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Growth, production and food preference of rohu *Labeo rohita* (H.) in monoculture and in polyculture with common carp *Cyprinus carpio* (L.) under fed and non-fed ponds

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Abstract

An experiment was carried out in 18 earthen ponds to investigate the effects of the addition of common carp *Cyprinus carpio* (L.) and artificial feed on natural food availability, food utilization and fish production in rohu *Labeo rohita* (Hamilton) ponds. Ponds were fertilized fortnightly with cow manure, urea and triple super phosphate. Rohu was stocked in all ponds at a density of 1.5 rohu m^{-2}. All treatments were carried out in triplicate. Treatments were: rohu with and without formulated feed, rohu plus 0.5 common carp m^{-2} with and without feed, and rohu plus 1 common carp m^{-2} with and without feed. The time period between stocking and harvesting was four and half months. Stocking 0.5 common carp m^{-2} enhanced natural food availability in the pond, food utilization and rohu growth and production ($P<0.05$). The effect was less pronounced when stocking 1 common carp m^{-2}. Formulated feed administration did not influence phytoplankton availability ($P>0.05$) but increased zooplankton and benthic macroinvertebrate availability ($P<0.001$). Feed administration also enhanced growth of rohu and common carp ($P<0.001$). Rohu naturally ingests more phytoplankton than zooplankton but in the presence of formulated feed rohu shifted its natural food preference from phytoplankton to zooplankton. Common carp naturally ingests mainly zooplankton and benthic macroinvertebrate and small quantities of phytoplankton. However, when offered formulated feed, the latter becomes the preferred food item.

Keywords: Food preference; Food availability; Polyculture; Pond; Rohu; Common carp

1. Introduction

Semi-intensive carp polyculture is an age-old popular practice in south Asia, especially in Bangladesh and India, where it is the main aquaculture production system (Miah et al., 1997; FAO, 1997; Reddy et al., 2002). Between July 1999 and July 2000 the total inland fish production of Bangladesh was about 650,000 metric tons. More than 80% of this production was realized in semi-intensive culture systems (DOF, 2001). The key characteristic of these systems is the reliance on the combination of natural and artificial feed (Hepher and Pruginin, 1982; Moore, 1985). In addition, polyculture is preferred, based on the assumption that each species

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stocked has its own feeding niche that does not completely overlap with the feeding niche of other species. In consequence, a larger fraction of the natural food available in the pond is used in multi-species systems. In some cases, one species enhances the food available for other species, thus increasing further the total fish yield per unit area (Swingle, 1966; Hepher et al., 1989; Miah et al., 1993).

In south Asian polyculture, a wide variety of fish species are cultured. Among those species, rohu *Labeo rohita* (Hamilton), catla *Catla catla*(Hamilton) and mrigal *Cirrhinus cirrhosus* (Bloch) are very popular (Uddin et al., 1994; FAO, 1997; Miah et al., 1997; Kanak et al., 1999). Between July 1998 and July 1999, these 3 species contributed 70% of the total inland aquaculture production in Bangladesh (DOF, 2001). Nevertheless, production systems are continuously changing. Nowadays, farmers prefer to stock rohu because rohu enjoys a higher consumer preference and market value. The farmers also prefer to stock common carp *Cyprinus carpio* (L.) as a bottom feeder instead of mrigal because common carp grows faster than mrigal and the overall production is higher when combined with rohu and catla in polyculture ponds (Dewan et al., 1985; Wahab et al., 1995; Milstein et al., 2002). Wahab et al. (2002) conducted an experiment with rohu, catla, punti *Puntius sophore* (Hamilton), common carp and mrigal in semi-intensive polyculture and achieved a 60% higher yield of rohu with common carp as bottom feeder compared to mrigal.

Rohu is known as a water column feeder mainly feeding on plankton (Das and Moitra, 1955; Dewan et al., 1977; Jhingran and Pullin, 1985; Wahab et al., 1994) and common carp is a bottom feeder mainly feeding on benthic macroinvertebrate and zooplankton (Tang, 1970; Spataru et al., 1980; Hepher and Pruginin, 1981; Spataru et al., 1983). When artificial feed is applied, common carp readily accepts artificial feeds (Yashouv and Halevy, 1972; Spataru et al., 1980; Schroeder, 1983; Milstein and Hulata, 1993). The food and feeding habits of rohu and common carp might differ according to the overall food and feed availability. Stirring effect of common carp may enhance nutrient availability, which in turn increase natural food availability in the ponds (Yashouv, 1971; Milstein et al., 1988, 2002). Such principles are commonly accepted but have never been well quantified. However, the quantitative effects of common carp density on food availability and feed intake remain unclear (Wahab et al., 1995; Milstein et al., 2002). Indeed, most studies which tried to analyze the quantitative relation of food web ecology of polyculture ponds rely on percent occurrence numbers of different food items in the gut (Dewan et al., 1991; Wahab et al., 1995; Azim et al., 2004). However, due to the large size variation of the natural food item, these data provide a poor indication of the actual biomass present in the pond or ingested by fish. Volumetric or weight measurements of gut content is a better indicator of the contribution to total food intake. Considering the above issues, the goal of this study was to elucidate the effects of artificial feed and addition of common carp on natural food availability, food preference, food intake, growth and fish production in semi-intensive rohu ponds.

2. Materials and methods

2.1. Study site and pond preparation

The 4.5 months experiment was conducted between March and July 2003 in 18 earthen ponds located at the Fisheries Faculty Field Laboratory, Bangladesh Agricultural University, Mymensingh, Bangladesh. All ponds were rectangular in shape with a size of 100 m^2 and an average depth of 1.2 m. The ponds were supplied by groundwater from an adjacent deep tube-well. Prior to the experiment, ponds were drained, renovated, aquatic vegetation was removed and fishes and macrofauna were eradicated. All ponds were treated with agricultural lime ($CaCO_3$) at a rate of 250 kg ha^{-1} and filled with water 7 days prior to fertilization. 1250 kg ha^{-1} of decomposed cow manure, 31 kg ha^{-1} of urea and 16 kg ha^{-1} of triple super phosphate (TSP) were applied to all ponds one week before stocking, followed by fortnightly applications of the same amounts for the duration of the study period.

2.2. Experimental design

A factorial design was used, the factors being common carp stocking density (3 levels: 0, 0.5 and 1 common carp m^{-2}) and feed addition (2 levels: feed addition and no feed addition). All ponds were stocked with 1.5 rohu m^{-2}. The combinations of the two factors resulted in the following 6 treatments: rohu alone without (formulated) feed (treatment 0C), rohu alone with feed (0C-F), rohu plus 0.5 common carp m^{-2} without feed (0.5C), rohu plus 0.5 common carp m^{-2} with feed (0.5C-F), rohu plus 1 common carp m^{-2} without feed (1C), and rohu plus 1 common carp m^{-2} with feed (1C-F). All treatments were executed in triplicate.

2.3. Fish stocking and management

Rohu (mean individual stocking weight per pond ranged between 20.3 and 21.1 g) and common carp (20.6–21.4 g) fingerlings collected from a nearby

nursery were released into the ponds in the afternoon. The 30% protein diet contained fish meal (protein: 57.5%, inclusion in feed, 37%) rice bran (14%, 47%), mustard oil cake (14%, 15%) and vitamin premix (0%, 1%), and was applied daily at 15 g $kg^{-0.8}$ day^{-1} starting the day after stocking until the day prior to harvesting. Feeding rates per pond were adjusted monthly after weighing minimum 20% of the fishes stocked.

2.4. Assessment of plankton and benthic macroinvertebrate

Water samples for plankton analysis were collected fortnightly taking 1-l samples at 10 randomly selected locations in each pond with a Niskin sampler. Each composite 10-l sample was then passed through a 10-μm mesh plankton net. Each concentrated plankton sample was then transferred to a plastic bottle and diluted to 100 ml with formalin and distilled water to obtain a 5% buffered formalin solution. Plankton numbers were estimated in a Sedgewick–Rafter (S–R) cell. A 1 ml sample was put in the S–R cell and was left 10 min to allow plankton to settle. The plankton in 10 randomly selected fields in the S–R cell was identified up to genus level and counted. As determination keys were used Ward and Whipple (1959), Prescott (1962), Belcher and Swale (1976) and Bellinger (1992). Plankton density was calculated using the formula,

$$N = (P \times C \times 100)/L$$

with N=the number of planktonic organisms per liter of pond water; P=the number of planktonic organisms counted in ten fields; C=the volume of the plastic bottle holding the sample (100 ml); L=the volume of the pond water sample (10 l). The benthic macroinvertebrate samples were collected fortnightly with an Ekman dredge. In each pond, bottom mud samples were collected from 3 random locations and washed through a 250 μm mesh size sieve. Benthic macroinvertebrate remaining on the sieve was preserved in a plastic vial containing a 10% buffered formalin solution. Identification keys used for benthic macroinvertebrate were Brinkhurst (1971) and Pinder and Reiss (1983). Benthic macroinvertebrate density was calculated using the formula,

$$N = Y \times 10,000/3A$$

with N=the number of benthic organisms (numbers m^{-2}); Y=total number of benthic organisms counted in 3 samples; A=area of Ekman dredge (cm^2).

2.5. Analysis of gut content

One fish per species per pond was collected each month for gut content analysis. Each fish was weighed individually and killed in ice water. The body cavity of the fish was carefully opened and 5 cm of the anterior gut was cut and preserved immediately in a jar containing 10% buffered formalin. The content from each 5 cm gut was carefully washed into a Petri dish and diluted to 50 ml with water. A 1 ml sub-sample was transferred by a pipette to a S–R cell containing 1000 1-mm^3 fields and left for 10 min to allow the solid particles to settle. The S–R cell was set up under a microscope and identification of food items was done in 10 square fields. The different food items collected from the gut were qualified and quantified up to the genus level. The calculations were done using the following formula,

$$N = P \times C \times 100$$

with N=no. of a specific food item available in 5 cm gut, P=total no. of specific food observed in 10 fields, and C=volume (ml) of sample in the Petri dish.

2.6. Fish harvesting

At the end of the experiment ponds were drained and all fish were harvested and weighed up to the nearest 0.1 g. Specific growth rate (% body weight day^{-1}) was calculated using the formula,

$$\mathrm{SGR} = [\ln \mathrm{WT_F} - \ln \mathrm{WT_I}] \times 100/T \text{ (Hopkins, 1992)}$$

with WT_F=average final fish weight (g), WT_I=average initial fish weight (g), T=duration of the experiment (days).

2.7. Data calculations and analysis

The biovolumes of plankton and benthic macroinvertebrate were calculated using literature values (see Table 1). Zooplankton biovolumes were calculated using length in their respective length/volume formula. In some cases, biovolume approximations were made using the values of species of similar shape.

Percent data were arcsine transformed before analysis, but non-transformed data are shown in Tables or Figures. All data were analyzed through two-way split-plot ANOVA except growth and yield data of fish. The two-way split-plot ANOVA was performed with common carp density and artificial feed as main factors and time as sub-factor (Gomez and Gomez, 1984). Fish

Table 1
Phytoplankton and zooplankton species individual biovolume as used to convert numbers into total biovolume

Group	Genus	Organism volume (μm^3)	References	Assumption
Bacillariophyceae	*Achanthes*	600	–	*Cyclotella*
	Actinella	600	–	*Cyclotella*
	Cocconeis	600	–	*Cyclotella*
	Cymbella	600	–	*Cyclotella*
	Cyclotella	600	Berman and Pollingher (1974)	–
	Fragilaria	810	Peerapornpisal (1996)	–
	Frustrularia	810	–	*Fragilaria*
	Gomphonema	600	–	*Cyclotella*
	Melosira	910	Berman and Pollingher (1974)	–
	Navicula	850	Berman and Pollingher (1974)	–
	Nitzschia	1240	Peerapornpisal (1996)	–
	Surirela	2630	–	*Phacus*
	Synedra	1240	–	*Nitzschia*
	Tabellaria	1240	–	–
Chlorophyceae	*Ankistrodesmus*	52	Beveridge et al. (1993)	–
	Actinustrum	52	–	*Ankistrodesmus*
	Bothriococcus	6190	Peerapornpisal (1996)	–
	Chaetophora	1326	–	*Anabaena*
	Chlorella	30	Berman and Pollingher (1974)	–
	Chrysococcus	6190	–	*Bothriococcus*
	Closteridium	335	–	*Closterium*
	Closterium	1675	Peerapornpisal (1996)	–
	Coelastrum	1208	Peerapornpisal (1996)	–
	Cosinodiscus	1208	–	*Coelastrum*
	Crucigenia	220	Peerapornpisal (1996)	–
	Elakatothrix	15	Peerapornpisal (1996)	–
	Geminella	1326	–	*Anabaena*
	Gonatozygon	1326	–	*Anabaena*
	Haematococcus	6190	–	*Bothriococcus*
	Merismopedia	896	–	*Pediastrum*
	Microspora	896	–	*Pediastrum*
	Oedogonium	896	–	*Pediastrum*
	Oocystis	250	Berman and Pollingher (1974)	–
	Pediastrum	896	Peerapornpisal (1996)	–
	Pleurococcus	6190	–	*Bothriococcus*
	Scenedesmus	115	Berman and Pollingher (1974)	–
	Selenastrum	115	–	*Scenedesmus*
	Sprogyra	1326	–	*Anabaena*
	Sphaerocystis	896	–	*Pediastrum*
	Tetraedron	85	Berman and Pollingher (1974)	–
	Tetraspora	90	–	*Tetraedron*
	Ulothrix	1326	–	*Anabaena*
	Volvox	30	–	*Chlorella*
	Zignema	1326	–	*Anabaena*
Cyanophyceae	*Anacystis*	1326	–	*Anabaena*
	Anabaena	1326	Beveridge et al. (1993)	–
	Coelospharium	1208	–	*Coelastrum*
	Gleocapsa	1208	–	*Coelastrum*
	Microcystis	11,300	Peerapornpisal (1996)	–
	Lyngbya	1326	–	*Anabaena*
	Aphanizomenon	1231	Peerapornpisal (1996)	–

Table 1 (*continued*)

Group	Genus	Organism volume (μm^3)	References	Assumption
	Aphanocapsa	1231	–	*Aphanizomenon*
	Aphanotheca	1231	–	*Aphanizomenon*
	Chroococcus	280	Berman and Pollingher (1974)	–
	Gomphospheria	1208	–	*Coelastrum*
	Oscillatoria	1326	–	*Anabaena*
Euglenophyceae	*Euglena*	1956	Peerapornpisal (1996)	–
	Phacus	2630	Peerapornpisal (1996)	–
	Trachelomonas	5089	Peerapornpisal (1996)	–
Rotifera	*Asplanchna*	483,840	–	*Polyarthra*
	Brachionus	483,840	–	*Polyarthra*
	Filinia	483,840	–	*Polyarthra*
	Polyarthra	483,840	McCauley (1984) and Bottrell et al. (1976)	Length (L)=120 μm volume=0.28 L^3
	Keratella	944,023	Bottrell et al. (1976) and McCauley (1984)	Length (L)=162.5 μm Volume=0.22 L^3
	Trichocerca	483,840	–	*Polyarthra*
Cladocera	*Daphnia*	483,840	–	*Polyarthra*
	Diaphanosoma	483,840	–	*Polyarthra*
	Moina	483,840	–	*Polyarthra*
Copepoda	*Diaptomus*	483,840	–	*Polyarthra*
	Nauplius	944,023	–	*Keratella*
	Monostyla	483,840	–	*Polyarthra*
	Cyclops	944,023	–	*Keratella*
Oligochaeta	–	1.273 (mm^3)	Riera et al. (1991)	Volume=$\pi LD^2/4$, with D=average diameter (0.4 mm), L=length (10.13 mm), $L=-1.408+28.835\ D$
Chironomidae	–	1.273 (mm^3)	–	Oligochaeta

Genus name in the assumption column indicates assuming similar biovolume of the genus given in the same row. All assumptions were made on the basis of average size under microscopic observation.

growth and yield data were analyzed by two-way ANOVA performing with the main factors (common carp density and artificial feed). Because of the scope of the present paper, we will discuss only the effects of main factors. The sub-factor time and its interactions with the main factors common carp densities and artificial feed addition, will be discussed in a separate article.

3. Results

3.1. Effects on plankton and benthic macroinvertebrate bio-volume

Phytoplankton samples contained four major groups (Bacillariophyceae, 14 genera; Chlorophyceae, 31; Cyanophyceae, 13 and Euglenophyceae, 3), zooplankton three (Rotifera, 6; Cladocera, 3 and Copepoda, 4), and benthic macroinvertebrate two (Oligochaeta and Chironomidae) (Table 2). In all treatments the same genera of plankton were found. The results of the ANOVA on the biovolume of major groups of plankton and total benthic macroinvertebrate are shown in Table 3. Common carp density affected the bio-volume of all the groups of phytoplankton, zooplankton and benthic macroinvertebrate except Bacillariophyceae. The mean total biomass of Chlorophyceae, Cyanophyceae, Euglenophyceae and total phytoplankton were higher in ponds with 0.5 than in ponds with 1 and 0 common carp per m^{-2}. In the case of Rotifera, Cladocera, Copepoda and total zooplankton, the mean total biomass was the highest with 0.5 common carp m^{-2}, followed by 1 and 0 common carp m^{-2}. In contrast, when considering the effects of common carp on benthic macroinvertebrate biomass, higher biomass was observed in treatments without common carp, followed by treatments with 0.5 and 1 common carp m^{-2}. The benthic macroinvertebrate biomass in the treatment without common carp was 1.7 and 1.9 times higher than in treatments with 0.5 and 1 common carp m^{-2}, respectively. The effect of artificial feed addition was not significant on any phytoplanktonic group but was significant for all zooplanktonic groups and total benthic macroinvertebrate biomass. The total zooplankton and benthic macroinvertebrate biomass in treatments with feed were 1.3 times higher than in treatments without feed.

Table 2
List of plankton and macro invertebrate recorded from the experimental pond water and gut content of rohu and common carp

Group	Genus	Pond water	Rohu gut	Common carp gut
Bacillariophyceae				
	Achanthes	×		
	Actinella	×		
	Cocconeis	×	×	×
	Cyclotella	×	×	×
	Cymbella	×	×	×
	Fragilaria	×	×	×
	Frustularia	×		
	Gomphonema	×	×	×
	Melosira	×	×	×
	Navicula	×	×	×
	Nitzschia	×	×	×
	Surirela	×	×	×
	Synedra	×	×	×
	Tabellaria	×	×	
Chlorophyceae				
	Actinastrum	×	×	
	Ankistrodesmus	×	×	×
	Botryococcus	×	×	×
	Chaetophora	×	×	×
	Chlorella	×	×	×
	Chrysococcus	×	×	×
	Closteridium	×	×	×
	Closterium	×	×	×
	Coelastrum	×	×	×
	Coscinodiscus	×	×	×
	Crucigenia	×	×	×
	Elakatothrix	×		
	Geminella	×	×	×
	Gonatozygon	×	×	×
	Haematococcus	×		
	Merismopedia	×	×	×
	Microspora	×	×	
	Oedogonium	×	×	×
	Oocystis	×	×	×
	Pediastrum	×	×	×
	Pleurococcus	×	×	×
	Pleurosigma	×	×	×
	Scenedesmus	×	×	×
	Selenastrum	×	×	
	Sphaerocystis	×		
	Sprogyra	×	×	×
	Tetraedron	×	×	×
	Tetraspora	×	×	
	Ulothrix	×	×	×
	Volvox	×	×	×
	Zignema	×	×	×
Cyanophyceae				
	Anabaena	×	×	
	Anacystis	×	×	×
	Aphanizomenon	×	×	×
	Aphanocapsa	×	×	×
	Aphanothece	×	×	×
	Chroococcus	×	×	×
	Coelospharium	×		×
	Gleocapsa	×		
	Gomphospheria	×	×	×
	Lyngbya	×	×	×
	Microcystis	×	×	×
	Oscillatoria	×	×	×
Euglenophyceae				
	Euglena	×	×	
	Tracchelomonas	×		
	Phacus	×	×	
Rotifera				
	Asplanchna	×	×	×
	Brachionus	×	×	×
	Filinia	×	×	×
	Keratella	×	×	×
	Polyarthra	×	×	×
	Trichocerca	×	×	×
Cladocera				
	Daphnia	×	×	×
	Diaphanosoma	×	×	×
	Moina	×	×	×
Copepoda				
	Cyclops	×	×	×
	Diaptomus	×	×	×
	Monostyla	×	×	×
	Nauplius	×	×	×
Macroinvertebrate				
Oligochaeta		×		×
Chironomideae		×		×

"×" indicates presence.

3.2. Effects on gut content

The gut content of rohu and common carp consisted of phytoplankton (rohu 51 genera and common carp 46), zooplankton (both species 13), benthic macroinvertebrate (rohu 0 and common carp 2 groups) (Table 2) and unidentified particles. Unidentified particles were more abundant in the treatments with feed than in the treatments without feed. Benthic macroinvertebrate was found in the gut of common carp but not in rohu. Euglenophyceae were only found in the gut of rohu. The results of two-way ANOVA on the biovolume of the major groups of plankton in the guts of rohu and common carp are shown in Tables 4 and 5, respectively. The biovolume of total phytoplankton and total zooplankton in the gut of rohu was higher with 0.5 than with 0 or 1 common carp m^{-2}. There was no effect of common carp density on the biovolume of all phytoplanktonic groups ($P > 0.05$) in the gut of common carp. The biovolume of total zooplankton and benthic macroinvertebrate in the gut of common carp was significantly ($P < 0.05$) higher in ponds with 0.5 than in ponds with 1 common carp m^{-2}.

Feed addition had significant effects on rohu's ingestion of all groups of phytoplankton and zooplankton

Table 3
Effects of common carp and supplementary feed on the abundance (based on total volume, $mm^3\ l^{-1}$) of different groups of plankton and macroinvertebrate in ponds based on two-way ANOVA

Variable	Significance (P value)			Tukey test				
				Common carp density			Feed	
	CC	Feed	CC × Feed	0	0.5	1	Yes	No
Bacillariophyceae	NS	NS	NS	0.039	0.041	0.041	0.041	0.040
Chlorophyceae	***	NS	NS	0.122^{b}	0.147^{a}	0.131^{b}	0.135	0.131
Cyanophyceae	**	NS	NS	0.077^{b}	0.103^{a}	0.081^{b}	0.088	0.085
Euglenophyceae	***	NS	*	0.027^{b}	0.061^{a}	0.035^{b}	0.044	0.038
Total phytoplankton	***	NS	NS	0.265^{b}	0.352^{a}	0.287^{b}	0.308	0.294
Rotifera	***	***	***	0.026^{c}	0.038^{a}	0.035^{b}	0.037^{a}	0.029^{b}
Cladocera	***	**	NS	0.007^{c}	0.014^{a}	0.010^{b}	0.011^{a}	0.009^{b}
Copepoda	***	**	*	0.009^{c}	0.016^{a}	0.013^{b}	0.014^{a}	0.011^{b}
Total zooplankton	***	***	**	0.042^{c}	0.067^{a}	0.057^{b}	0.062^{a}	0.049^{b}
Total macroinvertebrate in bottom ($cm^3\ m^{-2}$)	***	***	**	6.242^{a}	3.730^{b}	3.221^{c}	4.954^{a}	3.840^{b}

CC = common carp density; Feed = feed addition; CC × Feed = interaction of common carp density and feed. Mean values in the same row with no superscript in common differ significantly ($P<0.05$). If the effects are significant, ANOVA was followed by Tukey test. $^{*}P\leq 0.05$; $^{**}P<0.01$; $^{***}P<0.001$; NS, not significant.

except Chlorophyceae. The ingestion of Bacillariophyceae, Cyanophyceae, Rotifera, Cladocera and Copepoda was higher in treatments with feed than in the treatments without feed, whereas an opposite result was observed in case of the ingestion of Euglenophyceae. The volume of total phytoplankton ingested by rohu in treatments with feed was 1.3 times higher than in treatments without feed. Again, the quantity of zooplankton ingested by rohu in treatments with feed was 3.2 times higher than in treatments without feed. In case of common carp, the artificial feed had significant effects on the ingestion of all planktonic groups and benthic macroinvertebrate except Bacillariophyceae, but this effect was opposite to the effect in rohu. The ingestion of total phytoplankton and total zooplankton by common carp in treatments without feed was 1.3 and 1.7 times higher, respectively, than in treatments with feed. In general, common carp ate more benthic macroinvertebrate than plankton. For benthic macroinvertebrate too, intake was 1.9 times higher in treatments without feed than in treatments with feed.

3.3. Effects on yield parameters of rohu and common carp

Yield parameters of rohu and common carp are shown in Table 6. For rohu there were significant common carp stocking density and artificial feed main effects but no interaction effects on its average individual harvesting weight, survival, specific growth rate (SGR) and yield. For common carp, the main effects and their interaction

Table 4
Effects of common carp and supplementary feed on the composition of gut content of rohu (based on total volume, mm^3) of different groups of plankton and macro invertebrate based on two-way ANOVA

Variable	Significance (P value)			Tukey test				
				Common carp density			Feed	
	CC	Feed	CC × Feed	0	0.5	1	Yes	No
Bacillariophyceae	**	***	NS	$0.170^{a,b}$	0.199^{a}	0.147^{b}	0.263^{a}	0.081^{b}
Chlorophyceae	*	NS	NS	0.291^{b}	0.345^{a}	0.322^{a}	0.328	0.310
Cyanophyceae	NS	***	**	0.044	0.048	0.055	0.058^{a}	0.039^{b}
Euglenophyceae	NS	***	NS	0.078	0.082	0.062	0.053^{b}	0.095^{a}
Total phytoplankton	**	***	NS	0.583^{b}	0.674^{a}	0.586^{b}	0.685^{a}	0.544^{b}
Rotifera	NS	***	NS	0.243	0.272	0.251	0.381^{a}	0.130^{b}
Cladocera	**	***	**	0.173^{b}	0.229^{a}	0.248^{a}	0.324^{a}	0.110^{b}
Copepoda	**	***	**	0.090^{c}	0.171^{a}	0.132^{b}	0.216^{a}	0.046^{b}
Total zooplankton	**	***	*	0.506^{b}	0.672^{a}	0.632^{b}	0.920^{a}	0.286^{b}

CC = common carp density; Feed = artificial feed addition; CC × Feed = interaction of common carp density and feed. Mean values in the same row with no superscript in common differ significantly ($P<0.05$). If the effects are significant, ANOVA was followed by Tukey test. $^{*}P\leq 0.05$; $^{**}P<0.01$; $^{***}P<0.0001$; NS, not significant.

Table 5
Effects of common carp density and supplementary feed on the composition of gut content of common carp (based on total volume, mm^3) of different groups of plankton and macro invertebrate based on two-way ANOVA

Variable	Significance (P value)			Tukey test			
				Common carp density		Feed	
	CC	Feed	CC × Feed	0.5	1	Yes	No
Bacillariophyceae	NS	NS	NS	0.141	0.156	0.142	0.156
Chlorophyceae	NS	*	NS	0.178	0.204	0.157^b	0.225^a
Cyanophyceae	NS	**	*	0.058	0.055	0.051^b	0.062^a
Total phytoplankton	NS	**	NS	0.377	0.415	0.350^b	0.443^a
Rotifera	*	**	NS	0.206^a	0.168^b	0.152^b	0.223^a
Cladocera	NS	**	NS	0.261	0.227	0.179^b	0.310^a
Copepoda	*	***	NS	0.285^a	0.234^b	0.176^b	0.344^a
Total zooplankton	**	**	NS	0.753^a	0.629^b	0.506^b	0.876^a
Total macroinvertebrate	*	**	NS	3.733^a	2.846^b	2.310^b	4.270^a

CC = common carp density; Feed = artificial feed addition; CC × Feed = interaction of common carp density and feed. Mean values in the same row with no superscript in common differ significantly ($P<0.05$). If the effects are significant, ANOVA was followed by Tukey test. $^*P\leq0.05$; $^{**}P<0.01$; $^{***}P<0.0001$; NS, not significant.

were significant ($P<0.05$) for all growth parameters. Rohu performed better in the presence of 0.5 common carp m^{-2} compared to the other common carp stocking densities (Table 6). Stocking 0.5 common carp m^{-2} resulted in a 1.4 times higher total rohu yield than stocking 0 or 1 common carp m^{-2}. Individual average harvesting weight was 1.5 times higher in treatments with 0.5 common carp m^{-2} than in the treatments with 1 common carp m^{-2}, but total common carp yield was 1.2 times higher in treatments with 1 common carp m^{-2} than the treatments with 0.5 common carp m^{-2}.

Yield of rohu and common carp was better in treatments with feed than in treatments without feed (Table 6 and Figs. 1 and 2). For rohu, the total yield in treatments with feed was 1.5 times higher than in treatments without feed. For common carp, the total yield in treatments with feed was 2.1 times higher than in treatments without feed. The overall performance of rohu was better (highest average individual harvesting weight, 191.1 g; highest survival, 100%; highest specific growth rate, 1.62% body wt. day^{-1}; highest total fish yield, 2860 kg ha^{-1} 137 day^{-1}) in treatment 0.5C-F, followed by

Table 6
Effects of common carp density and supplementary feed on rohu and common carp average individual harvesting weight, survival, specific growth rate and yield, and total yield of fish (rohu plus common carp) in different treatments based on two-way ANOVA

Variable	Significance (P value)			Tukey test				
				Common carp density			Feed	
	CC	Feed	CC × Feed	0	0.5	1.0	Yes	No
Rohu								
Average individual harvesting weight (g)	***	***	NS	139.1^b	173.4^a	132.9^b	164.9^a	132.0^b
Survival (%)	***	***	NS	83.5^b	94.5^a	84.7^b	94.4^a	80.7^b
SGR (% body weight $days^{-1}$)	***	***	NS	1.39^b	1.55^a	1.35^b	1.51^a	1.35^b
Rohu yield (kg ha^{-1} 137 $days^{-1}$)	***	***	NS	1747^b	2473^a	1716^b	2343^a	1613^b
Common carp								
Average individual harvesting weight (g)	***	***	***	–	212.70^a	142.82^b	243.67^a	111.85^b
Survival (%)	***	***	**	–	99.3^a	90.7^b	98.7^a	91.3^b
SGR (% body weight day^{-1})	*	***	*	–	1.59^a	1.38^b	1.75^a	1.22^b
Common carp yield (kg ha^{-1} 137 $days^{-1}$)	*	***	*	–	1059^b	1314^a	1628^a	746^b
Total yield (kg ha^{-1} 137 $days^{-1}$)	***	***	***	1747^c	3532^a	3030^b	3428^a	2111^b

CC = common carp density; Feed = artificial feed addition; CC × Feed = interaction of common carp density and feed. Mean values in the same row with no superscript in common differ significantly ($P<0.05$). If the effects are significant, ANOVA was followed by Tukey test. $^*P\leq0.05$; $^{**}P<0.001$; $^{***}P<0.0001$; NS, not significant.

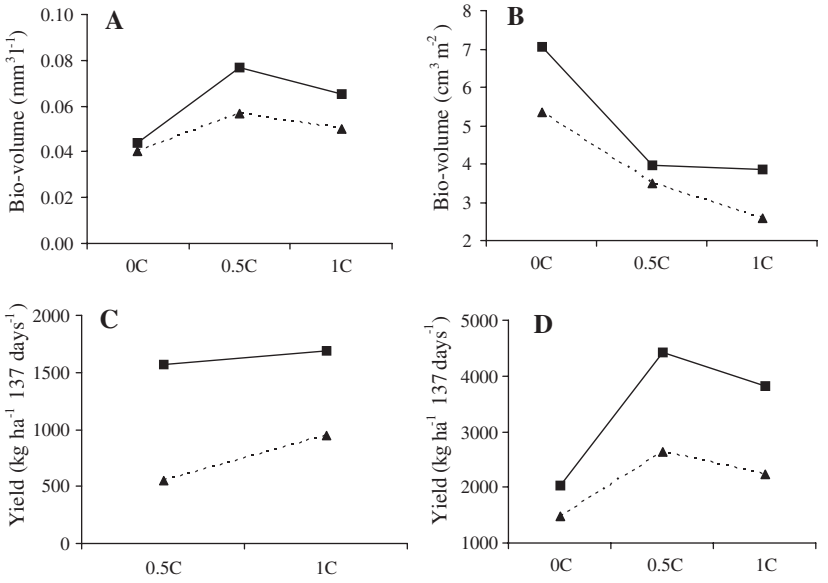

Fig. 1. Interaction effects of common carp density and artificial feed on the abundance of total zooplankton in the water (A), on the abundance of total benthic macroinvertebrate in the bottom mud (B), total common carp yield (C) and total fish yield (D). 0C = treatments without common carp, 0.5C = treatments with 0.5 common carp m^{-2} and 1C = treatments with 1 common carp m^{-2}. Dotted and solid lines indicate treatments without and with feed, respectively.

treatment 1C-F, 0.5C, 0C-F, 0C and 1C. Total yield of rohu in treatment 0.5C-F was 1.3 times higher than in treatment 1C-F, 1.4 times higher than in treatment 0.5C and 0C-F, 2 times higher than in treatment 0C and 2.2 times higher than in treatment 1C. The overall performance of common carp was also better (highest average individual harvesting weight, 314.3 g; highest survival, 100% and highest specific growth rate, 1.97% body wt. day^{-1}) in treatment 0.5C-F, followed by treatment 1C-F, 1C and 0.5C. Total yield of common carp in treatment 1C-F was similar to treatment 0.5C-F but 1.8 times higher than in treatment 1C and 3 times higher than in treatment 0.5C.

3.4. Effects on combined fish yield

There were significant effects of common carp density, addition of feed and their interaction on the combined fish yield (Table 6). The combined fish yield in treatments with 0.5 common carp m^{-2} was 1.2 times higher than in treatments with 1 common carp m^{-2} and around 2 times higher than without common carp. The combined fish yield in treatments with feed was 1.6 times higher than in treatments with no feed. The combined yield of rohu and common carp and their contribution to this total combined yield are shown in Fig. 2.

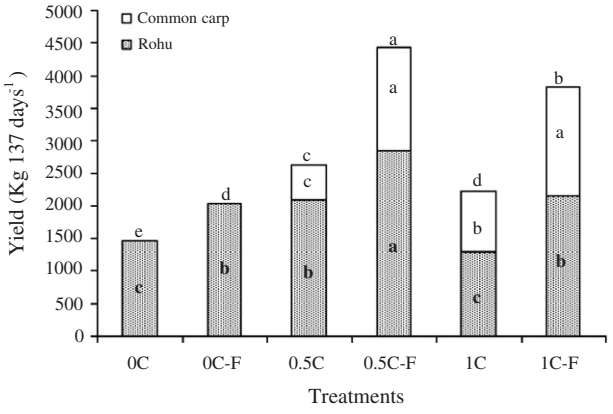

Fig. 2. Total yield of fish and relative contributions of rohu and common carp in the six treatments. Letters above and within the bar relate to total yield and species yield, respectively based on Tukey test, one-way ANOVA. Yields with no latter in common are significantly different ($P<0.05$).

4. Discussion

4.1. Effect on plankton and benthic macroinvertebrate biomass

The interaction between fish and food organisms is of utmost importance in polyculture systems (Milstein et al., 1988). Species with different feeding niches stocked at different densities can influence the natural food availability positively (e.g. by releasing nutrients from the pond bottom) or negatively (e.g. by direct ingestion) (Milstein, 1992; Milstein and Svirsky, 1996). According to Hepher et al. (1989) and Milstein and Svirsky (1996), stirring of sediments by common carp increases natural food availability by enhancing nutrient flows through the food web. A conceptual model of fish and food organism interactions, as influenced by common carp density and artificial feed using data from Tables 3–6 is given in Fig. 3. Browsing and burrowing for food by common carp helped to release nutrients from the bottom into the water column (Milstein et al., 1988, 2002). The nutrients released stimulated photosynthesis, increasing phytoplankton and zooplankton biomass (Milstein, 1992; Wahab et al., 1995, 2002). In this study, the effect of common carp addition on phytoplankton and zooplankton biomass was more pronounced with 0.5 common carp m^{-2} than with 1 common carp m^{-2} (central vs. right sections of Fig. 3). The possible reasons are: (1) more common carps increase turbidity (Meijer et al., 1990; Roberts et al., 1995; Parkos et al., 2003), reducing photosynthesis and hence primary production (Hosseini and Oerdoeg, 1988); (2) higher grazing pressure by fish and zooplankton. Increasing common carp density may lead to overgrazing on natural foods, eventually up to the point that recovery is not possible (Steffens, 1990). Most likely in this experiment the grazing pressure and

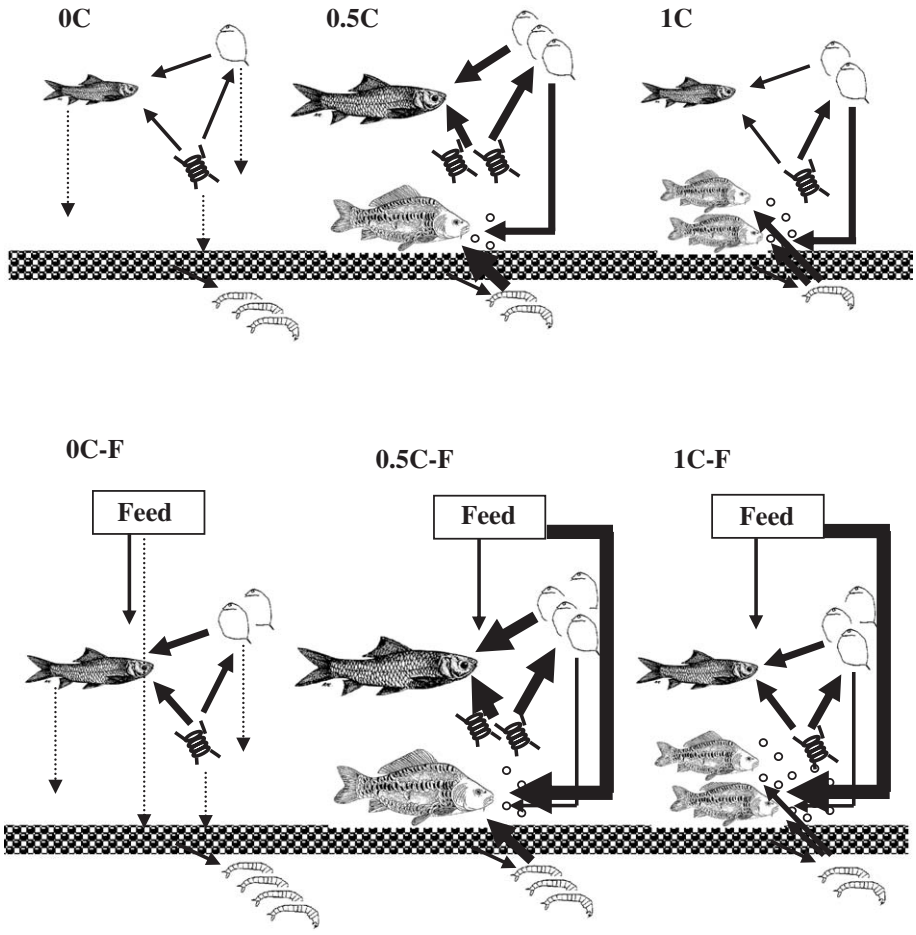

Fig. 3. Conceptual model of major different trophic relations in different treatments. Width of arrows towards similar direction among different treatments represents relative importance of effects. Size of the same species of fish represents growth performance. Arrows with dotted lines indicate sedimentation of particles on the bottom, but are not shown in all treatments to keep clarity.

phytoplankton production were similar resulting in no further effects of common carp on phytoplankton biomass in treatments with 1 common carp m^{-2}.

The lower rate of primary production also affected zooplankton production, resulting in less zooplankton biomass in treatments with 1 compared to 0.5 common carp m^{-2} treatments. Less turbidity and grazing pressure improved primary and secondary production in treatments with 0.5 common carp m^{-2}. A different trend was observed in the benthic macroinvertebrate biomass, which decreased with increasing carp density as feeding pressure of common carp on benthic macroinvertebrate increased (Fig. 3, comparison from left to right sections). This is in agreement with the results of Zur (1979), Riera et al. (1991), Tatrai et al. (1994), Zambrano and Hinojosa (1999).

In semi-intensive systems, artificial feed benefits the pond in two ways: it is either directly eaten by cultured animal or it indirectly supplies nutrients through decomposition by bacteria, fungi and protozoa (Moriarty, 1986, 1997; Milstein, 1992). In pond culture, 21% of the nitrogen and 19% of the phosphorous (Siddiqui and Al-Harbi, 1999) in the artificial feed are retained by the fish. Another 14% of the nitrogen and 21% of the phosphorous dissolves and is used by phytoplankton (Neori and Krom, 1991). The remaining nitrogen and phosphorous mainly stimulates bacteria, fungi and protozoa production, which in turn may be consumed by zooplankton (Tang, 1970; Langis et al., 1988). In the present study, artificial feed significantly affected the availability of food. A relatively higher quantity of zooplankton and benthic macroinvertebrate biomass in the pond were observed in treatments with feed than in those without feed, but feed had no significant effect on phytoplankton biomass (Fig. 3, comparison between upper and lower section). The possible reason may be that the higher quantities of zooplankton quickly harvested phytoplankton resulting in no significant effect of feed on phytoplankton biomass. Our results partially agree with those of Moriarty (1986) and Spataru et al. (1980). Moriarty (1986) observed higher meiofauna biomass in fed ponds than in those that did not receive feed. Spataru et al. (1980) found that zoobenthos was three times higher in ponds with artificial feed than in ponds without it.

4.2. Effect on gut content

Food ingestion in fish is highly variable and depends on a variety of factors, including availability of the different food items and feed, species combination and their interactions. Fishes can consume different food organisms in different amounts under various species combinations and densities (Milstein and Svirsky, 1996). Proper association of fish species may help to develop synergism. Stocking density influences individual food availability with high densities causing preferred foods to become depleted (Milstein, 1992). This might lead to shifts from planktivory to piscivory as with common carp eating tilapia fry at high density when there are insufficient other natural foods available (Spataru and Hepher, 1977). In the present study, in the presence of common carp more natural food was available, enhancing food intake. At a density of 1 common carp m^{-2} natural foods became limiting, affecting food intake of both rohu and common carp. This was not the case at a density of 0.5 common carp m^{-2} (Fig. 3).

Rohu ingested more phytoplankton and zooplankton in treatments with feed than in non-fed treatments. It preferred phytoplankton and zooplankton above artificial feed but the artificial feed had a fertilizing effect that increased phytoplankton and zooplankton abundance. Rohu showed an interesting shift in feeding behavior in the presence of artificial feed. It ingested twice as much phytoplankton than zooplankton in non-fed treatments. In contrast, in the presence of artificial feed rohu ingested 1.3 times more zooplankton than phytoplankton, although in both treatments more phytoplankton was available than zooplankton. In the presence of artificial feed, this shifting food habit of rohu from phytoplankton to zooplankton indicates that zooplankton is a more preferable food item than phytoplankton. This result in a way agrees with Miah et al. (1984), who reported that zooplankton is a preferable food item than phytoplankton for rohu fry.

A nearly opposite trend was observed in the food preference of common carp. Actually, common carp is an omnivorous fish (Merla, 1969; Chapman and Fernando, 1994), feeding on everything available in the pond but mainly on artificial feed, zooplankton and benthic organisms and detritus (Hepher and Pruginin, 1981; Man and Hodgkiss, 1981; Milstein et al., 1991; Liang et al., 1999). In the present study, it was shown that in non-fed ponds, common carp preferred benthic macroinvertebrate, followed by zooplankton and phytoplankton. In fed ponds it preferred artificial feed. Spataru et al. (1980) reported common carp ingesting artificial feed, benthic macroinvertebrate and zooplankton. In another study, Spataru et al. (1983) reported that the most frequent items of natural food in the guts of common carp consisted of insect larvae and pupae, oligochaetes and some zooplankton species. The largest weight of natural food consisted of chironomid larvae and pupae, oligochaetes and cladocerans. Schroeder (1983) observed that in fed

ponds 40% of common carp production is based on the artificial feed and 60% is based on natural foods.

The shifting food habit of common carp most likely hampers the increase in phytoplankton biomass in the fed treatments. In presence of artificial feed, common carp shifts preference from zooplankton and benthic macroinvertebrate to artificial feed, hence more zooplankton and benthic macroinvertebrate prevent algal biomass to increase even with more nutrients available (O'Brien and deNoyelles, 1974), resulting in the lack of effect of artificial feed on algal biomass. However, this shifting food habit of common carp most likely increased zooplankton biomass, which facilitated rohu to ingest more zooplankton in fed treatments.

4.3. Effect on fish growth parameters

The growth performances of rohu and common carp were affected by common carp density. Rohu growth increased when common carp was present, but the effect was stronger at a density of 0.5 common carp m^{-2} than 1 common carp m^{-2}. Rohu production and total production increased almost twice in the presence of 0.5 common carp m^{-2}. Growth performance of rohu was more or less similar in treatments without common carp and treatments with 1 common carp m^{-2}. This concurs with Wahab et al. (2002), who reported a 1.6 times higher rohu yield in the presence common carp. When fish density is high competition for food becomes important. Forester and Lawrence (1978) found that high density of common carp decreased standing crop of bluegill (*Lepomis macrochirus*, Rafinesque) through food competition, which caused the bluegill to eat their own eggs. Hepher et al. (1989) reported positive effects at the lower density of silver carp *Hypophthalmichthys molitrix* (Valenciennes) and negative effects at the higher density of silver carp on its own and other fish species performances, including common carp.

5. Conclusion

Strong synergistic effects in terms of availability of food, food intake, growth and production were obtained in rohu ponds with 0.5 common carp m^{-2}. These effects nearly disappeared in treatments with 1 common carp m^{-2} compared to carp-free controls. As expected, feed addition resulted in higher growth performance of rohu and common carp. So, polyculture with 0.5 common carp m^{-2} and 1.5 rohu m^{-2} with artificial feed was the best combination. Rohu shifted its feeding habit from phytoplankton to zooplankton in the presence of artificial feed. Common carp preferred benthic macroinvertebrate, followed by zooplankton and phytoplankton in non-fed ponds, but shifted to artificial feed when available. Natural food availability was quantified and fish growth and production measured. However, the relation between food availability and growth is not linear, so the underlying mechanisms need further study. In this context, a lot of additional information could be gained from direct observational studies focusing on food selectivity, feeding behavior and social interactions in mono or polyculture systems.

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