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Asian carp farming systems: towards a typology and increased resource use efficiency

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Abstract

Resource use efficiency in Asian carp farming systems is analysed based on a survey of 2493 farms of nine countries. Multivariate classification of farms by intensity and diversity identified six farm types: four types of specialized aquaculture farms at different levels of intensity, and two types of integrated agriculture–aquaculture systems. Pond-based, specialized semi-extensive systems (using mainly inorganic fertilizers and feeds of off-farm origin), and integrated semi-intensive systems (using feeds and fertilizer of both on and off-farm origin) are by far the most common types, accounting for 59% and 27% of all farms respectively. Specialized semi-extensive systems also show the highest protein and nutrient (N and P) use efficiencies, and among the highest labour use efficiency. Super-intensive cage farms are less efficient in nutrient and labour use, but provide very high returns to land and capital investment. On average, the aquaculture components of integrated agriculture–aquaculture systems are less nutrient, land, and labour efficient than specialized semi-extensive systems. Integrated semi-extensive systems (using organic fertilizers of on-farm origin) are particularly inefficient across all indicators. Hence in practice, gains in overall resource use efficiency through on-farm integration with agricultural production are constrained by the relative inefficiency of the aquaculture subsystems on integrated farms. Although such systems can likely be improved, integration as such is not a panacea to increasing resource use efficiency. Wide variation in resource use efficiency within all systems indicates potential for substantial efficiency gains through improved management regardless of the fundamental choice of system.

Keywords: carp, freshwater aquaculture, integrated systems, resource use efficiency, Asia

Introduction

Aquaculture is currently one of the fastest growing food production systems in the world with production increasing at an average rate of 8.8% per year during the past decade. In 1997, over 91% of the world's aquaculture output (36×10^6 t) was produced in Asia with China and India as the two leading producers (FAO 1999). Inland aquaculture accounts for about half of the total world aquaculture production and produces primarily finfishes (FAO 1999). The four most important cultivated fish species by weight are silver carp (*Hypophthalmichthys molitrix* Valenciennes), grass carp (*Ctenopharyngodon idellus* Steindachner), common carp (*Cyprinus carpio* L.) and bighead carp (*Aristichthys nobilis* Valenciennes) which make up half of the total finfish production, reflecting China's predominance in aquaculture (FAO 1997). Silver carp ($ 2.75 billion), grass carp ($ 2.74 billion) and common carp ($ 2.1 billion), respectively, were the fourth, fifth and sixth most valuable species in 1999 (FAO 2001).

Aquaculture depends on a wide range of environmental goods (feed inputs, land, water, etc.) and services (waste assimilation) (Beveridge, Phillips & Mackintosh 1997) and increased competition for resources of aquaculture with other production systems is a constraint to aquaculture expansion for meeting aquatic protein needs of human populations (Welcomme 1996). Carp farming is widely seen as one of the most ecologically efficient and environmentally sustainable forms of aquaculture, because it relies on low trophic level fish, and because polyculture of several species and integration of carp farming with agricultural systems provide opportunities for further efficiency gains (Naylor, Goldburg, Primavera, Kautsky, Beveridge, Clay, Folke, Lubchenco, Mooney & Troell 2000). However, Asian carp culture is a diverse industry operating at all levels of intensity, and the structure of the sector and the actual resource use efficiencies of the different production systems has been little studied (Little & Muir 1987; Edwards 1997). Imperfect technologies and the difficulties inherent in managing complex culture systems may lead to substantial differences between actual performance and theoretical potential in any type of aquaculture system. Hence generalizations about the resource use efficiency and environmental impacts based on conceptual models or on-station experiments may be misleading, and empirical analyses of operational farms are important to inform development strategies, research priorities and environmental policies.

The present study aims to evaluate the resource use efficiency of operational carp farming systems, with particular reference to the question of fertilization vs. feed-based systems, and the degree of on-farm integration into agricultural systems. The analysis is carried out in two steps. First, an objective empirical classification of Asian carp culture systems according to their level of intensity and diversity is developed; and second, the resource use efficiencies of the identified systems are compared.

Materials and methods

Data sources

The primary information upon which this study is based has been collected by the Network of Aquaculture Centres for Asia-Pacific (NACA) and was jointly funded by the Asian Development Bank (ADB) (ADB/NACA 1998). A total of 6323 carp farms in 14 different countries in Asia (Bangladesh, Cambodia, Hong Kong, Indonesia, India, Korea, Malaysia, Myanmar, Nepal, Philippines, Pakistan, China, Thailand and Vietnam) were surveyed (ADB/NACA 1998). The survey provided information on the farming site, the farming system (integrated, intensive, monoculture, polyculture, etc.), productivity and profitability, investments, environmental problems, production problems and social conflicts. Data were collected in 1994/1995 and stored in a database at NACA. The survey explicitly targeted farms where carps were the only or at least the main cultured species. Each country developed its own sampling design and not all countries selected farms at random. Local currencies used in the farm survey were converted into US dollars at 1994 exchange rates.

The present study uses data from Cambodia, Hong Kong, India, Korea, Malaysia, Myanmar, Nepal, Thailand and Vietnam. Farms with unused ponds were excluded as they resulted in missing values. The remaining farms were explored and outliers were removed. Finally, 2493 farms were left for analysis.

Classification

Data from the 2493 farms were used for factor and cluster analysis. The following 12 variables were used in the analysis: area of the aquaculture facility (pond, cage/pen or raceway), ratio of aquaculture facility area to total farm area, water added during the culture period, purchased inorganic fertilizer, total organic fertilizer, ratio of organic fertilizer collected on or off the farm to total organic fertilizer used, total feed added (purchased and collected on or off farm), ratio of feed collected on- or off-farm to total feed added, number of fish species cultivated, stocking density, total labour (family labour plus permanent or casual hired labour), and ratio of family labour to total labour used.

Factor analysis was used to create an entirely new and smaller set of composite variables to replace the original 12 variables (Bruman & Cramer 1997). All variables were normalized for the analysis. A correlation matrix provided an initial indication of the relationship among variables before computing the factors, which represented a linear combination of the variables. In order to increase the interpretability of the factors they were rotated using VARIMAX, an orthogonal rotation procedure (Hair, Anderson, Tatham & Black 1995). The factor scores were computed in order to replace the original 12 variables with the orthogonal linear combinations (Afifi & Clark 1990).

Fish farms were clustered according to the new factors. First, a hierarchical cluster technique (Ward's method) was used to estimate the number of clusters. A non-hierarchical, K-means clustering procedure was then used to obtain the cluster centres (Hair *et al.* 1995). For each variable individually, the K-means procedure also computed a one-way analysis of variance. The *F* statistic in this one-way ANOVA was useful for identifying variables that drove the clustering (SPSS 1997). The hypothesis that the initial variables differ significantly between the different clusters was tested using contingency tables and chi-squared statistics. This allowed the characterization of six main types of carp farming systems.

Resource use efficiency

After system classification, the efficiency of use of key resources [feeds and/or fertilizers, protein and nutrients (N, P), land, labour and capital] of the different systems was examined. In order to account for the use of on-farm resources in integrated systems, overall feed and fertilizer use efficiencies were calculated including and excluding inputs collected on farm. Protein and nutrient use efficiencies were calculated for all farms, based on survey data for inputs and outputs. The categories of inputs and outputs distinguished in the survey are given in Table 1, together with the values of nutrient (N, P) and protein content used in the analysis (based on Shigang 1989; Somsueb 1993; Gavine & Phillips 1994; USDA 1999; Zaher & Mazid 1995).

Capital use efficiencies were examined using the net capital ratio, the ratio of gross returns to capital costs (Kay 1981). Capital costs included land, depreciation of durable equipment, and working capital such as feeds, fertilizers, seeds, chemicals, water, vehicle operations, power, maintenance, materials, farm or pond rent, general overhead costs, taxes, insurance and interests. All comparisons of resource use efficiencies are based on median efficiencies and 25–75 percentiles.

Results

Classification

Factor analysis identified five orthogonal linear combinations of the 12 original, partially correlated variables. The rotated factor matrix is shown in Table 2. Factor 1 has three significant loadings with positive signs: total feed, total labour and stocking density. The first factor therefore indicates the overall intensity of the aquaculture practice. Factor 2 is composed of two groups of variables. The first group with a positive sign consists of the ratio of family labour to total labour, and the ratio of the amount of feed collected (as opposed to purchased) to the total amount of feed added. The second group with negative signs consists of the ratio of aquaculture facility area to total farm area, and the total pond area. Factor 2 therefore indicates the diversity of the overall farm, with the extremes of an integrated, family based agriculture–aquaculture system at one side, and a larger-scale specialized aquaculture system on the other. Factor 3 is characterized by the ratio of organic fertilizer collected to total organic fertilizer used, and the total amount of organic fertilizer. Both have a positive sign, and factor 3 therefore is an indicator of organic fertilizer use. Factor 4 is characterized by the amount of water added to the system, and the number of species grown. These factors are

Table 1 Values for nitrogen, phosphorus and protein content of fertilizer and feed inputs, and fish output used in the calculation of farm nutrient budgets. Based on Shigang (1989), Somsueb (1993), Gavine & Phillips (1994), USDA (1999) and Zaher & Mazid (1995)

	Nitrogen content (g N kg^{-1})	Phosphorus content (g P kg^{-1})	Protein content (g kg^{-1})
Feed inputs			
Mulberry/silkworm	60	3	375
Tree crops	38	1.7	238
Rice bran	21	20.8	131
Bamboo	3	0.4	19
Sugar cane	3.5	0.4	22
Vegetables	44	3	275
Upland crops	4.5	–	28
Dry feed	80	15	500
Dry feed ingredients	21	20.8	131
Green feed	40	3	250
Fertilizer inputs			
Cattle manure	2	0.4	0
Pig manure	2	2	0
Chicken manure	5	5	0
Duck manure	4	3	0
Manure	3	1.5	0
NPK	85	11.4	0
Output			
Fish	25.6	3.4	160

Table 2 Rotated factor matrix

Variables		Factors					
		Intensity	Farm diversity	Organic fertilizer	Aquasystem diversity	Inorganic fertilizer	Communality
Area of aq. facility	X_1	−0.05	*−0.51*	−0.14	−0.01	0.08	0.29
Aq. facilility/total area	X_2	−0.17	*−0.55*	−0.42	0.05	−0.12	0.52
Water added	X_3	−0.08	0.17	−0.06	*0.88*	0.12	0.82
Bought inorg. fertil.	X_4	−0.03	−0.12	0.06	0.02	*0.90*	0.83
Total org. fertilizer	X_5	−0.09	0.00	*0.73*	−0.06	0.33	0.65
Manure/tot.org.fertil.	X_6	−0.00	0.20	*0.82*	0.00	−0.22	0.75
Total feeds	X_7	*0.90*	0.13	−0.07	−0.05	0.06	0.84
Collected/total feeds	X_8	−0.08	*0.68*	−0.27	−0.05	−0.05	0.54
Number of species	X_9	−0.37	0.26	0.01	*−0.55*	0.29	0.59
Stocking rate	X_{10}	*0.68*	−0.03	0.06	0.17	−0.17	0.52
Total labour	X_{11}	*0.88*	0.16	−0.02	−0.05	0.05	0.82
Family/total labour	X_{12}	0.15	*0.70*	0.17	0.13	−0.03	0.56
Eigenvalues		2.47	1.88	1.28	1.09	1.00	7.72
% of common variance		20.6	15.7	10.7	9.1	8.3	64.3

negatively correlated, i.e. less water is added in diverse polyculture systems than in monocultures. Factor 4 can be described as an indicator of aquasystem diversity. Factor 5 is characterized by a single variable, the amount of purchased inorganic fertilizer. The five factors therefore give an indication of the intensity, farm diversity, organic fertilizers, aquasystem diversity and inorganic fertilizers.

Cluster analysis based on the five factors was used to identify principal farm types. Hierarchical cluster analysis indicated the presence of six clusters. Nonhierarchical cluster analysis was used to obtain the six cluster centres (Table 3). Clustering was influenced mainly by 'Intensity', and to a lesser extent 'Organic fertilizers', 'Farm diversity' and 'Inorganic fertilizers'. 'Aquasystem diversity' did not have a strong influence on the clustering.

The classification of carp farms thus resulted in six distinctively different types. These types are characterized in terms of the 12 original variables in Table 4. All 12 variables had a significant role in structuring the data. In a few cases where variables did not provide distinctive characteristics for a particular farm type, the range of the variable is given in brackets. The six identified types can be characterized as: super intensive, intensive, specialized semi-intensive, specialized semi-extensive, integrated semi-intensive and integrated semi-extensive systems. The distribution of cluster members by country is shown in Table 5.

Cluster 1: super-intensive systems

Super-intensive systems are exclusively pen/cage based and located mainly in Vietnam. One carp species (grass carp) is cultivated at a very high stocking density ($>100\,000$ fish ha^{-1}), using a large amount of mainly purchased grass feeds ($>50\,000$ kg ha^{-1} year^{-1}). A labour intensive (>2500 days ha^{-1} year^{-1}), family based system with a very high median production of 442 t ha^{-1} year^{-1} (Fig 1a).

Cluster 2: intensive systems

Intensive systems are based in pens/cages, raceways and ponds, and located in Thailand, Korea and Vietnam. The aquaculture enterprise takes up most of the farm area. One carp species is cultivated at high density and production is based primarily on purchased feeds. The system is labour intensive and may rely on either family or paid labour. A yearly production of 6.6 t ha^{-1} year^{-1} is obtained.

Cluster 3: specialized semi-intensive systems

Specialized semi-intensive systems are exclusively pond-based systems, located mostly in India. Polyculture of 3–10 carp species at low stocking densities, based on high inputs of purchased, inorganic and organic fertilizers and feeds. The system is labour extensive and relies mainly on paid labour. Production reaches 4.1 t ha^{-1} year^{-1}.

Table 3 Summary of cluster descriptions (cluster centres) for the proposed typology

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Intensity	*5.94*	*1.65*	−0.05	−0.12	−0.29	−0.12
Farm diversity	0.90	−0.78	−0.26	*−0.60*	*1.09*	0.65
Organic fertilizers	−0.46	0.65	0.33	−0.20	−0.41	*2.76*
Aquasystem diversity	−0.26	*1.33*	0.07	−0.02	−0.30	*−0.11*
Inorganic fertilizers	0.29	*−1.43*	*3.22*	−0.13	−0.01	−0.56
Number of cases	38	58	91	1444	674	188
Percentage of farms (%)	1	2	4	59	27	7

Table 4 Characteristics of the inland aquaculture systems identified by cluster analysis

Characteristics	Cluster 1 Super intensive	Cluster 2 Intensive	Cluster 3 Spec. semi-int.	Cluster 4 Spec. semi-ex.	Cluster 5 Integr. semi-int.	Cluster 6 Integr. semi-ex.	χ^2 (*P*-value)
Aquaculture facility area (ha)	< 0.1	< 2	0.1–5	0.1-.5	0.1–2	< 0.5	1146
Number of farms	38	42	71	1164	545	163	(< 0.01)
% of cluster members	100	72.4	78.2	80.6	80.9	86.7	
Aq. facility/total farm area (%)	0–25	75–100	(0–100)	75–100	(0–100)	0–25	990
Number of farms	30	44	91	1222	674	139	(< 0.01)
% of cluster members	78.9	75.9	100	84.6	100	73.9	
Water added (cm month^{-1})	0	(0−> 10)	> 10	0	0	0	167
Number of farms	38	58	37	1343	552	180	(< 0.01)
% of cluster members	100	100	40.7	93	81.9	95.7	
Bought inorg.fert. (kg ha^{-1} year^{-1})	0	0	> 250	(0−> 250)	0	0	377
Number of farms	38	56	91	1444	409	115	(< 0.01)
% of cluster members	100	96.6	100	100	60.7	61.2	
Tot.org.fert. (10^3 kg ha^{-1} year^{-1})	0–1	0–1	> 10	0–5	0–5	> 5	648
Number of farms	37	48	59	1023	516	143	(< 0.01)
% of cluster members	97.4	82.8	64.8	70.9	76.6	76.1	
Farm manure/tot.org.fert. (%)	0	0	0	0	0	75–100	1884
Number of farms	37	45	88	1441	668	165	(< 0.01)
% of cluster members	97.4	77.6	96.7	99.8	99.1	87.8	
Total feeds (10^3 kg ha^{-1} year^{-1})	> 50	(0−> 50)	1–50	0–5	0–15	0–5	1120
Number of farms	37	58	76	1114	550	138	(< 0.01)
% of cluster members	97.4	100	83.6	77.2	81.6	73.4	
Collected feed/total feed (%)	0–30	0	0	0	(0–100)	0	1006
Number of farms	34	57	69	1432	674	151	(< 0.01)
% of cluster members	89.5	98.3	75.8	99.2	100	80.3	
Number of species	1	1	3–10	1–5	4–10	3–10	938
Number of farms	33	56	71	1211	523	169	(< 0.01)
% of cluster members	86.8	96.6	78.1	83.9	77.5	89.9	
Stocking rate (10^4 fishes ha^{-1})	> 10	> 10	0–2	0–2	0–2	0–3	1628
Number of farms	37	52	81	1149	563	150	(< 0.01)
% of cluster members	97.4	89.7	89	79.5	83.6	79.8	
Tot.labour (10^2 days ha^{-1} year^{-1})	> 25	> 5	0–5	0–5	1–25	> 5	721
Number of farms	38	38	78	1070	461	140	(< 0.01)
% of cluster members	100	65.5	85.7	74.1	68.4	74.4	
Fam.labour/total labour (%)	75–100	(0–100)	0–25	0–25	75–100	75–100	928
Number of farms	36	58	60	1105	472	147	(< 0.01)
% of cluster members	94.7	100	65.9	76.5	70.0	78.2	

Each cell provides the characteristic range of the variable, and the number and proportion of cluster members falling within this characteristic range.

Table 5 Distribution of the identified carp farming systems by country

Country	Super intensive	Intensive	Specialized semi-int.	Specialized semi-ex.	Integrated semi-int.	Integrated semi-ex.
Cambodia				1	6	123
Hong Kong				8	35	6
India			77	704	171	9
Korea	2	17		14		3
Malaysia				10	136	1
Myanmar				436	6	1
Nepal	1	1	9	168	217	27
Thailand		31	5	59	39	15
Vietnam	35	9		44	64	3
Total	38	58	91	1444	674	188

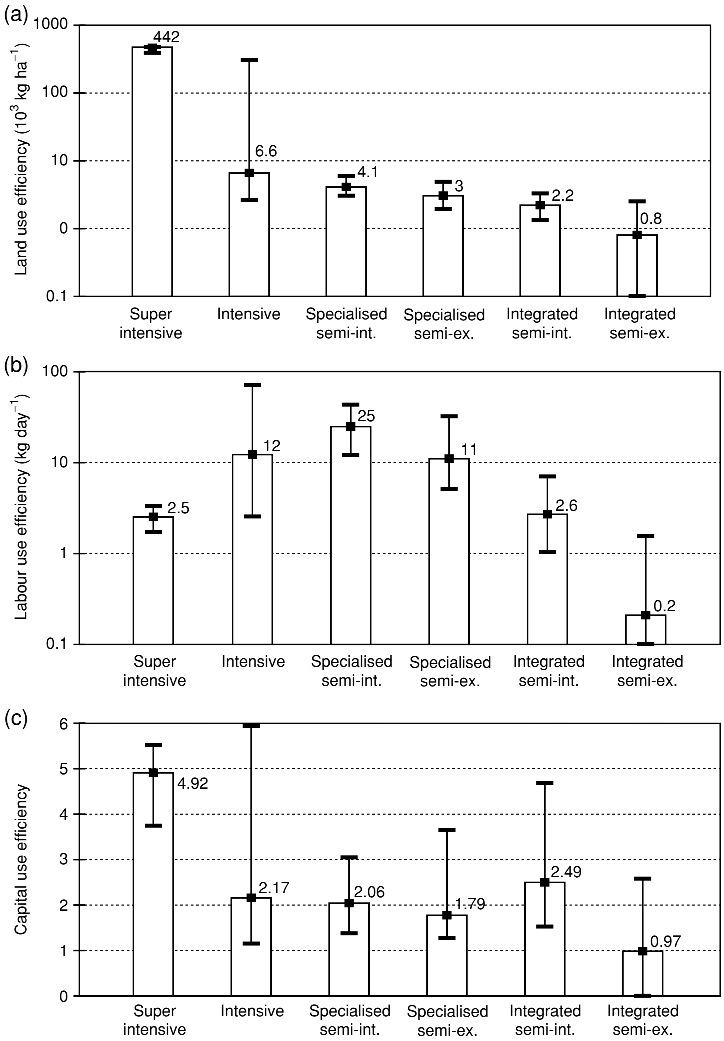

Figure 1 Land (a), labour (b) and capital (c) use efficiencies of different carp farming systems (medians and 25–75 percentiles). Capital use efficiency is given by the net capital ratio, the ratio of gross returns to capital costs.

Cluster 4: specialized semi-extensive systems

Specialized semi-extensive systems are mostly pond-based systems (with a small proportion, 3%, of pens/cages) located in India, Myanmar and Nepal. Most of the farm area is taken up by the aquaculture facility. Limited amounts of inorganic fertilizers and feeds are added, none of on-farm origin. Polyculture of 1–5 carp species, at low stocking densities. Low inputs of mostly paid labour. Production levels reach almost 3 t ha^{-1} year^{-1}.

Cluster 5: integrated semi-intensive systems

Integrated semi-intensive systems are almost exclusively pond-based systems, located mainly in Nepal, India and Malaysia but represented in all countries except Korea. The aquaculture facility takes up about half of the farm area. The feeds and fertilizer used are partly of on-farm origin. Polyculture of 4–10 carp species at low stocking density. Labour intensive, and based mainly on family labour. Median production 2.2 t ha^{-1} year^{-1}.

Cluster 6: integrated semi-extensive systems

Integrated semi-extensive systems are almost exclusively pond-based systems, located mostly in Cambodia but represented in all countries. The ponds take up less than one-fourth of the farm. Inputs of organic fertilizer (> 5 t ha^{-1} year^{-1}) mostly collected on the farm are supplemented by small inputs of purchased feeds. Polyculture of 3–10 carp species at a low stocking rate. Highly labour intensive and based mostly on family labour. Low production of less than 0.8 t ha^{-1} year^{-1}.

By far the largest proportion of the farms surveyed is of the specialized semi-extensive type (59%), followed by integrated semi-intensive (27%) (Table 3). The remaining four types account for only a small proportion of surveyed farms, but are represented in sufficient numbers to allow comparison of resources use efficiencies.

Resource use efficiency

Feed and fertilizer use

Feed and fertilizer use efficiencies are shown in Fig. 2, both for total feed and fertilizer and for purchased inputs. Feed and fertilizer efficiencies vary widely within most farm types. All specialized farm types rely predominantly on purchased inputs of feed (super-intensive and intensive systems), or fertilizer and feed (semi-intensive and semi-extensive systems). Specialized semi-extensive systems are overall the most feed and fertilizer efficient. Super-intensive systems are very feed inefficient compared with the other systems, a reflection on the fact that inputs consist primarily of grass. Only integrated semi-extensive systems use substantial amounts of collected (mostly on-farm) feed and fertilizer, but make very inefficient use of collected fertilizer.

Protein, nitrogen and phosphorus

Protein, nitrogen and phosphorus efficiencies are shown in Fig. 3. With the exception of specialized

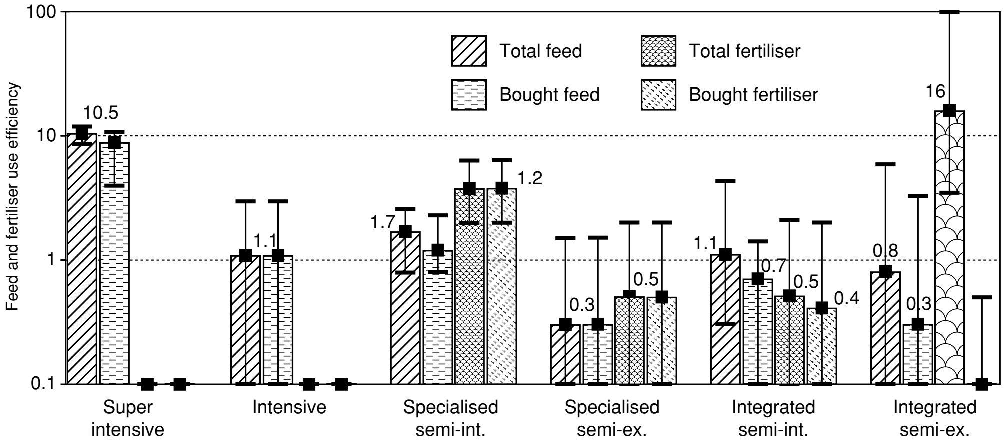

Figure 2 Feed and fertilizer use efficiency (weight of input over weight of fish) of different carp farming systems (medians and 25–75 percentiles).

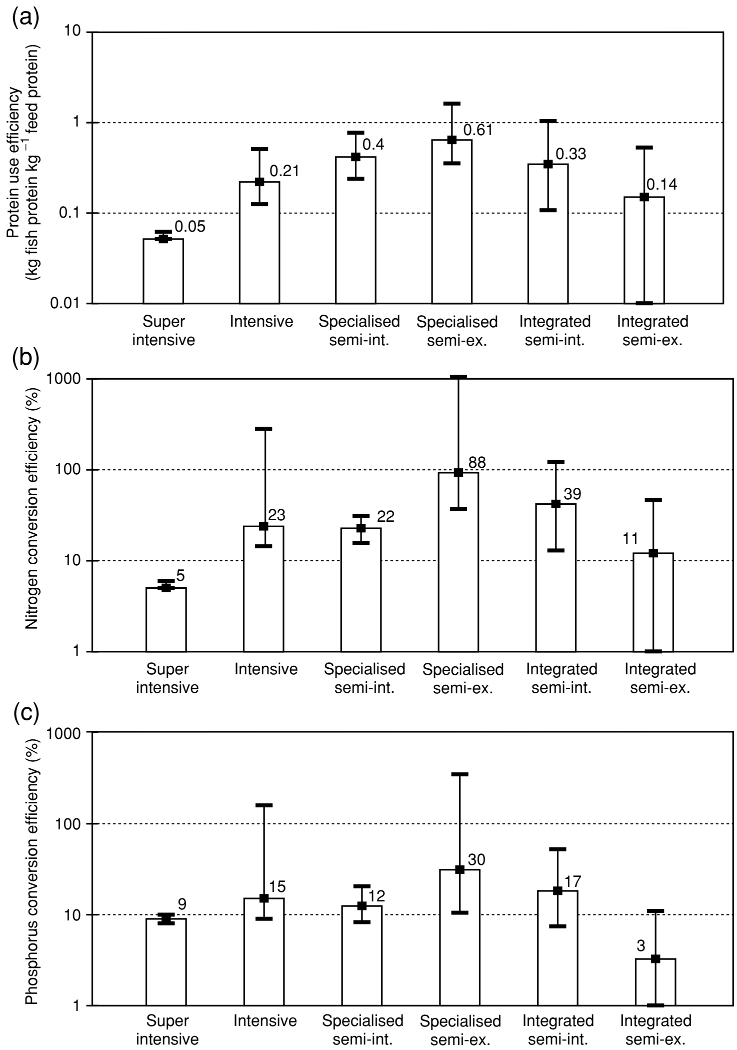

Figure 3 Protein (a), nitrogen (b) and phosphorus (c) use efficiency in different carp farming systems (medians and 25–75 percentiles). Protein efficiency (a) is given as weight of protein in produce over weight of protein in inputs, while N and P efficiencies are given as proportion of input incorporated into the produce.

semi-extensive systems, all aquaculture systems require inputs of feed protein in excess of outputs (Fig. 3a). Specialized semi-extensive systems are the most protein efficient, while super-intensive systems are the most inefficient by a wide margin. The percentile ranges of the remaining systems overlap widely.

Nitrogen and phosphorus efficiencies (Fig. 3b and c) show similar patterns, with specialized semi-extensive systems being the most efficient, followed by integrated semi-intensive systems. Super-intensive and integrated semi-extensive systems are the least efficient.

Land, labour and capital

Land, labour and capital efficiencies are shown in Fig. 1. Land use efficiency increases continuously with intensity, although only super-intensive systems are very substantially different from the others (Fig. 1a). Labour efficiency is highest, and approximately equal in intensive, and specialized semi-intensive and semi-extensive systems (Fig. 1b). Labour efficiency is substantially lower (by an order of magnitude on average) in super-intensive and integrated semi-intensive systems, and by far lowest in integrated semi-extensive systems. Capital use

Table 6 Comparison of median nitrogen (N) and phosphorus (P) use efficiencies determined for Asian carp farms with values reported for other systems

System	N efficiency (%)	P efficiency (%)	Source
Super-Intensive	5	9	This study
Intensive	23	15	This study
Specialized semi-intensive	22	12	This study
Specialized semi-extensive	88	30	This study
Integrated semi-intensive	39	17	This study
Integrated semi-extensive	11	3	This study
Experimental integrated	6–25	5–11	Edwards (1993)
Channel catfish	25	30	Boyd (1985)
Intensive shrimp	21	6	Briggs & Funge-Smith (1994)
Intensive salmon	20–45	15–28	IoA (1990); Storebakken, Shearer & Roem (2000)

efficiencies are similar at around two for all systems, except for super-intensive systems with a very high (about five), and integrated semi-extensive systems with a very low (about one) net capital ratio. The exceptionally high net capital ratio of super-intensive systems stems from a number of factors, including high value of the product, use of family labour (which is not costed in the net capital ratio), and the fact that costs associated with the maintenance of water quality are fully externalized.

Discussion

Multivariate classification of farms by intensity and diversity identified six farm types: four types of specialized aquaculture farms at different levels of intensity, and two types of integrated agriculture–aquaculture systems. Previous classifications are mostly conceptual rather than empirical, and tend to be uni-dimensional. For example, Coche (1982) and Muir (1995) classify systems by farming intensity alone, while FAO (1997) contrast profit-oriented, specialized systems using wage labour to subsistence-oriented, integrated systems using family labour, thereby linking attributes in a way that effectively creates a uni-dimensional continuum. Whereas elements of these conceptual typologies are borne out in the multivariate empirical analysis, they are inadequate to capture the true complexity of the carp farming sector. For example, while overall intensity is identified as an important structuring variable, the dichotomy of specialized vs. integrated systems has major implications for resource use efficiency. Likewise, while specialized semi-intensive and semi-extensive systems do indeed make far greater use of wage labour than integrated systems, the proportion of wage labour in intensive systems is highly variable and super-intensive systems rely almost entirely on family labour. Hence the development of empirically based, multidimensional farm typologies is an important step towards defining and targeting sectoral policies.

In the typology developed here, the term 'intensity' refers to the overall amount of feed, labour and fish seed inputs used in the production process (Table 2). In the typologies of Coche (1982) and Muir (1995), intensity classes are defined partly in relation to total inputs and outputs, but also imply particular qualities of feed inputs, e.g. use of formulated feeds in intensive systems. The present analysis shows that within Asian carp farming systems, the link between overall input and output levels and feed quality is not straightforward. This is best exemplified by the super-intensive systems, which combine the highest input and output levels of all farm types with the use of a low quality feed, grass. While it may be argued on the basis of feed quality that these systems should not classed as 'intensive', labelling them as less intensive than systems operating at much lower input and output levels would be inconsistent with the essentially quantitative meaning of 'intensity' (the measurable amount of some quality; Oxford English Dictionary).

Pond-based, specialized semi-extensive systems (using mainly inorganic fertilizers and feeds of off-farm origin), and integrated semi-intensive systems (using feeds and fertilizer of both on and off-farm origin) are by far the most common types, accounting for 59% and 27% of all farms respectively. These two types also show the highest protein and nutrient (N and P) use efficiencies, and performed well in terms of land, labour and capital use. It is interesting to note that the most common type of carp farming system (specialized semi-extensive) is also overall the most resource use efficient. The super-intensive cage farms are inefficient in nutrient and labour use (a result of using large quantities of a low-quality input), but provide very high returns to land (cage area) and capital investment. Clearly, there are tradeoffs between the use efficiencies of different resources, and local demand for these resources has implications for the relative merits of alternative systems.

With the exception of super-intensive and integrated semi-extensive systems, the nitrogen and phosphorus use efficiencies of Asian carp farms are similar to or better than those achieved in other well-developed intensive culture systems in which other species are raised (Table 6). The very high efficiencies of specialized semi-extensive systems are notable. It is likely that these values reflect natural inputs of N and P (through water inflow and runoff) that are efficiently complemented by relatively low intentional inputs.

The logic of integration as a means of increasing resource use efficiency in agriculture–aquaculture systems is pervasive and a great deal of research and extension effort has been devoted to these systems (Little & Muir 1987; Lightfoot, Bimbao, Dalsgaard & Pullin 1995). However, the empirical analysis of operational farms shows that on average, the aquaculture components of integrated agriculture–aquaculture systems are less nutrient, land and labour efficient than specialized semi-extensive systems. Integrated semi-extensive systems (using organic fertilizers) are particularly inefficient across all indicators. Integrated systems even rely on higher levels of purchased inputs per unit of output than specialized semi-extensive intensive systems, despite the fact that these are supplemented by inputs of on-farm origin. This suggests that integrated systems may be poorly managed overall, a fact that may be related more to the complexity of managing diverse farming activities than to integration as such. Clearly, it should be technically possible for integrated systems to at least match the efficiency of specialized semi-extensive systems, but management constraints may be difficult to overcome in practice. Hence despite of its technical potential, integration should not be seen as a panacea to increasing resource use efficiency.

The high degree of variation in resource use efficiency within categories suggests that in most systems, there is considerable potential to improve resource use efficiency through better management of inputs.

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