5. Discussions

5.1. Studies on the effect of manuring rate on fish production (Experiment No. 1)

There was autochthonous production of plankton in all the treatments, following the principle of pond fertilization. Plankton formed the main source of food since there was a direct correlation (r = 0.957; $P < 0.01$) between the weight gain of koi carp and the amount of plankton present in the five treatments (**Figure 10**). Earlier studies on the common carp are indicative of their preference for plankton as food (Lubzens *et al.*, 1984; Chakrabarti and Jana, 1990).

High application rates of cow dung and poultry manure in the C3 and P3 treatments significantly increased ($P < 0.05$) the alkalinity, PO_4 - P, NH_4 - N, NO_2 - N and NO_3 - N values of water. NH_4 - N, incorporated from organic manure application, as well as metabolism of the water body, might be considered an index of environmental stress (Jana and Chakrabarti, 1993). Jana and Barat (1984) observed an inverse relationship between NH_4 - N and DO. In our experiment, lower DO values were recorded in the C3 and P3 treatments. Critical evaluation of the data revealed that the concentration of NH_4 - N was inversely related to the abundance of cladocerans in the C3 (r = - 0.614; $P < 0.05$) and P3 (r = - 0.688; $P < 0.05$) treatments. Differences in the relative abundance of some groups of zooplankton might have contributed to the differential growth responses of the fish. Lower weight gain, SGR and survival rate of koi carp in the control treatment may be attributed to the insufficient quantity of zooplankton in the system (Szlaminska and Przybye, 1986).

It is well known that high yield of fish can be achieved by greater abundance of plankton in the culture system. However, it is not possible to increase the application rate of organic manures after a certain limit because this may reduce water quality, which cause stress for reproduction of essential zooplankton thereby causing adverse effect on fish growth. Studies on life history parameters of *Daphnia* sp. (Jana and Pal, 1983; Jana and Pal, 1985 a; Murugan, 1989; Urabe, 1988; Urabe and Watanabe, 1992) and *Moina* sp. (Jana and Pal, 1985 b; Jana and Pal, 1989) suggest that growth, reproductive potentials and longevity of each species are affected by the nutrient conditions of culture media. Dhawan and Kaur (2002 a) reported a decrease in cladoceran population with increased organic manure application in ponds. The presence of relatively higher density of zooplankton in C2 and P2, compared to C3 and P3 could be a consequence of relatively suitable environment in terms of water quality and food abundance (Jana and Chakrabarti, 1997). As a result, the weight gain of koi carp was significantly higher ($P < 0.05$) in the C2 and P2 treatments, compared to the C3 and P3 treatments, respectively. Similar decline in plankton abundance due to undesirable water quality with very high amounts of fertilizers have been reported by many authors (Lin *et al.*, 1997; Garg and Bhatnagar, 2000; Azim *et al.*, 2001; Cheikyula *et al.*, 2001). Perhaps, the significantly higher level of nutrients and low dissolved oxygen in the C3 and P3 treatments lowered the grazing activity by carp in these two treatments, compared to the C2 and P2 treatments, respectively. Again, the differences in the weight gain of koi carp observed among the different treatments were not essentially due to changes in the water quality, since, growth in the C1 and P1 treatments were significantly lower than C2 and P2 treatments, respectively, despite having good water quality. It might well be that the weight gain was more directly related to differences in food concentrations, although the zooplankton density and water quality were closely related to each other.

In any given application rate, the poultry manure appeared to be more effective compared to cow dung, which is in agreement with earlier findings by Singh and Sharma (1999). Poultry manure is preferred worldwide because of its high level of nitrogen and phosphorus concentrations (Knud-Hansen *et al.*, 1991). Although phosphorus was not analyzed in this study, total nitrogen in poultry manure was higher than cow dung. Nitrogen input was shown to be the key nutrient variable related to plankton production, which in turn influenced fish yield (Knud-Hansen *et al.*, 1993). In the present investigation, an application rate of 0.26 kg/ m^3 every 10 days, appeared to be the most suitable for koi carp tanks manured with cow dung and poultry excreta. Higher application rates reduced water quality, depleted the plankton population and caused adverse impact on the growth of fish.

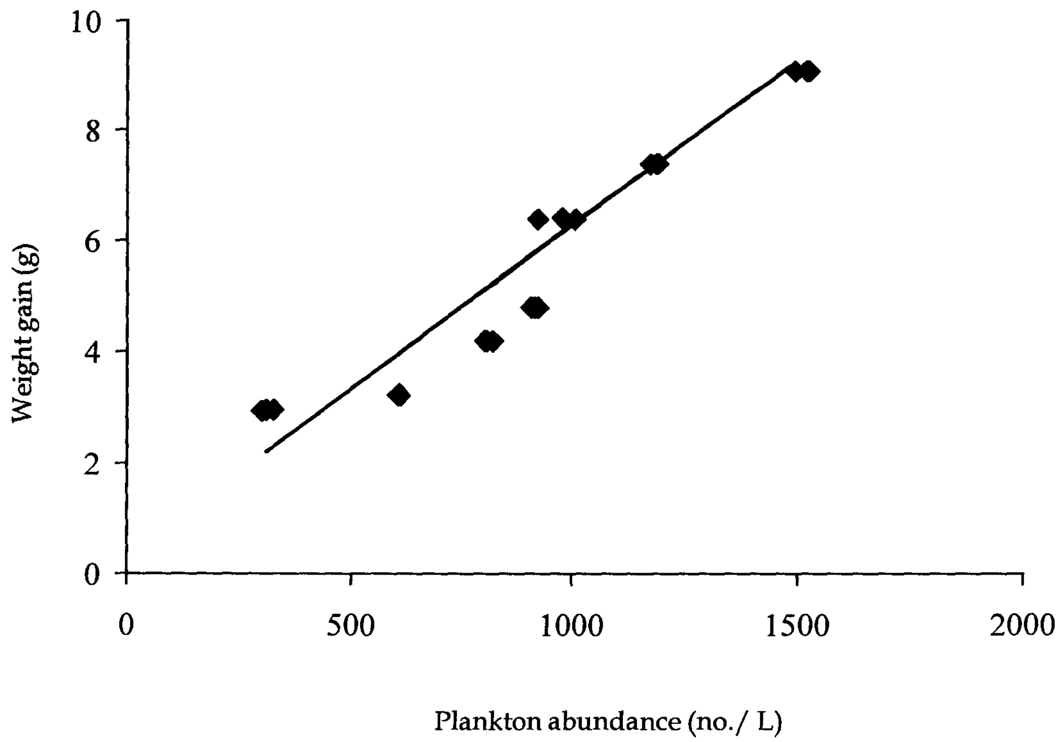

Figure 10 Relationship between weight gain of koi carp and plankton abundance in the seven treatments.

5.2. Studies on the effect of water exchange on fish production (Experiment No. 2)

In agreement with earlier findings (Chapter 5.1), there was autochthonous production of plankton in all the treatments, following the principal of pond fertilization. Plankton formed the main source of food since there was a direct correlation (r = 0.986; $P < 0.01$) between the weight gain of koi carp and the amount of plankton present in the five treatments (**Figure 11**).

Water exchange rates had a direct influence on the water quality in the different treatments. No exchange of water in the NE treatment significantly lowered the dissolved oxygen ($P < 0.05$) and simultaneously increased the specific conductivity, PO_4 - P, NH_4 - N, NO_2 - N, NO_3 - N and BOD, compared to the other treatments (**Table 8**). According to Pechar (2000), gradual accumulation of organic matter in a water body lead to subsequent dominance of biodegradation and decomposition processes and cause an oxygen deficit. The resulting release of nutrients leads to excessive levels of autotrophic production, as well as changes in the species composition of plankton. Through a dynamic multiple feed back process, the water quality deteriorates.

As discussed in Chapter 5.1, NH_4 - N might be considered an index of environmental stress. High concentrations of NH_4 - N were found to restrict the occurrence of many small protozoans like ciliates that are considered as excellent food for cladocerans (Pfister *et al.*, 2002). The presence of relatively higher density of cladocerans in the WE1, WE2, WE3 and WE4 treatments, compared to NE, might be a consequence of better environment in terms of water quality and food abundance. According to Herbert (1978), the maximum size reached by individuals of a particular species of *Daphnia* depends upon the food supply. Also, earlier studies on life history parameters of *Daphnia* sp. and *Moina* sp., as also discussed in Chapter 5.1, suggest that growth, reproductive potentials and longevity of each species are affected by the nutrient conditions of culture media.

Perhaps the significantly high level of nutrients and BOD, along with low DO concentration in the NE treatment lowered the grazing activity of the carp. The results clearly indicate that no water exchange in the NE treatment yielded the lowest number ($P < 0.05$) of saleable fish. In contrast to food fish production, where the total number of fish produced determines productivity, ornamental fish can only be sold once they have reached a particular size. Systematic discharge of water in WE1, WE2, WE3 and WE4 treatments significantly increased ($P < 0.05$) the number of marketable fish. Greater dilution of the manure in these four treatments improved the water quality and caused greater abundance of plankton, compared to the NE treatment, though the plankton volume within the four water exchange regimes were significantly different ($P < 0.05$) from one another. Differences in the relative abundance of some group of zooplankton might have contributed to the differential growth responses and survival of the carp. Non availability or non continuous supply of preferred food have been reported to influence cannibalism in koi carp larvae (Appelbaum *et al.*, 1986; VanDamme *et al.*, 1989). Rothbard (1982) reported low survival rates in common carp as a result of severe competition for food when stocked at high densities. Interestingly, reduction in cannibalism in common carp was demonstrated by Von Lukowicz (1979), when a continuous supply of live food was maintained. Food availability is probably the most important factor determining the cannibalism rate in fish larvae (Hecht and Appelbaum, 1988). As observed in this experiment, the influence of plankton level on growth heterogeneity and survival rate of koi carp supports this last hypothesis.

Survival rate of the koi carp was also influenced by the water quality. Nitrite ions are toxic to fish, causing methaemoglobinemia (Tomasso *et al.*, 1979). It is present in water as an intermediate in the bacterial oxidation of ammonia, the major nitrogenous waste product of fish, to nitrate (Das *et al.*, 2004). An increase in the nitrite content in water exerts considerable stress on the fish resulting in growth suppression, tissue damage and mortality (Lewis and Morris, 1986), leading to poor biomass production. Diminished respiration ability in nitrite-exposed grass carp, *Ctenopharyngodon idella* was reported by Alcaraz and Espina (1997). Korwin-Kossakowski and Ostaszewska (2003) also reported on the adverse impact on respiration and growth of common carp due to nitrite exposure. Allowable levels are therefore low. NO_2 - N levels above 0.06 mg/ L has been observed to cause a minimal degree of harm in rainbow trout, *Oncorhynchus mykiss* after 3 weeks exposure (Wedemeyer and Yasutake, 1978). The need to draw on such data arises from the relative absence of data on ornamental fishes. During our experiment, koi carp larvae were exposed to an average NO_2 - N concentration of 0.211 mg/ L in NE for 3 months, which was higher than the 0.06 mg/ L limit reported for rainbow trout.

Unionized ammonia is also regarded as highly poisonous to fish (Arillo *et al.*, 1981). The permeability of the uncharged and lipid soluble unionized ammonia (NH_3) to plasma membranes is higher compared with the ionized form and therefore, is considered to be the more toxic form (Meade, 1985). Earlier studies have shown that common carp are relatively sensitive to unionized ammonia with a reported LC_{50} value of 0.44 - 1.9 mg/ L (Dabrowska and Sikora, 1986; Xu *et al.*, 1994). Although unionized ammonia was not measured in our experiment, it may be assumed that high temperature and pH levels during the entire growth period would block the ionizing process of NH_3 to the relatively non-toxic NH_4 - N (Ng *et al.*, 1992). In our study, the average NH_4 - N in NE was 0.753 mg/ L, when the average pH was 7.36 and the average temperature above 30^0 C. Under these conditions, percentage of NH_3 in water was estimated to be about 2% of the NH_4 - N (Emerson *et al.*, 1975), i.e., 0.015 mg/ L, which is below the threshold limit of 0.44 mg/ L. However, according to Parma de Croux and Loteste (2004), even an incidental increase in the pH to more than 8.0 in such situation could lead to high mortality due to significant increase in NH_3 toxicity. Mortality may also arise due to depressions of feeding when water quality is sub-standard (Asano *et al.*, 2003). Probably, these factors may have influenced the low survival rate (60.43%) of koi carp in the NE treatment.

Continuous supply of oxygen through aeration is known to promote nitrification in ponds, thereby lowering ammonia levels (Avnimelech *et al.*, 1986). Since most farmers in India cannot afford aeration facilities, water exchange is used as an alternative to maintain water quality. However, high level of water exchange could flush out nitrifying bacteria leading to reduced nitrification and increased ammonia concentrations (Diab *et al.*, 1992; Milstein *et al.*, 2001). Perhaps, the solution lies in low level of water exchange (only 5%, as experimented in the present study), but with increased frequency. From the present investigation, a daily water exchange rate of 100 L (WE1) appeared to be the most effective for koi carp tanks manured with poultry excreta. No water exchange (NE) result in water quality deterioration, deplete the plankton population and cause adverse impact on fish growth.

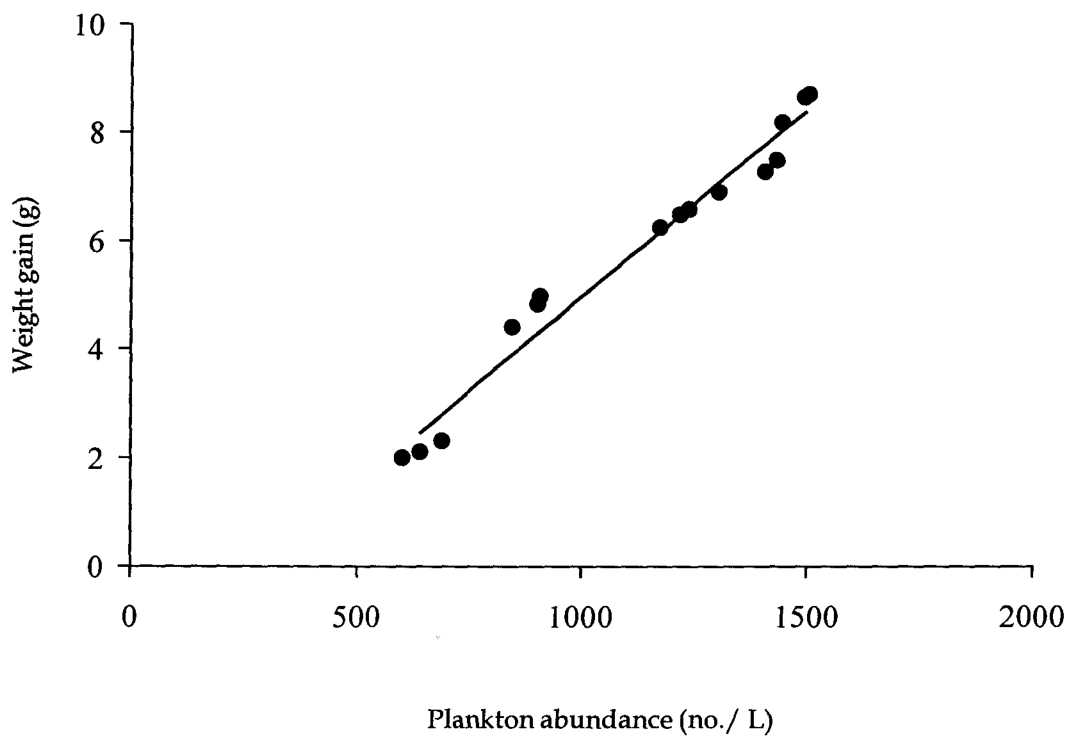

Figure 11 Relationship between weight gain of koi carp and plankton abundance in the five treatments.

5.3. Studies on the effect of stocking density on fish production (Experiment No. 3)

Growth rate of fish depends on many factors, but within the limits of the genetic growth potential of the species, they are principally a function of the availability of preferred food. Backiel and LeCren (1967), Hepher (1967), Bardach *et al.* (1972), Suresh and Lin (1992), Gress *et al.* (1996), Irwin *et al.* (1999), Metusalach *et al.* (1999), and Sharma and Chakrabarti (1999) indicated that growth of many species was density dependent and that there was an inverse relationship between stocking density and individual size of fish produced, primarily because the food supply had to be shared between individuals.

In our experiment, all the fish were fed to satiation. In addition, in the outdoor tanks, fish had access to algae, hence, food availability alone cannot have caused the differences in the growth rate between the different treatments. It is well known that carp fry respond quite rapidly to different stocking densities in their competition for space as well as food. Overstocking usually results in low survival rate, while reduced stocking leads to rapid growth of the fry (Rothbard, 1982; Rothbard and Yaron, 1995). Cage culture experiments in Israel have shown common carp to be extremely sensitive to stocking density (Feldlite and Milstein, 1999), where food availability was not a problem, but increased stocking density reduced the space volume available per fish. Violating behaviour requirements for space can affect growth through endocrine responses or disruption to feeding efficiency (Pankhurst and Van der Kraak, 1997; Schreck *et al.*, 1997). Fox and Flowers (1990) reported on increased losses due to cannibalism in juvenile walleye, *Stizostedion vitreum*, grown at high densities in intensive culture ponds. Cannibalism in many species of fish appears to be directly influenced by the availability of space and shelter (Smith and Reay, 1991; Herbert *et al.*, 2003).

Shelton *et al.* (1981) found that increasing stocking density had a profound negative impact on the growth of grass carp in small impoundments. Among ornamental fish, a similar effect of population density on growth rate was found by Olivier and Kaiser (1997) with juvenile swordtails fed to satiation, and Degani (1993) with angelfish, although, the later experiment was conducted indoors and the initial size of fish was more than 1 g. For our experiment, advanced larvae (0.14 ± 0.035 g) of koi carp were selected, since, tropical fish breeders in India usually sell fish larvae (of 2 - 3 weeks age) to fish growers. Large-scale fish production involves fry stocking in earthen ponds from where marketable fish are harvested after 3 - 4 months of culture. One of the bottlenecks in this industry is the large-scale loss of fish during the post larval stage, where mortality rates are very high before the fish reach 1 g size.

Environmental conditions in the culture tanks were influenced by the stocking density. High accumulation of excrements and metabolic wastes from the fish led to significantly higher concentrations of nitrogen compounds and simultaneously lowered the DO in D4 and D5, compared to other treatments. Low dissolved oxygen is considered as one of the limiting factors to fish production. A clear-cut relationship between fish yields and increasing levels of aeration was documented for tilapia (Teichert-Coddington and Green, 1993). According to Stone *et al.* (2003), repeated exposure to low DO can slow the growth process in goldfish.

Different species are differently sensitive to nitrogen toxicants. One of the common problems in koi carp culture is depressions of feeding when water quality is substandard. Asano *et al.* (2003) observed periods of depressed feeding in koi carp when ammonia levels were high and dissolved oxygen was low. Although unionized ammonia was not estimated in our experiment, it is known to be in equilibrium with the development of ammonium ions in water (Barat and Jana, 1990). Nitrite is also toxic to many species of fish (Barat and Jana, 1991). Although daily water exchange helped in controlling ammonium and nitrite level in the tanks, the significantly higher growth and survival rates of koi carp in the D1, D2 and D3 treatments, compared to D4 and D5, could be influenced by the better water quality in terms of higher dissolved oxygen and lower levels of nitrogen toxicants. Jana and Barat (1992) reported marked changes in water quality due to high stocking load of fish in culture tanks. Physiological stress and impaired growth due to poor water quality associated with crowding have been reported in rainbow trout (Zoccarato *et al.*, 1994) and summer flounder, *Paralichthys dentatus* (King *et al.*, 2000).

The results from the probability distribution indicate that stocking koi carp at a density of 0.3 fish/ L, rather than at higher or lower densities, yielded the highest number of saleable fish. In contrast to food fish production, where producers focus primarily on the total number of fish produced (Jolly and Clonts, 1993), ornamental fish can only be sold when they have reached a particular size. While the results consistently showed that increasing density reduced growth, it would appear logical to reduce the stocking density, so that a faster growth rate is allowed, and the fish can quickly reach the smallest marketable size (4 g).

However, no significant increase in price for koi carp that grow larger than the minimum marketable size (4 g) in India provide strong financial incentives for farmers to maintain fish at the smallest marketable size. The goal of production is to produce the highest number of fish of the given size (4 g) with consistently low size variation. Hence, although the weight gain of koi carp was considerably higher in D1 and D2 treatments, D3 (0.3 fish/ L) seemed to be the optimal density for stocking koi carp, since, the number of marketable fish was highest in that treatment.

The results suggest average size and survival rate of koi carp to be inversely related to stocking density, and, are in agreement with earlier studies with other fish species (Shelton *et al.*, 1981; Degani, 1993; Stone *et al.*, 2003). From the data obtained, a stocking density of 0.3 fish/ L appeared to be the most effective for stocking koi carp fry in tanks. The productivity should be measured in terms of number of marketable fish, which would favour a density of 0.3 fish/ L, compared to higher or lower stocking densities.

5.4. Studies on the effect of live-food treatment on fish production against conventional manuring regimen. (A) Comparative account of fish production throughout different seasons (culture periods) in a year, namely, winter, summer, monsoon and post monsoon (Experiment No. 4)

In agreement with earlier findings (Chapter 5.1 and 5.2), the linear relationship between the weight gain of koi carp and plankton abundance in the different treatments throughout the four growth trials exhibited a high correlation (r = 0.749; $P < 0.05$) (**Figure 12**).

Zooplankton is required as a first food for most cultured fish and contributes to faster larval growth and better survival (Prinsloo and Schoonbee, 1986; Lubzens *et al.*, 1987; Ludwig, 1999; Sharma and Chakrabarti, 1999; Al-Harbi and Siddique, 2001). In this experiment, exogenous introduction of live zooplankton significantly enhanced weight gain ($P < 0.05$) and reduced fish mortality ($P < 0.05$), compared to those of manured treatments (PM and CD) and control (C) in all seasonal trials. Although the amount of poultry manure used in the PM treatment was the same as applied in the plankton culture tanks from where plankton-rich water was transferred to the LF tanks, the zooplankton abundance (no./ L) was greater in LF, compared to PM in all seasons. In particular, the abundance of cladocerans was considerably higher (192.95% to 198.55%) in LF than the PM treatment throughout the four seasonal trials. Perhaps the selective grazing on young zooplankton, particularly cladocerans, by carp fry in the PM treatment reduced the chances of mass proliferation of zooplankton to the level as achieved in the plankton culture tanks in absence of any grazing pressure.

Another reason could be the water quality differences between the LF and the manured treatments. Earlier studies on life history parameters of *Daphnia* sp. and *Moina* sp., as also discussed in Chapters 5.1 and 5.2, suggest that growth, reproductive potentials and longevity of each species are affected by the nutrient conditions of the culture media. The maximum concentration of zooplankton in the LF treatment in all the seasonal growouts could be a consequence of improved water quality, expressed in terms of lower values of NH_4 - N and BOD, and higher values of DO and pH, which is conducive to fast reproduction of some of the major zooplankton constituting the main food item of carps (Jana and Chakrabarti, 1993). In general, plankton intake by carp tends to rise with increasing food availability and ultimately attains a distinct pleatue level (Jana and Chakrabarti, 1988). Any uneaten plankton in the LF treatment would undergo prolific reproduction under such conducive environment. Higher weight gain of carp in PM, compared to CD in all the seasonal experiments can be explained by the significantly higher abundance of zooplankton ($P < 0.05$) in PM, which is directly related to the higher nitrogen input (also discussed in Chapter 5.1), and is in agreement with earlier findings (Kapur and Lal, 1986; Singh and Sharma, 1999).

Apart from food supply, temperature is one of the most important factors determining somatic growth of fish (Brown, 1957; Houde, 1997). Most of the fish growth models include growth as a function of temperature (Soderberg, 1992; Ney, 1993). If possible, fish often prefer habitats with both, temperatures, which maximize physiological growth processes (Wooton, 1992; Hofmann and Fischer, 2002; Hofmann and Fischer, 2003), and a food supply which is always available (Kramer *et al.*, 1997). In our experiment, average water temperature during the winter growout was 18.58^{0}C (range 16^{0}C - 25^{0}C; n=12). The range of optimal temperature for fish growth is species specific (Weatherley, 1990) and is considerably lower for stenothermic than eurythermic fish. Although the common carp (consumable varieties) can tolerate extreme and fluctuating temperatures, the optimal range has been suggested as 26.7^{0}C to 29.4^{0}C (McLarney, 1987).

Survival rates of carp ranged from 70.50% (C) to 95.50% (LF) in the winter trial, and were lower by 2% to 8% in the different treatments than that achieved in the summer trial. According to Kinne (1970) and Schmidt-Nielsen (1997), as temperature decreases to the lower thermal limit for an animal, mortality occurs as a result of failure of enzyme systems and respiration. Before the lethal temperature is reached, the physiological condition of the animal may be significantly affected at sublethal temperatures, resulting in its higher susceptibility to disease and stress. Therefore, mortality is likely to occur at temperatures higher than the lower thermal limit under culture conditions, as experienced in our study, where, during the winter trial, high mortality was recorded, even though the lower temperature limit for common carp has been reported to be as low as 0 - 0.7^{0}C (McLarney, 1987). The success of carp aquaculture depends not only on survival, but also on growth rate of the cultured animals. In our experiment, weight gain of koi carp in all treatments was considerably lower in the winter trial compared to other seasons. In the LF treatment, under similar management conditions, the carp achieved 83.78% increase in weight gain during summer, compared to the winter growout. According to Horvath *et al.* (1992), metabolism and food demand of carp decreases gradually with decreasing water temperatures below 20⁰C, leading to lower growth rates.

Increased weight gain in other seasons, compared to winter has been reported with grass carp (Shrestha, 1999) and Indian Major Carps, rohu, mrigal and catla, *Catla catla* (Dhawan and Kaur, 2002 b). Usmani and Jafri (2002) obtained significantly lower digestibility rates for different food ingredients in two catfish species, *Clarias gariepinus* and *Heteropneustes fossilis* at 18⁰C than those obtained at 28⁰C or higher temperatures. According to El-Sayed *et al.* (1996), growth of nile tilapia was significantly reduced at temperatures below 21⁰C. Lower weight gain of koi carp during the winter trial in our experiment may also be related to the lower abundance (no./ L) of zooplankton in winter, compared to other seasons. Similar decrease in zooplankton abundance during winter has also been reported by Dhawan and Kaur (2002 b).

Significantly higher ($P < 0.05$) incidence of fish deformities (mostly scoliosis and bent fins) was obtained in the C treatment in all seasons. The percentage of deformed fish in the various treatments cannot be authentically explained with the available data. The absence of any earlier report with reference to deformities in koi carp related to its husbandry management makes it difficult to arrive at any conclusion. The deformities may have a genetic background since the experimental larvae were the offspring of a mixed commercial production from parents of different koi types that were randomly stocked in the tanks. It may also be environmentally induced. Significantly higher percent of fish with deformities in the control treatment could be attributed to lower abundance of plankton in the system throughout the year. Skeletal and other deformities are associated with nutritional deficiencies or imbalances in young fry and fingerlings fed on commercial diets and are rarely observed in ponds due to presence of live food (Malison, 2003). Another reason could be a possible leaching of nutrients out of the pelleted food applied in the control treatment. Goldblatt *et al.* (1979) demonstrated that pelleted diets exhibit a remarkable loss of vital nutrients, such as vitamins and amino acids, within a short period of exposure to water. High incidence of deformities in fish fed with commercial diets has been reported for crucian carp (Myszkowski *et al.*, 2002).

From the results of the normal probability distribution, the LF treatment appeared to be the most productive treatment, followed by the PM and CD treatments. The control treatment, however, did not produce any marketable fish in the winter, summer and monsoon growout, and even in the post monsoon trial, only 4.52% of stocked fish in this treatment attained marketable size. In contrast to food fish production, where the total mass of fish produced determines productivity (Jolly and Clonts, 1993), ornamental fish can only be marketed once they have reached a particular size, provided they are free from any deformities and meet the aesthetic requirements of the industry. Low growth rate of koi carp in the winter trial ensured that none of the stocked fish in the manured or control treatments attained marketable size. From the present investigation, the winter season appeared to be the most unproductive, as only the LF system produced saleable fish. Throughout the year, the live-food treatment (LF) appeared to be the most effective for koi carp tanks, compared to tanks manured with poultry excreta (PM) or cow dung (CD), through maintenance of better water quality and greater abundance of zooplankton in the system.

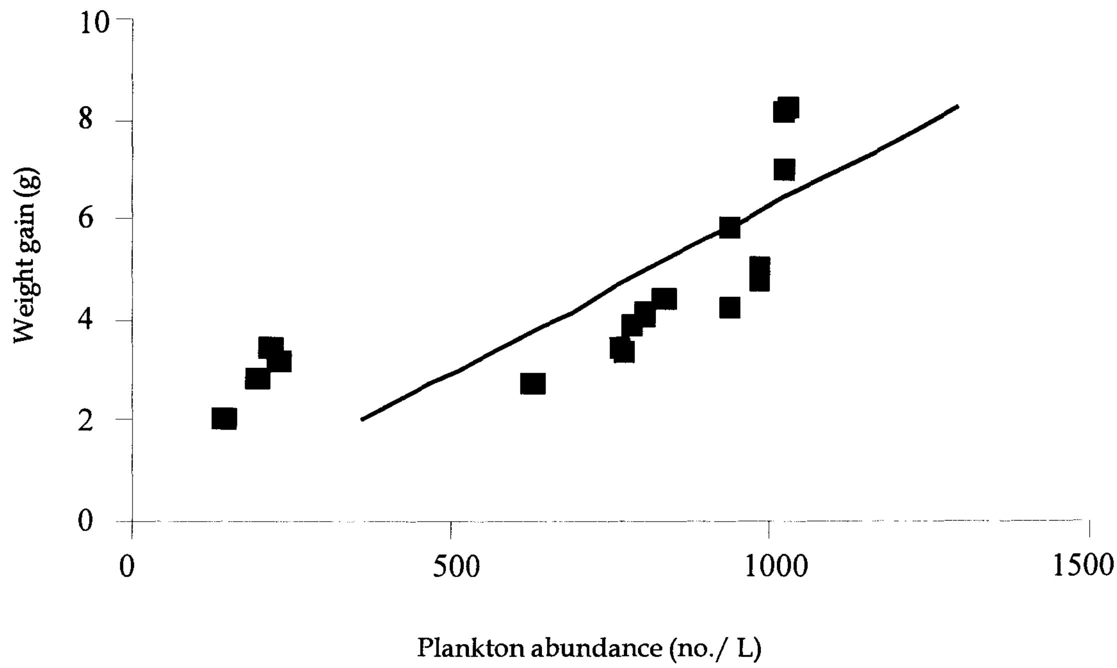

Figure 12 Relationship between weight gain of koi carp and plankton abundance in the four treatments during the different seasonal trials.

5.5. Studies on the effect of live-food treatment on fish production against conventional manuring regimen. (B) Comparative account of fish production in different culture systems, namely, concrete tanks and earthen ponds (Experiment No. 5)

This study shows that feeding of live zooplankton is potentially capable of supporting nearly 48.61% (ponds) to 66.92% (tanks) higher weight gain of carp than that obtained in the poultry manured treatments. Related to maximum plankton intake, the maximum concentration of plankton in the live-food units (in both tanks and ponds) was a consequence of improved water quality, expressed in terms of lower values of BOD and NH_4 - N, and higher values of DO and pH, which is conducive to fast reproduction of some of the major zooplankton constituting the food items of carp larvae (Jana and Chakrabarti, 1993), and also due to the regular introduction of live plankton.

All aquaculture production systems must provide a suitable environment to promote the growth of aquatic crop. Critical environmental parameters include the concentrations of DO, ammonia, nitrite and to a lesser extent nitrate, pH and alkalinity in the water of the production system (Losordo *et al.*, 1992). Although numerous literature are available on fish production in either pond or tank culture systems, very few authors have actually tried to compare the environmental parameters and fish production between both systems. Greater control over production has been the reason of increasing popularity of tank culture over the traditional method of pond fish production. However, in our experiment, manured ponds offered better environment for plankton reproduction in terms of lower NH_4 - N and NO_2 - N levels, compared to manured tanks. As also discussed in Chapters 5.1, 5.2 and 5.4, earlier studies on life history parameters of most cladocerans suggest that growth, reproductive potentials and longevity of many species are affected by the nutrient conditions of the culture media. High concentrations of NH_4 - N were found to restrict the occurrence of many small protozoans that are considered as excellent food for cladocerans (Pfister *et al.*, 2000). One of the possible reasons of higher NH_4 - N and NO_2 - N concentration in tanks could be that daily water exchange in tanks flushed out nitrifying bacteria, particularly *Nitrobacter* sp., leading to increased NH_4 - N concentrations and reduced nitrification (Avnimelech *et al.*, 1994). Significantly lower NO_3 - N concentrations in manured tanks, compared to manured ponds ($P < 0.05$) also lend support to this hypothesis.

In traditional pond culture, proper environmental conditions are maintained by balancing the inputs of fertilizers and feeds with the natural assimilative capacity of the pond. The pond's natural ecosystem, including photosynthetic algae and beneficial bacteria drives important biological processes that impact the daily oxygen cycle and provides a natural biofilter which breaks down harmful nitrogenous wastes (Losordo *et al.*, 1992). Although a 10 cm layer of soil was placed in the bottom of the experimental tanks, it failed to replicate the exact pond environment. Perhaps the stagnation of water in the tanks as compared to even limited wind driven mixture in the ponds caused the differences in the physico-chemical parameters of water in the two systems. A moderate manuring dose of 0.26 kg/ m^3 (corresponding to 2600 kg/ ha) every 10 days was applied to the culture tanks (TPM and TCD) and ponds (PPM and PCD) in this experiment. The traditional application rate of organic manures in Indian ponds in considerably high: 10000 kg/ ha as initial dose and a subsequent application of 5000 kg/ ha (Jhingran, 1991). According to Culver and Dabrowski (1998), optimal fertilization methods may vary from location to location. When the application exceeds the assimilatory capacity of the culture system, it leads to deterioration of water quality through accumulation of ammonia and nitrite (Hargreaves, 1998). In view of the similar manuring dose as applied to the tanks and ponds in the present experiment, it appears that the assimilatory capacity of the ponds was higher than that of tanks.

Under any management regime, higher weight gain and survival rates of koi carp were observed in the ponds, compared to culture tanks. Studies with other fish species have yielded similar results. Significantly lower growth rates of channel catfish, *Ictalurus punctatus* were obtained in concrete pools compared to earthen ponds (Shell, 1966). Although successful on a laboratory scale, tank culture of yellow perch (*Perca flavescens*) fingerlings is not widely practiced, and commercial production is carried out in ponds based on consumption of live food (Malison, 2003). Even in case of walleye, younger fry (upto 6.5 cm) are usually cultured in ponds as the growth rate is better, compared to tanks (Summerfelt, 1996). However, it may be difficult to maintain a steady growth rate of older fry (size > 10 cm) in ponds without the addition of extra feed (Jorgensen, 1996). According to Kinnunen (1996), pond culture is economically effective for the production of young walleye fingerlings, even if it may not be the choice for older size fingerlings (Raisanen, 1996). In case of ornamental carp culture, fish are marketed after attaining the minimum marketable size, i.e. 4 g (about 6 - 7 cm), and as evident from our experimental results, pond culture seems to be the better alternative, compared to tanks for any particular management regime.

Significantly higher percentage of deformed koi carp in the control treatments could be attributed to the commercial diet applied in these units. This is in agreement with earlier findings (Chapter 5.4). According to Malison (2003), skeletal and other deformities are associated with nutritional deficiencies or imbalances in tank cultured fry and are rarely observed in ponds due to presence of live food. In our experiment, significantly higher ($P < 0.05$) percentage of deformed carp was observed under any management regime in tanks, compared to ponds.

Both management regime and the type of culture system had an effect on the number of marketable fish. The live-food treatments for both tanks and ponds appeared to be highly productive, followed by the PPM treatment. Most treatments maintained in tanks were unproductive because of the significantly lower weight gain of koi carp. One of the possible reasons for the slow growth could be the culture season i.e. winter (December - February), and it appeared that a prolonged culture period could increase the productivity of most of the culture systems in terms of marketable fish produced.

Talking all the aforementioned aspects into account, it can be recommended to introduce live zooplankton into culture units for raising koi carp larvae. Due to differences in their basic nature, as also the differences in the size of the culture tanks and ponds employed, it was not possible to derive conclusions about which system was more productive. However, from the experimental results, earthen ponds appeared to be better alternative to concrete tanks for manure application through maintenance of better water quality due to their higher assimilatory capacity and greater abundance of plankton.

5.6. Studies on the effect of live-food treatment on fish production against conventional manuring regimen. (C) Examination of food selection and food preference of cultured fish in the different treatments (Experiment No. 6)

Electivity indices ranging from - 0.3 to + 0.3 are generally considered not significantly different from zero, and thus indicate non-selectivity feeding (Lazzaro, 1987). According to this interpretation, the koi carp larvae in our experiment did not show any significant food selectivity towards most planktonic organisms. Analyzed by plankton types, a strong rejection (below - 0.3) was observed only towards phytoplankton in LF and PM, and towards rotifers in LF and CD. There was no incidence of strong selection (above + 0.3). Analyzed by individual plankton, there was only one incidence of strong positive selection (towards *Daphnia* in CD).

However, other authors (Xie and Takamura, 1996; Serajuddin, 2000) have defined electivity values above + 0.01 as positive selection and below - 0.01 as negative, thus reducing the non-selectivity feeding range to - 0.01 to + 0.01. According to this definition, food selectivity of koi carp larvae was clearly demonstrated in the experimental results: positive selection for cladocerans and negative selection for the other groups, although the extent of selection or rejection differed markedly from one treatment to another.

Since cladocerans were found in larger proportions in the diet than in the environment in all the treatments, it implied that cladocerans constituted an important source of natural food for koi carp larvae held in any culture system. Because of the positive selection of cladocerans in all the treatments, it can be suggested that koi carp larvae had a preference for cladocerans as food despite copepods being the dominant plankton group in the environment of all treatments, except LF. This shows that koi carp larvae do not necessarily feed on the most abundant type of plankton.

Feeding strategy of planktivores is based on the structure and functioning of their branchial feeding apparatus viz. gill rakers (Serajuddin, 2000). The presence of mucous, which helps in consolidation and transportation of food items, could also improve the retention efficiency of the filter. Besides the characteristics such as shape and size of suspended particles and alteration capabilities of mesh size of gill rakers also play an important role in food retention (Serajuddin, 2000). Rejection of food items might be due to their size, which may be beyond the fish's capacity to deal with. Considering that koi carp larvae in our experiment were relatively young (0.13 - 8.67 g), the size of their mouths could be a constraint while consuming larger sized planktonic organisms. It is known that in nature, small mouth size of carp fry (Dabrowski and Bardega, 1984) acts as a constraint for optimal diet breadth during early stages (Werner, 1974).

The avoidance of food organisms may also be linked to distastefulness of food, especially when fish probes the aggregation of food items, as demonstrated by the differential secretion of mucous by grass carp under varied food conditions (Omarova and Lazareva, 1974). Negative selectivity (PM, CD and C) to outright rejection (LF) of phytoplankton by koi carp larvae is in agreement with earlier experiments with other fish species, namely, catla (Jafri and Mustafa, 1975), brown trout, *Salmo trutta* (Fitzmaurice, 1979) and common carp (Chakrabarti and Jana, 1990), where negative selection for phytoplankton were reported. The need to draw on such date arises from the relative absence of data on ornamental carps.

Higher weight gain, SGR and survival rate of koi carp in the LF treatment ($P < 0.05$) could be attributed to the significantly higher abundance of cladocerans in that treatment. The maximum concentration of zooplankton in the LF treatment was a consequence of improved water quality, expressed in terms of lower values of BOD, ammonium and nitrite, and higher values of DO and pH, which is conducive to fast reproduction of some of the major zooplankton constituting the main food item of carps (Jana and Chakrabarti, 1993), and also due to the regular introduction of live plankton. Plankton intake of planktivorous fishes varies with different feeding conditions. Jana and Chakrabarti (1990) reported the plankton intake of common carp in the live-food system was higher than in manured or control system.

A direct relationship between plankton intake and the average body weight of carp has been demonstrated by Chakrabarti and Jana (1991). Similar results were also obtained in our earlier experiments (Chapter 5.1, 5.2 and 5.4). The significantly lower weight gain, SGR and survival rates in the C treatment may be due to insufficient quantity of plankton in the system. Although an imported pelleted feed was applied in this treatment, it seems from the experimental results that the larvae did not prefer the pelleted feed. Similar results were obtained in earlier experiments (Chapter 5.4 and 5.5).

The deformities observed were mostly scoliosis and bent fins. As also discussed in Chapters 5.4 and 5.5, the significantly higher percent of fish with deformities in the control treatment could be attributed to lower abundance of plankton in the system. Even the number of marketable fish was highest in the LF treatment and is in agreement with the findings in Chapter 5.4 and 5.5.

From the findings of the present investigation, raising koi carp larvae in live-food ponds (LF) with introduction of exogenous plankton appears to be a better alternative than the conventional system of direct application of poultry manure (PM) or cow dung (CD) in the ponds.

5.7. Studies on the effect of live-food treatment on fish production against conventional manuring regimen. (D) Estimation of bacteriological counts of water and bottom sediment in the different treatments (Experiment No. 7)

The microbiological status of the water in which fish culture takes place depends on a wide variety of factors influencing the environment, the most important being the organic matter content (Rheinheimer, 1980; Sugita *et al.*, 1985 b; Zmyslowska *et al.*, 2003). Variations of heterotrophic bacteria in the water samples of the four treatments were the results of differences in management practices causing differences of organic loadings in the pond system. Thus the management regimes receiving organic manures (PM and CD) recorded significantly higher populations of total heterotrophic bacteria, compared to other treatments. The highly productive nature of the manured ponds was also supported by the greater abundance (no./ L) of total plankton, compared to the control treatment.

Low counts of heterotrophic bacteria in ponds not receiving any organic manuring have been reported earlier by many authors (Barat and Jana, 1990; Jana and De, 1990; Barik *et al.*, 2001; Majumdar *et al.*, 2002). As such, the control system appeared to be less productive, as also indicated from the significantly lower plankton abundance ($P < 0.05$), compared to the manured treatments. According to Ludwig (1999), when organic fertilizers are added to a pond, they are decomposed by bacteria and the water rapidly gains nutrients from the bottom. The released nutrients are rapidly utilized by phytoplankton and other bacteria, which are simultaneously grazed by single cell protozoan and other zooplankton. In control ponds, as also observed in our study, there are few nutrients, and hence few living organisms.

Although heterotrophic bacteria and phytoplankton are important components in the cycling of organic matter and inorganic nutrients in aquatic ecosystems, they may affect each other positively or negatively, depending on the nutrient conditions of their environment (Wang and Priscu, 1994; Kamjunke *et al.*, 1997; Duvall *et al.*, 2001). Because bacteria have a high surface area to volume (Currie and Kalff, 1984), it has been suggested that bacteria should be superior competitors with phytoplankton for nitrogen and phosphorus (Elser *et al.*, 1995). However, in our experiment, higher abundance of total heterotrophic bacteria in the manured treatments was correlated with high phytoplankton abundance (in PM, $r = 0.625$, $P < 0.01$; in CD, $r = 0.588$, $P < 0.01$).

Brett *et al.* (1999) suggested that the underlying mechanisms behind the positive correlation between phytoplankton and bacteria are tangled in complex interactions between factors such as inorganic nutrient concentrations, organic nutrient availability, protozoan bactivory, availability of physical substrate, as well as light and temperature. Such complications could prevent augmented bacterial populations from having significant effects on phytoplankton. In experiments by Cottingham *et al.* (1997), bacteria did not buffer phytoplankton responses to nutrient enrichment. In view of the continuous grazing pressure on bacteria and phytoplankton by zooplankton and on zooplankton by fish larvae, it is very difficult to estimate the exact population density of bacteria, phytoplankton or zooplankton in any aquatic system. However, the overall results clearly demonstrate the importance of pond management on the growth responses of heterotrophic bacteria.

The abundance of heterotrophic bacteria in the pond sediments did not differ significantly from one system to another. It implies that the sediment of all fish ponds in our experiment, regardless of the farming system, contained the optimal amount of essential nutrients necessary for massive growth of heterotrophic bacteria. Jana and De (1990) obtained similar results in the sediment of traditional and manure-treated ponds. According to Jinyi *et al.* (1988), because of the sedimentation of applied manure and pond mud in both manure-applied and control ponds, the amount of bacteria in the water column decreases from pond bottom to the surface layer of water with the continuous release of microorganism from the sediments. Similar results were also observed in our study.

Greater abundance of *Aeromonas* sp. and *Pseudomonas* sp. in the water and sediments of PM and CD, compared to the control treatment, indicate their sewage character. Very high counts of *Aeromonas* sp. and *Pseudomonas* sp. in ponds manured with animal excreta have been reported by many authors (Cloete *et al.*, 1984; Jinyi *et al.*, 1987; Jinyi *et al.*, 1988; Hamza *et al.*, 1998). The introduction of live plankton in the LF treatment, however, significantly reduced the population of total heterotrophic bacteria, as well as *Aeromonas* and *Pseudomonas* in both water and sediment, compared to the manured treatments.

The water quality was also influenced by management conditions. Significantly high NH_4 - N in the PM and CD treatments could be related to the greater abundance of heterotrophic bacteria in these treatments, since apart from ammonifying bacteria, which was not enumerated in our experiment, many heterotrophic bacteria are known to utilize nitrogen-rich substrate and release ammonia or ammonium salts (Jana and Barat, 1983). Yao and Zhaoyang (1997) reported that the contact layer between pond mud surface and water is the major source of nutrition. The organic nitrogen decomposed to NH_4 - N by bacterial activity adheres to the surface of the mud before being released in the water, where it continuously rises to the surface of the water and escapes to the air (Blackburn and Henriksen, 1983; Mei *et al.*, 1995).

Depletion of dissolved oxygen after manure application often leads to heterotrophic organisms in the water utilizing NO_3 - N as electron receptor instead of oxygen, thus converting it to nitrite (Boyd, 1990). Higher concentration of BOD, NH_4 - N, NO_2 - N and other nutrients, along with the higher counts of *Aeromonas* sp. and *Pseudomonas* sp. in the manure treated ponds may have lowered the grazing activity by the carp, compared to the LF treatment. Neutral to acidic pH in the water of majority of the treatments could be related to the acidic nature of water bodies in North Bengal (Nath *et al.*, 1994; Jha and Barat, 2003; Jha *et al.*, 2003).

Higher weight gain, SGR and survival rate of koi carp in the LF treatment could be attributed to the better water quality and significantly greater abundance ($P < 0.05$) of zooplankton in that treatment. The deformities observed were mostly scoliosis and bent fins. Significantly higher percentage of deformed koi carp in the control treatment could be attributed to: (1) low counts of live plankton, and (2) the commercial diet applied in that treatment, and is in agreement with earlier observations (Chapter 5.4, 5.5 and 5.6). Management condition also had an effect on the number of marketable fish and the LF treatment appeared to be more productive, compared to the manured treatments or control.

All aquaculture production systems must provide a suitable environment to promote the growth of aquatic crop. Although application of organic manure does not directly cause bacterial diseases in fish, the significantly greater abundance of pathogenic bacteria (*Aeromonas* sp. and *Pseudomonas* sp.) in the water and sediments of the manured treatments (PM and CD) imply, should the fish resistance to disease be low, the possibility of occurrence of bacterial disease is higher in these treatments. Therefore, proper pond management should be observed to prevent any chance of bacterial disease.

Though it is well known that high fish yield in culture systems can be achieved by higher abundance of plankton, perhaps it may not be possible to fertilize with manure because this may reduce water quality. Intensive stocking in ornamental fish ponds in India requires a standard water quality to be maintained throughout, so that fish growth is not adversely affected. In view of the financial constraints of marginal farmers who cannot afford modern aeration or waste-treatment equipments, raising of ornamental carp larvae in ponds fed exogenously with zooplankton is of considerable significance because such feeding would support high rates of survival and production through maintenance of better water quality and greater abundance of zooplankton in the system.

5.8. Studies on experimental ornamental fish polyculture. (A) Behavioural responses of two popular ornamental carps, koi carp and goldfish to monoculture and polyculture conditions in aquaria (Experiment No. 8)

The depths occupied by the two fish species under different experimental conditions were a function of: (1) Species-specific differences in mean depth preference. This could explain for the similarities in depth preference of monocultured fish of any particular species within two experimental batches in the absence of food. (2) Species-specific changes in depth in response to the addition of food. The preferences of the bottom tank levels by both fish species in the first batch in the presence of tubifex worm lend a support to this hypothesis. The reduction in mean depth recorded for monocultured koi carp in the second batch in the presence of plankton may also be influenced by the upward movement of the species towards the surface for grazing on the maximum amount of zooplankton available at the position of the tank where it was administered, before the live plankton could disperse to other areas of the tank. (3) Species-specific changes in depth in response to polyculture conditions. This was probably the most important factor and is associated with aggressive behaviour of individual species.

The two species exhibited considerable variation in the extent and type of aggression displayed. Goldfish in monoculture treatments appeared less aggressive, compared to monocultured koi carp in both experimental batches. Even in the polyculture treatments, goldfish attacked conspecifics or other species (koi carp) very rarely. On the other hand, koi carp were overwhelmingly more aggressive. The frequency of attack increased significantly in the presence of food. Food has shown to increase the rates of aggression in blue gourami (Syarifuddin and Kramer, 1996), gambusia, *Gambusia holbrooki* and swordtail (Warburton and Madden, 2003). The broader diversity of species-specific behaviours and salient stimuli may also have encountered heightened levels of activity. In a study of conspecific and interspecific interactions between brook trout, *Salmo gairdneri* (*Oncorhynchus mykiss*), Newman (1956) postulated that the presence of food increased feeding activity, which in turn increased aggressive activity as the focus of attacks was displaced from the food to fellow fish of both species. He further noted that feeding fish displayed some movements that are associated with aggression, such as body undulations, swift darting and biting, and suggested that such movements constituted sign stimuli eliciting attacks from other species.

The significantly higher rate of attacks in the polyculture treatments compared to monoculture conditions for both batches of fish question the very logic behind stocking koi carp and goldfish together. Although the impact of nipping on spinal and caudal abnormalities, or fin damages were not estimated in the present experiment, it could be suggested that sustained attacks, particularly on goldfish by koi carp under polyculture conditions could lead to stress and increased rate of deformities in pond polyculture. As discussed earlier, ornamental fish need to be visually attractive to be acceptable in the market, and deformed or stressed fish could be aesthetically unattractive to potential customers.

The two food items used in the two experimental batches (tubifex and plankton) were selected with a due consideration to the food availability under pond conditions. The impact of aggressive behaviour of koi carp was clearly demonstrated by the increased level of attack on goldfish in the polyculture treatments in both the experimental batches. Working with introduced poeciliid (gambusia) and native Australian fish, *Pseudomugil signifer*, Howe *et al.* (1997) observed that the prerequisites for competition exist when mixed populations of fish species are trapped in shrinking ponds during drought. In India, ornamental fish ponds are generally much smaller, compared to other aquaculture ponds, and competition pressure may severely affect the production status of the 'non aggressive' species under such confined habitat conditions.

Although the present laboratory-based findings should not be applied in a precise predictive way to judge interspecific interrelationships in ponds, they do illustrate behavioural mechanisms by which koi carp may negatively impact goldfish under confined conditions in ponds.

5.9. Studies on experimental ornamental fish polyculture. (B) Comparison of food selection and growth performance of koi carp and goldfish in monoculture and polyculture rearing in tropical ponds (Experiment No. 9)

The similarity in the types of organisms present in the gut of koi carp and goldfish may be due to the fact that all the ponds were maintained under similar management conditions and the food (plankton-rich water) was supplied form a series of ponds, also similar in size and management. Hence there was no difference in food resource between the experimental ponds. Water quality also was quite similar in all the treatments. Lower pH and dissolved oxygen in 100%K and 90%K-10%G treatments may be explained by koi carp stirring up mud from the bottom. Although earlier reports on koi carp are lacking, other carp species are known to create management problems in fish ponds by stirring up pond bottoms, thereby releasing nutrients from the soil (Wahab *et al.*, 2002), creating turbidity and lowering dissolved oxygen (Lutz, 2003).

In the present study, goldfish showed better weight gain in monoculture, compared to polyculture treatments, unlike the koi carp, which recorded no significant differences in growth parameters between different treatments. Within the different polyculture treatments, the highest growth for goldfish was recorded in 10%K-90%G. That polyculture affected goldfish production is clear from the experimental results, however, absence of any earlier report relating to polyculture of ornamental carps in tropical pond conditions makes it difficult to draw conclusions about factors responsible for this reduced growth rate and production. One of the possible reasons could be differences in the food selection by the two species, and competition for food between them under polyculture conditions.

The koi carp diet in the monoculture treatment (100%K) consisted of twelve genera of plankton, which was reduced to fewer species in the different polyculture treatments. A rejection of phytoplankton was observed in all treatments, and is consistent with earlier findings (Chapter 5.6). However, four genera of phytoplankton were identified in koi carp intestines collected from 100%K, compared to two genera in 90%K-10%G and 70%K-30%G, and one in each of the 50%K-50%G, 30%K-70%G and 10%K-90%G treatments. Greater diversity of food in the guts of monotypic populations indicate that segregation by cohabiting fish species results in consumption of a narrower range of food items in polytypic communities, than when only one species is present (Andrusak and Northcote, 1971; Clady, 1981). Being the more aggressive species in polyculture, koi carp could select its preferred group of plankton (cladocera) within this narrow range, and the electivity towards cladocerans recorded almost similar in all the treatments.

In goldfish, phytoplankton was absent and only six genera of zooplankton were obtained in the intestines of monotypic populations (100%G). The plankton diversity significantly increased ($P < 0.05$) in the gut content of polytypic goldfish communities. However, greater diversity of the diet does not necessarily suggest better feeding conditions, since fish populations often consume a greater variety of food items under adverse conditions than when food supplies are unlimited (Ivlev, 1961). Greater diversity of plankton from the guts of polycultured goldfish may be influenced by the consumption of their preferred food (cladocera) by the koi carp. In monoculture, goldfish recorded a very strong selection for the cladoceran, *Daphnia* (0.346) and the genera contributed 35.10% of the gut contents in 100%G, which was significantly reduced in polycultured goldfish ($P < 0.05$), recording only 19.04% in goldfish gut content in 90%K-10%G, with an electivity of 0.055. Simultaneously, there was increased consumption of copepods, rotifers and phytoplankton in polyculture, compared to monoculture.

Behavioural observations in the earlier experiment (Experiment No. 8) showed that koi carp were more active in the polyculture treatments, compared to monoculture. Similar aggressive behaviour of polycultured koi carp was also noted during the present study and could account for the increased rate of deformities and fin damages observed in goldfish in the polyculture treatments. However, it was not possible to document details of the interspecific interactions between koi carp and goldfish in pond conditions. The deformities in both species were mostly scoliosis, spinal and caudal abnormalities and bent fins, and could not have been induced environmentally, since the management conditions of all the treatments were similar. As discussed earlier, ornamental fish must be visually attractive to be marketable and deformed or damaged fish are not saleable, even if they attain marketable size.

The main tool for managing polyculture systems and maximizing fish production is the knowledge of fish-fish and fish-environment quantitative relationships (Milstein, 1992). The selection of fish species is therefore very important. One problem frequently encountered in polyculture involves the overlap of food or habitat preferences among species or even downright antagonism (Lutz, 2003). Brummett and Alon (1994) indicated that although growth of redclaw crayfish *Cherax quadricarinatus* was not adversely affected by the presence of nile tilapia in polyculture, tilapia growth and food conversion were significantly impacted by redclaw crayfish. Yashouv (1968) related similar problems encountered in polyculture of tench, *Tinca tinca* and common carp. In spite of feed being applied to ponds, the two species apparently competed for the same resources and carp production was reduced when tench was present. Studies on stable carbon and nitrogen isotope values from ponds polyculturing silver carp, *Hypophthalmichthys molitrix* and bighead carp, *Aristichthys nobilis* in China suggested that there were various degrees of dietary overlap between two species with an average of 60% of their food from the same trophic level (Gu *et al.*, 1996). In another experiment, Mattson (1998) recorded similar feeding preferences in *Oreochromis shiranus* and *Barbus paludinosus*, when offered an array of planktonic food in aquaria. In a study on polyculture of tench, common carp and bigmouth buffalo, *Ictiobus cyprinellus*, Adamek *et al.* (2003) observed food competition between tench and carp (60.8%) and between tench and bigmouth buffalo (47.4%). Vromant *et al.* (2002) recorded significant interspecific competition between nile tilapia and common carp in polyculture systems in intensively cultivated rice fields. The need to draw on such data arises from the relative absence of literature on ornamental carp polyculture. Whatever preliminary data available suggest that both koi carp and goldfish are likely to prefer the bottom tank level (Sandford, 1998) and eat similar food items (Axelrod and Vorderwinkler, 1970).

Another problem with polyculture wherever labour costs are relatively high involves handling and sorting species at harvest. In our experiment, every pond was netted three times at harvest, which could have aggravated fin damages. According to Milstein (1992), polyculture is the appropriate technique when the goal is production of low-cost fish. When the goal is production of more expensive fish, monoculture simplifies the management (Wohlfarth and Schroeder, 1979; Hepher and Pruginin, 1981). The financial risks associated with each species in the different combinations require proper evaluation (Milstein, 1992).

Polyculture had a direct effect on the number of marketable fish. The results clearly indicate that monoculture treatments yielded the largest number of saleable fish. As also described earlier, ornamental fish can only be sold once they have reached a particular size (4 g or more). From the present study, a diminishing return becomes apparent in ornamental carp polyculture, compared to monoculture. Besides, keeping in view of the dietary similarities of koi carp and goldfish, and the aggressive nature of koi carp in polycuture, possibly leading to increased deformities and lower weight gain and SGR of polytypic goldfish communities, it is suggested to refrain from polyculture of goldfish and koi carp until further documentations relating to stocking and standard management of polyculture of ornamental carps are available.