some of them with very high densities, so that the point of collapse of ecosystem could be established and an optimum management strategy could be determined on the basis of experimental results.

Summary and Conclusion

The ecology of the benthic macro-invertebrate community in intensively cultured earthen trout ponds at Howietoun, Central Scotland, was investigated over a period from May 1984 to January 1986. Fortnightly samples of benthic fauna were collected from a series of ponds in the flow through system. A large number of water and soil quality parameters, which were either particularly affected by fish farming or may be important for benthic ecology, were taken into consideration. The contribution of benthic fauna in the diet of the farmed brown trout was determined by monthly gut content analyses of the fish. Some observations on the diel feeding pattern were also made by sampling gut contents over 24 hour periods, once in summer and another in autumn. The overall response of benthos to fish culture was further evaluated experimentally by the use of enclosures which prevented the fish from predating a certain part of the pond bottom.

The dynamics of physical and chemical parameters of water and soil quality exhibited a seasonal pattern in both culture and control ponds. The water temperature was found to be closely related to that of the air. The conservative properties of the water were scarcely changed by the fish farming practices. Dissolved oxygen levels declined as the water passed through the ponds, and pH of water decreased as the water carried increasingly more CO_2 and oxygen consuming materials. The culture ponds were found to have far higher nutrient contents than the control pond. All the nitrogenous and phosphatic nutrients considered in this study were increased from the inflow to the outflow. This enrichment of water in the cultured ponds by the addition of unused feeds, faeces and other metabolites led to the increase in overall productiviy of the fish ponds. The analyses of pond soil and the recently sedimented materials collected in traps testified to the origin of high nutrient contents in the pond soil and sedimenting materials. These increased nutrients in both soil and water in the fish culture ponds reflected the eutrophication of the culture ponds caused by the release of fish metabolites, faeces and non-ingested food, derived from intensive fish culture.

The organic loading originating from fish culture greatly increased the abundance of benthic organisms particularly Oligochaetae and Chironomidae. The diversity of organisms was lower but the abundance of the tolerant organisms was very high and often exceeded 100,000 ind. m^{-2}. This high population in the intensive ponds may be associated with the improved feeding conditions of both detritivores and herbivores. Six major groups of benthic fauna, Oligochaetae, Chironomidae, Mollusca, Hirudinea, Asellidae and Sialidae, which are represented by 10, 16, 2, 2, 1 and 1 species respectively, were collected from the fish ponds. The number of species was reduced in the most enriched pond 14, which is the last pond in the series. Approximately 78-90% of the benthic fauna consisted of Oligochaetae. Chironomidae ranked second in importance. The number of organisms per m^2 was always lower in the stream stations. It was assumed, however, that the stream environment was the continuous source of eggs, larvae and imago of many pond invertebrates.

There appeared seasonal variation in the abundance of different species and groups of benthic animals. There were, generally, two peaks of major benthic groups, which were mainly associated with better feeding conditions and higher organic matter content of the soil. The abundance of benthos was higher in densely stocked ponds 11 and 14 and lower in thinly stocked brood pond 13. Differences in management between ponds may have been responsible for the observed differences in abundance of benthic fauna.

Not only abundance, but also dry biomass of benthos was very high in the cultured ponds, in which oligochaetes were the dominant contributor to the total biomass. The total biomass was also higher in the highly stocked ponds 11 and 14. Oligochaete biomass gradually decreased from pond 7 to pond 14, which indicated that the mean individual weight decreased with increased pollution level, even though the abundance of the worms significantly increased at the same time. In contrast, the biomass of Chironomidae was higher in pond 14 and increased as the water passed through the farm.

The annual dry weight production, as calculated using the 'growth increment summation' method, was found to show a very high level of production in the cultured ponds. This was 3 to 4 times higher than the control pond, which indicated that high rates of benthic production in the earthen fish ponds were stimulated by the fish farming practices.

The fate of this large standing crop of biomass and production is not fully understood. The farmed fish are utilizing a portion of this benthic fauna, which is about one tenth of the total volume of food intake by the fish, as revealed by the gut contents analyses. A small proportion of the natural food is derived from aerial/terrestrial invertebrates. Seasonal variation in the natural diet of the fish mainly coincided with the dominant occurrence of a particular species /group of organism(s). Size, behaviour and mobility of a particular organism may be important in its selection as prey. Diel feeding rhythms with a peak at dawn and another at dusk, as observed in wild trout, were found to be similar for the farmed trout. The fish may have maintained a low hunger threshold and continually fed in the earthen culture ponds, which is the inherited nature of wild brown trout thus making good utilization of the abundant benthic fauna. Brown trout were found to have selectively fed on the chironomid larvae, molluscs, Asellus and Sialis. Oligochaetes were recorded in small proportions in the trout diet, although they were the most dominant in abundance, biomass and production. This could have been due to their rapid digestion which may have led to an underestimate of their importance.

The intensification of fish culture activities in earthen ponds through the use of large amounts of pelleted feeds increases the abundance of benthic fauna. The benthic fauna are favoured by the increased organic loading and convert the unused feeds and faecal materials efficiently into high quality live protein, which are, in turn, consumed by fish. An attempt was made to evaluate the effect of fish predation and numerous other influences exerted by fish on the benthic fauna, by the use of enclosures. This study demonstrated a higher number of species and lower biomass and production of the benthic fauna outside the enclosures. Chironomidae were found to show opposite results with higher abundance, biomass and production on the outside. A few large species of Oligochaetae dominated the abundance inside and there were fewer larger chironomids with a higher proportion of predatory larvae inside the enclosures. The mean individual weight of oligochaetes was much higher (4 x) inside, which increased the dry biomass and production of the Oligochaetae as well as total benthos. The higher abundance, biomass and production of Chironomidae outside the enclosures was probably due to a decrease in predation by invertebrates outside and less competition for space, as the larger and predatory larvae of Chironomidae may have been selectively eaten by fish.

In conclusion, aquaculture in earthen fish ponds provides a better environment for the tolerant species of benthic macro-invertebrates, which are making use of the lost feed, faeces and other organic loadings, and transforming these into the live food for the cultured fish.

Appendices

Appendix 1

The 'growth increment summation' method may be summarized as follows:

For n sampling periods

$$\text{Production (P)} = \sum \bar{A}\,(B_2 - B_1)$$

$\bar{A}$ = mean abundance during any consecutive dates = $\dfrac{A_1 + A_2}{2}$ and

$B_2 - B_1$ = change in mean weight between these consecutive dates.

Details of the calculation of the production of benthic macro-invertebrates by the method of 'growth increment summation', where A = abundance per m^2 and B = mean individual dry weight (mg), are presented in Appendices II-VII.

App. II - 1

Oligochaeta - Pond 7

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1= D	Production (P) = C x D
20 May 1984	126,990	0.429			
5 June 1984	123,078	0.492	125,034	0.063	7.88
22 June 1984	157,758	0.451	140,418	- 0.040	- 5.77
6 July 1984	235,452	0.270	196,605	- 0.181	-35.99
22 July 1984	175,950	0.342	205,701	0.072	14.81
6 Aug 1984	149,598	0.485	162,774	0.143	23.28
22 Aug 1984	128,862	0.407	139,230	- 0.078	-10.86
7 Sep 1984	122,568	0.527	125,715	0.12	15.09
24 Sep 1984	131,238	0.527	126,903	0	0
26 Oct 1984	117,978	0.685	124,608	0.158	19.69
9 Nov 1984	88,908	0.310	103,443	- 0.375	-38.79
30 Nov 1984	116,622	0.346	102,765	0.036	3.70
15 Dec 1984	131,238	0.372	123,930	0.026	3.22
Total					87.67

= 131.50g m.$^{-1}$yr^{-1}

Date	A	B	C	D	P
5 March 1985	101,490	0.100			
20 March 1985	116,622	0.465	109,056	0.365	39.81
6 April 1985	134,640	0.430	125,631	- 0.035	- 4.40
26 April 1985	153,678	0.198	144,159	- 0.232	-33.44
10 May 1985	165,408	0.350	159,543	0.152	24.25
28 May 1985	172,890	0.095	169,149	- 0.255	- 43.13
14 June 1985	174,930	0.182	173,910	0.087	15.13
29 June 1985	203,490	0.170	189,210	- 0.012	- 2.27
14 July 1985	196,860	0.151	200,175	- 0.019	- 3.80
29 July 1985	193,290	0.160	195,075	0.009	1.76
14 Aug 1985	143,142	0.177	168,216	0.017	2.86
14 Sep 1985	126,822	0.604	134,982	0.427	57.64
14 Oct 1985	144,498	0.441	135,660	- 0.161	-21.84
21 Nov 1985	122,058	0.640	133,278	0.199	26.52
15 Dec 1985	150,450	0.620	136,254	-0.020	- 2.73
23 Jan 1986	146,370	0.650	148,410	0.030	4.45
Total					172.42

= 187.64g m.$^{-2}$yr^{-1}

App. II - 2

Oligochaeta - Pond 11

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	163,200	0.322			
5 June 1984	202,470	0.322	182,835	0	0
22 June 1984	146,370	0.322	174,420	0	0
6 July 1984	257,040	0.241	201,705	-0.081	-16.34
22 July 1984	207,060	0.311	232,050	0.07	16.24
6 Aug 1984	181,902	0.349	194,481	0.038	7.39
22 Aug 1984	160,818	0.347	171,360	-0.002	- 0.34
7 Sep 1984	140,082	0.148	150,450	-0.201	-30.24
24 Sep 1984	131,070	0.527	135,576	0.379	51.38
26 Oct 1984	150,108	0.282	140,589	-0.245	-34.44
9 Nov 1984	128,178	0.365	139,143	0.083	11.55
30 Nov 1984	186,150	0.138	157,164	-0.227	-35.68
15 Dec 1984	158,610	0.283	172,380	0.145	25.0
Total					111.56
					= 167.34 g $m.^{-2}yr^{-1}$
5 March 1985	174,252	0.136			
20 March 1985	183,768	0.383	179,010	0.247	44.22
6 April 1985	191,592	0.300	187,680	-0.083	-15.58
26 April 1985	164,388	0.262	177,990	-0.038	- 6.76
10 May 1985	170,172	0.300	167,280	0.038	6.36
14 June 1985	223,548	0.132	196,860	-0.168	-33.07
29 June 1985	219,642	0.130	221,595	-0.002	- 0.44
14 July 1985	273,360	0.136	246,501	0.006	1.48
29 July 1985	198,900	0.160	236,130	0.024	5.67
14 Aug 1985	175,440	0.178	187,170	0.018	3.37
29 Aug 1985	213,522	0.141	194,481	-0.037	-7.20
14 Sep 1985	168,132	0.227	190,827	0.086	16.41
29 Sep 1985	151,638	0.270	159,885	0.043	6.88
14 Oct 1985	171,528	0.260	161,583	-0.010	- 1.62
29 Oct 1985	198,390	0.263	184,959	0.003	0.56
21 Nov 1985	175,272	0.354	186,831	0.091	17.00
19 Dec 1985	164,562	0.460	169,917	0.106	18.01
23 Jan 1986	152,832	0.575	158,697	0.115	18.25
Total					138.20
					= 150.77g $m.^{-2}yr^{-1}$

App. II - 3

Oligochaeta - Pond 13

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	55,080	0.290			
5 June 1984	58,140	0.229	56,610	-0.061	-3.45
22 June 1984	56,100	0.156	57,120	-0.073	-4.17
6 July 1984	83,472	0.109	69,786	-0.047	-3.28
22 July 1984	56,442	0.187	69,957	0.078	5.46
6 Aug 1984	66,810	0.072	61,626	-0.115	-7.09
22 Aug 1984	65,112	0.033	65,961	- 0.039	-2.57
7 Sep 1984	55,248	0.289	60,180	0.256	15.41
24 Sep 1984	66,300	0.105	60,774	- 0.184	-11.18
26 Oct 1984	69,018	0.367	67,659	0.262	17.73
30 Nov 1984	69,360	0.340	69,189	- 0.027	- 1.87
15 Dec 1984	72,420	0.175	70,890	- 0.165	11.70
Total					50.3
					= 75.45g $m.^{-2}yr^{-1}$
5 March 1985	59,838	0.05			
20 March 1985	56,100	0.106	57,969	0.101	5.85
6 April 1985	53,208	0.700	54,654	0.606	33.12
26 April 1985	56,442	1.298	54,825	0.598	32.79
10 May 1985	58,308	0.142	57,375	- 1.156	-66.33
28 May 1985	64,260	0.141	61,284	- 0.001	- 0.06
14 June 1985	98,262	0.100	81,261	- 0.041	- 0.33
29 June 1985	100,980	0.090	99,621	- 0.010	- 1.0
14 July 1985	89,592	0.175	95,286	0.085	8.10
29 July 1985	88,230	0.120	88,911	- 0.055	- 4.89
14 Aug 1985	81,600	0.069	84,915	- 0.051	- 4.33
29 Aug 1985	72,762	0.100	77,181	0.031	2.39
14 Sep 1985	64,428	0.160	68,595	0.060	4.12
29 Sep 1985	59,160	0.180	61,794	0.020	1.24
14 Oct 1985	60,012	0.200	59,586	0.020	1.19
21 Nov 1985	52,698	0.180	56,355	- 0.020	-1.13
19 Dec 1985	75,312	0.229	64,005	0.049	3.14
23 Jan 1986	86,700	0.350	81,006	0.121	9.80
Total					101.74
					= 110.99g $m.^{-2}yr^{-1}$

App. II - 4

Oligochaetae - Pond 14

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	157,422	0.257			
5 June 1984	174,420	0.303	165,921	0.046	7.63
22 June 1984	199,920	0.313	187,170	0.010	1.87
6 July 1984	245,988	0.120	222,954	-0.193	-43.03
22 July 1984	199,920	0.167	222,954	0.047	10.48
6 Aug 1984	183,090	0.226	191,505	0.059	11.30
22 Aug 1984	169,830	0.288	176,460	0.062	10.94
7 Sep 1984	193,632	0.062	181,731	-0.226	-41.07
24 Sep 1984	173,058	0.082	183,345	0.02	3.67
26 Oct 1984	205,188	0.104	189,123	0.022	4.16
9 Nov 1984	202,638	0.141	203,913	0.037	7.54
30 Nov 1984	171,192	0.206	186,915	0.065	12.15
15 Dec 1984	179,688	0.105	175,440	-0.101	-17.72
Total					69.74

= 104.61g $m.^{-2}yr^{-1}$

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
5 March 1985	102,000	0.207			
20 March 1985	201,450	0.365	151,725	0.158	23.97
6 April 1985	167,790	0.260	184,620	-0.105	-19.39
26 April 1985	163,200	0.153	165,495	-0.107	-17.71
10 May 1985	187,680	0.471	175,440	0.318	55.79
14 June 1985	184,110	0.053	185,895	-0.480	-89.23
29 June 1985	232,050	0.090	208,080	0.037	7.70
14 July 1985	257,718	0.132	244,884	0.042	10.29
29 July 1985	282,708	0.160	270,213	0.028	7.57
14 Aug 1985	237,660	0.193	260,184	0.033	8.59
29 Aug 1985	149,088	0.081	193,374	-0.112	-21.66
14 Sep 1985	189,378	0.062	169,233	-0.019	- 3.22
29 Sep 1985	168,300	0.090	178,839	0.028	5.0
14 Oct 1985	197,880	0.070	183,090	- 0.02	- 3.66
29 Oct 1985	215,730	0.338	206,805	0.268	55.42
21 Nov 1985	186,150	0.345	200,940	- 0.003	- 0.60
19 Dec 1985	200,940	0.300	193,545	- 0.045	- 8.71
23 Jan 1986	175,440	0.236	188,190	- 0.064	-12.04
Total					174.33

= 190.18g $m.^{-2}yr^{-1}$

App. II - 5

Oligochaetes - Pond 9

Date		A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1= D	Production (P) = C x D
20 May	1984	41,820	0.316			
5 June	1984	31,620	0.255	36,720	- 0.061	- 2.24
22 June	1984	32,982	0.395	32,301	0.140	4.52
6 July	1984	46,920	0.221	39,951	- 0.174	- 6.95
22 July	1984	41,310	0.246	44,115	0.025	1.10
6 Aug	1984	34,848	0.291	38,079	0.045	1.71
22 Aug	1984	45,222	0.228	40,035	- 0.063	- 2.52
7 Sep	1984	30,258	0.309	37,740	0.081	3.06
24 Sep	1984	23,628	0.527	26,943	0.218	5.87
26 Oct	1984	24,822	0.685	24,225	0.158	3.83
9 Nov	1984	56,778	0.309	40,800	- 0.376	-15.34
15 Dec	1984	52,020	0.372	54,399	0.063	3.43
Total						23.52

= 35.28g m.$^{-2}$yr^{-1}

App. III - 1

Chironomidae - Pond 7

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1= D	Production (P) = C x D
20 May 1984	4,080	0.313			
5 June 1984	8,328	0.100	6,204	- 0.213	- 1.32
22 June 1984	11,730	0.230	10,029	0.13	1.30
6 July 1984	18,870	0.504	15,300	0.274	4.19
22 July 1984	21,762	0.350	20,316	- 0.154	- 3.13
6 Aug 1984	15,132	0.564	18,447	0.214	3.95
22 Aug 1984	14,112	0.300	14,622	- 0.264	- 3.86
6 Sep 1984	29,412	0.500	21,762	0.200	4.35
24 Sep 1984	19,212	0.254	24,312	- 0.246	- 5.98
26 Oct 1984	6,462	0.348	12,837	0.094	1.21
9 Nov 1984	10,200	0.327	8,331	- 0.021	-0.175
30 Nov 1984	5,952	0.888	8,076	0.561	4.53
15 Dec 1984	4,590	0.900	5,271	0.012	0.063
Total					19.59
					= 29.39 g m^{-2}. yr^{-1}
5 March 1985	14,790	0.400			
20 March 1985	13,602	0.053	14,196	- 0.347	- 4.93
6 April 1985	13,938	0.154	13,770	0.101	1.39
26 April 1985	9,180	0.255	11,559	0.101	1.17
10 May 1985	8,168	0.413	8,674	0.158	1.37
28 May 1985	7,650	0.469	7,909	0.056	0.44
14 June 1985	8,328	0.120	7,989	- 0.349	-2.79
29 June 1985	8,328	0.132	8,328	0.012	0.10
14 July 1985	7,650	0.144	7,989	0.012	0.096
29 July 1985	9,012	0.292	8,331	0.148	1.23
14 Aug 1985	10,878	0.440	9,945	0.148	1.47
14 Sep 1985	23,118	0.119	16,998	- 0.321	-5.46
14 Oct 1985	5,268	0.509	14,193	0.390	5.54
21 Nov 1985	11,562	0.812	8,415	0.303	2.55
19 Dec 1985	18,870	0.920	15,216	0.108	1.64
23 Jan 1986	11,562	1.042	15,216	0.122	1.86
Total					18.86
					20.57 g m^{-2}. yr^{-1}

App. III - 2

Chironomidae - Pond 11

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	6,462	0.312			
5 June 1984	7,308	0.100	6,885	- 0.212	-1.46
22 June 1984	8,838	0.363	8,073	0.263	2.12
6 July 1984	17,508	0.504	13,173	0.141	1.86
22 July 1984	19,212	0.318	18,360	- 0.186	-3.41
6 Aug 1984	19,038	0.350	19,125	0.032	0.61
22 Aug 1984	15,978	0.173	17,508	- 0.177	-3.09
7 Sep 1984	23,628	0.500	19,803	0.327	6.48
24 Sep 1984	10,200	0.340	16,914	- 0.160	-2.70
26 Oct 1984	15,642	0.478	12,921	0.138	1.78
9 Nov 1984	9,180	0.928	12,411	0.45	5.58
30 Nov 1984	5,268	0.713	7,224	- 0.215	-1.55
15 Dec 1984	14,112	0.946	9,690	0.233	2.26
Total					20.69
					= 31.04 g $m.^{-2}$ yr^{-1}
5 March 1985	24,990	0.400			
20 March 1985	18,192	0.400	21,591	0	0
6 April 1985	12,408	0.157	15,300	-0.243	-3.72
26 April 1985	10,710	0.112	11,559	-0.045	-0.52
10 May 1985	8,160	0.413	9,435	0.301	2.84
14 June 1985	9,522	0.120	8,841	-0.293	-2.59
29 June 1985	9,012	0.132	9,267	0.012	0.11
14 July 1985	9,522	0.144	9,267	0.012	0.11
29 July 1985	9,180	0.292	9,351	0.148	1.38
14 Aug 1985	15,132	0.440	12,156	0.148	1.80
28 Aug 1985	11,388	0.443	13,260	0.003	0.04
14 Sep 1985	11,052	0.119	11,220	- 0.324	- 3.64
28 Sep 1985	8,838	0.509	9,945	0.390	3.88
14 Oct 1985	31,278	0.509	20,058	0	0
29 Oct 1985	23,802	0.898	27,540	0.389	10.71
21 Nov 1985	9,348	0.913	16,575	0.015	0.25
19 Dec 1985	11,562	0.977	10,455	0.064	0.67
23 Jan 1986	7,818	1.042	9,690	0.065	0.63
Total					22.42
					= 24.46 g $m.^{-2}$ yr^{-1}

App. III - 3

Chironomidae - Pond 13

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1= D	Production (P) = C x D
20 May 1984	10,878	0.336			
5 June 1984	6,798	0.100	8,838	-0.236	- 2.086
22 June 1984	4,080	0.363	5,439	0.263	1.430
6 July 1984	5,442	0.711	4,761	0.348	1.658
22 July 1984	7,992	0.318	6,717	-0.393	-2.640
6 Aug 1984	15,978	0.350	11,985	0.032	0.384
22 Aug 1984	14,958	0.173	15,468	-0.177	2.738
7 Sep 1984	40,632	0.203	27,792	0.03	0.834
24 Sep 1984	27, 540	0.200	34,086	- 0.003	- 0.102
26 Oct 1984	18,018	0.198	22,779	- 0.002	- 0.046
9 Nov 1984	11,052	0.454	14,535	0.256	3.721
15 Dec 1984	4,932	0.845	7,992	0.391	3.125
Total					13.89
					= 20.84 g m.$^{-2}$ yr^{-1}

5 March 1985	8,328	0.400			
20 March 1985	7,992	0.269	8,160	- 0.131	-1.069
6 April 1985	11,052	0.190	9,522	- 0.079	-0.752
26 April 1985	8,838	0.347	9,945	0.157	1.560
10 May 1985	10,368	0.413	9,603	0.066	0.634
28 May 1985	10,032	0.469	10,200	0.056	0.571
14 June 1985	7,650	0.120	8,841	- 0.349	- 3.086
29 June 1985	4,758	0.210	6,204	0.09	0.558
14 July 1985	5,268	0.300	5,013	0.09	0.451
29 July 1985	5,100	0.545	5,184	0.245	1.270
14 Aug 1985	6,798	0.790	5,949	0.245	1.458
28 Aug 1985	9,690	0.443	8,244	- 0.347	-2.860
14 Sep 1985	42,330	0.425	26,010	- 0.018	-0.468
29 Sep 1985	26,688	0.683	34,509	0.258	8.903
14 Oct 1985	12,750	0.662	19,719	- 0.021	- 0.414
21 Nov 1985	7,140	0.913	9,945	0.251	2.496
19 Dec 1985	4,590	0.977	5,865	0.064	0.375
23 Jan 1986	7,140	1.042	5,865	0.064	0.381
Total					18.66
					= 20.36 g m.$^{-2}$ yr^{-1}

App. III - 4

Chironomidae - Pond 14

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	7,482	0.050			
5 June 1984	8,160	0.060	7,821	0.01	0.078
22 June 1984	10,032	0.362	9,096	0.302	2.75
6 July 1984	16,152	0.362	13,092	0	0
22 July 1984	15,300	0.318	15,726	-0.044	-0.69
6 Aug 1984	13,260	0.350	14,280	0.032	0.46
22 Aug 1984	15,132	0.240	14,196	-0.110	-1.56
7 Sep 1984	13,260	0.601	14,196	0.364	5.17
24 Sep 1984	16,488	0.429	14,874	-0.175	-2.60
26 Oct 1984	21,420	0.253	18,954	-0.176	-3.34
9 Nov 1984	18,870	0.888	20,145	0.635	12.79
30 Nov 1984	16,152	0.935	17,511	0.047	0.82
15 Dec 1984	6,972	0.998	11,562	0.063	0.73
Total					22.80

= 34.20 g $m.^{-2}$ yr^{-1}

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
5 March 1985	9,348	0.400			
20 March 1985	18,870	0.577	14,109	0.177	2.50
6 April 1985	15,978	0.775	17,424	0.198	3.45
26 April 1985	14,448	0.582	15,213	-0.193	-2.94
10 May 1985	9,690	0.608	12,069	0.026	0.31
14 June 1985	7,818	0.120	8,754	-0.488	-4.27
29 June 1985	6,288	0.180	7,053	0.060	0.42
14 July 1985	7,818	0.240	7,053	0.060	0.42
29 July 1985	11,052	0.449	9,435	0.209	1.97
14 Aug 1985	9,858	0.658	10,455	0.209	2.19
29 Aug 1985	11,052	0.443	10,455	-0.215	-2.25
14 Sep 1985	19,038	0.433	15,045	0.010	0.15
29 Sep 1985	27,708	0.709	23,373	0.276	6.45
14 Oct 1985	50,322	0.709	39,015	0	0
29 Oct 1985	28,902	0.985	39,612	0.276	10.93
21 Nov 1985	11,898	0.947	20,400	-0.038	-0.78
19 Dec 1985	11,562	0.994	11,730	0.047	0.55
23 Jan 1986	15,300	1.042	13,431	0.048	0.64
Total					29.98

= 32.71 g $m.^{-2}$ yr^{-1}

App. III - 5

Chironomidae - Pond 9

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	3,060	0.313			
5 June 1984	2,382	0.100	2,721	- 0.213	- 0.58
22 June 1984	1,530	0.100	1,956	0	0
6 July 1984	4,248	0.230	2,889	0.130	0.38
22 July 1984	6,120	0.167	5,184	- 0.063	- 0.33
6 Aug 1984	9,012	0.350	7,566	0.183	1.38
28 Aug 1984	7,992	0.147	8,502	- 0.203	- 1.73
6 Sep 1984	10,032	0.155	9,012	0.008	0.07
24 Sep 1984	9,690	0.155	9,861	0	0
26 Oct 1984	7,308	0.384	8,499	0.229	1.946
9 Nov 1984	4,422	0.513	5,865	0.129	0.76
15 Dec 1984	2,718	0.746	3,570	0.233	0.83
Total					5.37

$= 8.06\ g\ m.^{-2}\ yr^{-1}$

App. IV - 1

Mollusca - Pond 7

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2 - B_1 = D$	Production (P) = C x D
20 May 1984	2,208	0.400			
5 June 1984	2,040	0.710	2,124	0.310	0.658
22 June 1984	3,060	0.600	2,550	-0.090	- 0.230
6 July 1984	2,382	0.520	2,721	-0.080	- 0.218
22 July 1984	2,208	0.602	2,295	0.082	0.188
6 Aug 1984	2,382	0.300	2,295	- 0.302	- 0.693
22 Aug 1984	2,718	0.400	2,550	0.100	0.255
7 Sep 1984	2,718	0.600	27,180	0.200	5.436
24 Sep 1984	2,040	0.750	2,379	0.150	0.357
26 Oct 1984	2,040	0.880	2,040	0.130	0.265
9 Nov 1984	1,530	0.650	1,785	- 0.230	- 0.411
30 Nov 1984	1,020	0.600	1,275	- 0.050	- 0.064
15 Dec 1984	852	0.629	936	0.029	0.027
Total					7.19
					= 10.79g $m.^{-2} yr^{-1}$
5 March 1985	1,188	0.378			
20 March 1985	1,188	0.521	1,188	0.143	0.170
6 April 1985	1,362	0.412	1,275	-0.109	- 0.139
26 April 1985	2,718	0.382	2,040	- 0.030	- 0.061
10 May 1985	2,550	0.264	2,634	- 0.118	- 0.311
28 May 1985	2,382	0.272	2,466	0.008	0.020
14 June 1985	2,550	0.489	2,466	0.217	0.535
29 June 1985	2,718	0.474	2,634	- 0.015	- 0.040
14 July 1985	1,530	0.446	2,124	- 0.028	- 0.059
29 July 1985	3,228	0.296	2,379	- 0.150	- 0.357
14 Aug 1985	1,872	0.394	2,550	0.098	0.250
14 Sep 1985	2,382	0.283	2,127	- 0.111	- 0.236
14 Oct 1985	1,872	0.368	2,127	0.085	0.181
21 Nov 1985	1,530	0.367	1,701	- 0.001	- 0.002
19 Dec 1985	852	0.702	1,191	0.335	0.399
23 Jan 1986	1,188	0.566	1,020	- 0.136	- 0.139
Total					1.60
					= 1.75g $m.^{-2} yr^{-1}$

App. IV - 2

Mollusca - Pond 11

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	2,550	0.342			
5 June 1984	2,718	0.151	2,634	-0.173	-0.456
22 June 1984	3,060	0.286	2,889	0.135	0.390
6 July 1984	2,382	0.405	2,721	0.119	0.324
22 July 1984	1,020	1.324	1,701	0.919	1.563
6 Aug 1984	2,040	0.968	1,530	- 0.356	-0.545
22 Aug 1984	3,060	0.789	2,550	- 0.179	- 0.456
7 Sep 1984	2,040	0.679	2,550	- 0.110	- 0.281
24 Sep 1984	2,718	0.484	2,379	- 0.195	- 0.464
26 Oct 1984	3,060	0.185	2,889	- 0.299	- 0.864
9 Nov 1984	2,208	0.958	2,134	0.773	1.650
30 Nov 1984	2,550	0.664	2,379	- 0.294	- 0.699
15 Dec 1984	1,872	0.403	2,211	- 0.261	- 0.577
Total					3.93
					= 5.90g $m.^{-2} yr^{-1}$
5 March 1985	2,040	0.267			
20 March 1985	1,872	0.400	1,956	0.133	0.260
6 April 1985	1,698	0.421	1,785	0.021	0.037
26 April 1985	1,188	0.566	1,443	0.145	0.210
10 May 1985	2,550	0.257	1,869	- 0.309	- 0.578
14 June 1985	1,872	0.528	2,211	0.271	0.599
29 June 1985	3,402	0.396	2,637	- 0.132	- 0.348
14 July 1985	3,228	0.416	3,315	0.020	0.066
29 July 1985	2,892	0.464	3,060	0.048	0.147
14 Aug 1985	2,892	0.455	2,892	- 0.009	- 0.026
29 Aug 1985	3,228	0.579	3,060	0.124	0.379
14 Sep 1985	4,422	0.457	3,825	- 0.122	- 0.467
29 Sep 1985	4,080	0.385	4,251	- 0.072	- 0.306
14 Oct 1985	2,718	0.495	3,399	0.110	0.374
29 Oct 1985	2,892	0.461	2,805	- 0.034	- 0.095
21 Nov 1985	2,208	0.593	2,550	0.132	0.337
19 Dec 1985	1,872	0.503	2,040	- 0.090	- 0.184
23 Jan 1986	1,698	0.529	1,785	0.026	0.046
Total					2.46
					= 2.68g $m.^{-2} yr^{-1}$

App. IV - 3

Mollusca - Pond 13

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	4,590	0.341			
5 June 1984	3,402	0.231	3,996	- 0.110	- 0.440
22 June 1984	4,422	0.286	3,912	0.055	0.215
6 July 1984	3,402	0.443	3,912	0.157	0.614
22 July 1984	3,738	0.462	3,570	0.019	0.068
6 Aug 1984	3,060	0.543	3,399	0.081	0.275
22 Aug 1984	4,080	0.653	3,570	0.110	0.393
7 Sep 1984	4,248	0.549	4,164	- 0.104	- 0.433
24 Sep 1984	3,738	0.422	3,993	- 0.127	- 0.507
26 Oct 1984	2,550	0.809	3,144	0.387	1.217
30 Nov 1984	1,698	0.770	2,124	- 0.039	- 0.083
15 Dec 1984	1,872	0.660	1,785	- 0.011	- 0.196
Total					2.78
					= 4.17g.m.$^{-2}$yr^{-1}

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
5 March 1985	2,382	0.283			
20 March 1985	2,718	0.422	2,550	0.139	0.354
6 April 1985	1,362	0.419	2,040	- 0.003	- 0.006
26 April 1985	3,402	0.354	2,382	- 0.065	- 0.155
10 May 1985	4,590	0.532	3,996	0.178	0.711
28 May 1985	4,932	0.454	4,761	- 0.078	- 0.371
14 June 1985	4,080	0.390	4,506	- 0.064	- 0.288
29 June 1985	3,402	0.426	3,741	0.036	0.135
14 July 1985	2,892	0.487	3,147	0.061	0.192
29 July 1985	4,932	0.379	3,912	- 0.108	- 0.422
14 Aug 1985	2,550	0.819	3,741	0.440	0.118
29 Aug 1985	4,422	0.567	3,486	- 0.252	- 0.878
14 Sep 1985	4,590	0.504	4,506	- 0.063	- 0.284
29 Sep 1985	4,080	0.539	4,335	0.035	0.152
14 Oct 1985	3,228	0.630	3,654	0.091	0.333
21 Nov 1985	2,718	0.660	2,973	0.030	0.089
19 Dec 1985	2,550	0.614	2,634	- 0.046	- 0.121
23 Jan 1986	2,382	0.562	2,466	- 0.052	- 0.128
Total					2.08
					= 2.27g m.$^{-2}$yr^{-1}

App. IV - 4

Mollusca - Pond 14

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	2,550	0.225			
5 June 1984	2,208	0.623	2,379	0.398	0.947
22 June 1984	2,550	0.330	2,379	-0.293	-0.697
6 July 1984	3,060	0.203	2,805	-0.127	-0.356
22 July 1984	2,892	0.462	2,976	0.259	0.770
6 Aug 1984	3,060	0.462	2,976	0	0
22 Aug 1984	1,530	1.089	2,295	0.627	1.439
7 Sep 1984	3,228	0.330	2,379	-0.759	-1.806
24 Sep 1984	2,382	0.722	2,805	0.392	1.099
26 Oct 1984	2,040	0.729	2,211	0.007	0.015
9 Nov 1984	1,020	0.704	1,530	-0.025	-0.038
30 Nov 1984	1,188	0.319	1,104	-0.385	-0.425
15 Dec 1984	852	0.484	1,020	0.165	0.168
Total					4.44
					$= 6.66g\ m.^{-2}yr^{-1}$
5 March 1985	1,872	0.272			
20 March 1985	1,188	0.297	1,530	0.025	0.038
6 April 1985	678	1.136	933	0.839	0.783
26 April 1985	1,362	1.318	1,020	0.182	0.186
10 May 1985	2,550	0.526	1,956	-0.792	-1.549
14 June 1985	4,080	0.429	3,315	-0.097	-0.322
29 June 1985	3,738	0.456	3,909	0.027	0.106
14 July 1985	2,550	0.453	3,144	-0.003	-0.009
29 July 1985	3,228	0.460	2,889	0.007	0.020
14 Aug 1985	2,208	0.792	2,718	0.332	0.902
29 Aug 1985	2,718	0.524	2,463	-0.268	-0.660
14 Sep 1985	2,718	0.405	2,718	-0.119	-0.323
29 Sep 1985	2,040	0.466	2,379	0.061	0.145
14 Oct 1985	2,040	0.764	2,040	0.298	0.608
29 Oct 1985	1,530	0.873	1,785	0.109	0.195
21 Nov 1985	1,362	0.646	1,446	-0.227	-0.328
19 Dec 1985	1,020	0.726	1,191	0.080	0.095
23 Jan 1986	678	1.096	849	0.370	0.314
Total					3.39
					$= 3.70g\ m.^{-2}yr^{-1}$

App. IV - 5

Mollusca - Pond 9

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	342	0.439			
5 June 1984	1,020	0.746	681	0.307	0.209
22 June 1984	342	0.439	681	- 0.307	- 0.209
6 July 1984	1,698	0.514	1,020	0.075	0.077
22 July 1984	510	0.463	1,104	- 0.051	- 0.056
6 Aug 1984	1,188	0.264	849	- 0.199	- 0.169
22 Aug 1984	678	0.746	933	0.482	0.482
7 Sep 1984	852	0.495	765	- 0.251	- 0.251
24 Sep 1984	1,020	0.330	936	- 0.165	- 0.154
26 Oct 1984	1,020	0.724	1,020	0.394	0.402
9 Nov 1984	342	0.705	681	- 0.019	0.013
15 Dec 1984	168	1.268	255	0.563	0.144
Total					1.33

$= 2.0 g.m.^{-2} yr^{-1}$

App. V - 1

Hirudinea - Pond 7

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	1,362	0.550			
5 June 1984	1,530	0.575	1,446	0.025	0.036
22 June 1984	1,188	0.600	1,359	0.025	0.034
6 July 1984	852	0.415	1,020	-0.085	-0.087
22 July 1984	1,362	0.550	1,107	0.035	0.039
6 Aug 1984	1,362	0.800	1,362	0.250	0.340
22 Aug 1984	2,718	0.167	2,040	-0.633	-1.291
7 Sep 1984	2,718	0.760	2,718	0.593	1.612
24 Sep 1984	1,362	0.780	2,040	0.020	0.040
26 Oct 1984	1,188	0.500	1,275	-0.280	-0.357
9 Nov 1984	852	0.500	1,020	0	0
30 Nov 1984	510	0.700	681	0.200	0.136
15 Dec 1984	852	0.400	681	-0.300	-0.204
Total					2.24
					$= 3.36 g.m.^{-2} yr.^{-1}$
5 March 1985	1,530	0.240			
20 March 1985	1,872	0.330	1,701	0.090	0.153
6 April 1985	1,530	0.330	1,701	0	0
26 April 1985	1,698	0.170	1,614	-0.160	-0.258
10 May 1985	2,550	0.550	2,124	0.380	0.807
28 May 1985	1,698	0.475	2,124	-0.075	-0.159
14 June 1985	2,040	0.400	1,869	-0.075	-0.140
29 June 1985	1,362	0.320	0,701	-0.080	-0.136
14 July 1985	1,362	0.240	1,362	-0.080	-0.109
29 July 1985	2,382	0.428	1,872	0.188	0.352
14 Aug 1985	1,872	0.600	2,127	0.172	0.366
14 Sep 1985	2,550	0.600	2,211	0	0
14 Oct 1985	2,040	0.697	2,295	0.097	0.223
21 Nov 1985	1,530	0.460	1,785	-0.237	-0.423
19 Dec 1985	1,188	0.444	1,359	-0.016	-0.0217
23 Jan 1986	1,020	0.409	1,104	-0.035	-0.039
Total					1.90
					$= 2.07 g.m.^{-2} yr^{-1}$

App. V - 2

Hirudinea - Pond 11

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	6,120	0.550			
5 June 1984	2,892	0.575	4,506	0.025	0.113
22 June 1984	9,180	0.600	6,036	0.025	0.151
6 July 1984	4,932	0.415	7,056	-0.085	-0.600
22 July 1984	6,120	0.230	5,526	-0.185	-1.022
6 Aug 1984	8,328	0.250	7,224	0.020	0.144
22 Aug 1984	10,200	0.250	9,264	0	0
7 Sep 1984	11,730	0.095	10,965	-0.155	-1.699
24 Sep 1984	10,542	0.510	11,136	0.415	4.621
26 Oct 1984	5,778	0.510	8,160	0	0
9 Nov 1984	5,100	1.066	5,439	0.556	3.024
30 Nov 1984	2,892	0.465	3,996	-0.601	-2.402
15 Dec 1984	3,228	0.254	3,060	-0.211	-0.646
Total					8.05
					$= 12.08 g.m.^{-2} yr^{-1}$
5 March 1985	3,402	0.240			
20 March 1985	9,012	0.330	6,207	0.090	0.559
6 April 1985	10,542	0.330	9,777	0	0
26 April 1985	12,750	0.270	11,646	-0.060	-0.699
10 May 1985	7,140	0.550	9,945	0.280	2.785
14 June 1985	5,100	0.400	6,120	-0.150	-0.918
29 June 1985	4,248	0.320	4,674	-0.080	-0.374
14 July 1985	3,738	0.240	3,993	-0.080	-0.319
29 July 1985	2,550	0.420	3,144	0.180	0.566
24 Aug 1985	7,140	0.600	4,845	0.180	0.872
29 Aug 1985	10,368	0.250	8,754	-0.350	-3.064
14 Sep 1985	9,180	0.600	9,774	0.350	3.421
29 Sep 1985	6,798	0.649	7,989	0.049	0.391
14 Oct 1985	5,100	0.697	5,949	0.048	0.286
29 Oct 1985	2,208	0.490	3,654	-0.207	-0.756
21 Nov 1985	3,402	0.460	2,805	-0.030	-0.084
19 Dec 1985	2,550	0.444	2,976	-0.016	-0.048
23 Jan 1986	1,872	0.409	2,211	-0.035	-0.077
Total					8.88
					$= 9.69 g.m.^{-2} yr^{-1}$

App. V - 3

Hirudinea - Pond 13

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2 - B_1 = D$	Production (P) = C x D
20 May 1984	2,208	0.550			
5 June 1984	2,208	0.575	2,208	0.025	0.055
22 June 1984	2,040	0.600	2,124	0.025	0.053
6 July 1984	678	0.414	1,359	-0.186	-0.253
22 July 1984	2,550	0.400	1,614	-0.014	-0.023
6 Aug 1984	1,872	0.700	2,211	0.300	0.663
22 Aug 1984	2,892	0.500	2,382	-0.200	-0.476
7 Sep 1984	2,718	0.500	2,805	0	0
24 Sep 1984	3,060	0.970	2,889	0.470	1.358
26 Oct 1984	2,208	0.600	2,634	-0.370	-0.975
30 Nov 1984	1,698	0.500	1,953	-0.100	-0.195
15 Dec 1984	1,020	0.500	1,359	0	0
Total					2.13
					= 3.20g.m.$^{-2}$yr^{-1}
5 March 1985	2,040	0.240			
20 March 1985	1,872	0.330	1,956	0.090	0.176
6 April 1985	3,228	0.330	2,550	0	0
26 April 1985	2,040	0.270	2,634	-0.060	-0.156
10 May 1985	1,872	0.550	1,956	0.280	0.548
28 May 1985	1,188	0.475	1,530	-0.075	-0.115
14 June 1985	2,040	0.400	1,614	-0.075	-0.121
29 June 1985	1,367	0.319	1,704	-0.081	-0.138
14 July 1985	1,367	0.309	1,367	-0.010	-0.014
29 July 1985	1,188	0.420	1,278	0.111	0.142
14 Aug 1985	2,892	0.600	2,040	0.180	0.367
29 Aug 1985	2,550	0.643	2,721	0.043	0.117
14 Sep 1985	2,550	0.600	2,550	-0.043	-0.110
20 Sep 1985	1,872	0.649	2,211	0.049	0.108
14 Oct 1985	1,872	0.697	1,872	0.048	0.090
21 Nov 1985	1,362	0.460	1,617	-0.237	-0.383
19 Dec 1985	1,020	0.444	1,191	-0.016	-0.019
23 Jan 1986	1,020	0.409	1,020	-0.035	-0.036
Total					1.55
					= 1.69g m.$^{-2}$yr^{-1}

App. V - 4

Hirudinea - Pond 14

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	2,892	0.550			
5 June 1984	3,060	0.575	2,976	0.025	0.074
22 June 1984	3,060	0.600	3,060	0.025	0.077
6 July 1984	2,550	0.415	2,805	-0.085	-0.238
22 July 1984	4,080	0.230	3,315	-0.185	-0.613
6 Aug 1984	6,120	0.969	5,100	0.739	3.769
22 Aug 1984	7,140	0.500	6,630	-0.469	-3.109
7 Sep 1984	3,402	1.032	5,271	0.532	2.804
24 Sep 1984	4,932	0.943	4,167	-0.089	-0.371
26 Oct 1984	3,402	0.300	4,167	-0.643	-2.679
9 Nov 1984	2,892	0.409	3,147	0.109	0.343
30 Nov 1984	3,060	0.700	2,976	0.291	0.866
15 Dec 1984	2,040	0.688	2,550	-0.012	-0.031
Total					7.93
					$11.90 g.m.^{-2} yr^{-1}$
5 March 1985	3,738	0.160			
20 March 1985	3,402	0.330	3,570	0.170	0.607
6 April 1985	5,100	0.330	4,251	0	0
24 April 1985	5,100	0.640	5,100	0.310	1.581
10 May 1985	3,738	0.550	3,570	-0.090	-0.321
14 June 1985	2,040	0.400	2,889	-0.150	-0.433
29 June 1985	2,382	0.320	2,661	-0.080	-0.213
14 July 1985	2,040	0.289	2,661	-0.031	-0.082
29 July 1985	3,228	0.420	2,634	0.131	0.345
14 Aug 1985	5,778	0.600	4,503	0.180	0.811
29 Aug 1985	4,248	0.722	5,013	0.122	0.612
14 Sep 1985	3,912	0.600	4,080	-0.122	-0.498
29 Sep 1985	4,248	0.649	4,080	0.049	0.200
14 Oct 1985	1,362	0.698	2,805	0.049	0.137
29 Oct 1985	4,248	0.490	2,805	-0.208	-0.583
21 Nov 1985	2,208	0.460	3,228	-0.030	-0.097
19 Dec 1985	1,698	0.445	1,953	-0.015	-0.029
23 Jan 1986	1,020	0.507	1,359	0.062	0.084
Total					4.38
					$= 4.78 g m.^{-2} yr^{-1}$

App. V - 5

Hirudinea - Pond 9

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	1,020	0.550			
5 June 1984	1,188	0.575	1,104	0.025	0.028
22 June 1984	1,020	0.600	1,104	0.025	0.028
6 July 1984	1,188	0.415	1,104	- 0.185	-0.204
22 July 1984	1,020	0.250	1,104	- 0.165	-0.182
6 Aug 1984	852	0.500	1,530	0.250	0.383
22 Aug 1984	2,382	0.433	1,617	- 0.067	- 0.108
7 Sep 1984	1,188	1.022	1,785	1,589	1.051
29 Sep 1984	1,530	0.367	1,359	- 0.655	-0.890
26 Oct 1984	1,362	0.550	1,446	0.183	0.265
9 Nov 1984	1,188	0.500	1,275	- 0.050	-0.064
15 Dec 1984	510	0.400	849	- 0.100	- 0.085
Total					1.76

$= 2.64 g\ m.^{-2} yr^{-1}$

App. VI - 1

Asellidae - Pond 7

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	168	1.880			
5 June 1984	168	1.400	168	- 0.480	- 0.080
22 June 1984	852	1.550	510	0.150	0.077
6 July 1984	510	1.670	681	0.120	0.082
22 July 1984	678	1.400	594	- 0.370	- 0.220
6 Aug 1984	852	1.367	765	- 0.033	- 0.025
22 Aug 1984	1,020	1.500	936	0.133	0.124
7 Sep 1984	510	1.567	765	0.067	0.051
24 Sep 1984	342	1.301	426	- 0.266	- 0.113
26 Oct 1984	342	0.792	342	- 0.509	- 0.174
9 Nov 1984	342	0.301	342	- 0.491	- 0.168
30 Nov 1984	168	1.101	255	0.800	0.204
15 Dec 1984	168	1.202	168	0.101	0.017
Total					0.56

= 0.84g m.$^{-2}$ yr^{-1}

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
5 March 1985	510	0.820			
20 March 1985	342	0.851	426	0.031	0.013
6 April 1985	510	1.980	426	1.129	0.481
26 April 1985	678	2.642	594	0.662	0.393
10 May 1985	1,020	0.500	849	- 2.142	- 1.819
28 May 1985	852	0.899	936	0.399	0.373
14 June 1985	852	0.600	852	-0.299	- 0.255
29 June 1985	510	0.900	681	0.300	0.204
14 July 1985	678	1.100	594	0.200	0.119
29 July 1985	342	1.251	510	0.151	0.077
14 Aug 1985	342	2.780	342	1.529	0.523
14 Sep 1985	510	1.186	426	- 1.594	- 0.679
14 Oct 1985	1,188	0.481	849	0.295	0.250
21 Nov 1985	852	1.147	985	- 0.334	- 0.329
19 Dec 1985	510	1.700	681	0.553	0.377
23 Jan 1986	510	1.300	510	- 0.400	- 0.204
Total					2.81

= 3.07g m.$^{-2}$ yr^{-1}

App. VI- 2

Asellidae - Pond 11

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	678	1.250			
5 June 1984	1,362	1.400	1,020	0.150	0.153
22 June 1984	342	1.550	852	0.150	0.128
6 July 1984	510	1.100	426	- 0.450	- 0.192
22 July 1984	678	1.549	594	0.449	0.267
6 Aug 1984	1,188	1.250	933	- 0.299	- 0.279
22 Aug 1984	1,020	1.500	1,104	0.250	0.276
7 Sep 1984	678	1.723	849	0.223	0.189
24 Sep 1984	1,362	1.300	1,020	- 0.423	- 0.431
26 Oct 1984	852	0.500	1,107	0.200	0.221
9 Nov 1984	342	0.886	597	- 0.386	- 0.230
30 Nov 1984	678	0.600	510	- 0.286	- 0.146
15 Dec 1984	342	1.567	510	- 0.033	- 0.017
Total					1.46
					= 2.19g.m.$^{-2}$yr^{-1}
5 March 1985	678	0.820			
20 March 1985	852	0.850	765	0.030	0.023
6 April 1985	1,020	1.981	936	1.131	1.059
26 April 1985	342	2.640	681	0.659	0.449
10 May 1985	1,020	0.500	681	-2.140	-1.457
14 June 1985	342	0.895	681	0.395	0.269
29 June 1985	852	0.900	597	0.005	0.003
14 July 1985	510	1.100	681	0.200	0.136
29 July 1985	678	1.251	594	0.151	0.090
14 Aug 1985	678	2.780	678	1.529	1.037
29 Aug 1985	678	4.029	678	1.249	0.847
14 Sep 1985	1,530	1.186	1,104	-2.843	- 3.139
29 Sep 1985	1,367	1.394	1,449	0.208	0.301
14 Oct 1985	1,020	1.481	1,194	0.087	0.104
29 Oct 1985	852	1.0	936	- 0.481	- 0.450
21 Nov 1985	678	1.60	765	0.600	0.459
19 Dec 1985	342	1.699	510	0.099	0.050
23 Jan 1986	510	1.700	426	0.001	0.0004
Total					4.83
					= 5.27g.m.$^{-2}$yr^{-1}

App. VI - 3

Asellidae - Pond 13

Date	Ai	Bi	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	852	1.250			
5 June 1984	342	1.400	597	0.150	0.090
22 June 1984	678	1.550	510	0.150	0.077
6 July 1984	1,020	0.835	849	- 0.715	-0.607
22 July 1984	342	1.400	681	0.565	0.385
6 Aug 1984	1,367	1.246	855	- 0.154	-0.132
22 Aug 1984	678	1.500	1,023	0.254	0.260
7 Sep 1984	510	1.567	594	0.067	0.040
24 Sep 1984	1,188	1.300	849	- 0.267	-0.227
26 Oct 1984	342	1.085	765	- 0.215	-0.164
30 Nov 1984	342	1.287	342	0.002	0.0007
15 Dec 1984	510	1.400	426	0.113	0.048
Total					0.90

= 1.35g.m.$^{-2}$yr^{-1}

Date	Ai	Bi	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
5 March 1985	342	0.819			
20 March 1985	1,362	0.850	852	0.031	0.026
6 April 1985	852	1.981	1,107	1.131	1.252
26 April 1985	168	2.643	510	0.662	0.338
10 May 1984	1,188	0.477	678	- 2.166	-1.469
28 May 1985	1,530	0.900	1,359	0.423	0.575
14 June 1985	1,362	0.600	1,446	-0.300	-0.434
29 June 1985	1,020	0.900	1,191	0.300	0.357
14 July 1985	342	1.099	681	0.199	0.136
29 July 1985	1,530	1.250	936	0.151	0.141
14 Aug 1985	342	2.778	936	1.528	1.430
29 Aug 1985	1,362	2.015	852	-0.763	-0.650
14 Sep 1985	1,188				
29 Sep 1985	1,872	0.717	1.617	-1.298	-2.099
14 Oct 1985	1,362	1.924	1,617	1.207	1.952
21 Nov 1985	1,188	1.600	1,275	-0.324	-0.413
19 Dec 1985	852	1.700	1,020	0.100	0.102
23 Jan 1986	510	1.500	681	-0.200	-0.136
Total					6.31

= 6.88g.m.$^{-2}$yr^{-1}

App. VI - 4

Asellidae - Pond 13

Date	A	B.	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	342	1.251			
5 June 1984	342	1.520	342	0.269	0.092
22 June 1984	342	1.842	342	0.322	0.110
6 July 1984	510	1.867	426	0.025	0.011
22 July 1984	510	1.825	510	-0.042	-0.021
6 Aug 1984	510	1.251	510	-0.574	-0.293
22 Aug 1984	678	1.333	594	0.082	0.049
7 Sep 1984	678	1.516	678	0.183	0.124
24 Sep 1984	342	0.836	510	0.320	0.163
26 Oct 1984	510	0.500	426	-0.336	-0.143
9 Nov 1984	168	2.679	339	2.179	0.739
30 Nov 1984	510	1.700	339	-0.979	-0.332
15 Dec 1984	168	1.565	339	-0.135	-0.046
Total					1.29
					= 1.94g $m.^{-2}yr^{-1}$
5 March 1985	342	1.110			
20 March 1985	342	0.850	342	-0.260	-0.089
6 April 1985	510	1.980	426	1.130	0.481
26 April 1985	342	2.640	426	0.660	0.281
10 May 1985	1,020	0.598	681	-2.042	-1.391
14 June 1985	1,188	0.429	1,104	-0.169	-0.187
29 June 1985	1,020	0.939	1,104	0.510	0.563
14 July 1985	852	1.100	936	0.161	0.151
29 July 1985	678	1.192	765	0.092	0.070
14 Aug 1985	342	2.778	510	1.586	0.809
29 Aug 1985	510	4.024	426	1.246	0.531
14 Sep 1985	1,020	1.185	765	-2.839	-2.172
29 Sep 1985	1,362	1.400	1,191	0.215	0.256
14 Oct 1985	852	1.480	1,107	0.080	0.089
29 Oct 1985	678	1.000	765	-0.480	-0.367
21 Nov 1985	678	1.600	678	0.600	0.407
19 Dec 1985	168	2.893	423	1.293	0.547
23 Jan 1986	342	1.699	255	-1.194	-0.304
Total					4.19
					= 4.57g $m.^{-2}yr^{-1}$

App. VI - 5

Asellidae - Pond 9

Date	A	B	$\frac{A_1+A_2}{2} = C$	$B_2-B_1 = D$	Production (P) = C x D
20 May 1984	168	1.250			
5 June 1984	342	1.400	255	0.150	0.038
22 June 1984	342	1.550	342	0.150	0.051
6 July 1984	168	6.679	255	5.129	1.308
22 July 1984	678	1.401	423	-5.278	-2.233
6 Aug 1984	852	1.25	765	-0.151	-0.116
22 Aug 1984	510	2.106	681	0.856	0.583
7 Sep 1984	678	0.656	594	1.450	0.861
24 Sep 1984	510	0.335	594	-0.321	-0.191
26 Oct 1984	342	0.447	426	0.112	0.048
9 Nov 1984	510	0.300	426	-0.147	-0.063
15 Dec 1984	168	1.202	339	0.902	0.306
Total					3.20

$= 4.80 g\ m.^{-2} yr^{-1}$

App. VII - 1

Sialidae - Pond 7

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	678	3.400			
5 June 1984	1,020	3.250	849	- 0.150	-0.127
22 June 1984	852	1.700	936	- 1.550	-1.451
6 July 1984	678	2.350	765	0.650	0.497
22 July 1984	2,382	1.000	1,530	- 1.350	-2.066
6 Aug 1984	1,020	2.050	1,701	1.050	1.786
22 Aug 1984	1,362	1.800	1,191	- 0.250	-0.298
7 Sep 1984	852	2.000	1,107	0.200	0.221
24 Sep 1984	1,020	3.535	936	1.535	1.437
26 Oct 1984	852	2.700	936	- 0.835	-0.782
9 Nov 1984	1,020	4.133	936	1.433	1.341
30 Nov 1984	510	2.300	765	- 1.833	-1.402
15 Dec 1984	342	3.099	426	0.799	0.340
Total					5.62
					= 8.43g m.$^{-2}$yr^{-1}
5 March 1985	342	4.333			
20 March 1985	168	3.768	255	- 0.565	-0.144
6 April 1985	510	3.200	339	- 0.568	-0.193
26 April 1985	342	5.099	426	1.899	0.809
10 May 1985	678	1.701	510	- 3.398	-1.733
28 May 1985	1,020	2.000	849	0.299	0.254
14 June 1985	1,188	1.795	1,104	- 0.205	- 0.226
29 June 1985	1,020	2.500	1,104	0.705	0.778
14 July 1985	2,208	1.745	1,614	- 0.705	-1.138
29 July 1985	1,188	4.059	1,698	2.314	3.929
14 Aug 1985	1,362	4.028	1,275	- 0.031	-0.040
14 Sep 1985	1,020	2.400	1,191	- 1.628	-1.940
14 Oct 1985	852	2.700	936	0.307	0.281
21 Nov 1985	678	2.300	765	- 0.400	-0.306
19 Dec 1985	342	4.251	510	1.551	0.791
23 Jan 1986	342	5.099	342	0.848	0.290
Total					7.13
					= 7.78g m.$^{-2}$yr^{-1}

App. VII - 2

Sialidae - Pond 11

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	510	5.10			
5 June 1984	1,362	1.831	936	- 3.269	-3.060
22 June 1984	1,362	1.273	1,362	- 0.558	- 0.760
6 July 1984	1,362	2.396	1,362	1.123	1.530
22 July 1984	1,530	1.773	1,446	0.740	1.070
6 Aug 1984	852	3.927	1,191	2.154	2.565
22 Aug 1984	1,020	1.800	936	- 2.127	-1.991
7 Sep 1984	1,362	2.247	1,191	0.447	0.532
24 Sep 1984	678	3.535	1,020	1.288	1.314
26 Oct 1984	678	4.062	678	0.527	0.357
9 Nov 1984	510	4.329	594	0.267	0.159
30 Nov 1984	510	2.300	510	- 0.029	-0.015
15 Dec 1984	342	3.099	426	0.799	0.340
Total					7.87
					= 11.81g m.$^{-2}$yr^{-1}
5 March 1985	342	4.333			
20 March 1985	510	3.767	426	- 0.566	- 0.241
6 April 1985	342	3.199	426	- 0.568	- 0.242
26 April 1985	678	4.804	510	1.605	0.819
10 May 1985	678	1.700	670	- 3.104	- 2.080
14 June 1985	1,020	2.300	849	0.600	0.509
29 June 1985	1,362	2.500	1,191	0.200	0.238
14 July 1985	1,362	2.650	1,362	0.150	0.204
29 July 1985	1,362	3.325	1,362	0.675	0.919
14 Aug 1985	1,530	3.506	1,446	0.181	0.262
29 Aug 1985	678	3.934	1,104	0.428	0.473
14 Sep 1985	510	2.400	594	- 1.534	- 0.911
29 Sep 1985	1,530	2.550	1,020	0.150	0.153
14 Oct 1985	852	2.817	1,191	0.267	0.318
29 Oct 1985	510	2.500	681	- 0.317	- 0.216
21 Nov 1985	678	2.300	594	- 0.200	- 0.119
19 Dec 1985	510	4.447	594	2.147	1.275
23 Jan 1986	510	4.708	510	0.261	0.133
Total					5.30
					= 5.78g m.$^{-2}$yr^{-1}

App. VII - 3

Sialidae - Pond 13

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	678	4.299			
5 June 1984	1,188	3.726	933	- 0.573	-0.535
22 June 1984	1,188	1.949	1,188	- 1.777	-2.111
6 July 1984	1,367	2.116	1,278	0.167	0.213
22 July 1984	2,040	1.000	1,704	- 1.116	-1.902
6 Aug 1984	1,188	2.050	1,614	1.050	1.695
22 Aug 1984	1,530	1.735	1,359	- 0.315	- 0.428
7 Sep 1984	1,188	2.000	1,359	0.265	0.360
24 Sep 1984	1,188	3.535	1,188	1.535	1.824
26 Oct 1984	852	2.700	1,020	- 0.865	-0.882
30 Nov 1984	342	2.301	597	- 0.399	-0.238
15 Dec 1984	168	3.696	255	1.395	0.356
Total					4.45
					= 6.68g $m.^{-2}yr^{-1}$
5 March 1985	678	4.378			
20 March 1985	510	3.963	594	- 0.415	- 0.247
6 April 1985	678	3.200	594	- 0.763	- 0.453
26 April 1985	678	5.395	678	2.195	1.488
10 May 1985	678	1.848	678	- 3.547	- 2.405
28 May 1985	1,362	2.000	1,020	0.152	0.155
14 June 1985	1,530	2.300	1,446	0.300	0.434
29 June 1985	1,698	2.500	1,614	0.200	0.323
14 July 1985	1,188	2.650	1,443	0.150	0.216
29 July 1985	1,872	4.059	1,530	1.409	2.156
14 Aug 1985	2,040	3.996	1,956	- 0.063	- 0.123
29 Aug 1985	510	3.933	1,275	- 0.063	- 0.080
14 Sep 1985	852	2.400	681	- 1.533	- 1.044
29 Sep 1985	1,362	2.550	1,107	0.150	0.166
14 Oct 1985	852	2.700	1,107	0.150	0.166
21 Nov 1985	510	2.300	681	- 0.400	- 0.272
19 Dec 1985	342	4.251	426	1.951	0.831
23 Jan 1986	342	5.099	342	0.848	0.290
Total					6.23
					= 6.80g $m.^{-2}yr^{-1}$

App. VII - 4

Sialidae - Pond 14

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	852	2.950			
5 June 1984	1,020	3.250	936	0.300	0.281
22 June 1984	1,020	1.700	1,020	- 0.155	- 0.158
6 July 1984	1,188	2.350	2,208	0.650	1.435
22 July 1984	1,188	1.000	1,188	- 1.350	- 1.604
6 Aug 1984	1,362	2.049	1,275	1.049	1.337
22 Aug 1984	1,530	1.800	1,446	- 0.249	- 0.360
7 Sep 1984	678	2.000	1,104	0.200	0.221
24 Sep 1984	1,530	3.535	1,104	1.535	1.695
26 Oct 1984	1,020	2.700	1,275	- 0.835	- 1.065
9 Nov 1984	510	4.133	765	1.433	1.096
30 Nov 1984	1,362	2.300	936	- 1.833	- 1.716
15 Dec 1984	510	3.100	936	0.800	0.749
Total					6.82

= 10.23g $m.^{-2} yr^{-1}$

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
5 March 1985	168	4.333			
20 March 1985	510	3.767	339	- 0.566	- 0.192
6 April 1985	1,020	3.200	765	- 0.567	- 0.434
10 May 1985	1,020	1.700	1,020	- 1.500	- 1.530
14 June 1985	1,188	1.460	1,104	- 0.240	- 0.265
29 June 1985	1,188	2.500	1,188	1.040	1.236
14 July 1985	1,020	2.650	1,104	0.150	0.166
29 July 1985	1,362	2.590	1,191	- 0.060	- 0.071
14 Aug 1985	1,362	3.997	1,362	1.407	1.916
29 Aug 1985	1,020	3.933	1,191	- 0.064	- 0.076
14 Sep 1985	1,188	2.400	1,104	- 1.533	- 1.692
29 Sep 1985	1,188	2.550	1,188	0.150	0.178
14 Oct 1985	678	2.700	933	0.150	0.140
29 Oct 1985	1,362	2.499	1,020	- 0.201	- 0.205
21 Nov 1985	852	2.300	1,107	- 0.199	- 0.220
19 Dec 1985	510	4.251	681	1.951	1.329
23 Jan 1986	510	5.100	510	0.849	0.433
Total					5.40

= 5.89g $m.^{-2} yr^{-1}$

App. VII - 5

Sialidae - Pond 9

Date	A	B	$\frac{A_1+A_2}{2}$ = C	B_2-B_1 = D	Production (P) = C x D
20 May 1984	168	3.405			
5 June 1984	168	3.250	168	0.155	0.026
22 June 1984	168	3.405	168	0.155	0.026
6 July 1984	342	2.351	255	- 1.054	-0.269
22 July 1984	342	2.0	342	- 0.351	-0.120
6 Aug 1984	342	2.050	342	0.050	0.017
22 Aug 1984	678	1.799	510	- 0.251	-0.128
7 Sep 1984	1,020	2.0	849	0.201	0.171
24 Sep 1984	510	3.54	765	1.54	1.178
26 Oct 1984	342	2.699	426	- 0.871	-0.371
9 Nov 1984	342	4.135	342	1.436	0.491
15 Dec 1984	168	3.101	255	- 1.034	-0.264
Total					1.91

= 2.87 g m.$^{-2}$ yr^{-1}

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