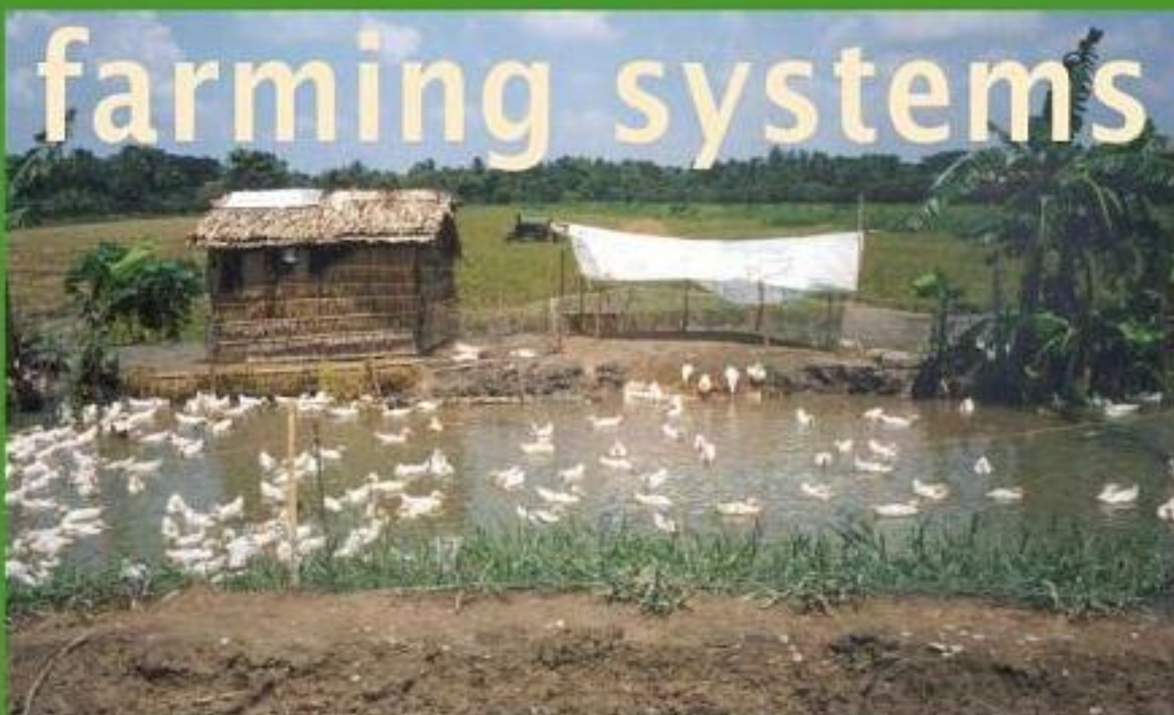
Fishponds in farming systems



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Multi-species fishpond and nutrient balance

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Abstract

The efficiency of pond aquaculture largely depends on species combination, stocking density and ratio, and the quantity and quality of nutrient inputs. In semi-intensive polyculture, fish production is mainly based on natural productivity, which greatly depends on nutrients availability in the water column. The addition of benthivorous fish enhances the release of nutrients from the sediment, stimulating phytoplankton productivity and accelerating the flux of nutrients to higher trophic levels. Density of benthivorous fish is very important. Optimum density of benthivorous and planktivorous fish in polyculture can improve synergistic effects, which increase nutrient retention efficiency in fish and decrease nutrient losses. Besides decreasing nutrient loss this type of polyculture maximises resource utilisation. This type of aquaculture is very appropriate in Asia, where investments in waste treatment are minimal or non-existent.

Keywords: nutrients, polyculture, carp, synergism, behaviour

Introduction

Multi-species aquaculture (polyculture) is based on the assumption that each species stocked has a feeding niche that does not completely overlap with the feeding niche of the other species present. Therefore, by stocking multiple species, a more complete use is made of the space and natural food available in the pond, maximising resource utilisation. In some cases, one species enhances food availability, and hence production of another species, a phenomenon that is referred to as 'synergism' (Swingle, 1966; Hepher *et al.*, 1989). When synergism occurs, nutrient use efficiency is increased while environmental impacts from fish farming will be reduced. The number of species combinations that can be made in polyculture is enormous. In addition, numerous biotic and abiotic factors also influence farming success. Therefore, in experiments designed to understand synergism, environmental conditions should be standardised as much as possible, and the number of species stocked should be limited.

Polyculture is commonly applied in semi-intensive ponds in which the flow of nutrients through the food web depends to a large extent on nutrient availability in the water column. In undisturbed water bodies, diffusion across the sediment-water interface is the main mechanism by which nutrients become available in the water column (Wetzel, 1975; Avnimelech and Kochva, 1999). In aquaculture ponds, the fluxes of nutrients between sediment and water column are enhanced by fish-driven re-suspension, which quickly becomes more important than diffusion (Ritvo *et al.*, 2004; Tarvainen *et al.*, 2005). Fish-driven re-suspension is particularly important in low-input ponds, where fish production depends almost entirely on natural food availability. Sometimes farmers know that resuspension of nutrients has a positive effect on production; e.g. in Bangladesh harrowing the pond bottom to re-suspend nutrients is a traditional method to enhance pond production (Beveridge *et al.*, 1994) The objectives of this paper are (1) to review how interactions among fish species affect nutrient concentrations, nutrient accumulation, natural food availability and total fish production, and (2) to analyse the underlying mechanisms explaining synergism for growth and production.

Synergistic effects in multi-species pond

Due to synergistic effects, the growth and production of some fish species may be higher in polyculture than monoculture (Table 3.2). Silver carp *Hypophthalmichthys molitrix* grown in polyculture with common carp *Cyprinus carpio* attains a higher harvest weight than when grown in monoculture (Yashouv, 1971; Hepher *et al.*, 1989). Rohu *Labeo rohita* and total pond production increase by factors of 1.4 and 2, respectively, in the presence of common carp (Rahman *et al.*, 2006). Synergistic effects among fish species can be explained mainly on the basis of two interrelated processes: (1) increase in natural food availability and (2) the improvement of environmental conditions in the pond. Both processes enhance growth and production of fish. The mechanism through which the stocking of an additional species contributes to increased food availability and improved environmental condition largely depends on its specific place in the pond food web (Milstein, 1992). Synergistic effects are

Table 3.2. Reported yield in different mono and polyculture systems. All ponds were fertilised. Some ponds received in addition artificial feed (referred to as "Feed"), some ponds received substrate for periphyton development (referred to as "Periphyton").

Nutrient source	Culture systems	Yield ($t\ ha^{-1}\ yr^{-1}$)*	Reference
-	Monoculture (silver carp)	2.1	Hepher *et al.*, 1989
-	Polyculture (silver carp, common carp, hybrid tilapia, grey mullet & grass carp)	3.9	Hepher *et al.*, 1989
-	Monoculture (silver carp)	0.24	Hepher *et al.*, 1989
-	Polyculture (silver carp, common carp, tilapia, mullets & grass carp)	2.0	Hepher *et al.*, 1989
Periphyton	Monoculture (rohu)	2.4	Azim *et al.*, 2001
Periphyton	Monoculture (catla)	1.4	Azim *et al.*, 2001
Periphyton	Polyculture (rohu & catla)	3.1	Azim *et al.*, 2001
Feed	Monoculture (rohu)	5.4	Rahman *et al.*, 2006
Feed	Polyculture (rohu & common carp)	10.2-11.8	Rahman *et al.*, 2006
-	Monoculture (rohu)	3.9	Rahman *et al.*, 2006
-	Polyculture (rohu and common carp)	5.9-7.0	Rahman *et al.*, 2006

*Reported values were extrapolated to annual production. Seasonal differences in growth and production were not considered.

more pronounced between benthivorous and herbivorous species. Benthivorous fish have very large effects on the pond ecosystem. Most benthivores, when feeding on benthic material increase oxygen availability in the sediment, accelerating the mineralisation and re-suspension of nutrients, which in turn has a large impact on the abiotic and biotic quality of the overlying water column (Northcote, 1988). Common carp is a very well known benthivore that has a larger impact on pond productivity than most other benthivorous species. For example, Wahab *et al.* (2002) achieved a 60% higher yield in rohu with common carp as bottom feeder compared to mrigal *Cirrhinus cirrhosus*. In an another study, Parkos III *et al.* (2003) observed larger increases in phytoplankton biomass and in total phosphorus availability in the presence of common carp than in the presence of channel catfish *Ictalurus punctatus*.

At higher densities, common carp may influence production negatively through: (1) over-grazing of zooplankton and benthic macro-invertebrates to an extent that recovery is not possible, (2) increases in pond soil redox potential values to >200 mV through increased oxygen supply, which may in turn cause the precipitation of soluble phosphorus (PO_4-P) as inorganic particles (e.g. with iron as iron (III) phosphate) (Holdren and Armstrong, 1980; Bostrom *et al.*, 1988; Boyd, 1995) and (3) an increase in turbidity due to re-suspended particles, which reduce light penetration and hence photosynthesis. However, considering both positive and negative effects on production, stocking densities of benthivorous fishes are important. Rahman *et al.* (2006) observed that total fish production was significantly lower in rohu ponds (1.5 rohu m^{-2}) where 1 common carp m^{-2} was stocked compared to ponds with 0.5 common carp m^{-2}. A possible explanation might be the inter-species competition for food with increasing fish density. Forester and Lawrence (1978) found that high density of common carp decreased standing crop of bluegill *Lepomis macrochirus* (Rafinesque) through food competition, which resulted in the bluegill ingesting their own eggs.

Another important factor is nutrient input as feed or fertiliser. The type of nutrients input may regulate the synergistic effects among benthivorous fishes (Figure 3.2). For example, higher nutrient inputs may increase the synergistic effects of benthivorous fishes on fish production. Rahman *et al.* (2006) observed the highest total fish yield of 11,800 kg $ha^{-1}yr^{-1}$ in high input ponds at 15,000 rohu plus 5,000 common carp ha^{-1}. This was 1,800 kg higher than the previous highest production record found in the literature for south Asia (10,100 kg $ha^{-1}yr^{-1}$; Mathew *et al.*, 1988). Obviously, there is an optimum level of nutrients input. More research is needed in this aspect.

Natural foods and its utilisation in multi-species pond

Selection of suitable species combinations to optimise production and food utilisation in ponds is very important in order to optimise nutrient use efficiency (Milstein *et al.* 1988). In fertilised ponds, fishes mainly feed on phytoplankton, zooplankton, benthic macro-invertebrates and detritus. The amounts of these natural foods in lakes and ponds (Table 3.3) are influenced by management factors, such as fish species combinations in polyculture, fish stocking density and ratio, and nutrient input quality and quantity (Milstein, 1993; Diana *et al.*, 1997). Fish feeding habits have an important influence on natural food availability, both directly by consumption and indirectly through influencing the food web and nutrient availability. For instance, bottom

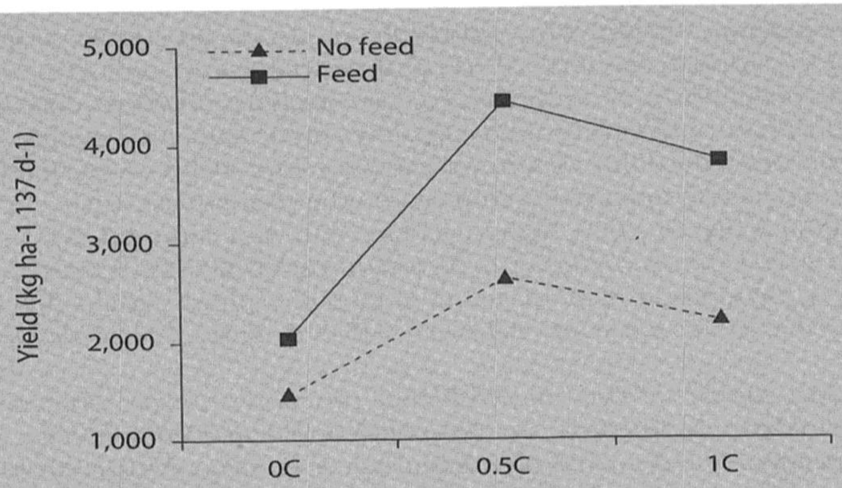

Figure 3.2. Interaction effects of common carp density and artificial feed on the total fish yield. 0C, 0.5C and 1C indicate treatments without common carp, with 0.5 common carp and 1 common carp m^{-2}, respectively (Rahman et al., *2006).*

Table 3.3. Reported biomass of natural foods in fishponds. (FM = fresh matter; DM = dry matter; int. = integrated).

Food types	Biomass	Unit	Pond system	References
Phytoplankton	44-65	gFM m^{-3}	Pig-fish int.	Yang, 1994
Phytoplankton	29-36	gDM m^{-2}	Int. fish	Takamura *et al.*, 1995
Phytoplankton	1-71	gFM m^{-3}	Shrimp	McIntosh *et al.*, 2001
Phytoplankton	121	gDM m^{-2}	Fish	Tang, 1970
Phytoplankton	265-352	mm^3FM m^{-3}	Fish	Rahman *et al.*, 2006
Zooplankton	3-5	gDM m^{-2}	Int. fish	Takamura *et al.*, 1995
Zooplankton	10-13	gFM m^{-3}	Pig-fish int.	Yang, 1994
Zooplankton	10	gDM m^{-2}	Fish	Tang, 1970
Zooplankton	2	gDM m^{-2}	Eutrophic	Iwakuma *et al.*, 1989
Zooplankton	42-67	mm^3FM m^{-3}	Fish	Rahman *et al.*, 2006
Zooplankton	4-10	gDM m^{-3}	Nursery	Molodtsova-Zaikina, 1977
Benthos	9-36	gDM m^{-2}	Nursery	Molodtsova-Zaikina, 1977
Benthos	15-70	gDM m^{-2}	Fish	Wade & Stirling, 1999
Macroinvertibrate	4	gDM m^{-2}	Fish	Oerlti, 1993
Macroinvertibrate	3.2-6.2	cm^3FM m^{-3}	Fish	Rahman *et al.*, 2006
Detritus	130	gDM m^{-2}	Pig-fish int.	Yang, 1994
Detritus	83	gDM m^{-2}	Pig-fish int.	Yang, 1994

feeders, such as common carp, searching for benthic macro-invertebrates re-suspend sediments, thereby influencing nutrient availability in the water column, which in turn affects photosynthesis and subsequently phytoplankton and zooplankton production. Rahman *et al.* (2006) found increases in phytoplankton (8-33%) and zooplankton (36-60%) biomass in the presence of benthivorous common carp. However, without planktivorous fish, nutrients accumulated in the plankton will not be transferred into fish biomass. The faecal pellets produced by planktivorous species make part of the plankton production available to benthivorous species like common carp or even omnivorous species like tilapias. Therefore, it makes sense to combine benthivorous or planktivorous fish, as each species benefits through increased food availability.

Fish density also plays an important role in food availability and its utilisation. If fish density is too great grazing pressure could be so high as to prevent recovery. In this case fish production will be negatively affected. For example, higher densities of phytoplanktivorous fishes reduce phytoplankton, which in turn adversely affects the production of zooplankton and the growth of zooplanktivorous fishes. With increasing stocking density competition increases, fish shift to less preferable foods as their preferred food items become depleted (Milstein, 1992). Rohu will eat more phytoplankton when zooplankton availability is less and will shift from phytoplankton to zooplankton when zooplankton is more abundant in the presence of common carp. Rohu ingested smaller quantities of phytoplankton and zooplankton when the abundance of these food items was reduces under high density of common carp (Rahman *et al.*, 2006).

Fish behaviour in multi-species pond

Social interaction between/among species may influence fish grazing, swimming and resting behaviours. For example, when three species of sunfish, the bluegill (*Lepomis macrochirus*), green sunfish (*L. cyanellus*) and the pumpkinseed (*L. gibbosus*), are stocked separately in ponds, each species preferred to forage mostly on invertebrates in the vegetation, but when they are stocked together, the diet of the green sunfish showed no change, the bluegill concentrated partially on prey from the water column, especially zooplankton, and the pumpkinseed largely fed on prey from the sediment (Werner and Hall, 1976, 1977, 1979). So, fishes behave differently when stocked in different species combinations.

In the presence of common carp, grazing, swimming and social behaviour of rohu were found to change. When rohu and common carp were cultured together, rohu spent 47-52% of the time in the company of common carp, increased their active time by 51-62% and decreased intra-specific schooling time by 55-71%. The net result is that rohu spent relatively more time grazing near the bottom instead of in the water column where the density of zooplankton is less (Rahman *et al.*, personal communication). Hence, in the presence of common carp, rohu ate more zooplankton, which resulted in better growth (Rahman *et al.*, 2006). Behaviour of common carp also changed with density. In treatments where common carp densities were highest, common carp spent relatively more time swimming in the water column at the expense of time grazing near the bottom. Spending more time swimming in the water column and less time grazing near the bottom might be the cause of reductions in individual growth rates of common carp at high densities. More research is needed to understand the underlying mechanisms of the observed changes.

Nutrients balance in multi-species pond

Earthen ponds receiving artificial feeds are the most widely used type of aquaculture production systems. The principal fate of artificial feed in ponds is supplying organic nutrients driving primary production and bacterial decomposition. Stable isotope studies have indicated that most fish production in ponds is based on natural food items, even in pellet fed ponds where 50-80% of fish and shrimp production is based on natural food (Schroeder, 1983; Anderson *et al.*, 1987). Therefore, pond aquaculture can benefit from improved strategies for natural food production and utilisation. This will also lead to less pollution from pond aquaculture. Even in ponds receiving protein-rich pellets, it was shown that only 11-35% of the supplied N and 13-36% of P was retained as fish biomass (Table 3.4). A large fraction of the unused N and P accumulated in the system affecting water quality in the overlaying water column. Most of these nutrients accumulated in the sediment where in absolute terms the quantities are 100-1000 times higher than in the water column (Biro, 1995). Re-suspension can transfer these nutrients back into the water column. However, re-suspension not only affects water quality

Table 3.4. Reported accumulation efficiency (%) of input nutrients by fish, phytoplankton, water and sediment.

	Accumulation (%)			
Types	N	P	System	References
Ictalurus punctatus	26.8	30.1	Earthen pond	Boyd, 1985
Oreochromis niloticus	18-21	16-18	Earthen pond	Green and Boyd, 1995
Hybrid tilapia	17.5	-	Earthen pond	Acosta-Nassar *et al.*, 1994
Sparus aurata	26	21	Marine pond	Neori and Krom, 1991
Sparus aurata	29	36	Marine pond	Krom *et al.*, 1985
Sparus aurata	21	26	Marine pond	Krom and Neori, 1989
Oncorhynchus mykiss	18.9	13.2	Circular tank	Foy and Rosell, 1991
Carp	11	32	Earthen pond	Avnimelech and Lacher, 1979
Penaeus monodon	24	13	Shrimp pond	Briggs and Funge-Smith, 1994
Penaeus monodon	22	-	Shrimp farm	Jackson *et al*, 2003
Phytoplankton	0.74	-	Earthen pond	Acosta-Nassar *et al.*, 1994
Particulate matter	46	50	Marine pond	Krom and Neori, 1989
Water	10.4	-	Earthen pond	Acosta-Nassar *et al.*, 1994
Water	14	21	Marine pond	Neori and Krom, 1991
Water	13	22	Marine pond	Neori and Krom, 1991
Detritus	10	17	Marine pond	Krom and Neori, 1989
Sediment	70	35-40	Earthen pond	Green and Boyd, 1995
Sediment	31	84	Shrimp pond	Briggs and Funge-Smith, 1994
Sediment	11	15	Marine pond	Neori and Krom, 1991
Sediment	14	-	Shrimp farm	Jackson *et al.*, 2003
Loss to atmosphere	0.92	-	Earthen pond	Acosta-Nassar *et al.*, 1994

but also the fraction of nutrient input accumulated in benthos, zooplankton, phytoplankton and culture animals. Rapid mineralisation and utilisation of nutrients not retained by culture organisms will improve water quality and natural food availability, improving the nutrient conversion ratios.

Nitrogen and phosphorus retention efficiency in fish biomass have been shown to almost double in polyculture with rohu and common carp, resulting in more nutrients passing through the pond food web and less nutrients accumulating in the sediments (Rahman *et al.*, personal communication). In polyculture, nitrogen and phosphorus accumulation in the sediment was reduced by 17-22% and 34-36%, respectively (Figure 3.3). It remains to be seen if a similar effect would be observed with species with more flexible feeding habits like tilapia compared to rohu. Also, it remains interesting for future research to compare the effects of man-made bottom disturbance through harrowing with the effects of fish driven re-suspension on nutrient use efficiency and production.

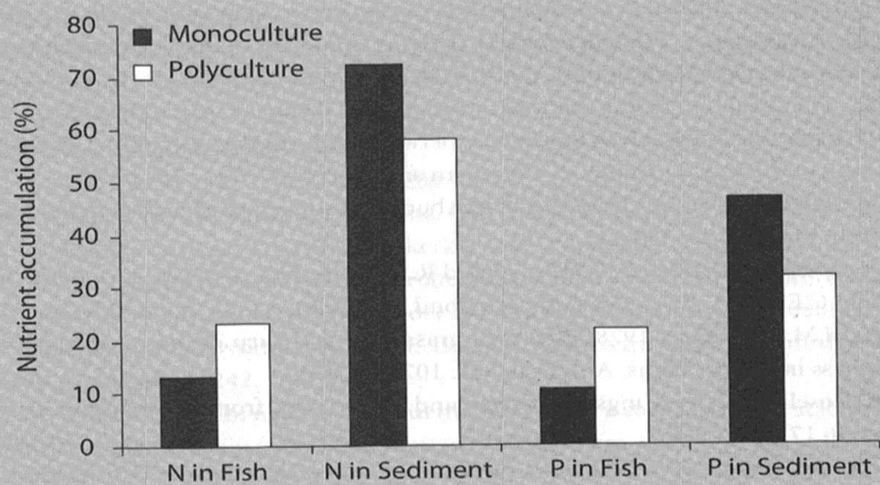

Figure 3.3. Comparison between mono (rohu) and polyculture (rohu plus common carp) on N and P accumulation (%) in fish and sediment. Higher total nutrients input and total fish densities were used in polyculture than monoculture. N and P values of polyculture are the mean of two polyculture system (rohu plus 0.5 and 1 common carp m^{-2}) (reproduced from Rahman et al., personal communication).

Conclusion

Inclusion of a benthivorous species at appropriate ratios and densities considerably contributes to increased production and greater nutrient efficiency in polyculture systems. As a result, also pollution from aquaculture per kg fish produced is reduced. These findings are particularly important in Asia, where investments in waste treatment are minimal or non-existent.

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