BIOMANIPULATION OF THE ECOLOGY OF EARTH PONDS TO STIMULATE THE PRODUCTION OF BROWN TROUT (*Salmo trutta* L.)

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By

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DEDICATION

This thesis is most affectionately
dedicated to my children

Whose precotious nature helped me
transcend thinking without loosing
my commitment to science.

ABSTRACT

A study of various biomanipulation strategies to maximize plankton and macroinvertebrate production in earthen ponds for the benefit of cultured brown trout, *Salmo trutta* L., was carried out in the Howietoun fishery in Central Scotland between March 1988 and January 1990. During the first year, replicate ponds were treated with low and high phosphorus only (LP, HP), high phosphorus and nitrogen (HPN), low and high chicken (LC, HC), high chicken and cow manure (HCC), with two untreated controls (CTRL). The effect of treatments on physico-chemical parameters of pond water and soil, suitable for trout culture was also evaluated; along with primary production.

All the inorganic treatments produced significantly more Bacillariophyceae, Chlorophyceae and Cyanophyceae than the CTRL, but HPN produced vastly more algae than the others. All inorganic treatments stimulated zooplankton, but the advantage of HPN was far less significant than with algae. The organic trials responded to all treatments, but more positively to HC & HCC in the zooplankton. The role of decaying plankton and organic organic manure as sources of detritus and carbon, providing nutrients for optimum biological production, is discussed.

The application of HC and combination of HCC gave the highest benthos production, with the dominant groups encountered in the order: Oligochaeta > Chironomidae > Asellidae > Sialidae > Hirudinea > Mollusca, all eaten by trout. Total abundance, biomass and dry weight production

production estimates during the 6 month's culture period were in the range, 3.51-134 x 10^3 ind. m^{-2}, 26-113 g m^{-2} and 14.7-70 g dry wt m^{-2} respectively. Nutritional composition varied among the natural groups, but was well within nutrient requirements for cultured trout. Aquatic macrophytes in some ponds favoured production of Asellidae, Mollusca and lately, Gammaridae, presumably due to greater three-dimensional surface area which influences development of plankton.

Overall fish growth response conformed to a seasonal cycle, and significantly varied between the CTRL and ponds that received the same fertilizer treatments (HPN, HC and HCC). Highest annual production estimates of 619.7 kg ha^{-1} yr^{-1} and 1439.6 kg ha^{-1} yr^{-1} was obtained in the HCC, pond 1 (fed natural food only) and CTRL pond 8 (fed artificial pelleted diet, with supplemental natural food) respectively. The beneficial effects on abundance and biomass of plankton and benthos exerted by the fertilization treatments, compatible with adequate water quality for salmonids, is examined in relation to feeding conditions and growth of juvenile trout stocked at various densities during the following summer. Cost-benefit analysis of the controlled and manured culture conditions shows that for each pound spent, a benefit or economic impact of £3 : 78 and £6 : 40 respectively is derived. Practical management implications and economic considerations of pond ecosystem manipulation under both temperate and tropical conditions are discussed in the light of the present findings.

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CHAPTER ONE

INTRODUCTION

1.1. GENERAL INTRODUCTION

The biomanipulation and productivity of an aquatic ecosystem in relationship to human food production, especially protein, is of crucial importance to aquaculturists. Aquatic ecosystems could be natural or man-made earthern ponds, concrete tanks or dams. In recent years, there has been growing interest amongst scientists towards proper resource development, management and rehabilitation of oligotrophic and hypertrophic aquatic ecosystems. Unlike the temperate regions, where numerous limnological works have been carried out, in the tropics such studies and reports with special reference to nutrient levels, water quality characteristics, benthic ecology and primary and secondary production have been scanty. Even in temperate regions, past efforts have been limited to fundamental research on natural water bodies, and little effort has been focused on manipulation of aquaculture systems.

Mori & Ikushima (1980), Maitland (1981), Lennan *et al* (1985), Boyd (1979, 1986), Stirling (1985) all stressed the importance of more systematic studies to provide adequate knowledge of the dynamics of water quality characteristics. These are useful tools in the proper management, utilization and expansion of aquacultural production under both semi-intensive and extensive conditions. The goal of rational pond management is therefore, to fully utilise the existing ecological niches in the pond, in addition to supplementary feed, to produce fish to its optimum carrying capacity.

Based on limnological data obtained, it is possible to evaluate and manipulate ecological conditions in aquatic ecosystems for increased production. These could also be integrated in various disciplines connected with aquatic resource development. Such data are also useful for monitoring pollution connected with aquaculture and public health. Muir & Beveridge (1987) have observed that aquaculture development, though generally desirable socio-economically, has considerable implications for water resource use. These include low gross production value and possible high pollution potential compared with many other agricultural and industrial uses. Therefore, aquaculture integration with other activities is likely to be the most effective means of development. This can be accomplished by sharing water use or enhancing its value sufficiently to allow investment in improved water supply or treatment.

Although the concept of integrated aquaculture with other activities like crop and animal husbandry is not new, the current worldwide trend is towards intensive culture, with emphasis on complex and more often, expensive technology, high energy and resource inputs and specialisation. Several studies have demonstrated the dietary importance of invertebrates to trout in natural environments (eg Maitland, 1965; Macan 1966; Berglund, 1968, 1982; Hepher, 1988; Wahab *et al.*, 1989 and Stirling & Wahab, 1990). the role of benthos in waste management is also well recognised

(Kirk, 1971; Sabine, 1978; Aston & Milner, 1981) and these organisms on harvesting represent valuable foodstuffs suitable for feeding fish directly or incorporated in artificially formulated diets.

Although the problems outlined above may prove to be only a manifestation of conditions not subject to direct resolution, it is important that problem definition be directed towards areas that can be easily applied for the benefit of mankind (Bardach, 1986; McSweeny, 1986; Little & Muir 1987).

1.2 WATER QUALITY

Water quality parameters play a significant role in management procedures of aquatic ecosystems. The ultimate goal of environmental research in aquaculture, firstly, is to develop quantitative methods for predicting the effects of environmental manipulations on fish culture, and, secondly, to devise management procedures which will predictably improve and stabilize environmental quality at minimum cost. It is, therefore, important that continous research and data compilation of water quality characteristics are used to corroborate findings and make them more applicable.

Temperature influences development, distribution and abundance of aquatic organisms, including fish. These organisms are tolerant of certain temperature ranges, outside which they cannot function (Blank, 1953; Hynes, 1960; Opuszynski. 1967; Tatarko, 1970; Hilton & Slinger, 1981; Fast, 1985; Opuszynski *et al.*, 1989). Spawning ceases if temperature drops near or below tolerance level. Fish suffer heat shock when brought rapidly from lower to higher temperatures, while disease organisms respond to variations, causing losses to aquatic life. Depending on specific nature of the water body, temperature also determine the amount of dissolved oxygen water can hold.

In an extensive review of temperature effects on nutritional requirements of fish, Hilton and Slinger (1981) reported that the standard envoronmental temperature at which maximum growth and feed efficiency are attained in rainbow trout and salmon were 15°C and 10°C, respectively, while growth was slower at 7°C. They also reported that, in the utilization of diets with different nutritional composition, protein requirement for optimum growth of trout was about 40% over a temperature range of 7-18°C. Besides, increased fat in diets at low ambient temperature resulted in fat deposition. Fats were better tolerated by fish at temperatures above 15°C when there is a high tendency for hyperactivity and thus increased need for reserves of energy. In a study on warm water fish, Fast (1985) also reported that channel catfish (***Ictalurus punctatus***) cease feeding between 8-10°C, and maximum digestion rates occur between 26-30°C. These fish also show optimum growth at 30°C and decreased growth above 32°C.

Turbidity in an aquatic environmental could be caused by both inorganic and organic matter. Organic sources include plankton, while inorganic sources are mainly negatively charged coloidal clay particles which remain dispersed and in suspension (Fast 1985). Problems caused by inorganic turbidity include reduced light penetration and this affects photosynthetic efficiency. Besides, it affects artificial pond fertilozation due to absorbtion or adsorbtion of phosphorus on the sediment layers (Lennen *et al*, 1985). Turbidity also restricts animal vision, and consequently foraging and feeding capacity; while filter feeding organisms are at risk of abrasion to sensitive structures like the gills (Warren 1971). Hart (1986) also showed that high pond turbidity and associated food limitation tend to reduce standing stocks of the daphnoid zooplankton. In a study to evaluate the efficiency of various materials in reducing pond turbidity, Fast (1985) reported that application of farm yard manure and plant hay at the rate of 2,400 kg ha^{-1} and 500 kg ha^{-1}, respectively, in pond water having 25mg l^{-1} turbidity reduces turbidity. This is achieved through a series of chemical reactions involving decomposition, leading to increased carbondioxide concentration, decreased pH and consequently, precipitation of clay particles. Similarly, Boyd (1979) reported that aluminium sulphate when applied at the rate of 20mg l^{-1} gave a 97% efficiency in decreasing initial pond turbidity from 830 mg l^{-1} to 24 mg l^{-1}.

Organic suspended solids or particulate matter exert a biochemical oxygen demand (B.O.D.), leading to oxygen depletion. The B.O.D. is therefore an important parameter used in measuring oxygen consuming properties of water. It is also used as an indicator of degree of pollution. Stirling (1985) reported that oxygen uptake of a water sample is approximately proportional to bacterial population activity, quantity of organic materials and plankton present in unfiltered natural water.

Hydrogen ion concentration (pH), a measure of the acid/base condition of water, is important to the aquaculturist because it influences toxicity of many substances like ammonia, hydrogen sulphide and free - CO_2. Similarly, pH can be sensitive to balance between photosynthesis and respiration in aquatic communities (Fast, 1985; Stirling, 1985; Flower & Nicholson; 1987). Rimon & Shilo (1982), in a review of factors affecting intensification of fish breeding in Israel, reported that water pH fluctuated in a diurnal cycle and was controlled by the intensity of photosynthesis. They also showed that photoassimilation of free-CO_2 caused elevation of water pH, while release of carbon-dioxide by respiration during the night led to the lowering of pond water pH. Free-CO_2 which is toxic to fish, is most prevalent at pH < 6.5. Banerjea (1967) and Jothy (1968) emphasized the importance of sediment pH and water quality for monitoring a good fishery. Based on data obtained, it is possible to evaluate and manipulate soil condition for increased fish production. Boyd (1979) reported that a soil pH range of 6.6-9.3 supports aquatic life, while ponds with soil pH above 5.9 would seldom require liming, provided 20 mgl^{-1} total hardness was present in the water. Soils of alkaline pH have been shown to reduce the solubility of important micronutrients like iron and manganese, while phosphate is often not readily available to some aquatic plants because it is precipitated with calcium in waters with high pH (Donahue *et al.,* 1977).

Alklalinity is a measure of the buffering capacity of water and therefore important in any pond manipulation study. In a review of Schaeperclaus' (1933) data on pond productivity related to total alkalinity, Fast (1985) reported that alkalinity in the following range are significant in pond culture: 0.0 mequiv.l^{-1}: strongly acid water, unuseable for hatchery purposes and limimg is unprofitable in most cases; 0.1-0.5mequiv.l^{-1}: variable pH, poor CO_2 supply, water unproductive with risk of fish mortality; 0.5-2.0m equiv. l^{-1}: medium productivity and CO_2 supply, and pH is variable; 2.0-5.0 m equiv.l^{-1}: optimal productivity and CO_2 supply, and variations in pH is only within narrow limits; >5.0 m equiv. l^{-1}: though rarely found, pH is very constant, fish health not endangered and productivity alleged to decline, though not proved scientifically.

Total hardness and alkalinity tend to be positively related, because in most freshwaters the major anions associated with calcium and magnesium, ie carbonates and bicarbonates, predominate. It is generally believed that waters with high a concentration of sodium carbonate is an indication of high alkalinity. Besides, high concentration of calcium sulphate implies greater hardness than alkalinity (Boyd, 1979; Fast, 1985; Stirling, 1985). In aquaculture management, high values of total hardness are prefered to soft water which are deficient in calcium and magnesium. These are essential for the development of mollusc and crustacean shells and fish bones and scales (Stirling, 1985).

Dissolved oxygen (D.O.) concentration is critical to the success or failure of aquacultural practices. Pond biomanipulation strategies such as fertilization do not only aim at plankton production as a source of food for fish, but also enhance oxygen production for utilisation by the aquatic biota which feed and grow best at D.O. concentration near air saturation (Fast, 1985; Boyd, 1986; Boyd *et al.,* 1986). In shallow ponds, oxygen concentration tends to be constant throughout the water column, from dawn to late afternoon when supersaturation, sometimes > 16.0 mgl^{-1} or 200%, can be attained (Rimon & Shilo, 1982) and drops gradually at dusk and during the night when there is no photosynthetic activity (Abeliovich, 1967; Fast, 1985; Vincent *et al.,* 1986; Wahab, 1986). Under tropical conditions, Tucker *et al.,* (1978), fast (1985) and Boyd (1986) reported that fish production can be achieved if DO levels do not fall below 25% saturation ($\approx$ 1-2 mgl^{-1}) during the night, after dawn. This however depends on species, because D.O. saturation as low as above is considered too low for salmonids. With proper pond management through fertilisation, metabolism of aquatic plants results in uptake of CO_2 and production of D.O. This helps to maintain D.O. and pH of the aquatic system within acceptable levels, while the new plant biomass enters the food web (Pruder 1986).

Another important consideration in role of pond manipulation *vis-a-vis* D.O. production is the changes that take place in the benthic environment. Apart from fish and zooplankton, benthic macroinvertebrates and bacteria in the sediment also account for D.O. losses from the pond water as a result of metabolism. Similarly, higher consumption rates by suspended matter occurs when there is excessive amount of organic materials or feeds. Schroeder (1975) reported that respiration by pond mud may range between 8-125 mg O_2 m^{-2} hr^{-1}. Wahab's (1986) extensive review of the works of Jonasson & Krustiansen (1967), Dermott *et al.*, (1977), Martien & Benke (1977), Rosenberg (1977) showed that the oxygen requirement of benthos is critical to their survival. Besides, food cannot be metabolized efficiently to maintain positive production if D.O. levels are < 1 mgl^{-1}. Even chironomid larvae, which are tolerant of poor oxygen conditions due to possesion of haemoglobin, spend much time pumping water through their tubes and growth is inhibited when D.O. level is < 4% saturation. Similarly, Aston (1973a) reported that oligochaete egg production only remains constant upto a critical low level of D.O. when production ceases. Ackefors (1986) and Phillips and

Beveridge (1986) reported that in both fresh and marine waters, accumulation of wastes like faeces and uneaten food at the bottom could also cause oxygen deficient conditions.

Ammonia is considered the second most important water quality factor limiting fish production, after D.O. It is an important source of nutrient for phytoplankton and also the major end product of protein catabolism excreted by aquatic animals. Ammonia in water consists of an unionised (NH_3) and ionised form (NH_3^+). The unionised form can be toxic to fish and other animals, especially at high temperatures and pH levels, causing gill damage and mortality (Emerson *et al.,* 1975; Shilo & Rimon, 1982; Stirling, 1985; Meade, 1985; Hason & Macintosh, 1986). Ammonia can originate from direct excretion by fish cultured on an intensive feeding regime of high nitrogen containing feeds (Kaushik 1980) fertilisation; crash of an algal bloom and water supply polluted with sewage (Boyd, 1982; Shilo & Rimon, 1982; Neil *et al.,* 1981; Rimes & Goulder, 1987). Inspite of numerous studies on ammonia and its associated ions with respect to fish culture, more research is needed with the aim of controlling its level through various pond manipulation strategies. Shilo & Rimon (1982) and King & Garling (1985) proposed a series of hypothesis needing further investigations. These include: first, optimization of nitrogen fertilisation and manuring procedures to minimize ammonia generation; second, periodic removal of suspended particulate matter residing close to the pond bottom. This involves optimisation of pond treatment between culture cycles by mechanical turnover of the soil during dry periods and CaO treatment; thirdly, the possibility of polyculture systems, such as inclusion of carp and tilapia which consume detritus and certain species of cyanobacteria in a sufficient ratio to remove at least 5 - 10% of cyanobacteria blooms daily.

Nutrients, particularly nitrate (NO_3-N) and phosphate (PO_4-P) and as recently proposed, by Cammen & Walker (1986) and Kullberg & Peterson (1987), carbon, play a significant role in pond productivity. Phosphorus is the main limiting nutrient for phytoplankton, being the scarcest and tends to form complexes with different metal ions. Phosphorus exists in many forms, but that most relevant to aquaculture is dissolved reactive phosphorus which is soluble and available for phytoplankton growth (Stirling, 1985). Due to the extensive and conservative nature of phosphorus and, coupled with the extremely small concentrations required for production of freshwater plant biomass, attention has been focused on appropriate concentration needed in order to minimize deleterious effects that would result from eutrophication (King & Garling, 1985). Besides, phosphorus tends to be conserved in pond sediment once added and gradually released; compared to other nutrients like nitrogen which are easily lost through denitrification processes.

It is generally difficult to assess the absolute supply of NO_3-N in water bodies because the concentration is dependent on dynamic relationship between factors such as the amount of nitrate washed along with other allochthonous inputs, rate of regeneration from bottom deposits of dead organic matter and rate of utilisation of nitrate by phytoplankton (Olaniyan, 1969). King & Garling (1985) reported that, although a linear series of ponds does allow for maximum use of phophorus, resulting in dominance of blue green algae in downstream ponds, a major constraint in predicting optimum nutrient utilisation and yield is the maintainance of sufficient nitrogen. A potential source of nitrogen for phytoplankton and bacteria is dissolved organic nitrogen which is excreted by fish, mainly as urea. In most developing countries, animal waste from livestock and poultry are common sources of cheap nutrients for aquaculture practices (AIT/ODA, 1986; Little & Muir, 1987). A Current area of pond nutrient enrichment research is focussed on chanelling the protein supplied by nitrogen fixation, obtainable from the action of heterocyst forming cyanobacteria (Little & Muir, 1987). Consequently, polyculture of different fish species could offer an opportunity of efficiently converting these protein-rich dietary sources into edible fish meat.

Organic carbon, also recently implicated as nutrient source, significantly contributes to pond mineralization, though the potential is not fully exploited for aquaculture benefit. (Vannote *et al.*, 1980; Sunders *et al.*, 1980; Kaplan & Bott, 1983, 1985; Cammen & Walker, 1986; Kullberg & Peterson, 1987). This source of nitrient originates from metabolites excreted by fish, residual fish food and dead algae. They contain store of free energy and nutrient elements, which on release at intervening steps become available for construction of living protoplasm (Sunders *et al.*, 1980), but are seldom directly consumed by fish. Rybak (1969), Harrison *et al.*, (1971), Hargrave (1972a), Wetzel *et al.*, (1972) have reported attempts to estimate decomposition in sediments, but with some technical difficulties. However, the intensity of decomposition in sediment is several times greater than in open water. Differences occur in the intensity of sediment decomposition. Moreover, the proportion of total decomposition varies with depth and basin morphometry (Sunders *et al.*, 1980). In a series of experiments using artificially generated detritus without bacteria, Saunders (1969, 1972a) reported that zooplankton assimilated organic detritus directly. Further research lies in the possibility of utilizing the sediment niche and its good resources for the benefit of fish.production.

Chlorophyll-a and primary production, which estimation is based on phytoplankton standing crop, have been documented for various seasons and regions (Hussany, 1967; Bailey-Watts & Duncan, 1981; Boyd, 1982; David *et al.*, 1983, Khan *et al.*, 1983; Stirling & Dey, 1990). Bailey-Watts & Duncan (1981) and David *et al* (1983) reported that a lower rate of productivity in winter season was partly a function of lower chl-a standing crops and influence of cool season phytoplankton community which are dominated by large centric diatoms. Stirling & Dey (1990), reported a strong inverse relation between Chl-a and NO_3-N, NH_3-N and PO_4

during, the summer in a Scottish West Coast lake, implying a significant uptake of nutrients in the surface water by phytoplankton. Similarly, they showed that chlorophyll values predicted from a phosphorus-depended eutrophication model agreed with observed values, but light limitation by self-shading and suspended fish farm wastes, aided by wind-induced turbulences, was believed to control algal growth rates and biomass.

Biological factors of considerable interest in aquaculture are phyto- and zooplankton. Quantitative research information on their reproductive, diurnal migratory and grazing behaviour are well documented in the literature (Hutchinson, 1957; Holden & Green, 1960; McAllister, 1969; McLaren, 1974; Gant, 1974; Maitland *et al.,* 1981; Reynolds, 1984; Disnberger & Threlkeld, 1986; Macauley & Kalff, 1987;). These works also generally describe the overall distribution and abundance of the plankters, but not ecological manipulation strategies to stimulate their production.

Phytoplankton are floating algae which form the main source of primary production and food for zooplankton. These include green algae and diatoms, whose production primarily depends on phosphate and nitrate nutrient sources. In general, any factor adversely affecting phytoplankton population growth consequently affects zooplankton abundance. Zooplankton are composed of three main groups, namely, copepods (eg *Cyclops*), cladocerans (eg *Daphnia)* and Rotifers (e.g. *Brachionus*). Yesipora *et al.,* (1976), Stycznska-Jurewicz *et al.,* (1977) and Torrans (1985) reported that a high density of large predatory copepods e.g. *Leptodora* can reduce the abundance of young fish through predation. Therefore, the choice of appropriate plankton size and species to be used as source of natural diet for juvenile fish are important factors to be considered.

Under natural conditions, most fish feed on plankton prey. The crustacean zooplankton are particularly important live food for the young stages of various fish species. Young stages of *Salmo* and *Oncorhynchus* spp have been successfully reared on live zooplankton for short periods (Paul *et al.,* 1976; Fast, 1978; Urquhart & Barnard, 1979; Holm & Moller, 1984; Holm, 1986 & 1987). In preliminary experiments in net pens on first feeding of Atlantic salmon (*Salmo salar*) and rainbow trout (*Salmo gairdneri*) with live zooplankton, Holm *et al.,* (1982) reported high growth rates up to a certain period before declining. This implies that larvae successfully feed at early stage in order to develop a normal feeding behaviour. In addition to their visibility, suspension in water, and relatively small size, zooplankton have high reproductive potential, short generation time, high nutritional quality, and are palatable and easily ingested by fish larvae, fry and juveniles (Styczynka-Jurewicz *et al.,* 1977; Torrans, 1987). It is therefore important that desirable species be identified and mass produced as an integral part of any aquaculture hatchery relying on natural food. Besides, Lin (1985) and Post & McQueen (1987) emphasized the need for more research in relation to response of plankton to both inorganic and organic fertilization, their nutrient assimilation capacity with respect to utilisation of products of anaerobic decomposition of organic matter and transfer efficiency between various trophic levels.

1. 3 POND BIOMANIPULATION AND PRODUCTIVITY

The popular approach to strategies of aquatic ecosystem restoration by manipulation, in both temperate and tropical regions, is a thorough understanding of interaction between nutrient sources, plankton biomass, ecology of benthic invertebrates, fish stocking density and yield which can lead to better management practices. Unlike the established fertilisation practices in agriculture, the basis of optimal pond fertilisation has not yet been determined. The estimation of nutrients required for a pond depends on its morphology, hydrology, soil/water quality, type of fish cultured and fertiliser employed.

Inorganic fertilizers are composed of nitrogen, phosphorus and often potasium (N-P-K), with possible secondary nutrients like calcium, magnesium and sulphur. Trace elements may include boron, copper, manganese, iron, zinc and molybdenum. Organic fertilizers include animal manures and plant wastes, containing about 40-50% a carbon on dry weight basis (Woynarovich, 1975). These manure have a low N-P-K content and are thus required to be used in large quantities. Tang (1970) proposed that when organic fertilisers are applied in ponds, they tend to yellow three major pathways: firstly, it provides a source of nutrient (carbon & phosphorus) for photosythesis; secondly, it serves as a substrate for micro-organisms which is turn support the zooplankton population; and thirdly, it may be directly consumed by fish, crustaceans or insects. According to Yamada (1985), estimation of fertilizer requirements and application rates for one location may be unsuitable for another. These are often determined by empirical rather than scientific methods, because of difference in the pond's interacting biological, physical and chemical factors which are not well understood. Similarly, laboratory and *in-situ* manipulations to evaluate plankton-nutrient interaction have usually been done by single or multiple bioassays (Maslin & Boles, 1978; Mc Diffet, 1980).

Several workers have demonstrated the effect of manipulation strategies to improve adverse water quality conditions in situ. Zurbuch (1984), Hasselrot & Hultberg (1984), Rosseland & Skogheim (1984) and Shreiber & Rago (1984) in seperate studies of liming and neutralization of predominantly acidifed lakes and streams reported remarkable improvement form a pre-biomanipulation water pH range of 3.6-4.8 to an acceptable range of 6.0-7.5 in the ponds and both upstream and downstream at various depths ranging from 0-20m. There was also remarkable improvement in the recruitment and biotic composition of fish, plankton and benthos. Similary, Gunn & Keller (1984) and White *et al* (1984) in seperate manipulation studies to rehabilitate acidified habitat of Atlantic Salmon, using crushed limestone, showed improved water chemistry, especially pH, which enhanced the survival rate of incubating eggs, fry and adult fish. These studies indicate that extreme pH condition in acid water can be deleterous to aquatic organisms. Such conditions also result in decreased decomposition and mineralization of autochthonous and allochthonous organic materials. Some studies do not, however, suport this hypotheses of decreased microbial activity in acidified freshwater sediment. For example, Hultberg & Andersson (1982) and Eriksson et al (1983) have shown that, following neutralization by liming, the biomass of chironomids often decreases substantially, possibly due to reduced precipitation of humic substances which are important nutrients for chironomid larvae..

In seperate studies of effects of nutrient enrichment, Henry et al (1984) and Ibanez et al (1984) showed significant increases in phytoplankton and primary production when nitrogen and phosphorus source were used in combination. Boyd (1982) considers a concentration of 0.5-0.1 mgl^{-1} dissolved phosphorus in water as adequate for most fertilization programmes. Similarly, Boyd & Musig (1981) showed that the concentration of filterable orthophosphate in ponds increased by more than 0.28 mgl^{-1} when triple superphosphate and ammonium nitrate were applied at the rate of 19.5 kg ha^{-1} and 10.6 kg ha^{-1}, respectively. In a study of the relationship between pond fertilization and fish production, Boyd (1976) reported that ponds fertilized with 45kg ha^{-1} of inorganic fertilizer yielded 947kg ha^{-1} ***Tilapia aurea***. However, Schroeder (1978, 1980), reported that adding manure to inorganically fertilized ponds did not cause any increase in primary production, although fish yield increased from 10-15 kg ha^{-1} day^{-1} to 32kg ha^{-1} day^{-1}. This was attributed to increased microbial community which is also good source of nutrients. Supplementary diets are often added to ponds to obtain rapid fish growth, but not all food resources are consumed. Besides, it has been established that detritus, which is particulate matter in association with bacteria, fungi, algae, skin debris (scales and slime), faecal waste material and macroinvertebrates tend to accumulate at the bottom (Colby ***et al*** 1972, Penczak ***et al*** 1982). Microbial ecologists have long recognized that detritus, including animal manure, is not only a rich source of nutrients for the pond benthos which provide food for fish, but also provides a mechanism for rapid recycling of nutrients. (Cranwell, 1976; Ghosh & Mohanty, 1981; Howard-Williams, 1985; Maskey & Boyd, 1986; Robinson et al, 1987). These nutrients may also be released into the water column as result of mineralizatiion and promote development of phytoplankton and periphyton and hence, indirectly the benthic fauna. The latter contribute significantly to the diet of pond reared carps and trout (Yashouv, 1966; Petr, 1968; Stirling & Wahab, 1990).

The value of manure as a direct source of feed for fish is small (Lu & kevern, 1975), compared to its beneficial effect on natural food production. These natural diets have been shown to fulfil a major role in the food web supporting fish populations (Schreoder, 1978; Schreoder & Hapher, 1979; Shaw & Mark 1980; Harpher & Pruginin, 1981). Similarly, Kerns & Roelofs (1977) found poultry waste to be of low direct nutritional value to fish, but considered bacteria and protozoa present in the particles of high nutritional value. Recycling of plant and animal wastes to fish has also been the subject of much research, especially in the tropics (Edwards 1980), and manipulating detrital food chains has far reaching implications for waste utilization in aquaculture. The vast quantities of agricultural waste and low value by-products may be useable as supplementary detritus, added to culture ponds as compost and microbial substrate, either alone or mixed with livestock, poultry manures and macrophytes.

The beneficial effects of macrophytes in relation to their utilization and nutritional value for fish culture is extensively reviewed by Little (1979) and Little & Muir (1987). Some of the most favoured macrophytes are filamentous algae and duckweeds, compared to sedges, water lettuce and water hyacinth because young leaves which are more succulent and less fibrous, decay faster when composted. The composted manure can be used for macroinvertebrate culture on the pond bottom since they provide nutrients and a large surface area. Therefore, the utilization of macrophytes might be beneficial in reducing the need for imputs of high quality and costly feeds, thereby bringing new research perspectives to bear in future on waste fed aquaculture.

The association of submerged aquatic macrophytes with macroinvertebrates in lakes and ponds has long been recognised by ecologists (Krecker, 1939; McGaha, 1952; Rosine, 1955; Pieczynska, 1973; Soszka, 1975a,b; Greg & Rose; 1985; Korinek ***et al.***, 1987; Friday, 1987; Hargeby, 1990). Soszka (19756) reported that the ecological ralations between invertebrates and submerged macrophytes in eutrouphic lake are reciprocal and manifold. Three distinct characteristics were identified: first, the use of macrophytes by invertebrates during reproduction and development in which egg-masses are deposited on leaves and stems; second, grazing on macrophytes by the invertebrates and third, the effects of life activity which involves destruction through excessive consumption of the macrophytes. Macroinvertebrates show distinct differences in rate of colonization. Hargeby (1990), reported that in stands of winter-green ***Chara tomentosa***, ***Asellus aquaticus*** (Isopoda) dominated in abundance over chironomids (Diptera) and ***Gammarus lacustris*** (Amphipoda). On the contrary, in the stands of ***Nitellopsis obtusa*** which dies off during winter, Chironomidae was the dominating taxon. Active avoidance may not be the cause of low abundance because, in a preference test under field and laboratory conditions, Hargeby (1990) reported that exclusion of fish for 90 days from a ***Nitellopsis*** stand did not increase the distribution and abundance of ***Asellus***. However, introduction of ***Asellus*** to enclosures showed that the species was able to grow rapidly and reproduce in the habitat. Similarly, in the abundance of established ***Chara*** sp, the species structure of associated invertebrates shifted from a dominance of chironomids in September of the first year to a domance of ***Asellus*** the following year. These results supported the hypotheses that die-off of ***Nitellopsis*** in autumn limits slow colozers like ***Asellus*** and ***Gammarus*** from establishing dense populations in this habitat. The submerged plants therefore influence the degree of protection and food availability for different macroinvertebrates, compared with vegetation-free areas (Higler, 1975; Glowacka ***et al.,*** 1976 Crowder & Cooper, 1979; Dvorak & Best, 1982, Savino & stein, 1982; Gregg & Rose, 1985, Russo, 1987; Diehl, 1988). In this study, an attempt has been made at evaluating the role of pond fertilization in the development of macrophytes. Similarly, The influence of these plants on exploitation of natural food by trout stocked in the earthen ponds was observed.

Studies of benthic ecology in relation to aquaculture has only been recent and the relationship between soils and their benthic organisms is not well understood, while ecological theories are lacking in many potentially important soil-water processes. It has been proposed that organic nutrients built-up through various manipulations such as draining or flushing of ponds and subsequent reworking of the soil can contribute significantly to the diet of pond-reared fish (White, 1985; Friday, 1987; Kullberg & Peterson, 1987). Benthos, defined as '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) also acts together with cultured benthivorous fish in playing a significant role in nutrient release. For example, both oligochaetes and chironomids, which are ubiquitous in pond sediments, mix soils and pump proportionally large quantities of water into it. This increases pore water exchange and thus nutrient release (Lennan *et al.,* 1985; Bardach, 1986). In a study of the ecology of earth ponds in the Howietoun fish farm, Wahab (1986) and Stirling and Wahab (1990) reported seasonal changes in soil and water quanlity, benthos and their influence on trout diet. They also showed that fish selectively fed on Chironomid larvae, Mollusca, Sialidae and Asellidae, contributing about 5.5% and 19.1% by volume to the total diet in October and February, respectively. Hepher & Pruginin (1981) and Little & Muir (1987) also reported that in waste-fed ponds, both chironomid and zooplankton fulfil a major role in the food web as quality feeds supporting fish populations in natural ecosystems. Schroeder & Hepher (1979) and Hepher & Pruginin (1981) reported that increase in Zooplankton and Chironomids depend on increase in bacterial production which develops on organic matter of manure inputs to the ponds. Although bacteria donot serve as direct food source for trout, Beveridge *et al* (1989) have of recent reported their ingestion by the the Tilapia ***Oreochromis niloticus.*** Bacteria also function in continually releasing nutrients from soil, especially in the detrital aggregate by assimilating various organic compounds usually enhanced by benthos and fish. This is achieved through physical stirring of soil which allows for contact with overlying water, and consequently creating more effective nutrient gradients (Hargrave, 1970; Provini & Marchetti, 1976). Similarly, White's (1985) account of the works by Golterman *et al.,* (1969), Lee (1970) and Porcella *et al.,* (1970) show that when epipelic algae use up nutrients, chemical gradients are created, causing a more rapid nutrient flux from the soils. This continously stimulates nutrient uptake in the water column by planktonic algae for their growth.

Despite the previous studies on the contribution of benthos to the diet of pond reared trout, the role of pond manipulation strategies in stimulating the production of biological communities for trout culture, while maintaining adequate water quality, has not been reported. Therefore, aquaculture system which promote and establish the growth and maintenance of plankton and benthic community with optimun utilization need to be greatly explored. The present trend in aquaculture is towards semi-intensive and intensive culture systems, where there is a large amount of energy per tonne of fish produced, compared to extensive aquaculture. A thorough understanding of the complexities in pond ecosystem and subsequent manipulation will be useful in the economic asessment of resource utilization for both research and management evaluation in relation to long-term costs which reflect the present day value attached to those resources. (Leach,1975; Pemental *et al.*, 1983; Moore, 1985; Leung, 1986).

1.4 SPECIFIC AIMS AND OBJECTIVES OF THIS STUDY

From the proceeding sections on the background, present status and research potentials in relation to applied problems in aquaculture and biomanipulation of ecology of earthponds, this research aims at developing more profoundly in terms of continuation and expansion of the few pioneering works in order to relate the results to aquaculture resource evaluation and development for rational utilization. Specific aims and objectives are:

1. To study the variations in physical and chemical parameter of pond water and soil and primary production, throughout the fertilisation and fish culture periods.
2. To determine the effects of varying concentrations of inorganic fertilization on the development of phyto-and zooplankton.

3. To determine the optimum level, and effects of organic manure on the biomass and production of benthic macroinvertebrates.
4. To evaluate the pond nutrient balance and possible denitrification rates in relation to inorganic and organic loadings in order to establish efficiency of nutrient utilization and/or pollution risks.
5. To study *in-situ*, the effect of fish stocking density on the utilisation of natural food organsms under still-water culture conditions, while maintaining adequate water quality for sustained production.
6. To study the diet of brown trout cultured on natural diet alone and supplemented with artificial pelleted diet.
7. To evaluate the nutritional composition of cultured benthic macroinvertebrates, zooplankton and detritus, compared with manufacturer's specifications for artificial pelleted diet in relation to meeting the nutritional requirements for brown trout.

CHAPTER TWO

THE STUDY AREA

Background information on the study area is presented with respect to environmental conditions, trophic status of the water sources and management practices on the farm. This information serves as a useful tool in understanding the rationale behind manipulation of the ecology of earthponds used in this study to maximize production of available and potential natural resources.

2.1. GENERAL DESCRIPTION

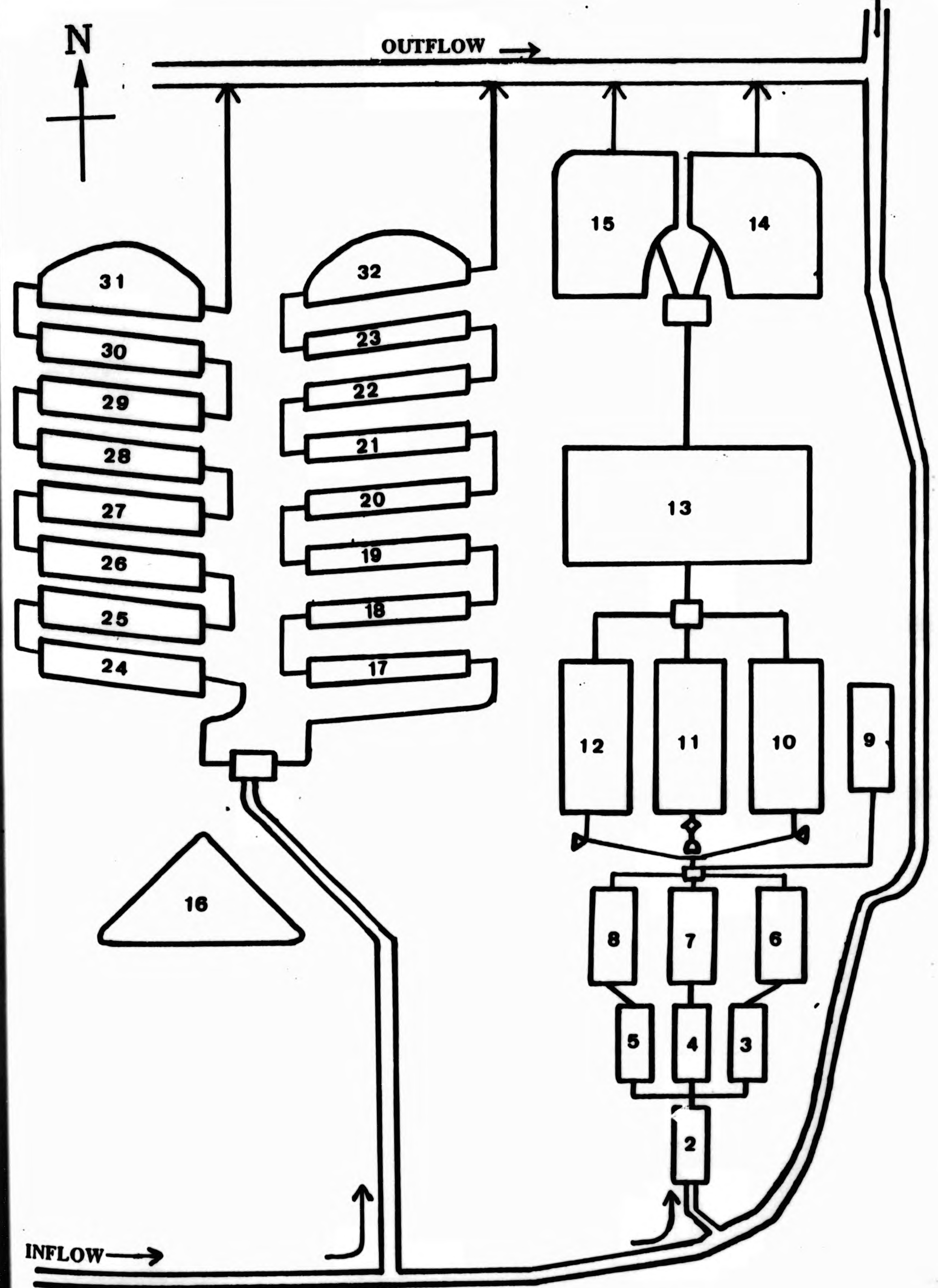
Howietoun fish farm (56^0N, $3^0$57W) is located on Suchie burn, 11 km SouthWest of Stirling. It was estabished by Sir James Maitland between 1871 and 1875 to conduct experiments on fish culture, utilizing the excellent water supply of the local burns and springs. In 1979, it was acquired by the Institute of Aquaculture, University of Stirling, to supplement its facilities as a centre for aquaculture research and training. Since its establishment, the farm has been providing high quality brown trout (*Salmo trutta*) for restocking of recreational water bodies rather than the more usual rainbow trout (*Salmo gairdneri*) for the table. Hence, quality of fish production and fitness for survival in the wild are as important as quatity.

The fish farm is established on an area of 10.1ha in the flattest land at the foot a the small glen or valley. Of this area 4.05 ha are ponds with a holding capacity of 40 tonnes of fish. There are about 40 earthen ponds in total, all varying in depth and size and carefully laid out to allow each pond to be served by gravity flow water (Fig. 1). The total drop in elevation from the top to bottom ponds is 6.39m, with a distance of 341m between them. Out of these ponds, fourteen (ponds 17-30) are used as nursery ponds, and for the purpose of this study, eight ponds were used (see Fig 1 & Table 1) and have an average dimension of 43m long x 3m wide (area = 0.013 ha) with a depth range of 1.0-1.5m. A summary of the various morphometric parameters are presented in Table 1. The larger ponds are mainly used as ongrowing or broodstock ponds throughout the year. In addition, there is a two-storey hatchery located approximately 1.5km upstream from the main earthen ponds, with a holding capacity of upto 20 million eggs per year, and facilities for hatching trays and first-feeding tanks.

2.2 ENVIRONMENTAL CONDITIONS

The environmental conditions of the fish farm is described in relation to its geology, meteorology, temperature,

Figure 1. Diagrammatic plan of fish ponds at Howietoun fishery and the water supply system. (Not drawn to scale).



sunshine and rainfall. The descriptions are based on information from the Stirling (sewage works) climatological station and some actual measurements reported by Wahab (1986).

2.2.1. GEOLOGY

Stirling town lies in the gap of the River Forth between Gargunnock and the Touch Hills of carboniferous volcanic lavas on one flank and the Ochill hills on other (Timms 1974). Similarly, Sauchieburn lies on the carboniferous lava, thus providing Howietoun fish farm with a suitable chemically stable substratum. Being built on old volcanic soil, with water supply mainly from the instrusive igneous rock originating around loch coulter, the water quality of the fish is considered better for fish culture than many highland water bodies.

2.2.2. METEOROLOGY

Meteorologically, Stirling and Sauchieburn maintain a balance between the mild west climate, characteristic of western Scotland and the drier, more continental conditions of coastal lowlands to the east (Timms 1974). Meteorological conditions influence freshwater ecosystems in a number of ways. For example, solar rediation, a main source of heat, influences fluctuations in water temperature, which in turn acts as a limiting factor in the distribution and abundance of aquatic organisms. Rainfall is a source of nitrogen dissolved in it and surface rainfall (e.g streams and rivers) which carry allochthonous materials from the surrounding land masses into the lakes and ponds. These influence the trophic status and productivity of the pond water.

2.2.3. TEMPERATURE, SUNSHINE AND RAINFALL

Wahab's (1986) measurement of monthly maximum, minimum and mean air and pond water temperatures reported highest values commonly occuring in the summer period of June and July, while lowest values occur during the winter months of November-January. The comparatively higher temperature advantages of the Stirling region is due to 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 Ochill hill barrier against the incursion of polar and arctic air masses from the north and east. Also, the enclosed lowlands warm up quickly during the summer to produce high maximum temperatures.

With regards to sunshine, there is usually a well defined seasonal cycle of incidence, typical of temperate latitudes. From the results of Wahab's (1986) data, computation of minimum and maximum hours of sunshine per month was, on the average, 37.5 hours during the winter period of November-December and 200 hours during the spring and summer periods of March -July respectively. Stirling lowlands being a common area of fog formation, development of radiation fog during winter periods tend to restrict the duration of sunshine. November and September are generally the wettest months, with mean monthly rainfall of 235mm, while the driest period is in the spring, with mean monthly rainfall of 38.3mm.

2.3. SOURCES OF WATER SUPPLY AND TROPHIC STATUS

The main source of water supply to the hatchery and fish farm is Loch Coulter which is fed by surface and spring waters around Touch Hills. The loch waters are regulated by a sluice and therefore under perfect control from flooding. Temperature of the colder surface water is balanced by the warmer spring water, so variations are kept to a minimum. From the loch, the main stream feeding the hatchery and ponds never rise beyond a few inches in flood, and any small rise is easily under control; and it never runs dry.

Roberts (1974) described the waters around Stirling as being generally oligotrophic and cooled in winter and spring by melting snow. As the resulting water flows, it becomes more eutrophic in the lower reaches of the rivers, where drainage, along with allochthonous materials from the richer farming areas, adds nutrients. Where rivers are not smoothed by lochs or reservoirs, they tend to show a pattern of flash spates (Smith 1974). Recently, a complicating factor is the acid nature of most stream and river waters in Scotland (Exley and Phillips 1988).

A unique characteristic of the brooder and ongrowing ponds which have been in use continously is their high and consistent level of total alkalinity and hardness. These play a significant role in maintaining buffering conditions and thus preventing unusual pH fluctuation (Wahab 1986).

2.4. MANAGEMENT PRACTICES ON THE FISH FARM.

Management strategies adopted at Howietoun fishery are based on knowledge gained from the over 100 years of fish culture practices, combined with modern techniques standardized by the Institute of Aquaculture scientists through research and teaching experience.

The culture cycle in the grow-out ponds starts in March. After spending 2 years in the ponds, the trout are netted, from February omwards, graded and transported to various waters for restocking in the early spring. About 200 fish are usually selected from the current year's production to supplement the existing broodstock, while the oldest and largest ones are being sold for restocking. The main ongrowing ponds (ponds 10,11,12,14, & 15; Fig. 1) are drained during April-May after completion of the culture cycle. These are left empty for 7-15 days to remove excess bottom sediment layers and allow elimination of toxic gases (e.g H_2S) by the spring sunshine. The ponds are then filled and left for 8-10 days before restocking with about 8,000 fish of 75g weight, equivalent to stocking density of 41,000 fish ha^{-1}. However, ponds 14 & 15 are stocked with 10,000 small sized fish of 50g weight at density of about 67,000 fish ha^{-1}. The fish are usually fed artificial pelleted diet at the rate of 2.5% body weight per day, 3x daily, with size of the pelletted feed increased with increase in fish growth. In the event of heavy rainfall and water becoming turbid, feed is not usually given as it will be wasted. Besides, the fish seldom detect and consume the feeds under such conditions. A summary of management parameters in relation to stocking density and feed inputs are presented in Table 1.

Pond 13, used for broodstock, is managed differently fron the other ponds. It is lightly stocked with large fish (

Table 1. Morphometric And Management Parameters At Howietoun Fish Farm

	ONGROWING AND BROODSTOCK PONDS						D-PONDS	NURSERY PONDS	
	7	9	11	13	14	16	31&32	17-23[c]	24-30
Area (ha)	0.032	0.083	0.194	0.234	0.153	0.119	0.035	0.013	0.017
Mean Depth (m)	1.80	3.50	3.0	3.50	3.0	1.25	1.25	1.0	1.5
Residence time (h)	5.50	Static	73.0	35.9	40.0	30.0	30.0	2.5	8.0
Stocking density (No/ha)	31,500	Unstocked	41,000	2,130	6,700	252,100	333[b]	Unstocked	294,117
Individual weight at stocking (g)	30.0	-	65.4	$1\text{-}3.0\times10^{3}$ [a]	31.7	0.55	-	-	15-20
Feed Input(May-Jan)(Tonnes/ha)	11.3	0	10.28	3.66	13.7	0.02	0.003	-	0.089

[a] Broodstock fish only
[b] Stocked with grass carp (Ctenopharyngodon idella) only
[c] Experimental ponds used in this study

> 1kg) and fed with a large floating pelleted diet at the rate of 0.8% body weight/day. During the autumn (Oct.-Nov.), the brood fish are usually transfered to pond 9 in preparation to stripping the eggs and milt. Thus, pond 9 essentially serves as a 'bridal chamber', for holding brood fish during the winter, although it is sometimes used as an isolation and treatment pond for those fish exhibiting signs of minor infection.

Some of the nursery ponds used in this study (ponds 17-23) are seldom utilized, lying fallow for over 2 years, compared with the nursery ponds 24-30 which are managed in the same manner as ponds 14 and 15. The triangular shaped pond 16 is often left dry, without filling. In the past, it was stocked with juvenile fish. Recently, a culture trial is being conducted in which 30,000 trout fry are stocked and fed a total of 1.5kg day^{-1} of artificial pelleted feed. The D-shaped ponds 31 & 32 are only stocked with grass carp (*Ctenopharyngodon idella*) at a very low density (333 fish/ha) and fed on pelleted diet at the rate of 0.25kg day^{-1}. These ponds, which receive all the effluent from the triangular and nursery ponds (Fig. 1), are often more eutophic with greater growth of aquatic macrophytes. Management of both triangular and D-shaped ponds is less intensive compared to the others described above. It is hoped that the research findings of the present study will be applied to these ponds, first on trial basis before being adopted on a large scale in the long run.

In general, despite the fairly intensive management of the farm, eutrophication is seldom observed. However, during the summer months of July-September, floating aquatic weed (e.g *Lemna sp*) lightly cover the ponds, while luxuriant growth of large aquatic macrophytes (e.g *Phragmatis communis*) surround the banks. These have been reported by Wahab (1986) to habour many terrestrial insects and flies, some of which may have spent part of their life cycle in mud on the pond bottom. The relevance of all the ponds to the present study is discussed in relation to earthpond manipulation and its management implications.

CHAPTER 3

MATERIALS AND METHODS

A detailed plan of study involved sampling for physico-chemical parameters, primary production, benthic algae and biological characteristics. Throughout the study period, choice of parameters to analyse and sampling frequency was determined by the objectives and nature of the manipulation of the earthpond ecology. During the summer period when it was most convenient for carrying out both inorganic and organic fertilization, variable properties like pond water temperature, pH, D.O., B.O.D., free - CO_2, suspended solids, ammonia and nitrite were measured much more frequently than the conservative ones such as conductivity, hardness and alkalinity. All these variable parameters are important to the aquaculturist because they are closely correlated with growth, food utilization and incidence of diseases in farmed fish and benthic macroinvertebrates (Stirling, 1985).

3.1 EXPERIMENTAL DESIGN

This study was carried out in two major phases under field conditions, backed up with laboratory analysis. These phases included firstly, inorganic followed by organic fertilization for the production of natural food, principally plankton and benthic macroinvertebrates, and secondly, testing the efficacy of fertilization for trout culture. The experimental design for the two fertilization programmes was based on establishing the effectiveness of three discrete nutrient levels for natural food production in trout culture while maintaining adequate water quality. In the second year, two fish stocking densities were evaluated for efficiency of natural food exploitation and compared with control conditions in which fish also received artificial feed. Data obtained were further used for computation of inorganic nutrient balances in the earthen ponds.

3.2 POND PREPARATION

Prior to commencement of fertilisation, the experimental nursery ponds had been lying for over 2 years and had to be cleared of vegetation by manual cutting and then using a strimmer. 'Round-up' herbicide was then applied to completely kill the weed. A soil pH test (described in Section 3.4.2) to assess the liming rate gave a value in the range 4.0 - 4.5, so a total of 20kg ($\approx$ 1,500 kg ha^{-1}) slaked lime was applied to each pond. The liming also serves as a good sterilant for pond muds, killing potential predators and parasites. After liming, the ponds were left fallow for a week, filled with stream water and allowed to stabilize for 3 weeks before actual commencement of fertilization and sediment and soil analysis. This liming sustained a favourable pH range of 5.7-6.0 and 6.8-7.2 for soil and water, respectively, throughout the 30 month study period. The ponds were held with static water throughout the trials, except for water changes on a few occasions in the second year to improve condition for the fish stock.

3.3 POND FERTILIZATION

Two principal manipulation strategies were employed: First, to compare inorganic with organic fertilization without fish present, and then to add fish to these treatments. The fertilization trials were carried out consecutively during the summer of 1988. Due to shortage of ponds, the organic treatments (July - December) had to follow on from the inorganic treatments (May - July). For the inorganic fertilization trials, replicate ponds were treated with high phosphorus and nitrogen (HPN), high phosphorus (HP), low phosphorus (LP) and untreated control (CTRL), while replicate ponds in the organic fertilization trial were treated with high chicken and cow manure (HCC), high chicken manure (HC), low chicken manure (LC) and untreated control (CTRL). Table 2 shows details of manipulation and fertilization rates n the various ponds.

TABLE 2 Manipulation of inorganic and organic fertilization rates during the fertilization trials, without fish.

TREATMENT	FERTILIZATION RATE
INORGANIC	
1 Control [CTRL]	No fertilization
2 High phosphorus & nitrogen [HPN]	19.6 kg ha^{-1} triple superphosphate as P/day + 44.2 kg ha^{-1} Urea as N/day
3 High phosphorus [HP]	19.6 kg ha^{-1} triple superphosphate/day
4 Low phosphorus [LP]	9.8 kg ha^{-1} superphosphate/day
ORGANIC	
1 Control [CTRL]	No fertilization
2 High chicken & cow manure [HCC]	12.5 kg/wk chicken manure + 25.0 kg/wk cow manure
3 High chicken [HC]	12.5 kg/wk chicken manure
4 Low chicken [LC]	5.0 kg/wk chicken manure

The main objectives of inorganic ferilization were to stimulate firstly, plankton production and secondly, the establishment of periphyton or benthic algae production which act as good sources of detritus and carbon. With regard to the organic fertilization, the rates applied were about 2½ times greater than 100 kg ha^{-1} recommended under tropical conditions by Schroeder (1980) and Little and Muir (1987), but this is in line with that recommended by Huet (1986), since organic manure has a low N:P ratio and the rate of breakdown under temperate conditions is likely to be slower. The main objective was to stimulate production of macroinvertebrate groups. All fertilizers used were thoroughly mixed with pond water in a 80 l plastic container to form a slurry before being evenly applied along the entire length of the ponds. All fertilisation was carried out under static water condition.

3.4 DETERMINATION OF WATER QUALITY CHARACTERISTICS AND PRIMARY PRODUCTION, WITHOUT FISH

Determination of physical factors, temperature and electrolyte conductivity was carried out *in-situ*, while all the other parameters were determined in the laboratory after collection in 500ml pre-washed sampling bottles. All samples were collected between 10.00 and 13.00 hrs biweekly during the fertilization and fish culture trials. Prior to commencement of both fertilisation trials, all physical and chemical parameters, primary production and biological conditions were measured. The pre-manipulation (0) data obtained represented a theoretically unproductive trophic status, taken as a reference point for comparisons of the response to various fertilization treatments. Water samples were usually collected a day before fertiliser application. Triplicate samples were collected from the inlet, middle and outlet of each experimental pond.

3.4.1 WATER TEMPERATURE

This was measured using a mercury thermometer which was inserted approximately 12 cm below pond water surface for 5 minutes, when the thermometer reading would have stabilized. Triplicate readings were recorded at the inlet, middle and outlet stations of the ponds.

3.4.2 pH

Water pH was determined electronically as described by Stirling (1985) using a Phillips digital meter, model PW

9409, fitted with a glass electrode. The meter was standardized by two buffers at a pH 4.0 & 7.0, and measurements performed in the laboratory within a few hours of sampling. Soil pH prior to liming and throughout both fertilization trials was determined by the 1:2.5 soil:water (W/V) ratio method as described by Boyd (1982). Triplicate sediment samples collected with a trowel from each pond were transported to the laboratory in plastic containers. 20g of each sample was moisturized in 50 ml deionized water and stirred at regular intervals of 5 minutes for 1 hour. The soil pH was then measured as described for water samples.

Determination of liming rate prior to commencement of fertilization was carried out as described by Boyd (1982). Buffer solution consisting of 20g P-nitrophenol, 15g boric acid, 74g potassium chloride and 10.5g potassium hydroxide dissolved in 1l distilled water was used for determining pH in buffered solution. Prior to measurement, the pH meter was calibrated at pH 8.0 with a mixture of 20 ml each of distilled water and buffer solution. The values of soil pH and soil pH in buffered solution were used to read liming requirements from the table of constants given by Boyd (1982).

3.4.3 ELECTROLYTE CONDUCTIVITY

Conductivity was measured with a battery operated meter, model pHOX. The procedure involved setting the meter to zero point, followed by pre-rinsing the sproule electrolytic conductivity cell with the water sample. Fresh sample was then poured into the sproule and readings noted accordingly.

3.4.4 TOTAL HARDNESS

This was determined according to Stirling (1985) and involved diluting 25 ml of pond water sample to 50 ml with distilled water. 1 ml of buffer and inhibitor solution were added, followed by 2 drops of Erichrome black-T indicator. The resultant reddish solution was titrated with EDTA (disodium salt of ethylenediamine tetracetic acid) drop by drop until a light colour end point was observed.

3.4.5 TOTAL ALKALINITY

Total alkalinity was determined according to Stirling (1985). Three drops of 'BDH 4.5 indicator' solution was added to 100ml of water sample and the resulting blue coloured mixture titrated with standard hydrochloric acid, until a pale pink colouration as end point was observed.

3.4.6 SUSPENDED SOLIDS

This was determined according to Stirling (1985). Triplicate batches of 47 mm Whatman GF/C filter papers were numbered, washed in a tray of distilled water and dried in a hot air over at 75°C for 1h. 500 ml of pond water sample was then filtered through the pre-washed, pre-dried and pre-weighed filter paper, using a venturi suction pump fitted to water a tap. The filter paper was then placed on aluminium foil, dried at 105°C for 12 hours, cooled and re-weighed. The content of suspended solids was calculated from the difference in weight, divided by volume of water sample and results expressed in mgl^{-1}.

3.4.7 DISSOLVED OXYGEN

The modified Winkler method was used in determining D.O. The field procedure involved filling 100ml stoppered bottles with sample water collected directly from the ponds, ensuring that no air bubbles are trapped. Within a few minutes of filling, 0.5ml each of manganous sulphate and Winkler's reagent were introduced and the stopper replaced firmly and transported to the laboratory. After allowing the precipitate to settle, 1ml of conc H_2SO_4 was introduced and stopper replaced firmly and quickly, without trapping air and well shaken until the brown precipitate dissolved. 50ml of the resulting yellow solution of free iodine was transferred to a conical flask and titrated with standard 0.0125M thiosulphate until a faint yellow colour remains. A few drops of starch indicator was added and titration continued until a blue colour is discharged. Calculation was based on the following equation:

$$D.O.(mg l^{-1}) = \frac{V_1(D) \times M(D) \times 8 \times 1000}{V_2}$$

where D = sodium thiosulphate ($N_2S_2O_3$)

M = molarity of $N_2S_2O_3$ used = 0.0125

V_1 = titrant volume of $N_2S_2O_3$

V_2 = volume of water sample titrated.

3.4.8 BIOCHEMICAL OXYGEN DEMAND

Amber coloured 100ml sampling bottles were used for determination of BOD_5. Triplicate samples for each station in the ponds were collected following the same procedure for D.O. The oxygen content was determined immediately in one of these samples, whilst the remaining two samples were firmly stoppered, covered with aluminium foil and incubated in the dark at 20°C for 5 days. At the end of this period, the D.O. level was determined by the usual Winkler titration method.

3.4.9 TOTAL AMMONIA

Determination of total ammonia was by the pheno-hypochlorite method described by Mackereth *et al* (1978), and Stirling (1985). 10ml of phenol-nitroprusside reagent was added to 25ml of filtered water sample and mixed. 15ml of alkaline hypochlorite reagent was promptly added and flasks covered and kept in the dark for 1 hour at room temperature. Absorbance of the resulting blue colour which is stable for at least 24 hours was measured spectrophotometrically at 635nm with the 'UNIKON 810' spectrophotometer.

3.4.10 UNIONIZED AMMONIA

The proportion of total ammonia present as unionized ammonia (NH_3) is dependent upon pH and temperature of the water sample or solution at the time of sampling. Therefore, the unionized ammonia level was calculated using the formula described by Emerson *et al.* (1985):

$$NH_3 - N = \frac{\text{Ammonia - N}}{1 + 10^{(PKa - pH)}}$$

where Ammonia - N	=	measured concentration of total ammonia
pH	=	measured pH of water sample
pKa	=	negative logarithm of the ionization constant which depends on temperature which and calculated from the formula: $0.09018 + (\frac{2729.92}{T})$
T	=	absolute temperature in K(273.16 + t°C)

3.4.11 NITRITE - NITROGEN

This was determined according to Stirling (1985). The principle involved is that, in a strongly acid medium, nitrite reacts with sulphanilamide to form a diazonium compound which reacts with N-(1-naphthyl)- ethylene - diamine dihydrochloride (NED) to form a strongly coloured azo compound. 1ml of sulphanilamide solution was added to 50ml of filtered water sample, mixed and after 5 minutes, 1ml of N.E.D. solution was added. The mixture was left for 10 minutes and the absorbence measured spectrophotometrically against a reagent blank at 540nm within 2 hours.

3.4.12 NITRATE - NITROGEN

Precise determinations of nitrate are difficult because of the relatively complex procedure required. However, for quantitative work, a cadmium/copper column was used as described by Stirling (1985). In principle, nitrate is reduced to nitrite by the cadmium/copper column. The column was prepared by washing 20g cadmium filings with 100ml of 2M HCl and rinsing with distilled water. 40ml of $CuSO_4$ solution was added and the contents swirled until the blue colour disappears. 5ml of buffer solution was added to 50ml of filtered water sample, mixed and 20ml of this solution was placed in the column and allowed to run through to waste. A further 25ml of sample collected was then analysed for nitrite as described above.

3.4.13 DISSOLVED ORGANIC NITROGEN

Determination of D.O.N. was carried out on unfiltered water samples. The organic nitrogen is broken down by a potassium persulphate/sulphuric acid digestion to ammonia. Analytical procedure was according to Adamski (1976) and Stirling (1985) and involved chemical treatment of 25ml water sample, boiling, titrating and back titrating until solution becomes red. This is further diluted with 50ml distilled water and the resulting solution was analysed for ammonia as described in section 3.4.9.

3.4.14 TOTAL PHOSPHORUS

Unfiltered pond water samples were used for the analysis. In principle, phosphorus is converted to soluble inorganic phosphorus by digestion with a mixture of sulphuric acid and potassium persulphate. The resulting soluble inorganic phosphorus in the samples was then measured spectrophotometrically against a reagent blank at 690nm (Stirling 1985).

3.4.15 DISSOLVED REACTIVE PHOSPHORUS

This was determined according to Stirling (1985). In an acidified solution of filtered water sample, phosphate reacts with molybdate to form molybo-phosphoric acid, which is then converted to the intensely coloured molybdenum blue complex. The reacting phosphate is composed of orthophosphate and easily hydrolysable organic compounds and thus refered to as dissolved reactive phosphorus. The resulting blue complex was determined spectrophotometrically at 690nm.

3.4.16 FREE CARBON DIOXIDE

In nature, total carbon dioxide participates in interconnected ionic equilibria when dissolved in water, with most of the gas becoming bound in ionic form as bicarbonate and carbonate ions. Free-CO_2, on the other hand, refers to the concentrations of carbon dioxide plus carbonic acid, $[CO_2] + [H_2CO_3]$. It is important because at high concentration in farms with ground water supply, it may cause problems of kidney stone formation (nephrocalcinosis) in cultured fishes (Stirling, 1985). Free-CO_2 was calculated from the pH, temperature, alkalinity and conductivity of the water sample as described by

Mackereth *et al.* (1978).

$$\text{Free-}CO_2\ (\mu mol\ l^{-1}) = \left(\frac{r_1}{1 + 2r_2} \right) \times A$$

where r_1 = ratio of free - CO_2 and bicarbonate concentrations

$$= \frac{[\text{Free} - CO_2]}{[HCO_3^{-}]} = \text{antilog}\ (pH - PK_2)$$

r_2 = ratio of carbonate and bicarbonate concentrations

$$= \frac{[CO_3^{\ 2-}]}{[HCO_3^-]} = \text{antilog}\ (pH - PK_2)$$

where pK_1 and pK_2 = dissociation constants applicable to CO_2 system at various temperatures,

closely fitted by the following equations:

$$pK_1 = \left(\frac{3403.7}{T}\right) + (0.03279T) - 14.84$$

$$pK_2 = \left(\frac{2902.39}{T}\right) + (0.02379T) - 6.50$$

T is the absolute temperature in K (= t°C + 273.16).
The pK values were corrected for ionic strength as described in Mackereth *et al* (1978) and A= titration alkalinity in $m.eq l^{-1}$ (correction for hydroxyl

concentrations, $[OH^-]$ is negligible at pH <9).

3.4.17 CHLOROPHYLL - a

Chl-a concentration, with correction for phaeo-pigments, of the water sample was determined according to Strickland & Parsons (1972) and Stirling (1985). 500ml of water sample was filtered through a 45 mm diameter millipore HA fibre of 0.45µm-pore size. Near the end of filtration, 1 ml of 1% aqueous suspension of magnesium carbonate was added to prevent phaeophytinization of pigments due to acid conditions. 25 ml of 90% acetone was used for extraction in cool dark conditions for 24 hours. Extracts were centrifuged and chlorophyll absorption measured spectrophotometrically in cells of 4 cm at 665nm and 750nm. For determination of phaeophytins, two drops of 1.2M hydrochloric acid was added to the cuvette, mixed and covered with aluminium foil and allowed to stand in the dark for 10 minutes. Absorbance was remeasured at 750 and 665 nm. Calculation was based on the formula below:

$$\text{Chl-a } (\mu g.l^{-1}) = A \times K(A^{0}_{665} - A^{a}_{665}) \times \frac{V^2}{V_1 \times L}$$

where A^{0}_{665} & A^{a}_{665} = corrected absorbances at 665nm before and after acidification respectively.

V_1	=	volume of water sample filtered (in litres)
V_2	=	final colume of acetone extract (ml)
L	=	path length of spectrophotometer cuvette
A	=	absorption coefficient of Chl-a = 11.0
K	=	factor to equate the reduction in absorbancy to initial chlorophyll concentration, 1.7:0.7 or 2.43

3.4.18 PRIMARY PRODUCTION

The light and dark bottle method was used in determining primary production as described by Stirling (1985). Four light and three dark 125 ml bottles were filled with pond water from a depth of approximately 30 cm in three stations in each pond. One of the light bottles was immediately used to estimate the original oxygen concentration by the Winkler method, while the remaining bottles were tied to a rope and incubated for 6 hours, starting at 0900hrs and at approximately the 30 cm depth from which the water samples were collected. Dissolved oxygen was fixed immediately after the samples were brought out of the water and laboratory procedure for Winkler titration followed accordingly. Calculation was based on the method described by Wetzel & Likens (1979) and Stirling (1985). The results were doubled to obtain daily production rates and expressed as $mg.C.m^{-2}\ day^{-1}$.

3.5 DETERMINATION OF POND SOIL AND SEDIMENT CHARACTERISTICS DURING FERTILIZATION, WITHOUT FISH

Soil and sediment samples for both physico-chemical analysis and benthos enumeration were collected fortnightly in triplicate in each pond by scooping a $10cm^2$ x 3cm depth layer using a modified 'srape' sampler. The samples were then transported to the laboratory in polythene bags and allowed to settle for 30-60 minutes, since the soil occasionally mixes with interstitial water during lifting. The clear water was slowly decanted, and the soil sample thoroughly mixed and a portion was oven dried at 105°C for 12 hrs (Leach 1970, Wahab 1986). The analytical method for soil pH, the principal physical parameter has already been described in section 3.4.2.

3.5.1 BENTHIC ALGAL INDEX

This was measured as chl-a based on a slightly modified method described by Leach (1970). Triplicate samples of 0.5cm top layer of soil samples were cut and oven dried at 75°C for 12 hours. The samples were finely ground in a mortar and 0.5g weighed into a 50ml conical flask. About 0.1g of powdered magnesium carbonate was added to prevent acidity, followed by 20ml of 90% aqueous acetone and kept in the dark for 12 hours. Samples were centrifuged and optical densities measured at 663 and 750nm. The extracts were then acidified with 2 drops of 10% HCl and absorbance remeasured. Functional chl-a was calculated based on the formula used for chl-a, except that the corrected absorbance used was 663nm and results expressed as $\mu g.g^{-1}$.

3.5.2 TOTAL CARBON AND NITROGEN

The Perkin-Elmer 240 elemental analyser was used for determining both carbon and nitrogen proportion in the pond sediment samples. Prior to analysis, triplicate blank readings were determined using acetanilide. 10mg of triplicate subsamples were weighed separately into clean boats and combusted in the analyser. Individual results were calculated from the bar graph recordings and results expressed as percentages.

3.5.3 TOTAL PHOSPHORUS

Sediment samples were analysed for total phosphorus according to Strickland & Parsons (1972), as modified in the Institute of Aquaculture. Sub samples of 0.2g were measured in triplicate and antibump granules and 15 ml conc. nitric acid added. The mixture was boiled on a hotplate until dry and 2ml of 70% perchloric acid carefully added and heated for 20 minutes until emission of thick white fumes ceased. 5.0ml of ammonia solution (sp.gr. = 0.88, ≈ 35% NH_3) was added and heated till no smell of ammonia, followed by addition of 20 ml acidified water (2 ml conc. HCl made up to 1 l with distilled water). Samples were made up to 100ml with distilled water and analysed for total phosphorus as described by Stirling (1985).

3.6 COMPUTATION OF NUTRIENT BALANCES AND DENITRIFICATION RATES

Inorganic nutrient balances and denitrification rates in fertilised ponds prior to fish stocking are important management tools in predicting the efficient utilization of various nutrients supplied, pollution risks and possible control strategies. A basic assumption in this study is that substance budgets of the ponds are a function of the average loading and loss (outflow or sedimentation) (Vollenweider, 1969; Andersen, 1974).

Computation was based on methods described by Vollenweider (1969). The values of nitrogen retained in sediment ($N_{r(s)}$), phosphorus retained in sediment ($P_{r(s)}$) and sediment N:P ratio were obtained from direct analysis of pond water and sediment samples. Net nitrogen retained in pond sediment ($NN_{r(s)}$) was calculated based on the formula described by Vollenweider (1969):

$$NN_{r(s)}\ (g\ m^{-2}\ yr^{-1}) = P_{r(s)} \times N:P_{\ (sediment)}$$

Denitrification rates or nitrogen losses (N_l) from the ponds hypolimnetic layer was calculated by the difference method according to the formula given by Vollenweider (1969):

$$N_l = NN_{r(s)} - N_{r(s)}$$

3.7 ANALYSIS OF PLANKTON CHARACTERISTICS DURING FERTILIZATION, WITHOUT FISH

Phytoplankton samples for analysis were collected using a 2 l plastic bucket. Subsamples were preserved in 1ml lugols iodine for future identification. Zooplankton samples for analysis were collected using a plankton net (250 µm mesh), hauled across the pond in standard sweeps and following a sinusoidal path (Hall et al., 1970; Wetzel & Liken 1979). Subsamples were immediately preserved in 4% formalin for zooplankton. Numerical analysis of phyto-and-zooplankton was carried out using the Sedgwick - Rafter cell and counting chamber respectively as described by Wetzel & Liken, (1979) and Stirling (1985). Identification was based on external morphology using standard taxonomic texts like Scourfield & Harding (1966), Harding & Smith (1974) Belcher & Swale (1978).

3.8 ANALYSIS OF BENTHIC MACROINVERTEBRATES DURING ORGANIC FERTILIZATION, WITHOUT FISH

Triplicate samples of freshly collected pond soil were not preserved since it was easier to sort animals alive. Sorting was usually completed within 3 days. Animals were separated by suspending sediment samples in a sink half filled with water and repeatedly decanting through 0.25 and 0.5 mm sieves which retain most of the macroinvertabrates

(Kajak, 1968; Maitland & Hudspith, 1974). The materials were transferred to a 210 x 210 mm white tray and the big, heavy animals picked up. Where necessary, decantation was repeated a few more times for easy sorting from sediment and detritus (Wahab, 1986). Animals sorted out were placed in petri dishes for separation and enumeration with the aid of a low power dissecting microscope. Larger macroinvertabrates such as Mollusca, Hirudinea and Asellidae were counted without any aid. Identification of all animals was done according to Macan (1966).

3.8.2 ESTIMATION OF BENTHOS AND PRODUCTION

3.8.2.1 BENTHOS BIOMASS

Mean individual dry weights were determined by drying a subsample of 20 - 40 individuals at 65°C for 24 hours until a constant dry weight was obtained (Dermott & Peterson, 1974; Lindegaard & Jonasson, 1979). Ash-free dry weight for molluscs was determined by subtraction of ash remaining after incineration in a muffle furnace for 4 hours at 550°C (Crisp, 1984; Wahab et al., 1989).

3.8.2.2 BENTHOS ANNUAL PRODUCTION

Several workers (eg Fager, 1969; Mann, 1969; Winberg, 1971; Crisp, 1984; Downing & Rigler, 1984; Wahab, 1986) have extensively reviewed the merits and demerits of different methods used for computation of secondary production. Some of these methods include 'removal-summation' (Boyson-Jensen, 1919), 'instantaneeous growth rate' (Ricker, 1946; Allen, 1949), 'Allen curve' (Allen 1951), 'size-frequency' or 'average cohorts' (Hynes & Coleman 1968), and 'increment-summation' (Winberg 1971), all of which require direct information or assumptions concerning all or some population parameters like population density, biomass, growth rate, voltinism and life span (Bird 1982, quoted by Wahab 1986) which often limit their use. For example, life histories of many macroinvertebrates are not fully understood, especially the degrees of voltinism, the rate and causes of mortality in freshwater ecosystem. Due to these conceptual difficulties and diversity of equations used, Winberg's (1971) 'growth increment summation' recommended by Downing and Rigler (1984) was adopted for this analysis, because it is conceptually and mathematically simple. The computation was based on the product of mean abundance between sucessive sampling periods and the increment in mean individual dry weight, or ash-free dry weight for Mollusca (Wahab 1986), during the six month culture period. The results are presented both for the duration of the culture period and on an annual basis, calculated *pro rata* by multiplying observed production by 12/6.

The following equation was used for the computation of production (P) as described by Downing & Rigler (1984):

$$P = \Sigma A(\Delta B)$$

where A = mean abundance (m^{-2}) during any consecutive sampling date, given by:

$$\frac{A_1 + A_2}{2}$$

ΔB = changes in mean individual dry weight between consecutive sampling dates, given by: $B_2 - B_1$.

Where appropriate, negative values obtained, whether real or apparent were not subtracted from the total production (Maitland & Hudspith 1974). The overall annual production (P) and mean biomass (B) values obtained were used for computaion of P/B ratio.

3.9 IDENTIFICATION OF AQUATIC MACROPHYTES

Submerged and floating aquatic macrophytes that developed during both fertilization programmes were collected from different locations of each pond. Floating vegetation samples were collected by hand net, while submerged and rooted vegetation which emerged above the water surface were uprooted with a 'scrape' sampler, taking care not to damage them. Representative samples were placed in polythene bags and preserved in freezer for further identification which was completed within 7 days while the plants were still fresh. Identification was based on external morphology as described by Haslam *et al.*, (1982). All identifications were further checked by Dr John Proctor of the Dept. of Biological Sciences, University of Stirling.

3.10 FISH CULTURE EXPERIMENT

This was based on the fertilization treatments which gave the best plankton and macroinvertebrate production in the previous year's experiment, ie high chicken & cow manure ((HCC), high chicken manure (HC) and high phosphorus and nitrogen fertilizer (HPN). A summary of manipulation of nutrient levels and fish stocking density is presented in Table 3. 'Control' (CTRL) ponds 7 and 8 in year two of the fish culture studies were not used in the sense of no fertilisation as in year one, but reflected normal semi-intensive management practice on the farm, depending largely on artificial pelleted food. These are not replicates because:

(a) different stocking density of trout in the earthen ponds.

(b) different water flow regimes, with pond 7 almost static (or 'minimum' flow), but pond 8 normal flow-through with residence time of about 6 hours.

(c) different sizes of pond, especially CTRL pond 8 being larger in size.

Even manure treatments were not replicated truly because of low and high stocking densities. Therefore, unless indicated otherwise, results as 'treatment means' are not presented for both ponds together. The fish were cultured for 7 months (July 1989 to January 1990).

3.10.1 COLLECTION AND MAINTENANCE OF FISH STOCK PRIOR TO STOCKING IN EARTHEN PONDS

The principal fish stock used for the experiment was brown trout (*Salmo trutta* L.). A total of 300 trout (0+ year class) were netted from the main growing ponds of Howietown fish farm, graded and transferred to 4m diameter circular fibre glass tanks fed with continous flow through of water which was normally about 15 ± 0.5°C. The fish were maintained for 2 weeks by feeding them with artificial pelleted diet placed in an automatic feeder. During the maintenance period, fish were monitored for symptoms of stress and diseases such as lack of feeding response, inactive swimming when disturbed, appearance of secondary infections like fin and tail rot and fungal growth on the body. Such fish were not selected for restocking in the experimental ponds, as poor condition could have significant effects on the results of the work.

3.10.2 STOCKING AND MAINTENANCE OF FISH

Prior to restocking and throughout the culture period, water quality parameters were monitored, first biweekly and then weekly. The physico-chemical parameters monitored were temperature, pH, total alkalinity, D.O., B.O.D., suspended solids, total phosphorus, nitrate, nitrite and total ammonia, measured as described previously.

Healthy fish were regraded in approximately same length and weight class, and three days prior to restocking, fish were deprived of food. A summary of stocking density in the

Table 3 Manipulation of nutrient levels and stocking density in fish culture trial.

[a]Pond No./Treatments	Pond No. (see Fig.1)	No./Pond	[b]Fish Stocking Density (No ha^{-1})
1 (HCC)	17	50	3875
2 (HCC)	18	25	1937
3 (HPN)	19	50	3875
4 (HPN)	20	25	1937
5 (HC)	21	50	3875
6 (HC)	22	25	1937
7 (CTRL)	23	25	1937
8 (CTRL)	27	50	3875

[a] Legends and details are as outlined in Table 2, except control (CTRL) ponds received artificial pelleted diet at 1% body wt. day^{-1}.

[b] Average length and weight of fish at commencement of stocking are 18.0cm and 60g respectively.

respective ponds is presented in Table 3. It was also assumed that since they were fed solely on artificial pelleted diet, they were unfamiliar with benthic food organisms. This proposition is the basis on which one of the null hypotheses on acclimatization to feeding on natural food is tested. Fish in ponds 1-6 were allowed to feed on natural diet of *Asellus, Chironomus, Gammarus*, mollusca, oligochaetes, *Sialis* and zooplankton only, compared to control ponds 7 & 8 which were fed artificial diet, of 'Trout grower' pelleted feed (Ewos Ltd, Westfield, Bathgate, Scotland, U.K.) 3x daily at the rate of approximately 1% body weight, in addition to the natural food. Throughout the culture period, all ponds were covered with polypropylene netting to protect fish from predation by the herons.

3.10.3 GROWTH MEASUREMENT

Throughout the culture period, fish were monitored for growth at monthly intervals. At least 50% of fish in each pond was sampled by dip net after lowering the water level. They were anaesthetized prior to handling in an aqueous solution of 40 mgl^{-1} benzocaine as described by Ross & Ross (1984). Important growth parameters measured in the field were length and weight, and these were further used in computation of fish condition factor and specific growth rate.

3.10.3.1 LENGTH AND WEIGHT MEASUREMENTS

Anaesthetized fish were placed on a measuring board for fork length (from tip of snout to the fork of the tail) measurement and immediately weighed to the nearest 0.1g with a battery operated electronic balance. Fish were then replaced in clean fresh water for recovery before being returned to the ponds.

3.10.3.2 CONDITION FACTOR

Condition factor, which is usually based on the analysis of length-weight data is generally considered a good indicator of the 'well-being or fitness' of fish. The choice of an index is dependent on its underlying condition and properties of a particular data set. The Foulton condition factor (FCF), which is most widely used because it relates weight of fish to its length in a manner readily visualized and easy to compute (Bolgen & Connoly, 1989), was choosen for this study. Computation was based on the length-weight relationship:

$$W = aL^b$$

where W = weight (g) L = fork length (mm). The constants,

$$a = 0.01, \qquad b \approx 3$$

are parameters of the regression of $\log_{10}$ weight on $\log_{10}$ length. This relationship is an approximation used as an index for comparative purposes and is given by:

$$C.F. = \frac{W \times 100}{L^3}$$

The product should be equal to 1 for fish of average natural condition, but will be < 1 or > 1 for fish of below or above average condition respectively.

3.10.3.3. SPECIFIC GROWTH RATE (S.G.R)

Assuming fish growth to be exponential and continous as described by Brown (1957), and where food is not limiting, growth rate was calculated as rate of increase in weight per unit weight during a sufficiently small time interval, so that final weight (Wt_f) after a time interval is given by:

$$Wt_f = Wt_i e^{kt}$$

where Wt_i = initial weight, e = base of natural log (2.303)

k = instantaneous or specific growth rate

t = time interval (days)

Rearranging the equation in order to calculate SGR in % - body weight per day,

$$SGR = \frac{(\log_e Wt_f - \log_e Wt_i)}{t} \times 100$$

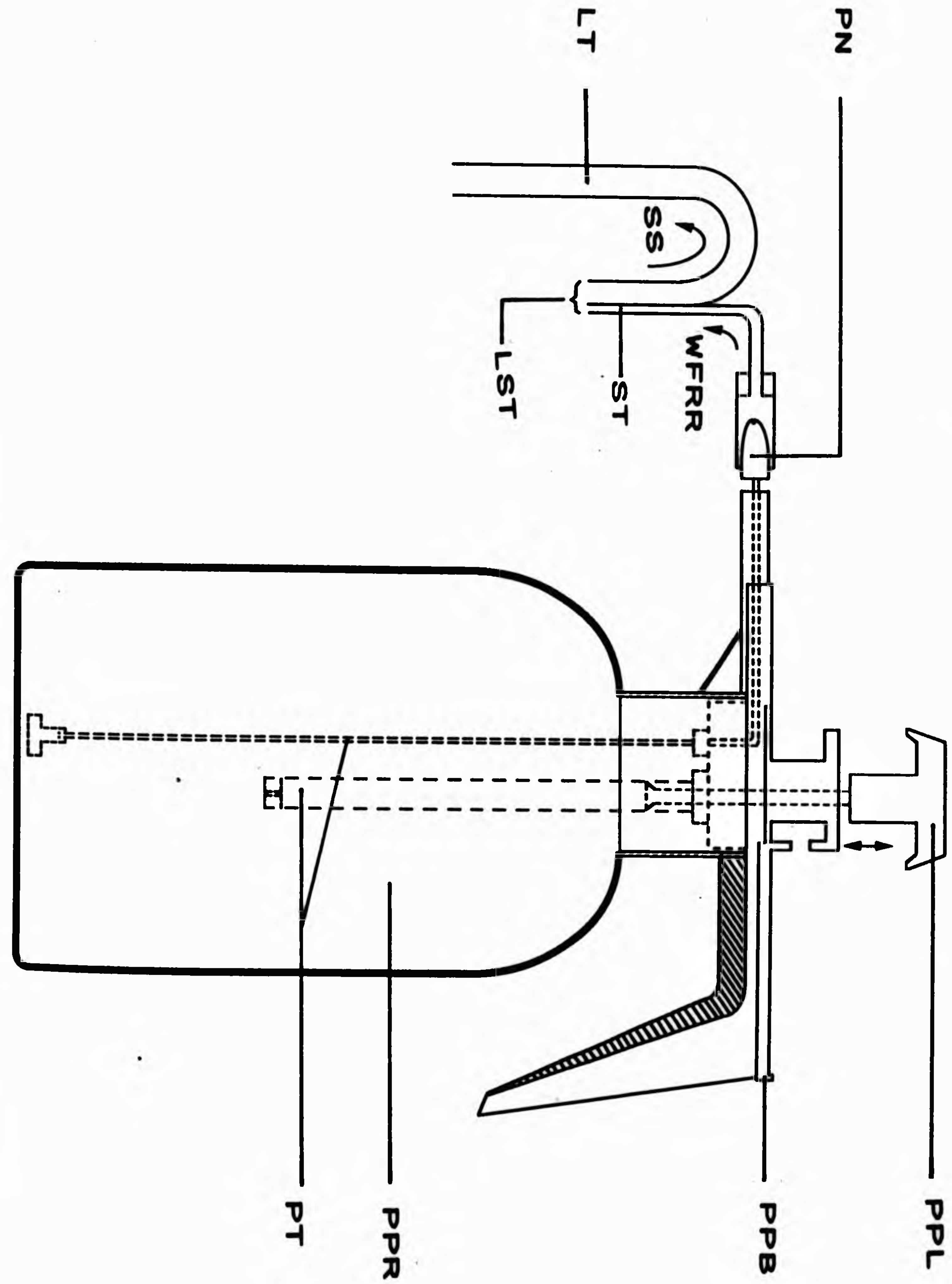
3.10.4 STOMACH CONTENT ANALYSIS

Petridis & O'Hara (1988) and Waddell (1988) have extensively reviewed several methods used in removing stomach contents from live fish, including their advantages and disadvantages. Stomach flushing technique is commonly used on carnivorous fish with a well defined stomach, though modified devices have been sucessfully used on omnivorous species (e.g. *Tinca tinca*) and grass carp (*Ctenopharyngodon idella*). The devices operate on the same principle: injection of water by means of a pump or bulb through a tube (Seaburg, 1957; Gaudin *et al.*, 1981; Georges & Gaudin, 1984), a pipette (Strange & Kennedy, 1981) or needle (Meehan & Miller 1978) combined with backflushing by suction, gravity, or external pressure on the abdomen.

In this study, stomach content analysis of trout was carried out following modified technique described by Waddell (1988), but further modified by Stirling & Larkins (Unpubl.). The modified pump (Fig.2) has a water injection tube on the outside of the pump reservoir, which has a capacity of 1.25 l. Two transparent rubber tubes of 9 mm external diameter are firmly attached to the pump's nozzle. Prior to flushing, pressure is developed inside the system by pumping until the pump head becomes hard to press. One anaesthesized fish a time was inclined head down on a foam board and sampling tubes (LST) gently inserted into the oesophagus, until slight resistance was felt. Some quantity of water was pumped through the tubes and into the fish stomach by gently pressing the button (FB) forward. Any stomach content present could be seen running through the transparent tube into the sample bottle. After about 50 ml of water runs into the oesophagus and stomach contents pumped out, the water becomes clear, and this was assumed to indicate that the stomach contents had been fully pumped out. However, if the flushing liquid did not run clear before end of operation, reflushing was repeated to collect any remaining contents. On completion, fish was returned to fresh water in a separate container for full recovery, which usually takes about 5 minutes, before being returned

Fig. 2. Modified stomach flushing device.

PPL	=	Pressure pump lever
PPR	=	Pressure pump reservoir
PT	=	Pressure tubes
PPB	=	Pressure pump button
PN	=	Pump's nozzle
WFRR	=	Water from pressure pump reservoir
ST	=	Small (5mm external diameter) flexible PVC tubing.
LT	=	Large (8mm external diameter) flexible PVC tubing.
SS	=	Direction of movement of stomach contents tube
LST	=	Large and small flexible tubings sellotaped to each other and carefully inserted into fish oesophagus. Water pumped through ST, into oesophagus, flushes stomach contents which then passes through LT and emptied into 200ml sampling bottle.



to the earthen ponds. This technique of collecting stomach contents has the advantage of not having to sacrifice the fish.

Stomach samples collected in the jar were allowed to settle and excess water decanted, taking care not to loose any consumed material. Fresh samples preserved in the deep freezer were later analysed in a petri dish under x10 magnification for natural food items, detritus and pelleted diet. On completion, the food items were oven dried at 65°C for 24 hours and preserved in a deep freezer for further proximate analysis.

3.10.5. ANALYSIS OF FOOD INTAKE

Analysis of food intake generally falls into two main categories, identified by Hyslop (1980) and Hepher (1988). First, those which examine diet of a fish population with a view to assessing the species nutritional standing. Such studies may consider seasonal variation in the diet and/or dietary composition between different sub-groups of some species, e.g. year classes or different species living in the same or comparable habitat, all with the aim of discerning whether there is competion for food (Maitland, 1965, 1974; Staples, 1975; Arawomo, 1976; Ikusemiju & Olaniyan, 1977; Olatunde, 1978; Stirling & Wahab, 1990). The second category is concerned with studies which attempt to estimate the total amount of food consumed by a fish population. (e.g. Allen 1951). This may involve calculation of daily ration or energy budget besed upon field studies (Staples, 1975; Sainsbury, 1986) or laboratory determinations (Gerking, 1972; Solomon & Brafied, 1972; Stirling, 1972; Morgan, 1974; Elliot, 1976 b) or both (Brown, 1951, Mann, 1965; Cameron *et al.*, 1973; Swenson & Smith, 1973; Kuipers, 1975).

Several methods have been used in the analysis of fish food intake and extensively reviewed by Windell (1978). These include, first, the 'occurrence method' involving recording the numbers of stomachs containing different food categories that are readily identifiable. Although it provides crude qualitative picture of food spectrum (e.g. Crisp, 1963; Fagade & Olaniyan 1972), it gives a little indication of relative amount of bulk of each food category in the stomach. Second, the 'numerical method' involves recording the numbers of individuals in each category for all stomachs and the total expressed either as mean number of individuals per stomach or as a proportion or percentage in each food category (Stickney, 1976; Ikusemiju & Olaniyan, 1977; Crisp *et al.*, 1978, Adebisi, 1981). This method is most appropriate where prey items of different species are considered, but it tends to overemphasise the importance of small prey items which are consumed in large numbers and disgested more rapidly (Sikora *et al.*, 1972). Third, the 'volumetric method' involves sorting each food item or groups of food items from the stomach and displaced in a graduated measuring device; the displacement volume being equal to that of food items (e.g. Wolfert & Miller, 1978; Stirling & Wahab 1990). This method probably gives the most representative measure of bulk and applicable to all food items, though a major problem is the water trapped within the items, thus causing large errors in estimation. Fourth, the 'gravimetric method' involves measuring food consumed either on wet or dry weight basis. Generally, dry weight for bulk food items give lower error margin (Berg 1979), though it may overemphasize the contribution of single heavy item to the diet (Geoge & Hadley, 1979; Hellawell & Abel, 1971). Lastly, the 'subjective method' estimates food consumption by eyes, using the points system to minimize errors caused by subjectivity (Swynnerton & Worthington, 1940; Haram & Jones, 1971; Wahab, 1986; Waddell, 1988). Points allocated are proportional to estimated contribution of stomach volume, though this technique cannot be employed in cases where advanced stage of digestion is attained.

It is obvious that the choice of method depends on the nature of the experiment. In this study, a combination of numerical and gravimetric methods were chosen for the obvious reason that different food items consumed are being evaluated. Following stomach flushing, all food items consumed were enumerated and then oven dried to obtain the biomass of food consumed on dry weight basis for accurate determination of calorfic intake as recommended by Li & Brocksen (1977).

3.10.5.1. COMPUTATION OF RELATIVE DAILY FOOD INTAKE

The relative daily food intake (RFI) for trout in the various pond treatments was calculated using the formula:

$$RFI\ (\%) = \frac{W_{fe}}{F_{wf} \times t} \times 100$$

where, W_{fe} = total wet weight of food eaten

F_{wf} = total of the mean weight of fish

t = feeding period (days)

This formula applies to both natural and artifical pelleted diet, and the feeding time for natural food was assumed to be 3x day^{-1} at mean temperature of 18°C (Elliot 1975b). The RFI method enables comparison of rate of food intake of various fish size. However, it gives no information about the variation in food intake between individual fish of the group, because only the responses of the fish to food (in terms of growth rates) could be observed individually. It is however assumed that variability in food intake was reflected in variability in growth rates (Stirling 1972).

3.10.5.2. INDEX OF SELECTIVITY

This is a measure of degree of selectivity exerted by the fish upon the choice of food items, and was calculated by the following:

$$E = \frac{Pd - Pb}{Pd + Pb} \quad \text{(Ivlev, 1961)}$$

where E = electivity or selection index

Pb = proportion of food organisms present in the benthos group

Pd = proportion of food organisms in the diet

This formula applies only to natural food organisms. Values lying between 0 and + 1 represented positive selection for an organism, and the higher the volume, the greater the degree of selectivity by the fish and *vice versa*.

3.11. ANALYSIS OF NUTRITIONAL PARAMETERS

Analysis was carried out for fish samples, benthic macroinvertebrates, zooplankton, detritus and artificial pelleted diet. Prior to stocking in ponds, and at the termination of fish culture, five representative samples were randomly selected for initial and final carcass analysis. Fish samples and all fresh, uneaten benthic macroinvertebrates, zooplankton and detritus and those consumed, including artificial pelleted diet (obtained from stomach pump) were dried at 105^{0}C for 24 hours, stored in the deep freezer at -20^{0}C for subsequent analysis. Proximate compositions of fresh, uneaten artificial diet were obtained from the manufacturer's (Trout grower feeds- Ewos Ltd; Bathgate, Scotland) specification.

3.11.1. PROXIMATE ANALYSIS

The following parameters of proximate composition were analysed following the methods of AOAC (1980).

3.11.1.1. MOISTURE AND ASH CONTENT

For moisture content analysis, fresh triplicate samples were weighed, oven dried at 105^{0}C for 25 hours to constant weight, allowed to cool in a dessicator and reweighed. All subsequent determination were performed on dried, ground samples and result expressed as percentage of dry weight.

For ash content, this is the inorganic residue remaining after the organic matter has been burnt away. Analytical procedure involved heating dried samples in a muffle furnace for 4 hours at 550^{0}C and results calculated by difference.

3.11.1.2. CRUDE PROTEIN

The kjeldahl method was used in determining crude protein (N x 6.25). Triplicate samples each of 200mg of dried, ground samples were weighed into tubes. Two Kjeltabs (catalyst) and 5ml conc. H_2SO_4 were added to the samples and tubes placed in digestion block in the fume cupboard and digested for 1 hour at 420^{0}C, with occasional rotation. Samples were allowed to cool and 20ml of dejonised water and 5ml of sodium thiosulphate (330g/l $Na_2S_2O_3.5H_2O$) were added and distilled in 'Tecator Kjeltech' distillation unit. Titration was carried out in an automatic titrating machine. The blanks were run and average values used for end point comparison with sample titration. Calculation was based on the formula:

$$\% \text{ Crude protein} = \frac{(\text{Titration} - \text{Blank}) \times 0.2 \times 14.007 \times 6.25}{\text{Sample weight (mg)}} \times 100$$

3.11.1.3. CRUDE LIPID

This was analysed following Linford's (1965) modification of the chloroform-methanol extraction procedure of Folch *et al.*, (1956). This method extacts quantitatively both polar and non-polar lipid fractions, unlike the single extraction procedure such as Soxhlet extraction with ether (Lipin & Chernova 1970). 3g of triplicate samples were separately weighed and transfered to a homogenized tube and 5ml 2:1 (v/v) Chloroform-methanol mixture added from a Zipette dispenser. The mixture was homogenized with an Ultraturax-model TP 18/10 for about 5 minutes until all materials had uniformly dispersed in the solvent. The homogenate was filtered through Whatman No 1 filter paper under vacuum. The homogenizer and residue were washed out twice with fresh solvent, and residue re-homogenized with a further 5ml of solvent and then filtered. The combined filtrates were transfered to a 50 ml stoppered seperating funnel and made up to 20ml with fresh solvent, followed by 4ml of 0.05m aqueous KCl solution and mixture shaken to 'salt out' any protein impurities which pass into the aqueous phase. About 15 minutes was allowed for the lower organic phase containing the lipid to separate out. This lower phase was run into an aluminum foil dish and evaporated in the draught of a fume cupboard at room temperature, taking precautions to avoid contamination by dust. The aluminum dish was reweighed to obtain lipid content. Samples used, especially natural and pelleted diet were, retained for crude fibre analysis.

3.11.1.4. CRUDE FIBRE

This is the indigestible and stable carbohydrate portion of feed materials and feeds with no nutritional value, consisting principally of celluloses, hemicellus and lignin. These aid in efficient movement of food in the gut and also binding of food material. Analytically, it is defined as the loss on ignition of the dried residues remaining after the digestion of a sample in acid and alkali under specific conditions.

Analytical procedures involved weighing 2g of the samples used from lipid analysis into a round bottomed flask and adding about 0.5g antibumping granules. 200ml of near boiling 1.25 H_2SO_4 was added to the sample and water-cooled reflux condenser fitted. The mixture was boiled for 30 minutes, with occasional swirling of the flask. The contents were filtered through the buchner flask with sinterred glass disc filteration apparatus, taking care not to transfer any antibumping granules. The residue was washed with four, 50ml portions of near boiling 1.25% NaOH and boiled for 30 minutes, washed again with four 50ml portions of near boiling 1.25% H_2SO_4 and twice with 30ml near boiling petroleum either. The resulting sample was ashed in a crucible for 2 hours at 550^{0}C in a muffle furnace, cooled in a dessicator and reweighed. Crude fibre was calculated based on the formula:

$$\text{Crude fibre content } (\%) = \frac{(Y^{\cdot} - Y^{t})}{X} \times 100$$

where, $Y^{\cdot}(g)$ = dry crucible + residue

$Y_t(g)$ = dry crucible + ash

$X(g)$ = weight of sample

3.11.1.5. NITROGEN FREE EXTRACTIVES (NFE)

This is equivalent to crude or total carbohydrate (mono-and-polysaccharide) which is a measure of total hexose content of a sample after complete hydrolysis. It is calculated by the 'difference' method from results of crude protein (CP), crude lipid (CP), crude fibre (CF) and ash (A) as follows;

$$NFE\ (\%) = 100 - (\%CP + \%CL + \%A + \%CF)$$

3. 12. COST - BENEFIT ANALYSIS

In order to compare the cost of producing or culturing trout under controlled condition with organic manuring which benefits benthos, and hence the fish, a simple cost-benefit analysis was carried out using the formula described by Rutledge *et al* (1990):

$$\text{Cost benefit} = \frac{N_h \times V_f}{O_c} = \frac{\text{Revenue generated}}{O_c} \quad .....(1)$$

Where N_h = number of fish harvested

V_f = value of a single fish

O_c = operating cost = total cost of fish stocked.

The value of a single fish, hereafter refered to as aggregate cost per fish was computed in accordance with the proportion of fish size in the ponds. Thus, in the control ponds, 60% of the fish harvested had an average length of 25.5cm with a value of £2 : 07 per fish, while the remaining 40% had an average length of 28.1cm with a value of £2 : 31 per fish. Aggregate cost per fish of different length was computed as follows:

Aggreg. cost/fish = [(0.6 x 2.07) + (0.4 x 2.31)]....(2)

= £2 : 17

Similar principle of computation also applies to manured ponds. Thus, 30% of fish harvested had an average length of 22.9cm with a value of £1 : 48 per fish while 70% had an average length of 25.5cm with a value of £2 : 07 per fish. Aggregate cost per fish was computed as follows:

Aggreg. cost/fish = [(0.3 x 1.48) + (0.7 x 2.07)]....(3)

= £1 : 89

The operating costs considered in this study were mainly capital, labour and feed input. Capital costs covers nets and screens which can last for 4 - 5 years, depending on materials (I. Semple, Pers. comm.). Labour costs covers stock worker rate at £2 : 75 hr^{-1} for a total of 8 hours per day. Labour cost also include stocking, daily feeding, routine checks for nets, screens, fish health etc. Feed input includes cost of artificial pelleted diet and organic manure. The cost of artificial pelleted diet (= £480) used for this computation only covers the 215 days culture period. The cost of organic manure (£20 : 00) was derived from the purchasing price of £10 per ton of chicken and cow manure. The application of manure to stimulate production of natural food can also be considered as derived cost, since trout do not directly consume the manure.

Sales revenue in the cost benefit ratio is the money accruing or expected to be generated from sale of a given number of fish harvested from the ponds that had an initial high stocking density of 3,875 fish ha^{-1}. The value of a single fish is based on the current market price (Howietoun

Fishery) of different sizes of fish.

Break even point (B.E.P), which represents the number of fish that must survive to produce a 1 : 1 cost benefit ratio was calculated from equation 4 (derived from equation 1):

Cost benefit ratio = 1

therefore $\frac{(N_x \times V_f)}{O_c} = 1$

$$N_x = \frac{O_c}{V_f} \times 1 \ldots\ldots\ldots\ldots (4)$$

where N_x = break even quantity

The product of equation (4) represent the least number of fish that must survive to make up for the cost of production. In other words, it is a situation where the costs of production are exactly met by incoming revenue and the fixed costs are covered.

3. 13. STATISTICAL ANALYSIS

Prior to statistical analysis, all data were checked for heterogeneity of variance among groups in order to normalize the distribution curves. All physico-chemical and nutritional data were transformed to $\log_{10}(x + 1)$, while biological data were subjected to geometric mean transformation which accounts for the variance of population estimates which always increases with the value of the mean. The following analysis were performed:

1. One-way analysis of variance (ANOVA) to test the significance of variations between treatment means of parameters measured. Where relevant, comparison of the means was carried out by Duncan's (1955) Multiple Range Test (DMRT) and standard errors (± S.E) are given to indicate the range of the means (Sokal & Rohlf, 1981)
2. Two-way ANOVA to test the significance of variation in means of parameters measured, relative to ponds or treatments and sampling periods.
3. Pearson product-moment correlation coefficient to determine correlation between physico-chemical parameters and primary production of pond water during both fertilisation trials, without fish.
4. Analysis of covariance (ANCOVA) for comparison of fish growth rate at varying nutrient levels and stocking density (Snedecor & Cochran, 1973)
5. Graphical plots of regression lines with their significant correlation for growth rate, and length-weight relationship.

All statistical analysis were performed using the Minitab statistical package (Ryan *et al.*, 1988) on the University's mainframe computer (VAXA) and results are reported at significant level of P = 0.05, unless stated otherwise. All figures were plotted on the Apple II Mackintosh computer with the Cricket Graph software.

CHAPTER FOUR

RESULTS

The results of these biomanipulation studies have revealed a wide variation in physico-chemical and biological characteristics of the various experimental treatments. Interpretation of the results based on information derived from Figures 3-99, Tables 4-27 and statistical analyses were also related to known limnological, ecological and aquacultural principles. In the graphical presentation of physical and chemical parameters, primary production and biological characteristics during pond fertilization, prior to fish culture, the pre-manipulation (0) data represent a theoretically unproductive trophic status which is taken as a reference point for comparison of responses to various inorganic fertilization treatments.

4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS, PRIMARY PRODUCTION AND EUTROPHICATION, WITHOUT FISH

The results of water quality characteristics and primary production during both inorganic fertilization are presented in Figures 3-37, while the overall mean values for each fertilization treatment are shown in Tables 5 and 6. The results of Pearson product-moment correlation analysis which shows the interrelationship between various parameters are presented in Tables 7 and 8.

4.1.1 TEMPERATURE

Mean monthly variations in water temperature are presented in Fig. 3. Throughout the study period, water temperature remained isothermal, considering the shallow nature of the ponds. The highest mean value was 23.0^{0} C during the summer period in June. In both fertilization treatments, there was no significant variation ($P>0.05$) between ponds compared to significant variations ($P<0.05$) between periods during the organic fertilization (Table 5).

4.1.2 pH

Figures. 4 and 5 show the variation in pH during inorganic and organic fertilization, respectively. In both cases, pH rose steadily from 7.0 to 7.5 at the pre-manipulation state to 7.9 to 8.4 in the control (CTRL), low phosphorus (LP) and high phosphorus & nitrogen (HPN) treatments in response to liming. In summer, three peaks of alkaline values were recorded in the high phosphorus (HP), LP and HPN treatments (Figure 4).

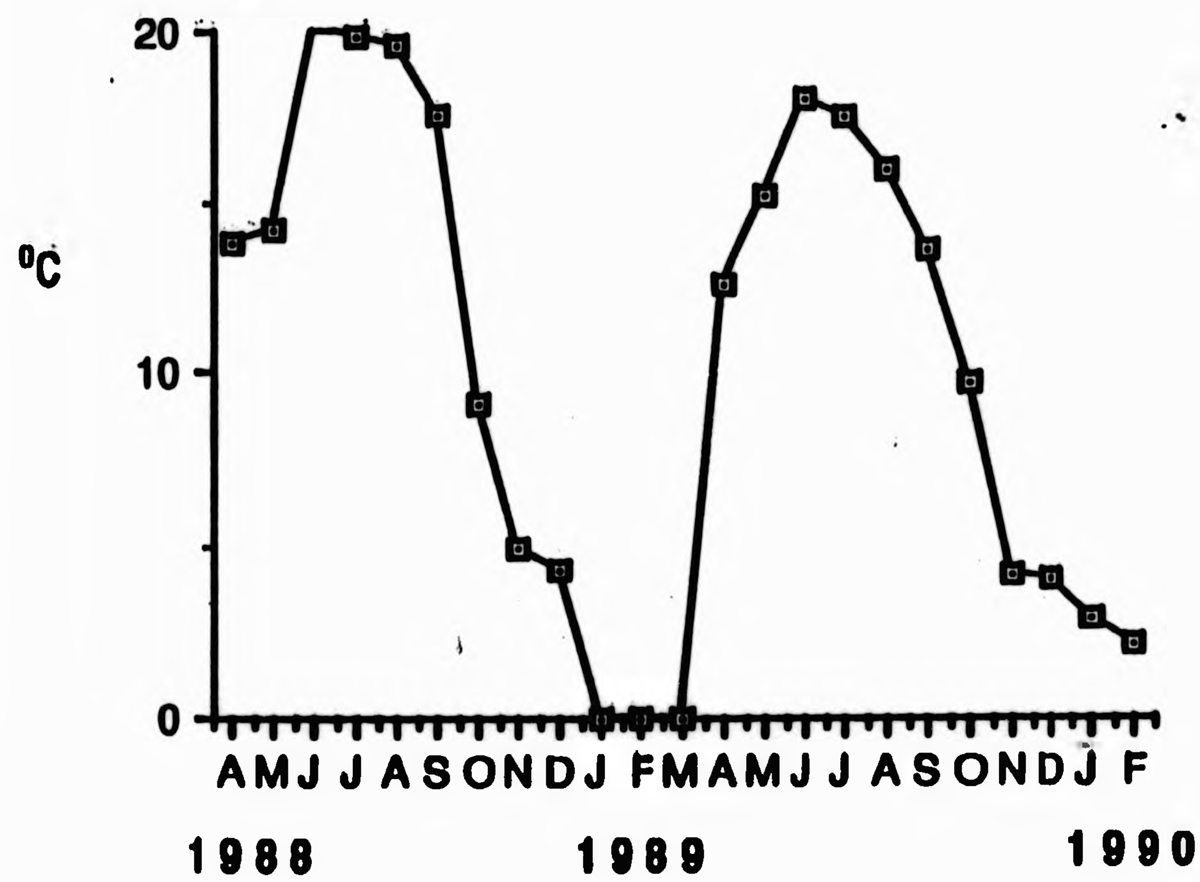


Fig. 3. Mean monthly variations in pond water temperature.

Figures 4-5. Variations in pond water pH during inorganic and organic fertilization trial, without fish.

Day 0 = Premanipulation values
CTRL = Control treatment
LP = Low phosphorus
HP = High phosphorus only
HPN = High phosphorus and nitrogen

LC = Low chicken manure
HC = High chicken manure
HCC = High chicken & cow manure.

Fig. 4 INORGANIC

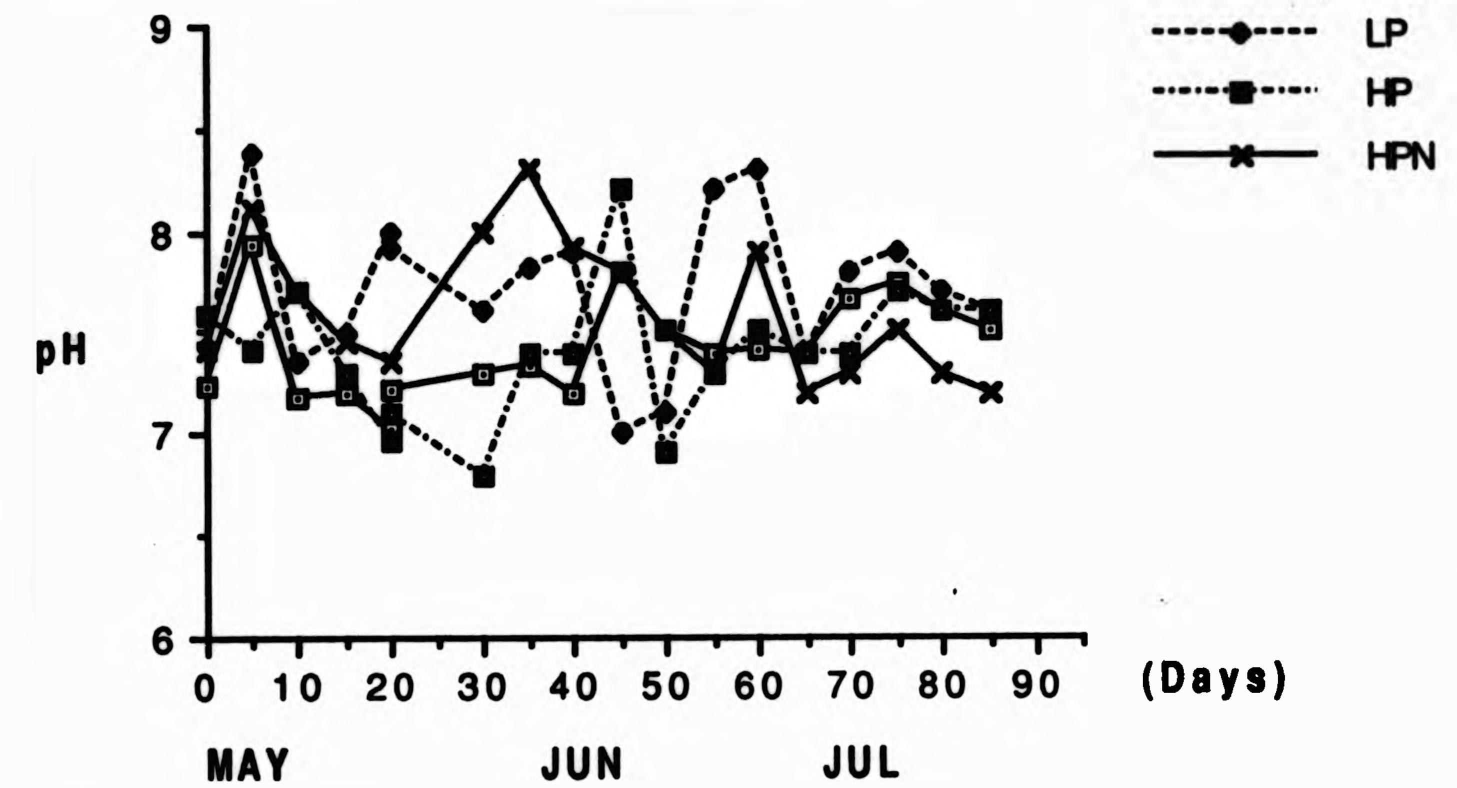
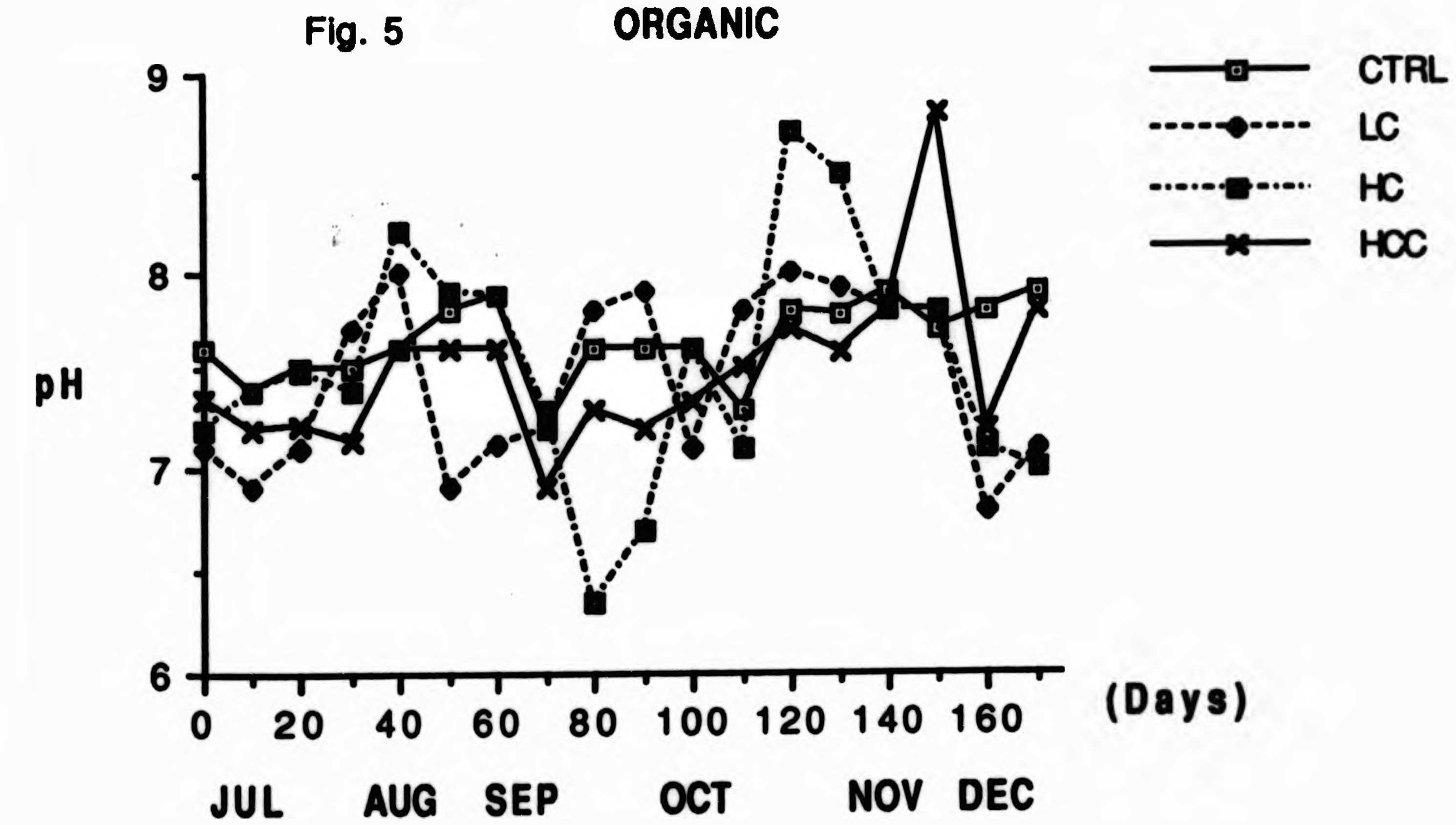


Fig. 5 ORGANIC



With regard to organic fertilization treatments (Fig. 5), the pH range was 6.3 to 8.8. Throughout the summer and winter periods, values for all treaments were within the alkaline range, except for high chicken (HC) and low chicken (LC) treatments which became slightly acidic in September and December, respectively. The CTRL treatment had the least fluctuation. Two-way ANOVA (Table 4) showed significant ($P<0.05$) between pond treatments and periods. In general, the pH values were within acceptable limits for trout survival.

4.1.3 CONDUCTIVITY

Conductivity values with inorganic treatments, are presented in Fig. 6, and showed consistent increase following first fertilization; unlike organic fertilization (Figure 7) which showed little fluctuation apart from the control. In both cases, the mean conductivity ranged from 84 to 148 $uScm^{-1}$ and there was a significant variation ($P<0.05$) between treatments and periods (Table 4).

Fig. 6 INORGANIC

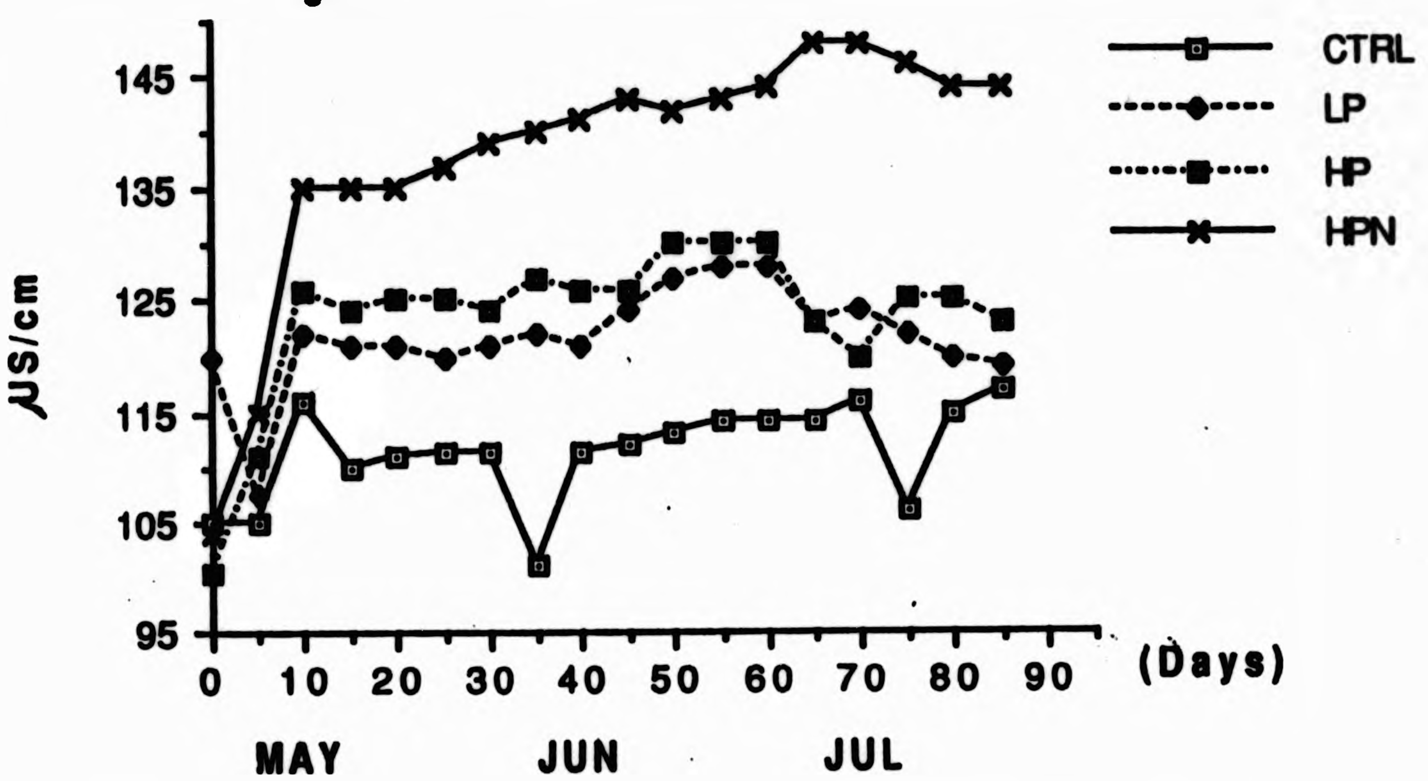
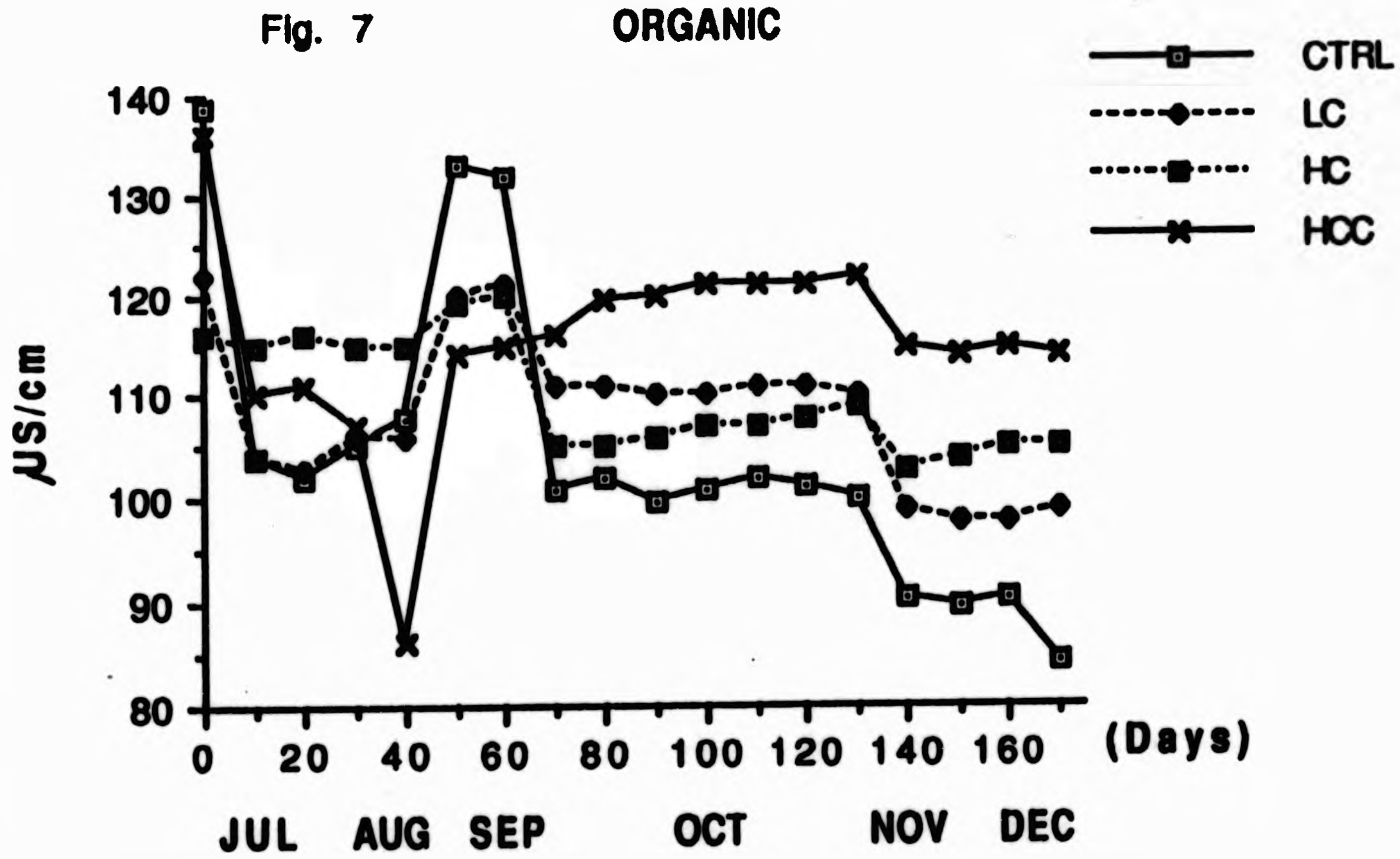


Fig. 7 ORGANIC



Figs. 6-7. Variations in pond water conductivity during inorganic and organic fertilization, without fish. Key is as explained in caption to Figs. 4-5).

Fig. 6 INORGANIC

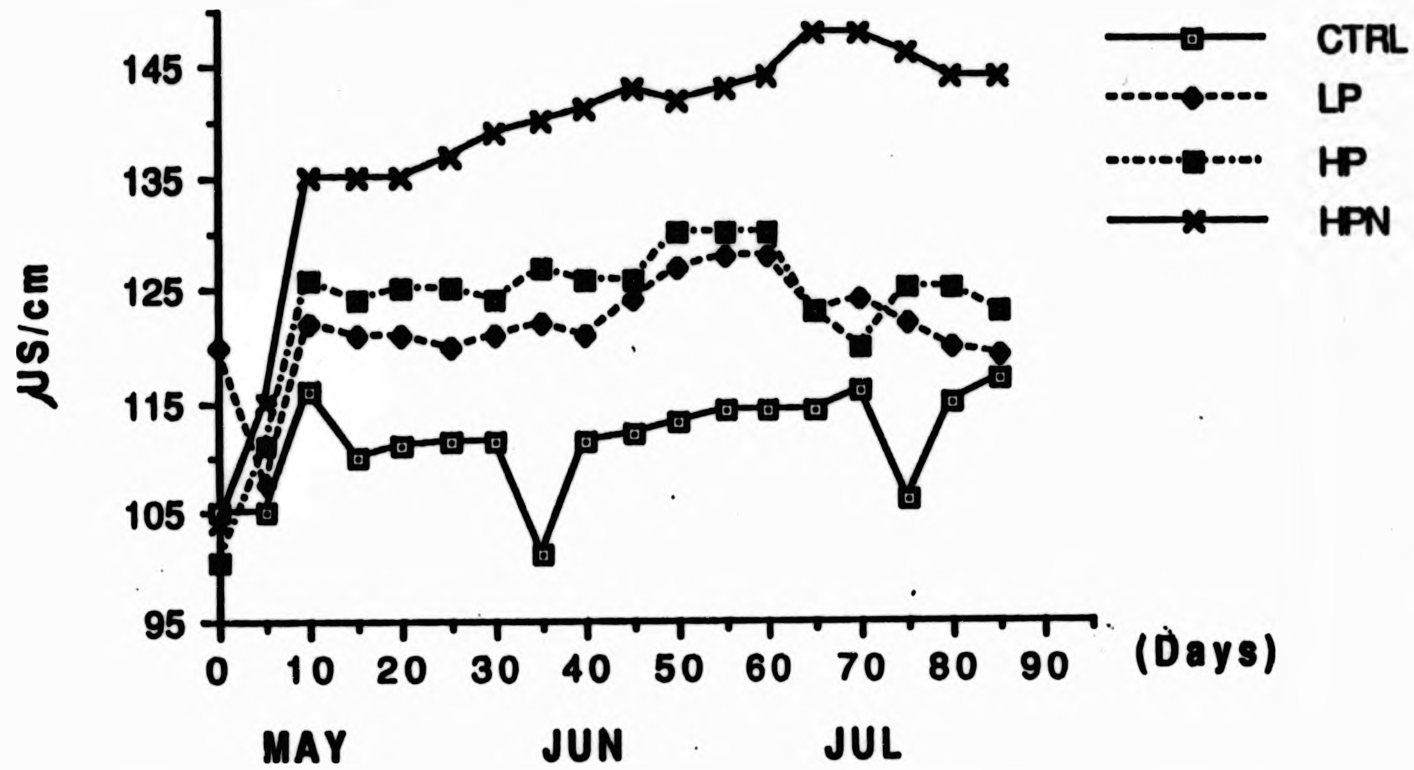
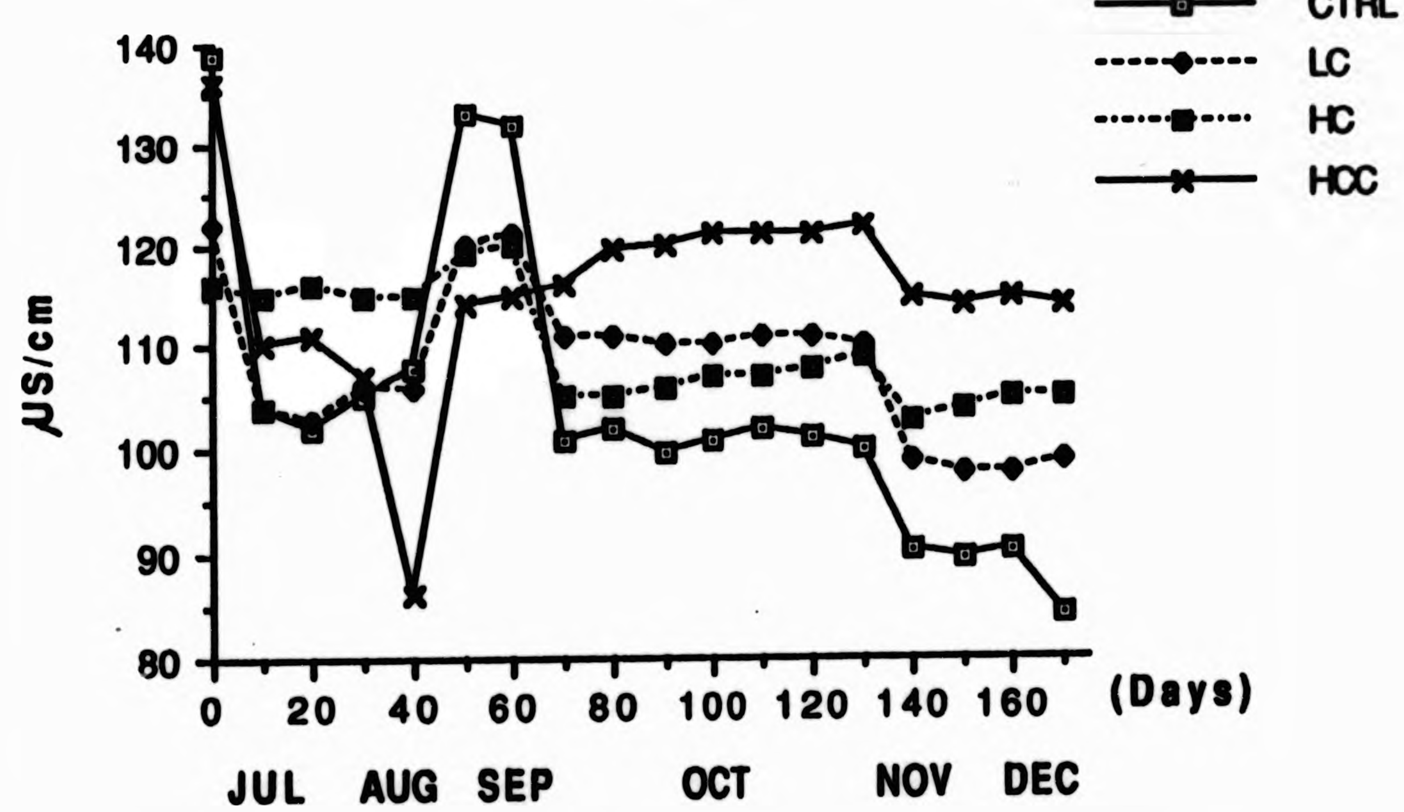


Fig. 7 ORGANIC



Figs. 6-7. Variations in pond water conductivity during inorganic and organic fertilization, without fish. Key is as explained in caption to Figs. 4-5).

4.1.4 TOTAL HARDNESS

Variations in total hardness during inorganic fertilization are presented in Figure 8. The initial response pattern was slow, and the range 41.2-110 mg $CaCO_3l^{-1}$ was lower than the range 20-120 mg $CaCO_3l^{-1}$ for organic fertilization treatments (Figure 9). These latter values were related to the carry-over effect of inorganic fertilization during the first phase of the experiment. Both fertilization programmes showed significant variations (P<0.05) between treatments and periods (Table 4).

4.1.5 TOTAL ALKALINITY

Total alkalinity, which ranged from 0.73 to 3.10 $meql^{-1}$ for both fertilization programmes, is shown in Figs. 10 & 11. In general, fertilization treatments do not seem to influence alkalinity values. For example, during the organic fertilization, the highest recorded value of 3.0 $meql^{-1}$ was in the control (CTRL) and high chicken (HC) treatments. In both fertilization treatments, there was no significant variation (P>0.05) between ponds, compared to the significant variation between periods.

Fig. 8 INORGANIC

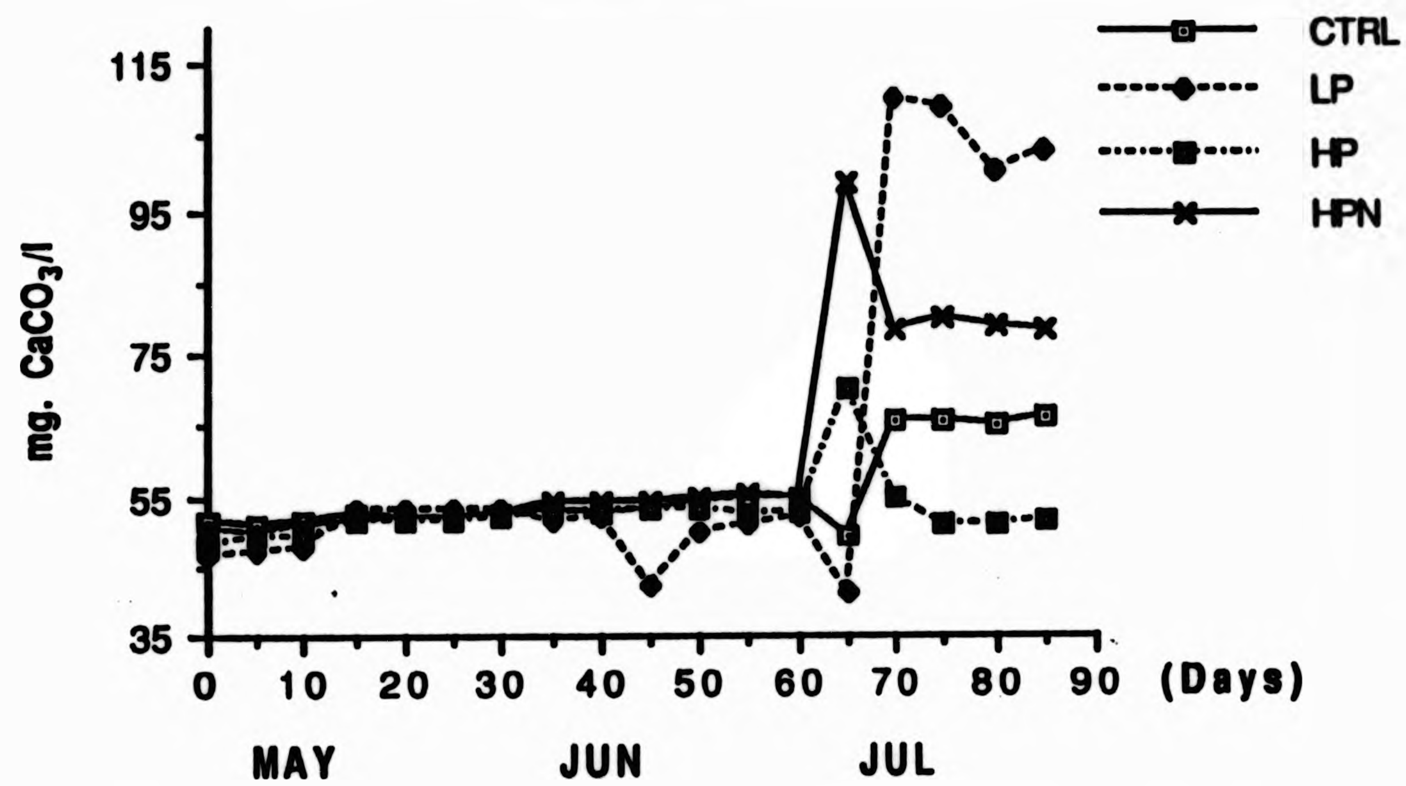
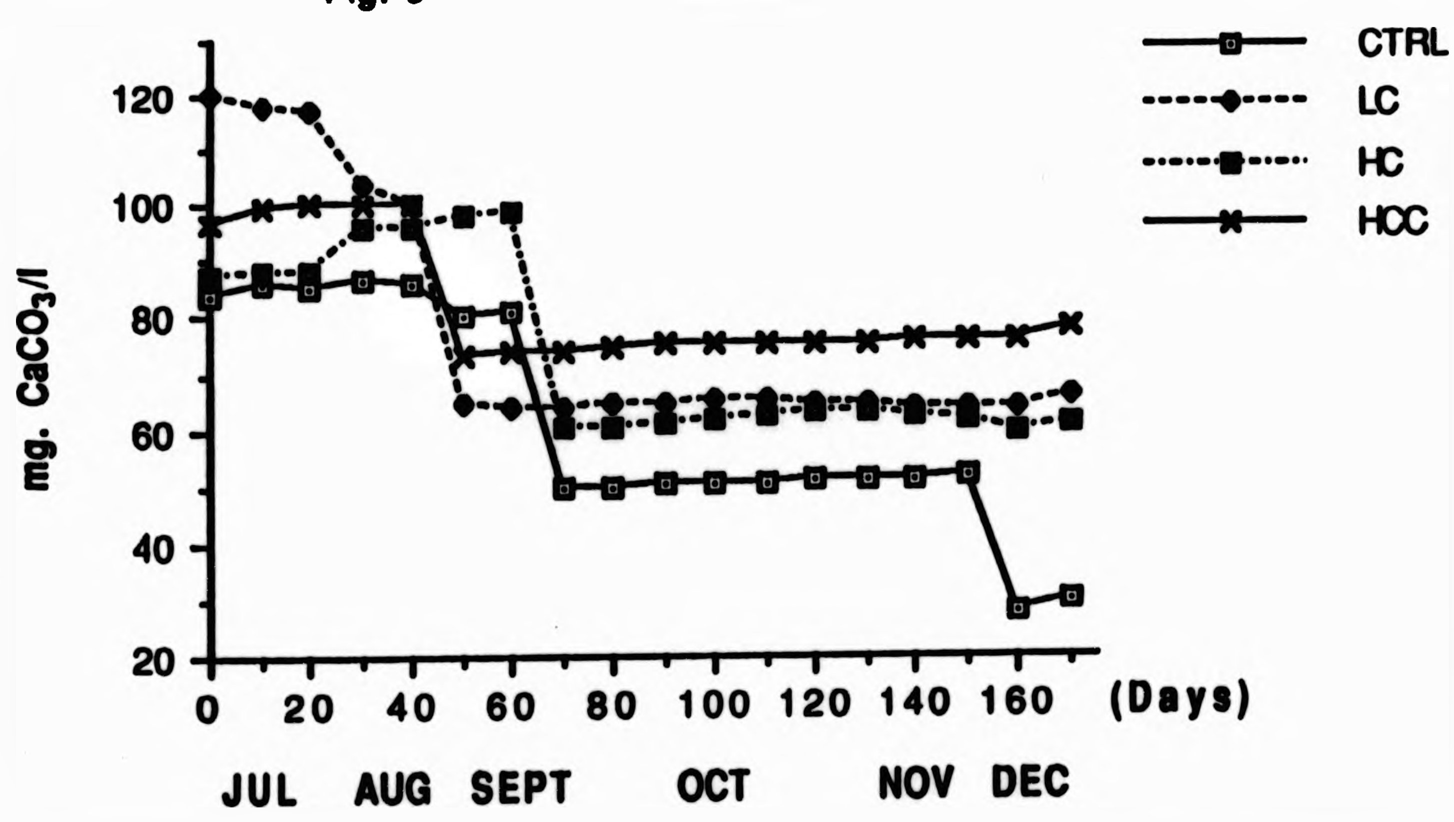
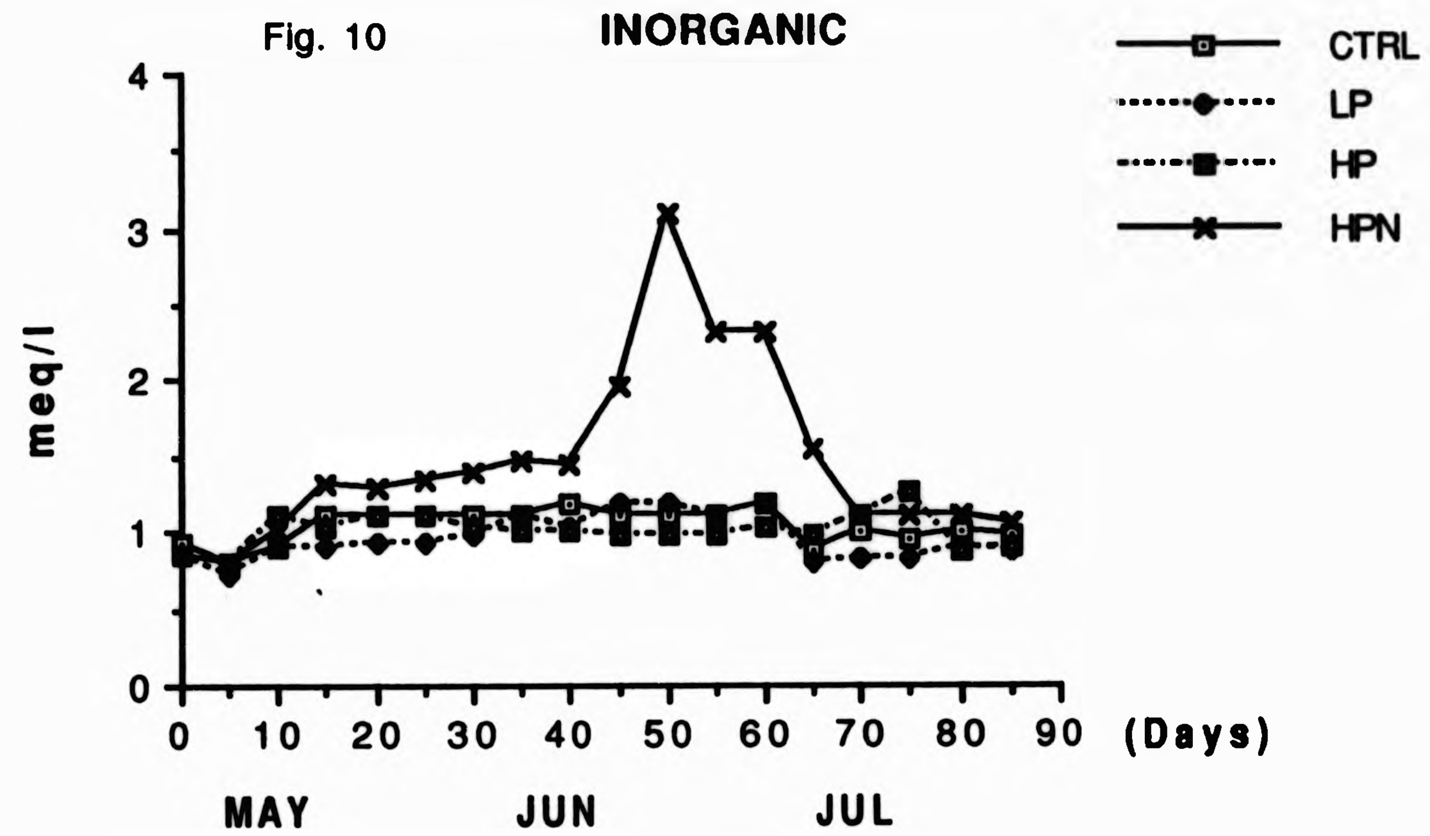
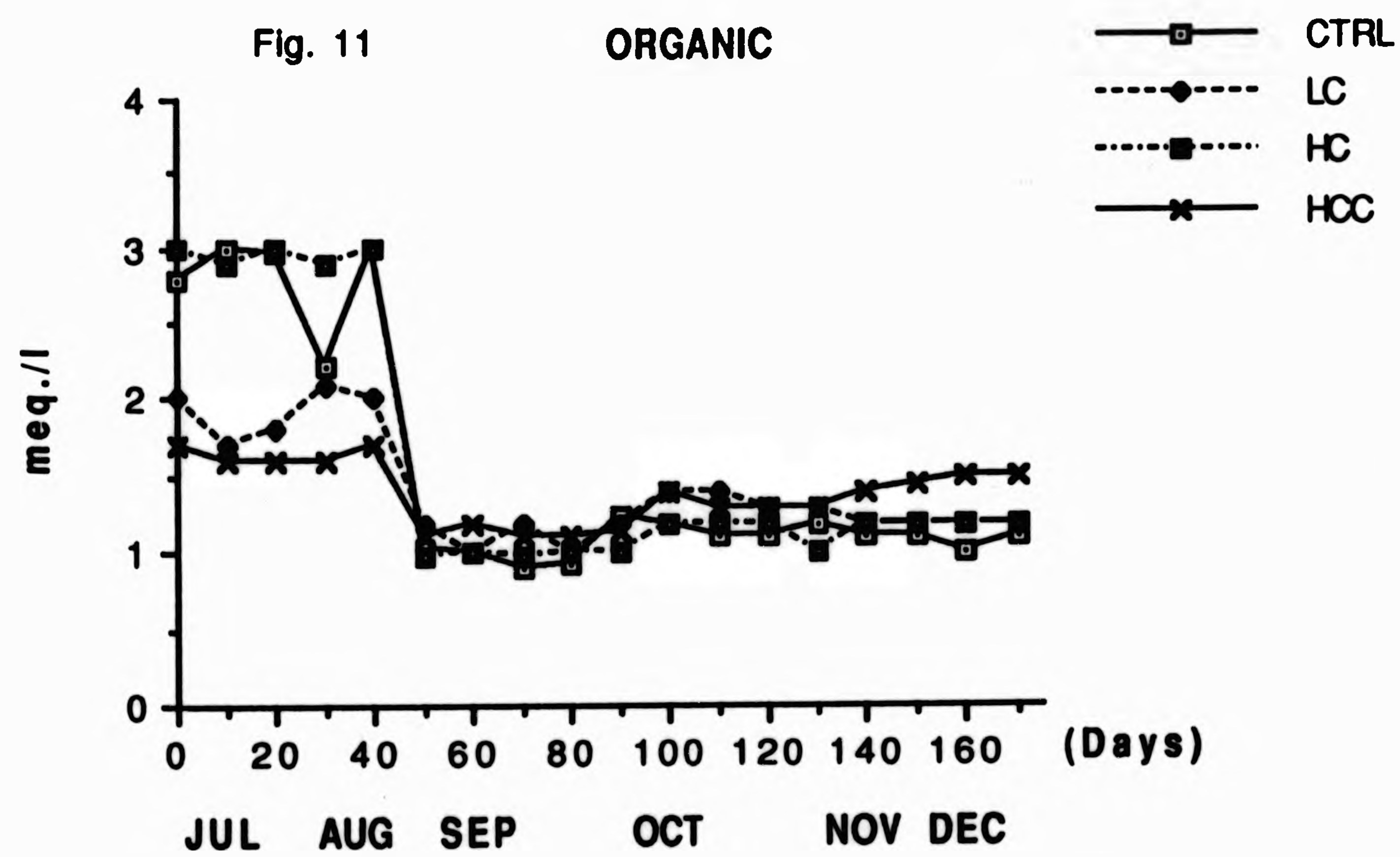


Fig. 9 ORGANIC



Figs. 8-9. Variations in Total Hardness during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).





Figs. 10-11. Variations in Total Alkalinity during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.1.6 SUSPENDED SOLIDS

Suspended solids varied significantly between pond treatments and periods ($P < 0.05$) of both inorganic and organic fertilization, the highest values being obtained with HPN and high chicken and cow (HCC) treatments (Figs. 12 & 13). Higher values were recorded in the CTRL than LP and HP during most of the experiment. In the organic treatments, suspended solids ranged from 4.2 to 14.1 mgl^{-1} (Fig. 12). In both fertilization programmes, the high values may not be unrelated to plankton bloom and addition of organic manure.

4.1.7 DISSOLVED OXYGEN

The mean daytime values for inorganic and organic fertilization are presented in Figs. 14 & 15 respectively. Dissolved oxygen concentration was generally higher in the inorganic (range: 8.32-14.5 mgl^{-1}) than organic (range: 7.20-12.5 mgl^{-1}) treatments. The highest value recorded in HPN (Fig. 13) during the summer coincided with increased

Fig. 12 INORGANIC

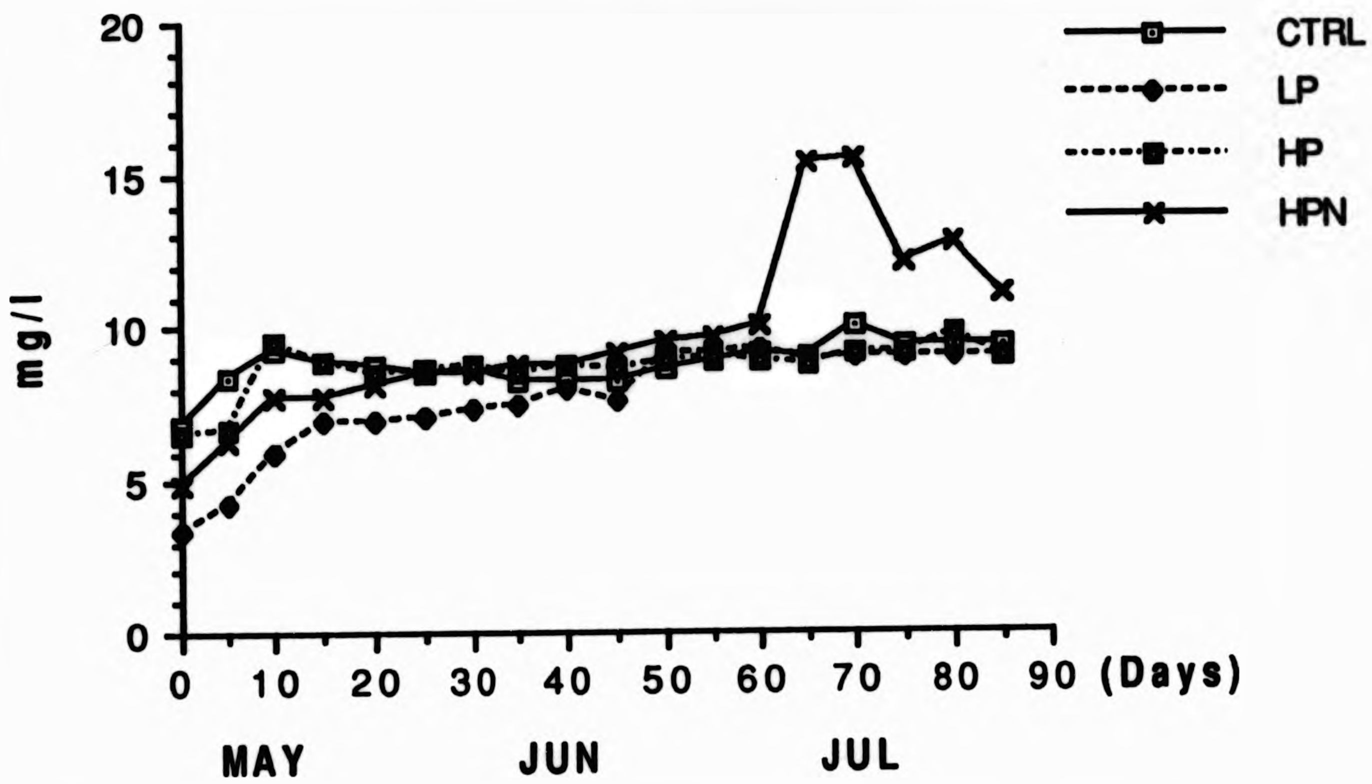
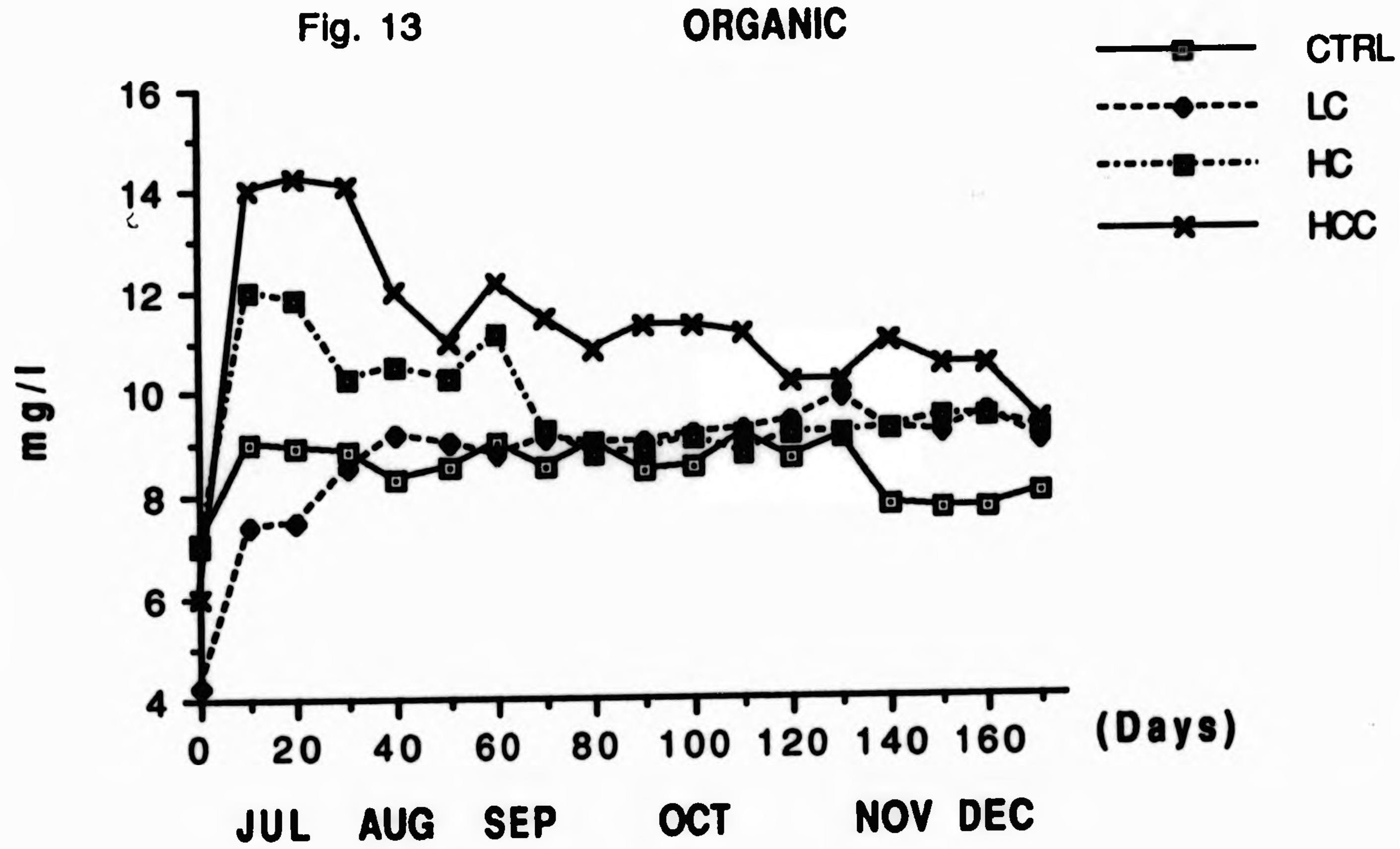
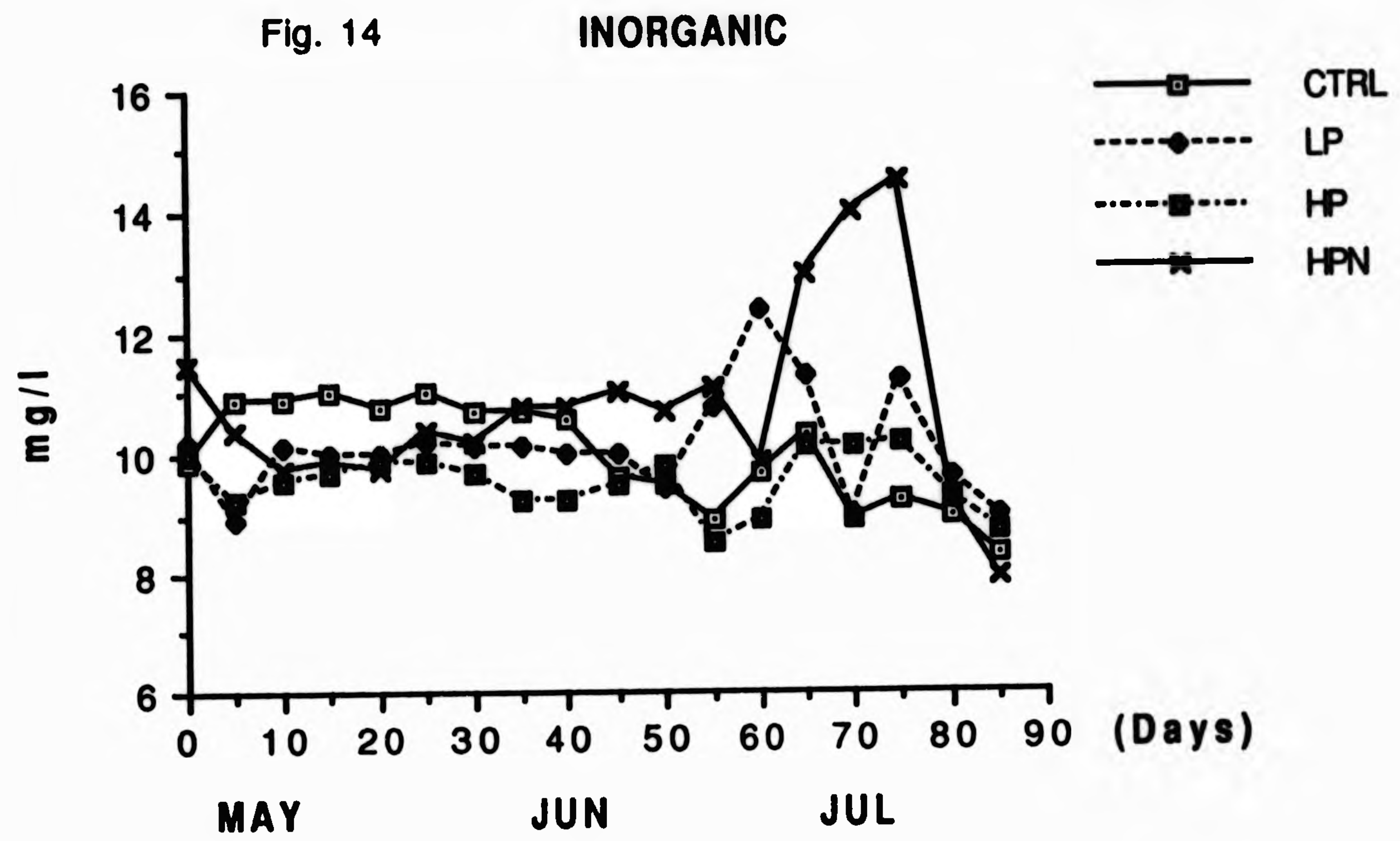
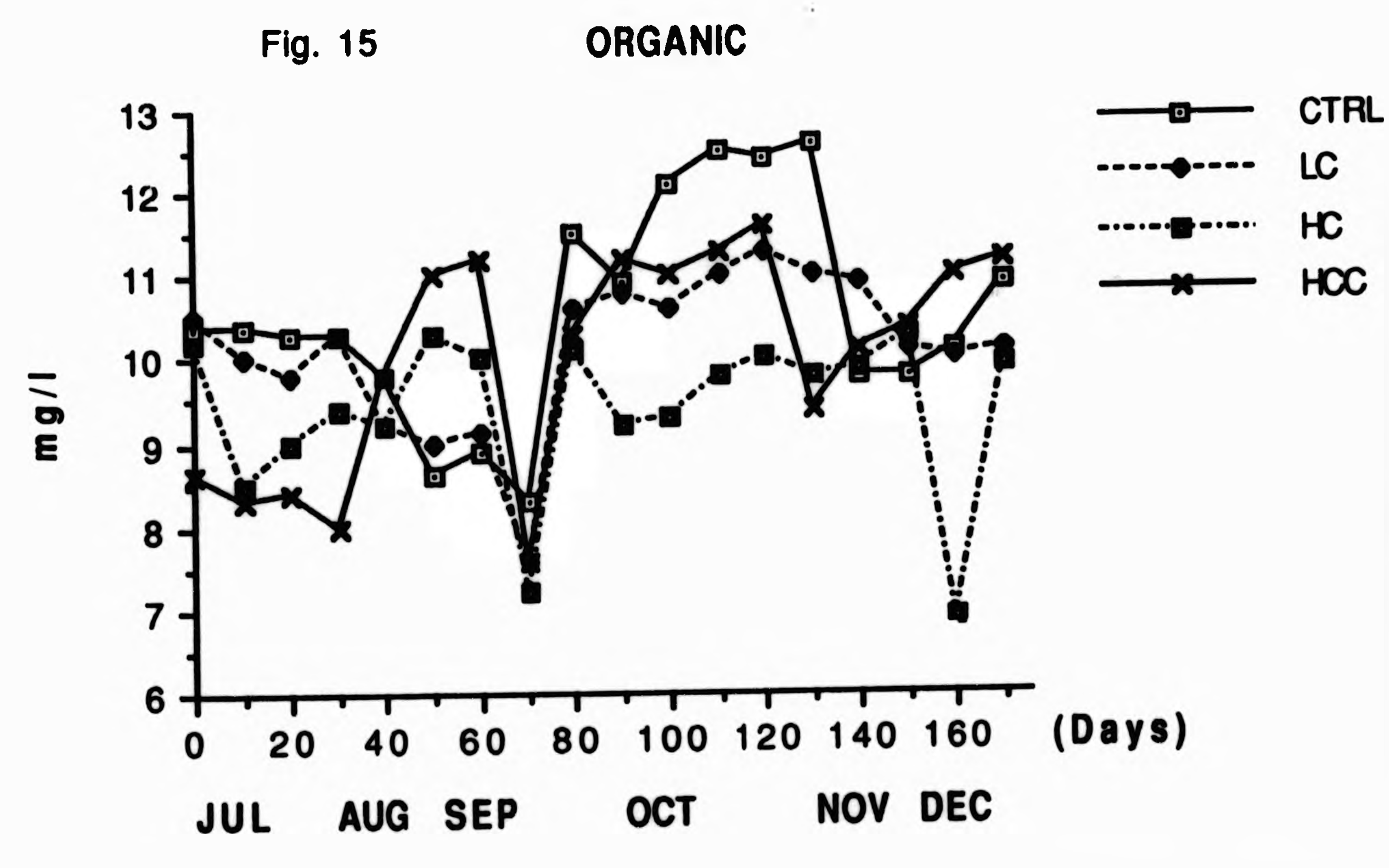


Fig. 13 ORGANIC



Figs. 12-13. Variations in Suspended Solids during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).



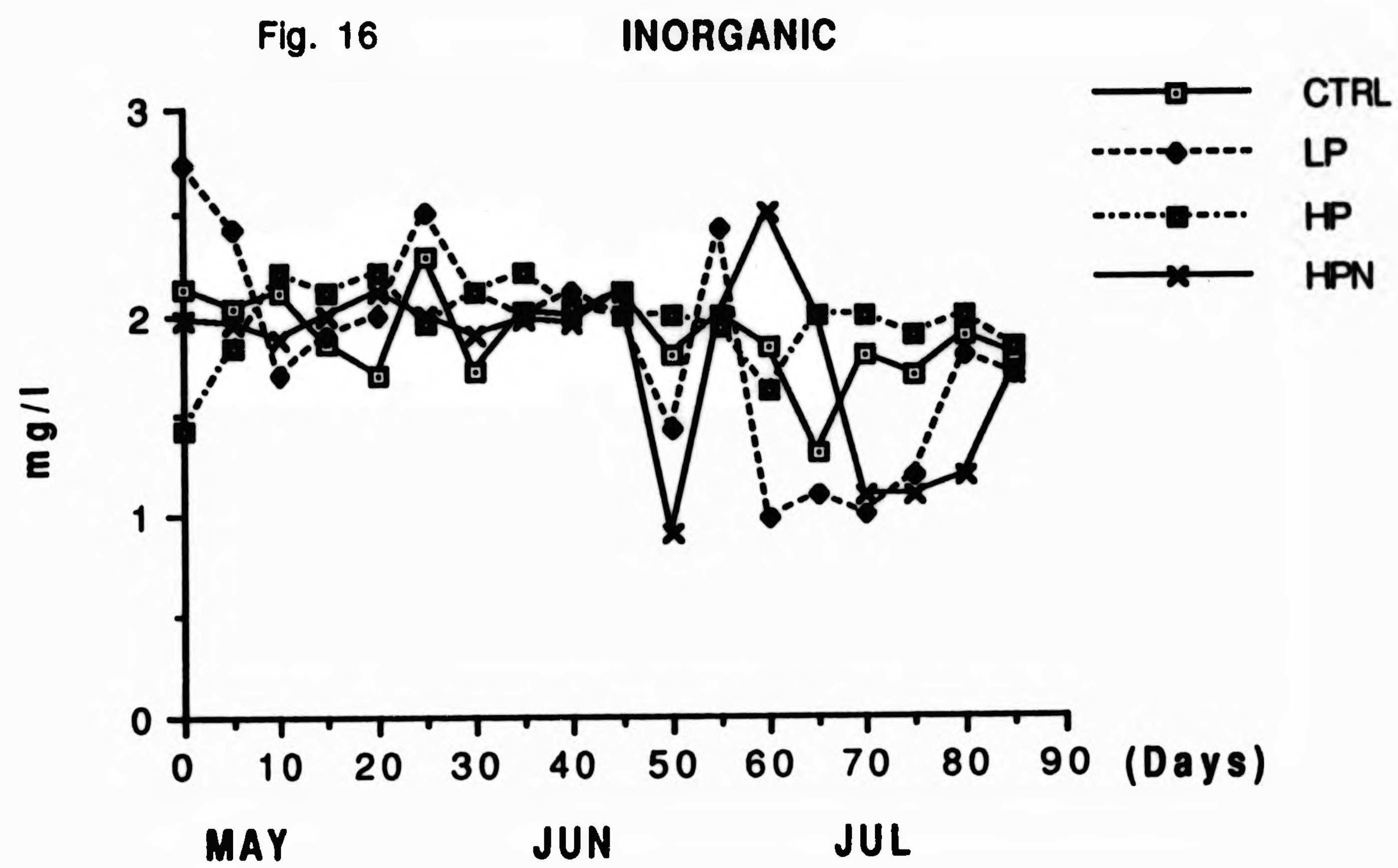


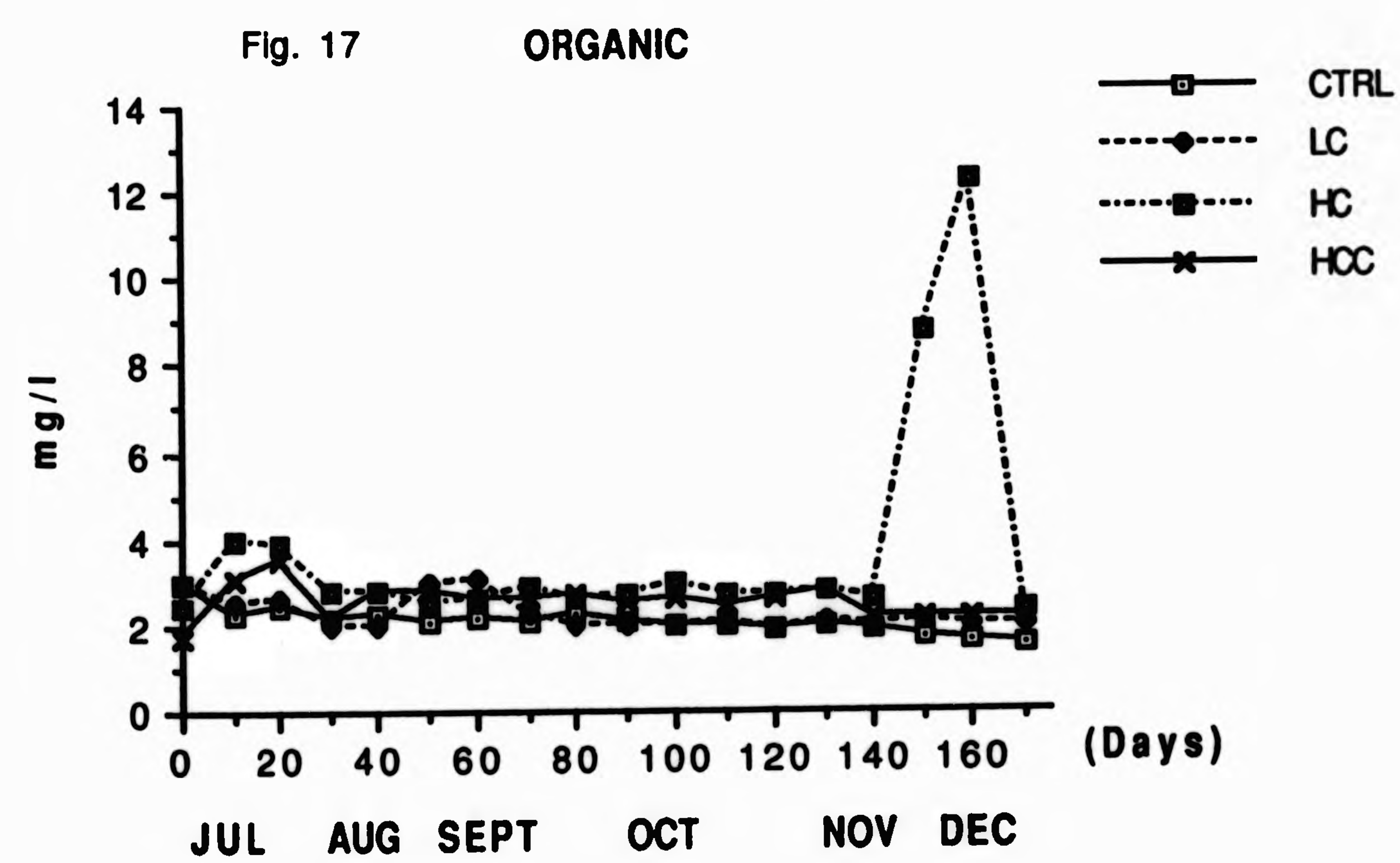
Figs. 14-15. Variations in Dissolved Oxygen during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

primary production (Fig 37). In the organic fertilization, low values were recorded in the HC and HCC treatments. A comparison of fluctuations in D.O. and biochemical oxygen demand (Fig. 17) during organic fertilization shows that high BOD recorded in HC coincided with fall in D.O. There was significant difference ($P < 0.05$) between pond treatments in both fertilization trials (Tables 5 & 6) but the values did not fall to limits considered detrimental to trout survival in culture ponds.

4.1.8 BIOCHEMICAL OXYGEN DEMAND

In the inorganic fertilization (Fig. 16), there were fluctuating patterns, with four peak values recorded at various times under LP and HPN treatments, though within acceptable limits for trout survival. In comparison with organic fertilization (Fig. 17), there was an upsurge in HC treatment in November, reaching a maximum value of 12.3 mgl^{-1}. This may be due to re-suspension of anaerobic sediment following manure input.

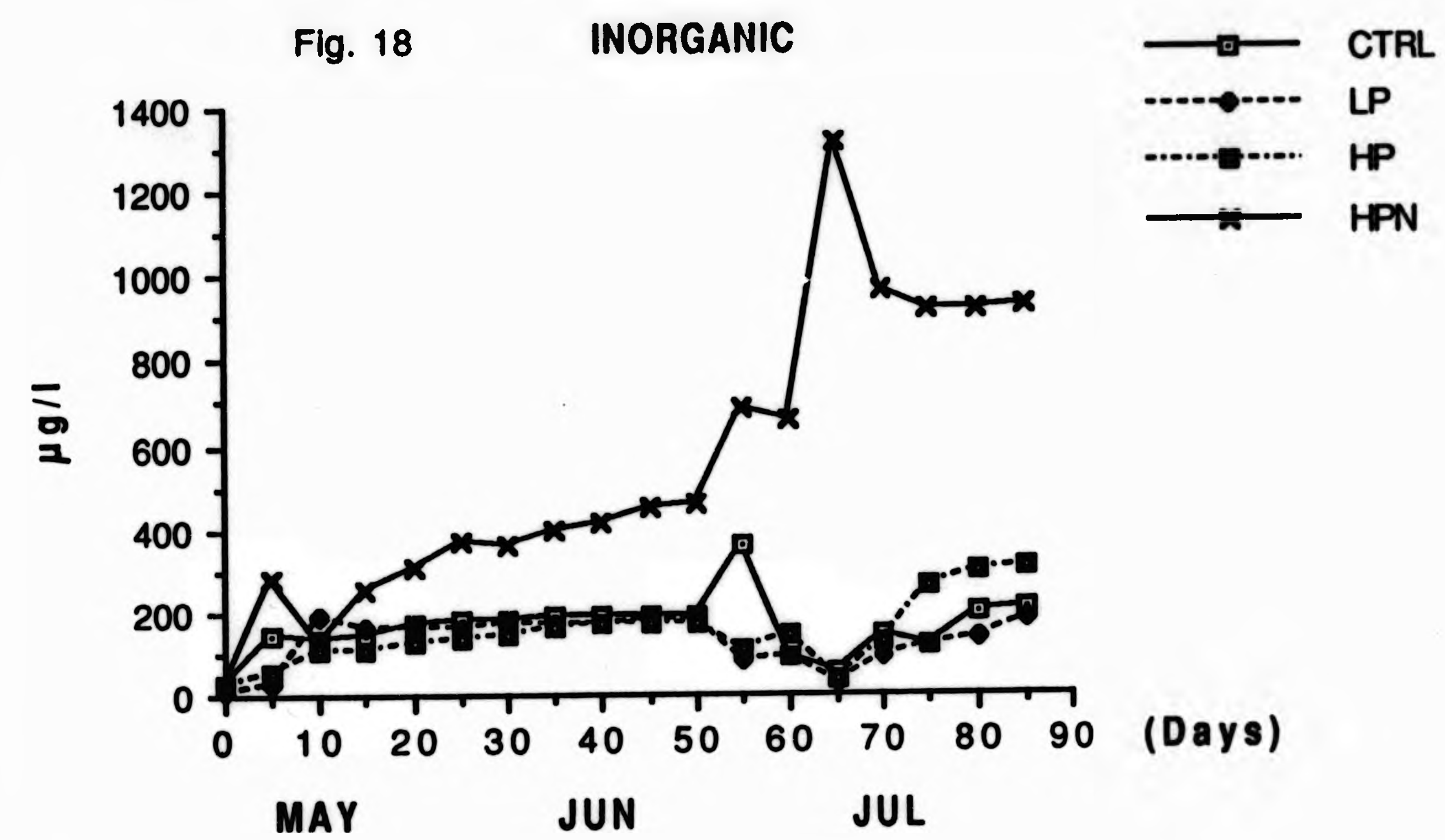


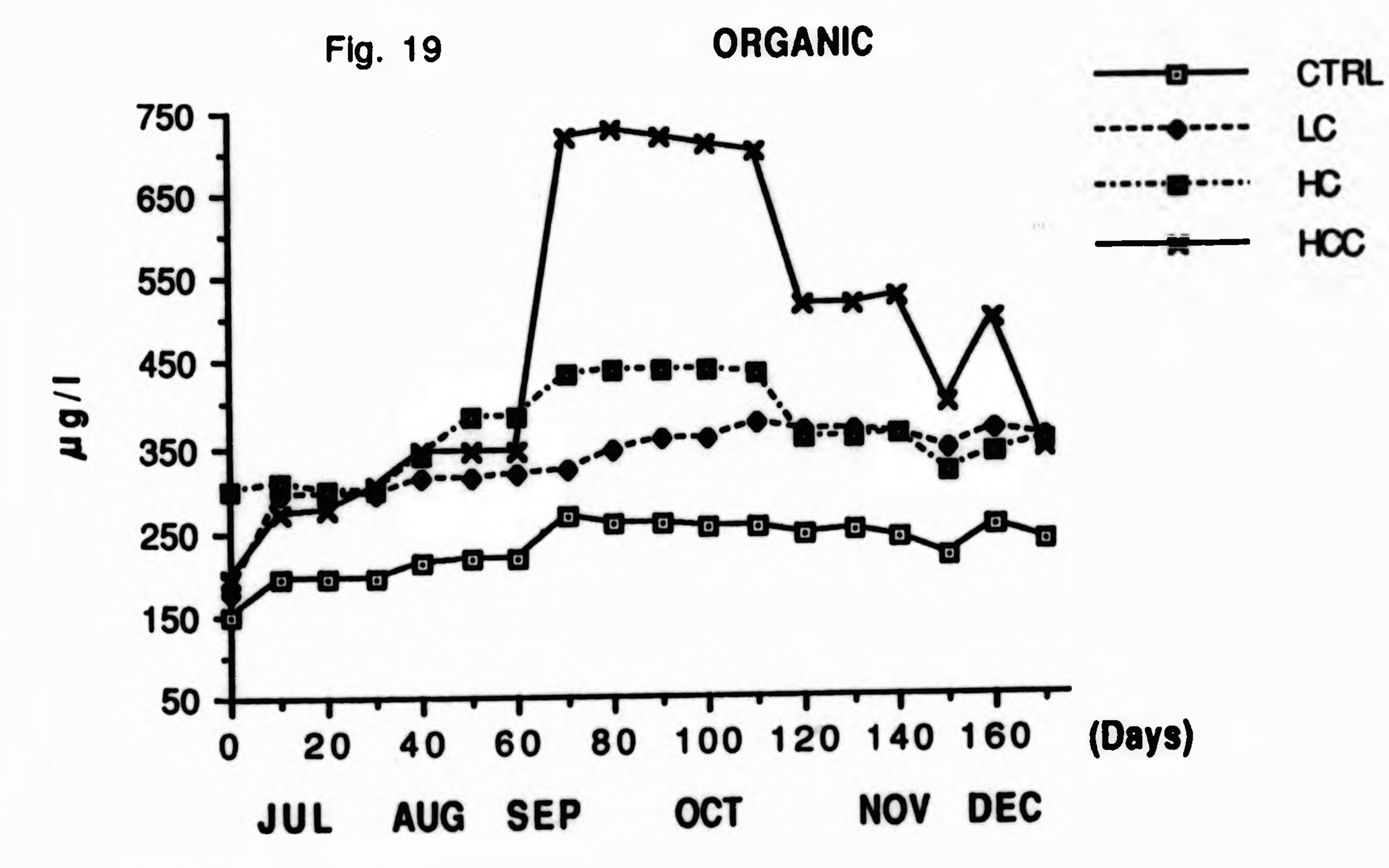


Figs. 16-17. Variations in Biochemical Oxygen Demand during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.1.9 TOTAL AMMONIA

From the graphical presentation of variations in the inorganic and organic fertilization (Figures 18 & 19), differences in total ammonia concentration were consistent with increasing rates of fertilization. In both fertilization programmes, there were highly significant differences ($P<0.01$) between the means (Tables 5 & 6); HPN and HCC produced the highest ammonia levels, followed by LC and HC, which were still higher than the organic control, but LP and HP were not significantly greater than the inorganic control.





Figs. 18-19. Variations in Total Ammonia during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.1.10 UNIONISED AMMONIA

In both fertilization programmes, the unionised ammonia (Figs. 20 & 21), whose values are dependent on total ammonia, temperature and pH, showed similar patterns of fluctuation, especially if HPN and HCC treatments are excluded. Peak levels with HPN and HCC were 18.0 and 14.7 ugl^{-1} respectively. The UIA in all treatments was less than 5% of total ammonia, with similar differences between treatments (Tables 5 & 6).

4.1.11 NITRATE-NITROGEN

Figures 22 & 23 show the variation with inorganic and organic fertilization, respectively. Table 5 shows that only HPN showed a significant response to inorganic fertilization. Comparatively, the organic manuring had higher values at the premanipulation (0) state for all treatments. The highest value of 602 ugl^{-1} was recorded in the HCC treatments. Both HCC and HC had significantly higher means, followed by LC (Table 6).

Fig. 20 INORGANIC

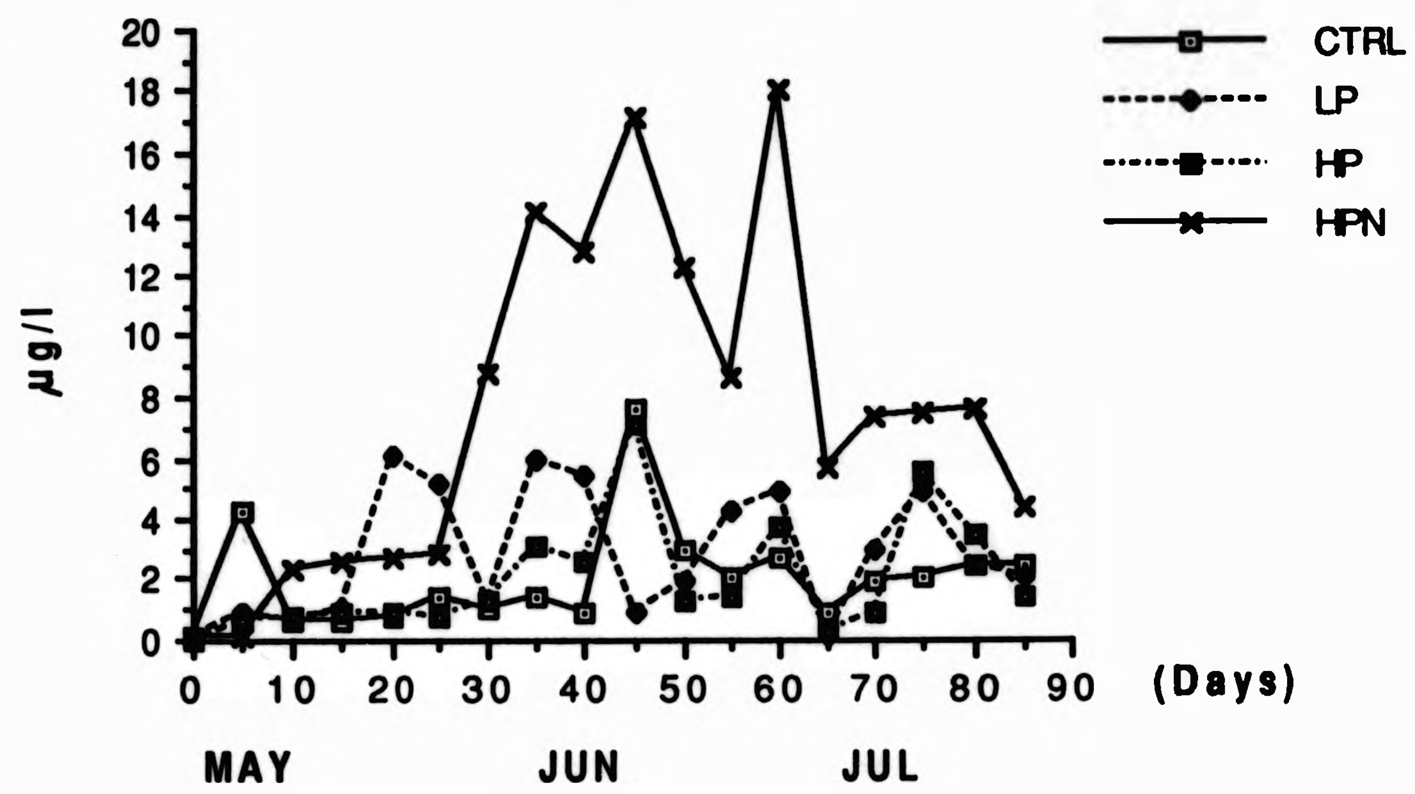
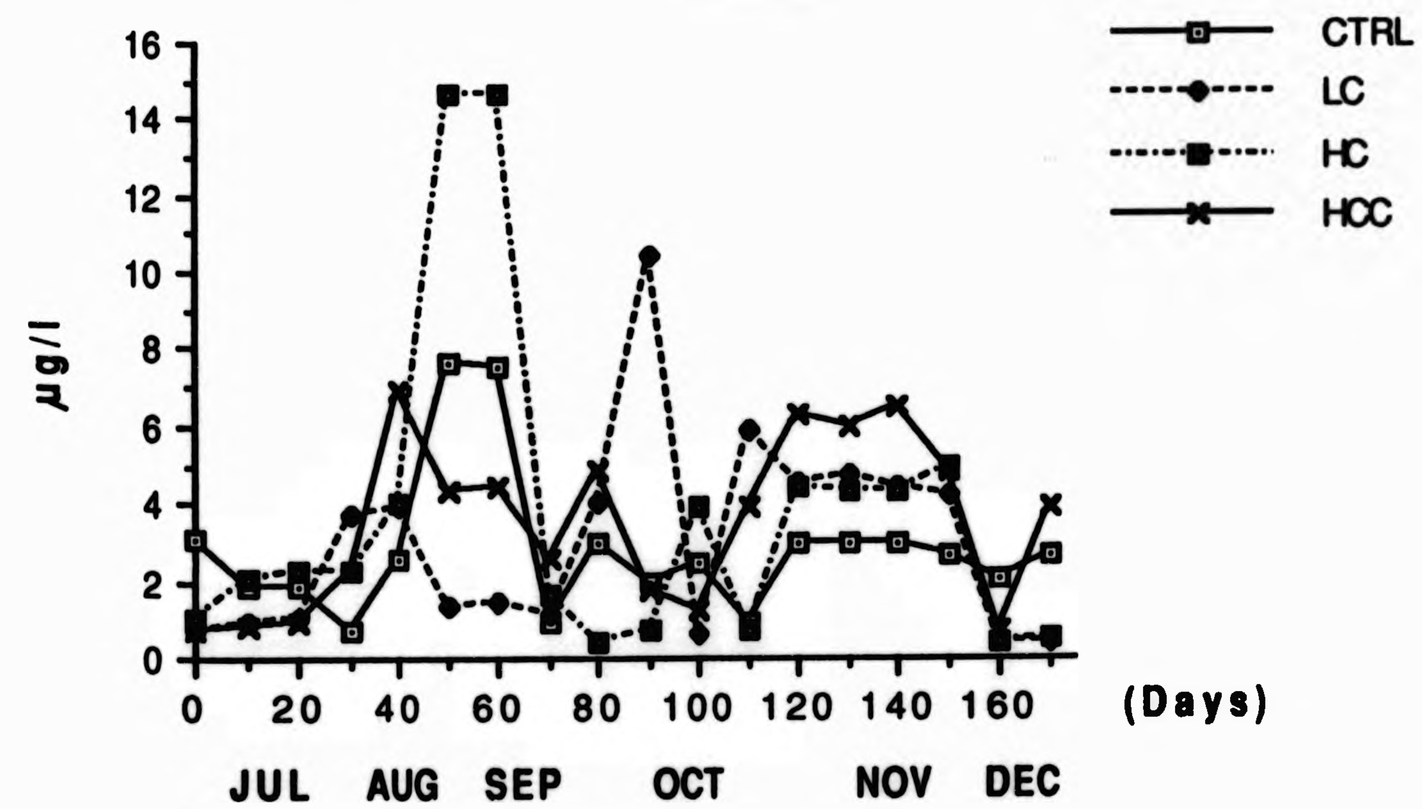


Fig. 21 ORGANIC



Figs. 20-21. Variations in Unionized Ammonia during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

Fig. 22 INORGANIC

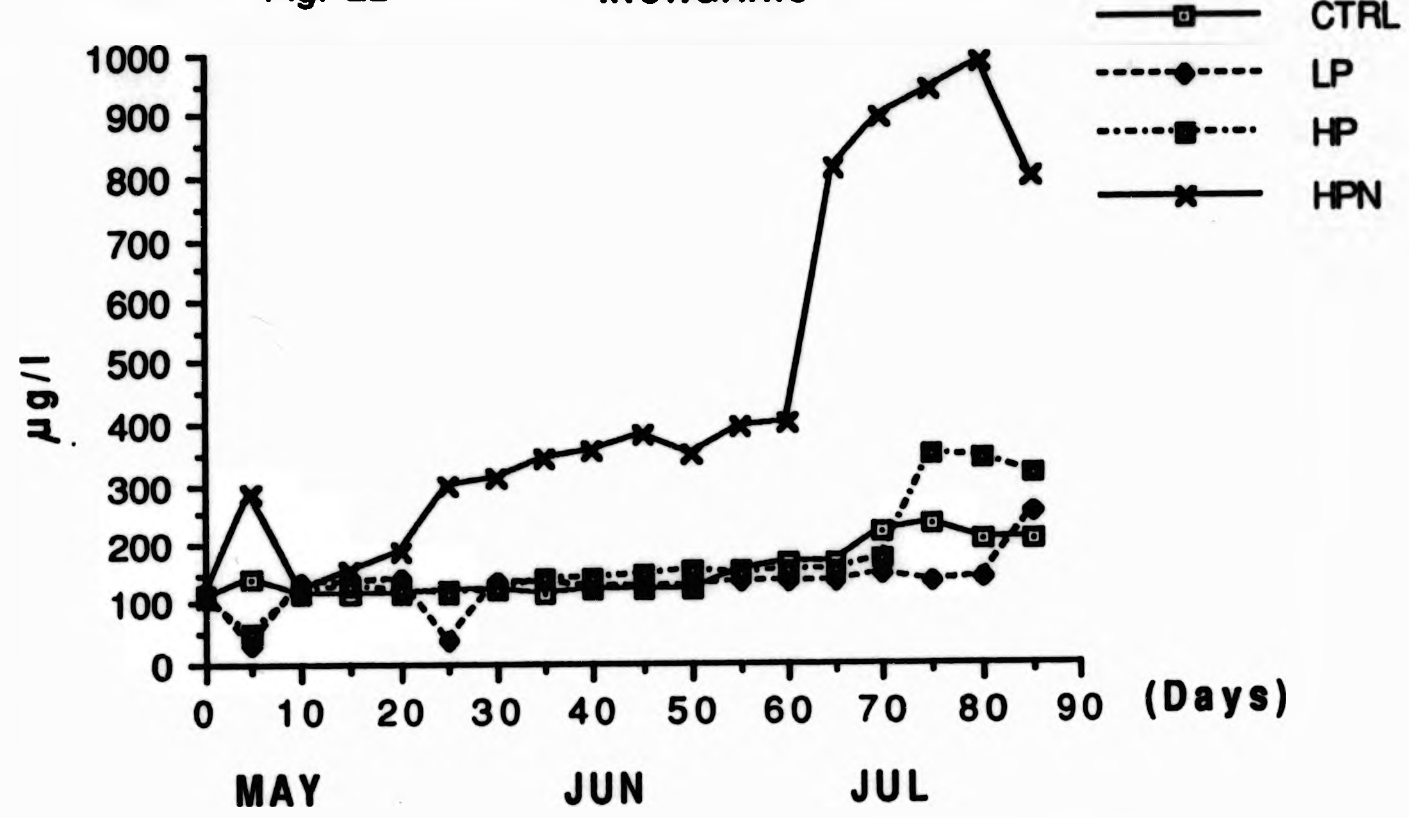
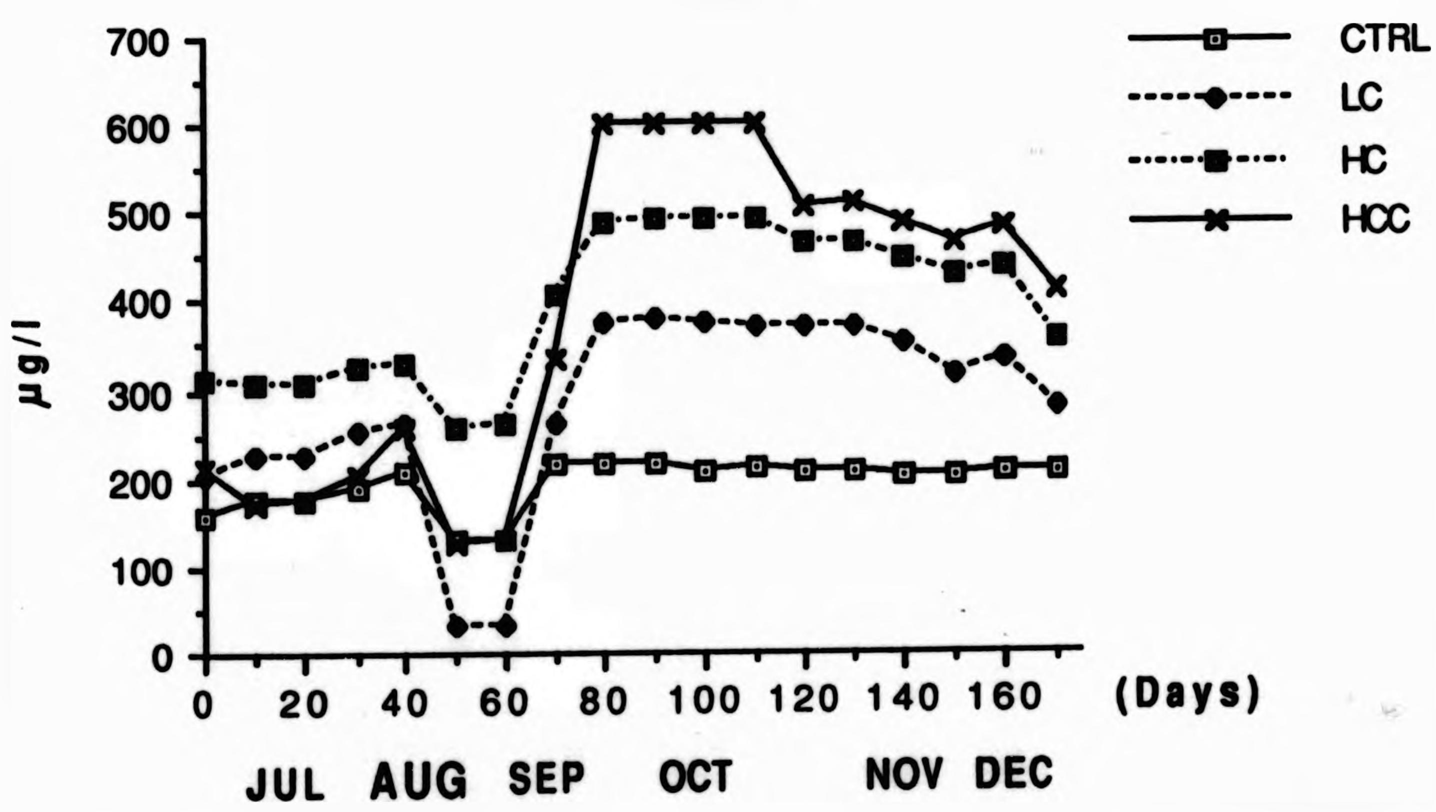


Fig. 23 ORGANIC



Figs. 22-23. Variations in Nitrate-Nitrogen during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.1.12 NITRITE-NITROGEN

At the commencement of inorganic fertilization, there was a decline in NO_2-N concentration in all treatments (Fig. 24) followed by an upsurge, especially in HPN to attain a peak value of 27.4 ugl^{-1}. Differences between treatment means were similar to nitrate, with highest values in HPN and HCC followed by HC and LC (Tables 5 & 6).

4.1.13 DISSOLVED ORGANIC NITROGEN

In both inorganic (Fig. 26) and organic (Fig. 27) treatments, dissolved organic nitrogen increased from low premanipulation values, the rate of increase being related to the nitrogen input. The inorganic treatment means in Table 5 shows that, as with ammonia and nitrate, there is a significant increase with LC and HC, and even greater with HCC.

Fig. 24 INORGANIC

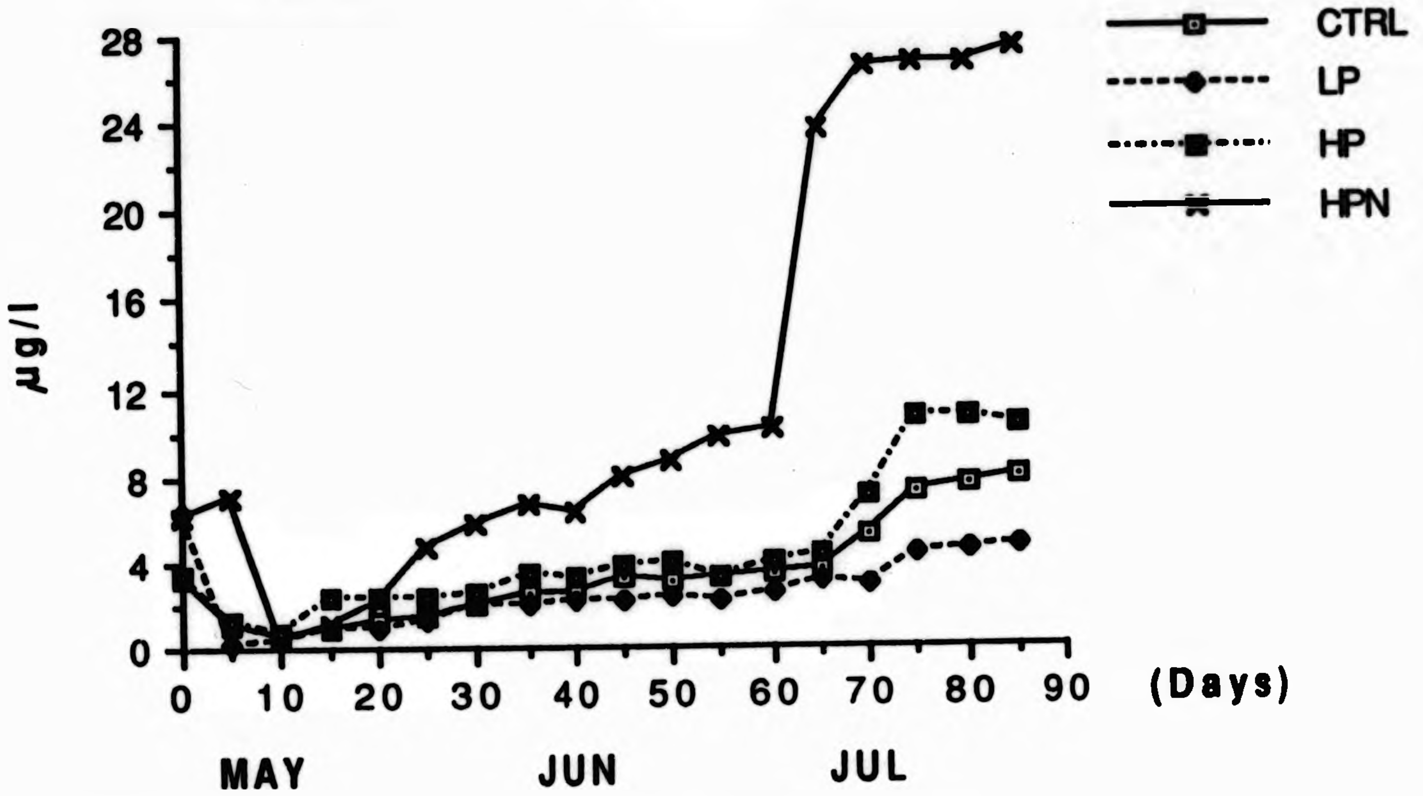
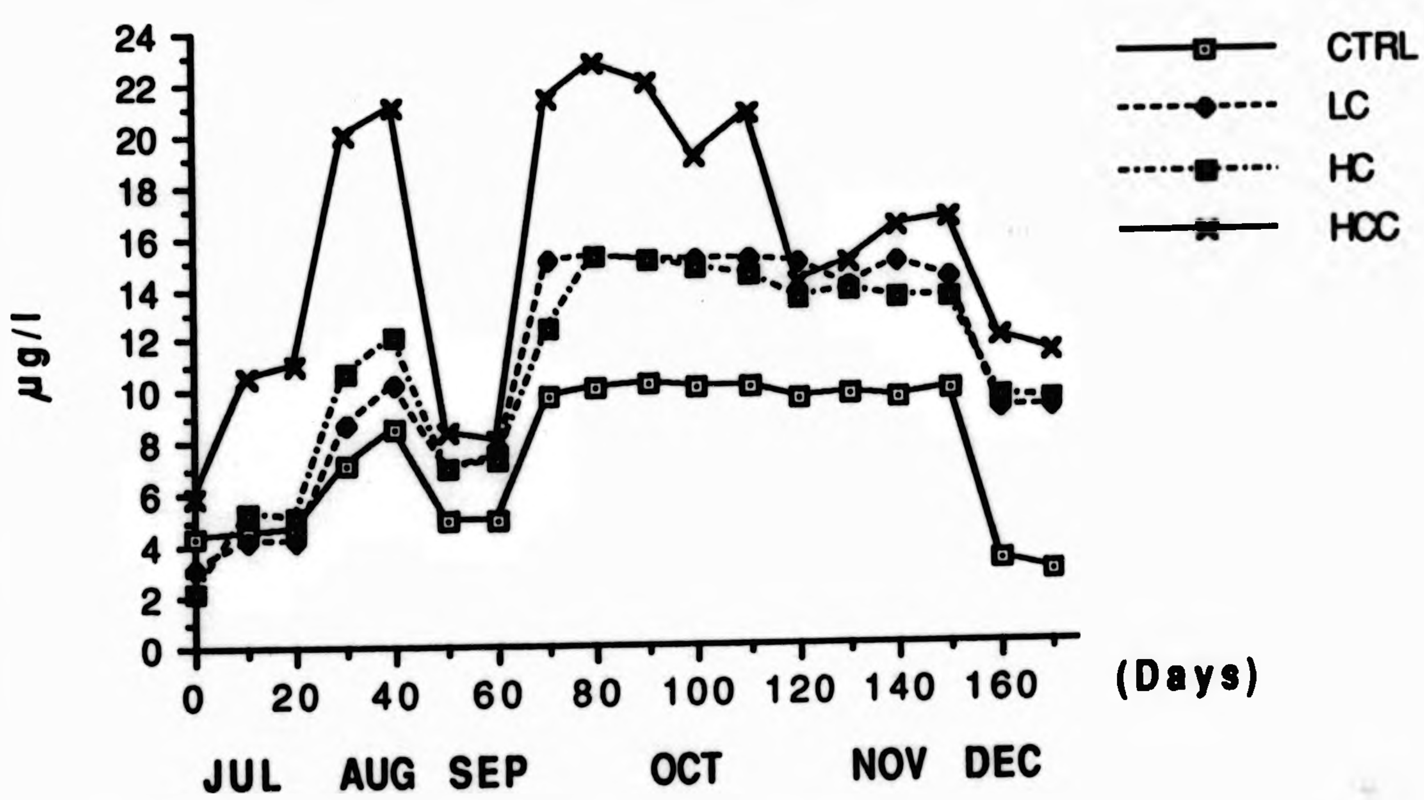


Fig. 25 ORGANIC



Figs. 24-25. Variations in Nitrite-Nitrogen during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

Fig. 26 INORGANIC

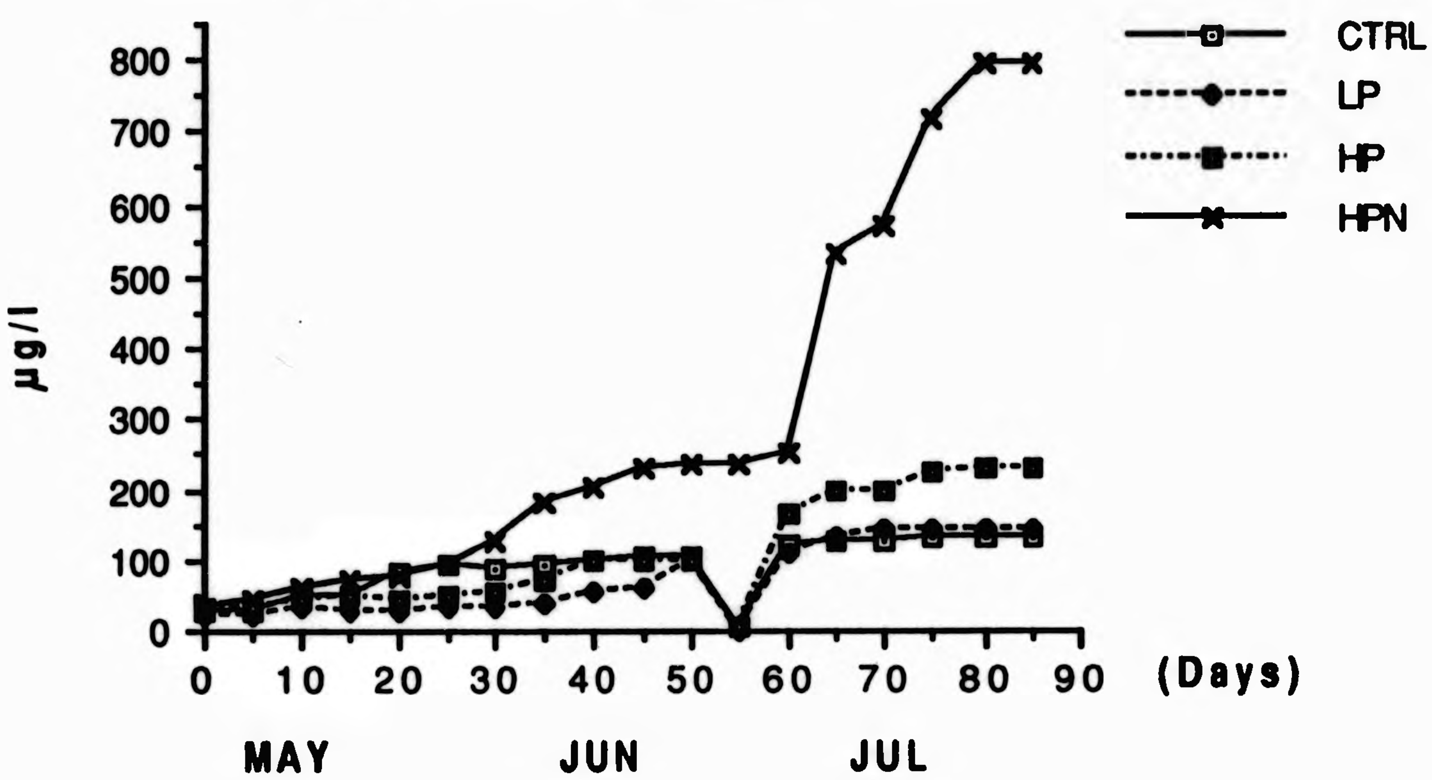
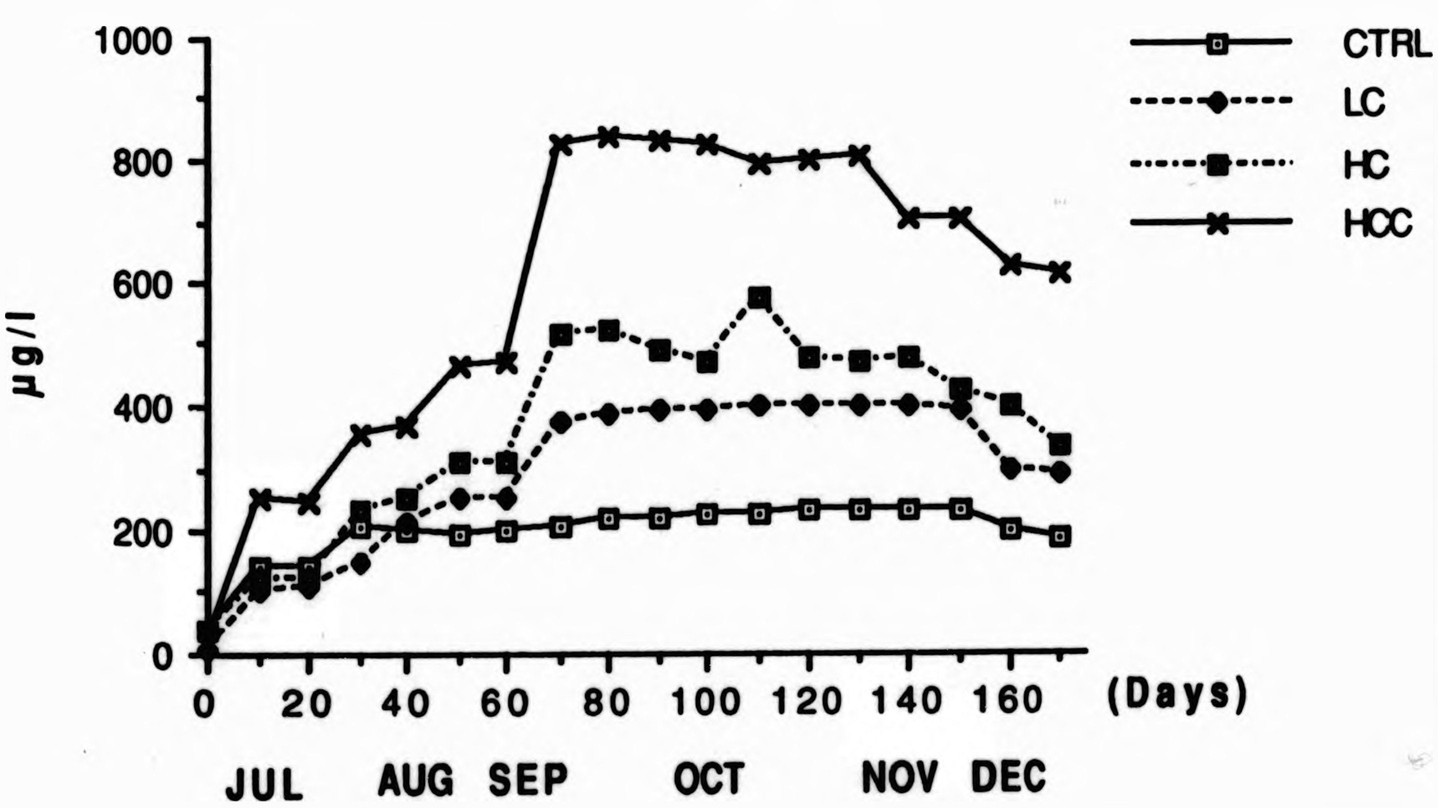


Fig. 27 ORGANIC



Figs. 26-27. Variations in Dissolved Organic Nitrogen during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.1.14 TOTAL PHOSPHORUS

The variations during inorganic and organic fertilization are shown in Figures 28 & 29 respectively. The phosphorus concentration increased throughout the inorganic trial in accordance with increased fertilizer application. More stable levels were maintained during organic manuring, but they dropped in November, in spite of continous fertilization possibly due to phosphorus binding or adsorption in the sediment. Mean values were in accordance with inorganic phosphorus applications, as shown in Table 5. Table 6 shows that there is a significant response in treatments with high organic fertilization rates in contast with the control.

4.1.15 DISSOLVED REACTIVE PHOSPHORUS

Figures 29 & 30 show the variations in inorganic and organic fertilization, respectively. As with total phosphorus, levels increased during fertilization and were maintained with organic fertilization after much higher

Fig. 28 INORGANIC

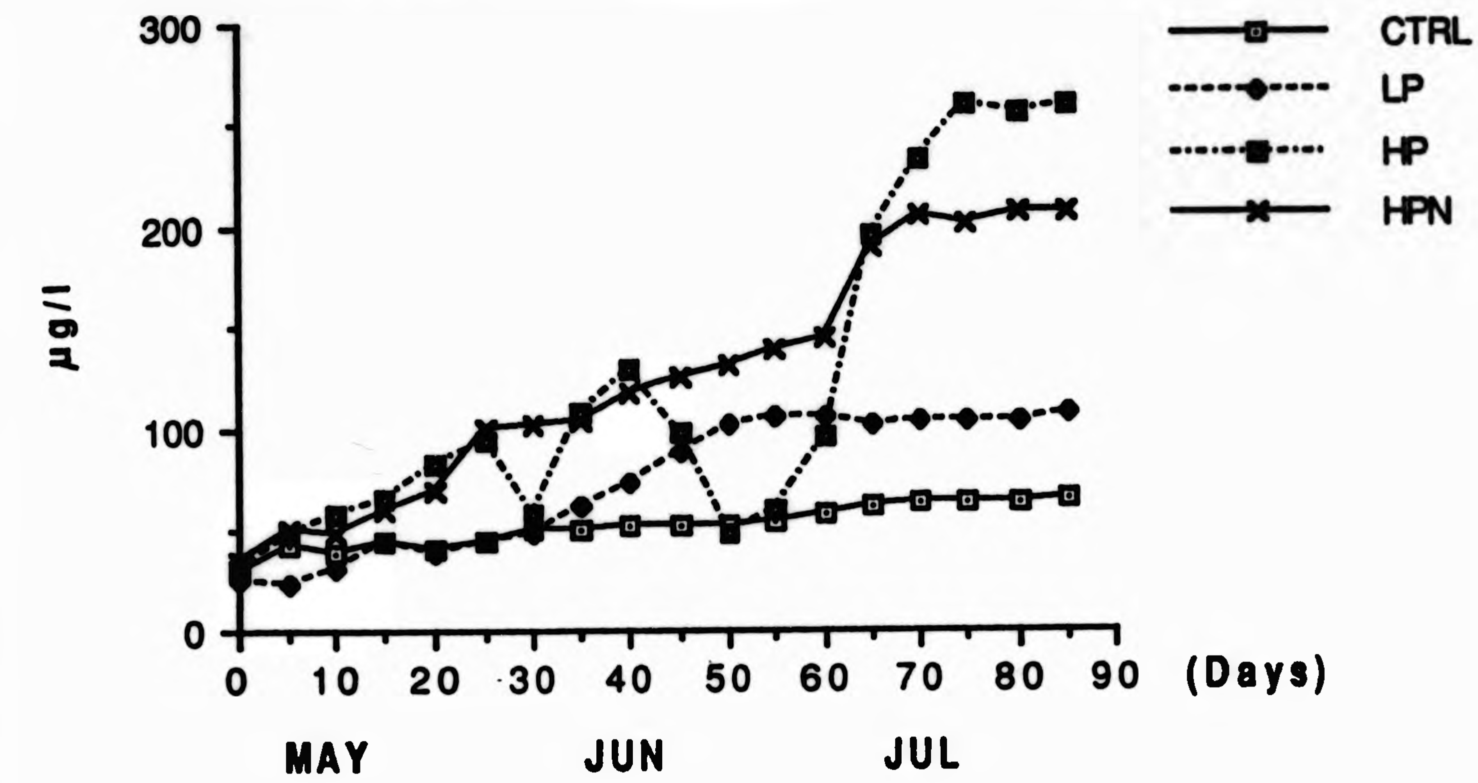
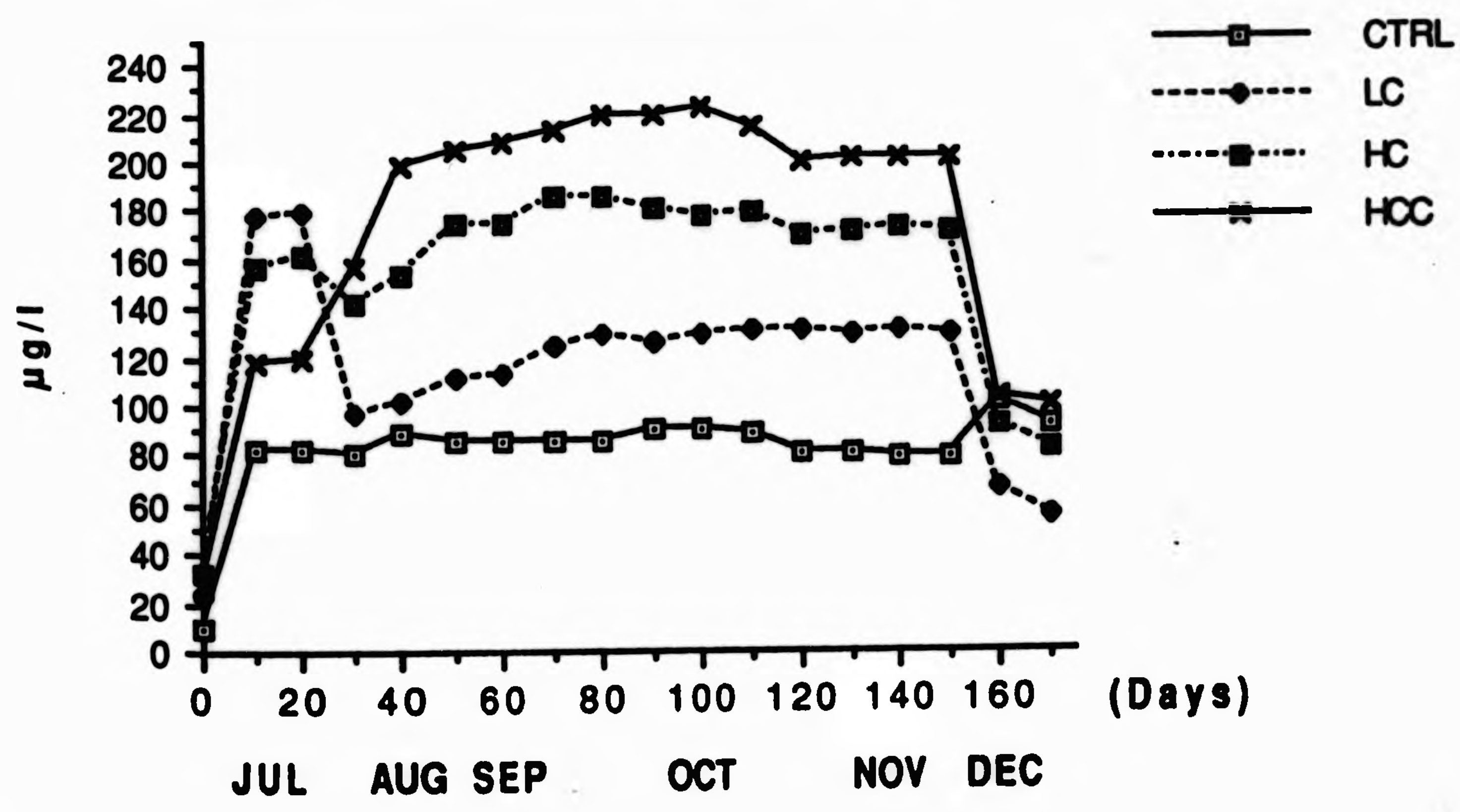


Fig. 29 ORGANIC



Figs. 28-29. Variations in Total Phosphorus during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

Fig. 30 INORGANIC

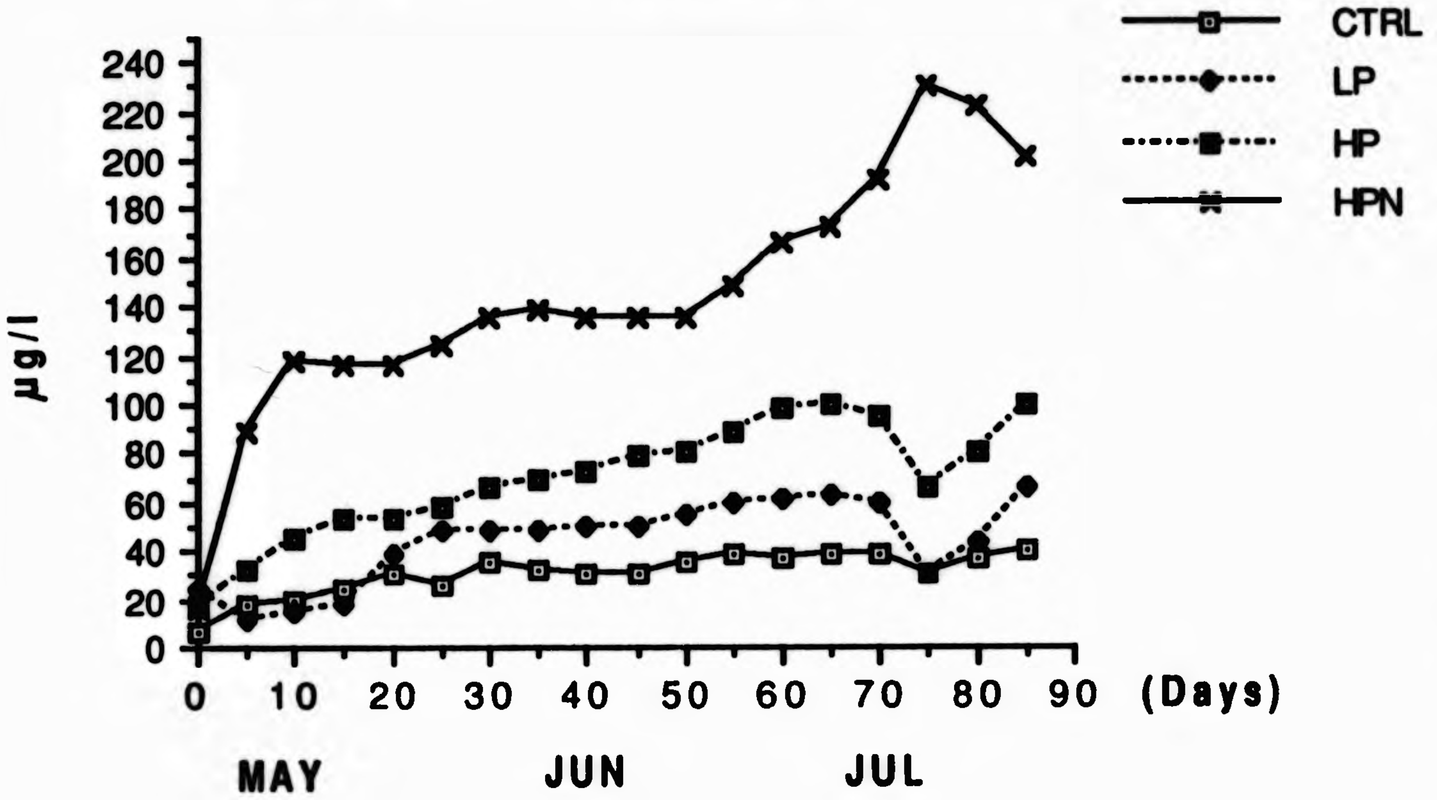
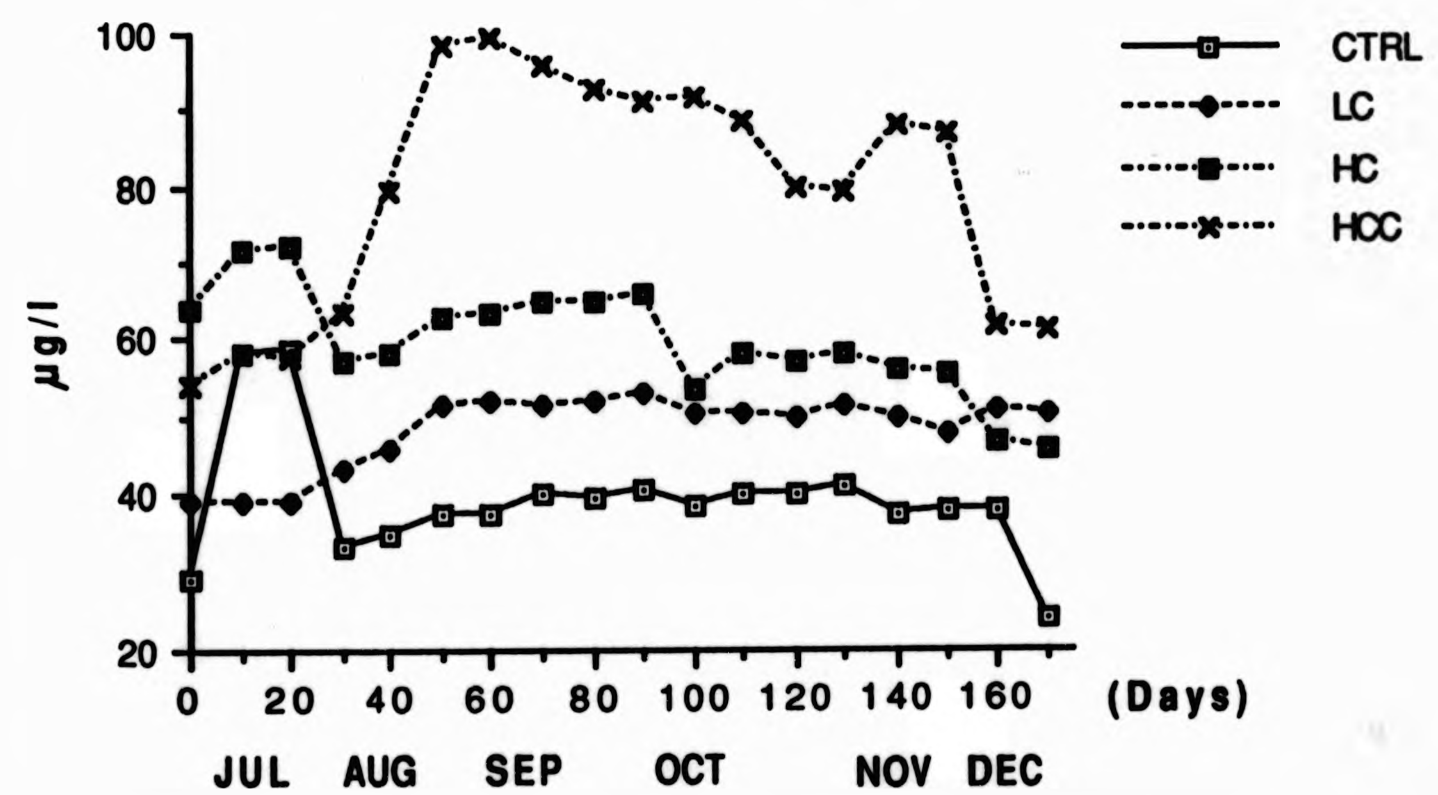


Fig. 31 ORGANIC



Figs. 30-31. Variations in Dissolved Reactive Phosphorus during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

premanipulation levels. Differences between treatment means (Tables 5 & 6) follow those described for total phosphorus, except that carry-over effect is not reflected in organic treatments which had lower values than the organic.

4.1.16 FREE - CARBON DIOXIDE

This showed marked fluctuation in both fertilization programmes (Figs. 32 & 33), with peaks of 1.4 and 0.45 ugl^{-1} in inorganic and organic treatments, respectively, but these values did not approach 136 ugl^{-1} considered lethal for trout.

4.1.17 CHLOROPHYLL-a

The trends in mean values for inorganic and organic fertilization are shown in Figs. 34 and 35, respectively. At the commencement of inorganic fertilization, there was a slow response pattern in Chl-a concentration, followed only in the case of HPN by a marked fluctuating increase

Fig. 32

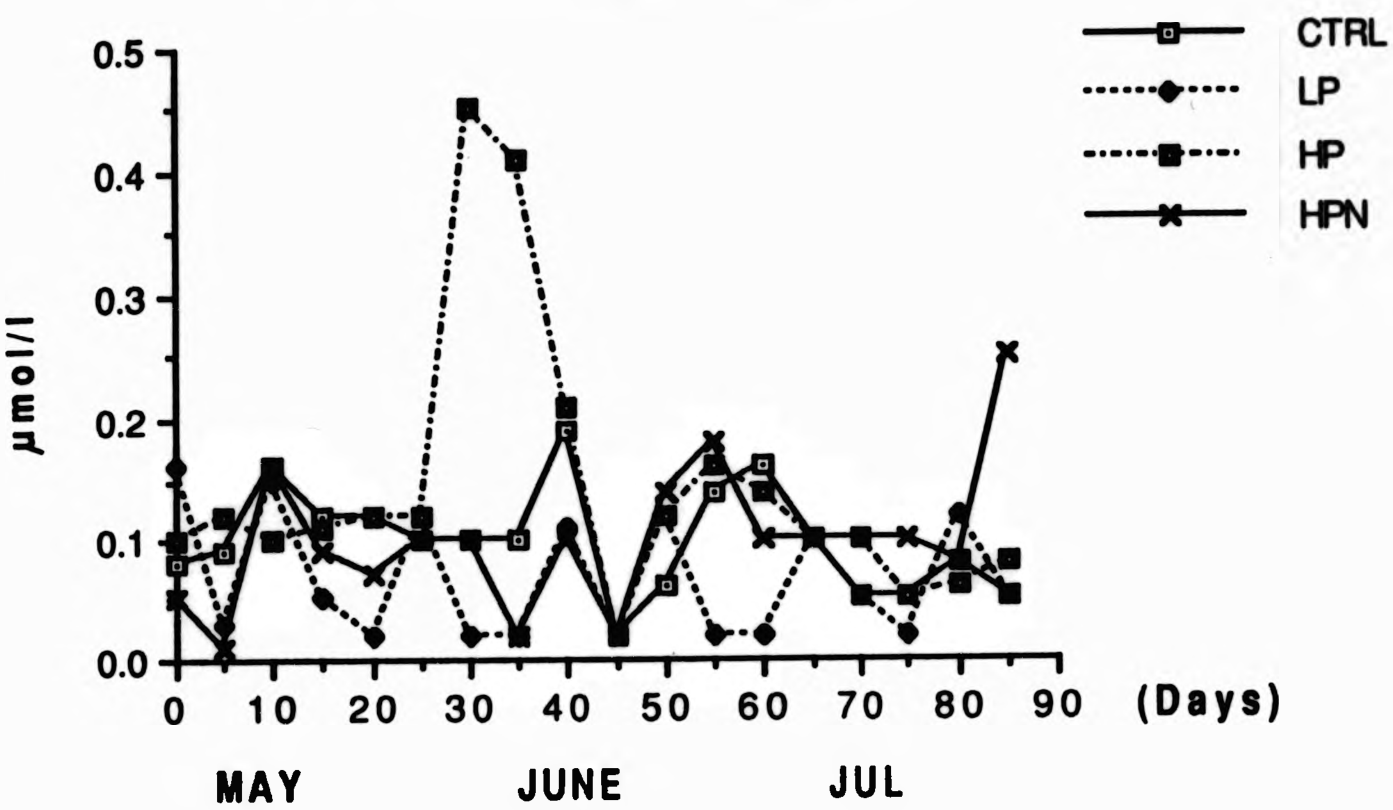
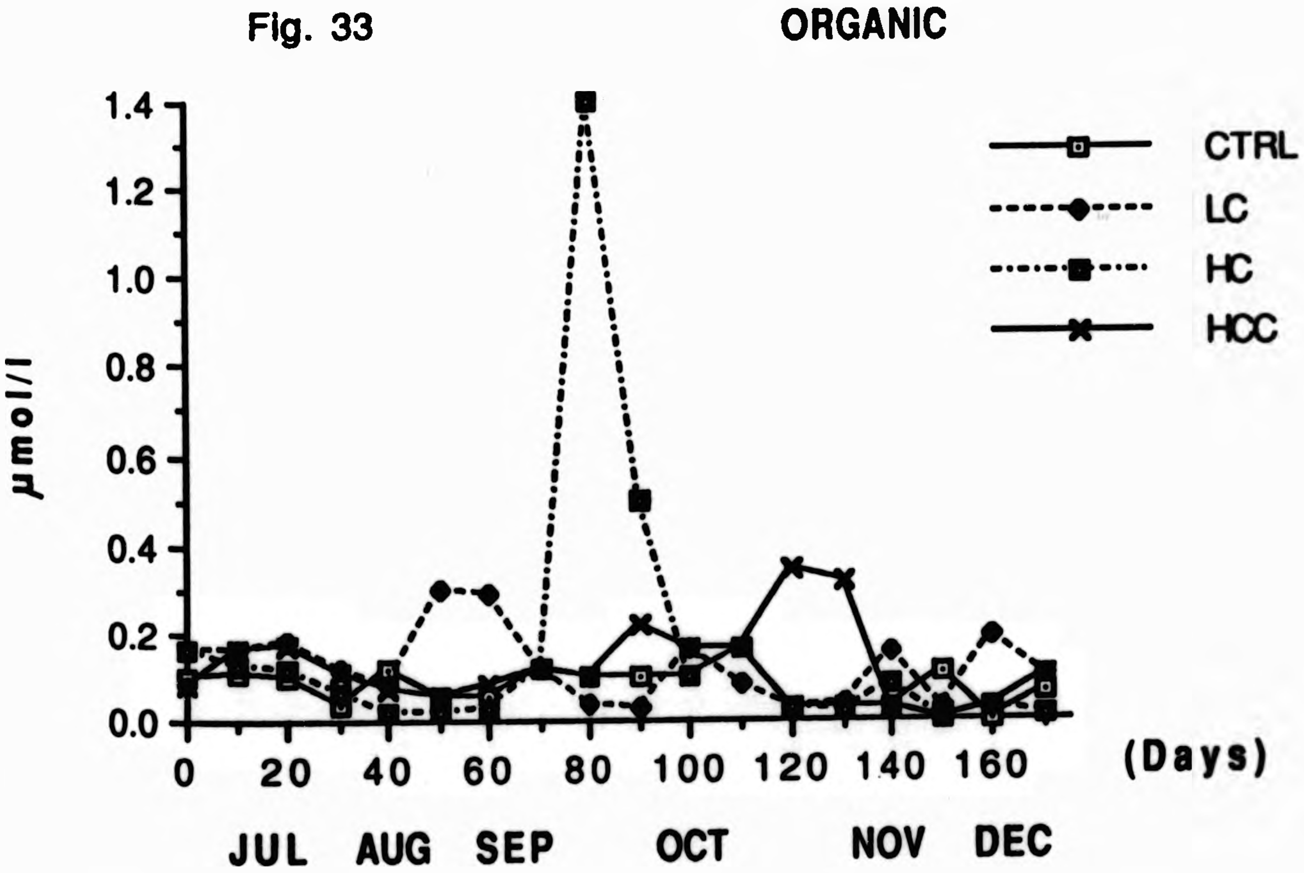


Fig. 33



Figs. 32-33. Variations in Free-Carbon dioxide during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

during June, attaining a peak value of 56.0 ugl^{-1} on 4/7/88. Table 5 confirms that only the HPN treatment produced a significant difference from the control. In comparison, all three manure treatments produced significantly more Chl-a than the control.

4.1.18 PRIMARY PRODUCTION

The response pattern during inorganic fertilization was slow, followed by a sudden upsurge on 30/6/88, attaining peak value of 1.2 g $C.m^{-2}day^{-1}$ (Fig. 36).
Similarly, only HPN showed a significant response to inorganic fertilization (Table 5). The organic manuring, on the other hand, had higher values at the premanipulation (PM) state for all treatments, with the highest value of 608 mg $C.m^{-2}day^{-1}$ recorded in the HCC treatment (Fig.37). Both LC and HC treatments had significantly higher mean primary production than the control (Table 6), with HCC showing a significant additional response.

Fig. 34 INORGANIC

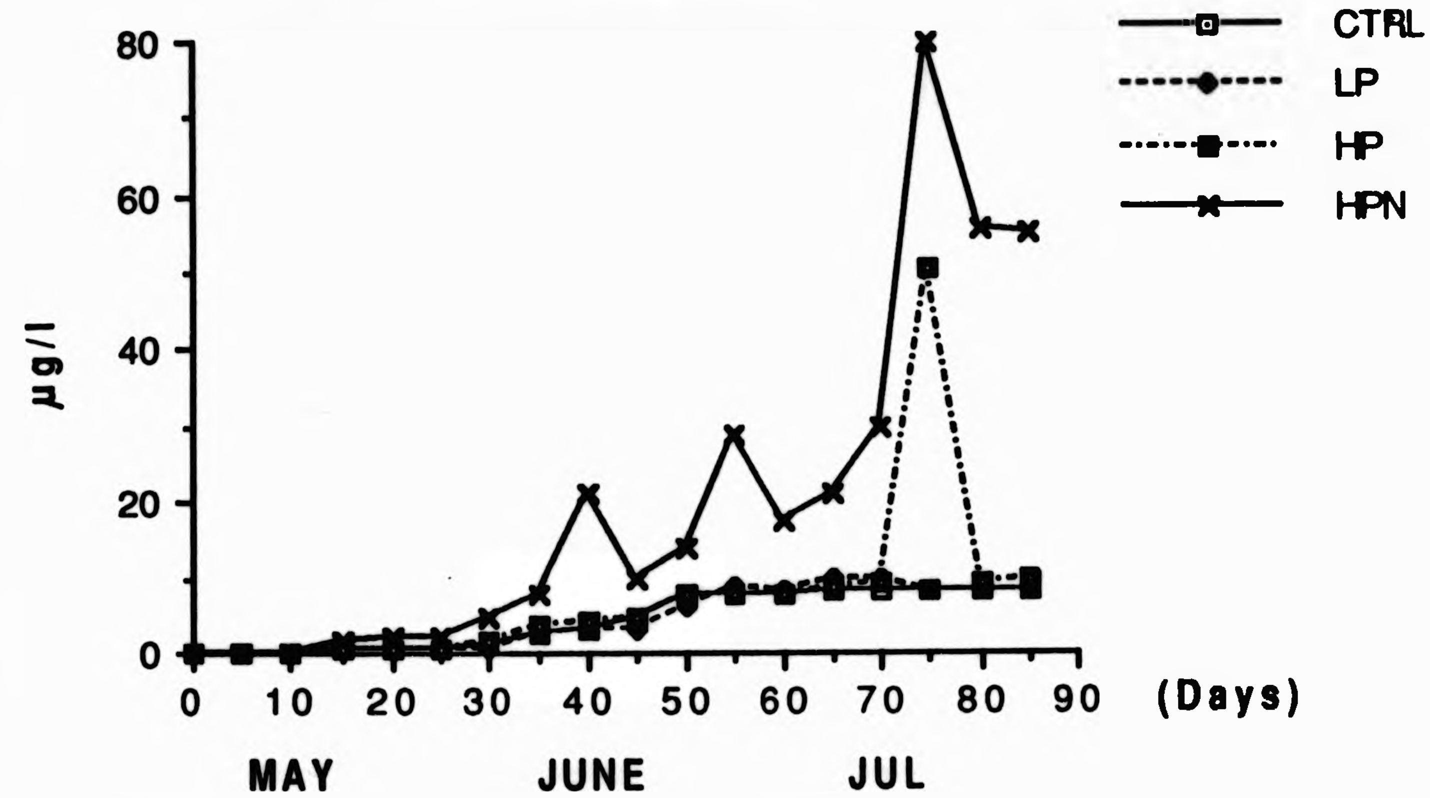
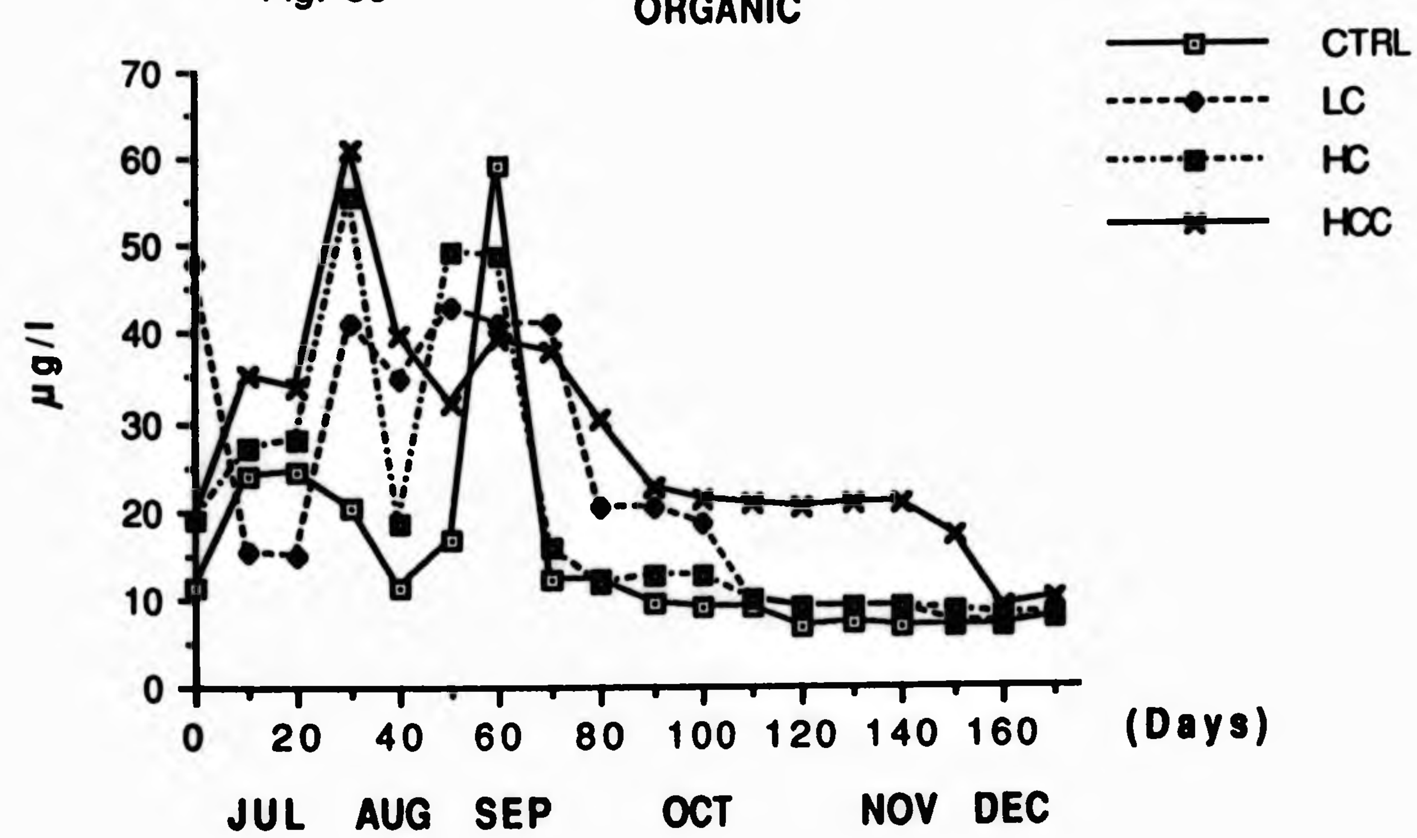
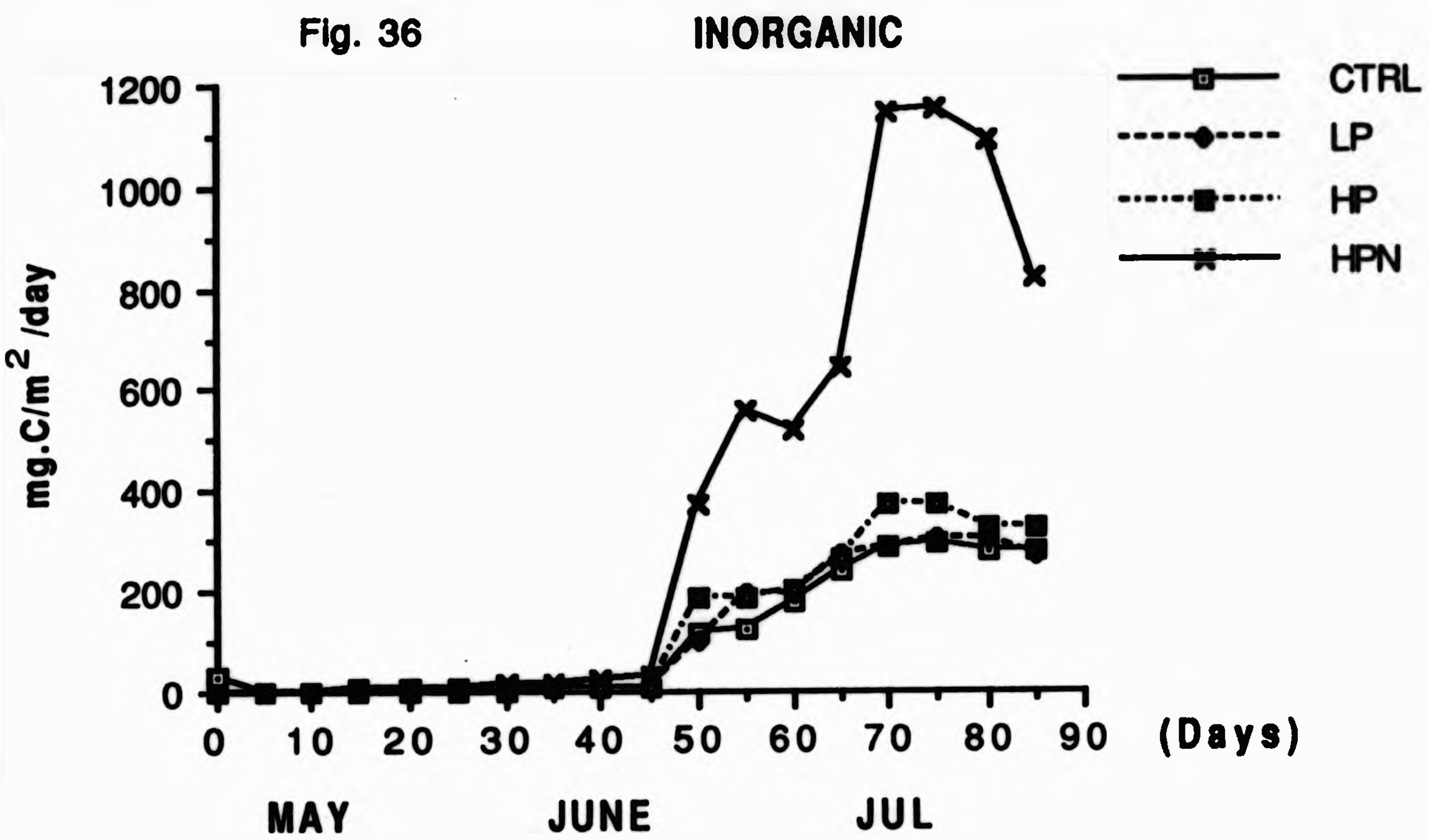
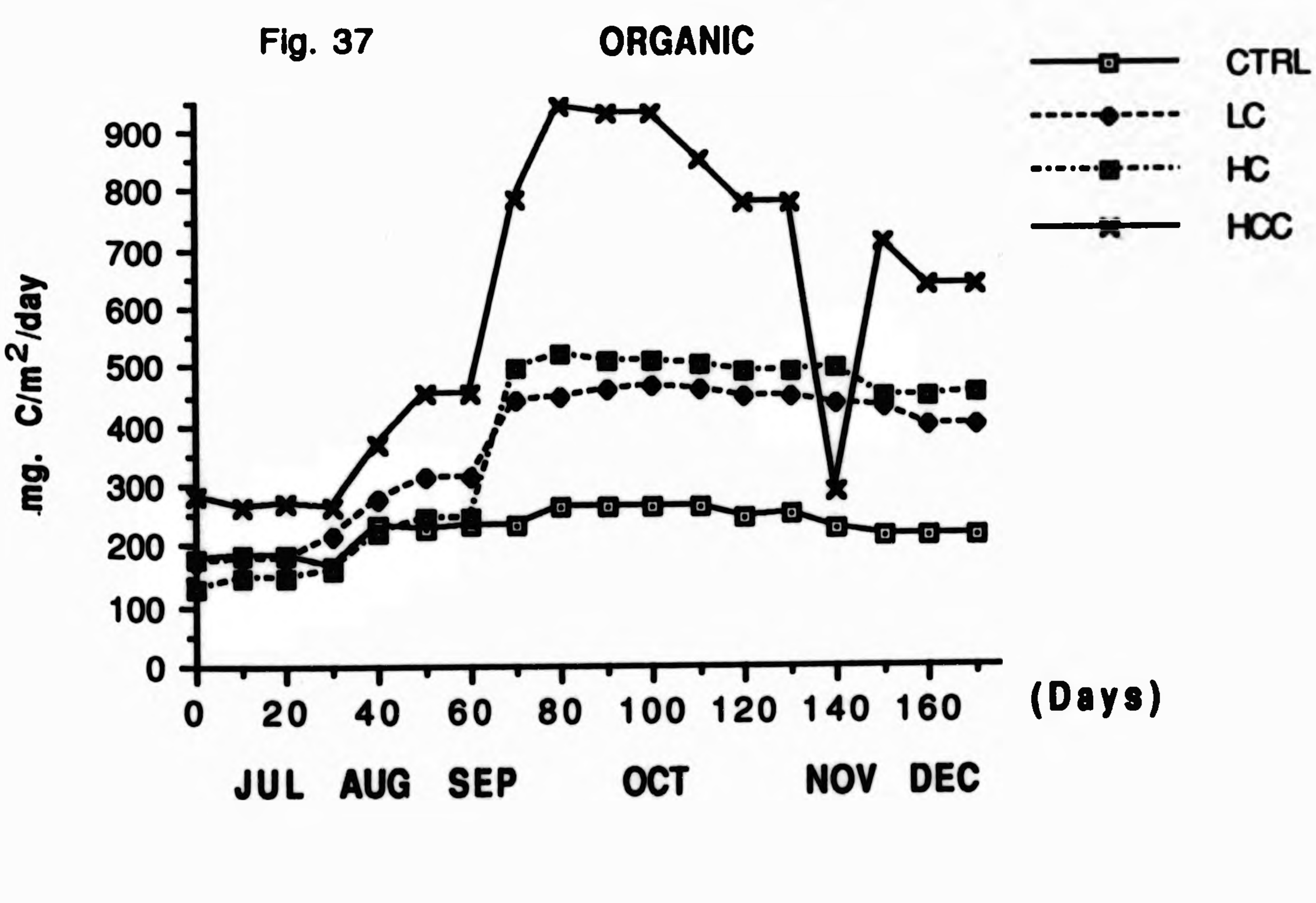


Fig. 35 ORGANIC



Figs. 34-35. Variations in Chlorophyll-a during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).





Figs. 36-37. Variations in Primary Production during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

TABLE 4 F-Values and their associated levels of significance for two-way ANOVA on log transformed data of physico-chemical parameters of pond water during inorganic and organic fertilization, and primary production, without fish. (*, ** refer to P levels of ≤ 0.05 and ≤ 0.01 respectively, NS=not significant).

	INORGANIC		ORGANIC	
	SOURCES OF VARIATION		SOURCES OF VARIATION	
	Between ponds	Between periods	Between ponds	Between periods
Temperature	1.87 NS	0.95 NS	1.32 NS	3.21 *
pH	3.71 *	2.83 *	3.86 *	5.13 **
Conductivity ($\mu s\ cm^{-1}$)	158.1**	11.3 **	1.00 NS	0.80 NS
Total Hardness ($mg\ l^{-1}$ $CaCO_3$)	12.7 **	21.5 **	7.63 **	10.3 **
Total Alkalinity ($meq\ l^{-1}$)	1.01 NS	3.50 *	0.93 NS	13.9 **
Total Suspended Solids ($mg\ l^{-1}$)	10.3 **	8.21 **	45.9 **	32.1 **
Dissolved Oxygen ($mg\ l^{-1}$)	1.03 NS	3.31 *	20.3 **	1.03 NS
Biochemical Oxygen demand ($mg\ l^{-1}$)	2.30 **	3.43 **	18.9 **	12.3 **
Total Ammonia ($\mu g\ l^{-1}$)	92.5 **	7.3 **	80.5 **	15.3 **
Unionized Ammonia ($\mu g\ l^{-1}$)	3.30 *	17.3 *	3.20 *	24.3 **
Nitrate - N ($\mu g\ l^{-1}$)	48.5 **	10.2 **	18.3 **	7.35 **
Nitrite - N ($\mu g\ l^{-1}$)	43.2 **	24.1 **	5.39 **	12.1 **
Dissolved organic nitrogen ($\mu g\ l^{-1}$)	15.8 **	8.87 **	54.2 **	18.2 **
Dissolved reactive phosphorus ($\mu g\ l^{-1}$)	38.1 **	9.32 **	44.8 **	3.39 *
Total phosphorus ($\mu g\ l^{-1}$)	130.1**	3.95 *	19.7 **	6.66 **
Free - Carbon dioxide ($\mu mol\ l^{-1}$)	3.02 *	0.14 NS	0.93 NS	2.93 *
Chlorophyll - a ($\mu g\ l^{-1}$)	9.47 **	1.96 NS	9.36 **	43.6 **
Primary production ($mg.c.m^{-2}d^{-1}$)	11.5 **	29.1 **	21.1 **	8.89 **

TABLE 5 Overall mean monthly values and standard errors of physico-chemical parameters of pond water at varying in organic fertilization levels and primary production, without fish. (Mean values in the same row bearing the same superscripts are not significantly different at P=0.05).

	POND TREATMENT			
	CTRL	LP	HP	HPN
pH	7.4 ± 0.1	7.7 ± 0.12	7.4 ± 0.1	7.6 ± 0.1
Conductivity ($\mu s\ cm^{-1}$)	112 ± 1.1^{a}	112 ± 1.1^{a}	124 ± 1.7^{b}	138 ± 2.7^{c}
Total Hardness ($mg\ l^{-1}$ $CaCO_3$)	55.4 ± 1.40^{ab}	62 ± 5.8^{b}	52.6 ± 1.1^{a}	58.5 ± 4.8^{b}
Total Alkalinity ($meq\ l^{-1}$)	1.0 ± 0.02	1.0 ± 0.04	1.0 ± 0.02	1.5 ± 0.1
Total Suspended Solids ($mg\ l^{-1}$)	8.8 ± 0.2^{a}	7.7 ± 0.4^{a}	8.7 ± 0.20^{ab}	9.7 ± 0.7^{b}
Dissolved Oxygen ($mg\ l^{-1}$)	10.0 ± 0.20^{b}	10.2 ± 0.2^{b}	9.5 ± 0.1^{a}	10.8 ± 0.4^{b}
Biochemical Oxygen Demand ($mg\ l^{-1}$)	1.9 ± 0.05	1.9 ± 0.1	2.0 ± 0.05	1.8 ± 0.1
Total Ammonia ($\mu g\ l^{-1}$)	145 ± 13.1^{a}	130 ± 14.1^{a}	157 ± 18.7^{a}	548 ± 82^{b}
Unionized Ammonia ($\mu g\ l^{-1}$)	2.02 ± 0.77^{a}	2.85 ± 0.95^{ab}	2.01 ± 0.45^{a}	7.51 ± 2.47^{b}
Nitrate - N ($\mu g\ l^{-1}$)	148 ± 10.1^{a}	142.7± 6.90^{a}	170 ± 18.7^{a}	443 ± 71.7^{b}
Nitrite - N ($\mu g\ l^{-1}$)	3.3 ± 0.5^{ab}	2.5 ± 0.4^{a}	4.4 ± 0.7^{b}	11.6 ± 2.3^{c}
Dissolved Organic Nitrogen ($\mu g\ l^{-1}$)	88 ± 9.7^{a}	70 ± 12.2^{a}	103 ± 19.5^{a}	279 ± 65.1^{b}
Total Phosphorus (μg l-1)	51.4 ± 2.4^{a}	73.3 ± 7.9^{b}	121.4± 19.2^{c}	126 ± 14.2^{c}
Dissolved Reactive Phosphorus ($\mu g\ l^{-1}$)	30.6 ± 2.1^{a}	43.9 ± 4.1^{b}	69.9 ± 5.6^{c}	144 ± 12^{d}
Free - Carbon dioxide (μ mol l^{-1})	0.10 ± 0.01^{b}	0.07 ± 0.01^{a}	0.14 ± 0.03^{b}	0.10 ± 0.01^{b}
Chlorophyll-a ($\mu g\ l^{-1}$)	4.3 ± 1.0^{a}	4.4 ± 0.9^{a}	4.8 ± 1.0^{a}	17.9 ± 4.6^{b}
Primary Production ($mg.c.m^{-2}\ d^{-1}$)	103.1 ± 28.8^{a}	109 ± 30.8^{a}	126 ± 35.4^{a}	356 ± 106^{b}

TABLE 6 Overall mean monthly values and standard error of physico - chemical parameters of pond water at varying organic fertilization levels and primary production, without fish. (Mean values in the same row bearing the same superscripts are not significantly different at P=0.05)

	POND TREATMENT			
	CTRL	LC	HC	HCC
pH	7.6 ± 0.1^{a}	8.4 ± 0.09^{b}	7.6 ± 0.2^{a}	7.5 ± 0.1^{a}
Conductivity ($\mu s\ cm^{-1}$)	103 ± 3.2^{a}	107 ± 1.4^{ab}	110 ± 1.3^{b}	116 ± 1.1^{c}
Total Hardness ($mg\ l^{-1}\ CaCO_3$)	59.9 ± 4.8^{a}	78.6 ± 5.0^{bc}	73 ± 0.9^{b}	80.9 ± 2.6^{c}
Total Alkalinity ($meq\ l^{-1}$)	1.5 ± 0.7^{a}	1.4 ± 0.1^{a}	1.5 ± 0.2^{a}	1.4 ± 0.1^{a}
Free - Carbon dioxide ($\mu mol\ l^{-1}$)	0.1 ± 0.05^{b}	0.06 ± 0.01^{a}	0.22 ± 0.08^{b}	0.10 ± 0.0^{b}
Total Suspended Solids ($mg\ l^{-1}$)	8.5 ± 0.1^{a}	8.9 ± 0.2^{a}	9.8 ± 0.2^{b}	12.4 ± 0.03^{c}
Dissolved Oxygen ($mg\ l^{-1}$)	10.7 ± 0.3^{b}	10.0 ± 0.3^{b}	8.1 ± 0.2^{a}	9.9 ± 0.3^{ab}
Biochemical Oxygen Demand ($mg\ l^{-1}$)	2.0 ± 0.1^{a}	2.2 ± 0.1^{a}	3.8 ± 1.0^{ab}	2.6 ± 0.1^{b}
Total Ammonia ($\mu g\ l^{-1}$)	232 ± 6.0^{a}	329 ± 11.1^{b}	370 ± 12.3^{b}	485 ± 42^{c}
Unionized Ammonia ($\mu g\ l^{-1}$)	6.5 ± 1.01^{a}	10.7 ± 2.31^{ab}	17.0 ± 4.41^{b}	17.8 ± 2.77^{b}
Nitrate - N ($\mu g\ l^{-1}$)	195 ± 6.7^{a}	283 ± 26.7^{b}	398 ± 20.8^{c}	404 ± 42^{c}
Nitrite - N ($\mu g\ l^{-1}$)	7.6 ± 0.7^{a}	11.4 ± 1.0^{b}	11.3 ± 0.83^{b}	15.8 ± 1.21^{c}
Dissolved Organic Nitrogen ($\mu g\ l^{-1}$)	206 ± 6.7^{a}	306 ± 26.4^{b}	383 ± 33.8^{b}	571 ± 61.3^{c}
Total Phosphorus ($\mu g\ l^{-1}$)	85.5 ± 1.5^{a}	121 ± 7.6^{b}	160 ± 7.2^{c}	182 ± 10.7^{c}
Dissolved Reactive Phosphorus ($\mu g\ l^{-1}$)	36.7 ± 1.0^{a}	48.6 ± 1.1^{a}	59.5 ± 1.8^{b}	80.9 ± 3.6^{c}
Chlorophyll - a ($\mu g\ l^{-1}$)	10.3 ± 3.50^{a}	20.7 ± 2.88^{b}	20.1 ± 3.9^{ab}	27.3 ± 3.10^{b}
Primary Production ($mg.c.m^{-2}d^{-1}$)	228.0 ± 7.50^{a}	370.5 ± 25.3^{b}	384.1 ± 35.9^{b}	608.0 ± 62.0^{c}

TABLE 7 Pearson Product-Moment correlation of physico-chemical parameters and primary production of pond water during inorganic fertilization without fish.

(*, ** refer to P levels of 0.05 and 0.01 respectively).

	Tot Alk.	Tot Amm.	B.O.D.	Chl-a	Cond.	DRP	D.O.	D.O.N	Free-CO_2	Hard-ness	NO_3	NO_2	pH	Susp. Solids	Temp.	Tot phosp.	U.I.A
Total Ammonia	0.434**																
B.O.D.	-0.022	-0.179**															
Chl - a	0.093*	0.644**	-0.341**														
Conductivity	0.546**	0.703**	-0.029	0.477**													
Dissolved Reactive Phosp.	0.439*	0.780**	-0.110*	0.599	0.813**												
Dissolved Oxygen	0.209*	0.381**	-0.241**	0.140**	0.214**	0.205**											
Dissolved Organic Nitrogen	0.204	0.830	-0.302	0.863	0.609	0.740	0.259**										
Free - CO_2	-0.024	-0.002**	0.053**	0.023**	0.091**	-0.003**	-0.117	0.031**									
Total Hardness	0.003*	0.458**	-0.304*	0.455**	0.309**	0.332**	0.189**	0.534**	-0.043								
NO_3 - N	0.235	0.788**	-0.224**	0.675**	0.588**	0.698**	0.314*	0.828**	-0.046	0.408**							
NO_2 - N	0.190	0.847	-0.257	0.793	0.558	0.716	0.297	0.924	-0.008**	0.508	0.837**						
pH	0.052*	0.050**	-0.042*	-0.010**	0.002**	0.057**	0.012**	-0.097**	-0.538	0.015**	-0.078**	-0.078**					
Suspended Solids	0.235*	0.685*	-0.218	0.526**	0.529**	0.588**	0.317	0.687*	0.040	0.491	0.624	0.661	-0.161				
Temperature	0.344*	0.226**	-0.129	0.279**	0.397**	0.294**	-0.057	0.233**	0.015	0.161**	0.148**	0.112**	0.017	0.458**			
Total phosphorus	0.220**	0.565**	-0.139	0.555*	0.549**	0.620**	0.126*	0.668**	0.008*	0.328	0.566**	0.672**	0.020**	0.527*	0.276*		
Unionized ammonia	0.545	0.415	-0.063	0.209	0.409	0.455	0.217	0.274	-0.252	0.077	0.353	0.272	0.435	0.215	0.223	0.259**	
Primary production	0.102	-0.013	0.051	0.692**	0.213*	0.881**	0.421**	-0.193	-0.003	0.123	0.411**	0.089	0.322**	0.409**	0.563**	0.696**	0.096

TABLE 8 Pearson-Product-Moment correlation of physico-chemical parameters and primary production of pond water during organic fertilization without fish.

(*, ** refer to P levels of ≤ 0.05 and ≤ 0.01 respectively).

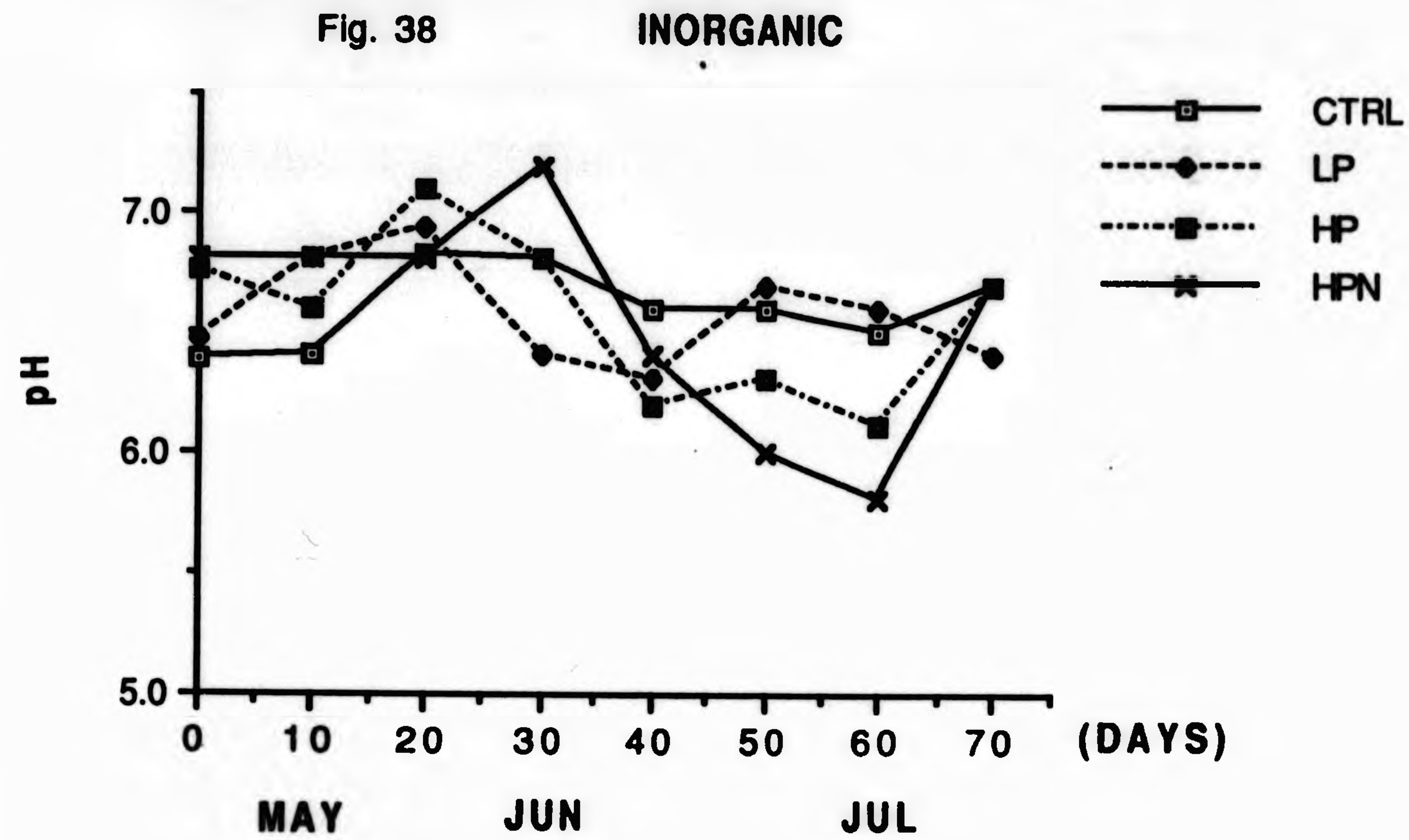
	Tot. Alk.	Tot. Amm.	B.O.D	Chl-a	Cond.	DRP	D.O	D.O.N	Free-CO_2	Hard-ness	NO_3-N	NO_2-N	pH	Susp. Solids	Temp.	Tot. phosp.	U.I.A
Total Ammonia	-0.305**																
B.O.D.	0.201*	0.176															
Chl - a	0.035	0.083	0.310**														
Conductivity	0.206*	0.181	0.229*	0.214*													
Dissolved Reactive phosp.	-0.140	0.739**	0.416**	0.249*	0.292**												
Dissolved Oxygen	-0.019	0.019	-0.346**	-0.323**	-0.102	-0.143											
Dissolved organic nitrogen	-0.384**	0.282**	-0.145**	-0.085	0.045	0.158	0.142										
Free - CO_2	-0.056	0.102	0.051	-0.043	-0.037	0.035	-0.031	0.020									
Total hardness	0.562**	-0.101	0.221*	0.280**	0.169	0.101	-0.201*	-0.360**	0.005								
NO_3 - N	-0.191	0.771**	0.092	-0.198	0.050	0.538**	0.175	0.299**	0.122	-0.189							
NO_2 - N	-0.352**	0.736**	0.122	0.090	0.034	0.591**	0.021	0.391**	0.122	-0.045	0.648**						
pH	0.044	-0.128	-0.149	0.020	0.027	-0.086	0.153	0.008	-0.401**	-0.046	-0.094	-0.067					
Suspended solids	-0.002	0.308**	0.361**	0.374**	0.114	0.475**	-0.196*	0.096	-0.025	0.122	0.127	0.367**	-0.048				
Temperature	0.319**	-0.121	0.326**	0.509**	0.330**	0.054	-0.440**	-0.254**	0.126	0.425**	-0.407**	-0.143	-0.107	0.155			
Total phosporus	-0.298**	0.712**	0.314**	0.278**	0.065	0.718**	-0.115	0.163	0.067	-0.010	0.562**	0.629**	-0.021	0.412**	0.025		
Unionized ammonia	-0.087	0.057	0.041	0.185	0.200*	0.097	-0.013	0.050	-0.163	-0.126	0.046	0.060	0.516**	0.035	0.054	0.240*	
Primary production	0.032	0.097	0.101	0.581**	-0.310**	0.322**	0.512**	0.283**	-0.017	0.018	0.262**	0.112	0.319**	-0.115	0.394**	0.208*	-0.013

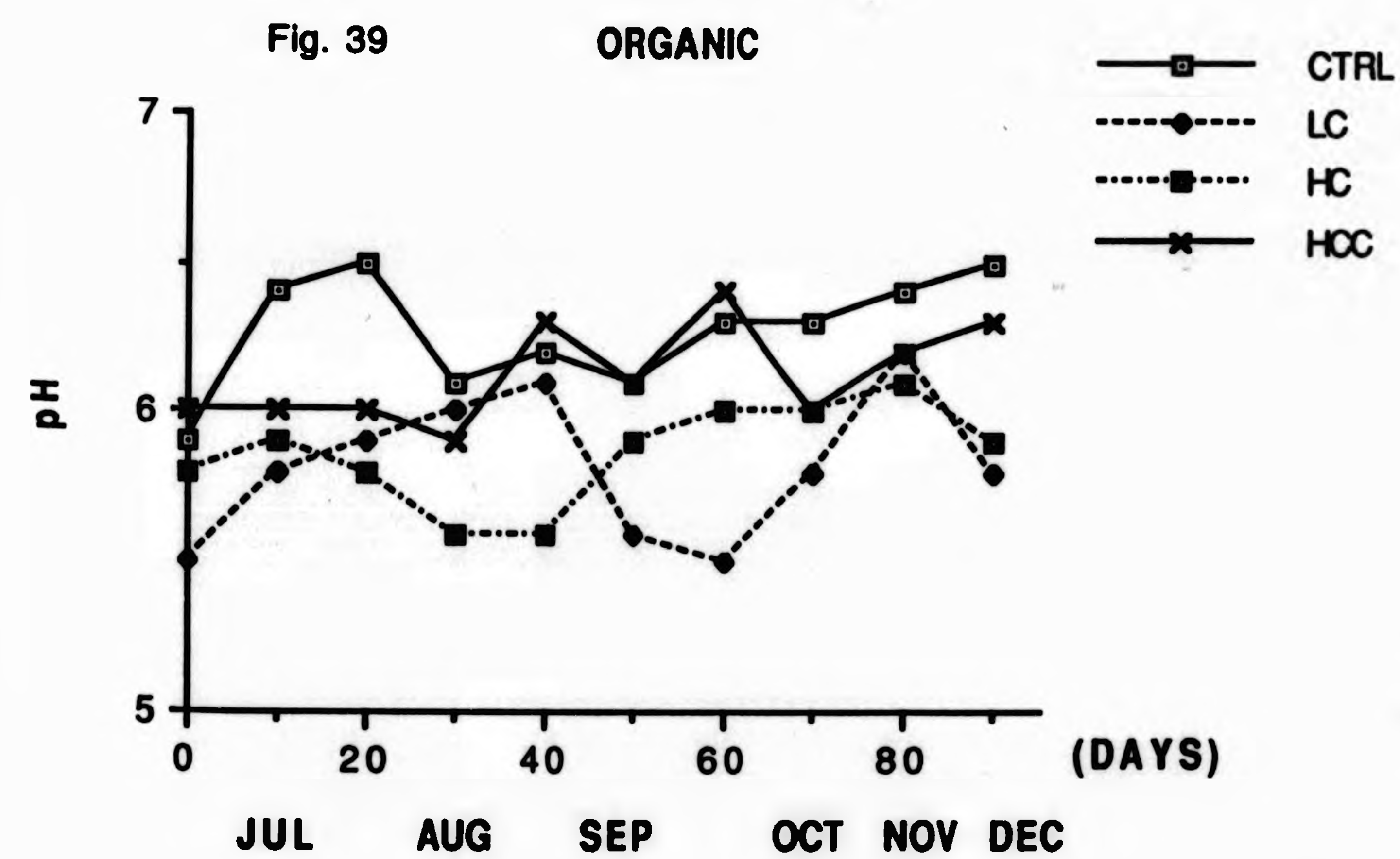
4.2 SOIL CHARACTERISTICS

The results of sediment parameters are presented in Figures 38 - 51 and Tables 9 & 10. Observation of the soil texture of the various experimental ponds shows that it consists mainly of fine sand particles, stones and pebbles, all of which influenced the development of benthic algae and macroinvertebrates. Based on the observed nutrient levels, the carbon:nitrogen, nitrogen:phosphorus ratio and nutrient budgets were calculated in order to assess the dynamics of mineralisation and/or nutrient utilization during fertilization.

4.2.1 pH

Variations in soil pH during inorganic and organic fertilization are shown in Figures 38 & 39, and the respective ranges were 5.8 to 6.9 and 5.5 to 6.3. Differences between ponds were significant ($P<0.01$, ANOVA) in the organic fertilization treatments, unlike the inorganic (Table 9).





Figs. 38-39. Variations in sediment pH during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.2.2 TOTAL CARBON

Figure 40 shows the variations in carbon content of the sediment during inorganic fertilization. Table 10 shows a significantly higher response in the LP, HP & HPN than the control. The response pattern for the organic manuring (Fig. 41) was higher at the premanipulation (PM) state for all treatments, while carbon reached 59.1% in the HCC treatments. Table 9 shows a significant response to all manure treatments.

Fig. 40

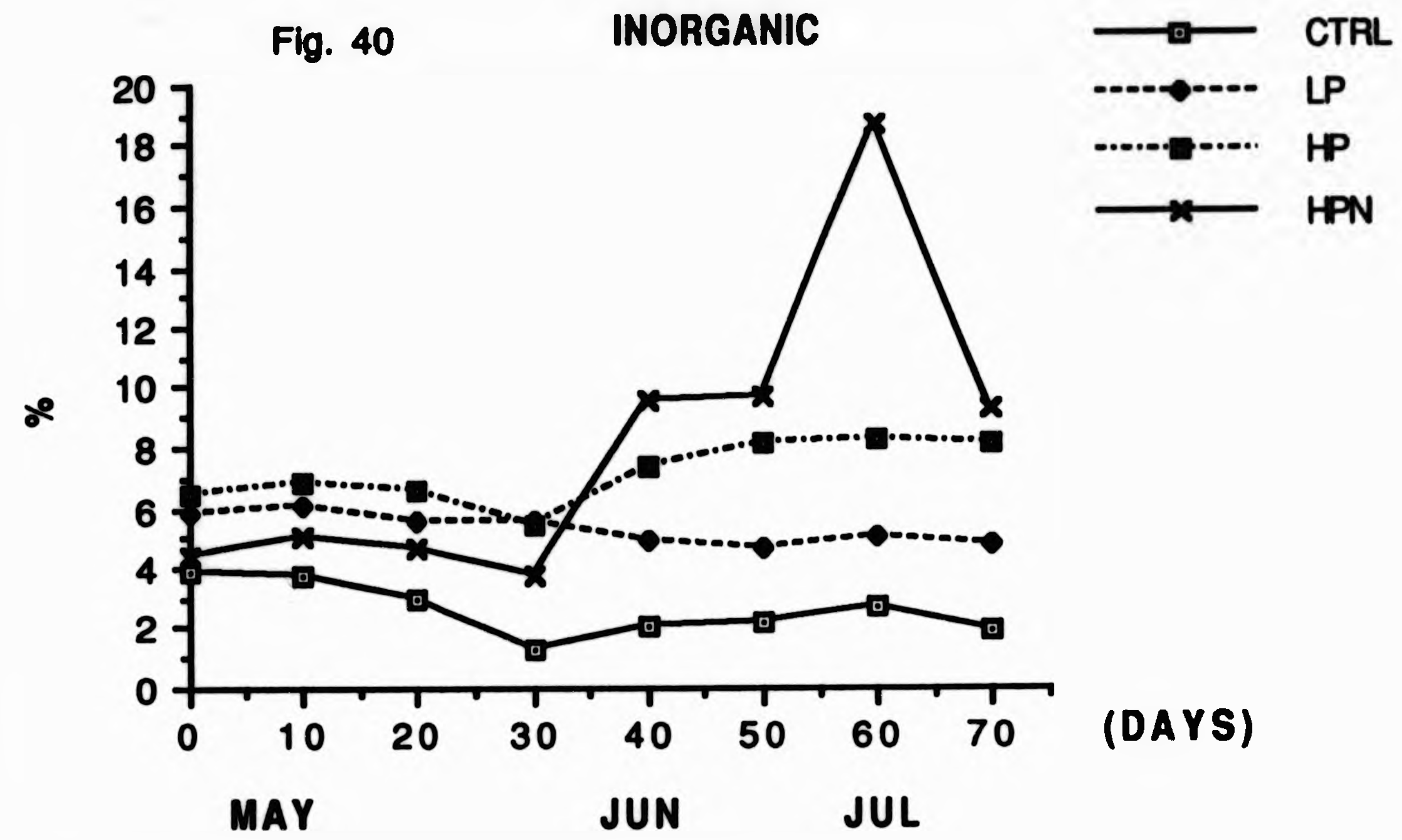
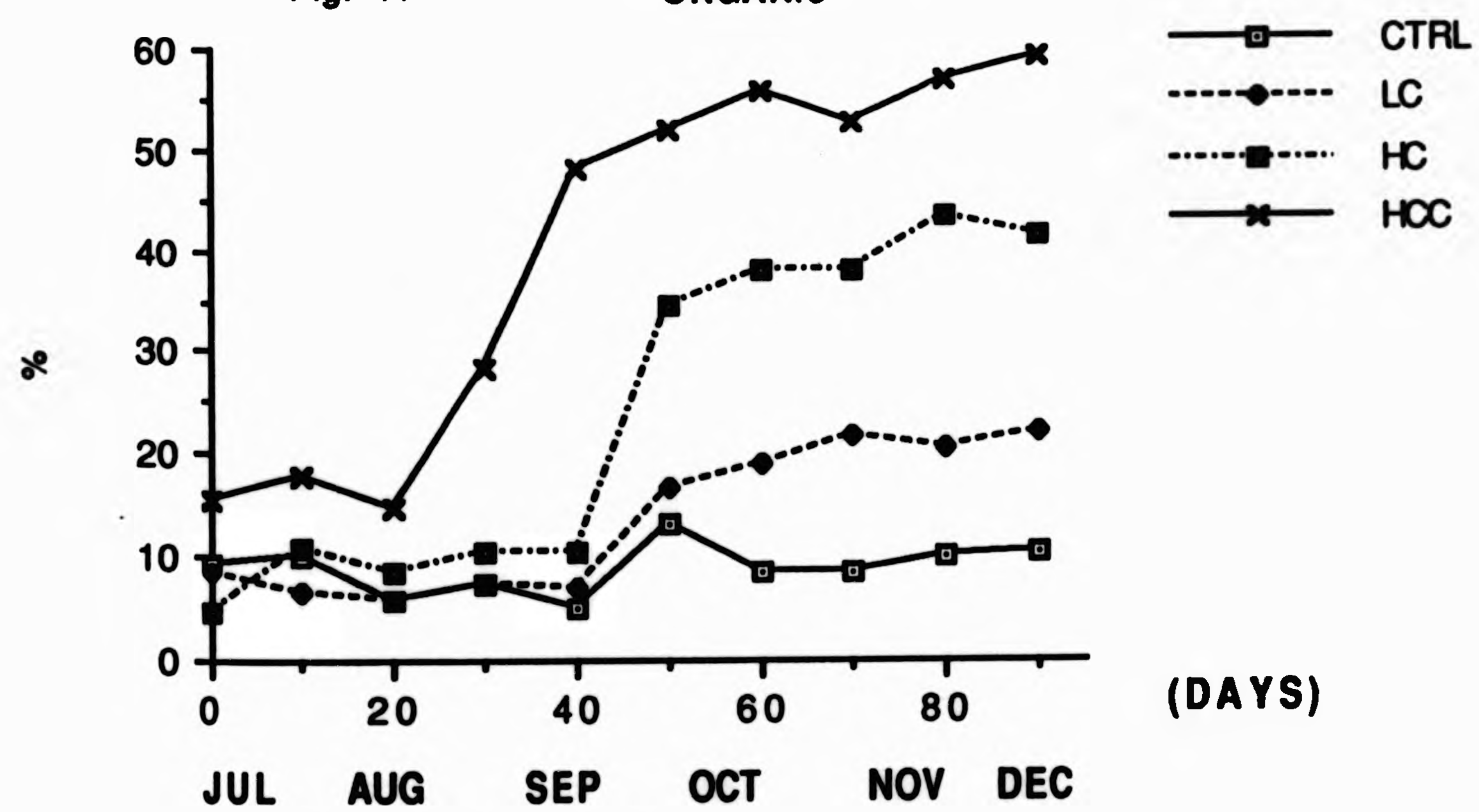


Fig. 41



Figs. 40-41. Variations in sediment Total Carbon during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.2.3 TOTAL PHOSPHORUS

Figures 41 & 42 show the variations in sediment phosphorus during inorganic and organic fertilization, respectively. Phosphorus accumulation in the sediment was initially slow, in spite of continous input of inorganic fertilizer. However, during the 4th week (9/6/88), there was an upsurge in both HP & HPN, attaining peak values of 4.7 and 4.4 mg g^{-1}, respectively. Comparatively, the range for organic fertilization was lower. Table 10 shows that only HC and HCC produced significant differences from the CTRL and LC.

4.2.4 TOTAL NITROGEN

The variations in soil total nitrogen during inorganic and organic fertilization are shown in Figures 43 & 44, respectively. Higher premanipulation values of 4.4% and 6.5% were recorded in the HPN and HP treatments respectively, but declined sharply on the 27/5/88. This was followed by a gradual increase, attaining peak value of 2.9% in the HPN. There was a higher response in the HP than

Fig. 42 INORGANIC

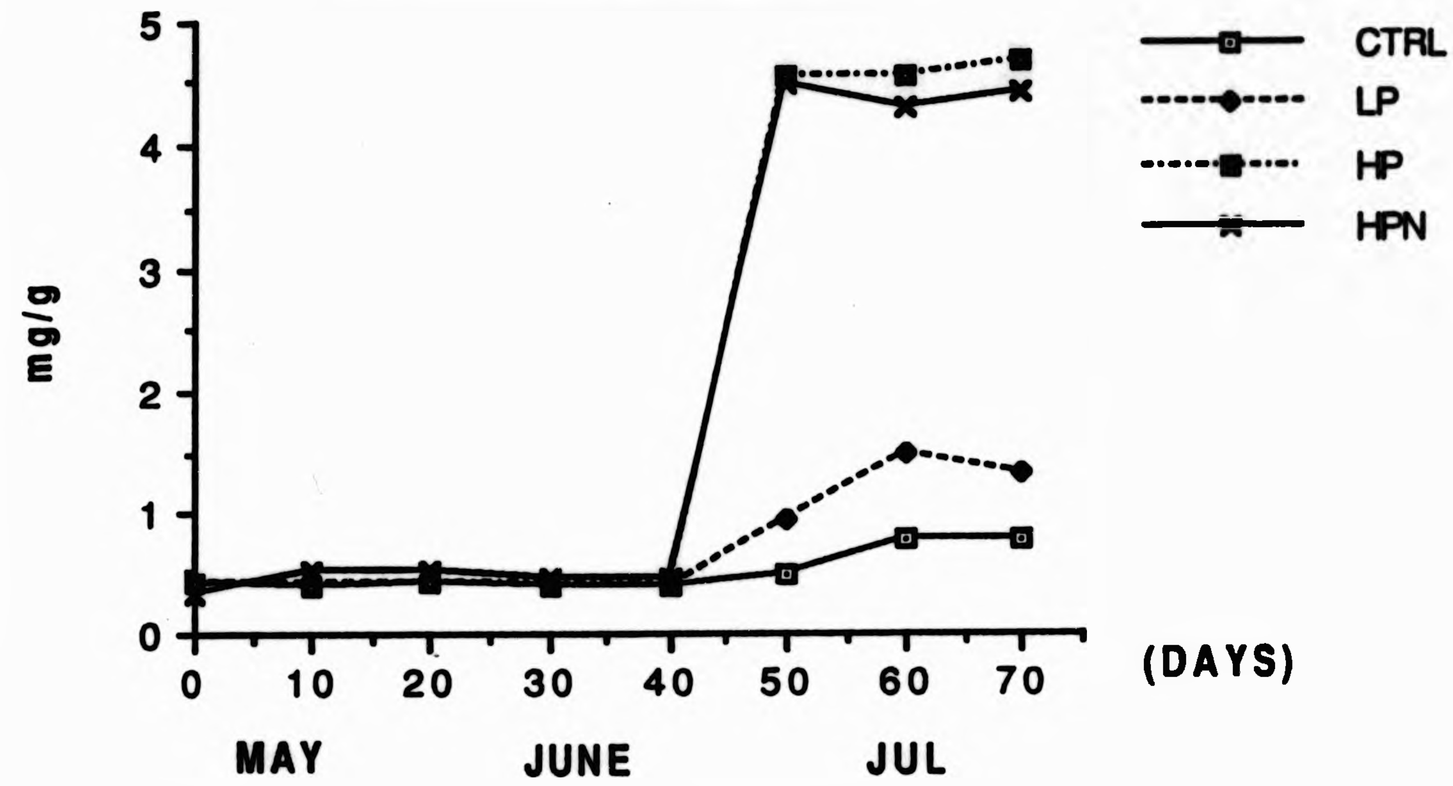
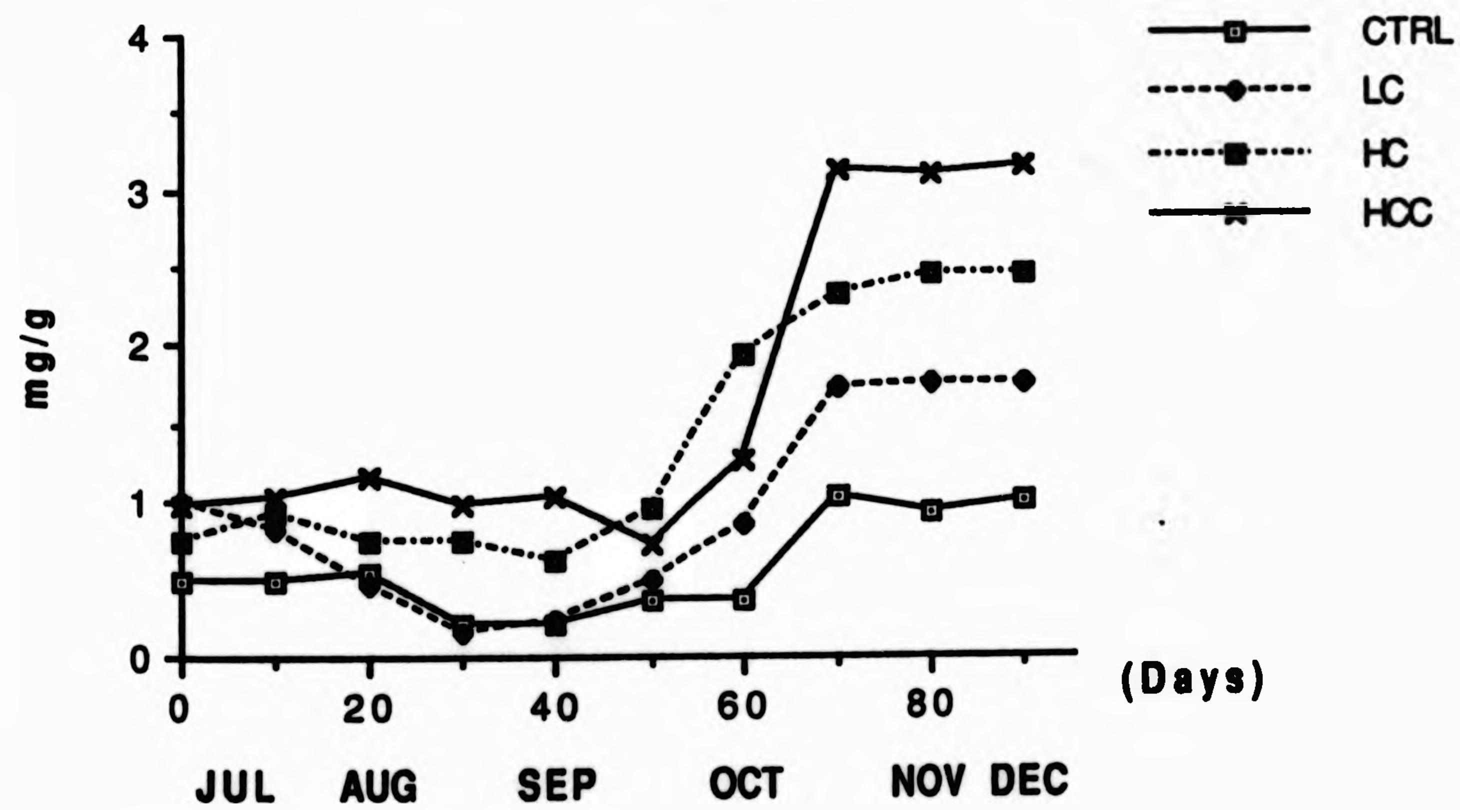
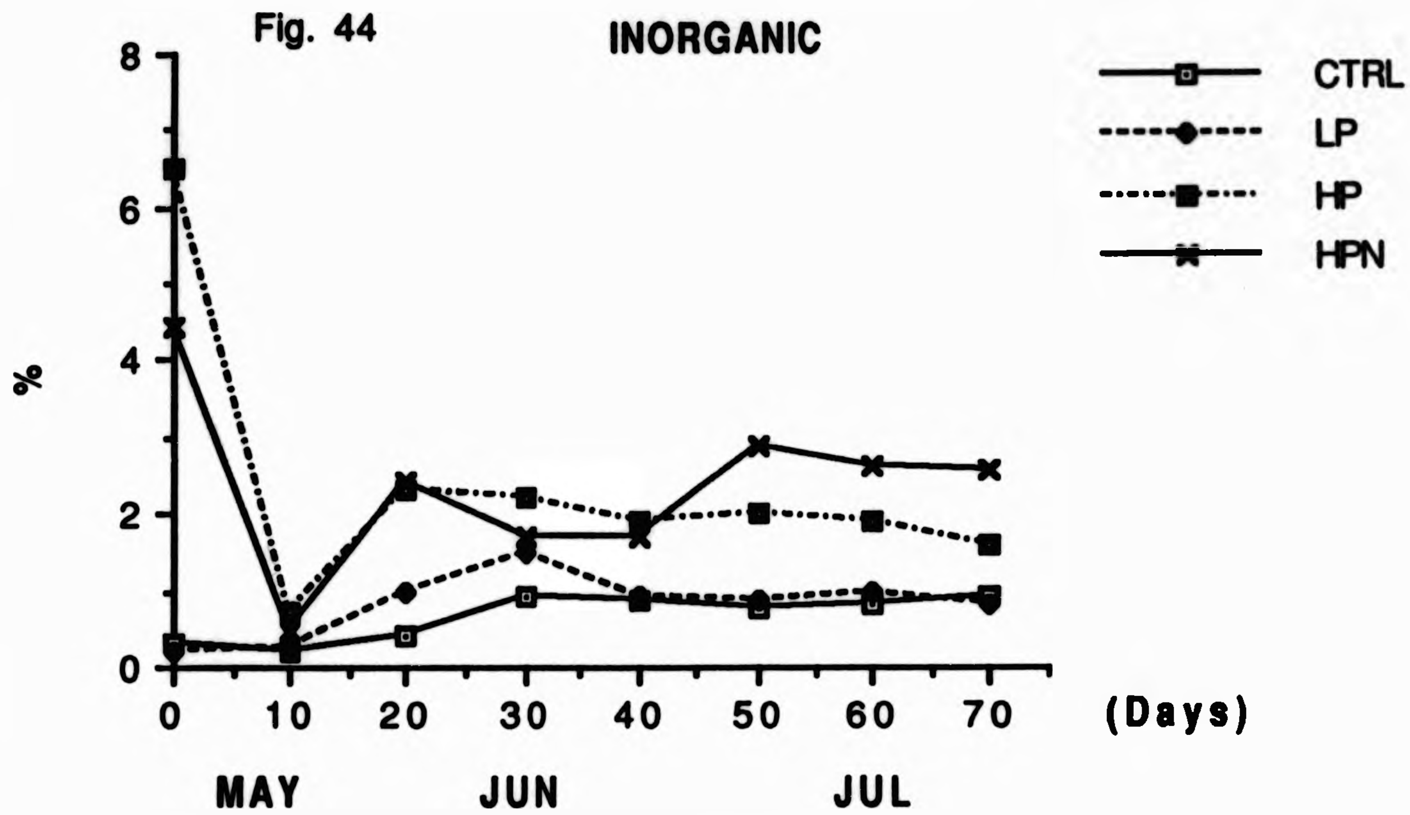
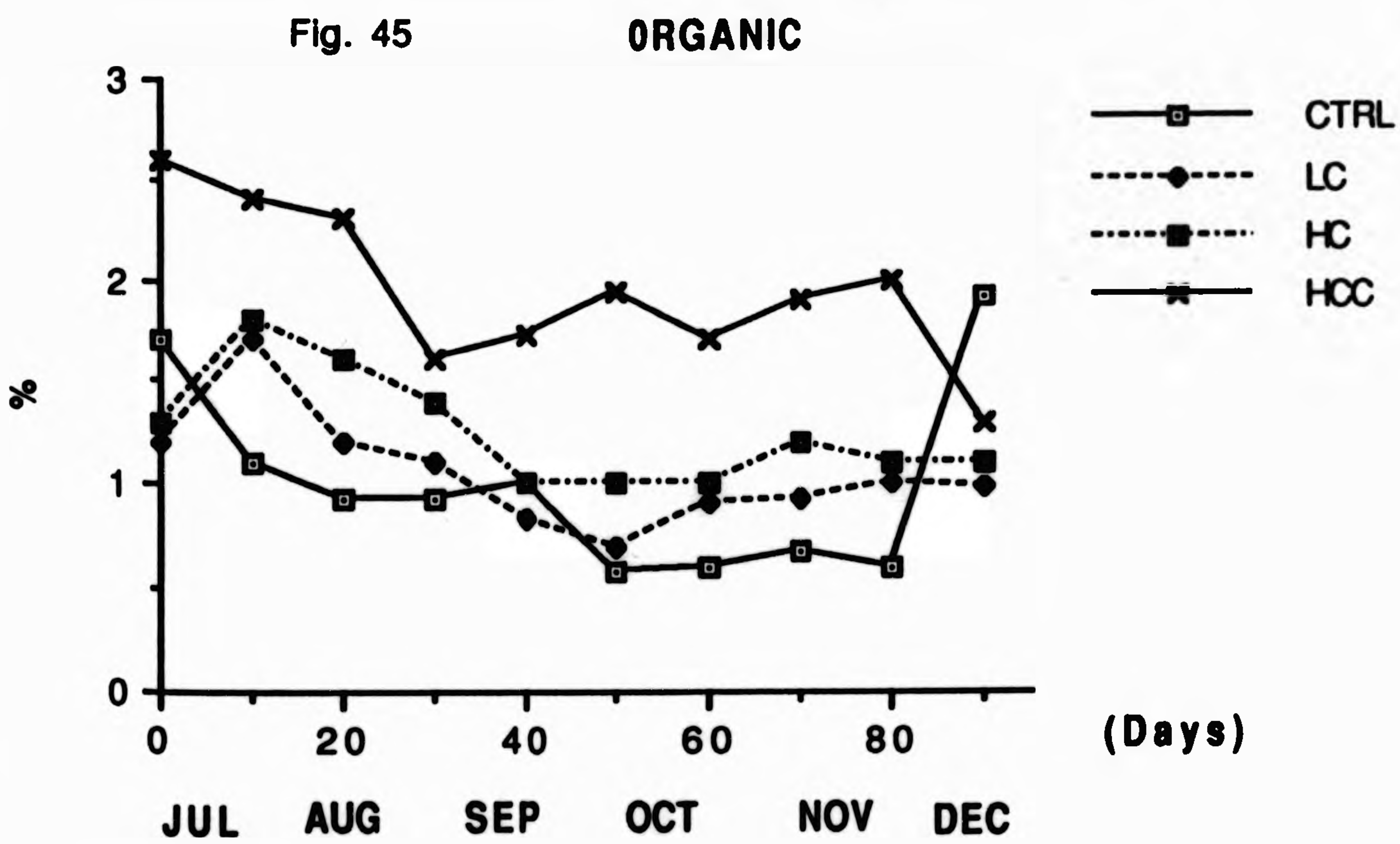


Fig. 43 ORGANIC



Figs. 42-43. Variations in sediment Total Phosphorus during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).





Figs. 44-45. Variations in sediment Total Nitrogen during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

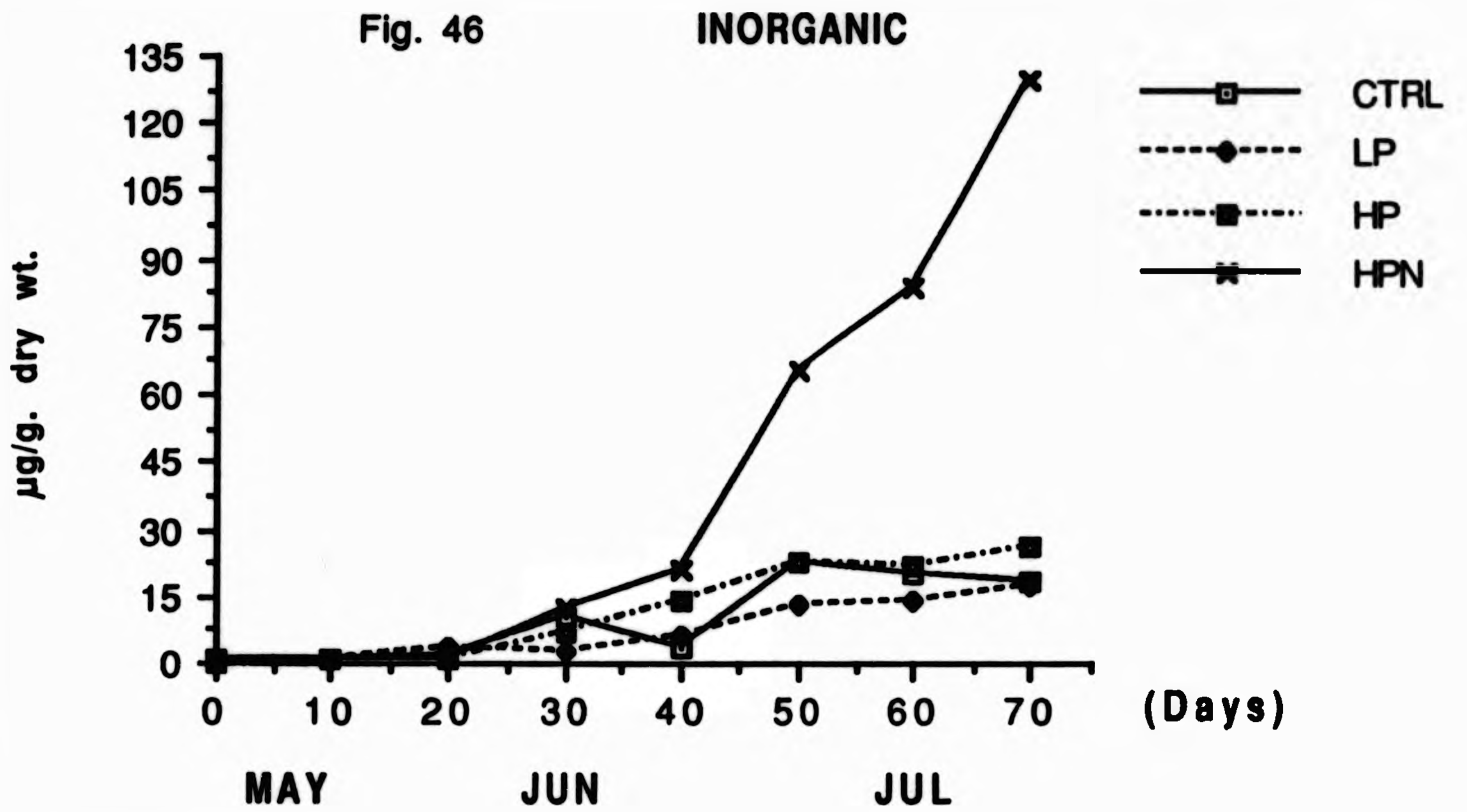
the HPN, but both treatments were not significantly different ($P > 0.05$, ANOVA) as shown in Table 10. In the organic treatments, Table 10 confirms that both HC and HCC were higher than the CTRL.

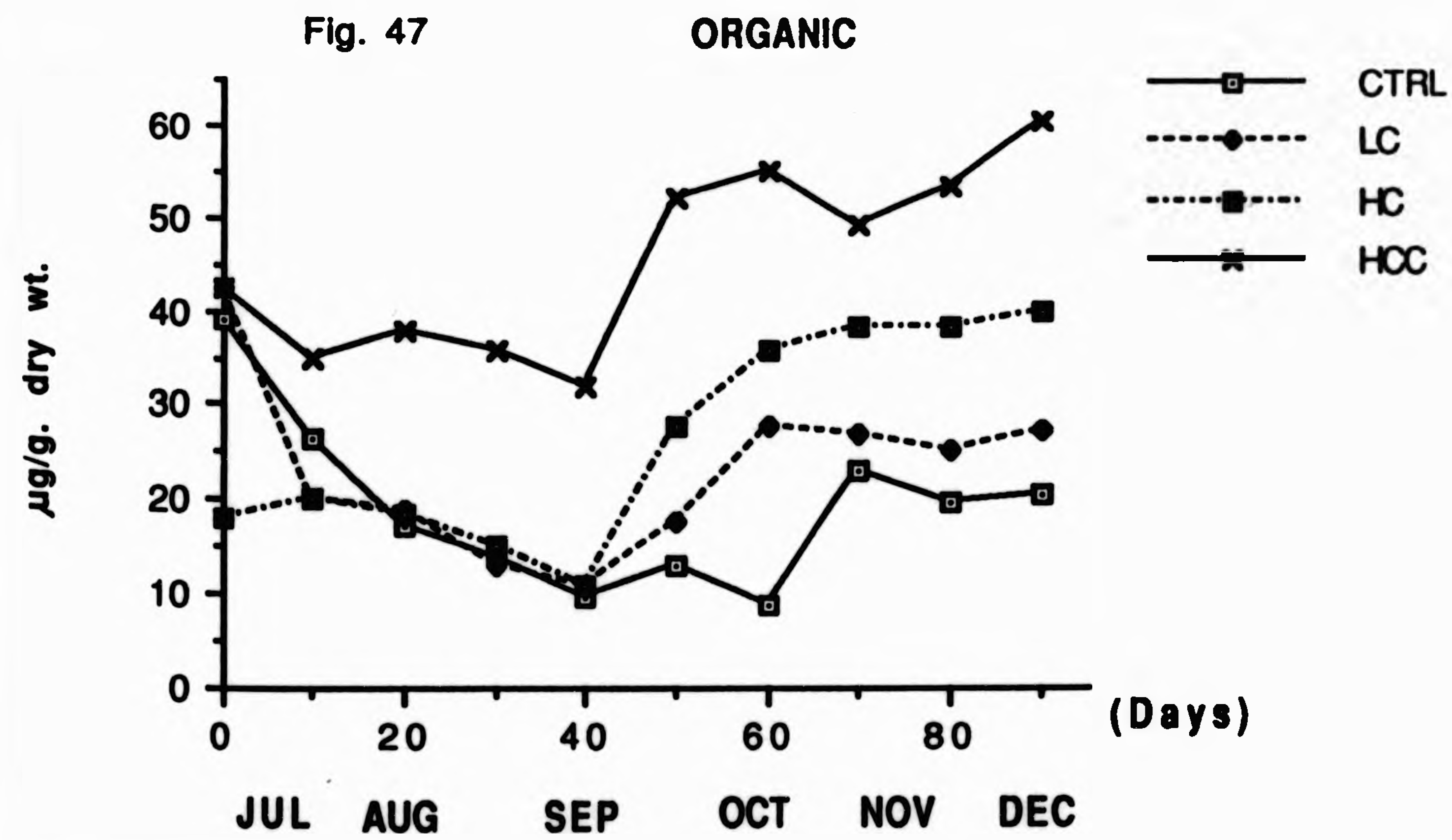
4.2.5. BENTHIC ALGAE

This was measured as chlorophyll-a and results presented in Figs. 46 & 47 for inorganic and organic fertilization, and the respective ranges were 0.03 - 130 and 8.6 - 60.2 $ug.g^{-1}$ dry wt. In both fertilization trials, only HPN and HCC showed significant response ($P < 0.05$) as evident in Table 10.

4.2.6 CARBON:NITROGEN, NITROGEN:PHOSPHORUS RATIO AND NUTRIENT BUDGET ANALYSIS

Figures 48-51 shows the variations in C:N and N:P ratio, while Table 11 is a summary of estimated nutrient balances



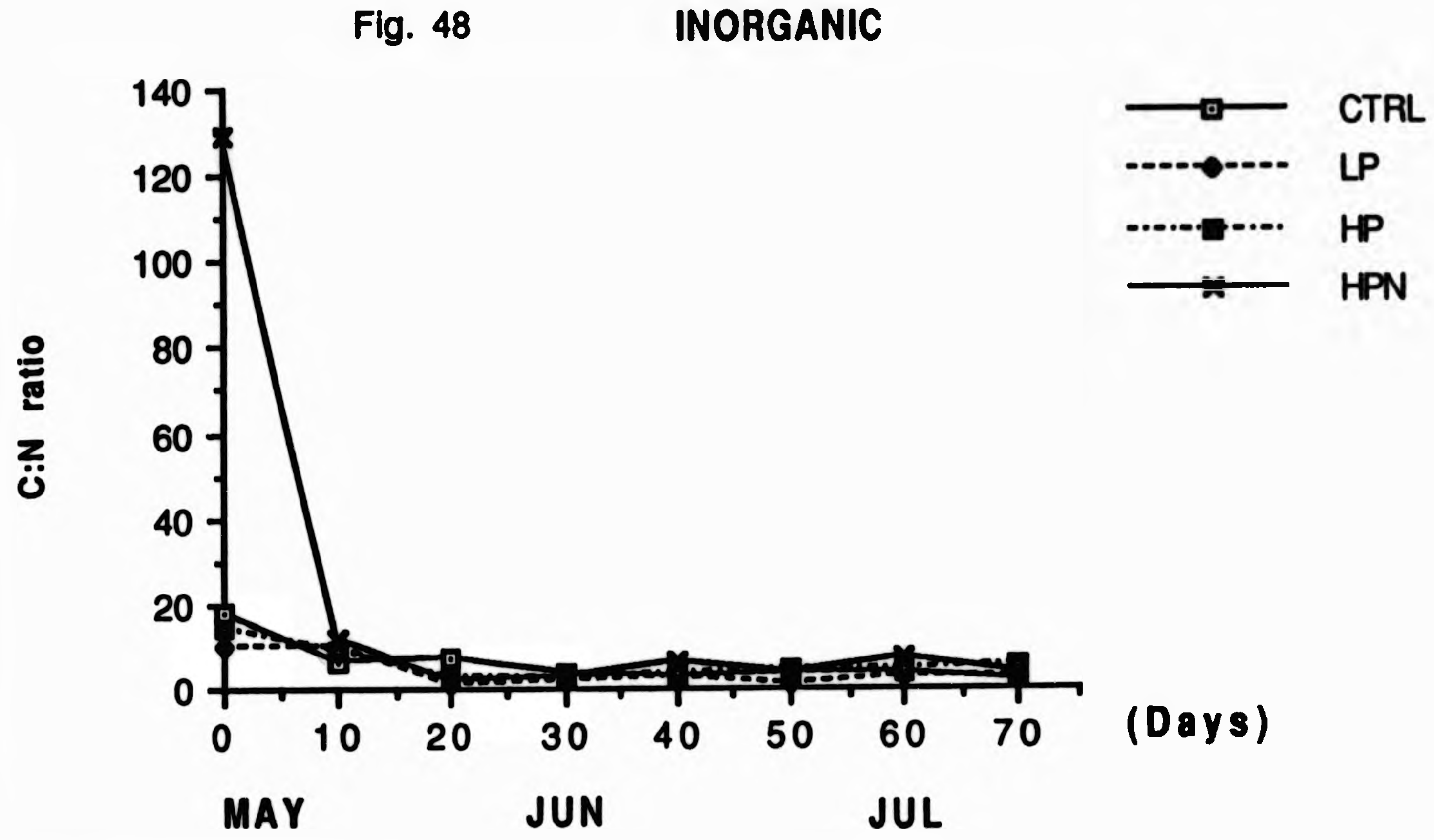


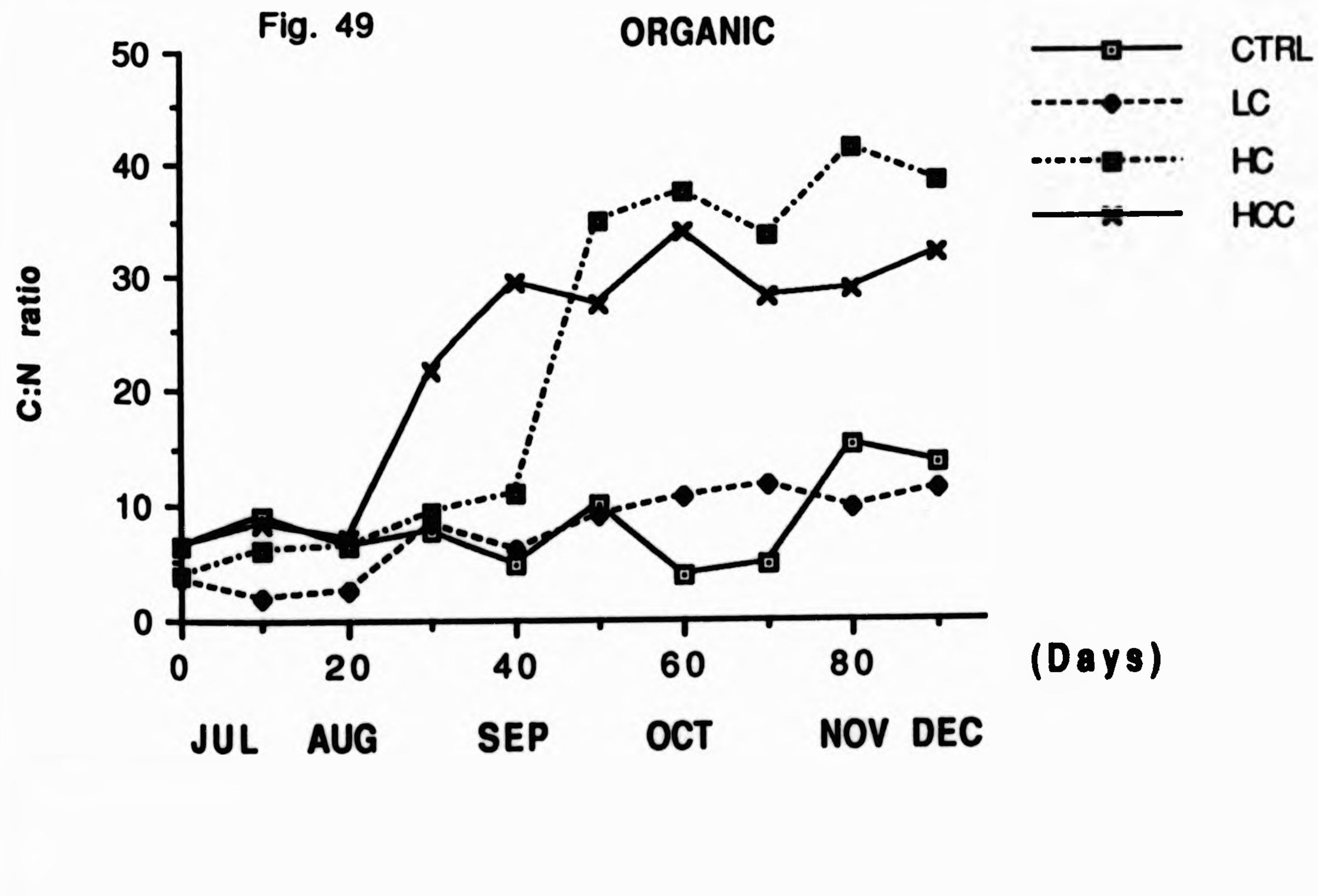
Figs. 46-47. Variations in Benthic algae (measured as Chl-a) during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

and denitrification rates during inorganic and organic fertilization, without fish. The nutrient budget analysis is an important tool in establishing mass balances which is useful in predicting efficient utilization, pollution risks and possible control strategies.

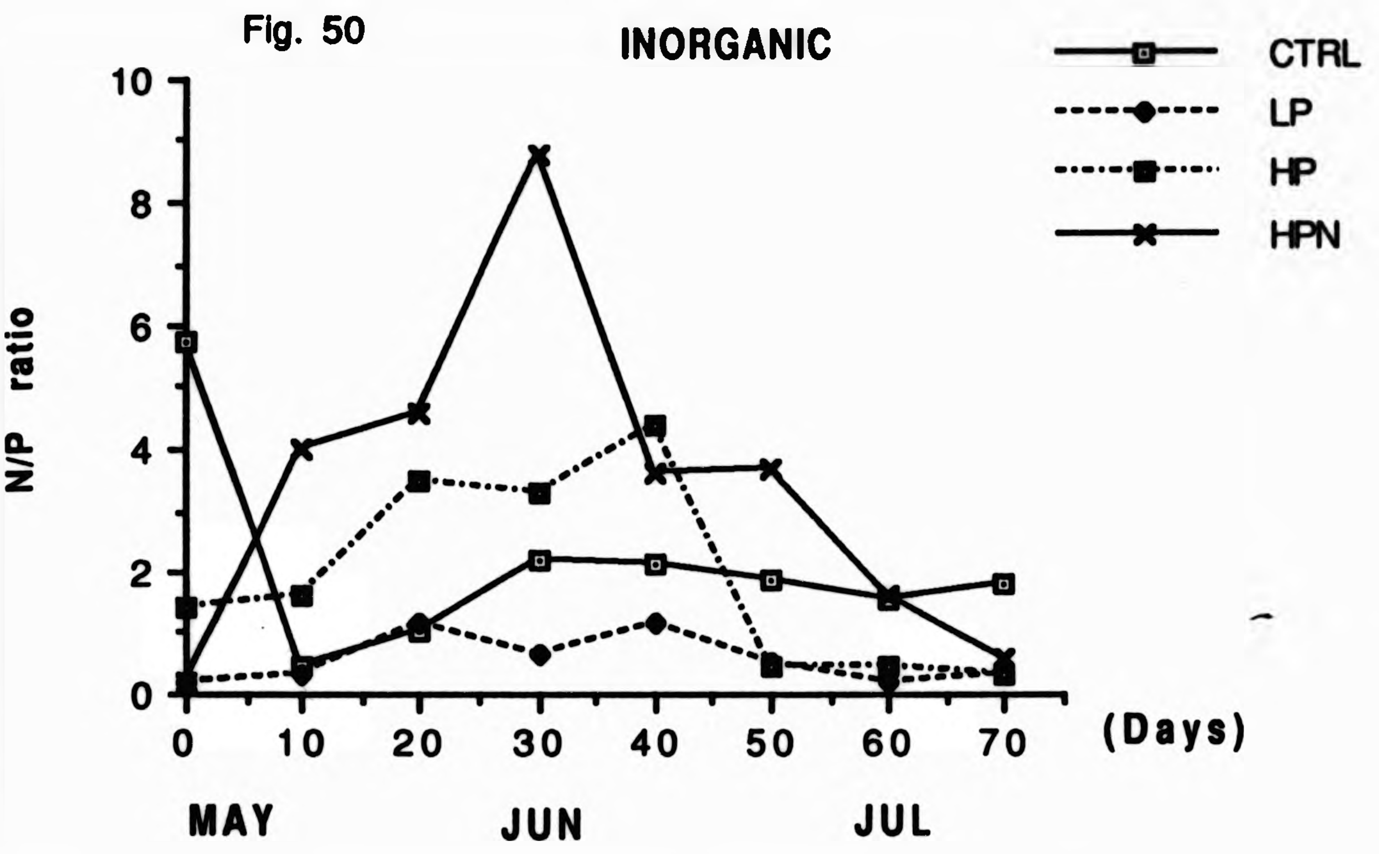
4.2.6.1 CARBON:NITROGEN AND NITROGEN:PHOSPHORUS RATIO

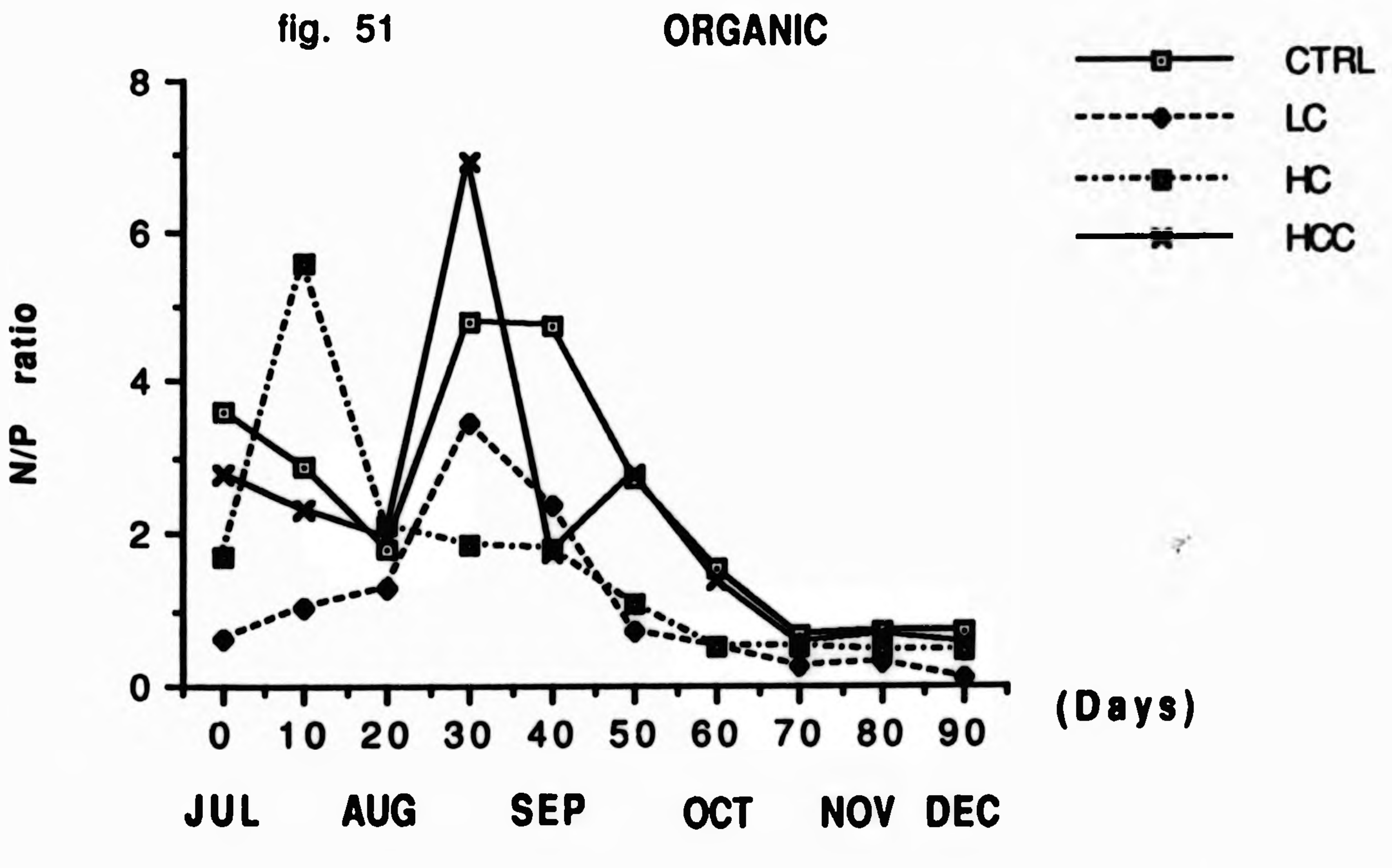
At the premanipulation state, C:N ratio in the inorganic treatments was high, especially in the HPN (Figure 48). However, at the start of fertilization on 27/5/88, there was a sharp decline and low values were maintained throughout the remainder of the experiment. The highest overall mean value of 20.8 in the HPN was significantly different from other treatments (Table 10). In comparison, organic fertilization had the highest ratio in both HC & HCC (Fig. 49), which were significantly different from the CTRL & LC as shown in Table 10.
Variations in N:P ratio during inorganic and organic fertilization are presented in Figures 50 and 51 respectively. Table 10 shows that only HPN had a significantly higher ratio. In contrast however, the organic manuring showed a significant increase with CTRL,





Figs. 48-49. Variations in Carbon:Nitrogen ratio during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).





Figs. 50-51. Variations in Nitrogen:Phosphorus ratio during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

TABLE 9 F-values and their associated level of significance for two-way ANOVA on log transformed data of physico-chemical parameters of pond soil during inorganic and organic fertilization, and benthic algae, without fish. (*, ** refer to P levels of ≤ 0.05 and ≤ 0.01 respectively, NS=not significant).

	INORGANIC		ORGANIC	
	SOURCES OF VARIATION		SOURCES OF VARIATION	
	Between ponds	Between period	Between ponds	Between periods
pH	0.89 NS	1.07 NS	13.6 **	0.33 NS
Total phosphorus ($\mu g\ g^{-1}$)	5.68 **	3.16 **	8.42 **	3.65 *
Total carbon (%)	4.97 *	2.99 *	30.7 **	8.22 **
Total nitrogen (%)	8.59 *	12.1 **	55.9 **	15.1 **
C : N ratio	3.82 *	18.3 **	7.09 **	2.93 *
N : P ratio	2.70 *	9.11 **	4.11 *	3.62 *
Benthic algae, as Chl-a ($\mu g.g^{-1}$ dry wt)	7.21 **	3.61 *	3.19 *	6.22 *

TABLE 10 Overall mean of physico-chemical parameters of pond soil at varying inorganic and organic fertilization levels, and benthic algae, without fish.

(Mean values in the same row bearing the same superscripts are not significantly different at P=0.05)

	INORGANIC				ORGANIC			
	CTRL	LP	HP	HPN	CTRL	LC	HC	HCC
pH	6.60 ±0.11	6.60 ±0.10	6.57 ±0.12	6.64 ±0.14	6.10 ±0.10[a]	5.80 ±0.10[a]	5.90 ±0.10[a]	6.30 ±0.10[b]
Total phosphorus (mg g^{-1})	0.58 ±0.098[a]	0.74 ±0.16[a]	2.02 ±0.77[ab]	2.99 ±0.74[b]	0.56 ±0.13[a]	0.69 ±0.20[a]	1.39 ±0.25[b]	1.65 ±0.33[b]
Total carbon (%)	2.83 ±0.38[a]	6.82 ±0.50[b]	8.01 ±0.21[c]	8.64 ±1.78[bc]	40.2 ±6.0[a]	13.5 ±2.20[b]	24.0 ±5.10[b]	8.80 ±0.80[c]
Total nitrogen (%)	0.75 ±0.11[a]	0.84 ±0.14[a]	2.78 ±0.76[b]	2.52 ±0.43[b]	1.10 ±0.0[a]	1.40 ±0.10[a]	1.80 ±0.10[b]	2.0 ±0.20[b]
C : N ratio	7.90 ±1.42[a]	9.31 ±1.74[a]	5.42 ±1.02[o]	20.8 ±8.22[b]	11.2 ±1.43[a]	14.2 ±1.73[a]	23.7 ±1.92[b]	22.3 ±1.49[b]
N : P ratio	1.45 ±0.57[a]	1.28 ±0.0[a]	1.85 ±0.55[a]	1.82 ±0.19[b]	2.17 ±0.15[b]	1.89 ±0.10[b]	1.21 ±0.32[a]	1.64 ±0.0[a]
*Benthic algae (µg.g^{-1} dry wt)	10.2 ±1.48[a]	7.69 ±2.41[b]	12.5 ±0.10[ac]	41.1 ±7.9[d]	19.1 ±3.20[a]	23.0 ±2.80[a]	26.2 ±3.50[a]	41.1 ±2.90[b]

* Measured as chlorophyll - a

HC & HCC. Generally, the N:P ratio of both fertilization trials were less than 12.0, implying that the pond water had a less than adequate supply of nitrogen, possibly due to the observed denitrification rate (Table 10).

4.2.6.2 NUTRIENT BALANCES AND DENITRIFICATION RATES

These showed variability in both fertilization trials (Table 11). Nitrogen retention was high in HP & HPN treatments, while high daily nitrogen losses or denitrification were observed in HPN. Phosphorus retention in the sediment showed significant variation in all the treatments, with HP having the highest mean value of 1.04 $g.m^{-2}yr^{-1}$. With regard to organic fertilization, both nitrogen retention and loss were highest in the HC and HCC treatments (Table 11).

TABLE 11 Estimated inorganic nutrient balances and denitrification rates during inorganic and organic fertilization, without fish.

	INORGANIC				ORGANIC			
	CTRL	LP	HP	HPN	CTRL	LC	HC	HCC
[1]**NUTRIENT RETENTION IN PONDS**								
Nr(s) ($g.m^{-2}.yr^{-1}$)	0.84 ±0.08[a]	0.78 ±0.0[a]	1.22 ±0.18[b]	3.41 ±0.55[c]	0.85 ±0.03[a]	1.33 ±0.0[b]	1.89 ±0.14[c]	2.21 ±0.20[c]
Pr(s) ($g.m^{-2}.yr^{-1}$)	0.25 ±0.01[a]	0.40 ±0.0[b]	1.04 ±0.01[c]	0.75 ±0.08[d]	0.36 ±0.02[a]	0.60 ±0.0[b]	0.66 ±0.02[c]	0.85 ±0.04[d]
[2]N : P ratio in sediment	1.45 ±0.57[a]	1.28 ±0.0[a]	1.85 ±0.55[a]	1.82 ±0.19[b]	2.17 ±0.15[b]	1.89 ±0.10[b]	1.21 ±0.32[a]	1.64 ±0.0[a]
[3]Net nitrogen retained in sediment ($g.m^{-2}.yr^{-1}$)	0.36	0.51	1.92	1.35	0.78	1.13	0.80	1.40
[4]Nitrogen losses ($g.m^{-2}.yr^{-1}$)	0.48	0.27	-0.70	2.06	0.09	0.20	1.09	0.81
Daily nitrogen losses ($mg.m^{-2}.d^{-1}$)	1.32	0.74	-1.90	5.65	0.25	0.55	2.98	2.22

[1,2] Values obtained from direct analysis of sediment samples.

[3] Calculated from the equation: Pr(s) x $N:P_{(sediment)}$ where, Pr(s) = phosphorus retained in sediment (Volleinweider, 1969).

[4] Calculated from the equation: Nr(s) - NNr(s) where Nr(s) = nitrogen retained in pond sediment and

NNr(s) = net nitrogen retained in sediment (Vollenweider, 1969).

4.3 PLANKTON COMMUNITIES

The abundances of phyto-and zooplankton are shown in Figures 52-65. The following analysis of the periodic variations relates to the overall pattern of pooled data for replicate ponds.

4.3.1 PHYTOPLANKTON COMPOSITION

Throughout the sampling periods, the various phytoplankton groups showed diversity in both species and total number. Dominant groups observed were Bacillariophyceae, Chlorophyceae, Cyanophyceae and Dinophyceae.

4.3.1.1 BACILLARIOPHYCEAE

Figures 52 & 53 represent the variations in total Bacillariophyceae populations during inorganic and organic fertilization respectively. Peak abundances of 9.5 and 8.8 x 10^5 cells l^{-1} were recorded in the HPN and HCC treatments respectively; and Tables 13 & 14 show the significant differences between treatment means. Two dominant genera observed in both fertiliztion trials were *Diatoma* and *Navicula* spp.

4.3.1.2 CHLOROPHYCEAE

In both fertilization trials, this group dominated the phytoplankton, with peak population of 4.3×10^6 cells l^{-1} observed in the HPN treatment. The response pattern for all the treatments was significantly different (Table 13), and consistent with fertilisation rates. During the organic fertilization, three peaks of abundance, 1.2, 8.5 and 1.0×10^5 cell l^{-1} observed in the LC, HC and HCC respectively, were followed a by sharp decline; and all the treatment means were significantly different from the control (Table 14). Dominant genera encountered in both fertilisation trials were *Ankistrodesmus sp*, *Chlamydomonas sp*, *Closterium sp*, *Cryptomonas sp*, *Oocystis sp*, *Scenedesmus sp*, *Staurastum sp*, *Tetraedon sp* and *Spirogyra sp*.

Fig. 52 INORGANIC

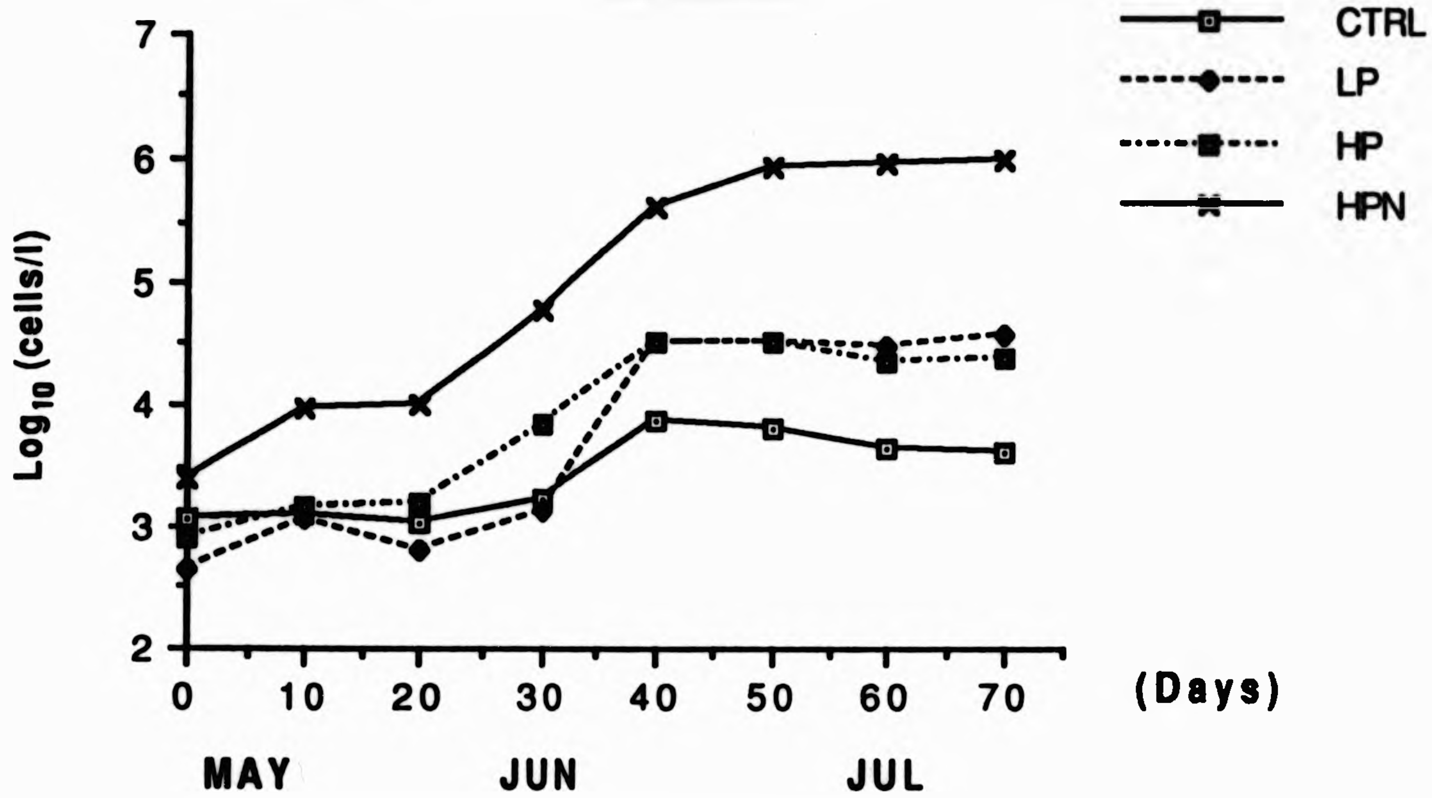
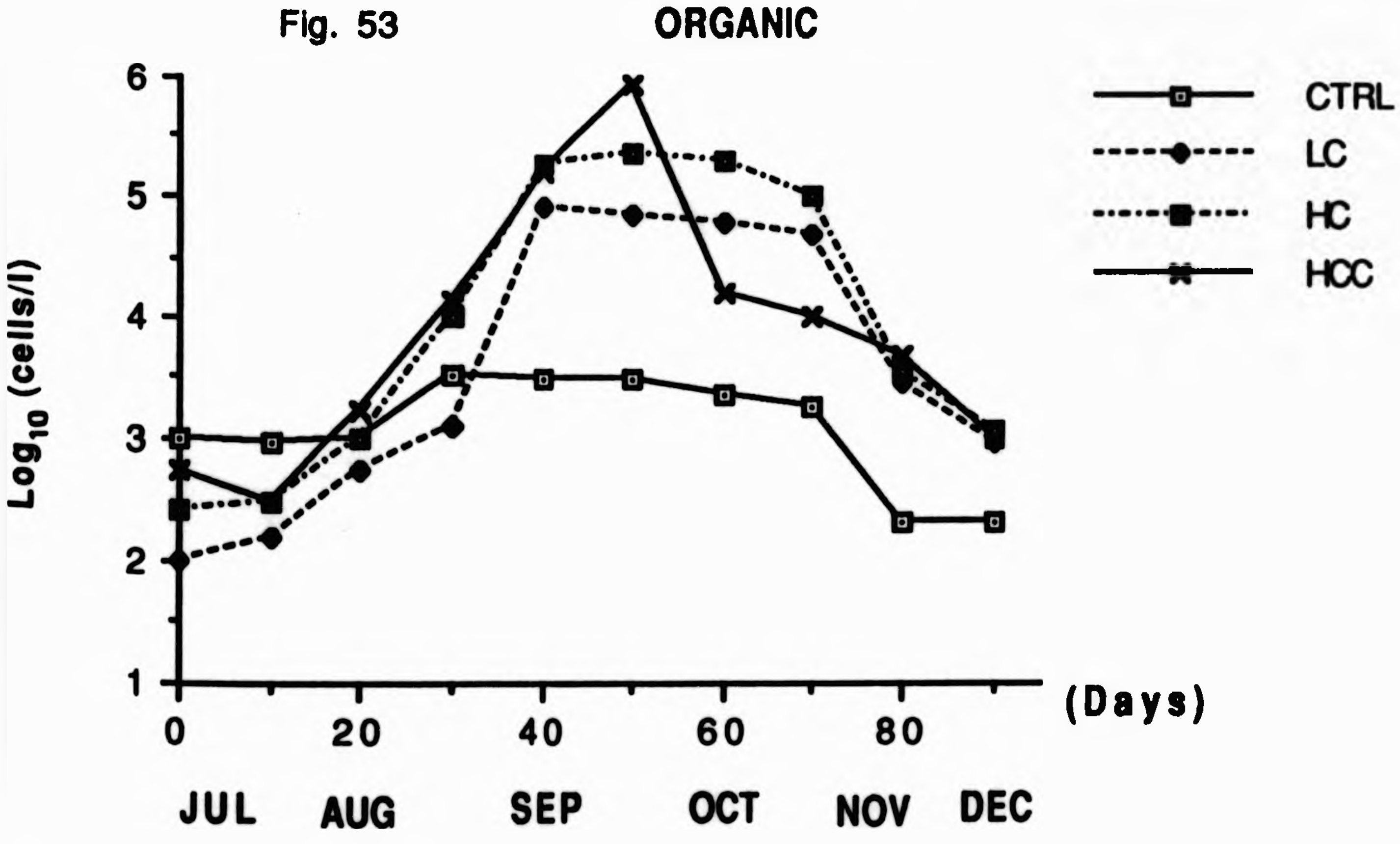


Fig. 53 ORGANIC



Figs. 52-53. Variations in abundance of Baccillariophyceae during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

Fig. 54 INORGANIC

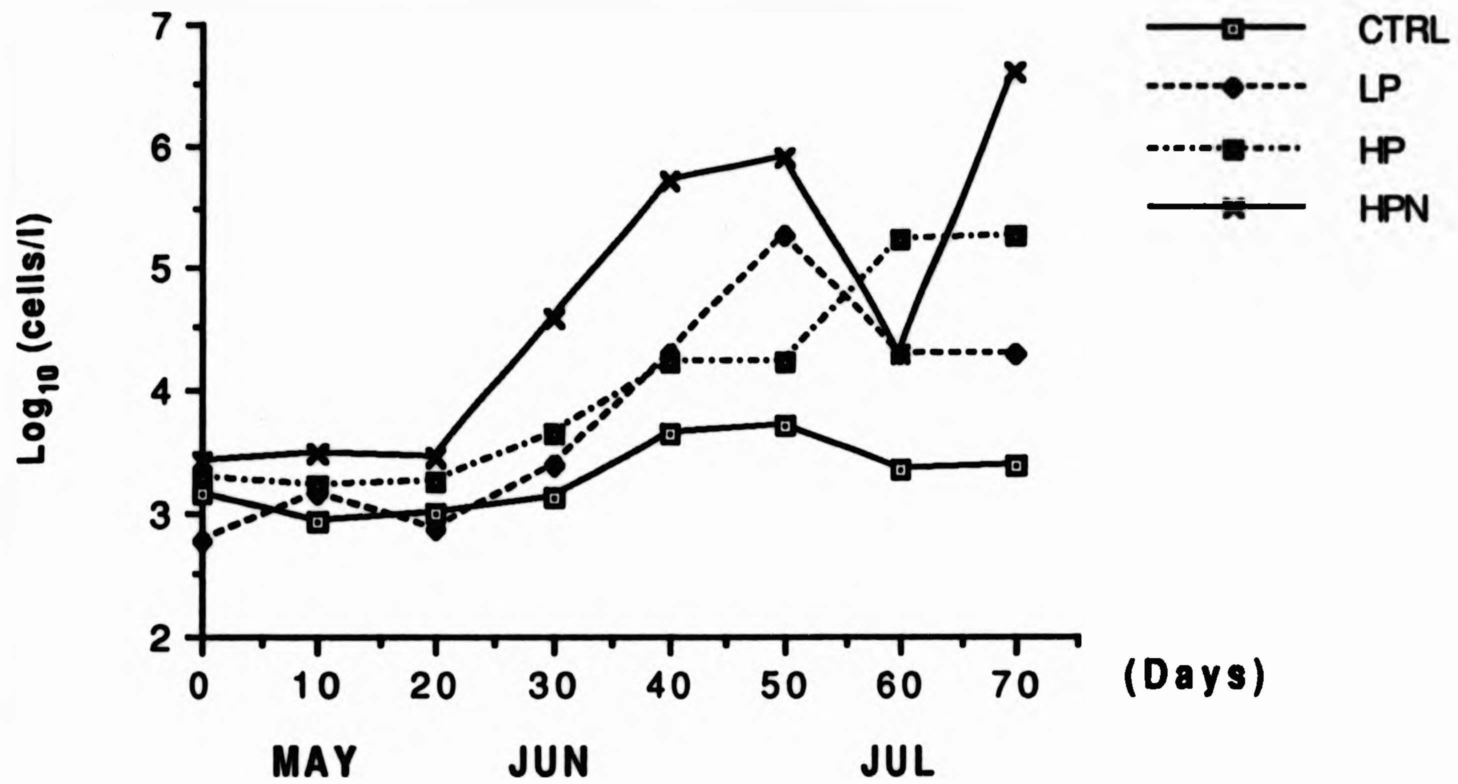
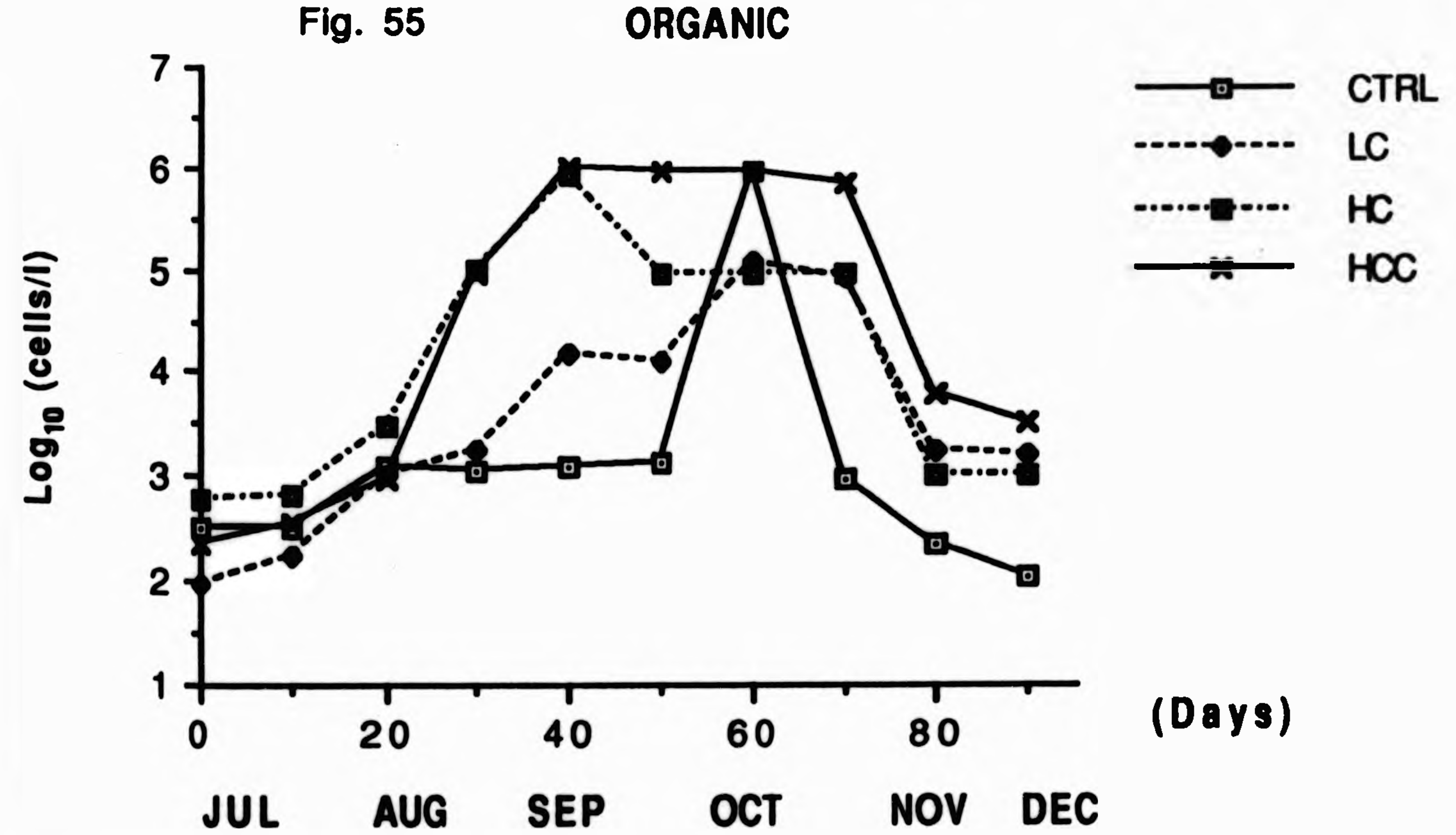


Fig. 55 ORGANIC



Figs. 54-55. Variations in abundance of Chlorophyceae during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.3.1.3. CYANOPHYCEAE

Figures 56 and 57 show the variations in the total population during inorganic and organic fertilization respectively. In both fertilization trials, dominant genera encountered were *Anabaena sp*, *Microcystis sp*, (mainly the two cell colonies) and *Oscillatoria sp*. In the inorganic fertilization, two peaks of abundance recorded were 30.0×10^3 cells l^{-1} (mainly represented by *Oscillatoria sp*) and 5.1×10^6 cells l^{-1} (represented by *Oscillatoria,* and *Anabaena spp*) in the LP and HPN respectively. Comparatively, three peaks observed during the the organic fertilization were 9.6×10^4, 9.3×10^5 and 1.10×10^6 cells l^{-1} in LC, HC and HCC respectively, with *Ocillatoria, Anabaena* and *Microcystis sp* constituting the bulk of the population. Response pattern to additional manuring after the population crash was minimal. HC and HCC produced similar levels of Bacillariophyceae, Chlorophyceae and Cyanophyceae.

Fig. 56

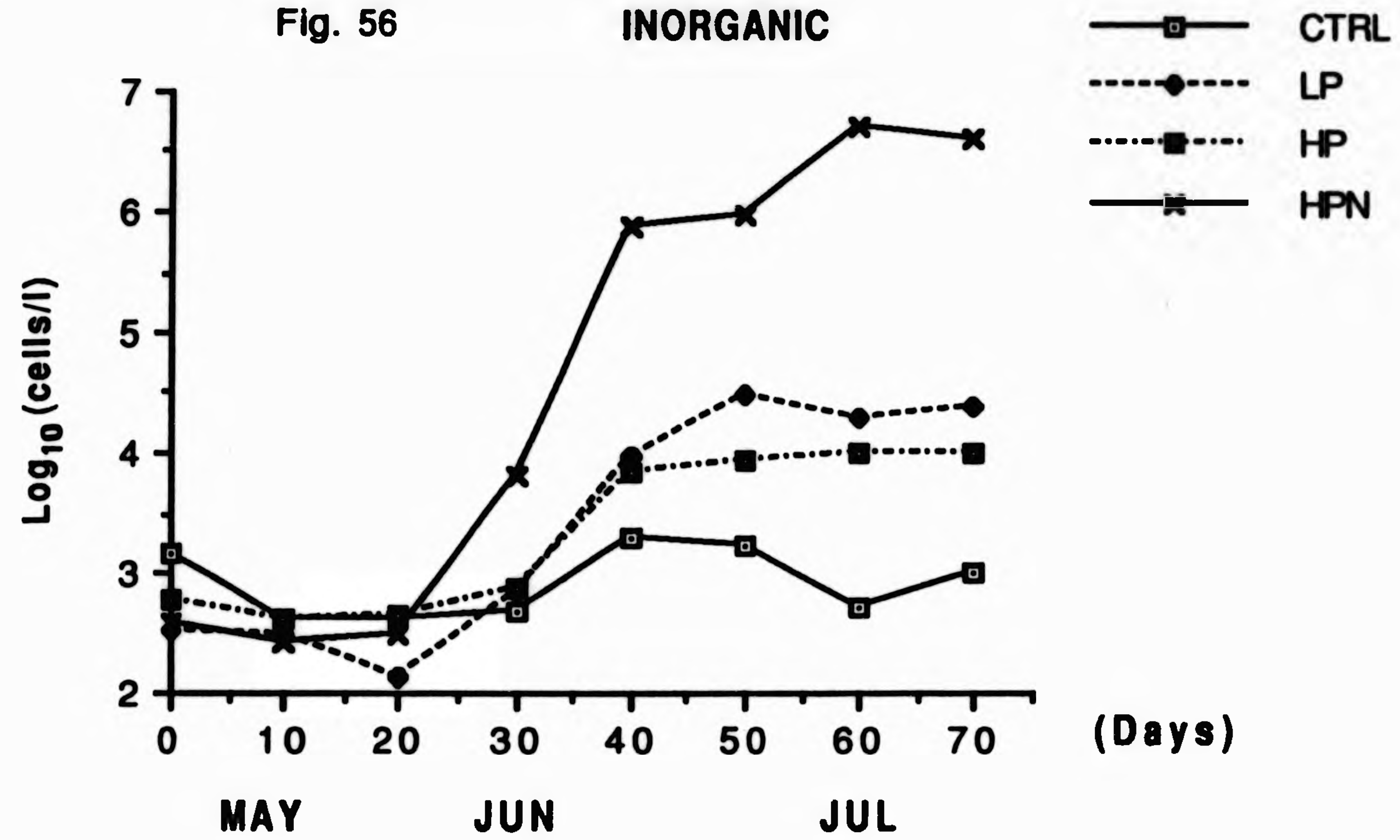
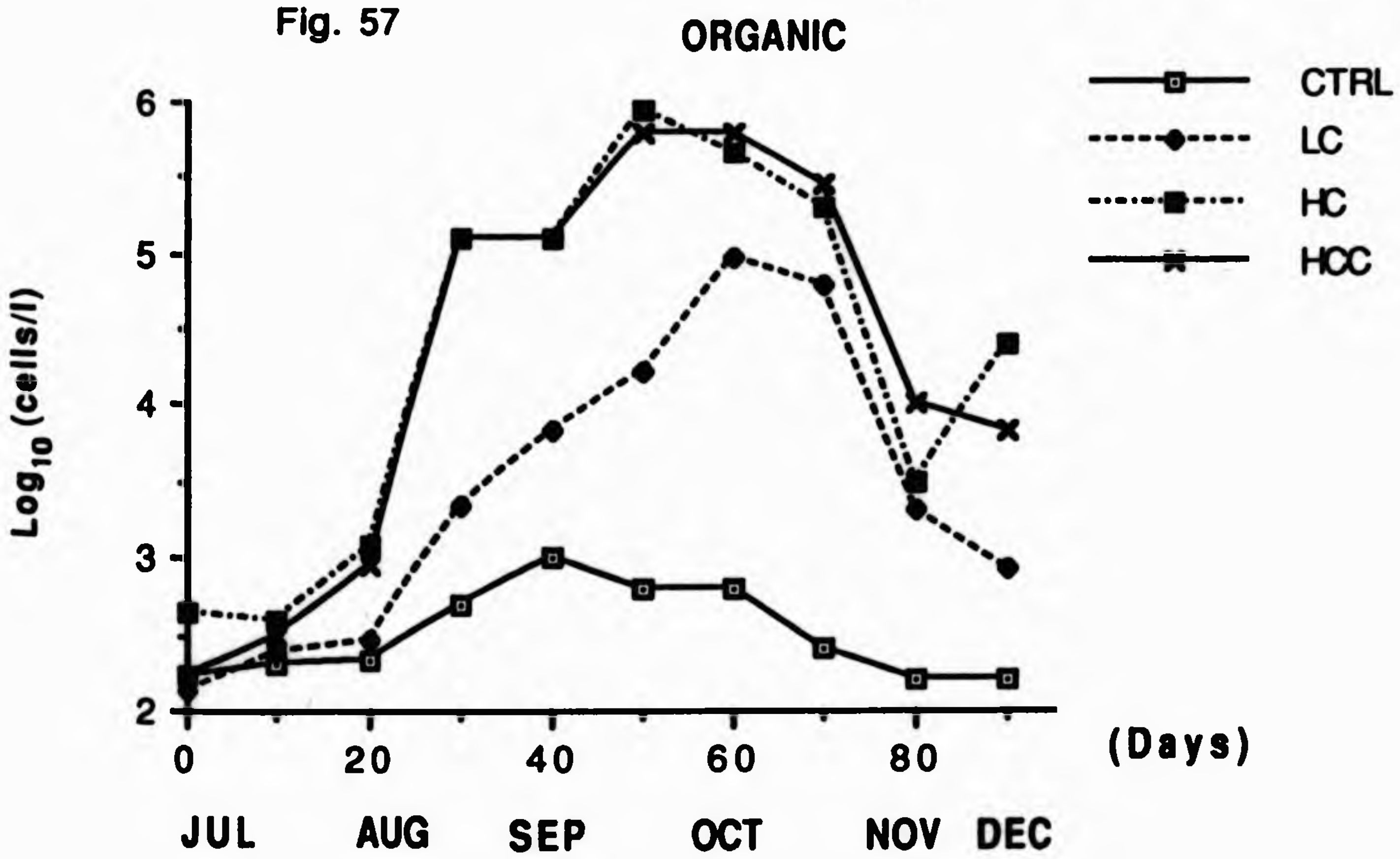


Fig. 57



Figs. 56-57. Variations in abundance of Cyanophyceae during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

4.3.1.4 DINOPHYCEAE

The variations for inorganic and organic fertilization are presented in Figs. 58 & 59 respectively. All four treatments in the inorganic fertilization showed an upsurge in Dinophyceae abundance after the 1st week (27/5/88) of fertilization, with a peak value of 3.2×10^4 cells l^{-1} in HPN treatment (Figure 58), but the treatment means were not significantly different (Table 13).

Comparatively, the abundance under organic fertilization was higher, with peak value of 5.11×10^4 cells l^{-1} in the HCC treatment. All the treatment means were significantly different from the control (Table 14). In general, the response pattern was consistent with increasing organic fertilizer dosage; although, they appeared to thrive well in CTRL or 'oligotrophic' condition compared with other groups. Dominant Dinophyceae genera were *Ceratium sp*, *Chrysococcus sp* and *Dynobryon sp*.

Fig. 58 INORGANIC

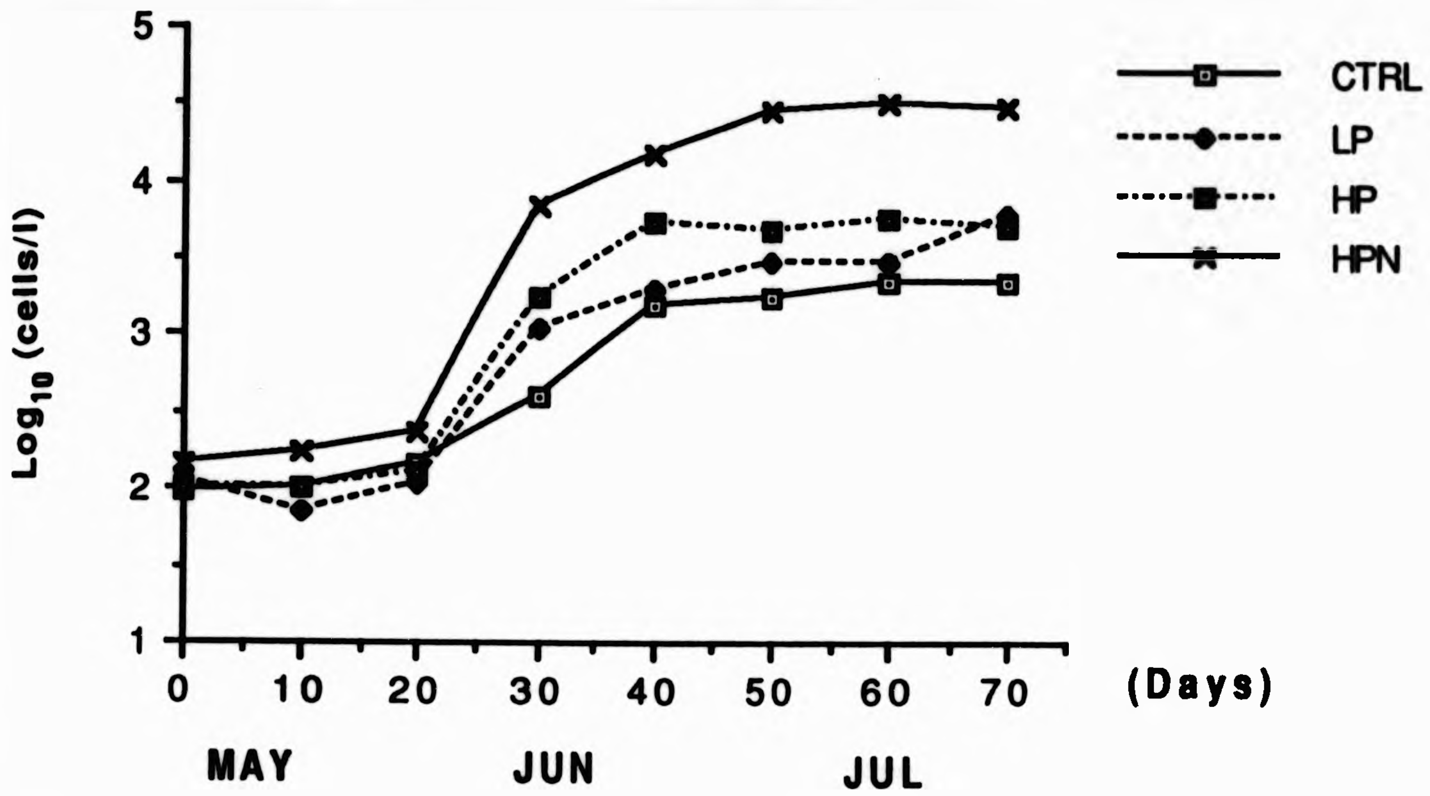
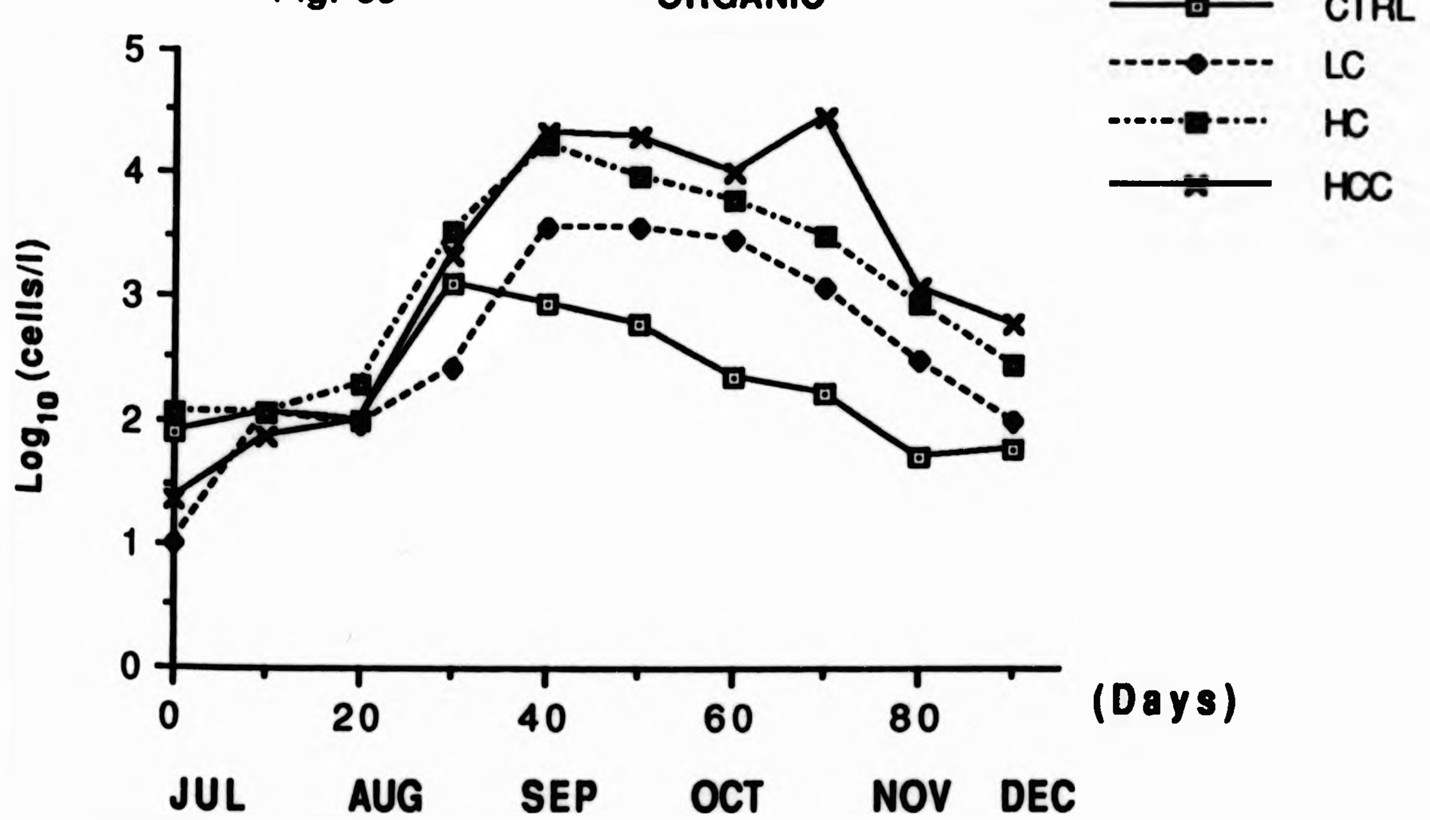


Fig. 59 ORGANIC



Figs. 58-59. Variations in abundance of Dinophyceae during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

TABLE 12 F-Values and their associated levels of significance for two-way ANOVA on geometric means of phyto- and zooplankton during inorganic and organic fertilization without fish. (*, ** refer to *P* levels of ≤ 0.05 and ≤ 0.01 respectively, NS=not significant).

	INORGANIC		ORGANIC	
	SOURCE OF VARIATION		SOURCE OF VARIATION	
	Between ponds	Between periods	Between ponds	Between periods
PHYTOPLANKTON GROUP				
Bacillariophyceae	3.62 *	2.63 *	3.75 *	2.58 *
Chlorophyceae	8.36 **	5.28 **	2.93 *	2.01 NS
Cyanophyceae	2.92 *	11.3 **	4.95 **	3.86 *
Dinophyceae	4.53 **	1.83 NS	2.61 *	0.95 NS
ZOOPLANKTON GROUP				
Cladocera	5.18 **	2.91 *	8.72 **	3.01 *
Copepoda	3.72 *	2.70 *	7.33 **	1.83 NS
Rotifera	8.68 **	6.31 **	3.55 *	2.93 *

TABLE 13 Overall mean abundance of phyto- and zooplankton groups at varying inorganic fertilization levels, without fish. (Mean values in the same row bearing the same superscripts are not significant different at $\underline{P}$=0.05).

	TREATMENTS			
	CTRL	LP	HP	HPM
PHYTOPLANKTON GROUP (x 10^4)				
Bacillariophyccae	0.33 ± 0.10^a	1.62 ± 0.58^b	1.54 ± 0.49^b	39.8 ± 15.5^c
Chlorophyceae	0.24 ± 0.10^a	3.10 ± 2.19^b	4.93 ± 2.76^b	120 ± 65.6^c
Cyanophyceae	0.08 ± 0.02^a	1.06 ± 0.44^c	0.47 ± 0.16^c	135 ± 17.8^d
Dinophyceae	0.12 ± 0.04^a	0.19 ± 0.07^a	0.29 ± 0.09^a	0.42 ± 0.51^a
Total	0.78 ± 0.25^a	5.91 ± 2.79^b	7.23 ± 3.46^b	295 ± 97.8^c
ZOOPLANKTON GROUP (x 10^3)				
Cladocera	0.21 ± 0.06^a	6.90 ± 2.53^b	13.5 ± 2.45^b	21.9 ± 3.98^b
Copepoda	0.17 ± 0.05^a	4.23 ± 1.60^b	4.01 ± 1.67^b	7.39 ± 2.55^b
Rotifera	0.33 ± 0.07^a	8.25 ± 3.15^b	13.5 ± 3.32^c	19.4 ± 3.50^c
Total	0.71 ± 0.19^a	19.4 ± 4.98^b	32.0 ± 6.80^{bc}	48.7 ± 10.1^c

TABLE 14 Overall mean abundance of phyto- and zooplankton groups at varying organic fertilization levels, without fish. (Mean values in the same column bearing the same superscripts are not significant different at $\underline{P}$=0.05).

	TREATMENTS			
	CTRL	LC	HC	HCC
PHYTOPLANKTON GROUP				
(x 10^4)				
Bacillariophyceae	0.17 ± 0.04^a	2.62 ± 1.19^a	7.17 ± 1.38^b	10.8 ± 2.74^b
Chlorophyceae	0.09 ± 0.02^a	2.30 ± 0.44^b	12.2 ± 9.23^c	35.6 ± 15.8^c
Cyanophyceae	0.04 ± 0.01^a	1.86 ± 0.17^b	28.2 ± 1.44^b	26.3 ± 2.3^b
Dinophyceae	0.04 ± 0.02^a	0.13 ± 0.01^b	0.39 ± 0.09^c	1.06 ± 0.18^d
Total	0.30 ± 0.09^a	6.94 ± 1.90^b	48.0 ± 12.3^c	74.1 ± 18.9^c
ZOOPLANKTON GROUP				
(x 10^3)				
Cladocera	0.05 ± 0.001^a	5.32 ± 1.71^b	43.7 ± 13.6^c	51.7 ± 15.1^c
Copepoda	0.01 ± 0.002^a	1.38 ± 1.01^a	33.8 ± 8.31^b	22.1 ± 6.49^b
Rotifera	0.05 ± 0.01^a	3.27 ± 0.25^b	36.9 ± 14.2^c	42.9 ± 16.9^c
Total	0.12 ± 0.0^a	9.97 ± 2.89^b	115 ± 35.3^c	117 ± 39.8^c

4.3.2. ZOOPLANKTON COMPOSITION

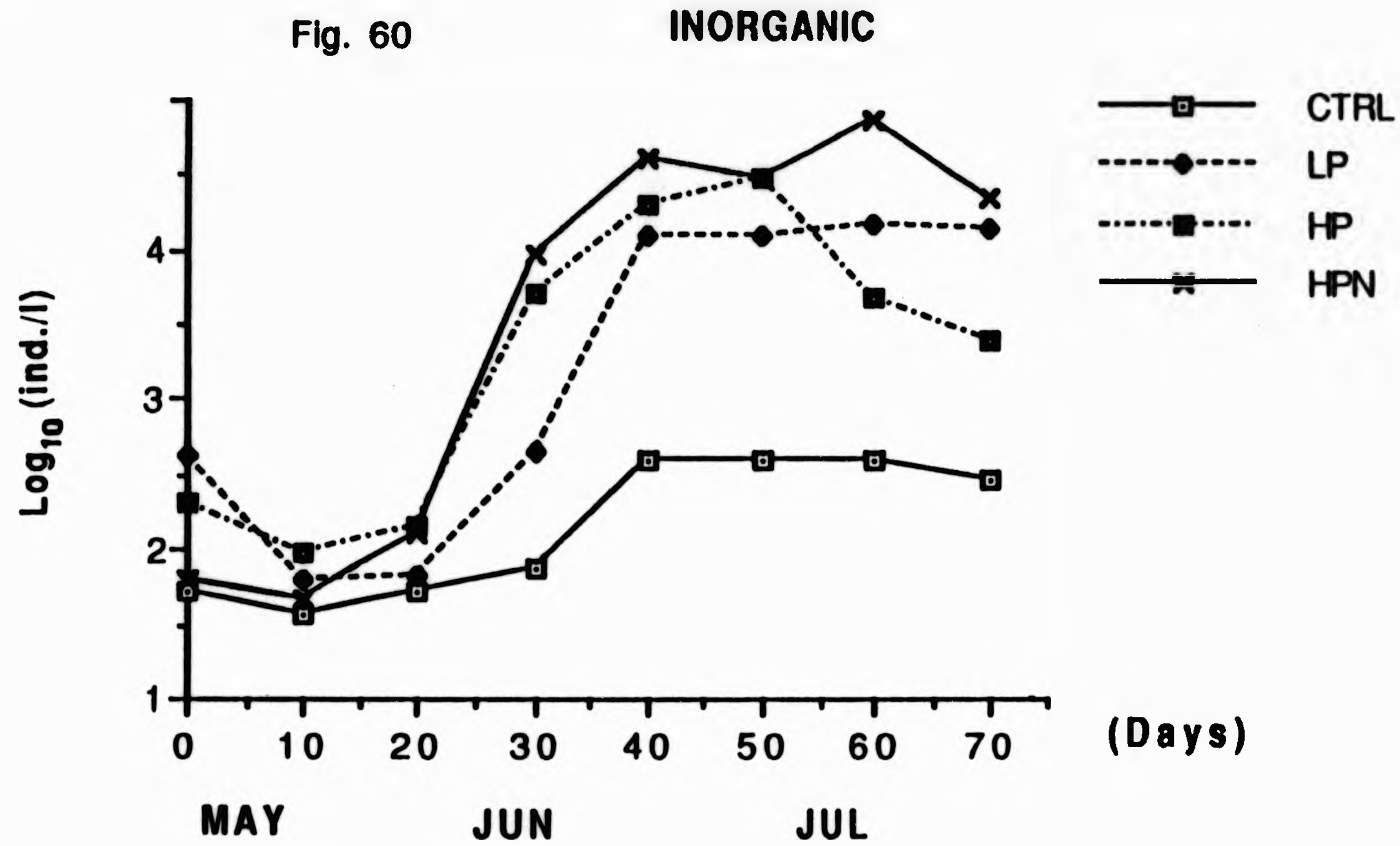
The dominant groups encountered in both fertilizations were Cladocera, Copepoda and Rotifera, with Cladocera and Rotifera appearing to be the leading groups. In contrast to phytoplankton abundance, the zooplankton response to organic fertilization was greater, particularly in the Cladocera and Rotifera groups. This difference might not be unrelated to the role of organic manure as a good source of carbon and bacteria, utilized by the zooplankton.

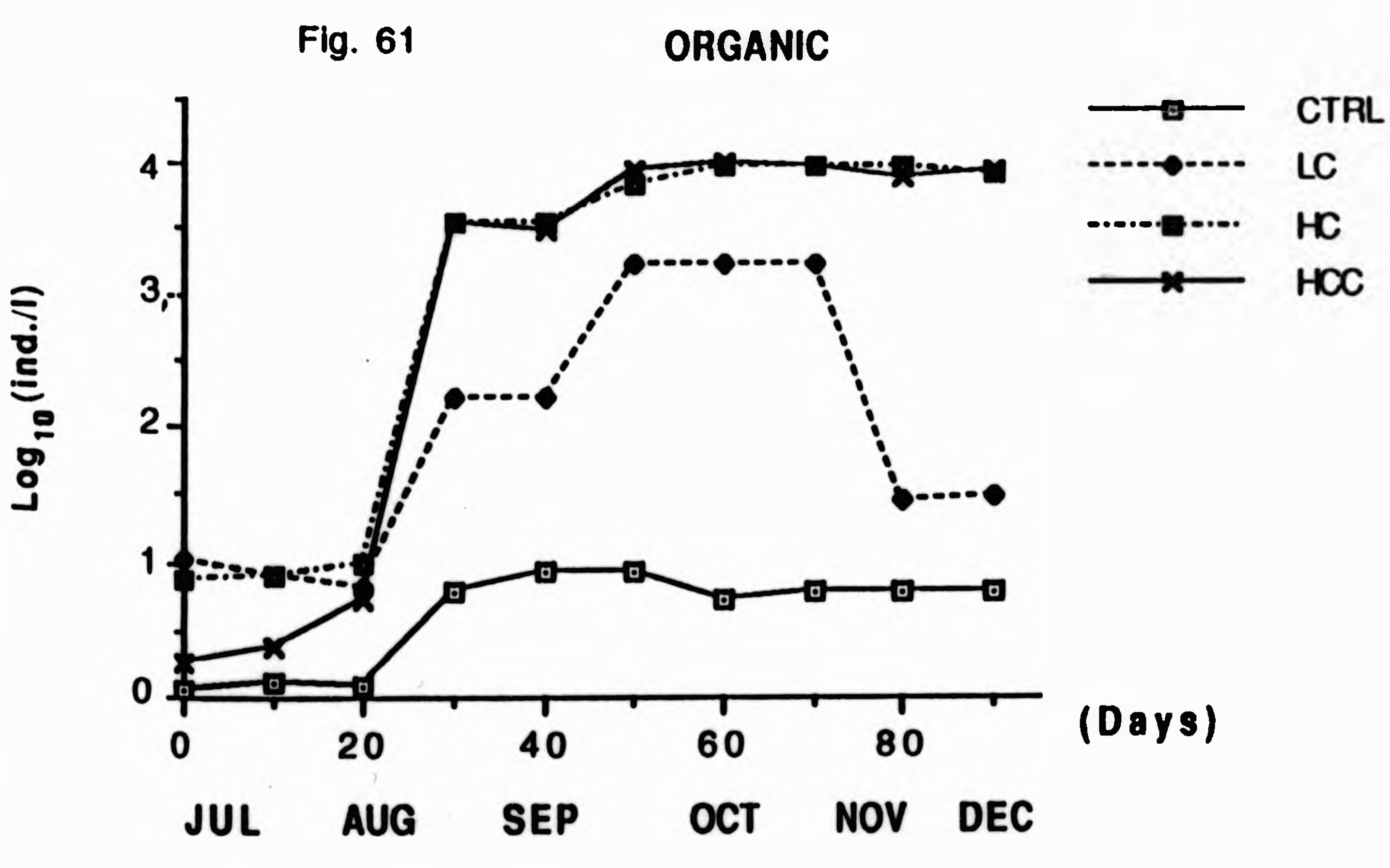
4.3.2.1 CLADOCERA

This group dominated the total zooplankton abundance. In the inorganic (Figure 60) and organic (Fig. 61) fertilization, peak abundance was 7.2 and 11×10^3 ind.l^{-1} in the HPN and HCC treatments respectively. Table 13 also shows significant response in all inorganic treatments while Table 14 shows significant incease with LC , and even greater with HC and HCC. During both fertilizations, dominant genera encountered were *Daphnia sp* and *Bosmina sp*.

4.3.2.2 ROTIFERA

This is the second largest group contributing to the total zooplankton abundance. In Fig. 62 which represents variations during inorganic fertilization, two abundance maxima of 7.0×10^3 ind.l^{-1} occured in the HPN and HP and both the treatment means were significantly greater than LP and control (Table 13). Organic fertilization showed the same pattern of treatment differences. *Brachionus sp* formed the dominant genera encountered.





Figs. 60-61. Variations in abundance of Cladocera during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

Fig. 62 INORGANIC

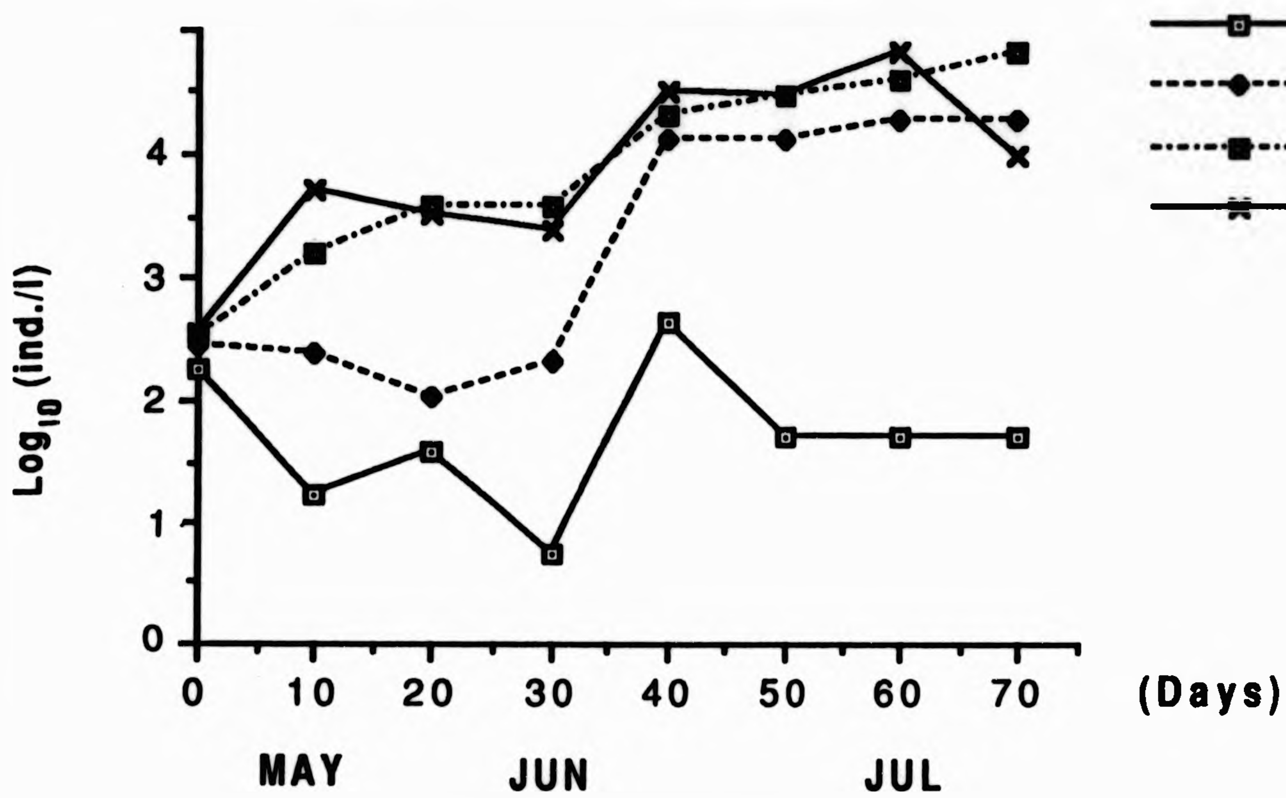
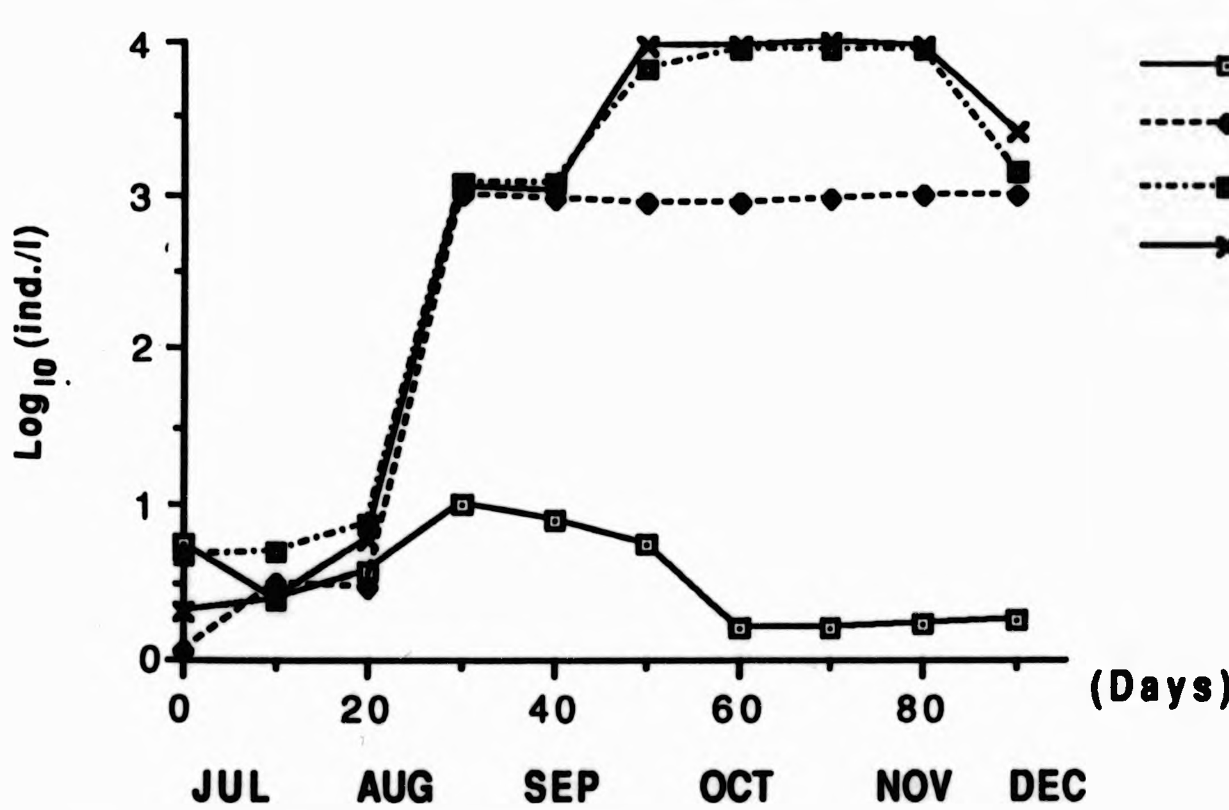


Fig. 63 ORGANIC



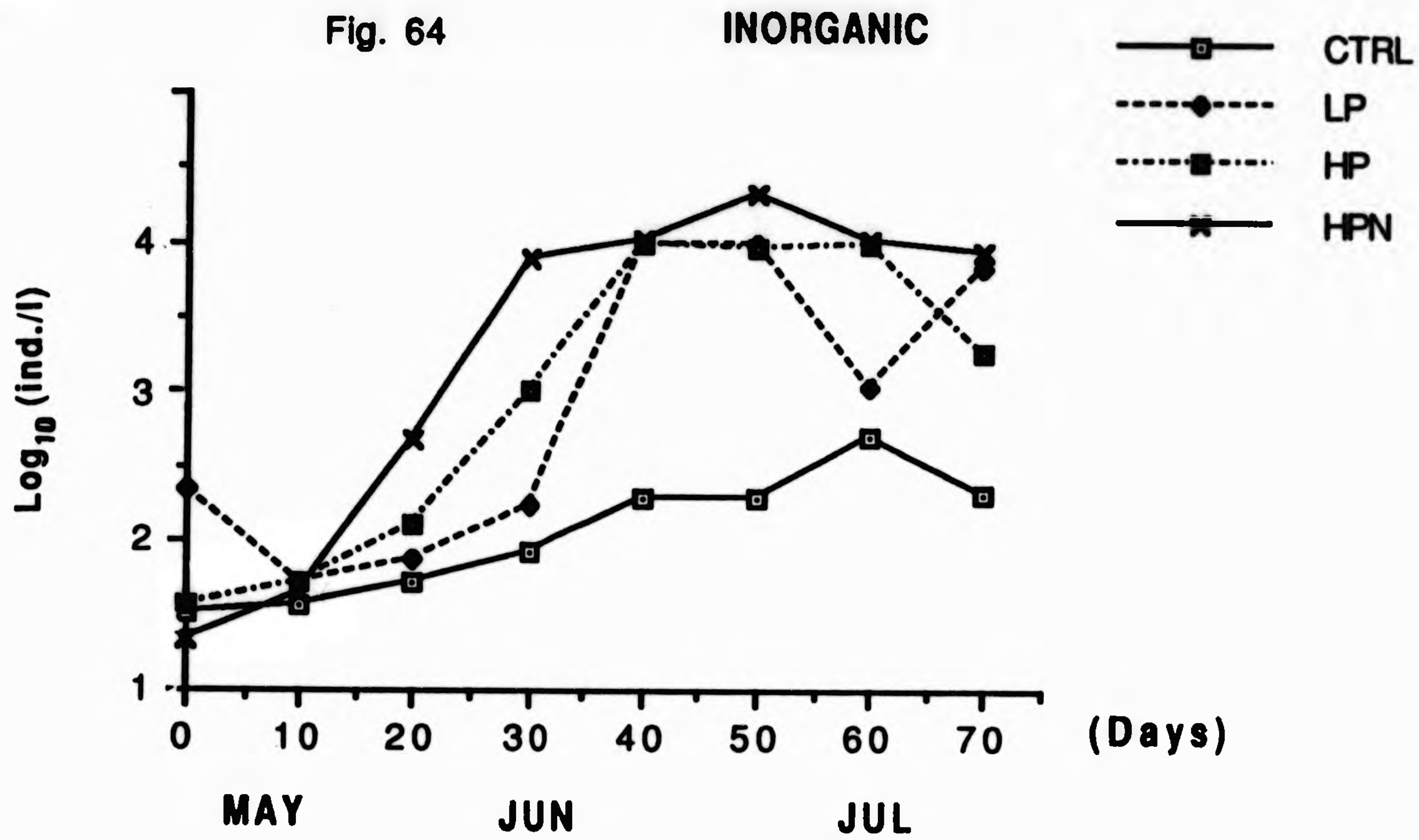
Figs. 62-63. Variations in abundance of Rotifera during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

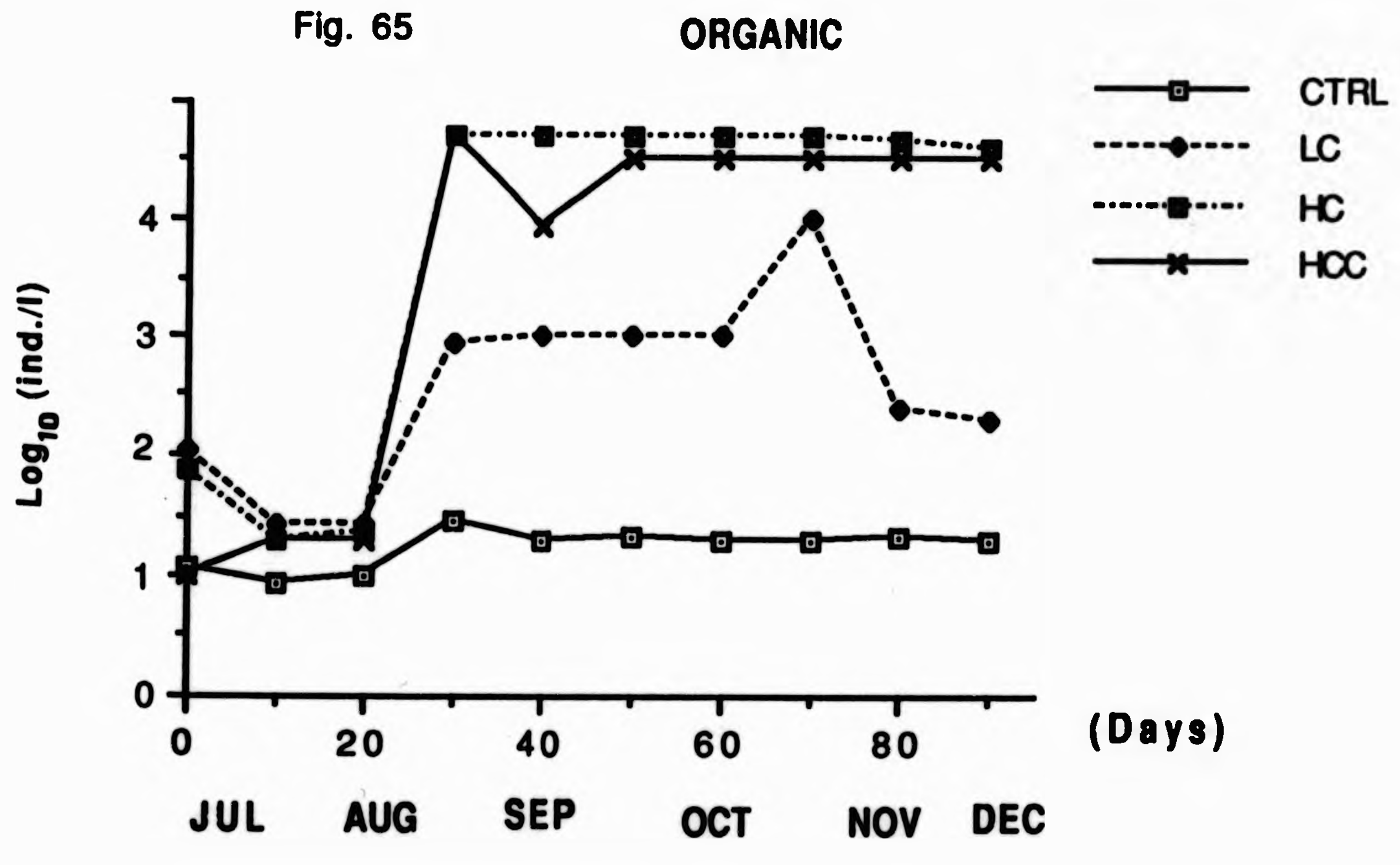
4.3.2.3 COPEPODA

In both fertilization programmes, this group accounts for the least population abundance as shown in Tables 13 & 14. In the inorganic fertilization, even after the first application, there was a decline in abundance in the LP, HP and HPN treatments. This was followed by a gradual increase, attaining peak values of 9.8, 21.1 and 10.0 x 10^3 ind.l^{-1} respectively. Organic fertilization (Figure 65) showed two peak abundance of 5.21 x 10^4 ind.l^{-1} and 4.98 x 10^4 ind.l^{-1} in HCC and HC respectively. The HC treatment however, remained unresponsive to additional manuring between the priods 8/9/88 - 7/12/88. The dominant genera encountered were *Cyclopoida sp*, *Diaptomus sp* and copepod nauplii.

4.4 GROWTH OF AQUATIC MACROPHYTES

The distribution and abundance of various aquatic macrophytes groups in the experimental ponds is summarised in Table 15. Throughout both fertilization trials, pond 2 which was treated with HP and HCC during the respective





Figs. 64-65. Variations in abundance of Copepods during inorganic and organic fertilization, without fish. (Key is as explained in caption to Figs. 4-5).

inorganic and organic trials, had the most abundant macrophytes with *Elodea canadensis, Lemna minor, Glyceria fluitans* and *Alisma plantago-aquatica* dominating. The development of all macrophyte groups in the ponds was more pronounced in August. Throughout the fertilization period, no attempt was made to control the aquatic macrophytes by chemical method, as this may have interfered with the development of plankton and macroinvertebrates being assessed.

Prior to commencement of fish culture, however, macrophytes were cut down using the Strimmer, Kawasaki model TD 33, but re-emergence was observed about 3 months into the culture cycle, despite termination of fertilization the previous year. Macrophyte development probably had some impact on dynamics of nitrate, phosphorus and D.O. during both fertilization and fish culture trials. Similarly, the young macrophytes which are succulent and less fibrous, and decay faster when composted, appeared to provide a good source of carbon and substratum with a high three dimensional surface area for development of epiphytic algae, on which macroinvertebrates such as molluscs and *Asellus* feed. The CTRL pond No. 8 which was used for fish culture showed little response to macrophyte colonization, probably due to its greater depth than the other ponds.

TABLE 15 Distribution and relative abundance index of aquatic macrophytes in the experimental ponds.

	PONDS							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Alisma plantago-aquatica (L.)	+	+ + +	+	+	+	-	-	-
Elodea canadensis (Minchx)	+ +	+ + +	+ +	+ +	+ +	+	-	-
Glyceria fluitans (L.)	+	+ + +	+	+ +	+	+	+ +	-
Juncus effusus (L.)	-	+ +	+ +	+	+	-	-	-
Lemna minor (L.)	+	+ + +	+	+	-	+	+	+
Myosotis scorpioides (L.)	-	+ +	+	+ +	+ + +	-	-	+
Typha latifolia (L.)	-	+ +	+	-	-	+	+	+

(-) = Absent, (+) = not abundant, (+ +) = abundant, (+ + +) = Very abundant.

4.5 MACROINVERTEBRATES ABUNDANCE, BIOMASS AND PRODUCTION

The responses to organic fertilization by the macroinvertebrate groups are presented in Figs. 66-75, while a comparison of annual production for the various benthos groups is presented in Table 18. The principal groups considered were Asellidae, Chironomidae, Hirudinea, Mollusca, Oligochaeta and Sialidae. Analysis of variance on log transformed data used for comparing benthos abundance between ponds and periods and between treatments, respectively showed significant differences ($P < 0.01$) between ponds receiving high chicken and cow manure, probably influenced by differences in particle size distribution and macrophyte abundance. Initial response of benthos development following first fertilization was slow.

4.5.1. OLIGOCHAETA

The Oligochaeta which made the largest contribution to total benthos was represented by *Tubifex sp*, *Lumbriculus sp* and *Limnodrilus sp*. Results of the treatment effects showed significant differences (P< 0.01) between the ponds (Table 16), with HC and HCC having the highest overall mean values. A summary of mean population biomasses, annual production and P/B ratios are presented in Table 18.

4.5.1.1 *Tubifex sp.*

This constitutes the commonest genus in the total Oligochaeta and benthos. Response to fertilization was evident after the 5th week (8/8/88) followed by a steady increase, attaining peak population density of 20.0 x 10^4 m^{-2} in the HCC treatment (Figure 66). The annual production was 349.3 g dry $wt.m^{-2}$ yr^{-1} and a P/B ratio of 0.57. However, the control pond had a higher P/B ratio of 0.70 than all the other treatments (Table 18).

4.5.1.2 *Lumbriculus sp.*

This constituted 12% of total oligochaetes in the ponds, with a peak population density of 10,015 $ind.m^{-2}$ in the HCC

Figs. 66-68. Variations in abundance of *Tubifex sp.*, *Lumbriculus sp.* and *Limnodrilus sp.* at varying organic fertilization levels, without fish. (Key is as explained in caption to fig. 5).

Fig. 66 *Tubifex sp.* (OLIGOCHAETA)

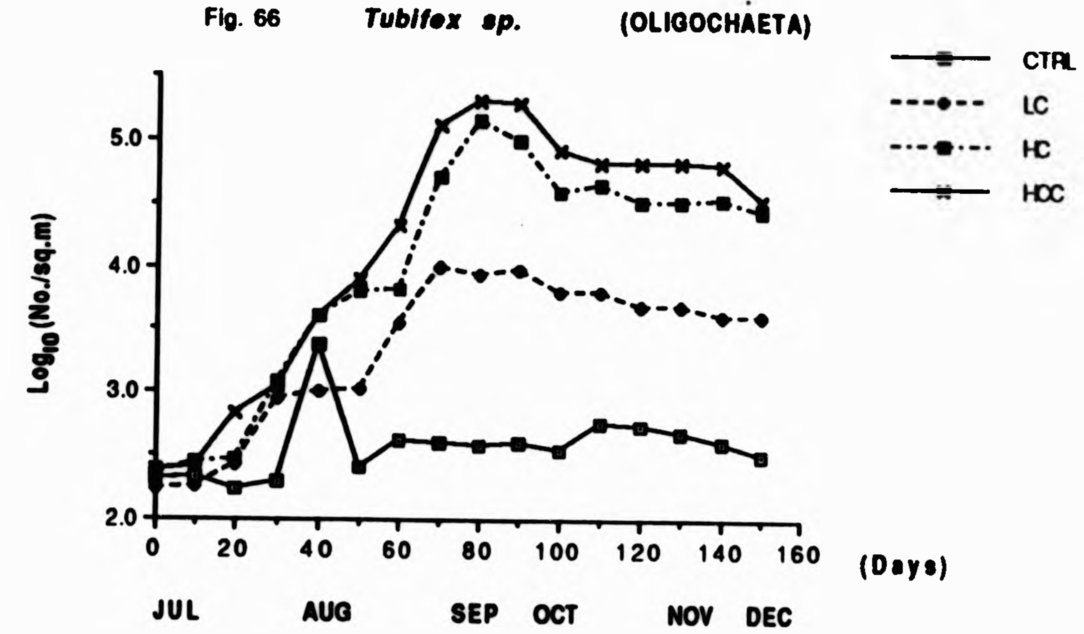


Fig. 67 *Lumbriculus sp.* (OLIGOCHAETA)

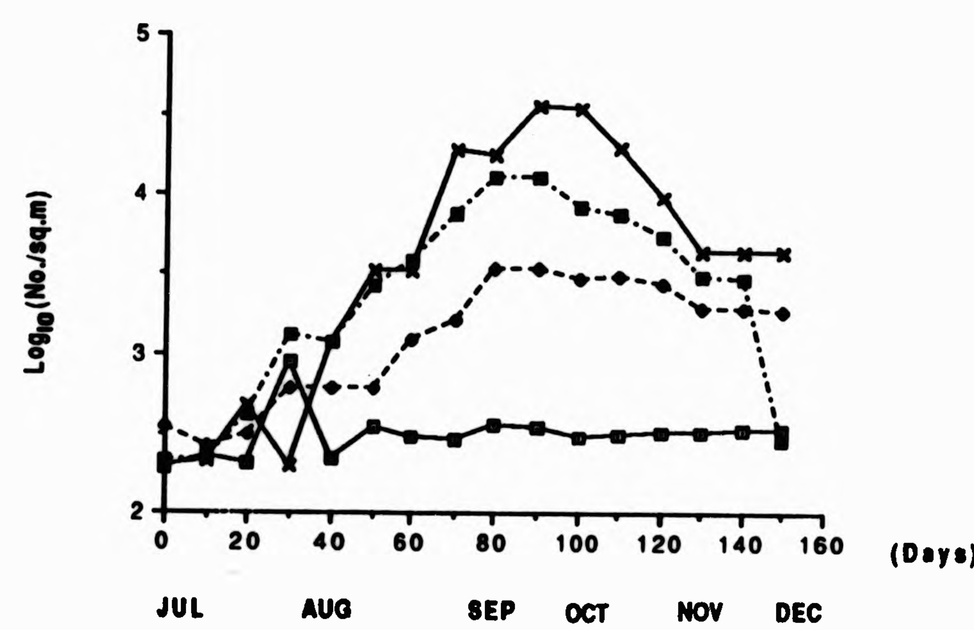
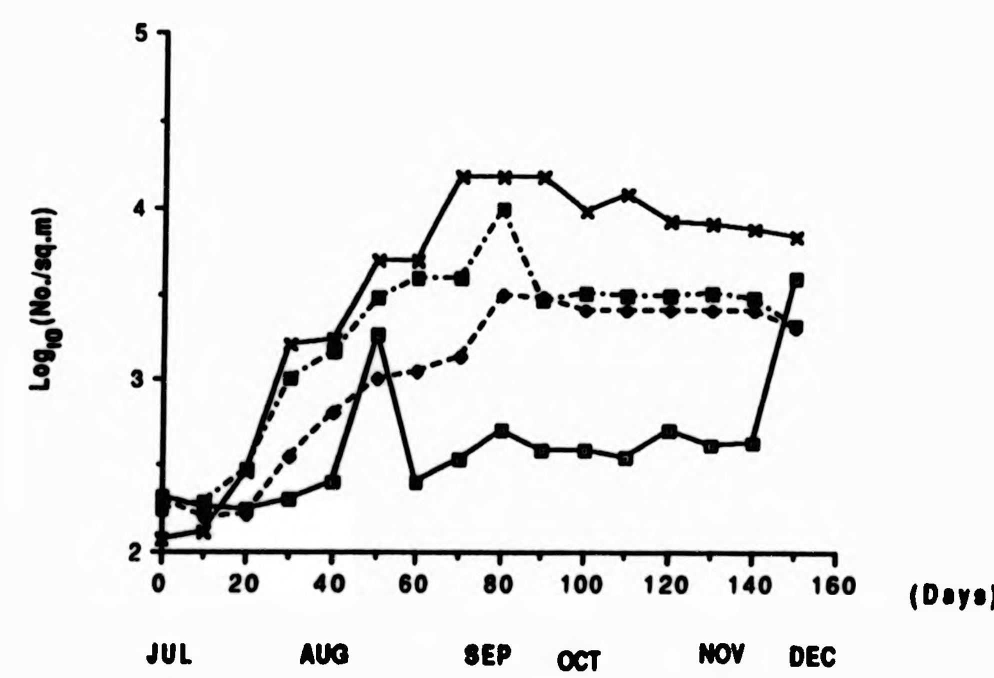


Fig. 68 *Limnodrilus sp.* (OLIGOCHAETA)



treatment (Figure 67). Table 16 shows that the variation between ponds was highly significant ($P<0.01$, ANOVA). The HCC treatment had the highest annual production of 209.6 g.dry wt.$m^{-2}yr^{-1}$.

4.5.1.3 *Limnodrilus sp.*

This made the least contribution of 6.0%. Throughout the fertilization trial, variations in total abundance followed an intermittent pattern (Figure 68). Despite the high annual production of 234.3 and 141.9 g.dry wt.$m^{-2}yr^{-1}$ in HCC and HC respectively, the LC treatment had the highest P/B ratio of 0.55 (Table 18).

4.5.2 CHIRONOMIDAE

Figure 69 shows the variations in *Chironomus sp* at different organic fertilization levels. There was an initial low response to fertilization,, but this was followed by rapid upsurges in the LC, HC and HCC treatments, with peak population densities of 1.1, 5.5 and 7.6 x 10^3 $ind.m^{-2}$ respectively. Although the annual production rates of 7.2, 20.7, 39.9 and 47.5 g dry $wt.m^{-2}yr^{-1}$ in the CTRL, LC, HC and HCC respectively were lower than those of the Oligochaeta and Asellidae, it had a higher P/B ratio. (Table 18).

Comparison of density distribution indexes of Chironomidae in the various treatments (Table 19) showed a more contagious distribution in the CTRL and HC ponds, unlike LC and HCC which had an even or regular distribution. In contrast with Asellidae, the *Chironomus sp* showed preference for muddy substrata of pond 1 (HCC) which had virtually no vegetation cover.

Fig. 69 ***Chironomus sp.*** **(CHIRONOMIDAE)**

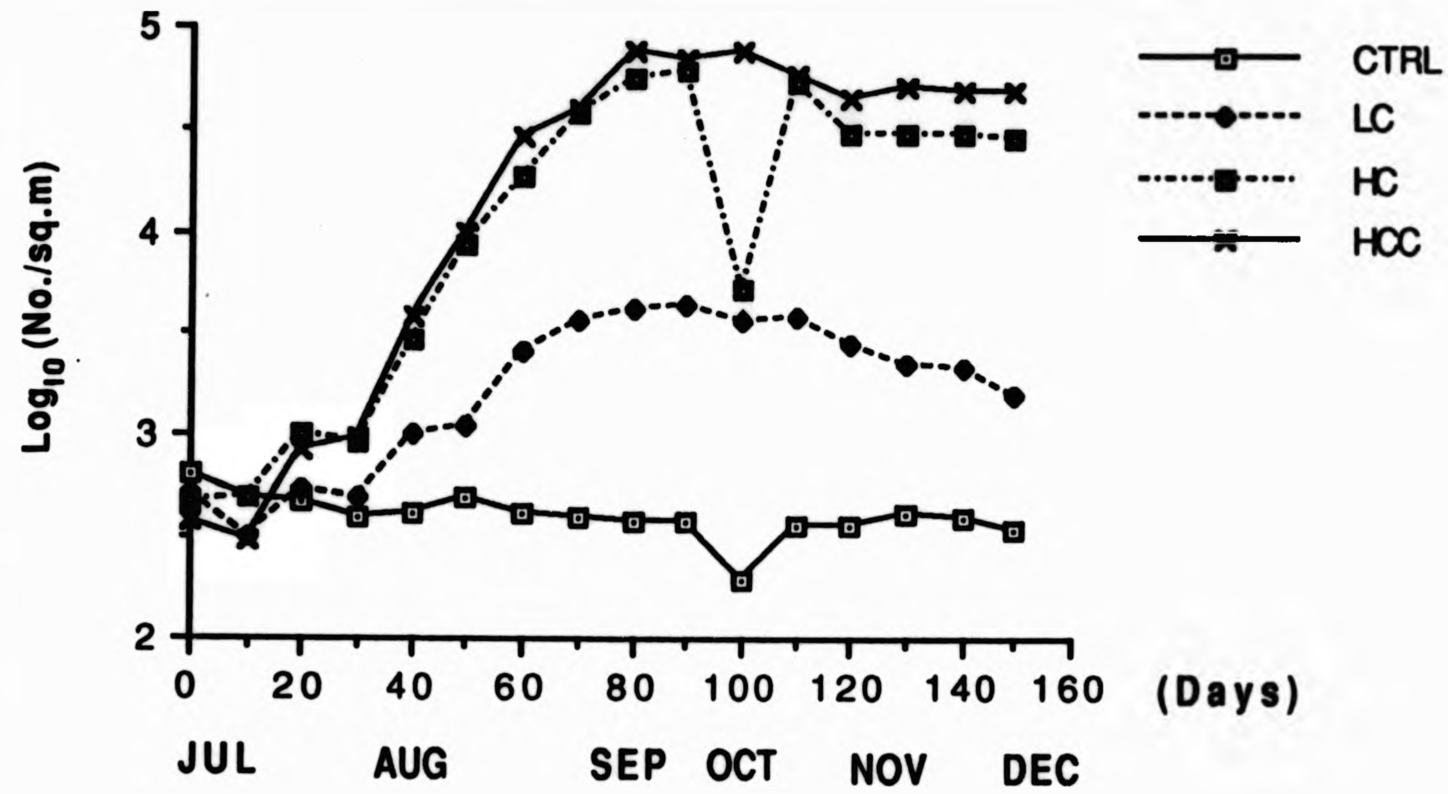
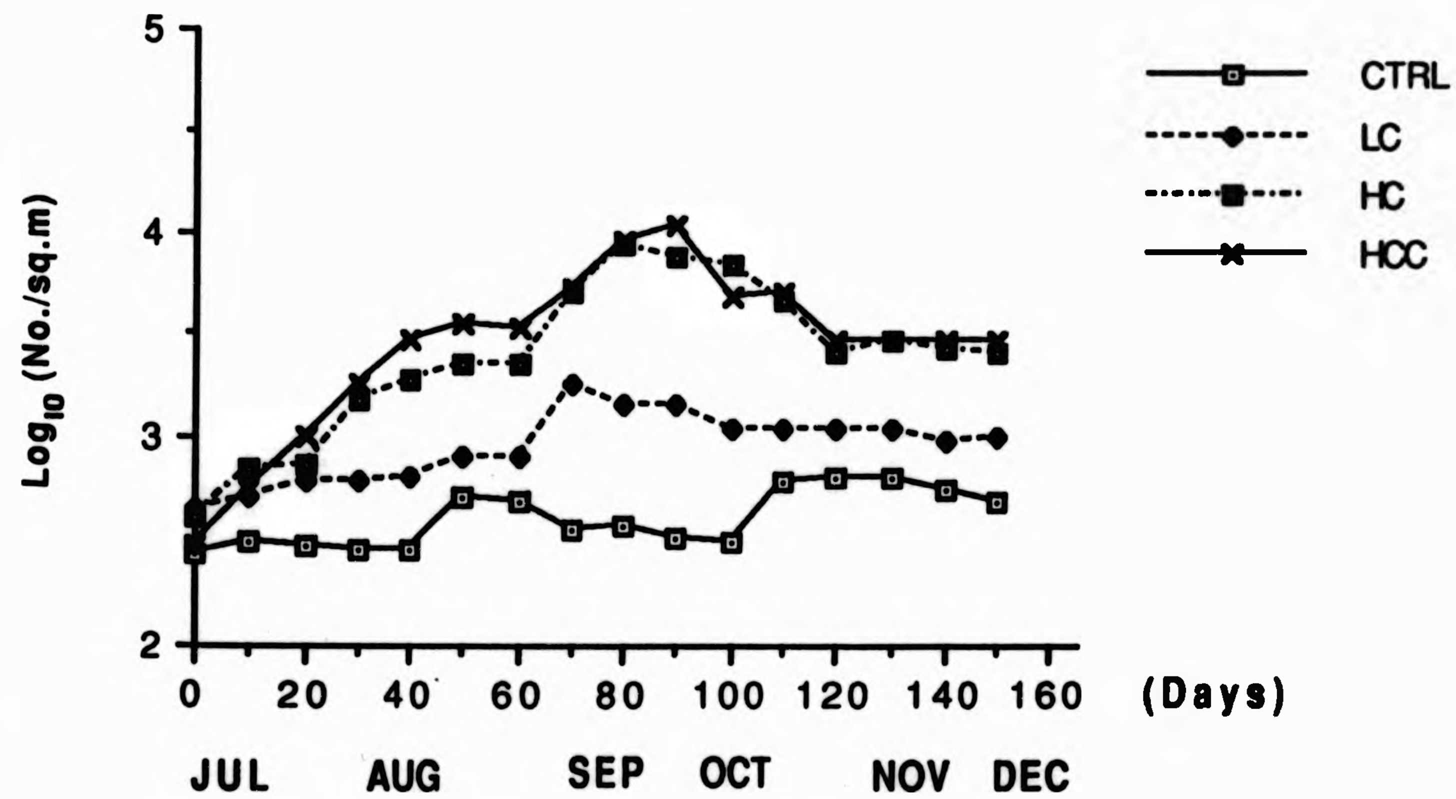


Fig. 70 ***Asellus aquaticus*** **(ASELLIDAE)**



Figs. 69-70. Variations in abundance of *Chironomus sp* and *Asellus aquaticus* at varying organic fertilization levels, without fish. (Key is as explained in caption to fig. 5).

4.5.3 ASELLIDAE

This was represented mainly by *Asellus aquaticus*. Two abundance maxima of 8.8 and 10.9 ind. m^{-2} in HC and HCC respectively was followed by intermittent decline as shown in Figure 70. Annual production shown in Table 18 was consistent with fertilization treatments in the ponds. The dispersion index (Table 19) showed an even distribution of *A. aquaticus* in CTRL, LC and HCC, compared to the HC treatment which had a random distribution. Similarly, the HC showed significant difference ($P<0.05$) in abundance between ponds, possibly due to differences in particle size (pond 4 had more coarse soils/stones than pond 5) which played an important role in stimulating benthos production.

4.5.4 SIALIDAE

The only representative species in this group was *Sialis lutaria* and it accounted for 2.56% of total benthos. Both HC and HCC treatments showed variable abundance and the respective mean numbers were 8,750 ind.m^{-2} and 8,912 ind.m^{-2} (Fig. 71). However, the HC treatment had the highest mean population

Fig. 71 *Sialis lutaria* (SIALIDAE)

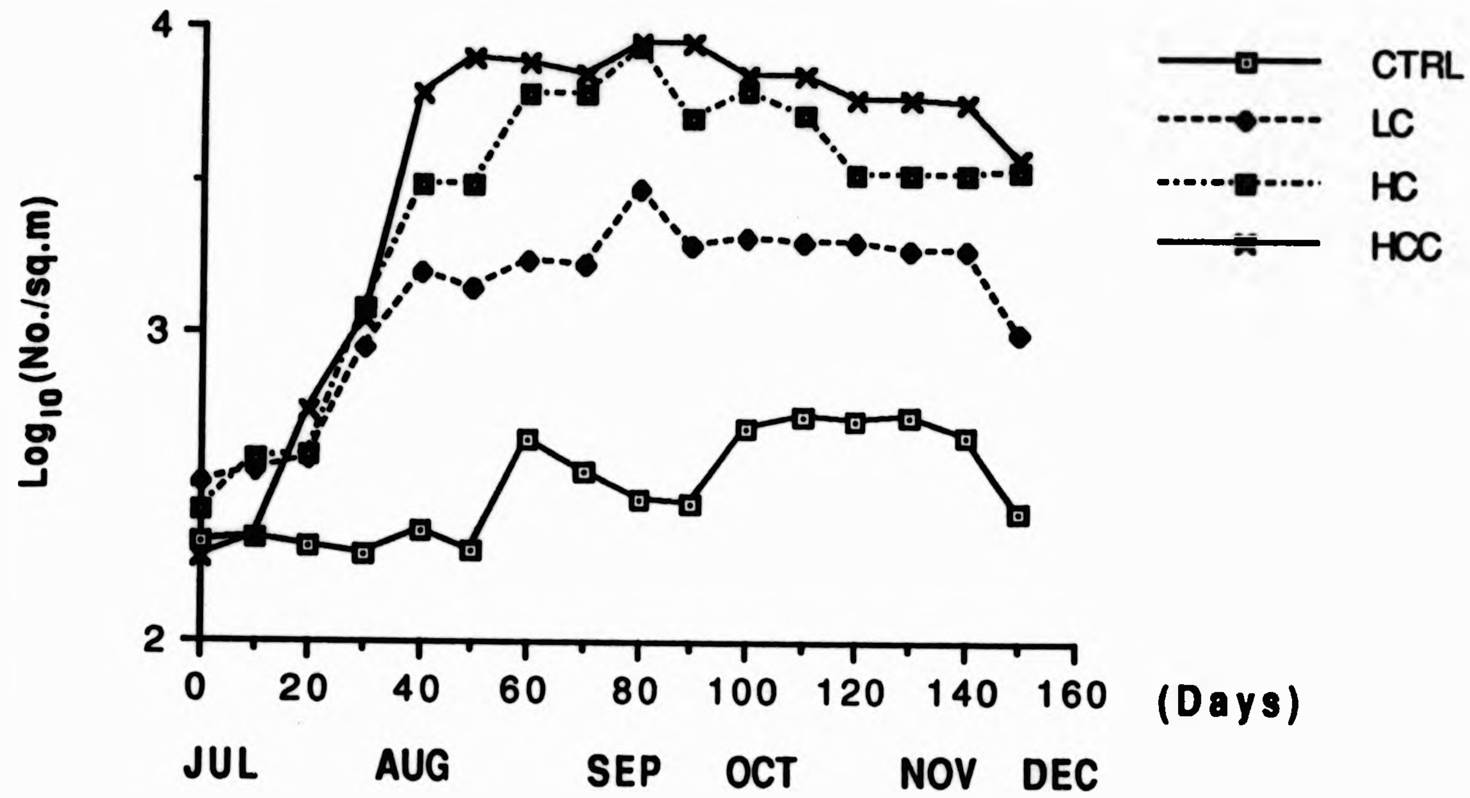
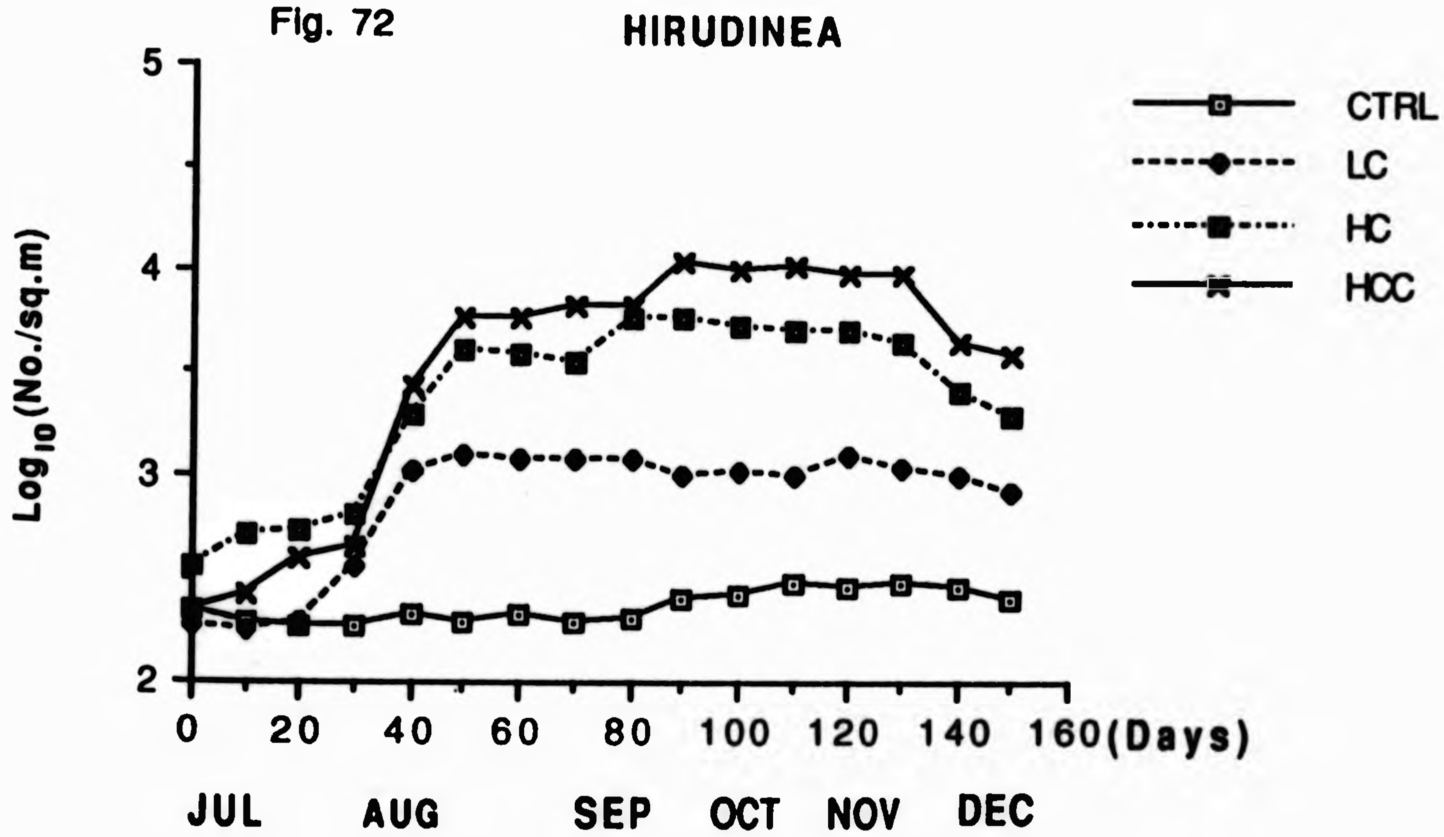


Fig. 72 HIRUDINEA



Figs. 71-72. Variations in abundance of *Sialis lutaria* and Hirudinea at varying organic fertilization levels, without fish. (Key is as explained in caption to fig. 5).

biomass of 10.8g.dry wt.m^{-2} (Table 18). Similarly to *A. aquaticus*, there was low abundance of Sialidae in pond 4 of the HC treatment, despite high manuring rate.

4.5.5 HIRUDINEA

Figure 72 shows the variations in total Hirudinea. Dominant genera were *Erpobdella* and *Helobdella sp.* Two abundance maxima of 5.8 and 10.9 x 10^3 ind.m^{-2} were observed in HC and HCC treatments respectively; though there was no significant difference between the treatment means (Table 17), compared to the control and LC.

4.5.6 MOLLUSCA

In comparison with other benthos, Mollusca made the least contribution of 1.79%. Dominant groups encountered were *Sphaerium sp, Lymnaea sp* and *Planorbis sp*, with population densities of 5.5, 6.2 and 6.9 x 10^3 ind.m^{-2} respectively, Figs. 73-75. Variations in abundance of *Planorbis sp., Lymnaea sp.* and *Sphaerium sp.* at varying organic fertilization levels, without fish. (Key is as explained in caption to fig. 5).

Fig. 73 *Sphaerium sp.* (MOLLUSCA)

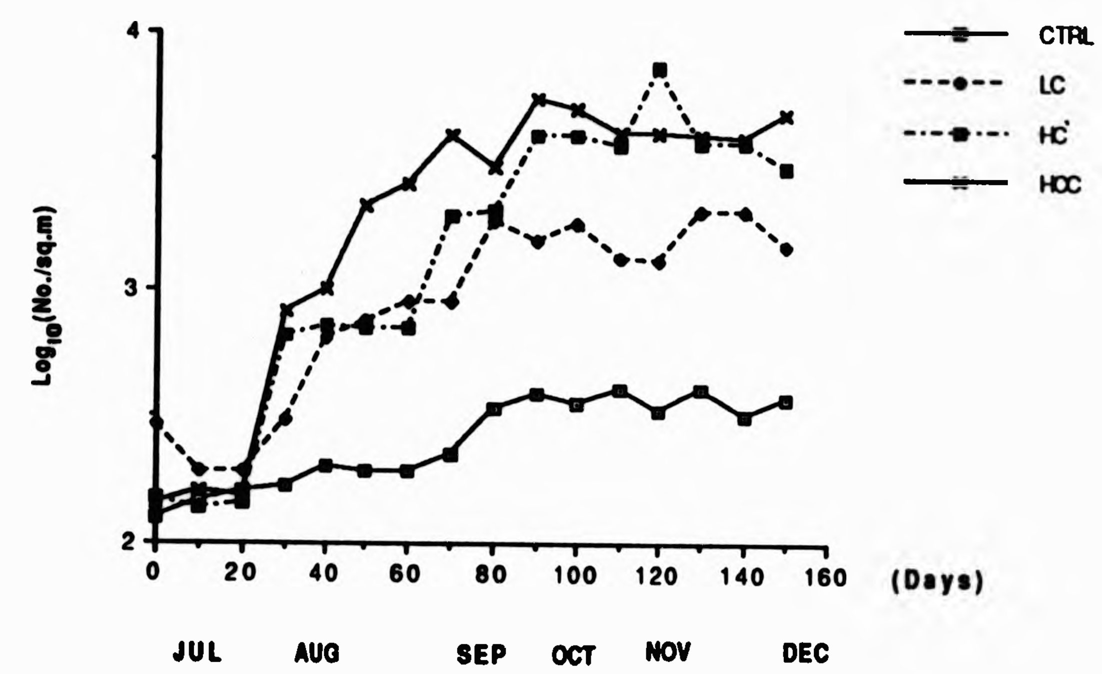


Fig. 74 *Lymnaea sp* (MOLLUSCA)

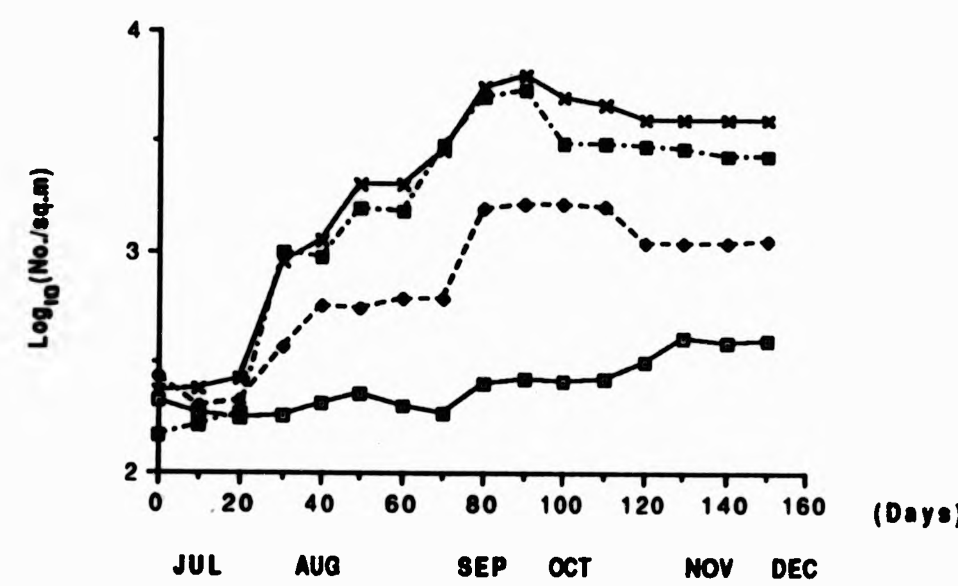


Fig. 75 *Planorbis sp.* (MOLLUSCA)

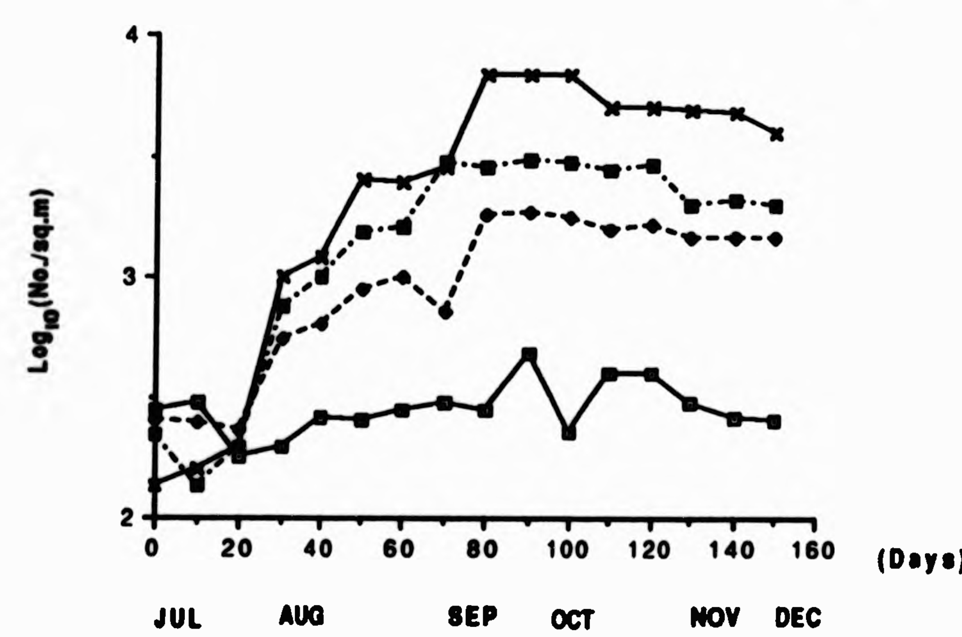


TABLE 16 F-values and their associated level of significance for two-way ANOVA on log transformed data of benthic macroinvertebrate groups during organic fertilization, without fish. (*, ** refer to P level of ≤ 0.05 and ≤0.01 respectively. NS = Note significant.)

	SOURCES OF VARIATION	
	Between ponds	**Between periods**
Asellus aquaticus	43.1 **	8.69 **
Chironomus sp.	43.5 *	11.6 **
HIRUDINEA	3.82 *	1.37 NS
MOLLUSCA		
Lymnaea sp. (Gastropod)	14.8 **	3.93 *
Sphaerium sp. (Bivalvia)	8.88 **	4.51 **
Planorbis sp.	11.5 **	2.01 NS
OLIGOCHAETA		
Lumbriculus variegatus	13.3 **	9.66 **
Limnodrilus sp.	10.7 **	1.89 NS
Tubifex tubifex	12.8 **	8.03 **
Sialis Lutaria	40.7 **	2.57 *

TABLE 17 Overall mean abundance of benthic macroinvertebrate (thousands m^{-2}) groups at varying organic fertilization levels, without fish. (Mean values in the same row bearing the same superscripts are not significantly different at $P=0.05$)

	TREATMENTS			
	CTRL	LC	HC	HCC
($\times 10^3$)				
Asellus aquaticus	0.28 ± 0.04^a	0.97 ± 0.09^b	3.14 ± 0.66^c	3.81 ± 0.72^c
Chironomus sp.	0.41 ± 0.02^a	2.22 ± 0.44^b	25.7 ± 5.46^c	34.9 ± 7.12^c
HIRUDINEA	0.74 ± 0.01^a	0.89 ± 0.11^b	3.59 ± 0.49^c	5.24 ± 0.98^c
MOLLUSCA				
Lymnaea sp. (Gastropod)	0.26 ± 0.02^a	0.89 ± 0.13^b	2.29 ± 0.40^c	3.0 ± 0.51^c
Sphaerium sp. (Bivalvia)	0.28 ± 0.03^a	1.10 ± 0.17^b	2.04 ± 0.40^c	2.51 ± 0.47^c
Planorbis sp.	0.29 ± 0.02^a	1.12 ± 0.15^b	1.84 ± 0.27^c	3.45 ± 0.62^d
OLIGOCHAETA				
Lumbriculus variegatus	0.29 ± 0.02^a	1.70 ± 0.30^b	2.77 ± 0.62^b	10.1 ± 3.10^c
Limnodrilus sp.	0.4 ± 0.01^a	1.63 ± 0.28^b	2.77 ± 0.56^c	6.96 ± 1.35^d
Tubifex tubifex	0.48 ± 0.13^a	4.10 ± 0.84^b	32.7 ± 9.96^c	58.8 ± 16.4^c
Sialis Lutaria	0.34 ± 0.03^a	1.52 ± 0.19^b	3.59 ± 0.59^c	5.34 ± 0.73^c

TABLE 18 **Estimates of biomass, mean weight and production for benthic macroinvertebrates at different organic fertilization levels, without fish.**

		CTRL	LC	HC	HCC
OLIGOCHAETA					
	X ± S.E., ind/m^2 (x10^{-3})	0.48 ± 0.13[a]	4.10 ± 0.84[b]	32.7 ± 9.96[c]	58.8 ± 16.4[c]
	Dry wt. biomass (g.dry wt.m^{-2})(B)	120 ± 13.1[a]	588 ± 97.1[b]	824 ± 76[c]	614 ± 144[c]
Tubifex tubifex	Mean individual weight (g.dry wt) (W)	0.25	0.14	0.03	0.01
	Production (g.dry wt.m^{-2}) (P)	24.1	112	114	175
	P : B ratio	0.20	0.20	0.14	0.28
	*Estimated Annual Production (E_{AP})	84.2	223	288	349
	*Estimated Annual P:B ratio ($E_{P:B}$)	0.70	0.40	0.35	0.57
	X ± S.E.	0.29 ± 0.02[a]	1.70 ± 0.30[b]	2.77 ± 0.62[b]	10.0 ± 3.0[c]
	B	49.5 ± 1.72[a]	242 ± 16.5[b]	436 ± 81[c]	430 ± 63.2[c]
Lumbriculus	W	0.17	0.142	0.16	0.043
	P	30.0	60.6	72.1	105
	P : B	0.61	0.25	0.17	0.24
	E_{AP}	59.9	121	144	210
	$E_{P:B}$	1.21	0.50	0.33	0.49
	X ± S.E.	0.43 ± 0.09[a]	1.63 ± 0.28[b]	2.72 ± 0.56[c]	6.96 ± 1.35[d]
	B	58.5 ± 1.72[a]	239 ± 2.89[b]	432 ± 89.7[c]	501 ± 211[c]
Limnodrilus sp.	W	0.13	0.15	0.16	0.07
	P	14.0	65.8	71.0	117
	P : B	0.24	0.28	0.16	0.23
	E_{AP}	27.9	132	142	210
	$E_{P:B}$	0.48	0.55	0.33	0.47

* Calculated pro rata, by multiplying observed production by 12/6.

Continue.....

TABLE 18

		CTRL	LC	HC	HCC
	X ± S.E.	0.28 ± 0.04[a]	0.97 ± 0.09[b]	3.14 ± 0.67[c]	3.80 ± 0.71[c]
	B	120 ± 17.6	196 ± 41.3	124 ± 33.7	128 ± 42.3
ASELLIDAE	W	0.43	0.20	0.04	0.04
	P	14.8	53.2	110	147
	P : B ratio	0.12	0.27	0.89	1.15
	E_{AP}	29.5	107	219	294
	$E_{P:B}$	0.25	0.54	1.76	2.30
	X ± S.E.	0.41 ± 0.02[a]	2.22 ± 0.44[b]	25.7 ± 5.50[c]	34.9 ± 7.12[c]
	B	8.99 ± 0.12[a]	12.6 ± 1.3[b]	18.1 ± 2.3[c]	18.3 ± 0.14[c]
CHIRONOMIDAE	W	0.02	0.01	0.001	0.001
	P	3.6	10.4	20.0	23.8
	P : B ratio	0.40	0.82	1.10	1.30
	E_{AP}	7.20	20.7	39.9	47.5
	$E_{P:B}$	0.81	1.64	2.20	2.60
	X ± S.E.	0.34 ± 0.03[a]	1.52 ± 0.19[b]	3.59 ± 0.19[c]	5.34 ± 0.59[c]
	B	3.11 ± 0.13[a]	6.89 ± 0.30[b]	10.8 ± 1.21[b]	7.12 ± 2.33[b]
SIALIDAE	W	0.01	0.01	0.59	0.74
	P	1.14	3.32	5.40	4.24
	P : B ratio	0.36	0.48	0.50	0.60
	E_{AP}	2.27	6.63	10.8	8.48
	$E_{P:B}$	0.73	0.96	1.0	1.19
	X ± S.E.	0.74 ± 0.01[a]	0.89 ± 0.10[a]	3.59 ± 0.59[b]	5.24 ± 0.76[b]
	B	0.51 ± 0.12[a]	0.46 ± 0.15[a]	10.8 ± 2.13[b]	7.12 ± 1.93[b]
HIRUDINEA	W	0.69	0.52	0.003	0.74
	P	0.86	1.50	5.40	4.24
	P : B ratio	1.69	3.25	0.50	0.60
	E_{AP}	1.72	2.99	10.8	8.48
	$E_{P:B}$	3.78	6.50	1.02	1.19
	X ± S.E.	0.43 ± 0.03[a]	1.83 ± 0.11[b]	4.21 ± 0.70[c]	4.66 ± 1.77[c]
	B	0.40 ± 0.08[a]	1.10 ± 0.14[b]	2.89 ± 0.35[c]	3.10 ± 0.17[c]
MOLLUSCA	W	0.93	0.60	0.68	0.66
	P	0.76	2.55	5.80	6.15
	P : B ratio	1.89	2.32	2.01	1.98
	E_{AP}	1.51	5.10	11.6	12.3
	$E_{P:B}$	3.78	4.60	4.0	3.90

TABLE 19 Density distribution (index of dispersion) of benthic macroinvertebrate groups at varying orgainc fertilization levels, without fish.

	CTRL	LC	HC	HCC
MACROINVERTEBRATES				
Asellidae	0.31	0.37	1.10	0.72
Chironomidae	1.22	0.64	1.50	0.79
Hirudinea	0.76	1.10	0.85	0.98
Mollusca	0.10	0.10	0.23	1.10
Oligochaeta	0.55	0.56	1.13	0.99
Sialidae	0.39	0.38	0.63	0.57

Values near 1 = randomness
> 1 = contagious distribution
< 1 = eveness in a regular distrubution

$$\text{Index of dispersion } (I_d) = \frac{\Sigma(\overline{X} - x)^2}{\overline{X}(n-1)}$$

observed in pond 2 of the HCC treatment (Figs. 73-75). Similarly, high abundance of these groups was in ponds that had more vegetation cover. The LC treatment which had an annual production of 5.10g ash-free dry wt.m^{-2} gave the highest P/B ratio of 4.6 (Table 18). Except for HCC which showed contagious distribution (Table 19), all other treatments had a regular density distribution.

4.6 FISH CULTURE

The results of fish growth rates, condition factor, food intake and harvest data are presented in Figures 77 to 97, Tables 21 to 24 and Plates 1 to 4. The fish culture, with benthos as main source of diet, was based on observations and reports by earlier workers regarding their potential as a good source of natural diet for trout in pond culture. Fertilization treatments which gave favourable plankton and benthos production were maintained for fish culture during the second year. Utilisation of the abundant natural diet and detritus was evaluated in relation to amount consumed, growth rate and survival. This was compared to a "control" which reflected the normal management practice on the Howietoun fish farm, depending largely on artificial pelleted diet.

The best overall growth response was in the HCC and HC treatments, which had abundant benthic macroinvertebrates and zooplankton, and this compared favourably with the control. Survival rate in all the ponds, except HPN treatments, was significantly higher than HPN, even at minimal flow rate. Similarly, nutritional values of natural food items consumed, conformed with nutritional requirements for trout. Evaluation of exploitation of benthos and zooplankton in the ponds by stomach content analysis showed variations between ponds with replicate treatments. An interesting observation was the absence of *Gammarus sp* during the first year of fertilization, but in the second year, these were present in the ponds and fish stomachs, though the amount consumed was not high compared to other natural food items.

4.6.1 PHYSICO-CHEMICAL CHARACTERISTICS OF POND WATER, DURING FISH CULTURE

Water quality parameters measured during fish culture (Table 20 & Fig. 76) remained within ranges similar to those obtained in the previous year's fertilization, except for some parameters which showed significant variation between treatments. For example, very low dissolved oxygen (2.8-3.8mgl^{-1}) was recorded in July in one HPN treatment only (pond 3 at high fish density) under still water conditions. The fall in D.O. also coincided with high summer temperature and increased B.O.D., suspended solids, nitrite and ammonia. However, commencement of water flow through the ponds in August (Figure 76) at minimum rates stabilized conditions and ensured high survival during the remaining experimental period (Table 21). This was evident from increased D.O. and fall in B.O.D., suspended solids and nitrite which play a significant role in toxicity of water.

Increased alkalinity coincided with improved water pH, possibly due to carry-over effects of liming which helps in maintaining the buffering capacity of pond water. These factors, combined with moderate levels of total phosphorus and nitrate-nitrogen has probably helped in maintaining biological productivity throughout the culture period.

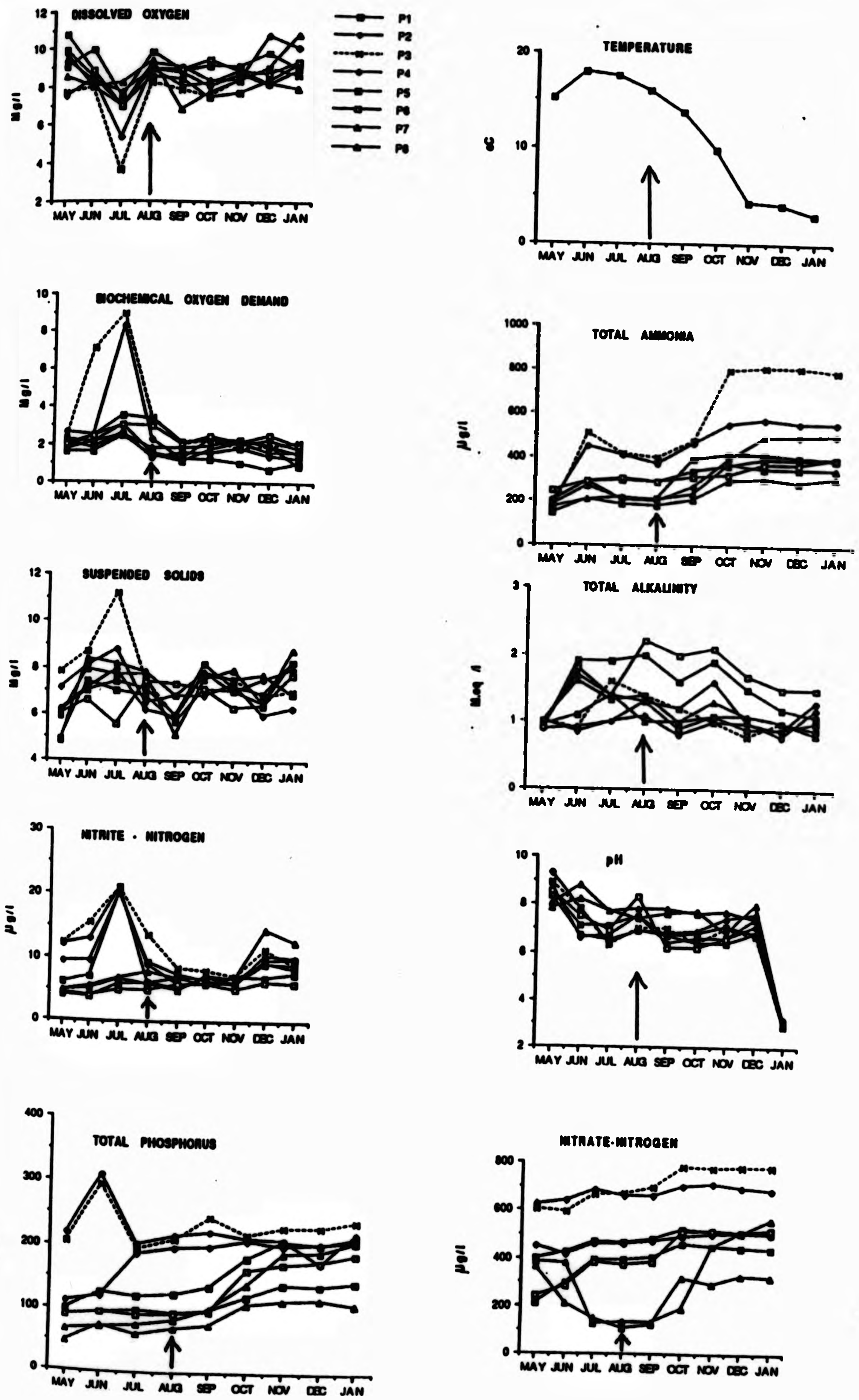


Fig. 76. Variations in physico-chemical parameters of pond water during fish culture trial in 1989-1990. (Pond treatments are as explained in Table 3, and arrow shows commencement of water flow).

TABLE 20 Overall mean values and standard error of physico-chemical parameters of pond water at varying fertilization levels and stocking density during fish culture trial.

	*P1(HCC)	P2 (HCC)	P3 (HPN)	P4 (HPN)	P5(HC)	P6 (HC)	P7 (CTRL)	P8 (CTRL)
pH	6.52±0.17	6.58±0.18	6.83±0.22	6.91±0.28	6.60±0.18	6.72±0.18	7.21±0.24	7.23±0.81
Total hardness($mgl^{-1}CaCO_3$)	85.7±0.33	90.2±0.30	84.8±0.36	78.4±0.63	79.7±0.56	78.9±1.14	91.2±0.34	90.4±0.29
Total Alkalinity($meq\ l^{-1}$)	1.10±0.10	0.85±0.10	1.10±0.10	1.10±0.01	1.56±0.02	1.46±0.10	1.12±0.02	1.18±0.01
Suspended solids (mgl^{-1})	6.21±0.14	7.10±0.56	7.79±0.38	7.11±0.34	6.74±0.16	5.86±0.23	7.22±0.73	7.32±0.28
Dissolved Oxygen (mgl^{-1})	9.10±0.20	8.92±0.40	8.63±0.41	8.0±0.57	8.31±0.28	8.94±0.14	8.38±0.36	8.51±0.38
Biochemical Oxygen Demand	1.54±0.30	1.70±0.18	3.52±0.27	2.79±0.16	2.32±0.17	2.37±0.11	1.68±0.16	1.88±0.12
Total Ammonia Ugl^{-1}	3.23±6.67	340±22.4	573±17.4	397±19.5	328±8..83	323±11.6	237±4.43	271±9.49
Nitrate -N (Ugl^{-1})	418±2.47	472±6.27	703±3.0	671±3.89	386±3.59	412±2.86	245±76.1	318±23.0
Nitrite - N(Ugl^{-1})	9.16±0.33	9.61±0.63	11.8±1.13	9.93±0.36	6.16±0.10	5.32±0.10	6.52±1.27	8.12±0.49
Total phosphorus	157±7.50	182±8.40	230±18.4	158±47.4	113±0.81	129±7.0	86.8±13.9	126±9.80

* Legends and details are as outlined in Table 2

4.6.2 FISH GROWTH

4.6.2.1 SURVIVAL RATE

The survival rate in various pond treatments is shown in Table 21. Control pond 8 had the highest survival rate of 96%, which contrasts with the 72% observed in the replicate CTRL pond 7. The HCC and HC ponds had higher survival rates in the range 80-86% than other ponds. Pond 3 (HPN) had the least survival rate of 64%, and this may not be unrelated to deterioration in some water quality parameters described above and other stress factors such as handling. The observed mortality in various ponds occurred during the first 6 weeks, but with improved management practice such as commencement of water flow at minimum rate and partial exposure of sediment to air during monthly fish sampling, no mortality occurred.

TABLE 21 Stocking density, growth and survival of brown trout (*Salmo trutta*) over 215 days

[a] Pond	Fish stocking density	INITIAL FISH STOCK Biomass [g]	INITIAL FISH STOCK Mean weight [g]	FINAL FISH STOCK No.	FINAL FISH STOCK Biomass [kg]	FINAL FISH STOCK Mean weight [g]	WEIGHT INCREASE Total [Kg]	WEIGHT INCREASE Individual [g]	[b] SGR [% day^{-1}]	SURVIVAL [%]
1	50	3.09	61.8	43	7.80	181.5	4.71	109.6	0.48	86.0
2	25	1.42	56.6	20	3.35	167.6	1.93	96.5	0.45	80.0
3	50	3.25	65.0	32	4.53	141.4	1.28	40.0	0.28	64.0
4	25	1.55	62.0	20	3.17	158.5	1.62	81.0	0.36	80.0
5	50	3.19	63.8	40	6.11	152.7	2.92	73.0	0.39	80.0
6	25	1.40	56.0	21	3.22	153.5	1.82	86.0	0.43	84.0
7	25	1.58	63.2	18	3.12	173.0	1.54	85.6	0.47	72.0
8	50	3.19	63.8	48	14.1	294.4	10.09	227.1	0.77	96.0

[a] Replicate ponds: HCC [P1,P2], HPN [P3,P4], HC (P5,56] & CTRL [P7, P8] . Ref. Tables 1 & 2 for explanation

[b] SGR = Specific Growth Rate = $\frac{(\log_e W_f - \log_e W_i)}{T_2 - T_1} \times 100$ Where W_i & W_f = initial & final weight of fish

T_1 & T_2 = initial & final time [days]

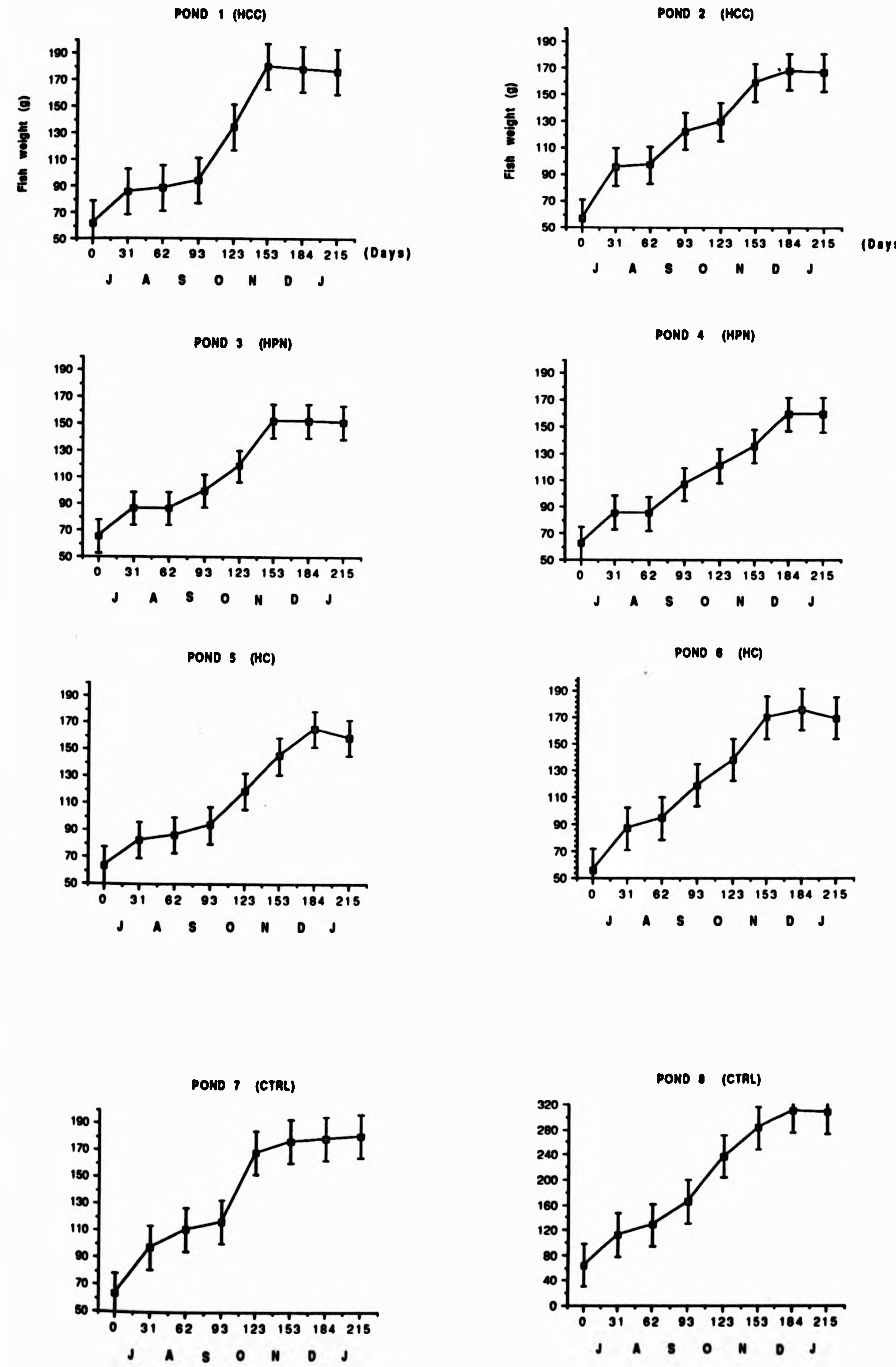
4.6.2.2 GROWTH RATE

Figure 77 shows the variation in growth rate according to fertilization treatment and stocking density while Table 21 is the result of regression analysis of $\log_e$ body weight against time for pond treatments. Growth is also reflected by the overall specific growth rate earlier shown in Table 21. Overall growth response in the various ponds conformed to a seasonal cycle in which there was rapid growth during June, slower in August/September and further acceleration in October, then universal cessation at the end of December/January. The highest growth rate was in CTRL pond 8 which had pelleted diet with supplementary natural food and comparison of regression line showed a significant difference ($P<0.05$) from replicate CTRL pond 7. Differences in growth rate between ponds receiving the same fertiliser treatments (HPN, HCC & HC) was significant (Table 22).

4.6.2.3 LENGTH-WEIGHT RELATIONSHIPS AND CONDITION FACTOR

The relationship between length and weight are shown in Figure 79 while the relationship between condition factor and time is shown in Fig. 80. It was evident that condition

Fig. 77. Relationship between fish weight and time at varying fertilization levels and stocking density. (Pond treatments are as explained in Table 3).



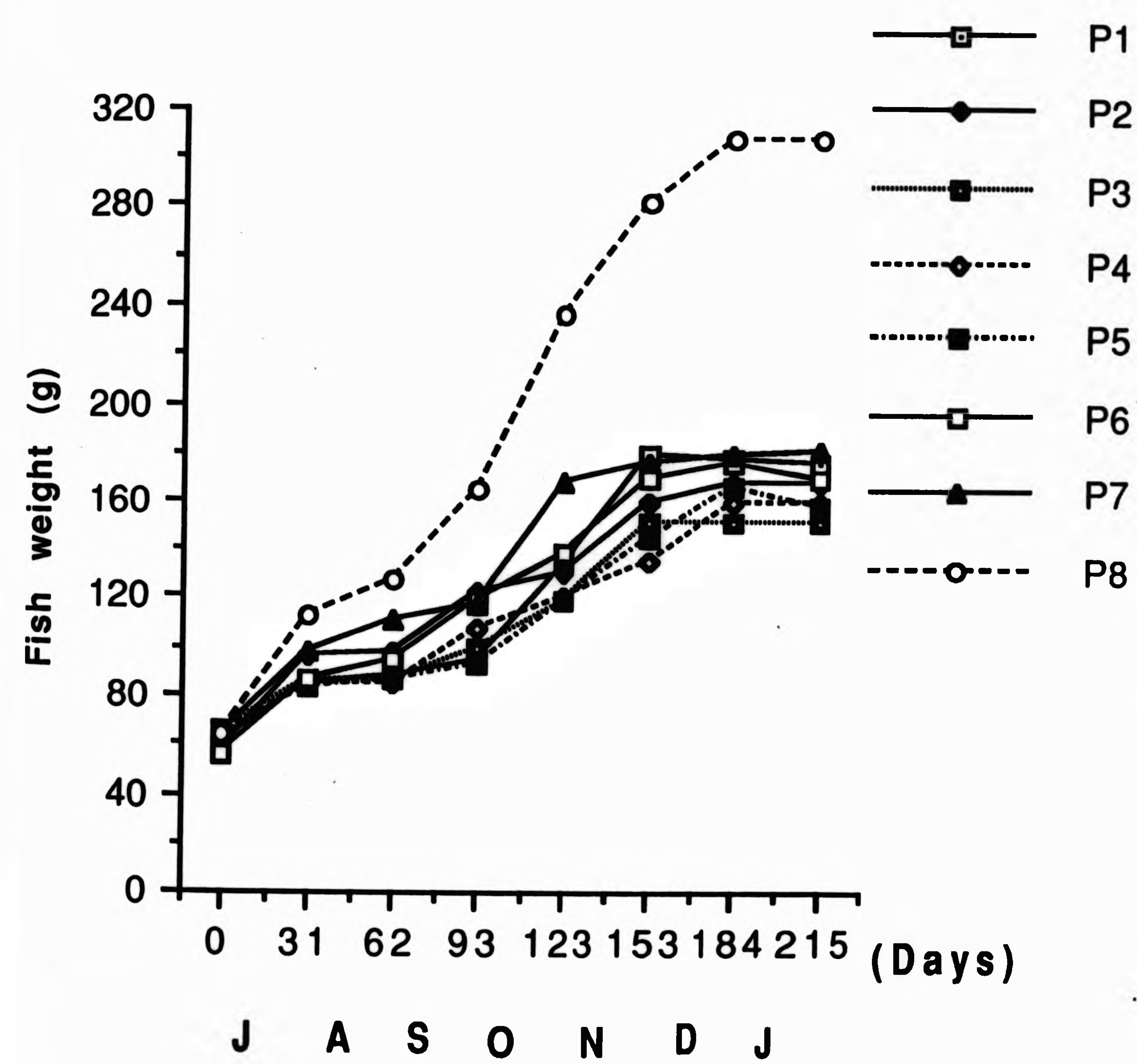


Fig. 78. Growth response of brown trout (*Salmo trutta* L.) at varying fertilization levels and stocking density. (Pond treatments are as explained in Table 3).

TABLE 22 Results of regression analysis of $\log_e$ Fish body weight (g) (Y) against time (days) (X) at different fertilization levels for the period, June to December (** refer to $P \leq 0.001$)

Pond Treatments	Fish Density	n	r	b	±	S_b	C	b/S_b
1 (HCC)	50	7	0.93	5.94×10^{-3}	±	6.84×10^{-4}	4.15	8.69**
2 (HCC)	25	7	0.88	5.34×10^{-3}	±	7.97×10^{-4}	4.23	6.70**
3 (HPN)	50	7	0.94	4.66×10^{-3}	±	4.67×10^{-4}	4.21	9.99**
4 (HPN)	25	7	0.94	4.73×10^{-3}	±	4.69×10^{-4}	4.21	10.1**
5 (HC)	50	7	0.97	5.03×10^{-3}	±	3.88×10^{-4}	4.17	12.9**
6 (HC)	25	7	0.94	6.03×10^{-3}	±	6.10×10^{-4}	4.17	9.89**
7 (CTRL)	25	7	0.89	5.53×10^{-3}	±	7.93×10^{-4}	4.30	6.94**
8 (CTRL)	50	7	0.95	8.39×10^{-3}	±	7.73×10^{-4}	4.32	10.8**

Form of equation: $Y = bx + C$

where b = instantaneous growth rate day^{-1}

S_b = standard error of regression coefficient

Fig. 79. Relationship between fish length and weight at varying fertilization levels and stocking density. (Pond treatments are as explained in Table 3).

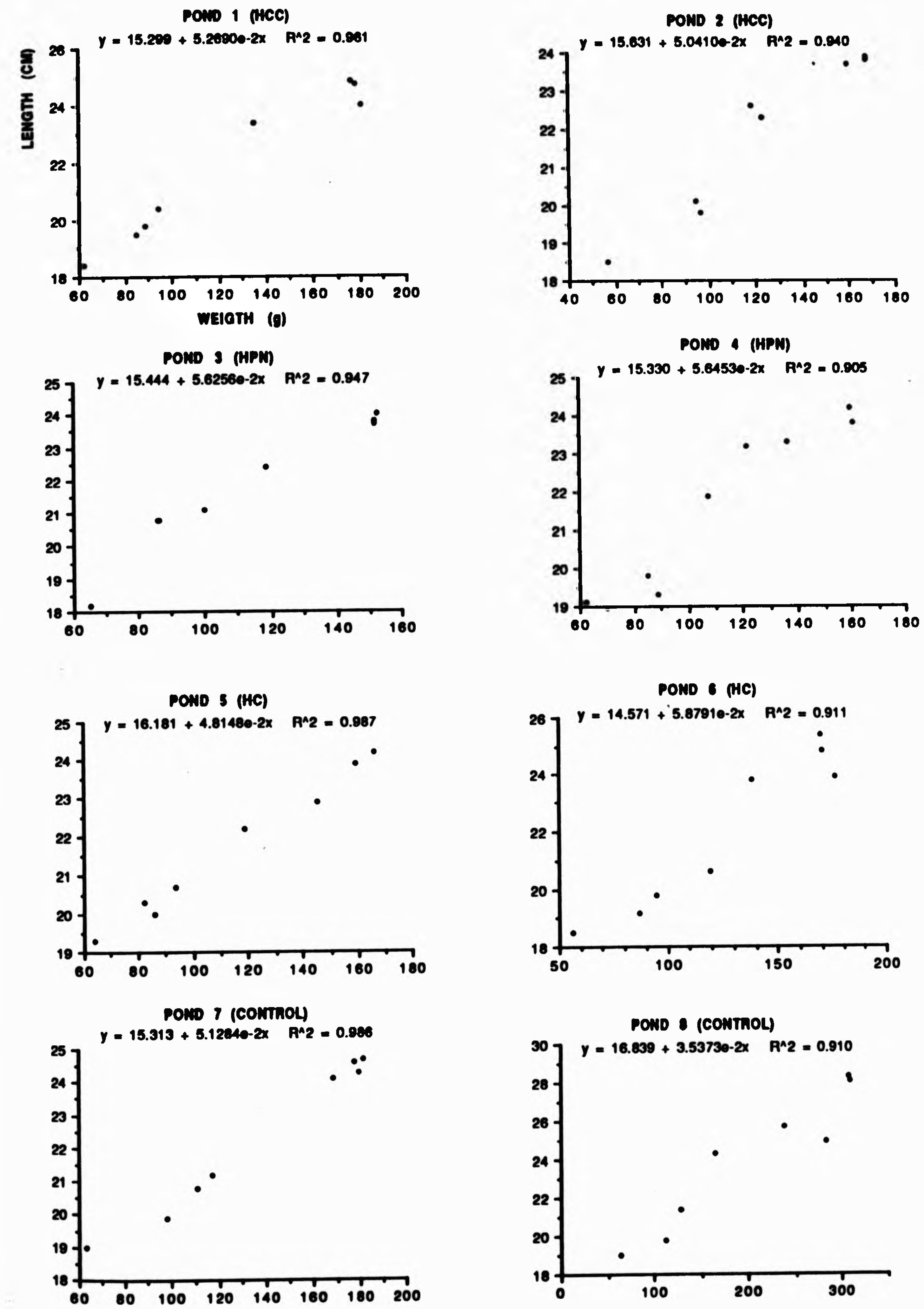
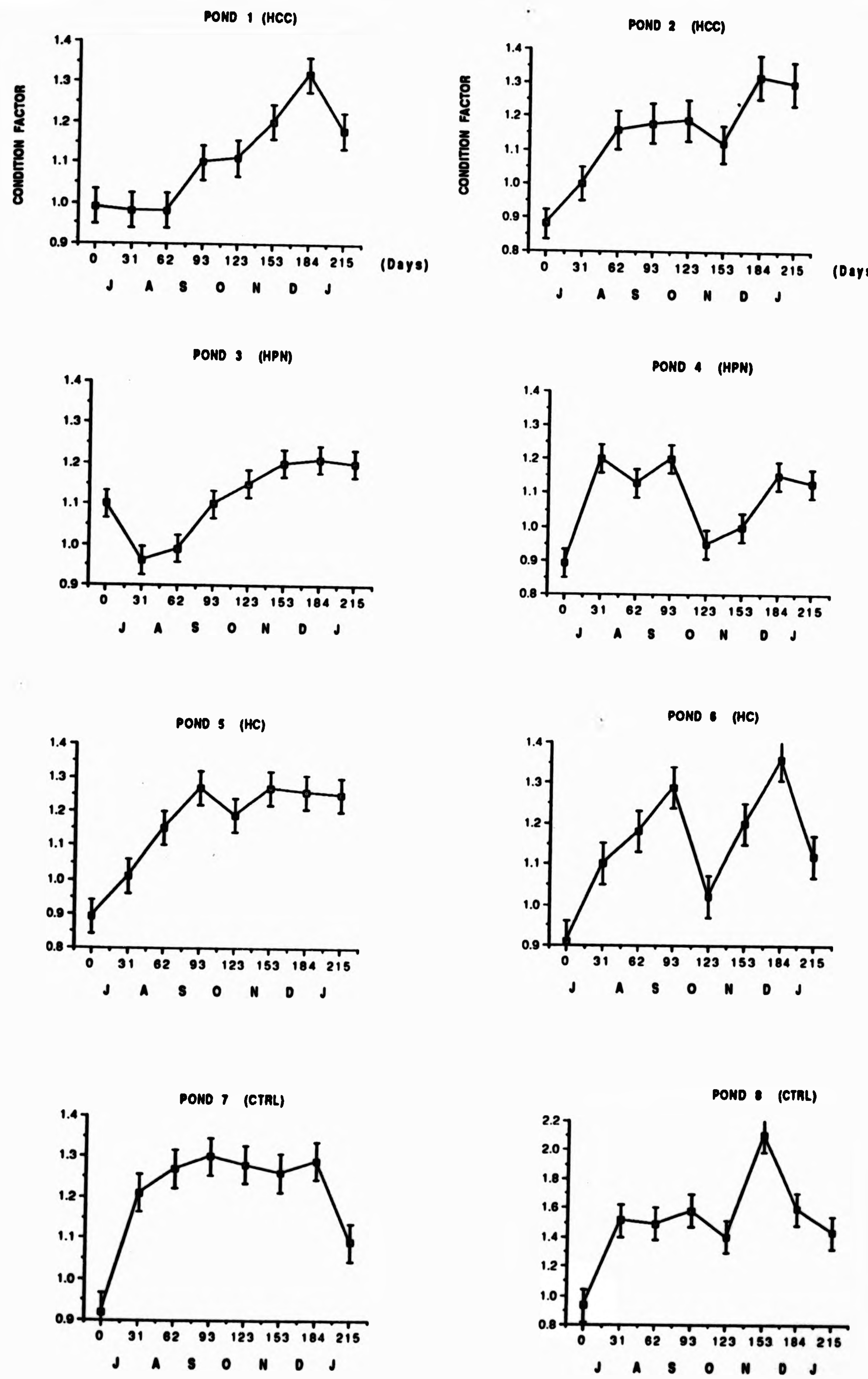


Fig. 80. Relationship between mean condition factor and time at varying fertilization levels and stocking density. (Pond treatments are as explained in Table 3).



factor of all fish increased, showing significantly high positive correlation ($P<0.005$) in both HCC treatments, pond 3 (HPN) and pond 5 (HC).

4.6.2.4 COLOURATION OF FISH SKIN AND FLESH

The density of erythrophores in the skin (Plates 1-3) and pink colouration of the flesh of fish (Plate 4) from the various pond treatments was more marked in fish fed natural diet in comparison to the fish from the control ponds except for the HPN treatment which had slightly dark colouration (Plate 2). Assessment of palatability of the cultured fish from the various pond treatments showed that it compares favourably well with the control. However, a general observation by most people served was the high fat content of fish from the control ponds. This is not surprising, considering the high fat content in the formulated pelleted diet, in contrast with the low level reported for macroinvertebrates.

PLATE 1

Density of erythrophores in the skin of brown trout (*Salmo trutta*) cultured on natural diet, under high chicken & cow fertilization.

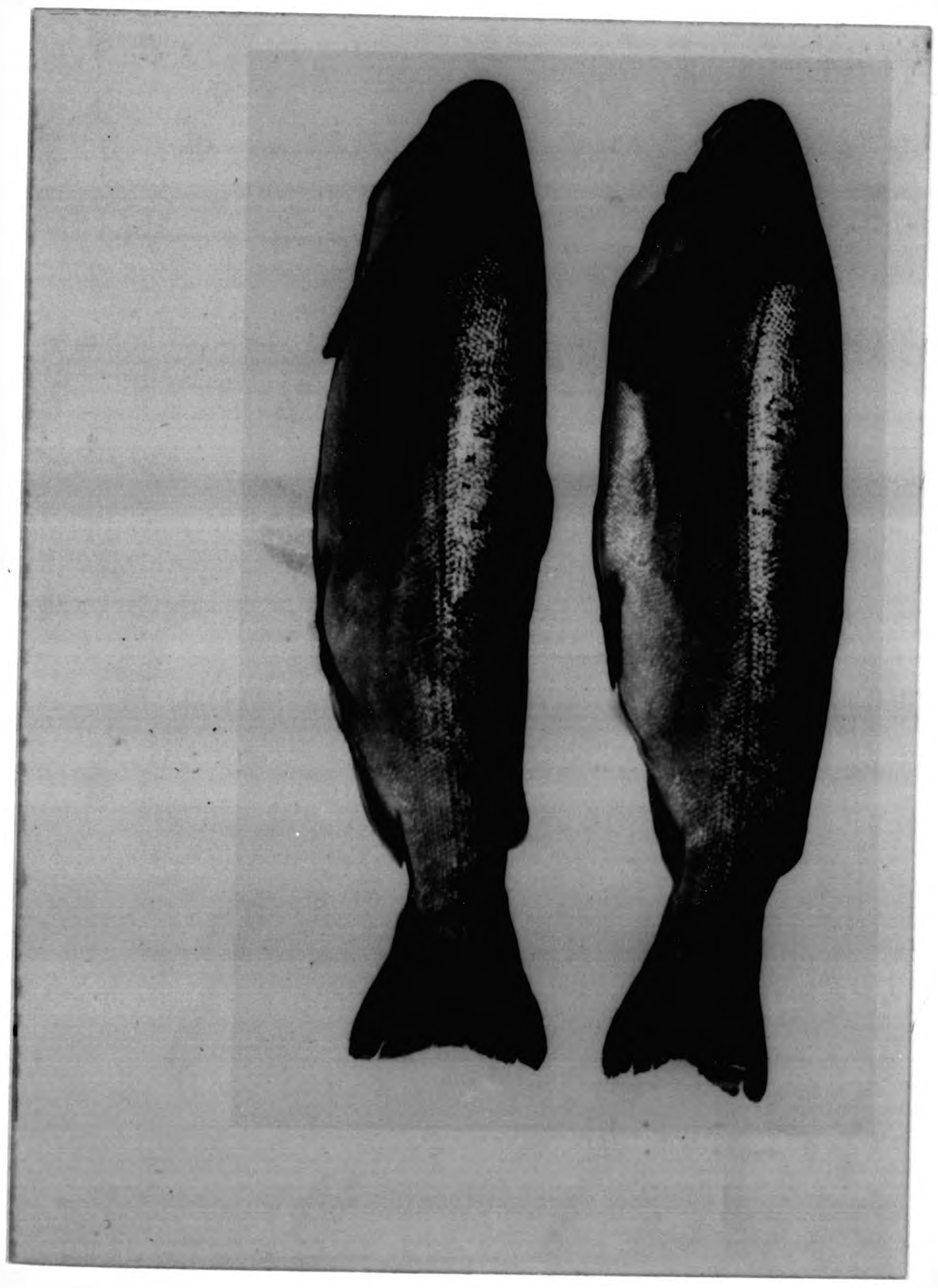


PLATE 2

Density of erythrophores in the skin of brown trout (*S. trutta*) cultured on natural food under high phosphorus & nitrogen fertilization. (Note: The small dark fish was the average size obtained at the end of culture period.

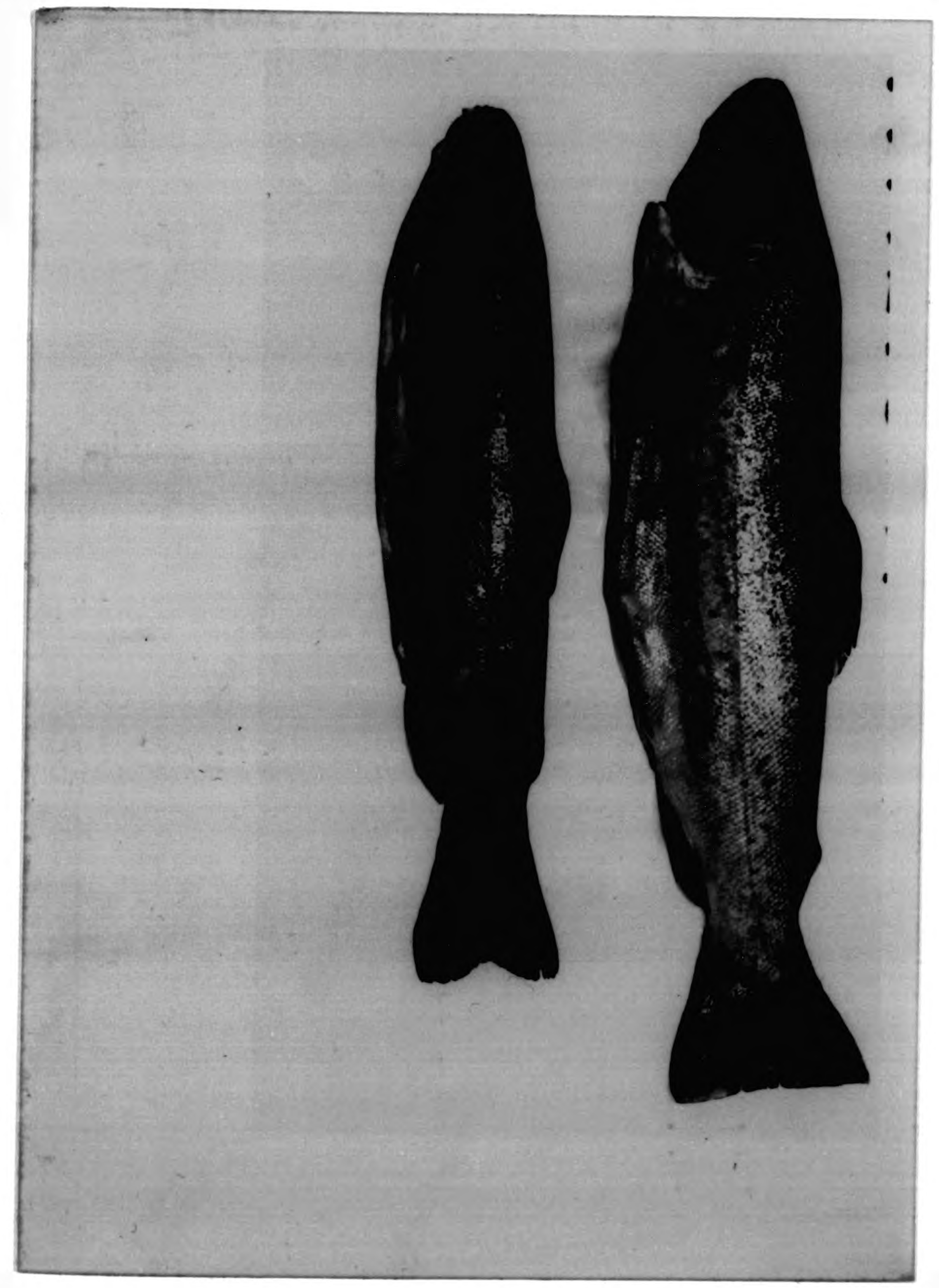


PLATE 3

Density of erythropores in the skin of brown trout (*S. trutta*) cultured on artificial pelleted diet, with supplemental natural food in the control experimental condition.

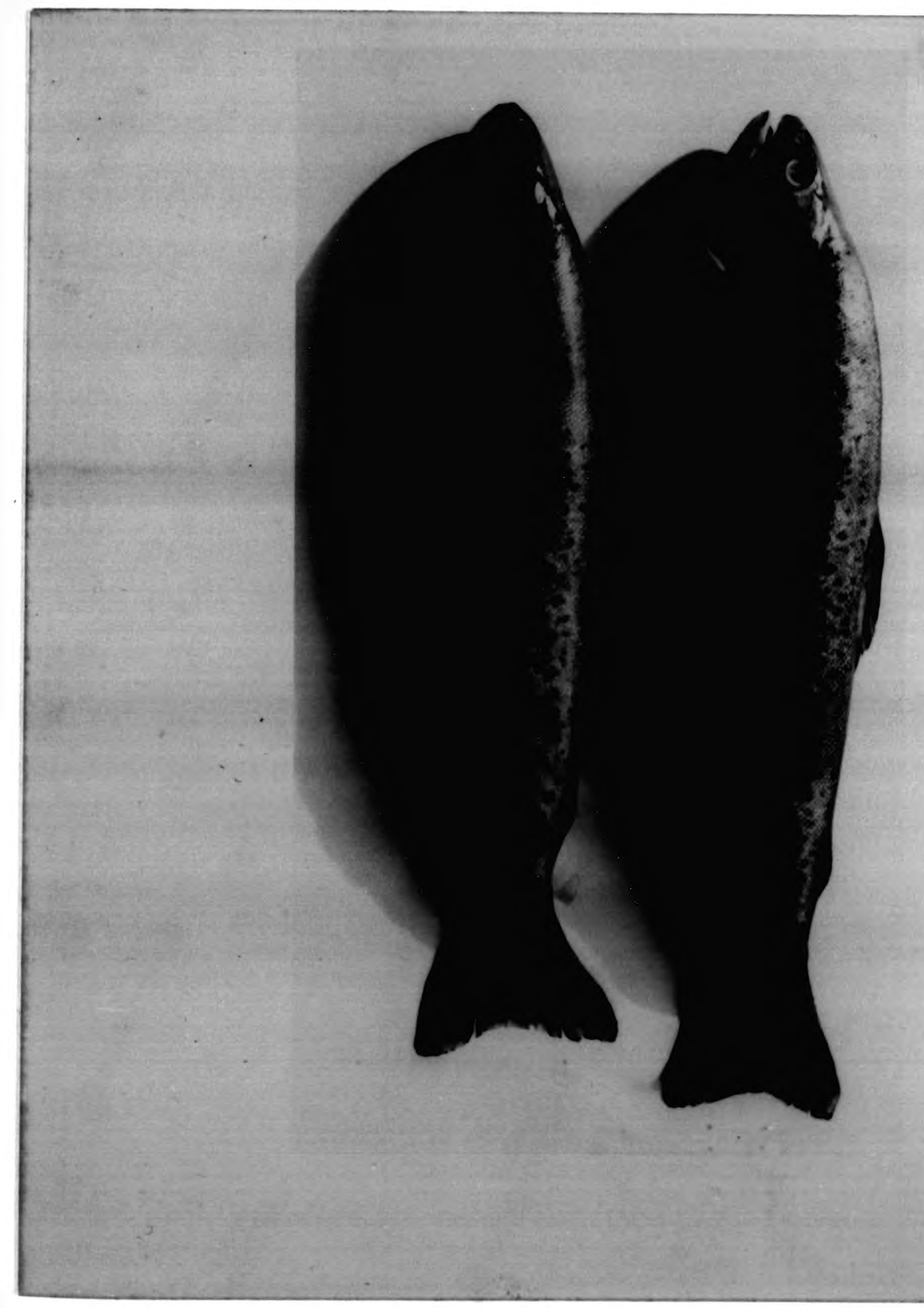
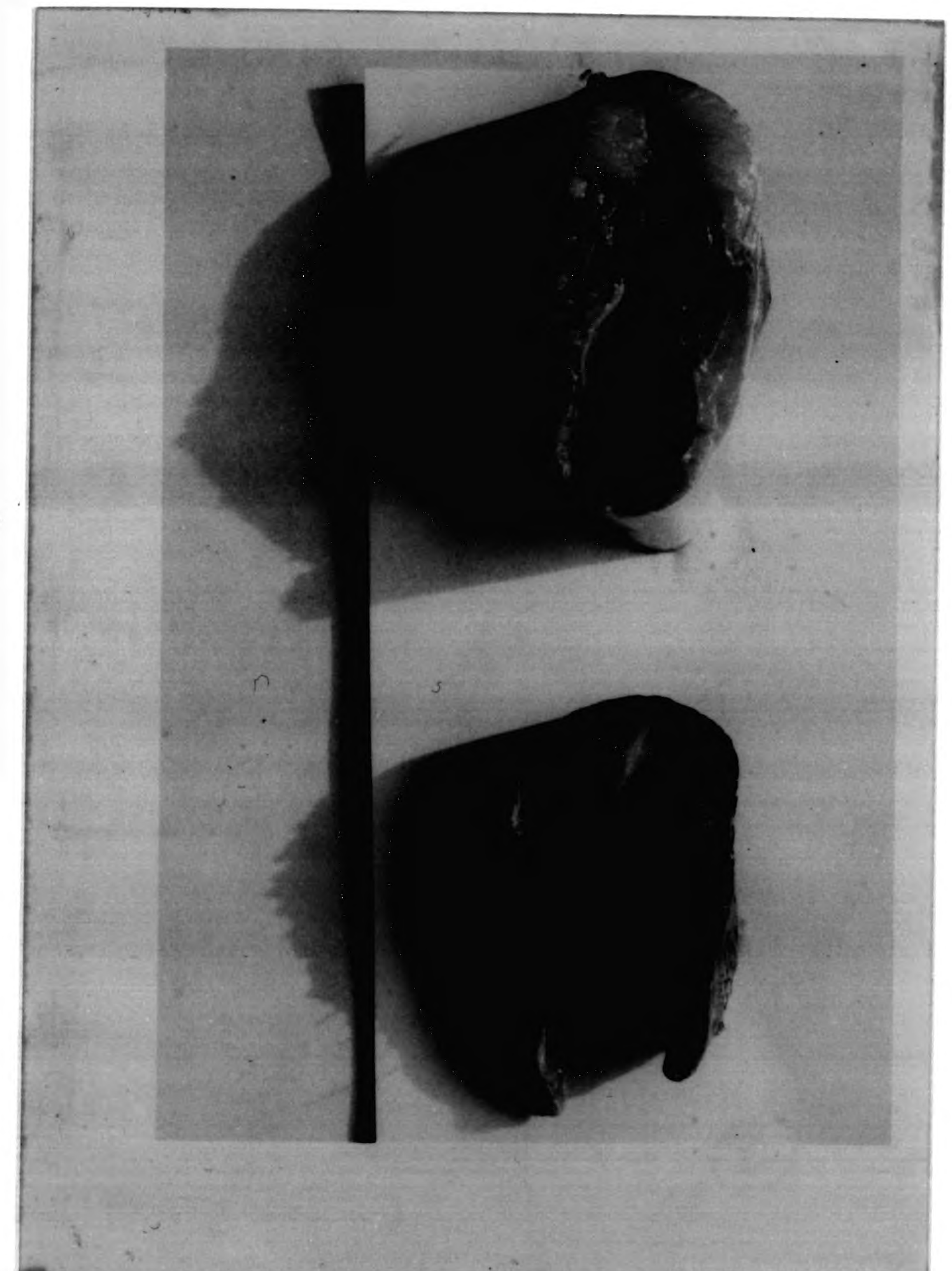


PLATE 4

Typical pink colouration of the flesh of brown trout, cultured on natural food and/or controlled condition.



4.6.3 STOMACH CONTENT ANALYSIS

The analysis of the stomach contents for natural and artificial pelleted diet show wide variation in both fullness and selectivity. During the monthly sampling, a total of 150 fish stomach contents were usually examined for food items. Despite regular feeding with artificial pelleted diet in the CTRL ponds, a considerable proportion of natural food was also consumed. Similarly, some detritus, plant fragments ane algae, especially *Spirogyra*, were consumed. These were however not accounted for in the enumeration of major food items, and it is likely that their uptake may be coincidental during search for macroinvertebrates in the sediment.

4.6.3.1 ESTIMATION OF FOOD INTAKE AND COMPOSITION BY STOMACH FLUSHING.

The results of mean monthly variation in relative contribution (% abundance) of total macroinvertebrates and zooplankton in trout stomach are presented in Figure 81. Table 23 shows the mean monthly value of food intake (dry wt. basis) by trout in the various pond treatments. Stomach pump sampling clearly showed predation on available benthos and it was also evident that fish tend to be selective, with *A. aquaticus, S. lutaria,* Oligochaeta, Mollusca and zooplankton constituting the bulk of food items consumed. Peak consumption period was between July - November, followed by a decline during the winter months of December and January (See Fig. 81 & Table 23).

In pond 2 (HCC), chironomids were least consumed, in spite of their abundance, compared to ponds 3 (HPN), 5 & 6 (HC), probably due to inaccessibility under a carpet of aquatic macrophytes which covered the bottom of this pond. In the Control pond 8 fed regularly with artificial diet, there was a higher proportion of artificial diet throughout the culture period. This contrasted with pond 7 which only showed favourable response to artificial feed during July-August, probably due to growth of macrophytes in the ponds, which tended to hide the food, and because brown trout are shy feeders and do not actively take pellets during hand feeding but search for them later.

A short-term trial was conducted in which fish in CTRL ponds 7 & 8 were deprived of pelleted food for one week in October. The result showed that fish in pond 7 did not show wide variation in their natural food consumption, compared to pond 8 which had higher electivity index (Table 26) and thus greater consumption of Oligochaeta, Chironomidae and *A. aquaticus*. Re-adjustment to consumption of artificial food

Fig. 81. Comparison of mean monthly variations in relative abundance of benthos and total zooplankton in trout stomach at varying fertilization levels and stocking density. (Pond treatments are as explained in Table 3).

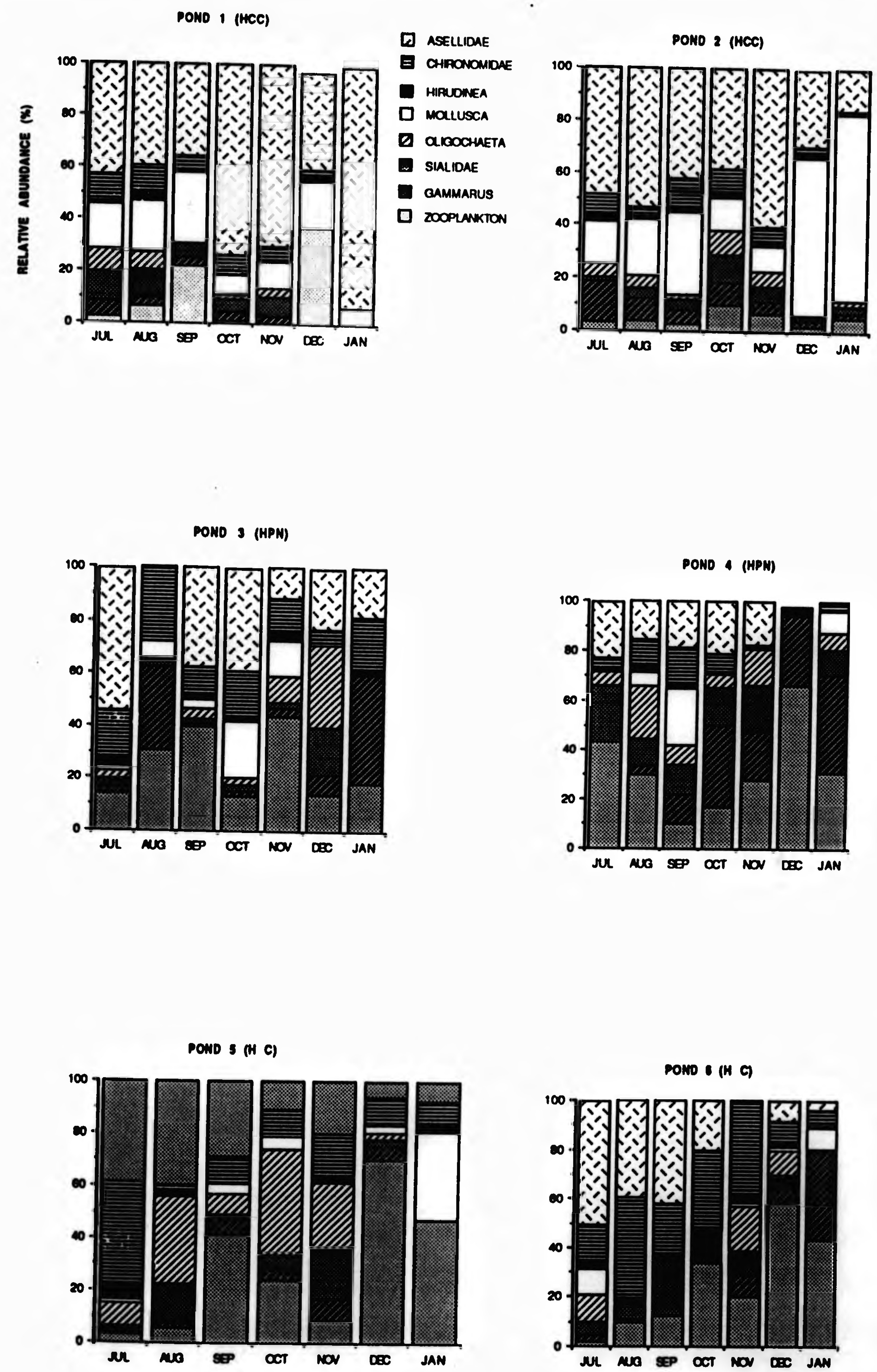


TABLE 23 Mean monthly values of stomach content (g dry wt) of fish for the period, July 1988 to January 1990.

[1] POND TREATMENTS

	P1 (HCC)	P2 (HCC)	P3 (HPN)	P4 (HPN)	P5 (HC)	P6 (HC)	P7 (CTRL)	P8 (CTRL)
JULY	1.35±0.16	0.94±0.10	0.89±0.04	0.98±0.01	0.98±0.07	1.44±0.08	2.83±0.12	2.35±0.39
August	2.11±0.31	2.37±0.24	0.63±0.13	1.07±0.39	1.13±0.26	2.72±0.34	2.70±0.16	3.38±0.60
September	2.48±0.12	1.79±0.16	0.40±0.03	2.11±0.10	1.98±0.08	2.73±0.19	1.75±0.31	2.25±0.44
October	3.15±0.12	1.19±0.11	0.46±0.01	1.38±0.22	1.29±0.19	1.93±0.37	1.63±0.19	2.88±0.52
November	1.60±0.15	1.35±0.15	1.35+0.13	1.18±0.11	1.43±0.39	2.66±0.38	2.10±0.13	2.93±0.63
December	1.79±0.13	1.95±0.10	0.82±0.17	1.86±0.08	1.92±0.39	2.14±0.11	1.69±0.34	4.64±0.81
January	1.88±0.14	1.84±0.05	0.05±0.002	0.43±0.08	1.02±0.21	2.31±0.16	1.21±0.11	2.99±0.11

[1] Legends and details are as outlined in Table 2, except control (CTRL) ponds received artificial pelleted diet at 1% body weight day^{-1}

[2,3] Dry weight stomach content artifical diet with supplemental natural diet.

in pond 8 was slow, only picking up in December-January during which natural food constituted <50% of the food consumed.

4.6.3.2 SELECTION OF NATURAL FOOD BY TROUT

Selective feeding on benthos diet by the fish in terms of Ivlev's Electivity index are presented in Tables 24 - 25. This index compares the frequency of occurence of major food items in the stomach with %-composition in the benthos. Electivity Index for artificial pelleted diet was not computed because of the obvious difficulty in quantifying its numerical abundance. Some assumptions based on the previous year's benthos analysis were taken into account while computing the electivity index. These include:

(i) That the densities of natural food organisms did not significantly change throughout the 6 months culture period, thus remaining stable;

(ii) The decline in natural food abundance during fish culture period is considered large enough to outweigh the variance within samples, and therefore, data are reasonably accurate to allow the current investigation of selectivity.

Consequently, any difference reflected in %-abundance of benthos will be due to trout predation.

The strong positive electivity for Asellidae and Mollusca seem to conform with their high abundance and easy accessibility in both sediment and on the surface of plants, unlike the Chironomidae which, inspite of their overall abundance, had strong negative selection in all the ponds, except pond 6 & 8 which showed weak positive selection. This is possibly due to regular supply of pelleted diet, with the result that the small amount of natural food encountered in the stomach is due to chance while consuming the pellets which settled in the sediment. Oligochaeta also showed strong negative selection in all the ponds, except ponds 1 & 5. *Gammarus* showed a weak positive selection in contrast to Hirudinea which, in spite of their abundance but because of thier inaccessibility, were negatively selected.

TABLE 24 Electivity index of macroinvertebrates for pond reared trout at varying stocking density.

		[a]PONDS							
		1	2	3	4	5	6	7	8
ASELLIDAE	% No. in Benthos)Pb)	4.56	5.41	9.72	5.48	6.70	14.4	14.0	2.90
	% No. in stomach (Pd)	36.8	59.2	50.0	49.2	41.1	28.2	48.3	4.32
	Benthic electivity index (BEI)	0.78	+0.83	+0.67	+0.80	+0.72	+0.32	+0.55	+0.20
CHIRONOMIDAE	Pb	43.9	46.6	22.2	49.5	44.9	13.8	12.9	18.5
	Pd	2.64	7.26	14.0	13.6	4.21	15.7	4.12	22.7
	B.E.I	- 0.89	-0.73	-0.31	-0.57	-0.83	+0.10	-0.52	+0.10
GAMMARIDAE	Pb	2.00	2.81	1.99	2.44	1.68	5.80	2.96	13.3
	Pd	2.22	2.47	1.00	2.10	2.00	8.20	3.78	4.40
	B.E.I.	+0.10	0.10	-0.33	-0.10	+0.10	+0.17	+0.12	-0.50
HIRUDINEA	Pb	6.41	7.80	8.88	6.28	5.10	7.34	8.24	10.2
	Pd	1.42	1.37	2.35	0.52	2.81	9.61	11.3	1.97
	B.E.I	-0.64	-0.70	-0.58	-0.85	-0.29	+0.13	+0.16	-0.68
MOLLUSCA	Pb	3.28	4.55	10.3	4.15	3.43	8.96	9.67	2.96
	Pd	22.6	15.9	22.0	11.6	33.1	15.7	27.6	1.83
	B.E.I.	+0.75	+0.55	+0.36	+0.47	+0.81	+0.27	+0.48	-0.24

[a]Legends and details are as outlined in Table 2

Continue.....

TABLE 24

		PONDS							
		1	2	3	4	5	6	7	8
OLIGOCHAETA	% No. in benthos(Pb)	33.0	26.0	24.8	25.9	31.4	13.2	12.7	41.2
	% No. in stomach(Pd)	45.1	1.41	3.32	2.80	48.7	7.20	2.18	2.20
	Benthic electicity index (B.E.I.)	+0.16	-0.90	-0.76	-0.81	-0.22	-0.29	-0.71	-0.90
SIALIDAE	Pb	6.80	6.78	15.2	6.30	6.82	11.0	11.7	6.98
	Pd	12.1	6.74	0.41	13.1	11.7	15.6	20.1	3.52
	B.E.I.	+0.28	-0.003	-0.95	+0.35	+0.26	+0.17	+0.27	-0.33

4.6.3.3 DEPRIVATION OF PELLETED DIET IN CONTROL PONDS

During estimation of food intake by trout, it was observed that in the CTRL ponds 7 & 8, there was greater preference for pelleted diet. In order to ascertain if negative selection of natural food was due to inaccesibility or preference for pelleted diet, a short term trial was conducted in which fish were deprived of pelleted diet for one week. The results are presented in Table 25. In both ponds, there was a moderate to strong positive selection for all natural food, except Mollusca in pond 8 which showed weak negative selection. *Gammarus* and Oligochaeta failed to elicit a feeding response in pond 7. The result of this trial implies that, even with regular supply of pelleted diet, under semi-intensive management practice, trout are able to adjust to consumption of natural food. Similarly, the consumption of pelleted diet was due more to its accessibility. During hand feeding, fish are able to take the pellets in the water column before they settle down in the sediment, thereby spending less energy and effort in foraging. However, no significant decline in abundance of natural food, which might be ascribed to trout predation could be detected over the 7-day period of the trial.

TABLE 25· Electivity index of macroinvertebrates in the stomach contents of trout in control ponds 7 & 8 deprived of artifial pelleted diet for one week (12 - 20 October 1989)

		[a]CONTROL POND 7	8
	% No. in stomach (Pd)	14.2	3.26
ASELLIDAE	% No. in stomach (Pd)	71.5	66.3
	Benthic electivity index (BEI)	+ 0.67	+ 0.91
	Pb	14.8	18.2
CHIRONOMIDAE	Pd	18.1	91.6
	B.E.I.	+ 0.10	+ 0.67
	Pb	3.56	15.7
GAMMARIDAE	Pd	2.89	47.1
	B.E.I.	- 0.10	+ 0.50
	Pb	9.31	8.82
HIRUDINAEA	Pd	17.3	21.1
	B.E.I.	+ 0.30	+ 0.41
	Pb	8.59	3.28
MOLLUSCA	Pd	50.7	2.51
	B.E.I.	+ 0.71	-0.13

[a]Codes are as explained in Table 2

Continue.....

TABLE 25.

		CONTROL POND 7	CONTROL POND 8
	% No in Benthos (Pb)	9.82	38.9
OLIGOCHAETA	% No. in stomach (Pd)	5.52	89.4
	Benthic electivity index (B.E.I.)	- 0.28	+ 0.40
	Pb	19.8	7.22
SIALIDAE	Pd	45.7	15.4
	B.E.I.	+ 0.40	+ 0.36

4.6.3.4 FOOD INTAKE AND GROWTH

The relationship between food intake, measured as wet weight and estimated as explained in section 3.10.5, and growth rate of fish stocked in the various ponds are represented in Figures 82-97. This relationship attempts to simultaneously explain the influence of water temperatuere and relative food intake (% wet weight) on fish growth during fish culture. Average values were used in the modelling and variations in food intake were not unexpected, especially in small fish where food intake was highest and variance in growth rates tend to be greater.
In all the ponds, temperature clearly affected the magnitude of food intake. (Figs. 82-89). For example, relative food intake (RFI) increased with rise in temperature and the range 5.0-14.9% per day was observed between 13.7-16.9^{0}C during the summer months of July-September. The low RFI recorded in HPN ponds 3 & 4 (Figs. 84 & 85) despite high water temperature is not unexpected in view of the low abundance of natural food. In all the ponds however, food intake fell progressively with fall in temperature during the winter period. However, compared with other pond treatments, the control ponds had significantly higher RFI values compared to other treatments at a given temperature (Figs. 88 & 89). With regard to the relation between food intake and specific

Fig. 82

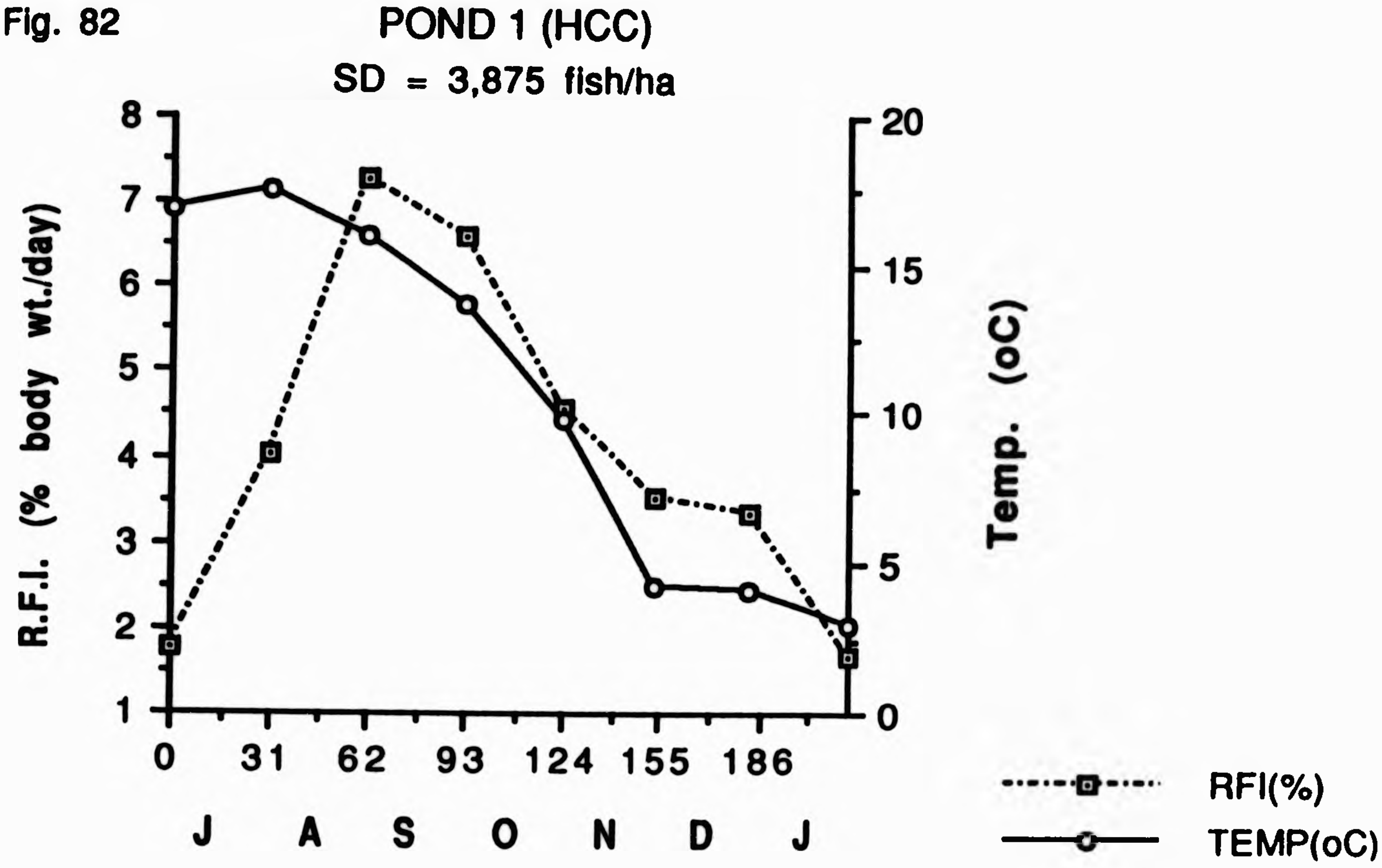
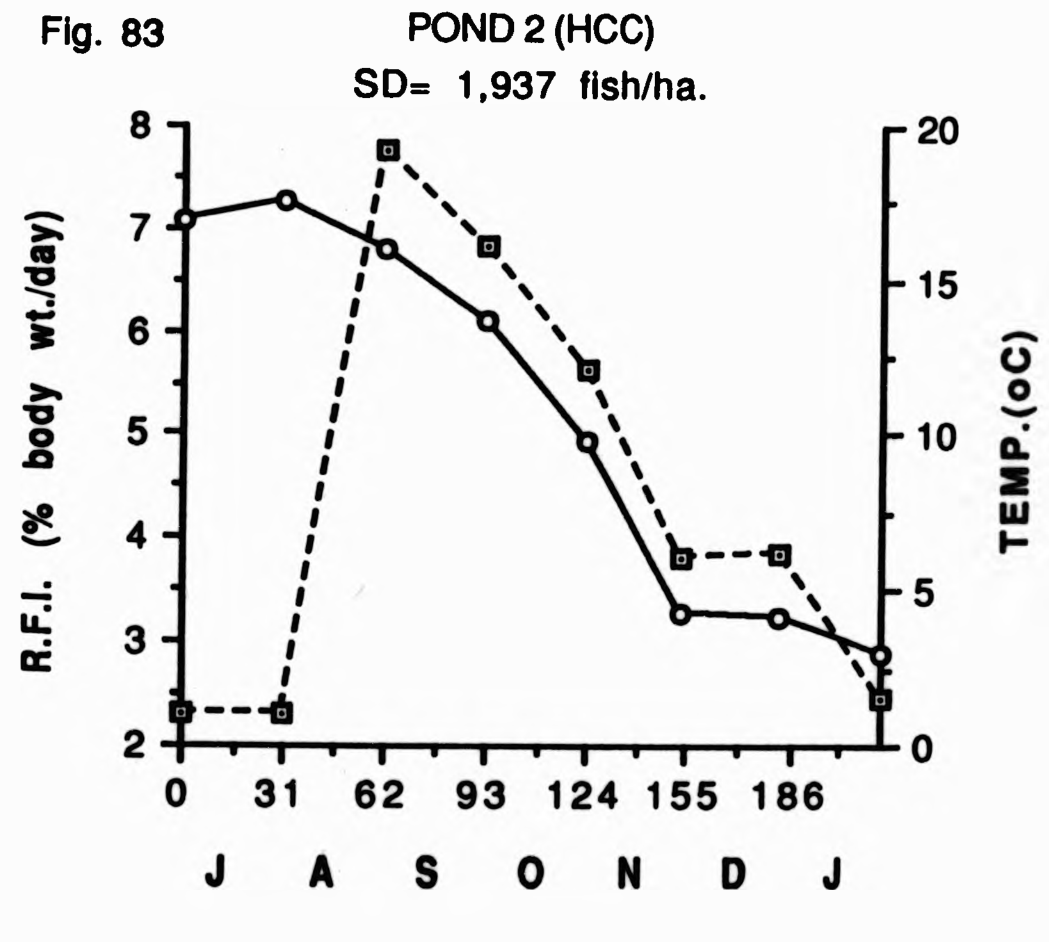


Fig. 83



Figs. 82-83. **Relationship between relative food intake of trout and water temperature, under high chicken and cow (HCC) fertilization and varying stocking density (SD).**

Fig. 84

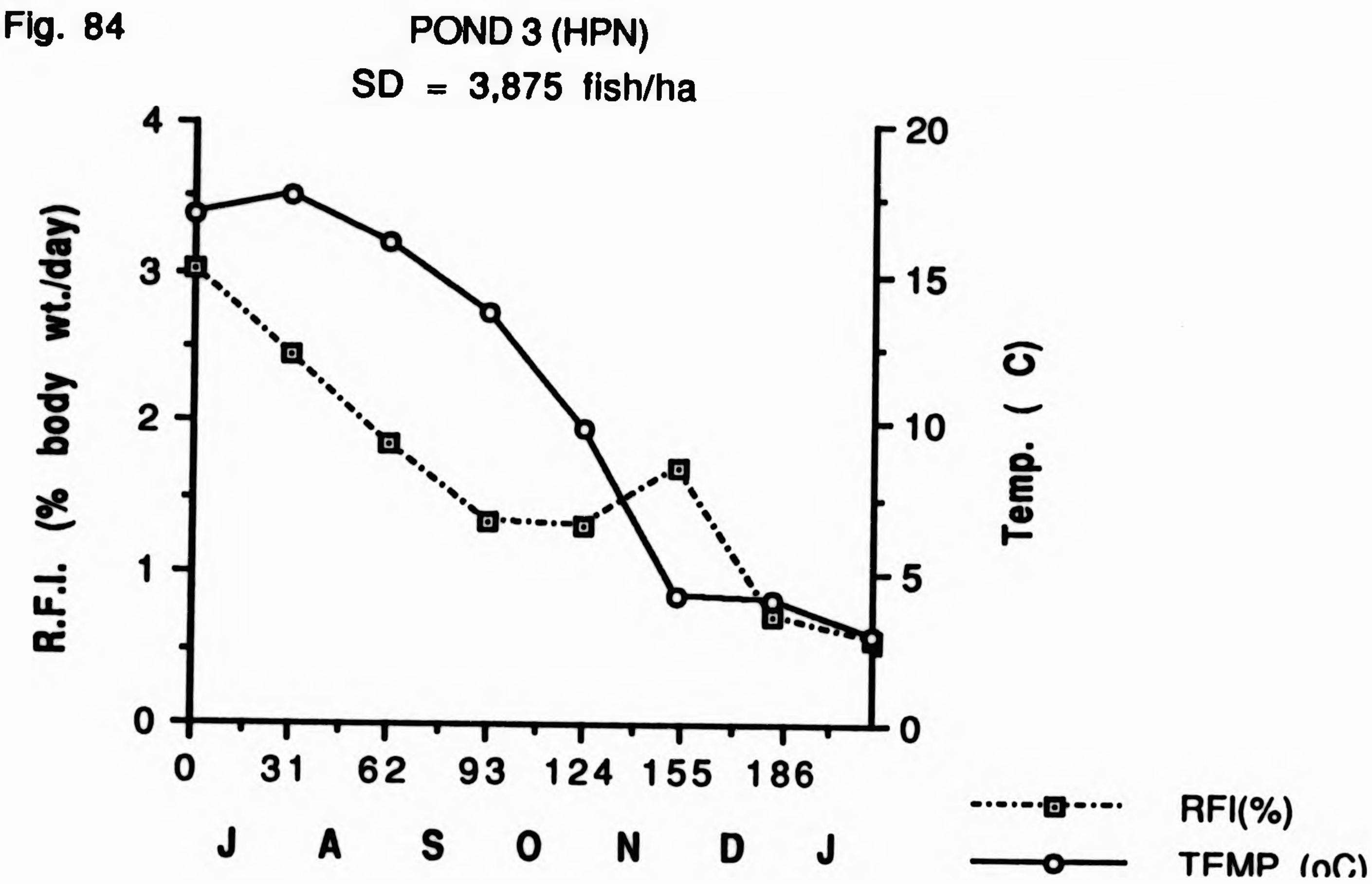
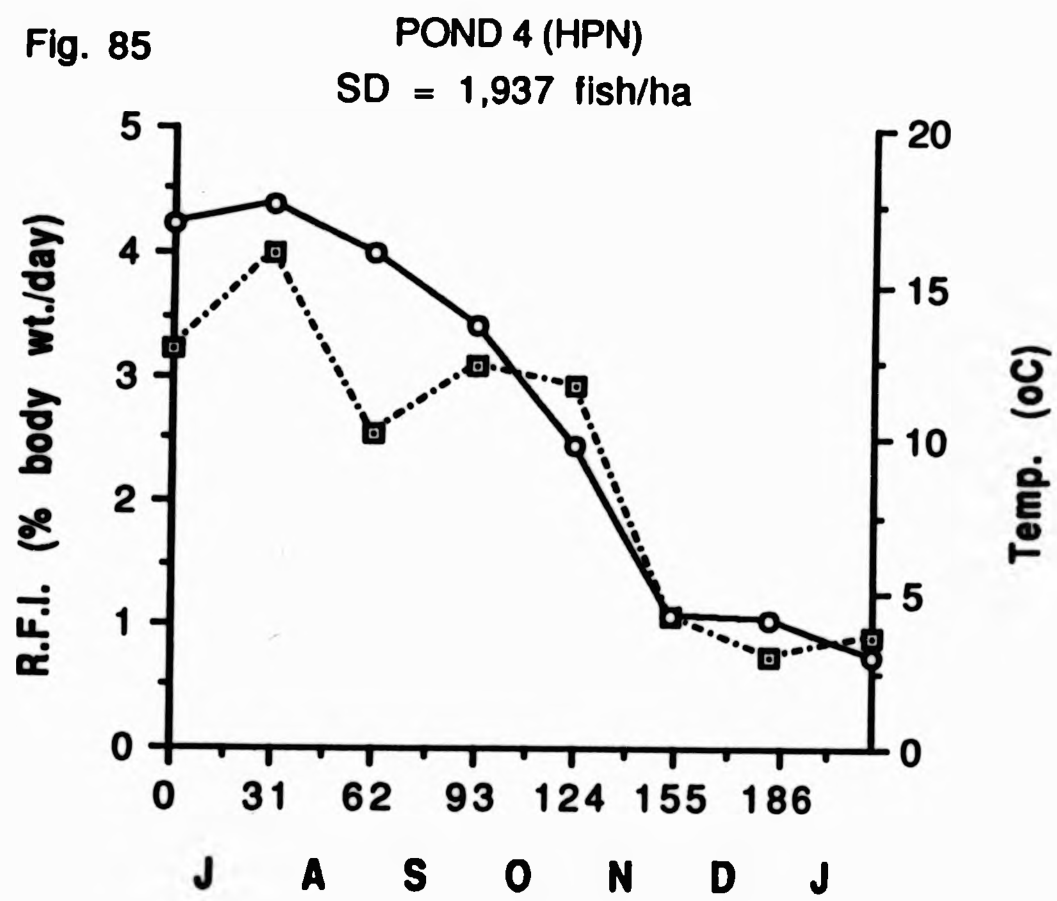


Fig. 85



Figs. 84-85. Relationship between relative food intake of trout and water temperature, under high phosphorus and nitrogen (HPN) fertilization and varying stocking density (SD).

Fig. 86

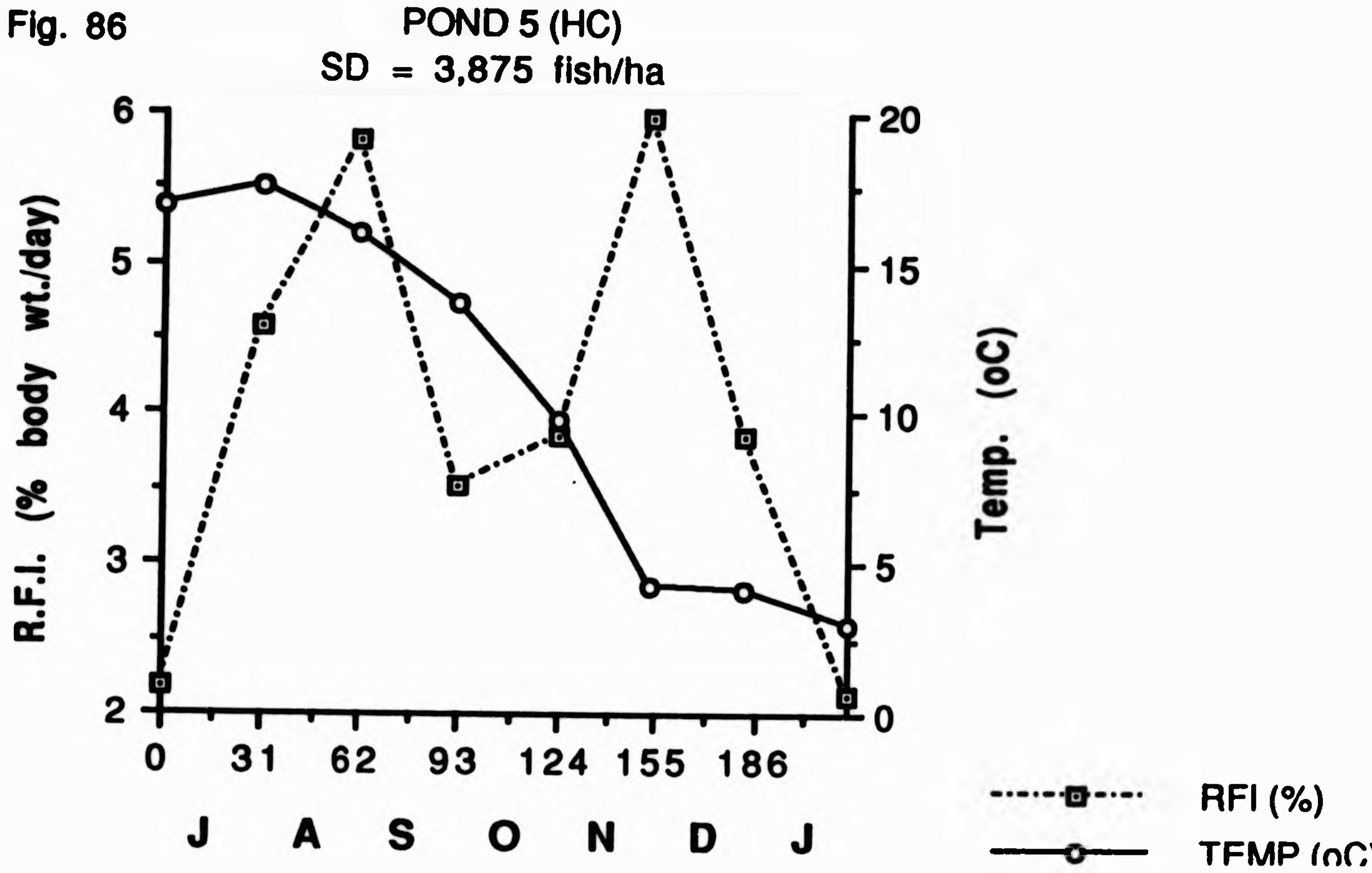
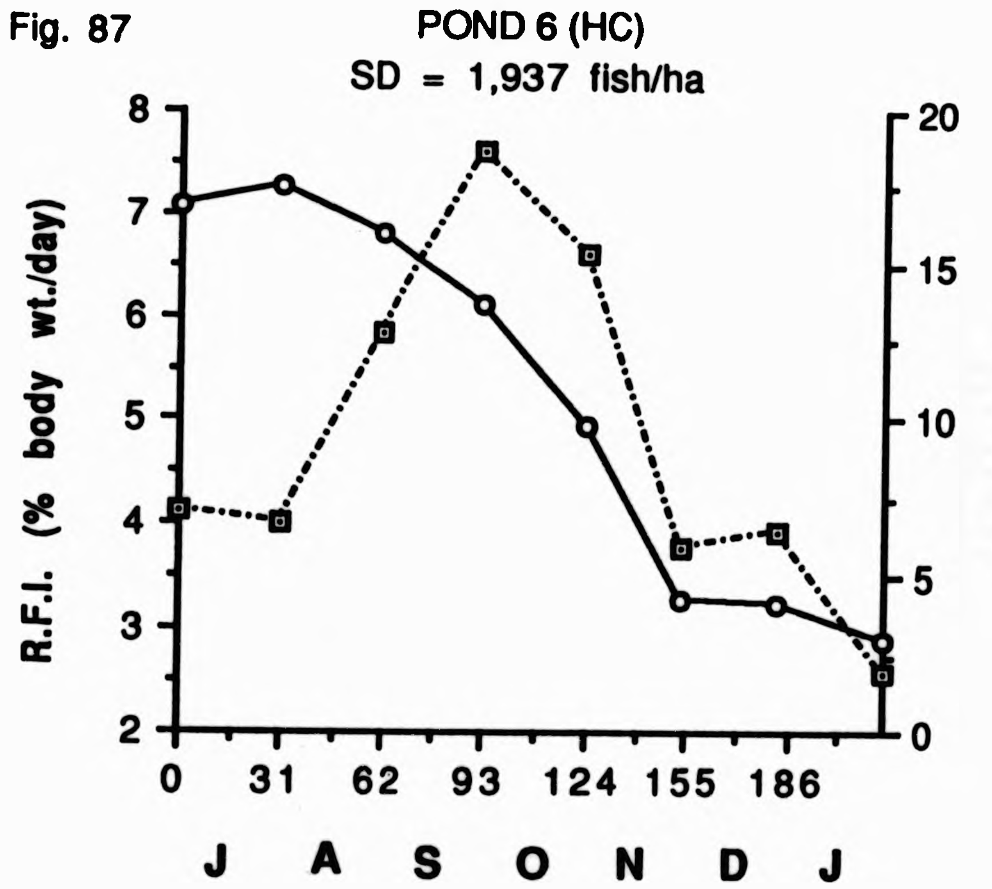


Fig. 87



Figs. 86-87. Relationship between relative food intake of trout and water temperature, under high chicken (HC) fertilization and varying stocking density (SD).

Fig. 88

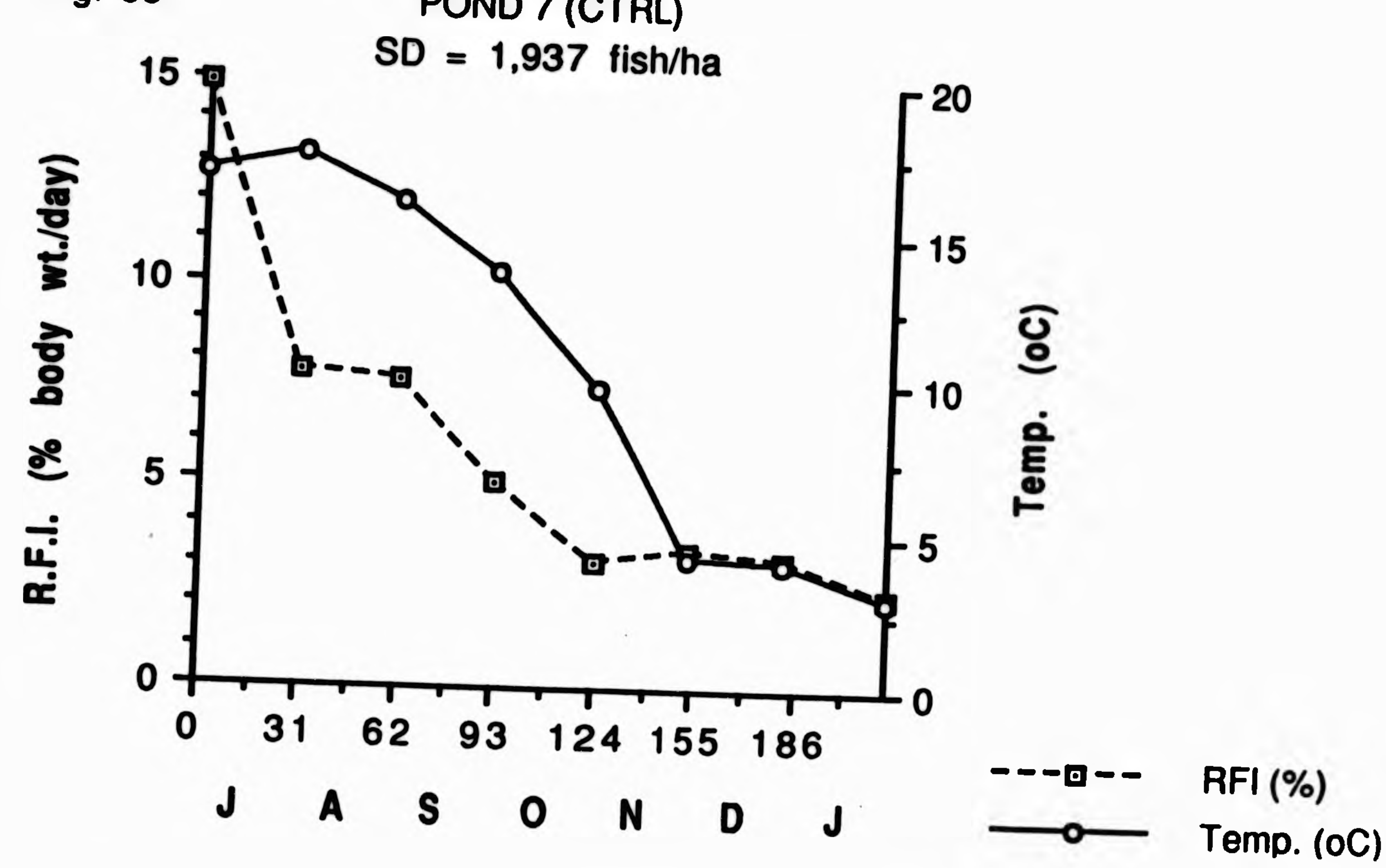
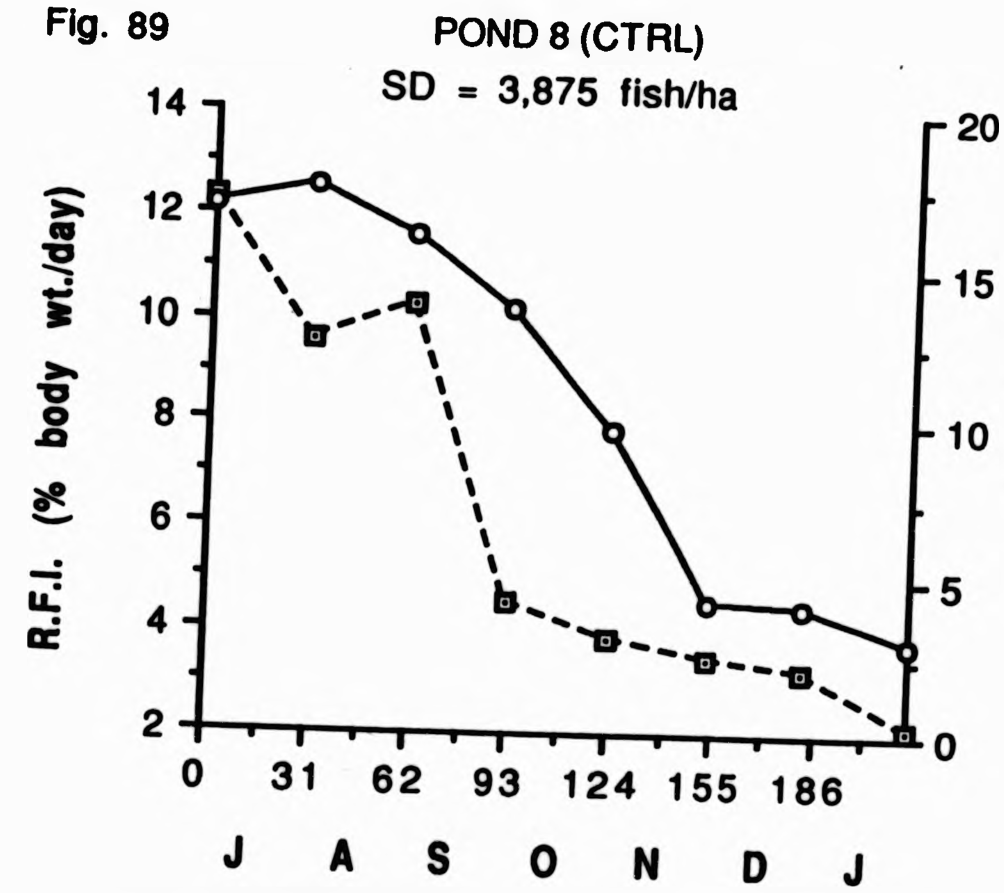


Fig. 89



Figs. 88-89. Relationship between relative food intake of trout and water temperature under controlled (CTRL) condition at varying stocking density (SD). The control ponds have in addition to natural food, artificial pelleted diet, fed at an average of 1% body weight, 3x day^{-1} throughout the culture period.

growth rate (% SGR), shown in Figure 90-97, it was evident that food consumption increased as the fish grows, attaining a peak value during July-September. However, RFI declined with decreasing SGR at the onset of winter. In contrast to bigger fish with high SGR, the smaller fish generally had higher RFI during the winter month in December. Similar to the conditions observed in RFI vs. Temp., ponds 3 & 4 (HPN) showed low SGR and RFI, compared to other ponds. This suggests that, in addition to low food abundance, other internal factors such as stress resulting from decline in water quality conditions at the onset of the culture experiment, had greater influence on food intake and consequently, its efficient utilization for growth. In the control ponds, at the onset of fish culture, pond 7 had the highest RFI of 14.9% per day and fluctuating growth patterns (Fig. 96). In comparison, replicate pond 8 had higher SGR, although RFI declined with declining SGR. (Fig. 97).This may be a result of fall in water temperature during the winter period which affected RFI and consequently growth rate, since in earlier observations, fish with lower SGR showed higher RFI.

Fig. 90

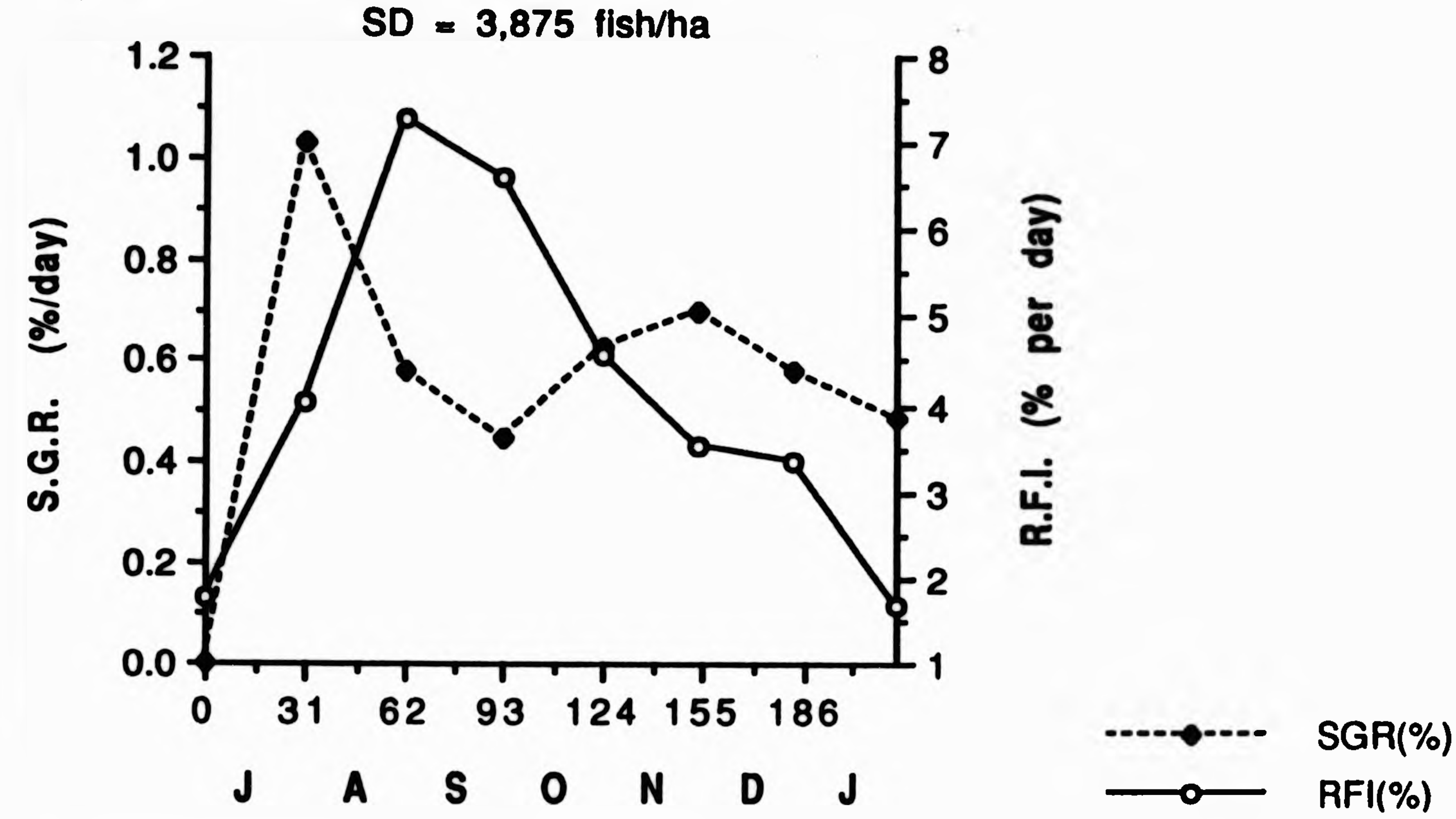
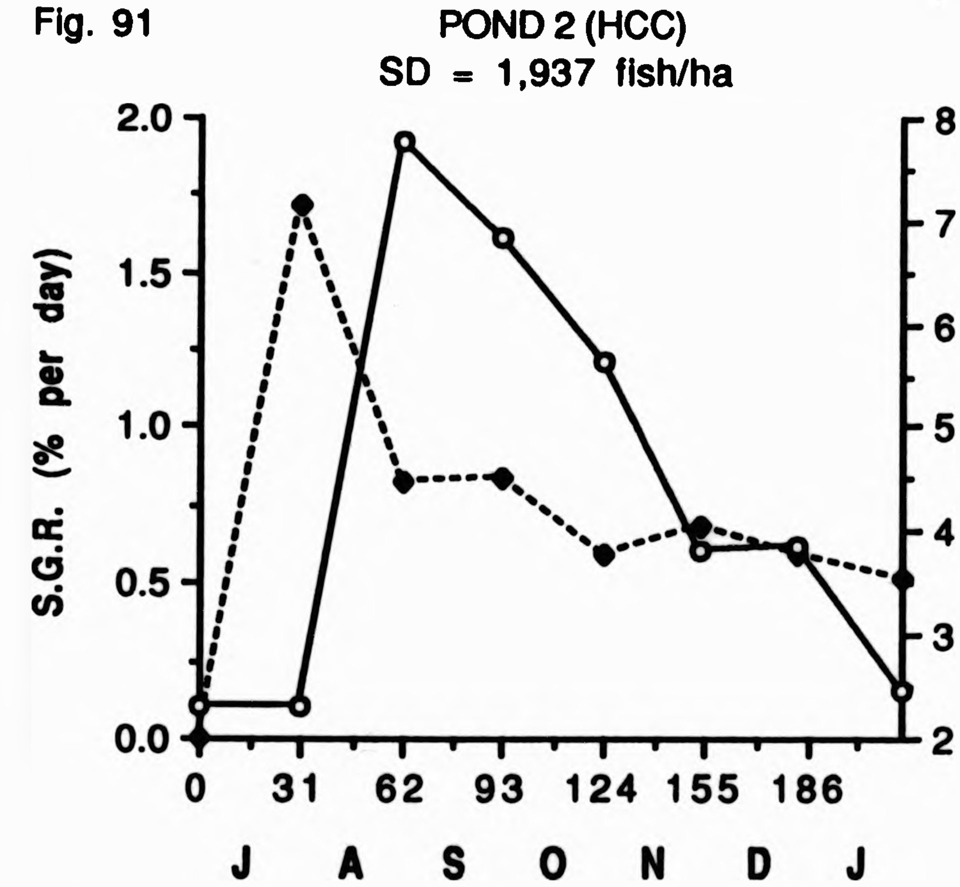


Fig. 91



Figs. 90-91. Relationship between specific growth rate and relative food intake of trout under high chicken and cow (HCC) fertilization and varying stocking density (SD).

Fig. 92

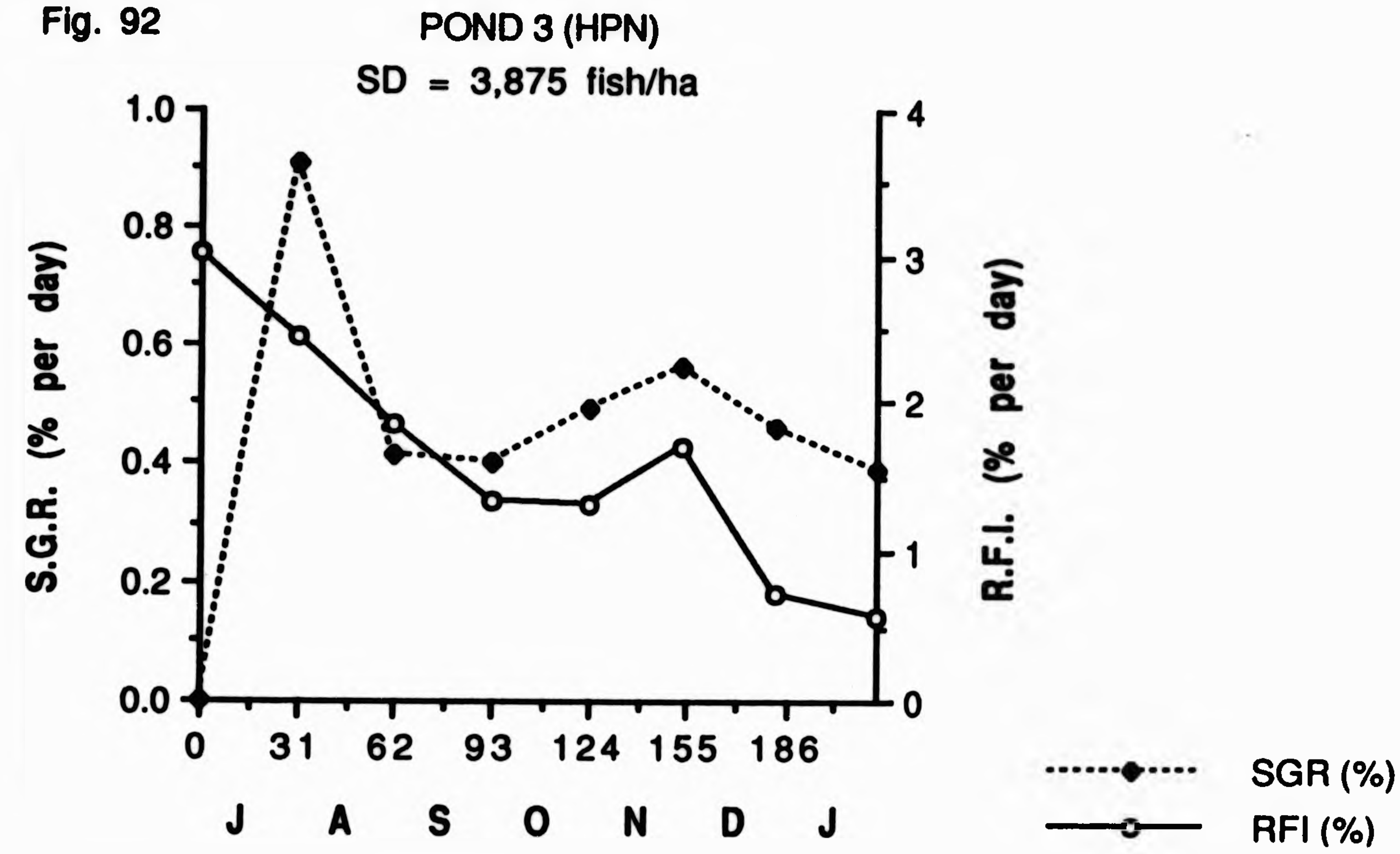
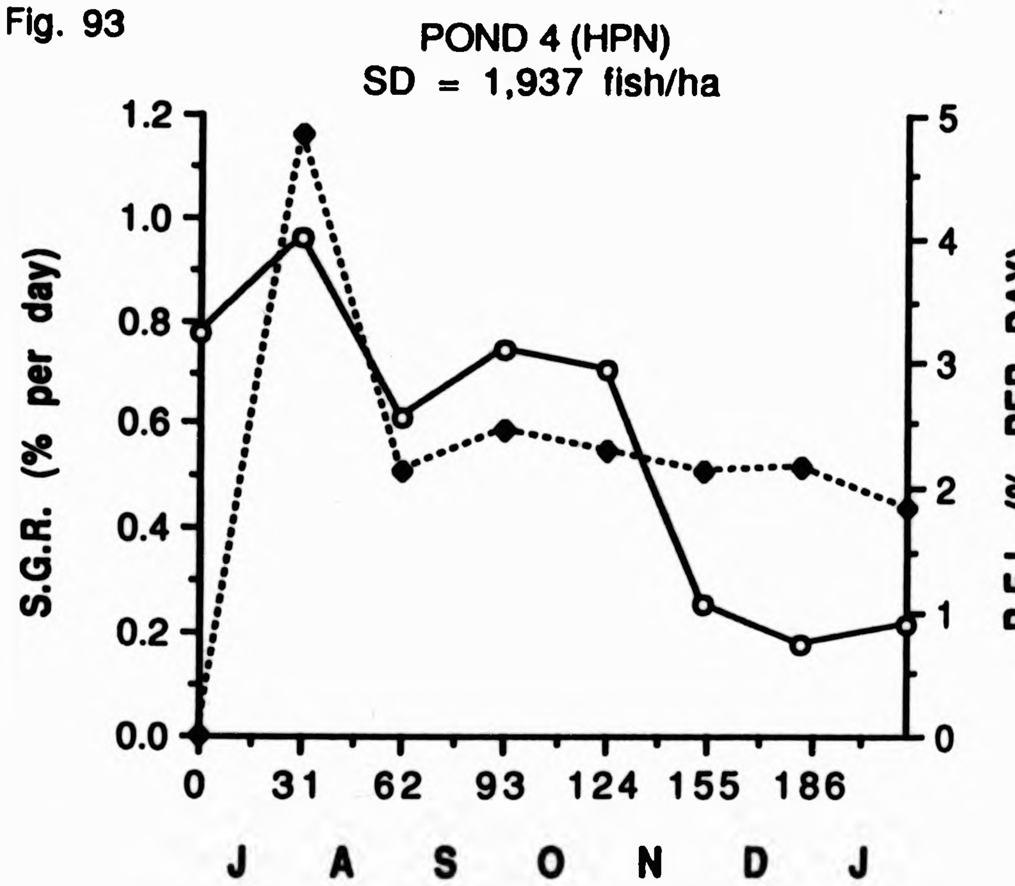


Fig. 93



Figs. 92-93. Relationship between specific growth rate and relative food intake of trout under high phosphorus & nitrogen (HPN) fertilization and varying stocking density (SD).

Fig. 94

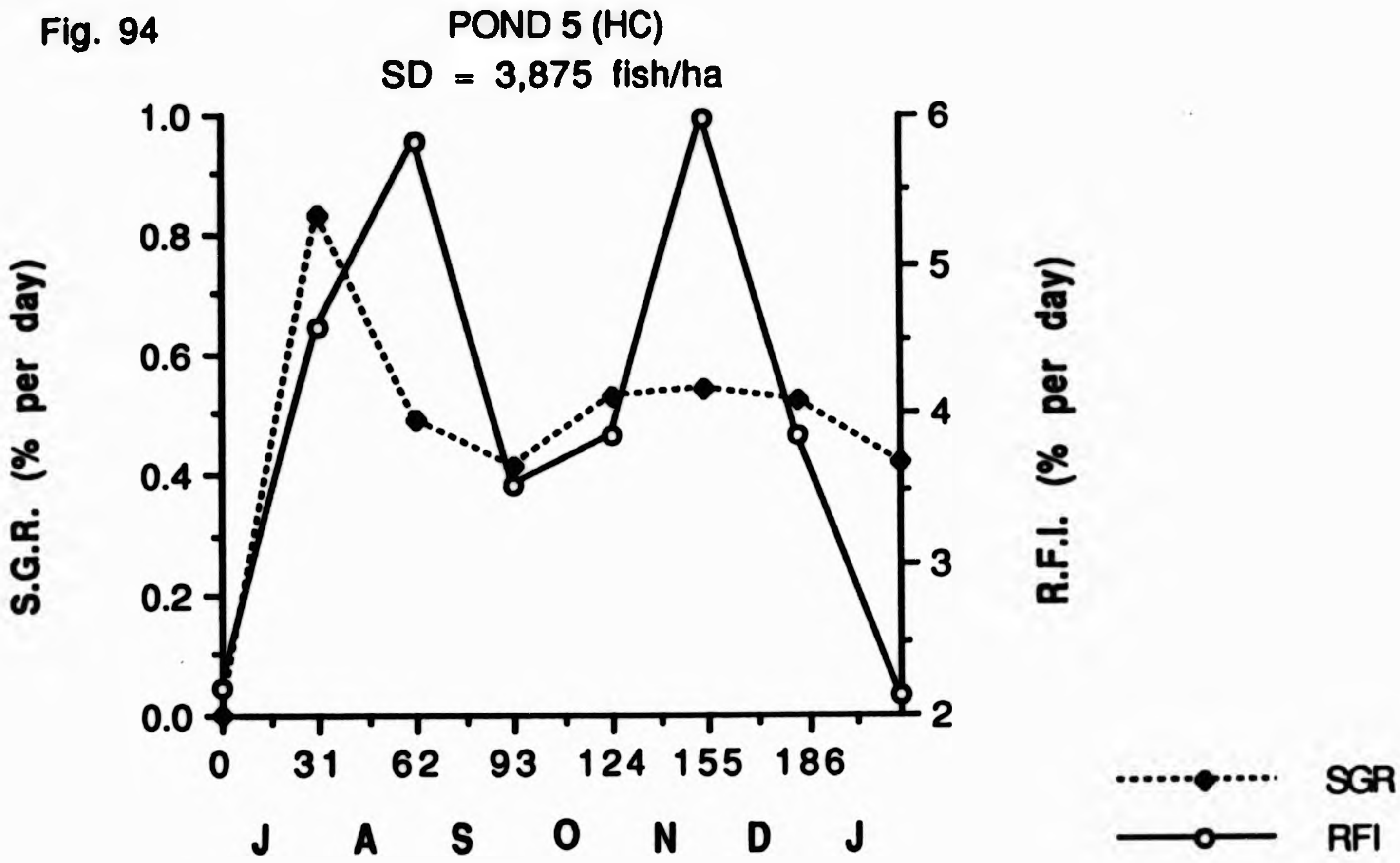
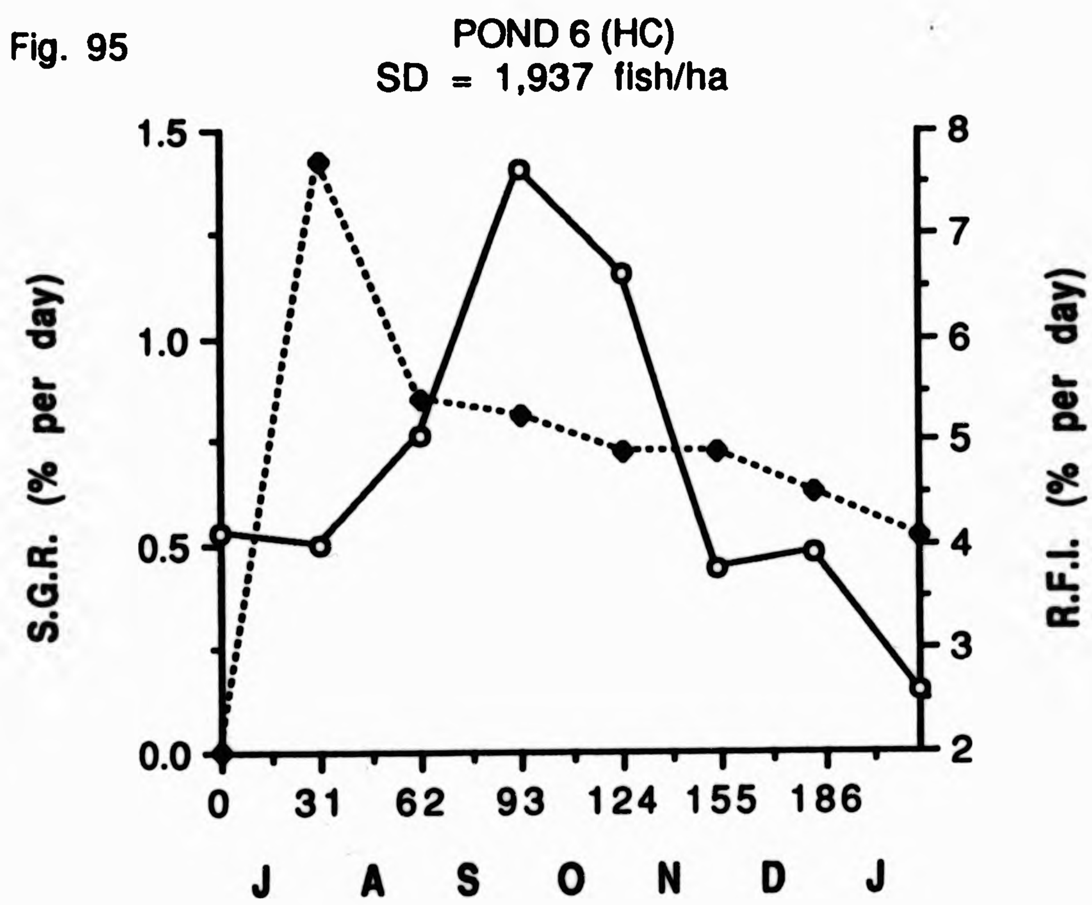


Fig. 95



Figs. 94-95. Relationship between specific growth rate and and relative food intake of trout under high chicken (HC) fertilization and stocking density.

Fig. 96

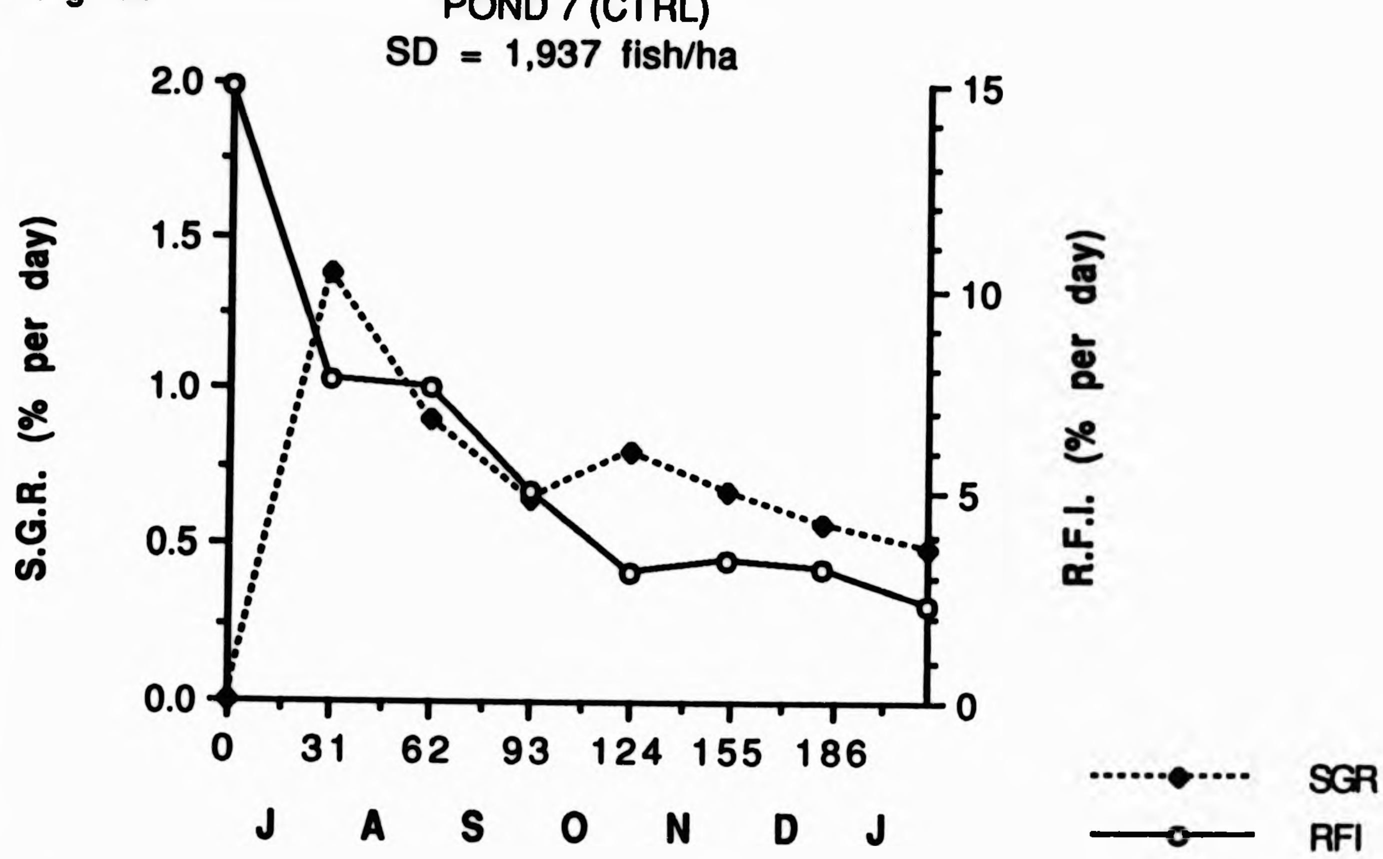
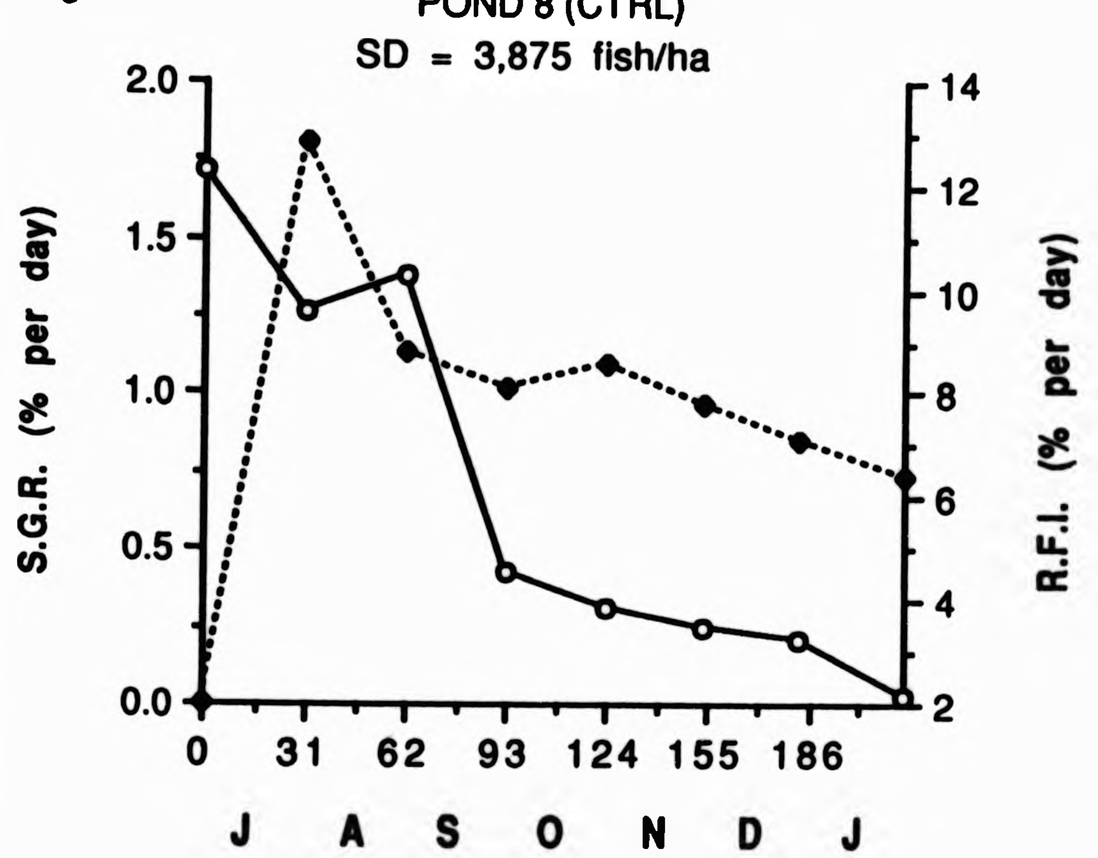


Fig. 97



Figs. 96-97. Relationship between specific growth rate and relative food intake of trout under controlled (CTRL) condition and varying stocking density. (Controlled conditions are as explained in Fig. 89).

4.7 NUTRITIONAL PARAMETERS

Results of nutritional parameters analysed are presented for fish and both artificial and natural food consumed in the ponds. Since the approach to this study is on applied aquaculture ecology, no attempt was made at evaluating in detail all nutritional aspects. Results of laboratory analysis of selected nutritional parameters for natural food and that of artificial diet were were verified with those of the manufacturer's (Ewos-Baker Ltd) specifications, except the results of analysis of diet obtained by stomach pumping. Evaluation of nutritional composition of all food items obtained from stomach pump was carried out and results of natural food proximate composition were pooled together for each genus and expressed as mean for each replicate pond treatment. It is therefore possible that the composition may vary among groups as a result of differences in developmental stages, seasons and feeding conditions. The results of proximate analysis shows that the natural food in the experimental pond compared favourably with artificial diet in meeting the nutritional requirements of trout.

4.7.1. NUTRITIONAL COMPOSITION OF NATURAL AND ARTIFICIAL PELLETED DIET

The nutritional composition of natural and artificial pelleted food and detritus are presented in Table 26. In comparison with artificial feed, it is apparent that except for detritus, *Gammarus* and Mollusca, all the macroinvertebrates were rich in protein. The protein content found in the analysis of natural food and detritus was in the range 36.8-57.3% (dry wt. basis), with Oligochaeta having the highest protein level, while the artificial feed had a mean value of 50%. In comparison, the artificial pelleted diet had relatively lower values for ash and fibre of 10% and 1.0%, respectively, while the lipids, NFE and gross energy had higher values of 17.5% and 5.29 Kcal g^{-1}, respectively. The higher lipid content of the artificial feed has important implications in relation to body weight, fatness and moisture content of fish in the control ponds as described in the preceding section.

TABLE 26 Proximate composition (% dry weight, except for moisture) and gross energy of natural and artificial pelleted diet (% dry wt. composition)

	% Moisture	% crude protein (N x 6.25)	% Ash	% Lipid	% crude fibre	% NFE[a]	Gross energy[b] (K cal/g)
ASELLIDAE	69.8	55.9	20.8	12.3	3.89	7.40	4.55
CHIRONOMIDAE	83.5	53.2	8.82	5.17	2.77	30.0	4.65
GAMMARIDAE	68.3	45.8	26.9	14.8	4.02	8.50	4.28
MOLLUSCA	-	36.8	36.5	6.98	7.10	12.6	3.28
OLIGOCHAETA	71.5	57.3	25.4	5.31	5.76	6.23	3.91
SIALIDAE	71.1	52.7	6.63	4.09	2.58	33.4	4.66
ZOOPLANKTON[c]	81.1	52.9	10.3	22.8	6.92	7.10	5.37
ARTIFICIAL DIET[d]	9.0	50.0	10.0	17.5	1.0	21.5	5.29
DETRITUS	85.7	46.9	13.9	19.3	8.37	11.5	4.89

[a] NFE = Nitrogen free extractives (as crude carbohydrate) : 100 - (% crude protein + crude lipid + % ash + % fibre)

[b] Calculated on the basis of: $\frac{(\%\ \text{protein} \times 5.5) + (\%\ \text{lipid} \times 9.5) + (\%\ \text{carbohydrate} \times 4.1)}{100}$

[c] Zooplankton (dry wt.) based on a mixture of rotifers, Cladocera and copepods.

[d] Trout grower feeds - Ewos Ltd. Westfield, Bathgate, Scotland. U.K.

4.7.2 CARCASS COMPOSITION OF CULTURED FISH

Table 27 shows the carcass composition of juvenile fish from the culture experiment. Although details of fish growth have earlier been described, the initial and final growth data included in this section are to support the observed variations in carcass composition of trout in the various ponds. The mean initial and final body composition profiles of trout in the various treatments (Table 27) indicate significant changes at termination of the experiment. The lowest mean final moisture content of 69.2% and 67.1% was recorded in CTRL ponds 7 & 8 respectively. There was however, no significant differences (P> 0.05) between ponds 1-7, compared with CTRL pond 8 which was significantly different (P< 0.05) from HCC, HPN treatment and pond 6 (HC).

Lipid content was significantly different (P< 0.05) between various treatments and also showed an inverse relationship with moisture content, particularly in CTRL ponds 7 & 8, in which decreased moisture content was followed proportionately with increased lipid content. The significantly lower lipid content of fish in HPN ponds 3

TABLE 27 Growth and proximate carcass composition of trout cultured on natural and artificial diet over 215 days (Mean values in the same column bearing the same superscripts are not significantly different at P = 0.05)

	INITIAL	P1 (HCC)	P2 (HCC)	P3 (HPN)	P4 (HPN)	P5 (HC)	P6 (HC)	P7 (CTRL)	P8 (CTRL)
		POND TREATMENTS[1]							
GROWTH									
Initial mean weight(g)		61.8^{a}	56.6^{a}	65.0^{a}	62.0^{a}	63.8^{a}	56.0^{a}	63.2^{a}	63.8^{a}
Mean weight gain(g/fish)		181.5	167.6	141.4^{a}	158.5^{b}	152.7^{b}	153.5^{b}	173.0	294.4^{d}
CARCASS COMPOSITION(% dry wt.)									
	INITIAL	FINAL (After 215 days)							
Moisture	74.6	73.4^{b}	71.5^{b}	72.4^{b}	70.8^{b}	69.9^{ab}	74.1^{b}	69.2^{ab}	67.1^{a}
Crude protein (N x 6.25)	56.2	72.8^{b}	73.1^{b}	62.9^{a}	66.9^{b}	70.0^{b}	69.4^{bc}	68.5^{c}	70.8^{c}
Lipid	16.1	14.4^{c}	11.1^{bc}	5.45^{a}	8.91^{a}	12.8^{b}	15.2^{c}	18.6^{d}	22.5^{e}
Ash	21.7	11.1^{d}	9.21^{cd}	21.9^{e}	21.2^{e}	14.3^{f}	12.1^{df}	7.12^{abc}	6.21^{a}
Nitrogen free extractives (by difference)	6.0	1.70^{b}	6.59^{d}	9.75^{e}	2.99^{c}	2.90c	3.30^{c}	5.78^{d}	0.49^{a}

[1] Fish in ponds 1 - 6 consumed cultured natural food organism only, while fish in ponds 7 - 8 consumed artificial pelleted diet with supplemental natural food.

& 4 compared with other treatments may be a reflection of low natural food abundance which mainly benefits plankton production. The mean final carcass protein content was significantly higher (P < 0.05) in the HCC and HC treatment than the replicate CTRL ponds.

Ash content was significantly higher in HPN than all the other treatments. The least value of 6.21% was recorded in the CTRL pond 8, which was however not significantly different (P > 0.05) from ponds 2 and 7 of the HCC and CTRL respectively. There was a clear trend in mean final carcass composition of carbohydrate (expressed as NFE), with least values of 0.49% and 1.70% in ponds 8 (CTRL) and 1 (HCC) respectively. The highest mean carcass NFE value of 9.75 was recorded in HPN pond 3.

4.8. COST-BENEFIT ANALYSIS.

A comparison of cost benefit analysis of trout cultured on artificial and natural diet is presented in Table 28. From the results, and with regards to the break even point, in the control ponds and at an operating cost of £1,470 and a price of £2 : 17 per fish, the breakeven point is 677 fish (26.5%). In the case of manured ponds, at an operating cost of £710 and a price of £1 : 89 per fish, the breakeven

TABLE 28 Cost-Benefit analysis of trout production based on artificial and natural diet only

	[a] CONTROL PONDS	[b] MANURED PONDS
***Operating Cost**		
Capital cost	£ 390: 00	£ 390:00
Labour	£ 600: 00	£ 300:00
Feed input	£ 480: 00	£ 20:00
Total cost	£1470: 00	£ 710:00
Sales Revenue		
Mean number harvested(ha^{-1})(N_h)	2,558	2403
Value of a single fish (£) (V_f)	2 : 17	1 : 89
Break even point	677	376
[c]Cost-benefit ratio (CBR)	1:3.78	1:6.40

[a] Estimated cost based on management practice on the farm in which fish are fed artificial pelleted diet only

[b] Estimated cost based on natural diet Cultured on organic manure only

[c] Calculated based on the formula : $CBR = \frac{N_h \times V_f}{Oc} \simeq \frac{\text{Revenue generated}}{\text{Operating cost}}$ (Rutledge, 1990)

* Approximate exchange rate : £1 = $1.89

point is 375 fish (15.6%). These are the least numbers of fish that would have to survive and be harvested in order to cover production cost, without necessarily resulting in any loss or benefit.

The cost benefit ratio shows that at the current high stocking density and number harvested, cost benefit generated are 1 : 3.78 and 1 : 6.40 in the control and manured ponds respectively (Table 28). This implies that for every £1 spent as operating cost, the sum of about £3 : 78 and £6 : 40 is generated in the respective ponds. Thus, the manured ponds appeared to yield greater benefit or economic impact to the farm *vis-a-vis* operating costs. Estimates for the number harvested is also based on average survival rate of 85% in both treatments. Under normal circumstances, not all fish in the ponds are harvested. Therefore, given that 20-50% harvest is maintained as commonly practiced on the farm, a *pro rata* cost benefit analysis will still result in greater benefit or economic impact in the manured than the control ponds.

CHAPTER 5

DISCUSSION

The effects of biomanipulation of the ecology of earthen ponds to stimulate the production of trout, while maintaining adequate water quality conditions, showed wide variations in response to the three discrete nutrient levels separately applied during the inorganic and organic fertilization. The highest of these fertilization levels did not create deleterious or anoxic conditions for benthos, plankton and fish under static and minimal water flow conditions.

A healthy pond environment is of paramount importance to the production of fish and its food organisms, especially when inorganic and organic fertilizers are applied. The physico-chemical parameters measured during fertilization and fish culture trials served as indicators of water quality and their suitability for trout culture, while plankton and macroinvertebrates were taken as biological indicators of potential food sources for growth and development of trout under natural conditions. At higher stocking density, trout exerted a greater influence on zooplankton. Clear trends towards greater food selectivity, improved utilization and growth in response to the abundant natural diet were also established, especially in ponds that had medium and high organic manuring. Variations in pond productivity *vis-a-vis* fish production may be accounted for by differing fertilization levels and that influence of environmental factors during the summer and winter periods. The nutritional composition of the natural diet, in comparison with artificial diet has also been established to meet the dietary requirements of cultured trout. However, other potentials in relation to their efficient utilization and energy budget analysis based on large scale trial under different environmental conditions need to be further explored, in order to maximize production at optimum cost. The goal of rational pond management, is to fully utilize the existing ecological niches in the ponds for high natural food production and consequently fish yield. This is discussed in the light of the present findings, and also related to pond ecosystem manipulation and implications for management.

5.1. POND FERTILIZATION

The processes of eutrophication in ponds as a result of inorganic and organic fertilization are reasonably well understood, having been studied extensively for over three decades (Ness, 1949; Vollenweider, 1969; Wohlfarth & Schroeder, 1979; Lathrop, 1988; Levine & Schindler, 1989). Schroeder (1980) reported that the characteristics of a pond morphometry make it an execellent environment for converting crude, inedible nutrient materials into high quality fish food. Nutrients and minerals originally bound in relatively indigestible form are released by intense microbial activity in the water column and at the pond bottom, and provide substrates for autotrophic and heterotrophic production of fish food.

The efficiency of fertilizers in stimulating eutrophication and natural food production depends largely on methods of application. Wohlfarth and Schroeder (1979) and Boyd (1981) reported that liquid fertilizers or those dissolved in water to form slurry are more effective than solid fertilizers especially as sources of phosphorus for fish ponds. In this study, the application of fertilizers in slurry form probably explains the fast response of eutrophication from oligotrophic status within 4 weeks of the commencement of the experiment. Several workers have made similar observations (DeNoyelles & O'Brien, 1978; Metzger & Boyd, 1980; Boyd *et al*, 1981, Tamatamah, 1990), suggesting that more efficient means of fertilizer application enhances aquatic productivity.

Despite thorough understanding of the processes of eutrophication and pond management resulting from different fertilization strategies, the mechanisms by which manure enters a natural food web are still not well understood. Wohlfarth and Schroeder (1979), Schroeder (1980) and Masser & McDiffet (1986) suggested that fertilizers applied in an aquatic ecosystem may enter the food web in several ways: first, as a food consumed directly by fish; second, as a source of minerals used in photosynthetic production of phytoplankton which are one of the first links in the a food chain and third, as a source of organic substrates and minerals for heterotrophic micro-organisms, which in turn may be consumed directly by zooplankton, benthos and/or fish. A summary of the conceptual model of the fate of applied fertilizers and food web in relation to fish production in aquatic ecosystems is presented in Fig. 98. Soluble inorganic nutrients in pond water are directly utilized by phytoplankton and macrophytes for growth and development. However, inorganic fertilizers alone have been reported to produce lower fish yields (10-15 Kg ha^{-1} day^{-1}) than is possible using organic manures (approx. 30 Kg ha^{-1} day^{-1}) (Schroeder, 1978). Phosphorus tends to be rapidly locked in the sediment and gradually released into the pond water through various chemical processes. Moores (1985), reported that during the input of organic materials into an aquaculture system, proliferation of natural food organisms is affected by the presence of other species. There has been no reported work on direct consumption of organic fertilizer by trout, except for incidental uptake of detritus and plant materials during exploitation of benthic food organisms (Waddell, 1988; Larkins, 1989; Stirling & Wahab,1990; Wade & Stirling, 1990) as also found in this study. However, several authors (e.g. Fish, 1955; Newell, 1979; Hargrave, 1976) concluded that the microbial community in detritus including decayed manure, and organisms essentially provide all nutrient requirements of fish feeding on it. The detritus substrate passes through the fish gut relatively unaffected and when voided as faeces, it is recolonized by micro-organisms and consumed

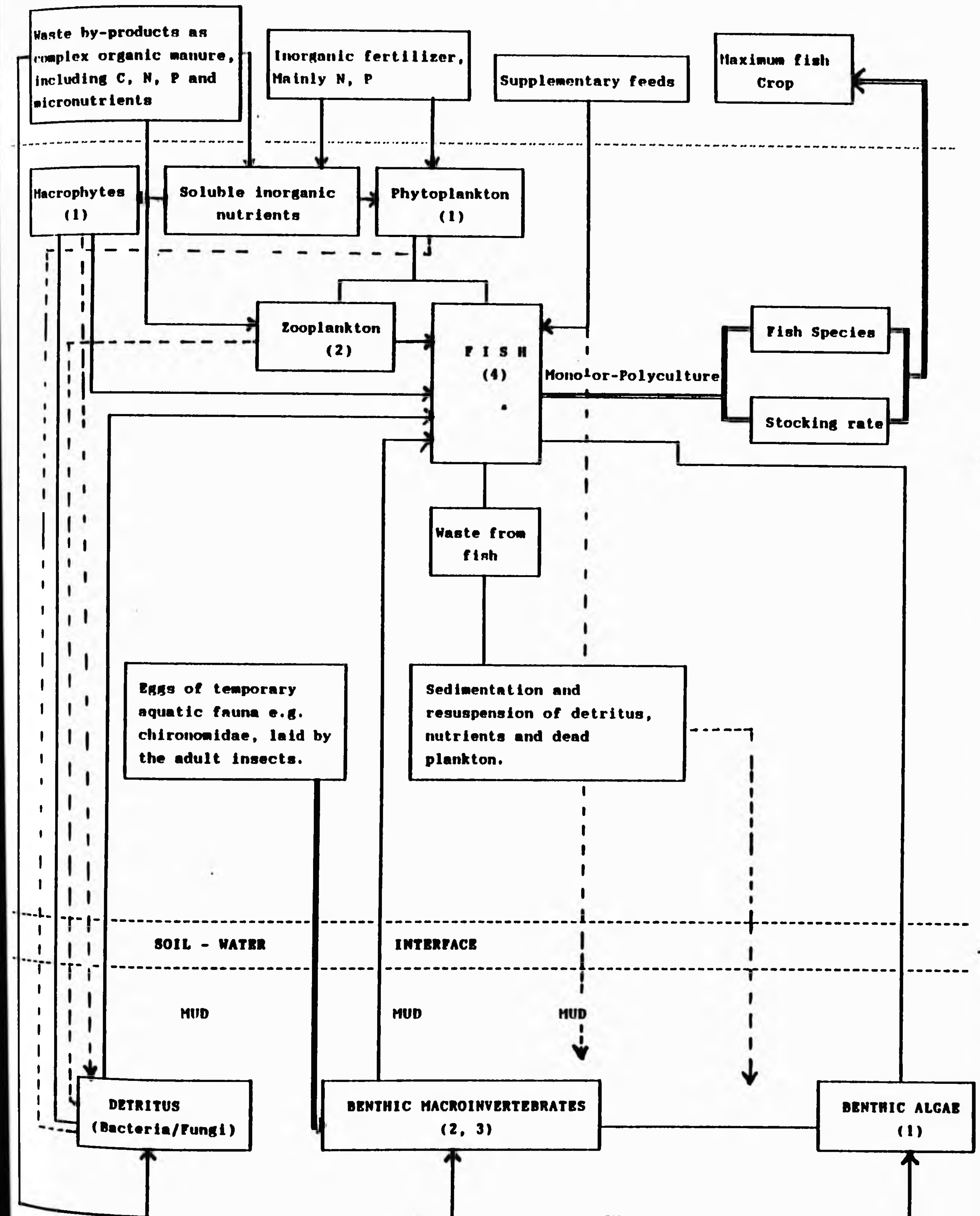
Fig. 88. Conceptual model of the fate of applied inorganic and organic fertilizer and food-web of fish in aquatic ecosystem. (Modified from Moore, 1985; Stirling & Phillips, 1990.)

———— Direct feeding

.... Transfer through decay processes

════ Secondary production

1, 2, 3, 4, Trophic levels.



again by the fish. It is therefore more plausible that since trout are predominantly carnivorous, the pathway of fertilizers in the heterotrophic food web which favours secondary production of natural food organisms is more beneficial.

Although direct consumption of inorganic fertilizer for development of natural food is not well established, liquid or slurry forms have been shown to be more effective than granular or solid forms in stimulating production (Boyd, 1981; Boyd & Musig, 1981; Boyd, 1986). Similarly, their role as a ready source of nutrients for plankton may be through physiological processes (DeNoyelles & O'Brien, 1978; Viola *et al,* 1986). This, however, contrasts with organic manures which are rich source of carbon and can be consumed directly by both zooplankton and benthos (Schroeder, 1980; Masser & McDiffett, 1986; Zhang *et al*, 1987). In addition, the manure contains free energy and dissolved nutrient elements available for construction of living protoplasm (Sunders *et al*, 1980).

Differences in efficiency of both inorganic and organic fertilizers in stimulating natural food production have been reported by Wohlfarth & Schroeder (1979). These authors demonstrated that in Brazil, mineral fertilizers were more effective than cattle manure in stimulating plankton production and hence fish growth; whereas at Ginosar, Israel, the opposite was the case. In the case of organic manure, they reported that chicken manure was more effective than cattle manure in stimulating plankton production at Ginosar. In this study, similar efficiency was found with high chicken (HC) manure, but a combination of high chicken and cow (HCC) manure was more efficient in production of zooplankton and benthos, and hence fish growth. These contradictions with low yield obtained at Ginosar may be due to management methods employed, most especially as cattle manure alone has been reported to contain less nutrients than chicken manure (Little & Muir, 1987).

Varying nutrient levels and stocking densities throughout the fish culture trial probably explains the differences in fish yield. Low fish yield in the high phosphorus and nitrogen (HPN) ($\approx$ 190.4 kg ha^{-1} yr^{-1}) compared with high chicken (HC) ($\approx$ 311 kg ha^{-1} yr^{-1}), high chicken and cow (HCC) ($\approx$ 437.4 kg ha^{-1} yr^{-1}) and control (CTRL) ($\approx$ 819.7 kg ha^{-1} yr^{-1}) may be due to the fact that inorganic fertilizers mainly benefit plankton production. This is further supported by the abundance of phytoplankton groups in the HPN treatment which are not easily digested by trout, being carnivorous, compared to herbivorous fishes. The low yield might have also resulted primarily from other factors such as improper stocking densities and/or use of fertilizer. Thus monoculture could result in inefficient utilization of natural food, especially when a species is restricted to a particular feeding habit (Odum, 1970), in contrast with polyculture which enhances efficient exploitation of all available feeding niches (Tang, 1970). Adequate stocking densities are also required as fish yields will increase with increasing density up to the carrying capacity of a pond (Hepher, 1975; Hepher *et al*, 1989). High fish yield on the other hand, has been attributed to pond design and construction appropriate to fertilization, although there are insufficient data to give exact parameters for this (Schroeder, 1980). However, based on studies of pond fertilization to stimulate fish production in Israel, Buck *et al* (1978) proposed that pond bottoms should contain adequate fine particles or mud for suspension in the water column in order to provide colonization foci for micro-organisms. Similarly, ponds should be relatively shallow in the range, 0.7 - 1.7m deep. Ponds used in this study appear to fulfil these conditions, and the high fish yield in the fertilized ponds may be attributed to high manuring rate which enhanced zooplankton and benthos production. In contrast, apart from the abundant phytoplankton not consumed by trout in the HPN treatment, the coarse substrate in replicate pond 3 that had high stocking density probably contributed to low production of benthic macroinvertebrates. Under this condition, benthos could not have benefited from periphyton and other dead planktonic organisms which mostly settled on the coarse stones rather than muddy substrate. This proposition is further supported by the reported works of Nalepa & Thomas (1976), Dermott (1978) and Winnell & Jude (1984).

Following the liming of ponds during the first year of study, favourable pH ranges of 5.7 - 6.0 and 6.8 - 7.2 for sediment and water respectively were sustained. This probably contributed to maintaining the buffering capacity of the aquatic ecosystem and consequntly, improved biological production. Boyd (1986) reported that, for a pond to respond properly to fertilization, bottom muds must not be highly acidic and the total alkalinity and total hardness of water should be > 20 mg l^{-1} as $CaCO_3$. Acidic muds strongly adsorb phosphate, while benthos, including bacteria do not grow well at low pH.

An important issue concerning the use of biomanipulation both as a restoration technique and enhancing pond productivity is the duration of its effects. Henrikson *et al* (1980) reported that the beneficial effects of fertilization lasted for at least 4 years in their experimental lakes kept free of fish. In contrast, Shapiro & Wright (1984) in their study in Round Lake, Minnesota, U.S.A reported that the effects persisted for 2 years when the lake was restored with planktivores, piscivores and benthivores. In this study, carry-over effects persisted throughout the first year of natural food production and the second year of fish culture trials. However, in the third year when the entire experiment was terminated, eutrophication occured in the late spring and summer, but was less pronounced than in the previous years. Nutrient gradients in the sediment and water column caused by biomanipulation probably explains the prolonged effects, especially during the warm season when increased temperature triggers a series of mechanisms which leads to gradual release or remobilization of limiting nutrients like phosphorus for development of plankton (Bjork-Ramberg, 1984; Shapiro & Wright, 1984; Bailey-Watts *et al*, 1987b; Drake & Heaney, 1987; Levine & Schindler, 1989).

During both fertilization programmes, the nutrient levels with highest combination, i.e., high phosphorus and nitrogen (HPN) and high chicken and cow manure (HCC) clearly showed greater response to plankton and benthos production. However, one-way ANOVA and Duncan Multiple Range Test did not always show significant differences in production between HP/LP, HP/HPN, HC/LC and/or HC/HCC. The fundamental hypothesis of the manipulation studies was that these three discrete nutrient levels would stimulate production proportional to their input levels, but it was not always the case. Similar findings have been reported by Hall *et al* (1970) and DeNoyelles & O'Brien (1978). Several workers (Hall *et al*, 1970; Edmonson, 1972; Morris & Lewis Jr., 1988) have proposed possible explanations leading to the rejection of this hypothesis. These include, first, the various nutrient levels may not necessarily result in significantly different nutrient concentrations in the ponds. Besides, since fertilizers have been continously added to the ponds, the oxidized sediments possibly bind the nutrientes, especially phosphorus. The favourable response by the natural food organisms in ponds that received high nutrient combinations may cause a nutrient gradient and consequent accumulation in the water column, thereby compensating for any short fall. Second, the response to different nutrient manipulation by autotrophic and heterotrophic production may not necessarily be in a linear fashion.

5.2. PHYSICO-CHEMICAL CHARACTERISTICS OF POND WATER QUALITY AND EUTROPHICATION, WITHOUT FISH.

The observed isothermal nature of the water temperature throughout the study was not unexpected, considering the shallow nature of the ponds which have a mean depth of 1.5m and a mean surface area of 195 m^2. This depth is less than the limiting depth of summer mixing (Z_m) of 6.3m predicted by Ragotskie (1978). The fluctuation in water temperature during the summer and winter periods is consistent with the environmental conditions. This lack of stratification has also been reported by Wahab (1986) and Stirling & Dey (1990) in the Howietoun ponds and Loch Fad which have mean depths of 3m and 5m respectively. The mean summer temperature range of 17.5 - 23^{0}C recorded during the fertilization and fish culture trials might have contributed in stimulating the growth and development of both natural food organisms and trout. Macan (1961, 1963), Morgan & Waddell (1961) and Maitland (1978) separately reported that day length and/or temperature regulate growth, life-cycle and distribution of freshwater animals. Similarly, Hilton & Slinger (1981) found that the standard environmental temperatures at which maximum growth and feed efficiency are attained in trout and salmon are 15°C and 10°C, respectively, while growth tends to be slower at 7°C. The upper permissible temperature of 21°C for members of the genus *Salmo* inhabiting temperate waters given by Alabaster & Llyod (1980) falls within limits recorded in this study, which favoured trout survival in the ponds.

The distribution and abundance of species common to enriched ponds have been related to favourable pH conditions and thus, availability of nutrients (DeNoyelles & O'Brien, 1978). In a study of whole lake nitrogen fertilization for controlling algal blooms in a hyper-eutrophic lake, Lathrop (1986) reported that high muddy pH values, in the range 9.5 - 11 resulted in dense algal blooms and higher concentrations of unionized ammonia. However, when algal blooms were less dense and the lake water became clear, pHs were generally in the range of 7.2 - 8.8. Boyd (1986) reported that in waters with naturally high pH and high calcium concentrations, phosphate applied in fertilizers may be quickly precipitated from the water as an insoluble calcium phosphate. He therefore suggested that phosphorus application rate must be greater in hard water of high pH than soft water with moderately low pH. In this study, the rise in pond water pH from 7.0 - 7.5 at the pre-manipulation state to 7.93 - 8.39 in the control (CTRL), low phosphorus (LP) and high phosphorus & nitrogen (HPN) treatments may be as a result of response to liming, as also suggested by Boyd (1981). In the organic treatments, throughout the summer and winter periods, pH values were within the alkaline range, except for low chicken (LC) and high chicken (HC) treatments which fell to acidic range in September and December respectively. Similar range of values have been reported by Jumppanen (1976) in a study of the effects of waste materials and waters in a lake ecosystem. During the breakdown of organic materials in aquatic habitats, fluctuations in the balance of oxygen and carbon dioxide occur and this has been shown to be accompanied by a slight fluctuation in pH (Beeton, 1965; Jumppanen, 1976). Stirling and Dey (1990) reported that less significant reduction in pH may result from the counteracting effect of fish respiration and high rate of photosynthesis at mid-day. Similarly, several workers (e.g. King,1970; Sreenivasan, 1970, 1976; Bales *et al*, 1980; Rimon & Shilo, 1982) reported a closer link between photosynthetic activity and pH in freshwater. Maitland (1978) reported that poorly buffered water may exhibit drastic fluctuation in pH, which may result in an imbalanced physiological adjustment of many aquatic organisms. In general, the ranges obtained in both fertilization trials could still be regarded as normal, being capable of supporting aquatic life, including trout (Boyd, 1979).

Conductivity values partly depend on the nature of dissolved substances in water, and high values indicate greater ability of a water body to carry electric charge, which in turn is related to the total ionic concentration

(Stirling, 1985). By-products resulting from plankton, benthos and fish excretion may have also contributed to maintaining the high values obtained in this study. Total hardness and alkalinity have been reported to be positively correlated (Boyd, 1979; Fast, 1985; Stirling, 1985), because of the predominance of carbonate and bicarbonate ions which are associated with calcium and magnesium. It is generally believed that water with high concentrations of sodium carbonate implies high alkalinity. Besides, high concentration of calcium sulphate indicates greater hardness than alkalinity. In pond aquaculture management, high values of total hardness are preferred to soft waters which are deficient in calcium and magnesium. These are essential for development of mollusc and crustacean shells and fish scales (Stirling, 1985; Wahab, 1986). In this study, although both hardness and alkalinity values were high and remained conservative, showing little fluctuation, the carry-over effects of liming rather than fertilization might have played a significant role as also observed by Boyd (1981).

During this investigation, the high values of suspended solids in the pond waters throughout fertilization and fish culture trials is not unexpected, considering the continuous fertilizer inputs, especially organic manure and the resulting plankton bloom. Besides, artificial pelleted feeds supplied to trout in the control ponds might have also contributed to the increased values. This proposition is supported by Boyd (1982) who reported that variations in the concentration of suspended solids in fish ponds depended upon the degree of mineralization, amount of suspended clay and plankton. Wahab (1986) reported that peak periods of total suspended solids in the Howietoun fish ponds occurred in the autumn and coincided with rainfall. Similarly, considerable amounts of organic solids were produced when feeds are supplied, which in combination with faeces are fragmented by the swimming activites of the fish. These assertions are further supported by Clark *et al* (1985).

The importance of dissolved oxygen to the success or failure of both semi-intensive and intensive aquaculture systems cannot be overemphasized. Several studies have demonstrated that fishes feed and grow best at dissolved oxygen concentration near air saturation (Boyd *et al*, 1978b; Tucker *et al*, 1978; Mackay & Toever, 1981; Parker & Davies, 1981; Cuenco *et al*, 1985; Fast, 1985; Carro-Anzalotta & McGinty, 1986; Boyd, 1986; Wade & Stirling, 1990). Throughout fertilization trials during the first year, prior to fish culture, dissolved oxygen never fell below 6.9 mg l^{-1}. However, the occasional fluctuation observed may not be unrelated to the breakdown of decomposed organic matter which results in uptake of oxygen from the aquatic ecosystem. Besides, Sharma *et al* (1987) reported that any oxygen depletion in fish ponds may be due to bacteria, phyto- and zooplankton respiration, sediment oxygen demand, nitrification and fish respiration. In addition to photosynthetic activities contributing to maintenance of high oxygen level in these nursery ponds, high values obtained may be a reflection of wind action which causes sequential changes of circulation, and thus favourable condition for mixing in the study area. This is further magnified by the funnelling effects of the surrounding hills. These observations are also in agreement with the reported work of Stirling & Dey (1990) on the impact of intensive cage farming on the phytoplankton and periphyton of Loch Fad, Scotland. Allott (1986) and Stirling & Dey (1990) reported that shallow lakes are prone to periodic breakdown of stratification and showed several episodes of less severe deoxygenation, especially in periods of cool windy weather when mixed oxygen-saturated water extends to lake bottoms greater than 5m depth.

It has been reported by Stirling & Phillips (1990) that the level of D. O. in the range, 0.9-3.4 mg l^{-1} is lethal for salmonids including trout, while values between 5-6 and 7.0 mg l^{-1} are ideal for ongrowing and hatchery conditions respectively. The severity of low oxygen is intensified at higher temperatures since metabolic rate and oxygen consumption are greater than at lower temperatures. These assertions are in agreement with the present findings in which very low D.O (2.8 - 3.8 mg l^{-1}) recorded in July in the HPN treatment under still water conditions contributed to 36% fish mortality. Schmittou (1969) reported that water exchange through a static system is a major limiting factor to growth. This agrees with the observations in this study because, commencement of water flow through the ponds at minimum rate improved water quality parameters such as dissolved oxygen, biochemical oxygen demand (B.O.D), ammonia and nitrite, especially in the pond 3 (HPN) (see Fig. 76). These improved conditions stabilized and ensured high survival during the remaining period of the experiment as also observed by Carro-Anzalotta & McGinty (1986) in a study of effects of stocking density on growth of *Tilapia nilotica* cultured in cages.

The increase in B.O.D during both fertilization and fish culture trials is supported by the strong inverse relation with dissolved oxygen as seen in Figures 14 - 17 and Fig. 76 (negative correlation coefficients under inorganic and organic fertilization all significant at $P < 0.05$; see Tables 7 & 8). The B.O.D has often been used to test the degree of pollution in a water body, since oxygen uptake is approximately proportional to three main factors; first, bacterial activity, which in turn, is dependent on the number of bacteria present; second, the quantity of organic materials present and third, algae and zooplankton present in unfiltered natural waters (Stirling, 1985). The observed low values in the range, 1.0 - 2.5 mg l^{-1} during the inorganic fertilization was within acceptable limits for trout survival. In contrast with inorganic fertilization, the maximum value of 12.3 mg l^{-1} may be due to resuspension of anaerobic sediment following manure input. During the fish culture, especially in the organically manured ponds, variations in B.O.D may be a reflection of higher food value of both the food consumed and manure input. Besides, high B.O.D implies rapid digestion and conversion by micro-organisms in the pond system (Schroeder, 1980). In practice however, increase in B.O.D *vis-a-vis* depletion of dissolved oxygen depends on the rate at which the wastes are broken down. However, the effect may not adversely affect plankton, benthos and fish survival because supply of oxygen may be compensated by photosynthesis during the day (Little & Muir, 1987). Total inorganic nitrogen (NH_4-N, NO_2-N, NO_3-N) and reactive phosphorus showed significant variation consistent with increased fertilization. Although the concentrations of total ammonia and unionized ammonia were high during the first year of fertilization, this contradiction with the reported works of Smith (1975), quoted by Wahab (1986), Alabaster & Lloyd (1980), Wahab (1986), Stirling & Dey (1990) is not suprising because of continuous inputs. Wahab (1986) reported that the low unionized ammonia found in Howietoun ponds stocked with fish and receiving continous flow of water was probably due to the coincidence of a decrease in pH and temperature during the increase in total ammonia. In addition to the influence of both inorganic and organic fertilization on the amount of nutrients available in the pond ecosystem, several authors (Campbell, 1973; Kaushik, 1980; Colt & Armstrong, 1981; Neil *et al*, 1981; Boyd, 1982; Shilo & Rimon, 1982; Rimes & Goulder, 1987) have reported that ammonia can originate from different sources which include, first, direct excretion by fish cultured on an intensive feeding regime of high nitrogen containing feeds; second, through direct fertilization or crash of algal blooms and third, water supply polluted with sewage.

In this study, during the fish culture period mortalities coincided with increased levels of ammonia, unionized ammonia and nitrite, in spite of the fact that fertilizer was not applied. However, with the commencement of water flow at minimum rates, these values returned to normal, with no further mortality recorded in the ponds. At present, there is insufficient evidence to suggest that the sublethal effects of ammonia can be attributed solely to the concentration of total ammonia (Colt & Armstrong, 1981). Earlier works by Wuhram & Woker (1948) and Tabata (1962) have demonstrated high correlation of unionized and total ammonia with pH. Colt & Tchobanoglous (1978) found that unionized ammonia reduced the growth of juvenile channel catfish (*Ictalurus punctatus*) in a linear manner over the range of 48 - 989 ug l^{-1} NH_3-N (approx. 0.31 -5.7 mg l^{-1} NH_4^+-N) during a 31-day growth trial. The EC_{50} (concentration causing 50% reduction in weight gain values was 517 ug l^{-1} NH_3-N for wet gain, and the no-growth level was 967 ug l^{-1} NH_3-N. These results contradict the popular assertions that only a particular lethal level of ammonia will have an effect on growth. In their reported work with rainbow trout yolk-sac fry, Burkhalter & Kays (1977) found that 50 ug l^{-1} unionized ammonia had a significant effect on growth; and suggested that an approximate no-growth level may range from 200-600 ug l^{-1} NH_3-N. Comparatively, the range of values reported by these various authors were also obtained in the present study during the fish culture trial. The reduced growth rate, especially in the HPN treatment, may be due to the observed high values, in addition to other interacting factors such as insufficient feed supply. Throughout the fish culture trial, the pond water had pH in the range of 6.8 - 9.4, except during the winter period of January 1990 when it fell to < 4.0. The favourable pH condition would cause most of the NH_3-N to volatilize to the atmosphere as observed by Sharma *et al* (1987). It is therefore likely that the lack of effect on fish growth in the HC, HCC and CTRL ponds, despite relatively high ammonia levels may be due to the counteracting effects of favourable pH and high dissolved oxygen resulting from the commencement of water flow and wind action, as also reported by Larmoyeux & Piper (1973), Ruane *et al* (1977) and Parker & Davis (1981). Mount (1973) reported that water pH values in the range of 6.5 - 9.0 at dawn are suitable for fish production; while the European Inland Fishery Advisory Commission (EIFAC) has set a concentration of 0.025 mg l^{-1} NH_3-N as the maximum allowable level to protect all life stages of fish.

In addition to nitrite (NO_2-N) originating from inorganic and organic fertilizers, it has also been reported that nitrites could originate from the reduction of nitrate by the bacteria in anaerobic mud or water (Hollerman & Boyd, 1980). Besides, an imbalance in nitrification processes often leads to accumulation of nitrite and when in excess amounts, it could be toxic to fish (Boyd, 1979; Colt & Armstrong, 1981; Lewis, Jr. & Morris, 1986). During fertilization, observed nitrite concentrations in the various pond treatments were not unexpected, and similar increased concentration was observed during fish culture. However, as the ponds became more conditioned through occasional draining during monthly fish measurements, there were improvements in nitrite conditions. As nitrite interferes with oxygen transport (Perrone & Meade, 1977; Colt & Armstrong, 1981; Lewis Jr., & Morris, 1986), the high summer temperature and low oxygen concentration observed in July should have produced high mortalities, especially in the organically treated ponds, but did not. This may be due to interference by some dissolved ionic substances such as calcium and chloride which have been shown to lower nitrite toxicity (Crowford & Allen, 1977; Perrone & Meade, 1977). In addition, the interactive effect of the favourably high alkalinity and hardess values might have played a role in counteracting nitrite toxicity to both natural food organisms and the trout.

During the organic manuring, prior to fish culture, changes occurred in the water chemistry on 8/9/88 & 29/9/88. Thus, The decrease in total ammonia concentration was followed by increase in nitrite and nitrate and a corresponding decrease in alkalinity and pH (Figs 4, 10, 19, 22 & 24). These are all associated with the onset of nitrification. Collins *et al* (1975) and Mackay & Toever (1981) found similar changes in the nitrogen concentrations as a freshly established recirculating system became reconditioned, although in their system, nitrite reached much higher concentration (15.5 mg l^{-1}) while nitrate increased more slowly. The simultaneous increase in nitrate and nitrite would suggest that both the *Nitrosomonas* and the *Nitrobacter* bacteria became established simultaneously. Similarly, Mackay & Toever (1981) suggested that nitrification of ammonia generates hydrogen ions, resulting in decreased pH and alkalinity. Although the ponds used in this study were well buffered, the rapid decline in alkalinity especially in the CTRL pond (Fig. 10) may be due to direct uptake of ammonia by algae and other aquatic plants as suggested by Brewer & Goldman (1976) and Mackay & Toever (1981).

Nitrate, a non-toxic and final product of nitrification plays significant role as a major source of nutrient to phytoplankton. Trojanowski *et al* (1985) reported that in ponds used for intensive fish culture, nitrogenous nutrients are rapidly assimmilated by phytoplankton which die-off and sediment to the bottom. These nutrients are not usually rapidly released from the sediment with the result that nitrate concentration in the water body remains low. Similar observations have been reported by Levine & Schindler (1987). The contradictory findings in this study may be explained by the fact that, in addition to the deliberate fertilization which created the observed nutrient gradients, epipelic diatoms and filamentous algae use up nutrients, thus creating chemical gradients which in turn cause more rapid nutrient flux from the soils. This postulation is in agreement with the reported findings of Golterman *et al* (1969), Lee (1970), Boyd (1979) and Stirling

& Dey (1990). The significantly high values of organic nitrogen during organic fertilization may be related to the high leaching and decomposition rate of manure as also suggested by Sharma *et al* (1986).

The role of phosphorus as a source of nutrient in a pond ecosystem is well documented in the literature (Golterman *et al*, 1969; Rigler, 1973; Jumppanen, 1976; DeNoyelles & O'Brien, 1978; Furness & Breen, 1978; Bailey-Watts & Duncan, 1981; Drake & Heaney, 1987; Stirling & Dey, 1990). Phosphorus exists in many forms, amongst which is dissolved reactive phosphorus which is soluble and available for phytoplankton growth (Stirling, 1985). Being the main limiting nutrient for phytoplankton development in fresh water, phosphorus is scarce and forms complexes with different metal ions. In a study of the influence of phosphorus retention by soils and sediments on the water quality, Furness & Breen (1978) reported that phosphorus levels in water tends to remain low despite substantial increase in loading rate. This observation is in agreement with the present findings during both fertilization programmes. This may be attributed to the marked phosphorus retention properties in the soil.

During inorganic and organic fertilization in June and August respectively, increased suspended solids load coincided with decreased phosphorus concentration in pond water during the same period (see Figs. 12-13 & 28-29). Thus suspended solids might have also favoured removal of phosphorus from the water column by adsorption. This is further supported by the strong correlation between suspended solids and total phosphorus during the inorganic (r^2 = 0.527, P < 0.01; Table 7) and organic (r^2 = 0.412, P < 0.01; Table 8) fertilization. Besides, water pH never dropped below 5.8, thus ensuring high retention capacity, as also reported by Furness & Breen (1978). These low concentrations in water, compared with sediment or soil would appear to make phosphorus the limiting nutrient in phytoplankton bioassays as has been demonstrated by Hemens *et al* (1977). Drake & Heaney (1987), on the other hand, observed that, in a eutrophic water body with elevated pH associated with an algal bloom, a significant amount of phosphorus is released by desorption from the aerobic sediments. Since pond systems are dynamic and phosphorus can be released from sediments, it may not be the limiting nutrient. This is evident from the fact that after enrichment with PO_4-P, the substrate may remove phosphorus from the overlying water until equilibrium concentration is attained, but during periods of phosphorus uptake by the biotic system, the equilibrium level is maintained by release from the substrate. Therefore, if phosphorus is not the limiting nutrient for phytoplankton growth, then nitrogen will be (Furness & Breen, 1978). This implies that an increase in nitrogen load could stimulate algal growth and removal of phosphorus from the sediments, thereby increasing the total phosphorus concentration in water. This postulation is also supported by the findings of Stirling and Dey (1990). These authors showed a strong inverse relation between chlorophyll and NO_3-N, NH_3-N and PO_4-P which reflects the complex dynamic balance between rates of supply from fish cages and sediments and uptake by algae, as modified by effective mixing of water which prevented establishment of anoxic conditions, dilution with low nutrient inflows and losses by sediment adsorption and through the outflow.

The above phenomenon would appear to support similar findings in this study in the well mixed ponds during the fish culture trial. However, it is not clear whether the fish also play any significant role in releasing locked phosphorus to the surrounding water through physical disturbance of bottom sediments while foraging for food, compared with carp culture systems in which such a phenomenon is evident as reported by Tatvai & Istvanovies (1986).

Free - CO_2 which refers to the concentrations of CO_2 plus carbonic acid, is important in fish farms because, at high concentrations in farms with a ground water supply, it may cause problems of kidney stone formation (nephrocalcinosis) in cultured fishes (Stirling, 1985). According to Leitritz & Lewis (1976), trout show distress when free-CO_2 level reaches about 25 mg l^{-1}, although fish can acclimate to higher CO_2 levels as reported by the U.S Fish & Wildlife Service (1978).

Phytoplankton species inhabiting oligotrophic waters with a limited supply of nutrients, only use free-CO_2 as a carbon source at high temperature and pH levels (Moss, 1973a, b;

Garvis & Fergussen, 1975). DeNoyelles & O'Brien (1978), in a study of phytoplankton succession in nutrient enriched ponds in relation to changing carbon, nitrogen and phosphorus conditions reported that free-CO_2 tend to remain at extremely low concentrations (1.0 ug l^{-1}), yet possibly rapidly replaced from the bicarbonate system or from direct uptake of bicarbonate. This observation substantiates the low free-CO_2 obtained in this study, especially during periods of bloom in the summer. This is also in agreement with Shapiro (1973), Stirling & Dey (1990) who reported that exhaustion of free-CO_2 during summer blooms limits green algae production. However, these authors noted that complete exhaustion in the system is minimized by respiratory CO_2 production from the high fish biomass and large bacterial and benthic community which is generated by farming activities. Similarly, Masser & McDiffett (1986) attributed significant variations in free-CO_2 to autochthonous primary production and allochthonous input.

Chlorophyll, a major photosynthetic pigment of plant materials, is universally distributed among photoautotrophic plants. Although several forms of chlorophyll are available, Chl-a has been widely used as a convenient correlative of biomass in estimating phytoplankton biomass and productivity (Reynolds, 1984b). It has also been reported that primary productivity depends on the primary production : plankton biomass ratio, with the result that many water bodies, especially in the tropics, are characterized by a low biomass of phytoplankton and hence low chlorophyll concentration, but none the less highly productive due to high rate of turnover (Stirling 1985). The high Chl-a content obtained in this study, especially in the HPN during the inorganic fertilization may be due to high phytoplankton abundance, which is also in agreement with Bailey-Watts *et al* (1987a), Morris & Lewis, Jr (1988) and Stirling & Dey (1990). In contrast however, the increased Chl-a concentration in the LP treatment on 4/7/88 (Fig 34) was not accompanied by a proportional increase in phytoplankton abundance. Similarly, it appears that HP alone does promote significantly more Chl-a than LP or CTRL only when nitrogen is also added, as the case in HPN, implying that these systems were nitrogen limited, not phosphorus; although phosphorus limitation in phytoplankton productivity has also been demonstrated in many lakes (Schindler, 1978; Bailey-Watts *et al*, 1987b; Lewis, Jr., 1988; Stirling & Dey 1990). A similar response was observed in the case of primary production.

Although phosphorus limitation in phytoplankton productivity has been demonstrated in many lakes (Schindler, 1978; Bailey-Watts *et al*, 1987b;), it appears that phosphorus addition promotes significantly more Chl-a only when nitrogen is also added, as the case of HPN, implying that these systems were nitrogen not phosphorus limited. A similar response was also observed in the case of primary production. Nitrogen limitation has also been reported by several workers, especially in middle to low latitudes (Talling, 1966; Lewis, 1974, 1983; White *et al*, 1985; Canfield, 1983; Vincent *et al*, 1984), but generally considered to be a transitory condition of minor importance to aquatic ecosystem productivity, because its deficiency may be offset by the growth of nitrogen fixing blue-green algae (Schindler, 1977). Stirling & Dey (1990) found that the supply of inorganic nitrogen was more than adequate in Loch Fad to account for subsequent biomass development, allowing for maximum nitrogen content of 5%, while also ignoring competition from periphyton and bacteria and continuos high nutrient fluxes from fish farms and sediments.

Several workers have previously recognized nitrogen limitation in both eutrophic or hypereutrophic temperate lakes (Maloney *et al*, 1972; Cleasson & Ryding, 1977; Kanninnen *et al*, 1982) and in tropical lakes (Talling, 1966; Lewis, 1974, 1983; Coulter, 1977; Zaret *et al*, 1981; Setaro & Melack, 1984; Vincent *et al*, 1984). However, recent examples of nitrogen limitation have been reported in less productive temperate lakes (White & Payne, 1977; White, 1982; White 1982; White *et al*, 1985), suggesting that at least short-term nitrogen limitation of phytoplankton communities may occur frequently on a global scale.

Smith (1979, 1982) has found that the variations in phytoplankton production and biomass due to a combined addition of nitrogen and phosphorus is much greater than that of phosphorus addition alone. Although the overall importance of nitrogen in regulating phytoplankton productivity in fresh water remains controversial, it is evident that short term productivity can be suppressed by lack of nitrogen during the interval between the onset of nitrogen limitation and the final compensatory response that offsets its limitation (Morris & Lewis, Jr., 1988). In a study of phytoplankton nutrient limitation in eight mountain lakes of central Colorado, U.S.A., Morris & Lewis, Jr., (1988) identified five categories of nutrient limitations: (1) no limitation, (2) nitrogen limitation, (3) phosphorus limitation, (4) concurrent limitation, characterized by a response only to simultaneous additions of both nitrogen & phosphorus and (5) reciprocal limitation, characterized by response only to addition of either nitrogen or phosphorus. Concurrent limitation is not widely recognized because it is generally believed that phytoplankton growth rate and yield are determined by the abundance of the single nutrient that is in the shortest supply (Morris & Lewis Jr., 1988), indicating extreme shortages of both nutrients. Reciprocal limitation on the other hand, does not violate the concept of single nutrient limitation. For example, differences have been observed for critical N:P ratios among phytoplankton groups by several workers (e.g. Rhee, 1978; Rhee & Gotham, 1980; Terry, 1980; Tilman *et al*, 1982; Stirling & Dey, 1990).

The interaction of nutrient components with chl-a, primary production, lake depth and light or temperature is well documented in the literature (Wood *et al*, 1973; Dillon & Rigler, 1974; O'Brien & DeNoylles, Jr., 1976; Mori &

Ikushima, 1980; John, 1986; Bailey-Watts *et al*, 1987b). Besides, pH and carbon nutrient have been reported to influence primary production (Jewson, 1976). Ganf (1975) and Talling *et al* (1973) reported an inverse relation between photosynthesis and high plankton biomass. Similar findings have been associated with high pH in temperate lakes like Loch Leven, Scotland (Bindloss, 1974) and Lake Vombsjon, Sweden (Gelin, 1975). However, high pH (> 9.5) by mid-morning has been reported to restrict carbon availability in enclosed systems at saturating light intensities, even in experiments lasting only one hour (Wood & Gibson, 1973). In this study, the fluctuation in primary production during both fertilization trials may be related to the observed phytoplankton abundance and effects of light intensity and temperature. This postulation is in agreement with Jewson (1976) who reported that the rise in production in Lough Neagh, Northern Ireland originated from differences in temperature coefficients (Q_{10}) and respiration rate (expressed as a fraction of gross photosynthesis), with the result that increases during summer do not necessarily lead to more favourable conditions for growth, as increase in respiratory losses may keep net yields of column photosynthetic activity low. It also suggests that any higher crop that might develop in the summer, if there was no nutrient restraint in the aquatic environment (as in the HPN & HCC in the present study) could soon become light limited by the increase in optical depth of the mixed layer as a result of self-shading and turbulent mixing which restricts the light received per algal cell (Gibson *et al*, 1971; Wood *et al*, 1973; Wood & Gibson, 1973; Stirling & Dey, 1990). Although nutrient concentrations in the surface water showed fluctuating patterns relative to primary production during this study, it is also possible that this is only of secondary importance as a limiting factor, considering the complexity of factors influencing production. For example, low values of primary production despite high standing crop may also imply light limitations due to the high proportion of cloudy days, as also observed by Wood *et al* (1973). It has been reported by Jumppanen, (1976) that introduction of nutrients, either through deliberate fertilization or allochthonous means, eutrophication resulting from such processes could reach a critical phase when production begins to exceed consumption and the residue of primary production starts to accummulate on the bottom. This results in increased decomposition and shortening of the food chain because primary consumers largely switch from planktonic to bacteria and detritus. Pruder (1986) and Sharma *et al* (1987) reported that in highly productive aquaculture systems, there exists an orderly balance in oxygen production and demand, and between CO_2 production and demand, or D.O. and pH would seldom remain within acceptable levels. From the results of various water quality parameters obtained in this study, the values did not exceed deleterious levels for plankton, benthos and trout, even with the highest nutrient application, i.e. the HPN and HCC in inorganic and organic fertilization respectively. This is futher supported by the fact that if the ponds were highly eutrophic, nutrient utilization would have been incomplete and other factors would have limited primary production (Jumppanen, 1976). From the results of this study also, increases in primary productivity and natural food abundance at different trophic levels seem to follow a sigmoid pattern, except for the controls and ponds that had low nutrient manipulation. Jumppanen (1976) reported that disturbances occurring in production as a result of increased eutrophication first appear at the level of primary consumers and presumably also benefit the secondary consumers, but generally extend the food chain and aquatic ecosystem. This proposition would appear to support obervations in this study; and even during the fish culture studies, carry-over effects of fertilization did not show extreme eutrophication that would have endangered aquatic life.

5.3 SOIL CHARACTERISTICS

This topic is discussed in relation to the influence of fertilization on physico-chemical parameters of the soil and its effects on the production of benthos during the study. Similarly, an account of sediment-water interaction *vis-a-vis* maintaining a favourable environment for trout culture is considered.

The improvement in soil pH from an extremely acidic condition to a more favourable range of 5.5 - 7.0 throughout the study period may be attributed to liming. This assertion is also in agreement with Boyd (1979, 1981), Hultberg & Anderson (1982), Eriksson *et al* (1983) and Shapiro & Wright (1984). These authors reported considerable improvement in soil-water quality and aquatic life following pond liming and subsequent fertilization. In a study of Howietoun fish ponds, Wabab (1986) attributed the slightly acidic pH of the soil to such factors as leaching during heavy rainfall, inherent acid parent material and most importantly, microbial action on the deposit material. In this study, the acidic pH of the soil may be due to accumulation of dead planktonic and benthos materials, metabolites and faeces whose slow decomposition by bacterial action leads to production of reduced products such as H_2S, methane and short-chain fatty acids which makes the pond soil acidic (Banerjea, 1967). The significant variation in pH between the organically treated ponds may be accounted for by differences in organic inputs. Several workers (e.g Andersen, 1975; Mandal & Moitra, 1975a; Trojanowski *et al*, 1982; Drake & Heaney, 1987) have reported the influence of soil pH on solubility of inorganic components like phosphorus. For example, the buffering capacity of sediments tends to generate steep pH gradients near the sediment-water interface, thereby significantly affecting the pH-mediated exchange of phosphorus at the sediment interface.

The phenomenon of phosphorus dynamics in soil or sediment is well documented (Vollenweider, 1969; Williams *et al*, 1970; Stevens & Gibson, 1977; Furness & Breen, 1978; Ojanen, 1979; Doremus & Clesceri, 1982; Anderson, 1974, Drake & Heaney, 1987; Morris & Lewis Jr., 1988). The high concentration of phosphorus in the HP and HPN treatments (Fig. 42) is not unexpected, considering the continuous inputs of phosphate fertilizer which is rapidly absorbed in the soil before being gradually released into the water column. This assertion is also in agreement with the findings of Andersen (1975), Boyd (1981) and Drake & Heaney (1987). However, subsequent low phosphorus concentrations in all the inorganic treatments between the period, 9-30th June 1988 may be due to rapid immobilization into the pond water as influenced by the high summer temperature, coupled with bioturbation in such shallow ponds as also reported by Andersen (1974) and Bostrom & Petterson (1982).

Although organic manures have been reported to contain low amounts of inorganic nutrients like phosphorus (Little and Muir 1987), the observed increase in phosphorus concentration in all the treatments (Fig 43) at the commencement of fertilization may be due to carry-over effects of previous inorganic fertilization. This implies that pond soil acts as traps over long periods of time (Vollenweider, 1969; Furness & Breen 1978). Several factors govern the retention and eventual release of phosphorus in soils, and this includes both anaerobic and aerobic conditions, pH and CO_2 concentration. Although the release of phosphorus from profundal sediments in lakes during anaerobic conditions has long been recognized (Mortimer, 1941, 1942, 1971; Bostrom & Pettersson, 1982; Drake and Heaney, 1987), phosphorus mobilization from sediments under aerobic conditions has more recently been recognized as a potentially significant nutrient source (Rippey, 1977; Holden & Armstrong, 1980; Fowler *et al*, 1987). Doremus & Cleceri (1982) separately reported that decomposition in eutrophic water bodies during the summer causes anoxia which destroys the oxidized microzone and reduces iron to the ferrous form, resulting in the release of phosphate formerly immobilized in sediments. However, overturn of the hypolymnion restores aerobic conditions in the sediment-water interface, thus allowing ferric oxide complexes to retain phosphorus again. Similarly, Drake & Heaney (1987) reported that the buffering capacity of sediments generates steep pH gradients near the sediment-water interface which in turn significantly affects pH mediated exchange of phosphorus at the sediment interface. Furthermore, destruction of a pH gradient at the sediment by wind-induced bottom currents results in maximum phosphorus release. However, wind-induced turbulence will also result in lowering pH within the pond epilimnion because of CO_2 invasion across the air-water interface which will ultimately reduce the rate of phosphorus release. Bioturbation, the processing of sediment by benthos has been implicated in sediment phosphorus dynamics (Lee, 1970; David *et al*, 1975; Neame, 1977; Granell, 1979). It is likely that the abundance of macroinvertebrates in the ponds, especially during organic manuring has played significant role in phosphorus mobilization across the sediment-water interface, largely through stirring as observed by David *et al* (1975) and Neame (1977).

Total nitrogen tends to accumulate in interstitial water of bottom sediments, from both allochthonous and autochthonous origin (Trojanowski *et al* 1982) and at high concentration, rapid denitrification tends to occur under both aerobic and anerobic conditions (Knowles, 1978; Klapwijk & Snodgrass, 1982). This phenomenon probably explains the sharp decline in sediment nitrogen from an initial high premanipulation values of 4.4% and 6.5% in the HP and HPN treatments respectively (see Fig 44), despite addition of nitrogen fertilizer in the latter treatment. It is also likely that during the period when the ponds were lying fallow, the aerobic sediment favoured the long-term survival of aerobes in a dormant state whose only anaerobic energy metabolism is linked to denitrification as proposed by Kaspar (1985). Chen *et al* (1972) and Andersen (1974) reported high rates of denitrification in shallow ponds, as result of oxidation of nitrogen compounds. This process is further magnified by wind action which stirs up the uppermost sediment layer. Similarly, Ojanen (1979) reported that denitrification is an important sink for nitrogen in eutrophic lakes, accounting for 50 - 70% of the net nitrogen load lost from sediments.

The relationship between nitrogen and phosphorus in ponds is well documented (Vollenweider, 1969; Andersen, 1974). This relationship is further confirmed from the strong correlation between the two nutrients seen in Tables 7 & 8 (correlation coefficients all significant at the P < 0.01). The N : P ratio has been widely used in predicting denitrification in ponds (Vollenweider, 1969). During both fertilization trials in this study, N : P ratios were less than 12.0, implying that the pond systems had less than adequate supplies of nitrogen, possibly due to the observed denitrification.

Denitrification processes have also been applied in aquatic ecology to monitor the degree of pollution (Vollenweider, 1969; Avnimelech & Zohar, 1986). The latter authors reported that the formation of anaerobic pockets is a common feature in ponds subjected to intensive culture systems, and denitrification is a fast process which tends to occur intensively under conditions of limited oxygen supply and high levels of organic carbon. Besides, additions of nitrates to ponds have been reported to further aid oxidation of any anaerobic pockets in the pond sediment because nitrates operate at redox potential below 340 mV, and thus can only be activated at anaerobic sites and easily monitored in water. In this study, the observed high denitrification rates in the CTRL, HPN and HC treatments imply that sedimented organic matter is broken down at a fast rate, which is also in agreement with Vollenweider (1969), Ojanen (1979) and Kasper (1985). Vollenweider (1969) reported that the higher the denitrification value, the more polluted the water body is likely to be. In this study however, denitrification rates did not exceed the absolute recommended value of 56.6 mg m^{-2} yr^{-1}.

The main sources of carbon in a pond ecosytem comprise dead plankton and metabolites excreted by animals (Trajanowski *et al*, 1982). The abundance of benthic algae during the inorganic fertilization probably contributed to the high carbon content of the pond sediment. as also reported by Schroeder (1980). Similarly, Leach (1970) reported that the standing crop of living plant material in the sediments is equivalent to about 15% of carbon in summer and 10% in winter, based on a carbon : chlorophyll ratio of 50 : 1. Besides, the annual production from these plants is equivalent to about one-third of mean organic carbon content of the sediments, clearly indicating a major source of carbon. In contrast, the high carbon content in the manured ponds may be related to input of manures which have high carbon content. This is also in agreement with the findings of Schroeder (1980, 1987), Masser & McDiffet (1986). Litynski (1971) and Korzenowski (1979) reported that the mineralization of organic matter in bottom sediments, usually accompanied by release of nitrogen and carbon compounds is reflected by the C:N ratio. Thus Korzenowski (1979) reported that C:N ratio of < 17 is indicative of rapid mineralization, leading to release of inorganic nitrogen compounds; while C:N ratio > 33 results in inorganic nitrogen taken up from the environment. The low C:N ratio throughout the inorganic fertilization, compared to organic would appear to have favoured mineralization. This postulation is also confirmed from the calculated high values of daily denitrification rates in the inorganic treatment (Table 11). In the HC and HCC treatments, the high C:N ratio may be attributed to the accumulation of organic substance as also observed by Trojanowski *et al* (1982). Besides, when C:N ratio remains between 17-33, mineralization proceeds without release of nitrogenous compounds, especially ammonia, because nitrogen in the organic matter is completely utilized by bacteria participating in this process. It is therfore plausible to conclude that the favourable mineralization rate at moderate C:N ratio, despite continous input of fertilization plays a significant role in controlling pollution in the experimental ponds. This lack of extreme pollution in the pond environment is further confirmed from the high survival rate of trout during the second year of fish culture trial.

5.4 ROLE OF PLANKTON IN POND ECOSYSTEM

Eutrophication has been shown to act in several ways to alter the plankton community of an oligotrophic water body, with the result that both phyto- and zooplankton abundance and species dominance are affected (Hall *et al*, 1970; DeNoyelles & O'Brien, 1978; Gulati *et al*, 1982; Hillbricht-Ilkowska, 1983a,b; Korinek *et al*, 1987; Sanders *et al*, 1987; Steinberg & Hartmann, 1988; Stirling & Dey, 1990). In addition to the role of phytoplankton as primary producers in the food web, they also use up nutrients in ponds, thus creating chemical gradients which in turn causes more rapid nutrient flux from the pond soil (Golterman *et al*, 1969; Lee 1970). However, when both algal and zooplankton populations crash, they tend to settle in the sediment, decay and act as a rich source of organic nutrients for development of benthic macroinvertebrates (Jonasson, 1969). In this study, and from the overall dominance structure of phytoplankton in the order: Cyanophyceae > Chlorophyceae > Baccillariophyceae > Dinophyceae, the lack of dinoflagellates may be due to their inefficiency in competing for nutrients with other plankton as also reported by Tifman (1976). The dominance of Cyanophyceae and Chlorophyceae is typical of eutrophic algal communities, as also reported by Reynolds (1984b), Steimberg & Hartmann (1988), Stirling & Dey (1990). The fluctuating pattern of algal abundance and chl-a, in spite of continuous fertilization may have been the result of grazing pressure exerted by the zooplankton. Shapiro & Wright (1984) also reported the importance of grazing in supressing phytoplankton abundance. They also found that when nutrient levels were more than doubled by addition of nitrogen and phosphorus, only small increases in chlorophyll concentrations and abundance were observed in the presence of an abundant *Daphnia* community. However, at low *Daphnia* population, fertilization caused great increases in algal abundance. With the low phytoplankton abundance during organic fertilization, the recurrent clear-water phases, especially in the LC and HC treatments indicate oligo-mesotrophic status in which zooplankton play an important role in phytoplankton dynamics.

In pond fertilization, inorganic nutrients, particularly nitrogen and phosphorus, have been widely reported to stimulate algal growth; but the low abundance of phytoplankton in the CTRL treatments of both fertilization trials indicates that both nitrogen and/or phosphorus were limiting. Similar observations have been reported by O'Brien & DeNoyelles (1976). Available inorganic carbon does not appear to limit total phytoplankton production, but it may influence the species composition, after addition of nitrogen and phosphorus (King 1970, 1972; Shapiro, 1973; DeNoyelles & O'Brien, 1978; Smith, 1982). Besides, Gavis & Ferguson (1975) reported that eutrophic species of algae are able to obtain their needed carbon from CO_2 at lower concentrations or perhaps absorb and utilize the bicarbonate that increases in concentration at increased pH levels. The low abundance of phytoplankton groups in the manured ponds may be attributed to insufficient limiting nutrients to stimulate carbon uptake (1963; Moss, 1969; O'Brien & DeNoyelles, 1976; DeNoyelles

& O'Brien, 1978). These workers have also reported that if an added nutrient is to stimulate carbon uptake, it must be within a limited time period so that it can be taken into the cell and processed in such a way that its organic end product acts to increase the rate of carbon uptake or utilization.

In addition to the influence of fertilization, algal response to nutrient enrichment has also been reported to be influenced by pond morphometry (Steinberg & Hartmann, 1988), changing physical conditions such as turbulence and euphotic zone (Reynolds, 1984a,b) and seasons (Sanders *et al*, 1987). Thus, shallow, turbulent water bodies favour algal development, particularly *Microcystis spp; Anabaena spp* and *Aphanizomenon spp* (Reynolds, 1984a,b) which have been found in abundance in this study. At the commencement of organic fertilization on 20/7/88, an increase in Bacillariophyceae was well pronounced till 29/8/88 (Fig 52) when continous manuring did not elicit any response from algal abundance. Similar findings have also been reported by Lui & Roels (1972), Sanders *et al* (1987) and possible explanations are based on the current theory that increased nutrient flux would have no impact on the species composition during other seasons. Phytoplankton composition and abundance have been used to classify trophic status and degree of pollution of aquatic ecosystems (Rawson, 1956; Hutchinson, 1967; Palmer, 1969; Sladecek, 1973). Stirling & Dey (1990) reported that in loch Fad, the clearest biotic indicator of eutrophy is the dominance by *Microcystis aeruginosa*. Similarly, Rawson (1956) and Hutchinson (1967) stressed the dominance of this species and the link between blue-green blooms and eutrophy. Most of the subdominant species observed during this study are strongly associated with eutrophic conditions and these include *Anabaena sp, Closterium sp, Microcystis sp* and *Oscillatoria sp*. The dominant Dinophyceae genera, including *Ceratium sp* and *Dinobryon sp*, common in the control ponds are typical of oligotrophic waters (Bailey-Watts & Duncan, 1981; Sanders *et al*, 1987; Stirling & Dey, 1990).

Due to their central position between autotrophs and heterotophs, zooplankton have long been recognized as forming an important link in the food web in aquatic ecosystems (Hall *et al*, 1970; Maitland *et al*, 1981; Gulati *et al*, 1982; Hillbricht-Ilkowska, 1983a,b). Similarly, the strategic position of zooplankton both in terms of feeding and energy flow in the ecosystem as well as its sensitivity to man-made and natural changes, make it very suitable for biological monitoring of water quality (Tevlin & Burges, 1979; Gulati *et al*, 1982; Karabin, 1985a,b; Vanni, 1987). For example, in hyper-eutrophic or polluted waters, zooplankton are usually amongst the first group to be wiped out.

The overall dominance structure shown by the zooplankton : Rotifera> Cladocera > Copepoda (organic treatment) may be due to the changing pattern of food resource availability of phytoplankton and phosphorus (Gulati, 1983; Hillbricht-Ilkowska, 1983a,b; Karabin, 1985a,b) and organic manure (Schroeder, 1980; Little &

Muir, 1987) which are locked up in the sediment and gradually released. Similarly, Vanni (1987) reported that increased nutrients in a shallow lake resulted in a greater proportion of cladocerans and a reduced proportion of copepods. Environmental conditions and water quality parameters have also been shown to influence the development and abundance of zooplankton. Dirnberger & Threlkeld (1986) and Hart (1986) reported that temperature, transparency and chlorophyll accounted for half the variability in zooplankton abundance. In this study, high zooplankton abundance in the organic treatments is supported by the strong relation between zooplankton, temperature and benthic algae index (correlation coefficients all significant at $P < 0.01$) which is also in accord with the findings of Hillbricht-Ilkowska (1983a,b). Hart (1986), on the other hand, found a non-significant correlation between zooplankton, Chlorophyll-a and temperature and attributed this to the fact that zooplankton responses to temperature appear very sluggish at low transparencies, implying that turbidity rather than temperature exerts the overriding effect on algal production (as chl-a concentration) and, consequently, zooplankton abundance.

Transparency has also been indirectly linked to the quality of suspended food and silt particles *vis-a-vis* zooplankton production. Thus phytoplankton abundance is regulated by light limitation from suspended sediments rather than self shading, leading to reduction in phytoplankton food available to zooplankton (Aruda *et al*, 1983; Hart, 1986). Reduced suspended solids and consequently improved water clarity are likely to stimulate phytoplankton production. This supports an increase in zooplankton biomass, followed again by a decline through a transparency gradient. Throughout this study, the observed fluctuation in zooplankton abundance might be due to other factors like predation by larger macroinvertebrates and/or mortality, rather than suspended solids which tend to increase only during periods of manure application. The organic manure in any case acts as good source of carbon and bacteria utilized by zooplankton (Schroeder, 1978).

5.5. MACROINVERTEBRATES PRODUCTION AND THEIR ROLE IN THE DIET OF POND REARED TROUT

5.5.1. MACROINVERTEBRATE PRODUCTION

The overall favourable response to organic manuring by the macroinvertebrate groups is not unexpected. It is postulated that organic nutrients, built up through various manipulations such as pond draining, reworking of soils and subsequent reflushing can promote development of benthos (Friday, 1987; Kulberg & Peterson, 1987). The benthos groups which contribute significantly to the diet of trout in this study include Oligochaeta, Chironomidae, Asellidae, Sialidae, Hirudinea, Mollusca and Gammaridae. These closely resembles those of fish ponds and lakes in both temperate (Kojak & Dusoge, 1973; Maitland & Hudspith, 1974; Potter & Learner, 1974; Wojcik-Migala, 1979; Smith *et al*, 1981b) and tropical (McDonald, 1956; Karim & Inglis, 1970; McLachlan, 1974; Darlington, 1977; McElravy *et al*, 1982; Leveque *et al*, 1983) regions.

Benthos forms an integral part of the trophic network (Korinek *et al*, 1987), and based on the degree of adaptation to aquatic environment, including fish ponds, they have been classified into two groups according to Humphries (1936): first, permanent fauna which complete their entire life cycle in the aquatic environment, e.g. oligochaetes of the families Tubificidae and Naididae; crustaceans, Hirudinea and Mollusca. Second, the temporary fauna which are associated with the aquatic environment for only part of the life cycle, e.g Chironomidae and Sialidae. Various workers (e.g Humphries, 1936; Anderson, 1969; Maitland & Hudspith, 1974; Potter & Learner, 1974; Smith *et al*, 1981a,b; Wahab, 1986; Korinek *et al*, 1987; Hargeby, 1990) have reported that life cycle adaptations are important in controlling seasonal periodicity, survival during short or long summers or winter sanitary draining, pattern and rate of colonizing new biotope and pattern of introduction of new generations into the aquatic ecosystem.

Despite the numerous studies on the distribution and abundance of benthos in ponds and lakes, the role of pond manipulation strategies to stimulate their production for trout culture under temperate conditions while maintaining adequate water quality has not been reported. Therefore, comparative discussions relevant to the present findings are based on similar culture conditions of oligotrophic, eutrophic and/or hyper-eutrophic aquatic ecosystems. Even in comparative analysis, difficulties are often encountered, because population densities of various organisms recorded in various investigations are a function of mesh-size used when sieving the samples (Jonasson, 1955; Potter & Learner, 1974); with the result that density of benthos recorded in the present study and those recorded elsewhere may not be particularly similar or meaningful. For example, in an intensive study of zoobenthos production in the sandy littoral area of a eutrophic lake (Loch Leven) in Scotland, Maitland & Hudspith (1974) reported average population densities of 13,973 and 24,400 ind. m^{-2} yr^{-1} for 1970 and 1971 respectively, using a mesh size of 500 um sieve. Any under estimation of population density would logically mean low production estimates, although the magnitude of the error may not be great (Potter & Learner, 1974). For ease of comparison with other works, results obtained during the six months culture period are estimated to annual rate, *pro rata* by multiplying observed production by 12/6.

In this study, oligochaetes made the largest contribution to the benthos, with a mean abundance and production values of 25.3 x 10^3 ind. m^2 and 264.4g.dry wt m^{-2} yr^{-1} recorded in the HCC which received the highest organic manure treatment. The high production obtained within the six months culture period follows closely those obtained by other workers (e.g. Potter & Learner, 1974; Erman & Erman, 1975; Siegfried, 1984; Wahab *et al*, 1989) from similar ecological conditions which have undergone eutrophication over a considerable number of years. The high production can possibly be explained by affinities of these organisms to certain sediment types such as fine silt with abundant organic materials as also reported by Holopainen & Paasivirta (1977), Saether (1980), Bazzanti & Loret (1982), Siegfried (1984), Stirling & Wahab (1990). Similarly, *Limnodrilus sp* and *Tubifex sp* have been reported to proliferate in conditions of oligotrophic conditions, oxygen depletion and of organic enrichment (Brinkhurst & Cook, 1974; Lang & Lang-Dobler, 1979). Being detritivores or collector gatherers (Hynes, 1970; Cummins, 1975; Anderson & Sedell, 1979), oligochaetes are likely to derive nutrients and energy from the organic content of the bottom mud and manure; and it has also been found that their rate of maturation and fecundity is positively correlated to these factors (Ladle, 1971; Kaster, 1981; Wahab, 1986). In addition to the organic enrichment, high summer temperatures and the shallow nature of the ponds probably contributed to the high production as also suggested by Saether (1980). Bazzanti & Loret (1980) ascribed extreme chemical conditions as being unfavourable for oligochaete development in lakes deeper than 10 - 30m. Erman and Erman (1975) found that oligochaete production increases with increasing peat depth over the range, 17.3 - 87.4cm. They attributed this correlation to the greater buffering capacity of the deeper rather than shallow peat because the former tend to reduce the rate of diel changes in oxygen, temperature and water level. It has also been shown that since oligochaetes are permanent fauna, with little ability for migration (Korinek *et al*, 1987), sufficient proportion must therefore be preserved during the entire period that the pond bottom is dry. For example, *Limnodrilus sp* and *Tubifex sp* are capable of remaining active and even reproducing in the drained bottom at ambient soil humidity above 50%; at which level *Tubifex* are capable of encystment over a long period of time and even at humidity as low as 20%. Therefore, in the muddy substrates and moist conditions of drained ponds, as found in most ponds used in this study, it is possible that part of the permanent fauna and/or eggs survived a long-lasting drainage while the ponds were fallow, and rapid regeneration was assured following re-flooding and manuring.

The highest turnover ratio (P/B) of *Tubifex tubifex* and *Lumbriculus sp* observed in the control ponds may be a reflection of relative increase in number of generation per year, especially in conditions where carrying capacity is not attained, and there is little competition for food resources. Wahab (1986) reported two distinct breeding periods for oligochaetes (April-June and September-November) at the Howietoun fish ponds, which also coincided with the period of this manipulation study. It has also been reported by several workers (e.g. Potter & Learner, 1974; Timm, 1974; Bonomi & Dicola, 1980) that oligochaetes can attain maturity within two months, with the result that up to 4-5 generations per year may be produced. Despite these postulations, difficulties have often been encountered in estimating oligochaete production and identifying the species; moreover, they can also reproduce by fragmentation. Therefore, Standen (1972) and Erman & Erman (1975) suggested that until more estimates of production are obtained, generalizations about oligochaete turnover ratios are of little value and must be interpreted with caution.

Larval Chironomidae which made the second largest contribution to the benthos in this study have been reported to be an important component of invertebrate communities in shallow water bodies (Potter & Learner, 1974). Most often, the difficulty encountered by several workers is the identification of the various stages and the very large number of species present, even in small water bodies (Pinder, 1986). In the Howietoun fish ponds, Wahab (1986) recorded eighteen species of Chironomidae, which is clearly a reflection of Pinder's opinion. Throughout this study, no attempt was made at classification beyond generic level due to time constraint. Therefore, reference to abundance or productivity is for total rather than species of chironomids.

In this study, both annual production and P/B ratio were correspondingly high with respect to the appropriate manure input. Sokolova (1971) found that P/B ratios for seventeen species of chironomids ranged from 2.9 - 36.0, with least value given by the univoltine species, and the values tend to increase with increasing number of generations per year. Potter & Learner (1974), however, reported similar relationship between voltinism and P/B values, but much lower and narrower mean range (3.2 - 7.6). Even amongst species, P/B values tend to vary, especially between univoltine and bivoltine species. In the present study therefore, the estimated P/B values of 0.81, 1.64, 2.20 and 2.60 obtained in the CTRL, LC, HC and HCC respectively is not unexpected for a eutrophic water body, as also found by Sokolova (1971), Potter & Learner (1974) and Wahab (1986). The Chironomidae, like Oligochaeta showed a preference for muddy substrates with virtually no vegetation cover. This preference probably justify their even or regular density distribution, especially in the LC and HCC treatments, unlike the contagious distribution in the CTRL and HC ponds. Similar distribution common to various types of benthos have also been reported by Potter & Learner (1974). The ability of Chironomidae to establish in both eutrophic and polluted conditions due to possession of haemoglobin is well documented (Oliver, 1971; Brinkhurst, 1974; Saether, 1980; Bazzanti & Loret, 1982; Jonasson, 1984; Siegfried, 1984), although a number of species are also limited to ultra-oligotrophic or strongly oligotrophic conditions (Saether, 1980). From the eighteen Chironomid species in Howietoun ponds, Wahab (1986) classified them as mesoeutrophic based on Saether (1979). Both chironomids and oligochaetes have evolved survival strategies under any adverse bottom conditions. Thus, being ubiquitous in pond sediments, they mix soils and pump proportionally large quantities of water into it, resulting in increased pore water exchange and oxygenation and also nutrient release (Lennan *et al*, 1985; Bardach, 1986).

Wahab (1986) reported a positive correlation of *Chironomus spp* population density with soil organic matter content, thus reflecting the importance of sedimentary organic matter and detritus in their diet. Similarly, Mandal & Moitra (1975b), quoted by Wahab (1986), observed that the high organic matter content of pond soil facilitated the growth of chironomid larvae in tropical fish ponds. Under temperate conditions, Lindegaard & Jonasson (1983) observed that *Chironomus spp* often benefit from autochthonous and allochthonous organic matter which has decomposed. It is likely, that in this study, the use of manure tremendously improved or stimulated production, being a rich source of nutrients and also, in combination with detritus acts as substrate for bacterial development which also benefit Chironomidae as observed by Korinek *et al* (1987). However, being a temporary fauna of aquatic environments, a special feature of the population dynamics of the Chironomidae is the emergence of adults following metamorphosis of mature larvae (Korinek *et al*, 1987). Therefore, variations in abundance and/or rate of regeneration will be influenced by the rate of insect emergence which in turn is regulated by temperature and quality and quantity of food (Sweeney & Vannote, 1978; Pinder, 1986). The decline in population abundance between October and December, despite additional manuring probably coincided with the flight period; rather than sole predation and/or mortality, especially as trout were not stocked. Similarly, Lindegaard & Petersen (1972) and Wahab (1986) observed that two flight periods, from June - September and December onwards were assumed from the absence of larvae in the pond bottom.

Asellus aquaticus was the most dominant crustacean species encountered in the ponds as also reported by Wahab (1986), although four species are listed as occurring in the British Isles by Maitland (1977), (quoted by Wahab, 1986). Other workers, e.g. Warwick (1959) and Smith *et al* (1981b) have also reported the presence of only *A. aquaticus* in different Scottish water bodies; while Warwick (1959) reported the presence of *A. meridianus*; in addition to this species there has not been any documented evidence of all these four species occurring together in any of the Scottish water bodies and no explanation to account for this. However, a general consensus amongst several workers (e.g. Moon, 1957; Tucker, 1958; Andersson, 1969; Hargeby, 1990; Wade & Stirling, 1990) is the abundance of *A. aquaticus* in localities ranging from small ponds with a substratum of thick mud and macrophytes to large lakes with substratum of boulders and stones. Throughout this study, as with other benthos groups, annual production and P/B ratio corresponded with appropriate nutrient levels, with both

HCC replicates showing the highest production. Aston & Miller (1980) and Holdrich & Tolba (1981) suggested that *Asellus* tends to be prevalent in areas with fairly high organic matter. Similarly, detritus, silt, fine debris and bacteria covering stones favour *Asellus* production. However, in the HC replicate pond, despite an equal manuring level, there was a significant difference in overall annual production, probably due to differences in particle size (pond 4 had more coarse soils/stones than pond 5) and abundance of macrophytes played an important role in stimulating production. The results of this study are in agreement with Soszka (1975), Perera-Ramos 1981 (quoted by Hargeby 1990) and Hargeby (1990). In a study of life-cycle and growth of *A. aquaticus*, Andersson (1969) reported that the nature of lake or pond bottom has a great influence on density and average weight of *Asellus*. Thus hard bottoms give the lowest number of individuals and lowest average weight; soft bottoms are intermediate and vegetative bottoms show the highest values. The preference for ecological niches with carpets of vegetation or macrophytes would seem logical in view of their food preferences. Thus, Williams (1962) and Wade & Stirling (1990) reported that the macrophytes, in contrast with hard or soft bottoms provide a good substrate with high three - dimensional surface area for development of epiphytic algae on which benthos feed. Andersson (1969) reported abundances of *Asellus* of up to 12,400 ind. m^{-2} in Lake Erken, Southern Sweden in a bottom area at 4 - 6m depth in a belt of *Cladophora* *aegagrophila* (L.). Similar observations of production of several generations have been reported by Hargeby (1990) in Lake Takern, Sweden, where the substrate is covered by a complex structure of *Chara sp.*

Production values (annual estimates) obtained in this study under various organic manuring treatments (see Table 18) were considerably higher than those recorded by Potter & Learner (1974) for eutrophic Eglws Nunydd reservoir, South Wales (37g dry wt m^{-2} yr^{-1}), Andersson (1969) for Lake Erken (31.6g m^{-2}) and Lake Maskejaure (16.9g m^{-2}), Mann (1971) for the River Thames (13.3g m^{-2}) and Wahab (1986) for Howietoun ponds (3.43g m^{-2} yr^{-1}). The P/B ratios of 3.2 and 4.1 reported by Mann (1971) and Potter & Learner (1974), respectively, were similar to annual estimates in the present study. A lower P/B ratio of about 2.1 was recorded by Andersson (1969) for the two Swedish lakes. Caution is, however, needed in drawing any authentic conclusion from these comparisons, because the high values obtained for this study were under conditions of fish exclusion in the ponds, in contrast with the other reports which had moderate to very high fish density which can result in high predation pressure and, consequently, low benthos production, biomass and/or turnover ratio, as also reported by Wahab *et al* (1989).

In addition to the favourable food source and substrate, physico-chemical qualities like temperature and dissolved oxygen influence growth and development of *A. aquaticus*. For example, Andersson (1969) reported that at a minimum temperature value of about 4°C, growth ceases, but at high temperatures from 15°C to an optimum of 20.5°C rapid growth resumes. This factor, coupled with a high oxygen requirement (Saether, 1980; Holdrich & Tolba, 1971) also influences reproductive rate. Being permanent fauna and therefore having a low colonization rate, such physico-chemical parameters are expected to play a significant role in maintaining population balance. These factors probably account for the steep increase in abundance at the start of the manuring in the summer period of July, especially in the HC and HCC treatments. The intermittent nature of the abundance curves in the HC and HCC (Fig 69) is probably explained by the considerable plasticity in the life cycle of *Asellus*. Andersson (1969) found that *Asellus* populations consisted of two overlapping generations, each member living for two years and reproducing once during its second year, mainly in August. However, in some cases, the animals lived for only a year, breeding in July, and post-reproductive individuals die soon after reproducing, with little overlap of generations. Potter & Learner (1974) on the other hand, reported small recruitment such that overlap of generations was barely detectable, compared with Steele's (1961; quoted by Potter & Learner, 1974) reported findings of two generations per year; and the post-reproductive animals from the summer generation did not die, but overwintered along with their offspring to reproduce again the following year. These assertions would also probably explain the lack of response by *Asellus* during the winter period of November - December, despite continous manuring. However, this plasticity coupled with the favourable water quality and abundant nutrients might have had considerable advantage in maintaining the abundance of the benthos through the second year when fish culture trials commenced, without continuous fertilization.

Sialis lutaria, which is the only representative species in the Sialidae family accounted for 2.56% of the total benthos. This group showed higher biomass in the HC than the HCC, possibly due to differences in substrate characteristics, because greater preference was shown for pond bottoms with coarse soils/stones rather than muddy bottom. Similarly, the observed fluctuation in population density may be due to young adults emerging from the pond. A general principle that can be applied to explain increases in production of the larvae of temporary fauna is based on the postulation by Korinek *et al* (1987), in which they stated that a sufficient innoculum of eggs by the mature adult must be available for rapid development of benthic fauna when the pond is flooded. Favourable nutrients and environmental conditions are also essential for the onset of egg development and hatching. Lellak (1969) reported that in addition to favourable environmental conditions, the fast rate of recolonization of ecological niches in an aquatic ecosystem is governed by several characteristics of the temporary fauna itself. These include:

(1). continous inoculation of suitable biotopes by egg deposition throughout the season (Korinek *et al*, 1987).

(2). high egg production and rapid larval development (Konstantinov, 1958).

(3). positive phototaxis and planktonic phase of life of the first larval instars making possible their rapid dispersion over the area of the pond (Lellak, 1968).

(4). the ability of the genera to feed on either fresh or decaying vegetation immediately after the bootom is flooded by water (Korinek *et al* 1987).

Under temperate conditions, as in this study, postulations 1-3 can only be fulfilled during the warm spring-summer periods, as breeding of these benthic organisms is temperature dependent, unlike the tropics where temperature favourable for these activities is guaranteed all year round. On the 4th postulation, it is likely that the organic manuring during the study provided an immediate and ready source of nutrient for the developing larva. Wahab (1986) reported summer increase in the population density of *S. lutaria*, comprising 40% of early larval instars. The larval stage has also been reported to actively feed on chironomid larvae and Oligochaeta (Giani and Laville, 1973; Griffiths, 1973, quoted by Wahab (1986)) which were in abundance in both HC and HCC ponds.

The observed increase in the abundance of Hirudinea or leeches at the commencement of the study in July may have coincided with the peak of the growing season, coupled with favourable environmental conditions and abundant natural food supply (Young & Ironmonger, 1979) and from the organic manuring as also reported by Mann (1957a: 1962) and Tillman and Barnes (1972). Wahab (1986) reported peak population density of these leeches in spring and autumn which was linked with their breeding season, usually during March - May and another from August - September. A similar life history has been reported by Potter & Learner (1974). Davies & Reynoldson (1976) on the other hand, reported a short breeding season in some leech populations in the Newsome pond, Canada during the spring; after which overwintering adults produced a brood and died. Leeches are carnivorous, preying on a variety of aquatic animals such as chironomid larvae and oligochaetes (Young & Ironmonger 1979) and Asellidae, Gammaridae, Ephemeroptera, Plecoptera and Odonata (Wahab, 1986). This factor might have also played significant role in regulating population density in the ponds.

The production values (estimated for a whole year) of leeches obtained in this study were lower than those reported by Dall (1979) from lake Esrom (18.0g m^{-2} yr^{-1}) and Murphy & Learner (1982) from the River Ely, U.K. (29.4g m^{-2} yr^{-1}) but much higher (about 12x) higher than that reported by Potter & Learner (1974) from the Eglwys Reservoir, South Wales, U.K. (0.87g dry wt m^{-2}). However, a similar value to that obtained in this study was also reported by Wahab (1986) from the Howietoun fish ponds (0.84 - 12.5g m^{-2} yr^{-1}). This similarity is not suprising, considering the fact that trout tend to reject these leeches in ponds despite the high stocking density; thereby maintaining a reasonably constant production value (Wahab *et al* 1989; Stirling & Wahab, 1990). Higher production values reported by other workers may be the result of the hiding nature of leeches, thereby saving them from intense predation. On the contrary, higher P/B ratios (annual estimates) of 3.37 and 6.5 were obtained in the CTRL and LC treatments when compared with 1.02 and 1.19 obtained in the HC and HCC treatments respectively. The values in the CTRL ponds follow closely that reported for *Helobdella stagnalis* by Potter & Learner (1974) from the Eglwys Reservoir (P/B = 3.5) obtained from two generations. These authors reported that P/B ratio tended to increase with increasing number of generations per year. It is likely that carry-over effects of previous inorganic fertilization and changing physico-chemical qualities of the pond environment might have influenced production, thus resulting in more than one generation and higher turnover ratio in the CTRL and LC pond treatments.

Total Mollusca, consisting of *Lymneaea sp*, *Sphaerium sp* and *Planorbis sp*, encountered in this study made the least contribution of 1.79% to total benthic production. Similar to other benthos groups, production was highest in the HCC followed by the HC and LC. However, as with *A. aquaticus* the highest production occured in replicate ponds that had abundant macrophytes which is also in agreement with Boycott (1936), Soszka (1975a,b), Lodge (1985) Lodge &

Kelly (1986), Rooke (1986), Wahab (1986), (1988) and Hargeby (1990). In contrast with HC and HCC, the LC gave the highest P/B ratio (annual estimates) of 4.6, possibly due to low abundance and hence less competition for food. Besides, the abundant macrophytes also provided better habitat and food resources as also observed by Wahab (1986). Similarly, Wahab (1986) reported the abundance of total Mollusca at Howietoun to be correlated with temperature, particulate organic matter, dissolved organic nitrogen, unionized ammonia, and negatively correlated with total hardness, calcium, total alkalinity, dissolved oxygen and nitrate. Not all these factors necessarily have biological effects on molluscs, as some may be chance correlations. Temperature is perhaps one of the most important factors because it triggers series of physiological processes which stimulate feeding, growth and breeding processes (Boycott, 1936). It is, therefore, possible that during this study, the high summer temperature played a role in stimulating production of the mollusca.

According to Wahab (1986), the intensification of fish farming and loading of organic materials may prevent the establishment of species found in other water bodies. This may not necessarily be the case, because with proper pond fertilization and management, deleterious effects may not arise. Throughout this study, the application of organic manure over a period of six months might have resulted in a heavy load of organic material, which is probably equivalent to several year's loading when fish are intensively stocked in ponds that had no prior history of fertilization, as is typical of Scottish and some other temperate lakes. This did not, however, adversely affect either benthos and fish production. It is therefore proposed that the rapid decomposition of the organic material by bacteria under favourably high temperature and in such shallow, ponds might have counteracted any adverse effect, as also reported by Schroeder (1978).

Sphaerium sp. is a useful indicator of molluscan conditions, capable of living in both brackish and fresh water where there are abundant minute organisms, chiefly microscopic algae and particles of organic matter, detritus suspended in the water and sufficient dissolved oxygen (Boycott, 1936; Ellis, 1978). All these conditions have been found to be adequately fulfilled during the study period. *Lymnaea sp.*, on the other hand are more tolerant and show preference to organically enriched aquatic ecosystems, feeding on decayed remains of aquatic macrophytes, especially algae which are scraped from the layers of larger plants and mud (Okland, 1969; Wahab, 1986).

During the first year of organic manuring to stimulate benthos production, *Gammarus sp* were not encountered, but in the second year of fish culture trial, they were found in abundance in ponds and from stomach content analysis of the trout. During this culture period, however, no attempt was made at evaluating their numerical abundance, biomass, annual production and turnover ratio due to time constraints, and the fact that not all the various manipulations of the nutrient levels (used for benthos production in the first year) were applied during the fish culture trial. This would have definitely affected any objective evaluation. Several workers have attempted to provide answers to the big question of late colonization of an aquatic ecosystem by some benthic macroinvertebrates. Chironomidae and Sialidae are temporary fauna, able to spread efficiently over large area due to airborne egg-laying females and a pelagic first larval stage (Oliver 1971), while permanent fauna like oligochaetes, Hirudinea, Mollusca and crustaceans continuously deposit their eggs in favourably moist soil conditions of ponds or lakes (Korinek *et al*, 1987). *Gammarus*, on the other hand, although permanent fauna, are slow colonizers, having a low reproductive rate of about 100 eggs per female (Berg, 1938; Hynes 1955). This implies slow recruitment and less ability to utilize a rapidly changing habitat, as also reported by Hargeby (1990). Besides, Reavell & Frenzel (1981) reported that the disappearance of *Gammarus pulex* from shallow lake areas coincided with replacement of *Chara aspera* by the annual *Potamogeton pectinatus*. They suggested that this disappearance was due to low dissolved oxygen conditions in the dense *Potamogeton* beds and/or decreased shelter against predation by water fowl during the winter. Studies in Polish lakes by Pereyra-Ramos (1981) confirmed the above postulation, by showing that invertebrate abundance increased in the vegetation of *Chara rudis* during the winter as majority of other plants died. From the above, and in relation to the present study, it is likely that *Gammarus sp* were not able to withstand the low oxygen conditions at the bottom following the continous inputs of organic manure at the commencement of the fertilization. Similarly, although *Potomageton sp* were not found in significant amount to be implicated in causing the lack of colonization, it is likely that the abundance of other macrophytes like *Elodea canadensis*, which have similar characteristics to *Potomageton spp* (Haslam *et al*, 1982), might have played a role in regulating colonization. In the second year, however, the establishment of other plants preferred by *Gammarus* might have induced rapid colonization, especially in ponds that had high nutrient supplies.

The discrimination against macrophytes in relation to colonization and feeding guilds has been reported by several workers (e.g. Glime & Clemmons, 1972; Gerrish & Bristow, 1979; Greg & Rose, 1982; Rooke, 1986). Most of the *Elodea spp* have stiff stems and closely packed whorls of leaves, able to trap large quantities of organic matter, unlike alternating leaves of most *Potomogeton sp* found in this study. This suggest that *Elodea sp* could intercept both fine and coarse particulate organic matter in the pond environment and invertebrate shredders like some Chironomidae, which chew both fine and coarse particulate organic matter could take advantage of this (Greg & Rose, 1982; Rooke, 1984). *Gammarus* are scrapers and grazers which feed on attached periphyton and would therefore prefer vegetation beds like the *Chara* with higher three-dimensional surface area for development of epiphytic algae. The absence of such vegetation beds would invariably affect rapid and efficient colonization. Interestingly however, *A. aquaticus*, like the *Gammarus sp*, are slow colonizers with an almost similar low reproductive rate, but were able to establish quickly during the first year of fertilization. A possible explanation of the observed difference is that, although *Asellus* are also scrapers/grazers, they can easily switch from epiphyton grazing to predation on chironomids during colonization of a pond environment and/or new vegetation stand, resulting in a dominance relationship of the taxa as reported by Hargeby (1990), based on a study of macrophyte associated invertebrates and the effect of habitat permanence in Lake Takern, Sweden. Similarly, according to the theory of disturbance and patch dynamics, habitat permanence over a time scale tends to enhance density dependent biotic interactions (Southwood, 1977, 1988; Pickett & White, 1985), with the result that the effects of density dependent animal interactions such as competition and predation become more pronounced in older macrophytes than in the newly established and less favourable ones (Hargeby, 1990). It is, therefore, likely that the competitive/predatory interactions between two taxa (e.g. Asellidae and Chironomidae), in addition to other potential competitors and predators must have played an important role in the species composition as colonization proceeds. This also probably explains the early non-equilibrium phases 1 & 2 (July-Sept., 1988) characterised by non-interactive or stochastic conditions (in which colonization is as a result of the presence of few populations) and later, equilibrium phases 3 & 4 (late Sept-Dec., 1988; see Figs. 66 - 75) characterised by interactive or deterministic forces. In this the benthic community structure is measurably affected by environmental or biotic factors like competition, parasitism and/or mortality as observed in this study and also in accordance with Minshall & Petersen Jr. (1985). These authors further proposed that phases 1 & 2 are also influenced by relative propensity of different species to drift, which is typical of stream benthic organisms. The equilibrium phase, once attained, would probably account for the low population fluctuation, despite additional manure in the LC, HC and HCC treatments.

It is also obvious from the present study that macrophytes play a very significant role in the development and complexity of earthpond ecology. Besides, the young macrophyte leaves, which are succulent and less fibrous, decay faster when composted. Their utilization might be beneficial in reducing the need for inputs of high quality and costly feeds, thereby bringing new research perspectives to bear in future of waste fed aquaculture.

Numerous indices have been used to establish degrees of pollution resulting from eutrophication processes, with respect to potential use of the aquatic environment. One of these indices include the distribution and abundance of a wide variety of plankton, macroinvertebrates (Stella *et al*, 1978; Saeter, 1980; Wiederholm, 1980) and invertebrates, especially fish (Bazzanti & Lozet, 1982). Reish (1960) distinguished four categories of benthic fauna which are used to reflect status of the biotope in the profundal region:

(1). severely polluted habitats in which bottom animals are nearly absent or only *Chironomus sp* and/or *Tubifex sp* occurring sparsely.

(2). polluted bottoms having maximum biomass and production is comprised mainly of species indicating eutrophy e.g. *Chironomus sp.*, *Tubifex sp.*, *Limnodrilus sp.*, *Sphaerium sp.*

(3). slightly polluted bottoms characterized by tubificids, *Chironomus sp.*, *Sphaerium sp.*, *Sialis lutaria* and *Asellus aquaticus*.

(4). undisturbed profundal region characterized by abundance of oligotrophic forms e.g. *Pisidium* and absence of *chironomus sp.*

Caution is however needed in applying these indices in the fertilized ponds used, because Reish's classification is largely based on waste disposal in all fresh water environments and it fails to include Lumbriculidae, normally represented in clean waters as reported by Bazzanti & Loret (1982). In this study, no deleterious effects of continuous manure input was detected. A further confirmation of lack of pollution threat to the water quality is the abundance of natural food organisms throughout the study period, and the high survival rate of trout stocked in the ponds under stillwater conditions. However, it has also been reported that benthos are considerably more tolerant of limiting environmental conditions (Warren, 1971; Jonasson and Kristiansen, 1967; Jonasson, 1978, 1984).

5.5.2. NUTRITIONAL COMPOSITION OF NATURAL DIET IN RELATION TO THE NUTRIENT REQUIREMENTS OF TROUT

The nutritional composition of natural food organisms for fish may vary both among and within species at different developmental stages, seasons and feeding conditions (Prus, 1970; Wissing & Hasler, 1971; Schindler *et al* 1971; Kosiorek, 1979). However, based on an extensive review of average values of nutrients found in proximate analysis of freshwater organisms by Albrecht & Breitsprecher (1969) and Hepher (1988), all the organisms considered in this study i.e. Asellidae, Chironomidae, Gammaridae, Mollusca, Oligochaeta, Sialidae and zooplankton were rich in protein, lipid, carbohydrate and ash. These authors gave the following average composition (%-dry weight in parenthesis): water, 85.8%; protein, 7.4% (52.1);

carbohydrate, 3.8% (27.3); lipid, 1.1% (7.7) and ash, 1.1% (7.7). These values closely follow those obtained in the present study, (see Table 27) on dry weight basis, except for water (74.2%); carbohydrate as NFE (19.8%); lipid (10.2%) and ash (115.2%). The calorific value of natural food has also been reported to resemble that of fish (Prus, 1970; Hepher, 1988), fluctuating in the range of 1.6-5.7 Kcal g^{-1} dry wt; the average being 3.9 Kcal g^{-1}, closely following the range 3.5 - 5.84 Kcal obtained in this study. The artificial diet (based on the manufacturer's specification - Ewos Baker Ltd, Bathgate, Scotland, U.K.), had the following composition: moisture (9%); protein (50%); carbohydrate (22.5%); lipid (17.5%); fibre (1.0%) ash (10%) and calorific value (5.34 Kcal g^{-1}) (Table 27). From the above comparison of the data, some important features are highlighted. First, the composition of the artificial diet closely resembles that of natural food, except for the low moisture content and higher lipid content of the former, implying that the fish will have to consume almost 4x more natural food to obtain some amount of dry matter and nutritional value (Smith, 1988). Secondly, the natural food contains much higher amounts of indigestible matter like ash and fibre, possibly due to a high uptake of organic matter supplied during manuring as also reported by Vijverberg & Frank (1965) and Salonen *et al* (1976).

In relation to the fulfilment of nutrient requirements of the cultured trout by the macroinvertebrates, this is discussed with reference to the major nutrients required by trout, namely, proteins, lipids (fats), carbohydrates, vitamins and minerals. Similarly, the role of ambient temperature which affects the efficient utilization of food for growth and the significance of the present work to the aquaculturist are briefly discussed.

The protein component of trout food is the single most important and expensive portion for the body building, and in some cases, source of energy for metabolism. Due to its expensive nature, nutritionists have been prompted to use the most economical and adequate protein sources available in diet formulation (Lovell, 1977; Hilton & Slinger, 1981). The latter authors reported that the optimal dietary crude protein level for very young trout is 45 - 50% of diet (as starter diets), while juvenile trout require 40% (production diets), and older trout require 35% (maintenance diet). It is obvious from the findings of the present study that natural food organisms more than adequately fulfilled the dietary protein requirement of the cultured trout.

Lipids or fats are also an important alternative source of non-protein energy, containing twice as much energy per unit weight as do proteins and nearly three times as much as carbohydrate (1972; Nagai & Ikeda, 1972, 1973; Stirling, 1972; Bever *et al*, 1977; Hilton & Slinger, 1981). Therefore, lipid or fats have a sparing action on protein metabolism by acting as a source of dietary calories instead of protein, with the result that protein is utilized for growth, as demonstrated in brook trout by Phillips *et al* (1966), quoted by Stirling (1972). Hilton & Slinger (1981) reported that practical trout diets normally contain 6-14% crude lipids or fats, but higher levels in the range, 15-20% may be beneficial to trout, due to the protein sparing effect of the fats. These ranges are in good agreement with the range, 4.1 - 22.8% obtained in this study for the benthos and zooplankton. The basic unit of lipids is the fatty acid which is an acyclic unbranched carbon chain. In a detailed review of lipid requirements of finfish, Cowey & Sargent (1977), Castell (1979), Hilton & Slinger (1981) and Roch *et al* (1988) reported that there are four major series of fatty acids: (1) the palmitoleic type from methyl group, omega-7; (2) oleic group, omega-9; (3) linoleic group, omega-6 and (4) linolenic group, omega-3. Of these, trout are unable to synthesize omega-3 and omega-6, with the result that diets are usually supplemented with animal seafoods or vegetable fats or some mixture of these to supply adequate level of the required concentration of omega-3 and omega-6 acids. Similarly, Mathias *et al* (1982) reported that amphipods contain 3% (dry weight basis) of linolenic or omega-3 fatty acids, mainly in the form of 18 : 3 omega-3, 20 : 5 omega-3 and 22:6 omega-3. This even exceeds the dietary requirement for essential fatty acids for trout (which is about 1% of diet, Castell *et al* 1972). The content of essential amino acid in these organisms have also been reported to sufficiently meet the dietary requirements of trout (Ogino, 1980). It is likely that the macroinvertebrates in the study can play a significant role in making up any deficiencies to pond reared trout.

The role of carbohydrate in fulfilling the dietary requirements of salmonids is a topic of considerable debate. Carbohydrate levels as high as 25% of the diet have been reported to be used efficiently by salmonids; while levels as low as 12% of the diet are also tolerable as reported by Austreng *et al* (1977), Pieper & Pfeffer (1979) and Shimeno *et al* (1979). Excessive carbohydrates in salmonid diet have been shown to be dangerous, producing an abnormally high glycogen content of the liver, depressed growth and increased mortalities, especially at low water temperature (Halver, 1972; Edwardo *et al*, 1977; Bergot, 1979). High values of carbohydrates (as NFE), in the range 11.3 - 36.0% were recorded for macroinvertebrates in this study, the highest being in Sialidae. Although Hilton & Slinger (1981) suggested that carbohydrate should not exceed 20% of the diet, excess carbohydrate may have been used as an alternative source of energy. In any case, their absence in the diet, including artificial feeds seldom has a deleterious effect because salmonids are efficient at glucose synthesis from amino acids (gluconeogenesis) or fats.

Other components of nutritional interest in trout culture are the ash, crude fibre, minerals and vitamin contents of the diet. In natural diets, both ash and crude fibre are usually present in reasonably high proportion as found in this study and reported by other workers (e.g. Kelso, 1973;

Driver *et al*, 1974; Mathias *et al*, 1982; Tacon *et al*, 1983; Watanabe *et al*, 1983; Davies, 1985; Smith, 1988). In contrast, artificial diets contain much lower proportions of these components, probably due to their little nutritive value. However, fibre content in diets acts as 'roughages' or 'bulk' which aid in facilitating movement and absorbtion of food materials in the fish digestive system. For example, Davies (1985) reported that the inclusion of 15 - 20% of cellulose as fibre improved protein utilization by contributing greater intestinal bulk, maximizing the turnover of mucosal cells, inducing enzymatic secretions, which might in turn improve the efficiency of protein absorbtion.

Mineral and vitamin contents, though not determined in this study, are known to contribute significantly to the diet of trout; and under natural earthen ponds conditions, they are a non-essential supplement in formulated diets because ascorbic acid, the main form of vitamin C is obtainable from aquatic macroinvertebrates and other food items like algae (Launer and Tiemeier, 1984). Hilton & Slinger (1981) reported that ascorbic acid is very unstable in practical and test diets, due mainly to moisture content of the diet, processing method, storage conditions and possibly significant losses resulting from leaching. Starter diets are usually at greatest risk from leaching due to their large surface area and accessibility of the water soluble vitamins to the aquatic environment. The problem is further exacerbated by low water temperature in which fish are relatively inactive, resulting in the small feed particle remaining in water for longer periods than at higher temperatures. Therefore, supplemental levels in excess of the recommended allowances for certain vitamins are supplied from natural ingredients.

Under natural earthen pond conditions, mineral and vitamin deficits develop only above a certain level of critical standing crop (CSC) in which case, addition of these nutrients to supplementary feeds is necessary (Hepher, 1988). For example, Lovell (1979) reported that channel catfish stocked at a density of about 3,750 kg ha^{-1} did not require ascorbic acid in the feed supplement, but a standing crop of about 6,270 Kg ha^{-1} fed a supplemental diet without ascorbic acid resulted in reduced growth rate and appearance of fish with deformed backs. Similarly, a combination of tilapia with 9,800 channel catfish ha^{-1}, both competing for natural food, resulted in the catfish showing signs of ascorbic acid deficiency, if the vitamin was not added to the catfish feed. Hepher (1979) found that maximum growth of common carp could be attained at a critical standing crop (CSC) of about 2.4 tons ha^{-1} fed a diet of 25% protein, with no vitamins, and only above this is growth rate affected due to vitamin deficiency. In the present study, the manipulated stocking densities of trout at 1937 and 3875 kg ha^{-1} fed on natural diet with no supplemental feeds (except the controls) may also be considered a favourable CSC, obtaining adequate vitamins and minerals from the earth ponds, considering the favourable growth rate and healthy condition of the fish throughout the culture period.

An additional nutritional advantage of natural food organisms to trout diet is that they usually contain high levels of carotenoid pigments, which may enhance the pink colouration of the skin and flesh. Possible functions of the pigments include: first, percursors to the synthesis of vitamins; second, performing respiratory functions under conditions of limited oxygen supply and third, increasing the tolerance to other harsh conditions like high temperature, ammonia and light intensity (Smith, 1988). Kennedy & Fitzmaurice (1971) reported that many adult trout that were initially white-fleshed on planting in Irish lakes developed pink or reddish coloured flesh possibly due to consumption of natural food. Similarly, Frost & Brown (1967) indicated that carotene obtained from Crustacea and Gastropoda are responsible for the colouring of trout musculature. In this study, it was found that the density of erythrophores in the skin and pink colouration of the flesh of trout from the HC and HCC treatments was more marked in comparison to fish from the control ponds. The trout in the HPN treatment, especially replicate pond 4, did not show such distinct colouration, maintaining their relatively white-flesh from the initial period of planting (see Plates 1 -4). This difference may be an indication of substantial consumption of natural benthic diet in these ponds, unlike the HPN treatment which had mainly favoured plankton production. Similar observations of pink musculature was also made on the trout stocked in Howietoun ponds by Wahab (1986), and it is suggested that this area warrants further investigation.

From the foregoing discussions, it is plausible that a combination of both natural and artificial foods can supplement any nutrient level in short supply to cultured fish and consequently reduce the cost of diet formulation (Lovell 1977). This has long been recognized by Israeli fish culturists (Hepher, 1988; Shilo & Sarig, 1989). Furthermore, commercially available trout rations are currently devised by 'least cost' formulation methods and rely upon information regarding the cost and nutritional value of the range of ingredients available in order to determine the optimum level of inclusion of each product in the diet (Stafford & Tacon, 1985). Naturally balanced diet provides an economically competitive price such that dietary protein requirement within a commercial trout ration is usually supplied using different ingredients present at a relatively low level in the diet. Thus any commercially available dietary ingredient would be subject to such analysis, and it is unlikely that any single product such as zooplankton, dried earthworm meal or *Gammarus* would be used exclusively to supply the dietary protein component in producing trout diet. The results of nutritional composition of natural food obtained in this study suggest that it can be successfully included in trout diets at low levels without necessarily incurring loss of fish growth or feed utilization efficiency. It is therefore proposed that the cost-benefit analysis and other potential benefit need further investigation.

5.5.3. DIETARY CONTRIBUTION OF MACROINVERTEBRATES TO TROUT FEEDING

Throughout the fish culture period, the role of macroinvertebrates in stimulating the production of trout under natural earthen pond conditions, with minimum flow rate and without supplementary feed has been clearly demonstrated. Fulfilment of this role is both from the perspective of their numerical abundance, easy accessibility to the trout and palatability. Several workers (e.g. Curio, 1976; Allan, 1978; Healey, 1979; Arawomo, 1981; Godin, 1981; Wahab *et al*, 1989; Stirling & Wahab, 1990) consider salmonid fishes as being generally opportunistic and generalized predators. Although they are mainly selective feeders, they show flexibility in timing of foraging behaviour. This permits opportunistic exploitation of prey whenever encountered, which is typical of predators or carnivores. Based on these observations, different methods have been used to evaluate the relationship between available food supply and their selectivity. Studies of the relationship between fish predation and benthic production have most often been descriptive, using correlations with fertilization (Patriarche & Ball, 1949, quoted by Hall *et al*, 1970; Hall *et al*, 1970; Schroeder, 1978; Boyd, 1981; Mishra *et al*, 1988), fish densities (Gurzeda, 1965; Hall *et al*, 1970; Opuzynski, 1979; Lien, 1981), fish production (Gerking, 1962) and invertebrate production (Buscemi, 1961; Momot, 1967). These descriptive methods did not give a substantial picture of the relationship between benthos dynamics and fish production as they were not designed to test specific hypotheses. However, other experimental manipulations provided more rigorous control in an attempt to establish the relationship between fish and benthos. These include, temporal changes in fish abundance (Ball & Hayne, 1952; Hayne & Ball, 1956; Macan, 1966; Korinek *et al*, 1987) and artificial enclosures (Lellak, 1966, quoted by Wabab *et al*, 1989; Kajak, 1966; Berglund, 1968, 1982; Wahab *et al*, 1989). These experimental manipulations, compared to the descriptive ones gave a better picture of the relationship, but were unreplicated and dominated by the effects of artificial enclosures. In this study, evaluation of the relationship between fish density and benthos was based on Ivlev's (1961) electivity index. Changes in the benthic fauna is assumed to be due to their being predated upon and the fish response in terms of growth.

The dietary composition of the trout stomach stomach further reinforces its carnivorous nature, feeding on all the different natural food organisms outlined earlier. This is also in agreement with earlier works of Allen (1938), quoted by Arawomo (1981), Maitland (1965), Elliot (1967), Frost & Brown (1967), Thorpe (1974), Arawomo (1981), Wahab (1986), Stirling & Wahab (1990). Occasionally, trout were also found to consume detritus and algae. Generally, the feeding pattern on natural food is also governed by availability, fish age, prey size, and environmental and limnological factors operating within the ponds.

Asellus aquaticus was the most dominant component of the diet, as evident from the stomach content analysis and the strong positive electivity in all the ponds, including the controls. The average percent contribution to fish diet in the ponds was 44.1%. However, differences were observed between the replicate ponds. For example, in pond 1 of the HCC treatment, *Asellus* contribution to the diet of trout was 59.2% in contrast with 36.8% in replicate pond 2. Similar discrepancies were also observed in the control pond 7 in which *Asellus* formed 48.3% of trout diet in contrast with 4.32% in the replicate pond 8 (see Table 24). This finding, however, contrasts with those of Arowomo (1981) and Wahab (1986). The differences might be due to the relative extent to which the animals are represented in the aquatic environment. In this study, as earlier discussed, *Asellus* production was higher in ponds that had dense physical matrix of macrophyte beds; and coupled with their large size and free swimming habit in the water column, they tend to be more vulnerable to trout predation. This postulation is also in agreement with Okland (1980), Berglund (1982), quoted by Hargreb (1990) and Hargreb (1990). This also probably explains the strong positive selection in control pond 7 which had abundant macrophytes and *Asellus*. In contrast, the weak positive selection in replicate control pond 8 is probably due to a regular supply of pelleted diet, with the result that the small amount of natural food consumed is due to chance encounter while consuming the pellets which settled in the sediment. Similar explanations may also hold true for the high positive selectivity of Mollusca in all but control pond 8.

Thorpe (1974) reported high abundance of mollusca in the stomachs of larger juvenile trout. It appears that as juvenile trout are being recruited into the adult stage, mollusc become more prominent in their diet and competition for other food items is reduced, as also found in this study. This was confirmed with the consumption of zooplankton during the early period of stocking, but with changes in size, they showed low consumption rate, especially with *Bosmina sp* and Copepoda. The presence of zooplankton in trout food has also been reported by Frost & Brown (1967), and Maitland *et al* (1981).

In spite of the dominance of oligochaetes in the benthos, they appear to make little contribution to the diet of trout as evident from the strong negative electivity in most of the ponds (Table 24). This may be attributed to the influence of the physical matrix of macrophytes at the pond bottom, and coupled with their hidden nature in the mud makes them virtually inaccessible to trout. However, in the absence of such a physical matrix, trout are able to fully exploit the pond bottom and predate on the oligochaetes. This was evident from the result of the short term trial in which they were deprived of artificial pelleted diet in the control ponds 7 & 8 for one week. The result showed highest selectivity in pond 8 which had no macrophytes, compared with pond 7 (Table 24). Larkins (1989) also failed to demonstrate greater dietary representation by oligochaetes, thus supporting the accessibility hypotheses. Grimas (1963) and Stirling & Wahab (1990) ascribed the inaccessibility to their hidden life within the sediment, in contrast with the surface dwelling, and therefore, more accessible chironomids. The controlled feeding trials of Waddell (1988) support this hypothesis, in which he demonstrated a neutral selection on oligochaetes when trout were presented with a mixture of fauna in a tank without sediment, but negative selection when sediment was present. Similarly, there was no evidence of oligochaete unpalatability. The alternative hypothesis of Pentelow (1932), (quoted by Stirling & Wahab 1990) and Kennedy (1969) is that the stomach contents of sacrificed fish reflects their relative digestibility, soft bodied oligochaetes being underestimated because of rapid digestion, while crustaceans and insects, especially their mouth parts and head capsules, tend to accumulate due to their more resistant cuticle as also found in this study with Asellidae, Gammaridae and Sialidae. The rapid digestion of oligochaetes is supported by their almost complete digestion within 4 hours at 5^0C, compared with 49 hours for a meal of *Gammarus* at the same temperature (Fange & Grove, 1979). Stirling & Wahab (1990) suggested that such a rapid digestion leads to underestimation of numbers compared to other taxa in the diet, thus giving a negative bias to their electivity index. However, this does not apply to the frequency of the occurrence method because the indigestible chaetas provide evidence of ingestion.

Several workers (e.g. Ball, 1961; Hunt & Jones, 1972b; Pedley & Jones, 1978; Brown *et al*, 1980; Arowomo, 1981; Stirling & Wahab, 1990) have emphasized the importance of chironomid larvae in trout diets. The latter authors also observed peak feeding on the larvae and pupae, coinciding with peak periods of emergence between April and August. In this study, strong negative electivity by trout occurred in all the ponds, except pond 6 of the HC treatment which showed weak positive selection. Allen (1938, 1951) postulated that the food of brown trout is primarily controlled by what is available, and secondly by the feeding behaviour of the fish. It is therefore possible that the presence of other larger macroinvertebrates like *Asellus, Gammarus* and *Sialis* make them more accessible than the mud inhabiting chironomids. This also implies that trout will have to spend less energy and effort in niche exploitation. Similar explanations might also account for the general lack of response to natural food predation by trout in the control ponds that received pelleted diet because during hand feeding, they are able to take the pellets in the water column which are visible, floating and readily available before settling down at the pond bottom. Hirudinea, in spite of their abundance were little utilized by the trout. Similar observations have also been made by Hunt and Jones (1972b) and Wahab (1986), who attributed this to their hidden nature and firm attachment to the substratum which makes it difficult for fish to prey on them. It is also likely that the lack of response to Hirudinea by trout is their unpalatable nature. Although the exact identity of the factor causing such unpalatability still remains to be elucidated, it is likely that malodour emanating from the coelomic fluid of the animal play a role as suggested by Edwards & Lofty (1977) and Tacon *et al* (1983) based on studies of palatability of different worm species to trout. It may be further deduced that eleocytes (cells within the coelomic fluid derived from phagositic amoebocytes) are responsible for the malodour, though components within other excretory cells (e.g chlorogogen cells) which are released into the coelomic fluid from the coelomic epithelium of the intestine could also be responsible. Thus, the dietary importance of the leeches and oligochaete worms deserve further investigation.

Throughout the study period, it was observed that peak feeding on oligochaetes, chironomids and *Sialis* coincided some amounts of plant materials, stone particles and detritus found in the stomach. This was even more pronounced during the winter period, which is well in agreement with Maitland (1965), Cunjak & Power (1987) and Stirling & Wahab (1990) who reported that trout concentrate near the bottom and feed there, avoiding the cold surface layer. Furthermore, Waddell (1988) suggested that trout at this time take mouthfulls of bottom materials, exploiting the rich organic matter including bacteria, plants and algae, oligochaetes and uneaten pelleted food.

Zooplankton consumption by trout was observed to be highest during the first six weeks of stocking. In some cases, these constituted over 45% of total food items in the stomach in all the ponds. However, as the fish grew, there was a shift away from its consumption to that of other larger macroinvertebrates, though they still showed an ability to turn to zooplankton food, probably due to high prey density which compensates for effort needed to exploit benthos, as also observed by Hall *et al* (1970). It would, therefore, appear that the importance of zooplankton under such semi-intensive condition may be at the beginning of the fish growing season before supplementary feeding and/or adapting to other natural food, as also reported O'Grady and Spillet (1987), Smith (1988), and Jonasson (1989). In a short term experiment using fertilized mesocosms, Tamatamah (1990) demonstrated the importance of zooplankton in the diet of brown trout fry; the average %-contribution being 54%, 33%, 8.2% and 14% for *Daphnia sp, Bosmina sp, Alonopsis sp* and *Brachionus sp* respectively.

Wahab (1986) found that terrestrial invertebrates, mainly different types of aerial insects and beetles, formed a considerable proportion of trout diet. This has also been reported by various workers dealing with trout feeding in natural water bodies (Allen, 1938; Maitland, 1965; Pedly and Jones, 1978; Arowomo 1981) and other omnivorous freshwater fishes like *Hydrocynus forskali* and *Eutrophus niloticus* (Lewis, 1973; Olatunde, 1978). Similarly, O'Grady (1983) observed that fish newly planted in natural water bodies consumed items near the surface, probably due to their being preconditioned to look for food during the normal fish farming feeding practices. Maitland (1965), on the other hand, suggested that aerial organisms falling on the water are randomly eaten by the fish. In this study, although larger terrestrial insects such as beetles were observed in great numbers, especially during the summer, they constituted only about 0.04% of the total macroinvertebrates consumed in all the ponds. This may be due to wide choice of other food items available to them as earlier discussed.

From the above discussions of the present findings and other related works, a generalisation which emerges is that, in addition to the natural food abundance, accessibility and palatability which determine the relative contribution to the diet of trout, other environmental factors and prey-predator relationship might have played a role in the feeding behaviour. For example, peak feeding periods were observed to be favoured during the warm spring/summer periods when temperature is generally high, compared to the winter period, as also observed by Arawomo

(1981), O'Grady (1983), Wahab (1986), Hesthagen & Johnsen (1989) and Kelly-Quinn & Bracker (1989). Similarly, the high level of dissolved oxygen in the ponds probably played significant role in trout feeding. The observed selectivity of the various groups not only reflected their importance but also probably the influence of size and accessibility. Pedley & Jones (1978) and Rigler (1979) reported that the behaviour, morphology and habitat preferences of fish play a major role in prey selectivity; while the prey size, behaviour, habitat, distribution and abundance determines its vulnerability. For example, during the early part of stocking, the small-sized juvenile trout showed high predation or selectivity on zooplankton, small sized *Asellus, Gammarus, Sialis* and *Tubifex*, but as the trout grew, the selectivity on prey showed that correspondingly larger organisms were consumed. Other factors implicated in prey-predator relationship is the hunger level, in which the degree of selectivity by fish decreases with increased hunger (Pyke *et al*, 1977) and/or decreased prey density (Ivlev, 1961; Werner and Hall, 1974; Collins, 1989; Wooton, 1990). According to the latter author, in the presence of abundant food, and in the absence of other confounding factors like predators, the rate of food consumption by fish will be determined by its feeding motivation. The rate of consumption is governed by two factors: first, systemic demand - i.e the demand for energy and nutrients generated by the metabolic rate and secondly, the rate at which the digestive system can process food (Colgan, 1973). These two factors interact to generate the motivational state of hunger and to determine appetite. Hunger is the propensity to feed when given the opportunity, while appetite is the quantity of food consumed before the fish cease to feed voluntarily. It is therefore proposed that the selection of natural food and its subsequent consumption by trout in the earthen ponds were likely to have been influenced by the above postulations. Personal observations during monthly pond drainage for measurements of fish growth parameters and stomach pump sampling showed the reverse of earlier observations. i.e. as benthos population declined, larger fish were found to consume small-sized prey and even filamentous algae like *Spirogyra*. This was more pronounced in the HPN treatment which had low abundance of natural food; while in the other ponds that had high organic treatments, low abundance of natural diet in the stomach was generally encountered in the smaller rather than the larger trout. Several workers (Yashouv, 1969; Jenkins, 1969; Stirling, 1972; Fausch, 1984; Metcalfe, 1986; Collins, 1989) have demonstrated that the most dominant fish, including salmonids, usually obtain the best feeding niche in terms of energetic profitability, both under laboratory and field conditions. Similarly, dominant fish tend to remain dominant in relation to their preferential access to food resources, and the extent of food deprivation of subordinate fish depends on the degree of competition, being greatest at high density and when availability of food is spatially and temporally restricted as reported by Yamagishi (1962), Stirling (1972), Li & Brockson (1977); Bachman (1984), Fausch (1984) and Metcalfe (1986). Godin (1981) postulated that salmonid behaviour such as continous swimming and foraging during feeding periods enhances maintenance of a full stomach, because they tend to feed at a relatively low hunger threshold and at a rate that balances gastric evacuation rate. This further permits opportunistic exploitation of available prey organisms whenever encountered.

All previous experiments in Howietoun fish ponds, especially involving fish stocking, have been based on management strategies adopted for the ponds, i.e. fish of the same age group, size and weight. Wahab (1986) reported that during the culture cycle, a proportion of the trout showed size dominance, but stomach content analysis of various fish sizes randomly caught failed to demonstrate any difference in the content of natural food organisms. Similarly, all sizes of fish caught from the same pond contained natural food organisms in their stomach. This, however, contrasts with the present findings in which trout demonstrated differences in their contents of natural food organisms, while those in the control pond 8 showed strong negative selectivity on natural food throughout the period they were fed artificial pelleted diet. Even where natural food was encountered it was dominated by only one or two groups such as zooplankton or *Gammarus* or *Asellus*, rather than fairly equal representation of all the major groups. Perhaps, an explanation for the observed differences could be that, Wahab's findings were based on the fact that fish were predominantly fed artificial diet 3x daily and equally spread over the pond area such that trout had an equal share. It is therefore unlikely that the dominance theory will hold true for the fish population.

5.6. FISH GROWTH AND CARCASS COMPOSITION

Throughout this study, in relation to fish culture trial, a general pattern that emerged was the fact that trout displayed a spectrum of survival rate, growth, and production responses at varying nutrient levels and stocking densities. For example, the organic treatments with their correspondingly abundant natural food resources stimulated trout growth and production more favourably than the inorganic treatment, as evident from the growth parameters and carcass composition measured. The overall growth pattern and annual production are discussed in relation to food availability and other exogenous or environmental factors observed.

5.6.1. FISH SURVIVAL AND GROWTH

The high survival of trout in spite of almost continous static water conditions may be due to relatively moderate stocking density and adequate water quality. It is also likely that during the monthly fish sampling, the lowering of water level partially exposes the sediment to air, which is known to correct fish growth retardation. This postulation has also been reported by Zohar *et al* (1984), Shilo & Rimon (1982) and Avimelech & Zohar (1986) during fish culture studies in various ponds in Israel. According to Flath & Diana (1985) and Wooton (1990), survival of juvenile and adult fish is generally governed by predation, disease, parasitism and more rarely, under natural conditions, exposure to lethal abiotic conditions. Similarly, the ability of fish to lay down lipid reserves and their capacity to survive long periods without food may reduce the importance of starvation as a cause of mortality, except under unusual circumstances. However, insufficient energy stores may reduce survival rate. In this study, predation, disease and parasitism may be ruled out as the possible cause of the observed 36% mortality in the HPN treatment, because predation amongst juvenile trout of the same age class is unknown, and in any case, all the ponds were adequately protected with nets from external predation by herons. Post mortem examinations did not show any sign of parasitic infection or disease manifestation. This is not unexpected, considering the stringent management practice adopted on the farm, which involves occasional bathing of the trout in malachite green, once out of the hatchery, prior to restocking. Besides, the liming strategy in the first year of this study might have contributed in maintaining sterility of the experimental ponds from harmful parasites.

It is therefore likely that adverse water quality conditions especially D.O., B.O.D., ammonia, U.I.A. and nitrite under still water conditions might have played a role in causing mortality, as also observed by Mackay & Toever (1981) for salmonids. An alternative hypotheses is the inability to lay down lipids and consequently energy reserves during the early period of stocking which could also be implicated in causing mortality. This is because trout are not able to fully utilize the predominantly plankton food resources in the HPN treatments, which are potentially good reserves for lipid as earlier discussed in subsection 5.5.2. Smith (1961), Volkov *et al* (1984) and Johnsen & Ugedal (1986) suggested that prolonged stay of fish in a hatchery can lessen chances of survival in a natural environment because of the length of time required to adapt to either pelagic and/or epibenthic feeding.

In relation to growth, fish are generally known to have an indeterminant growth pattern, in which growth potential, maturation and senility are more a function of size related physiology than chronological age (Brown, 1957, quoted by Hall *et al*, 1970). Evidence for this plastic growth is with reference to food, stocking density and competition amongst the species for common resources (Beckman, 1941; Poloheimo & Dickie, 1966b; Backiel & LeCren, 1967; Hepher, 1967; Hall *et al*, 1970; Hepher, 1988; Hepher *et al*, 1989; Wooton, 1990). According to Hepher (1988), the main environmental factors that could possibly account for any effects on growth rate are temperature, light, water quality, oxygen and fish catabolites. While the first two factors are independent of fish density in the pond, the latter three are density dependent. Thus, high fish biomass due to increased density or individual weight results in high oxygen requirement, which may in turn cause reduced oxygen concentration to a harmful level. High biomass coupled with high excreted catabolites, especially ammonia may accumulate, poison the fish and inhibit their growth.

Fish growth and production (Table 21) obtained in this study showed that even at relatively low stocking density, without continous flow, reasonable levels of fish production can be obtained by stimulating benthos productivity through manuring. Hall *et al* (1970) demonstrated that fish production was directly related to the production of macroinvertebrates in ponds. Besides, they suggested that the provision of a refuge by the weeds apparently permits an array of larger species to exist in the presence of fish which may in turn provide for greater fish production.

Evidence of favourable growth rate is also seen from the significant regressions of body weight on time. However, the growth rate declined during the winter period, which may be attributed to factors such as low temperature which tend to reduce metabolic activity and thus feeding rates, as evident from stomach pump samples. This observation also corroborate the findings of Brocksen & Bugge (1974), Elliot

(1975b, 1976c) and Cunjak & Power (1987). Another factor may be due to reduced supply of food resources in the experimental ponds as also noted by Hepher *et al* (1989). The reduced growth rate during the winter in ponds 4 (HPN), 6 (HC) and 7 & 8 (CTRL), contrasts with observations in ponds 1 & 2 (HCC), 3 (HPN) and 5 (HC). It is likely that condition factor of the trout, especially in the HPN treatment, was influenced by food supply and/or utilization rather than time, because, even during the winter sampling, values of condition factor were above average. Cunjak & Power (1987), on the other hand, reported that condition factors of stream-resident trout fell in early winter, remained low, then rose to original levels in the spring. They also observed that food intake did not vary markedly during the winter, which generates the question of whether trout activity and assimilation did contribute to the low winter condition. However, underwater observations by Cunjak & Power (1986b) showed that activity and agression are greatly reduced in winter. Thus the extent to which ingested foods are assimilated and the variations in condition factor at low temperatures deserves further study. The seasonal cycle of growth obtained in this study is not unexpected since most fish species conform to this (Bagenal, 1978). However, several factors regulate growth processes during a fish life span. These include food availability and competition, temperature and physiological conditions (Yashouv, 1969; Hepher, 1988, Wooton, 1990).

In a study of a fish pond as an experimental model for study of interaction within and among fish population, Yashouv (1969) has demonstrated that increased fish density of mixed species beyond the optimal limit results in a state of tension, compared with that in a monoculture which enhances competition. In both cases, the ultimate result is a decline in both growth rate and production. Thus the generalizations about the presence or absence of competition based on food analysis or fish distribution in different ecological niches are only valid within the limits of optimal density of the populations in the habitat. Surpassing these limits results in interspecific competition, while intraspecific competition will also increase. The phenomenon of intraspecific competition probably explains the observed reduced growth rate exhibited by a few trout in all the ponds. Jonasson (1989) reported that brown trout partly segregate in a habitat by size and age, depending also on stocking density. This segregation may be because different sized fish have different abilities to capture, handle and eat food organisms of the same size and behaviour. Moreover, fish have indeterminate growth (Weatherly and Gill, 1987) and will grow through many size classes during their life span. Profitability of a food patch will therefore vary between size and age groups of fish (Hart, 1986). This implies that fish are expected to feed in richer habitat and only shift habitat when profitability of one drops below that of another as demonstrated by Werner & Gilliam (1984). Fish at lower stocking density should benefit from less competition for available food as has been reported by Wohlfarth (1978) and Hepher *et al* (989).

The optimum temperature for growth in brown trout has been a subject of controversy amongst most workers, although a general concensus is that growth is slow at temperatures less than 7^{0}C and greater than 19^{0}C. Elliot (1975c) reported that the specific growth rate of two-year-old trout was most rapid at 7 - 9^{0}C and 16 - 19^{0}C. Swift (1955) reported maximum growth rate of yearling trout at 12^{0}C. Growth rate for other species of salmonids are best at 13^{0}C for *Salvelinus fontinalis* and approximately 15^{0}C for *Oncorhynchus nerka* fed on excess rations (Brett *et al*, 1969). In a series of experiments reported by Elliot (1975c), it has been shown that the specific relative growth (as % body wt day^{-1}) of brown trout fed maximum rations increased with increasing temperature from 3.8 to 12.8^{0}C. Maximum growth rate occurred between 12.8 and 13.6^{0}C, above which, growth decreased with increasing temperature up to 19.5^{0}C. The growth rate obtained in this study was highest in the organic treatments and controls at about 17.5^{0}C and lowest at about 4.5^{0}C. This corroborate Elliot's (1975c) finding and suggestion that at a certain stage of fish growth, optimum temperature could become progressively less apparent.

Considering growth rate on reduced ration as may occur under gradual depletion of natural food, growth tends to decrease markedly with increasing body weight due to the fact that large fish require more food for maintenance than small fish, thus leaving smaller scope for growth. The same applies to increases in water temperature, which also increases the maintenance metabolic rate. Elliot (1975c) suggested that increased swimming activity could decrease growth rate. Similarly, Brown (1957b) found that some latent physiological factors caused unexplained cycles in growth rate during normal life conditions. Thus in spite of constant environmental conditions, brown trout had an annual growth cycle, with an autumn check, a spring maximum, rapid summer growth and another autumn check which coincided with gonads maturation when fish became 3-year-old. Besides, individual specific growth rate fluctuated over a period of 4 - 6 weeks, during which time, rapid growth in length alternated with rapid growth in weight. Similarly, Stirling (1972) reported fluctuations in growth rate of European bass (*Dicentrarchus labrax*) cultured under laboratory conditions for six weeks. There was a marked decline over the first four weeks, then an increase in the 5th week and a decline in the 6th week.

Hepher (1988) reported that in conditions where natural food was sufficient to sustain growth, no significant difference was found in growth rate amongst fish in treatments that had artificial pelleted diet. This may also explain the case found in this study in the HCC and control treatments. However, the rich growth of macrophytes in replicate pond 7 probably accounts for its low fish performance because , unlike rainbow trout, brown trout are shy feeders and do not actively take pellets during hand feeding but search for them later and the macrophytes in this pond would tend to hide the food.

With regards to the computed values for relative food intake (R.F.I.), it is important to note that in the indirect computation, possibilities of errors arise when assuming that stomach are filled 3x day^{-1}. This is so even with fish samples under natural conditions. This method gives no information about the variation in food intake between individual trout, since only the responses of the fish to food (in terms of growth rate) could be observed individually. Although it is assumed that variability in food intake was reflected in variability in growth rate, caution must be taken when intepreting models in general.

RFI and temperature interact to influence growth rate as demonstrated by, Stirling (1972), Elliot (1975c,d), Hepher (1988), Quinton & Blake (1990) and Wooton (1990). In this study, RFI (as estimated from stomach sampling) increased with rise in temperature, and the range, 5 - 14.9% observed in the temperature range of 13.7 - 16.9^{0}C occurred during the summer period of July - September in all the ponds, coinciding with the peak growth period. In contrast, the low RFI recorded in the HPN treatments (ponds 3 & 4), despite the favourably high temperature, may be due to low abundance of natural food and other factors such as stress resulting from decline in water quality conditions at the onset of the culture period. This corroborates the findings of Hall *et al* (1970) who showed that at lower food levels, fish stomachs contain relatively diversified assemblages of species, which in the long run could prove inefficient and therefore contribute to differences in fish production. The energy content of a particular feed also affects its intake, since fish generally eat to satisfy their energy needs. In the case of trout, this is drastically reduced in adverse water conditions and/or presence of heavy algal growth (Hilton & Slinger, 1981) as was the case in the HPN treatments in this study. Similarly, Davies (1989) demonstrated a progressive decline in relative food intake (% body wt day^{-1}) with increasing dietary lipid level by rainbow trout which further consolidates the assertion by Hilton & Slinger (op. cit.).

It may be emphasized that ramifications of all the parameters influencing growth rate can also be related to the concept of 'compensatory growth' in fish. This is a phase of rapid growth, greater than normal or control growth rates, associated with adequate refeeding following a period of weight loss caused by undernutrition and/or intermittent starvation and feeding periods. This concept has been demonstrated by several workers (e.g. Bilton & Robins, 1973; Smith, 1981; Weatherley & Gill, 1981; Dobson & Holmes, 1984; Kindschi, 1988; Miglars & Jobling, 1989b; Quinton & Blake, 1990) under laboratory conditions, but obviously has direct application towards understanding the phenomenon of food intake and growth under field conditions. For example, in a given natural pond environment, where fish depend on natural food for growth and maintenance, an abundant supply will obviously enhance growth, but with time, the resources decrease resulting in reduced growth and metabolic changes such as a decline in protein synthesis. However, with improved food supply through high turnover or the fauna replacing itself at a high rate, then optimum feeding resumes, resulting in increased growth associated with compensatory growth response. Thus such a cyclically fed fish can achieve equal growth under favourable conditions in the pond (Quinton & Blake, 1990). Such possible mechanisms underlying the compensatory growth response might also account for the observed fluctuations in growth in the HPN treatment in which the rate of natural food replenishment is slower than the rate of its depletion.

5.6.2. CARCASS COMPOSITION

With regard to carcass composition, it is apparent that natural food in earthen ponds had a profound effect on trout carcass composition when compared to the initial fish carcass. Variations in carcass water content in all the fertilized ponds with natural food was significantly different from the control pond 8, probably due to differences in the type of food consumed. Several workers (Brett *et al*, 1969; Elliot, 1976c; Stirling, 1976; Wee, 1982; Stafford & Tacon, 1985; Wee and Ng, 1986; Hepher, 1988;

Davies, 1989) have demonstrated an inverse relationship between water content and lipid or fat level in different fish species. Swift (1955), quoted by Elliot (1976a) found that the major seasonal changes in the body composition of brown trout were due to variations in food reserves, mainly in the form of fat stored along the mesentaries and pyloric caecae. These fat reserves reached a peak of 23% during the summer, then fell to 5% in the autumn. Brett *et al* (1969), found a significantly high negative correlation between percent fat content, percent protein content and percent water content, and concluded that if the water content is known, then the fat and protein content can be estimated fairly accurately as demonstrated by Elliot (1976a). All these works support one of the conclusions in the present study, namely that the carcass water composition was mainly due to differences in lipid levels of consumed diet. Thus the lipid content of natural diet in the ponds were much lower than than that of the artificial pelleted diet fed to trout in the control pond 8 which were much fatter. However, the trout in replicate control pond 7 were leaner possibly due to the influence of abundant macrophytes which tended to hide the artificial pellets, making them unavailable to the trout, causing the latter to feeding on available natural food.

From the observed differences in the lipid or fat levels in the trout, it may be necessary to adjust feed formulations in order to minimize the adverse characteristics such as obesity and excessive visceral fat deposition (Davies, 1989). This is particularly relevant to the latter stages of farm production when trout approach marketable weights, to meet consumer and/or angler acceptability who generally prefer less fatty fish (H.P. Stirling, Pers. Comm.).

Carcass protein content in fish with adequate food supply tends to increase as the fish grows (Papoutsoglou & Papaparaskova-Papoutsoglou, 1978; Marais & Kissil, 1979; Steffens, 1981; Quinton & Blake, 1990). This clear trend was observed in all the ponds, the highest value being in the HCC treatments. It seems likely, as discussed earlier sub-section 5.5.2, that the protein quality of the food resources played an important role in the carcass composition. In comparison with herbivorous fish like the tilapia *Oreochromis niloticus*, Edwards *et al* (1985) reported that the body protein content did not show a consistent trend of increase when fed 100% water hyacinth replacements, possibly due to its high fibre content, indigestible organic matter and an inability to produce cellulase enzymes directly (Fish, 1960; Stickney & Shumway, 1974; Buddington, 1980). Similarly, the fish have limited ability to maintain a symbiotic gut flora capable of hydrolysing cellulose. This contrasts with their ability to digest significant amounts of detritus due to the relatively low gastric pH of tilapia which in fact is much lower than the optimal value for cellulase activity. It is thus proposed that detrital material, often supplemented by plankton and/or benthos, provide suitable food resource for most tilapia species (De-Silva, 1985). Salmonids on the other hand, are carnivorous and are not able to utilize plant materials efficiently. This probably explains the low carcass protein content obtained in the HPN treatments which mainly benefited plankton production, especially algae which are not susceptible to the trout's digestive enzymes.

The level of carbohydrate (as NFE) in a diet has a profound effect on fish carcass composition. In this study, the carcass NFE showed significant variations between ponds; with least values of 0.49 and 1.70% in the CTRL pond 8 and HCC pond 1 respectively, while the highest value of 9.75% was obtained in HPN pond 3. Carnivorous species are less able to metabolize carbohydrate than herbivorous species (Shimeno *et al*, 1979; Cowey & Sargent, 1979; Furuichi & Yone, 1989). Studies with salmonids have shown that feeding with high levels of carbohydrate lead to retarded growth, elevated liver glycogen and mortality (Phillips *et al*, 1948, quoted by Wee & Ng, 1986; Austreng *et al*, 1977). Accordingly, optimum levels have been recommended for use in trout diet. For example, Edwardo *et al* (1977) observed that rainbow trout grew best on diets containing not more than 17% dietary carbohydrate. Cowey & Sargent (1979) on the other hand, concluded from their studies and review of carbohydrate nutrition in fish that maximum acceptable dietary carbohydrate inclusion level for channel catfish, rainbow trout and plaice was 25%. According to these authors, optimum levels of dietary carbohydrates spare protein for growth and could be as effective as isocalorific amounts of fat as a source of energy. In contrast however, herbivorous and omnivorous species are able to utilize carbohydrate more efficiently. For example, Ufodike & Matty (1983) showed that increased levels of various dietary carbohydrate upto a maximum of 45% improved growth responses and food conversion efficiency in mirror carp (*Cyprinus carpio*). A similar favourable response has been demonstrated with tilapia (*O. niloticus*) fed 40% dietary carbohydrate (Anderson *et al*, 1984); while Wee & Ng (1986) reported that at relatively high lvel of 60% carbohydrate fed to *O. niloticus*, there was no detrimental effects on growth of carcass composition. However, Furuichi & Yone (1981) reported that carbohydrate levels of 40% retarded growth in the common carp (*C. carpio*).

5.7. COST-BENEFIT ANALYSIS

The differences in production cost and benefit between the two culture systems is not unexpected, considering the availability of organic manure at very cheap rate. Even the cost benefit ratios obtained were based on first year of production. This implies that higher returns could be expected in subsequent years years, because capital inputs are seldom replaced for as long as 4-5 years as earlier indicated. Despite the comparatively low cost benefit ratio obtained for the control ponds, it will be errorneous to conclude it is run at a loss, because the mean number harvested and used in this computation is well above the observed break even point. However, in situation where the cost-benefit ratio and interest rates are not viable, such an investment will appear to be uneconomical.

Managerial methods for production depends on production targets, environmental conditions etc. For example, when both systems of production are compared, producction cost is higher in the control condition due to purchase of the more expensive artificial pelleted diet; although higher fish production is obtained. The higher income derived from the manured ponds will tend to cover expenses incured over and above the projected value, thus making such enterprise worthwhile. It is therefore imperative that the farmer analysis the economic results of previous culture and plan accordingly for the future. Economic considerations should be a major factor influencing production, especially where the main thrust is introducing integrated farming rather than developing specific schemes likely to be capital intensive. It may also be argued that labour costs tends to be higher when fish are cultured on artificial pelleted diet due to frequency of feeding per day, on manual basis. This contrasts with organic manuring applied forthnightly to directly stimulate benthos production for the benefit of trout.

At the commencement of this study, the yearlings used for stocking the ponds cost about twenty-five pence (25p) each. Economically, fish culture tends to be critical at the fry to fingerling, rather than fingerling to adult due to high cost of production. For example, cost of artificial feeds for trout fry at various stages of growth is in the range of £845 - 895 per ton. It is thus proposed that more gains can be made in terms of economic viability if successful culture of fry to fingerling stage can be achieved with organic manuring under temperate conditions.

It may be concluded that the prospect for organic farming remains bright, especially when modern methods based on sound scientific, ecological, technological and economic principles are applied. According to Garhardsen (1977), such an innovation on a large scale for profit, in terms of better commercial and social return on investment, time and human efforts will be realised only by the informed and venturesome.

5.8. POND ECOSYSTEM MANIPULATION AND IMPLICATIONS FOR MANAGEMENT

One of the major aims of this study has been towards attaining rational management of the aquatic ecosystem capable of supporting the various pathways in those foodwebs that directly lead to increased production of fish biomass. These aspects are discussed in the light of the present findings with a view to having a better understanding of the practical implications and economic considerations of manipulation studies under Howietoun fishery conditions. Where relevant, a comparative analysis of the findings of other workers, under temperate and tropical conditions will be made.

Earth pond ecosystems are the most complex because of the complex pathways of the foodweb which provides for direct food consumption and utilization, all of which must be managed based on the conceptual model earlier described in Fig. 98. The goal of manipulating the ecology of earth ponds in Howietoun should be to maximize the efficiencies of both nutrient and energy towards the trout output. Thus culture strategy should as much as possible utilize the top pyramid of the food chain. With carnivorous fishes like the trout, it would appear to benefit from the 2nd & 3rd trophic levels outlined in Fig. 99. This contrast with herbivorous fishes which benefit from the 1st trophic level which is much more efficiecient because the energy and nutrient cycles do not pass through more than one trophic level before being consumed.

Although phytoplankton do not form a part of trout food, they obviously play a significant role as a primary link in the food chain, especially in sustaining zooplankton populations. (see Figs. 98 & 99). It has also been reported by Alderson & Howell (1973) and Spektorova (1979) that phytoplankton are useful in maintaining good water quality since they are capable of utilizing free ammonia (NH_4^+) as a source of

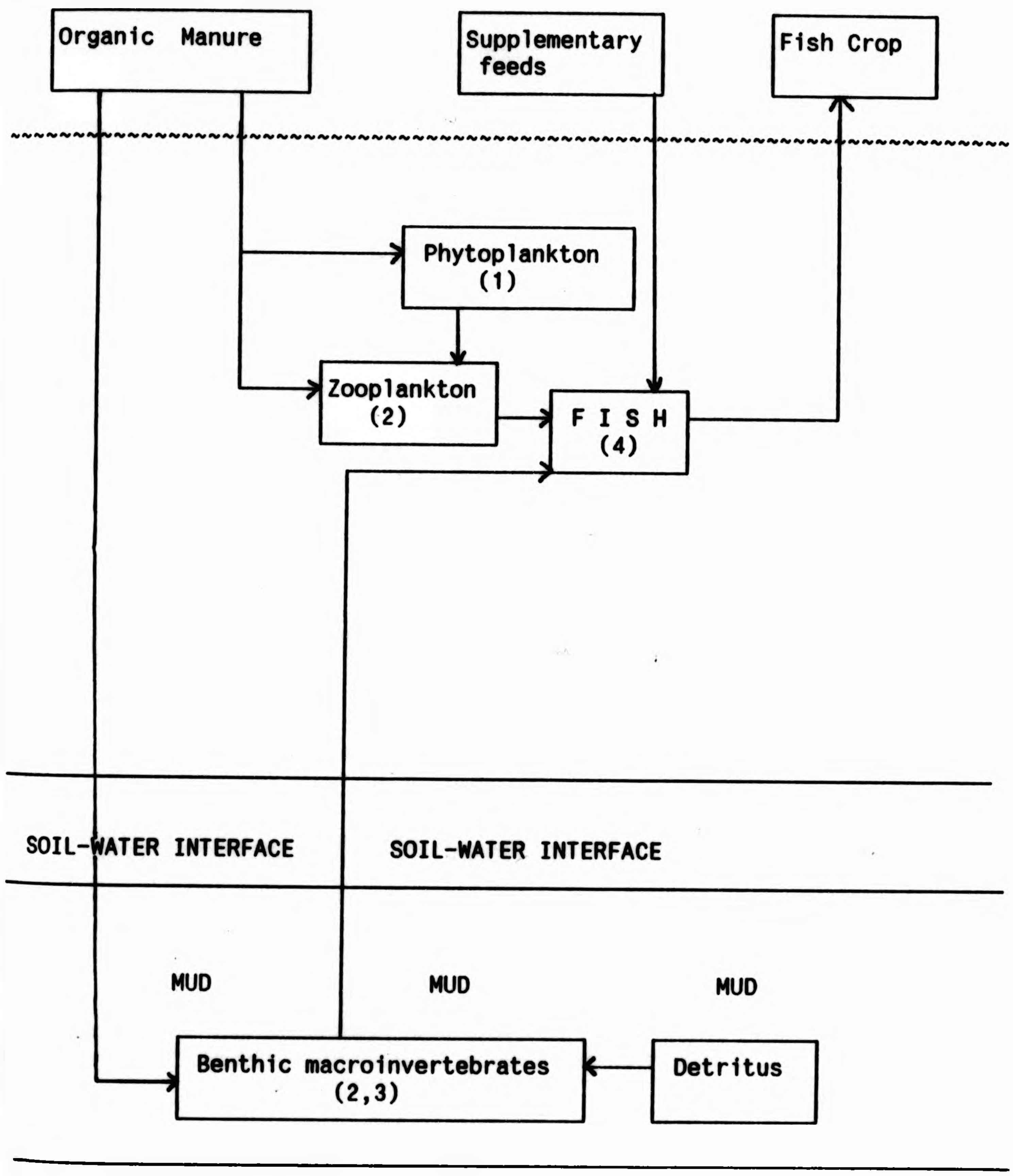


Figure 99. Manipulation strategy relevant to Howietoun Fishery (key is as explained in caption to Fig. 98)

nitrogen which in turn serves to detoxify the culture medium (Cohen *et al*, 1976). Proper fertilization that ensures optimum algal production thus ensures a regulatory mechanism of maintaining favourable water quality for trout.

Manipulation of nutrient concentrations, especially with organic manuring, resulted in a greater response in zooplankton abundance which formed a substantial part of the trout diet during the early period of the culture. The fry of trout and other fish species tend to benefit more from zooplankton abundance (Behrendt, 1986; Holm 1986; O'grady & Spillet, 1987; Ferman & Recometa, 1988; Smith, 1988; Hopkins & Manci, 1989). Tamatamah (1990) demonstrated the potential usefulness of zooplankton as source of food to trout fry in a mesocosm. Although this was a short term trial that could not evaluate growth rate, it clearly demonstrated consumption of zooplankton and the ability of the fry to survive the moderately fertilized still-water conditions. From the above discussion, it appears that a good management strategy which ensures adequate zooplankton abundance for long duration in earth ponds is most beneficial for continous survival of fish. Under tropical conditions, occasional pond draining to maintain good soil and hence water quality, followed by fertilization, could be carried out all year round due to favourably high temperature conditions. Under temperate conditions, however, spring/summer are the only favourably warm periods that can stimulate natural food production. If fertilization for continous production is to be carried out, then it should be initiated immediately after ice-melt

(Buttner, 1989). There are quite a number earthen ponds in the Howietoun fishery, some of which have for long layed fallow without being utilized. If zooplankton culture for use in larger ponds appear cumbersome to manage, one of the nursery ponds or small circular concrete tank could be used for small scale production. From experience in this study, a quick method of determining the relative abundance, at least, biweekly, can be carried out just after sunset when they tend to be randomly distributed or in the presence of artificial light they tend to congregate close to the surface of the pond water. These could be collected in a bucket or plankton net from the culture system and innoculated into the larger culture ponds stocked with fish fry. In addition to periodic sampling, other management decisions could be based on several factors: If water quality is good, the microcrustaceans tend to be abundant, in which case fertilization rates should be maintained, but if water quality deteriorates (e.g D.O.< $3.0mgl^{-1}$, pH >9.0, NH_4-N >$1.0mgl^{-1}$), then fertilization is excessive and should be reduced.

It is pertinent that by manipulating an ecosystem for production of prey organisms and by taking advantage of their natural behavioural tendencies to achieve an attracting and concentrating effect before presenting them to the fish, an elegant and perhaps cheap method has a great potential for application in semi-intensive culture system. Promising results showing high growth rate using zooplankton as a starter diet have been reported from Norway (Holm *et al*, 1982; Reinertsen *et al*, 1984; Holm, 1986), Israel (Lubzens *et al*, 1984), the Philippines (Ferman & Recometa, 1988) and United States (Buttner, 1989). However, a note of caution is that, in any given environment where this has never been practiced, it is important that before being put into large scale application, it is necessary to investigate any potential risk of parasites and/or pathogens that may be accidentally introduced.

According to Moore (1985), efficient strategies for managing semi-intensive systems include such components as:

(1). maximizing utilization of natural productivity to meet adequate nutrient requirements of the standing crop.

(2). fertilization where necessary to stimulate the pond ecosystem.

(3). introduction of species which are non-competitive with the primary species, but which make pond nutrient sources more available.

(4). feeds which are tailored to provide what the natural system does not.

The third strategy mainly involves introduction of birds like the ducks, chickens etc, widely practiced in the tropics (AIT/ODA, 1986; Little & Muir, 1987) and some temperate regions like Czechoslovakia (Korinek, Pers. comm.) and Hungary (Varadi, Pers. comm.). In the fourth strategy, supplementary feeds fed to fish in pond system tend to leach and are easily degraded by micro-organisms. Such feed should also serve as a detrital substrate. However, if the particle being colonized by microbes, and in turn consumed by the meiofauna, is of high nutrient quality and artificial feeds being added at the same time, the implication will be a loss of trophic level efficiency earlier outlined. Therefore, in situations where natural food production can be maximized for optimum fish production, addition of supplemental feed to the pond system may be a wasteful investment and must be considered with care.

In situations where there is limited supplies of land and water, conflicts do arise, but it is possible to improve utilization and minimize problems through better planning. Beveridge and Phillips (1990) proposed strategies of reducing water demand, which include reduction of seepage losses through better siting and management, and intensification of use and re-use of water through dual-purpose reservoirs. The latter may be more applicable to the tropical/semi-tropical conditions and developing nations. In Israel, for example, development of such reservoirs has improved utilization and reduced cost of water for aquaculture (Leventer, 1987, quoted by Beveridge & Phillips, 1990). In some cases, intensification of water usage has been improved through the use of concrete-lined ponds developed in Taiwan and Israel (Hepher, 1985), but the disadvantage from such systems is greater waste output, since there is little opportunity for the important processes of biotransformation to take place (Beveridge & Phillips, 1990). It would therefore appear that earth pond aquaculture will continue to play a significant role in aquatic food production, and this requires continous development and adoption of better management strategies through more meaningful research works.

According to Stirling & Wahab (1990), 'pond fish culture should strive in future for long-term sustainability in equilibrium with the environment, in which optimum use is made of natural food production. This means replacing the traditional objectives of ever increasing intensity and maximum yields per hectare, wholly dependent on artificial feeding, with one of maximum efficiency in an overall ecosystem context, concommittent with only moderate levels of intensification. Quite apart from environmental benefits, this should result in savings in the quantity of water used, and help to overcome critical periods of water shortage and/or high temperature. Furthermore, the objectives of classical investment appraisal over a relatively short period also need to be replaced by longer term perspectives which take full account of environmental impact, especially on water quality for other uses'.

Throughout this study, it appears that even the highest level of fertilizers used, except HPN favourably sustained both natural food and trout. However, there are obvious implications when badly planned management strategies are applied. For example, consideration must be given to stocking densities of fish in ponds that had been treated with fertilizer as a check against 'ichthyoeutrophication' in the long run. The theory of ichthyoeutrophication which has now assumed a wide dimension in present day fish farm management practices deals with the influence of eutrophication processes on fish, and of fish on the eutrophication process itself (Opuszynski, 1979). In other words, this theory assumes that changes in the aquatic environment caused by nutrient enrichment trigger a series of changes in both the natural community, and their environment. Attempts to counteract excessive ichthyoeutrophication have mainly been that of introducing large numbers of single fish species. This strategy appears controversial because, it only accelerates changes in fish community structure through predation, competition etc. Besides, the biocenose structure is important as a homeostatic factor, and the more complex the structure, the more precise will be the self-regulating mechanism of the ecosystem. If primary trophic structures, based on a single population, fill out a whole link of the food chain, the consequences will be low level of stabilization of the various ecological processes. Such a mass appearance with limited control mechanisms could lead to the destruction of the system as a whole (Trojan, 1975). Coupled with the above problems is the use of high phosphorus diet supplied to fish under semi-intensive and intensive culture conditions which further accelerates the processes of eutrophication (Phillips & Beveridge, 1986; Brown *et al*, 1987; Wiesmann *et al*, 1988; Beveridge *et al*, 1990; Beveridge & Phillips, 1990). The latter authors, in an extensive review of the environmental impact of aquaculture, also reported that the proportion of uneaten pelleted food varies from 1% to 30%, which confirms that culture system, type of feeds and management strategies are important determinants of wastage.

Beveridge (1987) has produced a model for fish cage management which attempts to limit production according to phosphorus loading. However, it is known from studies in temperate conditions that the model suffers from certain disadvantage and must be applied with caution (Beveridge *et al*, 1990; Nature Conservacy Council (1990), quoted by Beveridge *et al* (op. cit.), because they take no account of factors such as micronutrients. At present, compounded diets low in phosphorus are being developed to permit even greater fish production and organic loadings. (H. P. Stirling, Pers. comm.).

There have been no studies of the environmental impact of aquaculture in the tropics, but studies in the temperate regions appear to suggest that the discharge of wastes from farms can affect water chemistry of the receiving water bodies (Kilambi *et al*, 1976; Alabaster, 1982; Bergheim *et al*, 1982; Beveridge, 1984; Phillips *et al*, 1985a; Phillips & Beveridge, 1986). Intensive fish farming which mainly depends on artificial diet is not common in the tropics, but can also be expected to cause comparable changes in tropical environments, given that wastes will be similar and that productivity is also limited by light, phosphorus and nitrogen levels. Moreover, this response may be more rapid in view of the high temperature differences. It is paramount that lessons can be learned from the experience of intensification of fish farming and its environmental impact in the temperate regions, for better management strategies which can be more applicable and adaptable to tropical conditions at moderate cost.

Thus the use of such high phosphorus artificial diets in fish culture systems, especially cages, contrasts with planned pond fertilization programmes. Cage ecosystem cannot be manipulated to aquaculture advantage, only environmental impact may be minimized, e.g. by reducing phosphorus content of diet. Ponds on the other hand can be manipulated because they are semi-enclosed so impact on the environment can be controlled. For example, most dissolved inorganic nutrients like phosphorus from fertilizers are adsorbed in sediment and can be recircled in plankton and benthos to fish, while most of the excess accumulates *in situ*. Organic manures when applied in ponds are easily biodegradable, environmentally friendly and stimulate natural food production for fish culture. The latter is far easier to produce at moderate stocking densities and cost under semi-natural conditions in earth ponds also have benefits in terms of quality of produce (Stirling and Wahab, 1990). Besides, a positive advantage in the use of earthen ponds for fish cultured on natural food is that, for stocking purposes, such fish will adapt easily to the wild.

From the overall production pattern of macroinvertebrate and macrophyte development, an interesting pattern emerges in which the complex inter-relationships provides a kind of trade-off or compromise. The role of macrophytes in pond management strategy has been a subject of considerable interest to ecologists, although the actual mechanisms of their function in nutrient regulation is still not well understood. The large biomass of macrophytes which inhabit the peripheral zone of lakes tends to form an interface between the land and water body, and hence is important in trapping both dissolved and particulate materials entering from the land (Howard-Williams, 1981; Pandit, 1984). The macrophytes contribute to the primary energy source of food webs in the water (Rich *et al*, 1971; Wetzel & Hough, 1973) and also release nutrients that have been immobilized in the sediments (Pieczynska & Ozimek, 1976). Besides, they also contribute significantly in sediment stabilization and habitat diversification by providing substrate for periphyton and as source of shelter and breeding area for many macroinvertebrates (Howard-Williams & Liprot, 1980).

From past experiences and the result of the present study, it is plausible that any management strategy with regard to controlling macrophytes must be done with caution, even when fish are stocked. This probably justifies the deliberate decision not to eliminate the macrophytes completely during the study period, though it has to an extent affected grazing efficiency of the trout on the benthos during the fish culture trial. On the other hand, complete elimination would have probably inhibited development of *Gammarus* and other benthos which depend on the presence of macrophytes. A more appropriate management strategy for controlling the macrophytes, especially in shallow ponds would require periodic disruption of normal or continous vegetation development. This explains why most fish pond management involves draining for short periods between fish crops. It also aerates the soil, inhibits development of stable macrophyte populations and maintains a benthic communuty with maximum production potential (Hall *et al*, 1970). This strategy proved useful during the second year when some macrophytes were trimmed down prior to fish stocking. Abundant macroinvertebrates were still maintained and these improved fish condition as evident from the overall result of the fish production values and condition factors in the organically treated ponds.

The high quality of nutritional composition of natural diet obtained in this study, in comparison with the artificial pelleted diet, has obvious implication for aquaculture management. Considering the abundance of benthos, and if mixed culture of trout with a herbivorous or omnivorous species is to be implemented, some managemant strategies in terms of reducing the cost of expensive ingredients could be, firstly, replacement of the fishmeal (Tacon, 1981; Jackson *et al*, 1982) and secondly, utilizing the protein-sparing action of lipids or carbohydrates, thus reducing the amount of fishmeal required (Austreng *et al*, 1977; Anderson *et al*, 1984). The latter approach could be accomplished through the use of energy-rich ingredients in the eutrophic ponds that are rich in natural food such as bacteria and planktons for the herbivorous and omnivorous fish species. These energy-rich feeds act in much the same way as dietary lipid or carbohydrate does within a complete diet by sparing dietary protein for growth in this case, the protein-rich natural food organisms. This strategy has long been recognized by the

Israeli fish farmers. For example, Wohlfarth & Schroeder (1979) reported that replacing up to 30% of the pelleted feed added to ponds by manure did not cause any corresponding decrease in fish growth, presumably because the high quality natural food produced in the pond compensated for the decrease in pelleted feed. Similarly, it may not be necessary to provide micro-nutrients within any pelleted feed if natural production within the culture is sufficiently high to meet the nutrient requirement. On the other hand, if it becomes necessary that major nutrients are to be provided, it could be in the form simple practical feeds which farmers themselves can formulate and produce, thereby, reducing their dependence on high cost, conventional pelleted feeds. However, the minimum biomass of natural food organisms to supply the necessary micro-nutrients, the degree of presence of anti-nutritional factors (e.g. protease inhibitors) in plant protein and amino acid deficiencies or imbalances as suggested in earthworm meal (Yoshida & Hoshii, 1978; Amerio, 1983; Hilton, 1983) are not well understood and need further investigation.

In relation to fish growth and production, some interesting patterns that emerged include:

(1). To maximize growth rate of fish under natural conditions, it is necessary to first, take advantage of the most favourable environmental conditions like temperature, oxygen, etc. in the pond, and the pond's morphometry.

(2). ensuring adequate supply of feed.

(3). minimizing interspecific and/or intraspecific competition. This can be achieved by culturing young fish prior to sexual maturity before subsequent restocking.

The first strategy, under temperate conditions is best accomplished during spring/summer period when temperature conditions are favourably high. It is therefore not surprising that management practices in Howietoun fish farm closely follow the above propositions, which have over the years, proved successful (I. Semple, Pers. comm.). However, the potential of natural food from ponds will go a long way in optimizing economic returns most especially with appropriate balancing of utilization of both supplementary and natural food.

Stirling & Dey (1990) reported that predicting the ultimate limit of sustained fish production in a given aquatic environment depends largely on physical characteristics such as flushing rate, morphometry and degree of mixing. They further proposed that shallow, well mixed lakes would appear to have an upper limit of annual fish production of 3 - 4 tonnes ha^{-1} of the lake area, but the higher the production, the greater the risk from freak weather of algal blooms, poor water quality or disease.

In most semi-intensive and intensive culture systems, aeration is often used as a management tool to improve fish survival and growth. It has been demonstrated by Colt and Tchobanoglous (1981) that in a static pond, aeration may create a localized area of high dissolved oxygen that may prevent oxygen depletion problems. Depending on the wind direction and configuration of the ponds, surface aeration may add a significant amount of D.O. However, depending on pond depth, critical D.O levels may occur during a low windy period. These authors therefore concluded that artificial aeration may only have a limited effect on D.O., and suggested that it is necessary to start aeration well before the D.O drops to a critical level, as also demonstrated by Boyd *et al* (1978b) and Romaire *et al* (1978).

From experience in the present study, funneling effects of the surrounding hills through wind action help to maintain high D.O levels in the shallow pond waters, thereby ensuring high survival rate of trout under still-water conditions. However, under extremely low oxygen levels and absence of mixing, symptomatic treatments such as minimum water flow proved effective in ameliorating the situation and ensured continuous high survival and production. Thus such advantages of water exchange and the ponds' location in moderately exposed areas could aid in minimizing production costs that might arise if aerators are to be used.

In addition to improving water quality conditions, water flow or exchange rates have the benefit of influencing the probability with which a food item is encountered and thus the proportion of food which remains uneaten, while flow characteristics partly determine whether uneaten food and faecal particles remain intact and the proportion that settle within the system (Beveridge & Phillips, 1990). Therefore, controlled management of flow rate will appear to play significant role in trout culture, most especially in relation to the fate of available free floating natural food in a pond ecosystem.

Combined culture of fish species have been reported to enhance both inter- and intra specific competition which has the advantage of more efficient niche exploitation (Lien, 1981; Milstein *et al*, 1988). Besides, when fish of the same species and about the same size and age are stocked in ponds, the risk of cannibalism is minimized, else larger fish could outcompete the smaller ones, leaving less scope for the latter's growth.

With reference to Howietoun Fishery condition, an appropriate polyculture system *vis-a-vis* stocking strategy aimed at controlling weeds in a fertilized pond should be based on economic considerations rather than avoidance of cannibalism amongst the fish species. In Howietoun Fishery, a small number of grass carp (*Ctenopharyngodon idella*) are available, (see Table 1). Stocking these efficient herbivorous fish at moderately high density will be useful in controlling excessive weed growth.

Trout are carnivorous and have been reported to predate on smaller fishes like the fry of perch, *Perca fluviatilis*, (Thorpe, 1974) and minnow, *Phoxinus phoxinus*, (Lien, 1981). It is therefore likely that they could also predate on the carps, but the latter are of less economic value to both consumers and anglers in most temperate regions and Scotland in particular. Predation on carps by trout will thus appear to be an advantage with respect to population regulatory mechanism rather than loss to the farmer, provided sufficient number are available to ensure continuous weed control.

SUMMARY AND CONCLUSION

An investigation into the biomanipulation of the ecology of earthponds to stimulate the production of natural food and fish growth, while maintaining adequate water quality, was carried out at the Howietoun fishery between March 1988 to January 1990. During the first year of study, which involved pond fertilization, two principal manipulation strategies were employed: first to compare inorganic with organic fertilization without fish present and then second to add fish in the second year to those treatments that gave the best production of natural food. In the first year, water quality parameters and primary production of the pond waters were determined biweekly. Plankton abundance was analysed weekly, while soil and benthos production were evaluated fortnightly. During the second year, monthly sampling also involved measuring growth parameters and stomach content analyses of the fish. The results obtained from the various soil and water quality analyses were used to estimate nutrient balances and denitrification rates, while results of nutritional composition of natural and artificial diets were compared with respective carcass compositions.

Prior to enrichment, the water quality parameters in all the ponds were somewhat similar in their physico-chemical and biological parameters. However, during fertilization, water quality parameters, especially nitrate and phosphorus were generally consistent with increased fertilizer application. Dissolved oxygen never fell to limits detrimental to trout survival, posssibly due to the wind action which causes sequential changes of circulation and thus favourable condition for mixing in the exposed study area. Response pattern of primary production was slow, followed by sudden upsurge in productivity in the HPN treatment, while production resulting from organic treatment was much lower; although pre-manipulation values were much higher at commencement of experiment, possibly due to build up of nutrients over time. During the fish culture trials, water quality characteristics remained within ranges similar to those obtained during the first year's fertilization. Very low D.O., high nitrite, ammonia and algal bloom recorded in July in the HPN pond 3 under still water conditions contributed to 36% mortality. Commencement of water flow through the ponds at minimum rate stabilized and ensured high survival during the remaining period of the experiment. Physico-chemical analysis of pond soil characteristics showed high concentration of nutrients, particularly phosphorus and carbon, which is a reflection of the soil being a major sink for added nutrients. The low C : N ratio in the soil during the inorganic fertilization possibly played a significant role in favouring rapid mineralization, as also reflected in the calculated high value of daily denitritification rate; compared to the moderately high C : N ratio in the organic treatments.

In the phytoplankton analysis, Chlorophyceae and Cyanophyceae were dominant over the Baccillariophyceae and

Dinophyceae during both fertilization trials. The response pattern of Dinophyceae was consistent with increasing organic fertilizer dosage although they tend to thrive well in the CTRL or 'oligotrophic' condition. Three categories of phytoplankton nutrient limitation identified were: concurrent limitation, nitrogen limitation and no limitation in the CTRL, LP/HP and HPN treatments, respectively. Nitrogen was, however, the most frequently limiting nutrients but is considered to be a transitory condition of minor importance to the productivity of aquatic ecosystems because nitrogen deficiency may be offset by growth of nitrogen fixing blue-green algae. In the zooplankton groups, Cladocera and Rotifera appeared to be the dominant plankters over Copepoda in both fertilizations. The zooplankton response to organic fertilization was generally better. It is assumed that the added manures were good source of carbon and bacteria utilized by the zooplankton. Fluctuations in phytoplankton abundance were attributed to the increased grazing pressure by zooplankton.

The application of high chicken (HC) and a combination of high chicken and cow (HCC) manure generally gave the highest macroinvertebrate production. The main groups encountered were in the order: Oligochaeta > Chironomidae > Asellidae > Sialidae > Hirudinea > Mollusca. In addition to the available nutrients from the organic enrichment and the food web earlier described, high benthos production was also found to be associated with sediment types; in which fine silt with abundant organic materials and muddy substrates favoured high abundance, in contrast with coarse soils/stones, despite manuring. Macrophytes have also been found to influence the establishment of *Gammarus* and *Asellus* possibly due to the plants' high three-dimensional surface area for development of epiphytic algae which are good source of nutrient for these benthos. It is also considered that the slow colonization rate of the manured ponds by the *Gammarus* was due to late establishment of macrophytes preferred by the genus. Nutritional composition of the natural food has been found to be well within the nutritional requirements of trout. However, in comparison with the artificial pelleted diet supplied to the trout in the CTRL ponds, the lipid or fat content in the pellets was much higher. This probably accounts for the much higher lipid content of the pellet fed trout on harvesting. Fibre content in the natural diet was much higher but did not affect the assimilation efficiency of the natural food, except in the HPN ponds which mainly benefited algae growth and not easily assimilated by trout.

The dietary contribution of all the major natural food items has been found to be influenced by environmental factors, food availability and feeding behaviour of the fish. For exemple, the presence of larger macroinvertebrates like *Asellus, Gammarus* and *Sialis* makes them more acessible than the mud inhabiting chironomids. In general however, all major macroinvertebrates significantly contributed to the diet of trout, except Hirudinea which were rejected despite their abundance. This is possibly due to their unpalatable nature, although the exact identity of the causative factor is yet to be elucidated.

Growth rate as reflected by body weight against time and overall specific growth rate conformed to a seasonal cycle in which there was rapid growth during June, slower in August/September and further acceleration in October, then universal cessation at the end of December/January. Environmental factors, low food abundance and competition probably interact to account for the slower growth rate most pronounced in the HPN ponds. However, the accelerated growth is possibly explained by the concept of 'compensatory growth' response. The highest growth rate in the CTRL pond 8 was associated with constant supplies of artificial pelleted diet in addition to the supplementary natural food, moderate stocking density and larger pond surface area.

Management implications for pond manipulation *vis-a-vis* fish culture in the present study were evaluated and also related to other works under both temperate and tropical conditions. With planned fertilization, pond aquatic ecosystems are capable of maintaining adequate water quality and supporting the various pathways in those foodwebs that directly lead to increased fish biomass and production. Occasional pond draining to maintain good soil and hence water quality, followed by restocking improved trout performance during the culture trial. Development of macrophytes in the ponds, at moderate levels have been found to provide a kind of trade-off or compromise in relation to the complex inter-relationship with algae and macroinvertebrates. It is therefore suggested that the control of macrophytes should be done with caution.

In conclusion, aquaculture production will continue to be dominated by earthen ponds for some time to come, suggesting that the potential for applied research in this area is great. Generally, in ecology, hypothesis are seldom proved, rather they survive attempts to disprove them (Cousens, 1985). The main hypotheses tested in the present study was that biomanipulation of earthpond ecology through fertilization would principally stimulate the development of natural food for the benefit of trout, while maintaining adequate water quality. To a great extent, the results answered in the affirmative, but generated questions or areas of interest which need further research; and these include:

1. More studies on the complex inter-relationship between biological and chemical processes in aquaculture pond systems subjected to biomanipulation which promote and establish growth and maintenance of benthic communities.
2. The long-term duration over which a pond can sustain its natural food production capacity and the optimal rates of organic manure application.
3. Evaluation of suitable benthic species for

culture on a large scale basis; and developing innovative harvesting techniques suitable for earthen ponds conditions.

4. A study of the optimum fish stocking density in earth ponds and the efficiency with which the niches are exploited for natural food. This could be a useful management tool for establishing a pond's carrying capacity which will promote fish production at minimum cost. In this respect, a cost-benefit analysis of the entire culture conditions under semi-intensive systems in which fish are cultured solely on natural food from the fry stage, compared with those on artificial pelleted diet should be given top priority.

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