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Chinese integrated fish farming: a comparative bioeconomic analysis

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Abstract

This paper provides an overview of the structure and performance of Chinese integrated pond fish farming systems, based on analysis of survey data for 1013 ponds on 101 farms in eight Chinese provinces. A province-by-province examination of gross and net fish yields supports the traditional Chinese classification of provinces into high, medium and low productivity classes according to fish farm output; average net fish yields for surveyed ponds in each class were 7958, 4981 and 3321 kg ha^{-1} $year^{-1}$ respectively. The paper includes summaries and analyses of data on fish stocking and harvesting, use of feeds and fertilizers, fish–animal integration, capital inputs, and the overall cost and revenue structure in each productivity class. In addition to variations in aggregate input and output levels, a key difference between productivity classes is seen to lie in the stocking model utilized; filter-feeding fish dominate in poorer areas, while 'feeding fish' (grass carp, *Ctenopharyngodon idella* (Valenciennes), black carp, *Mylopharyngodon piceus* (Richardson), and omnivorous carps) dominate in high-productivity provinces. These results are examined in light of regional differences in culturing tradition, socio-economics, infrastructure, climate and geographical factors.

Introduction

Integrated pond fish farming in China, which dates back over 2400 years (Hu & Zhou 1989), involves a complex system of fish polyculture, production of poultry, livestock and crops, and the 'integrated' use of manure, grass and other crops as feeds and fertilizers (NACA 1989). The scientific foundations and regional diversity of these systems have yet to be fully understood.

This paper presents a comprehensive view of integrated fish farming in China, through the analysis of an extensive bioeconomic survey carried out in eight Chinese provinces (Fig. 1). Together these represent a major part of the diversity in Chinese integrated fish farming practice, in particular incorporating several of the provinces in the highly important Yangtze River basin. The paper analyses the various inputs and outputs in the Chinese integrated fish farming process and explores differences in farm performance between regions and between fish farming 'models' in China.

While integrated fish farming is practised across much of China, there is considerable variation in its development between regions of the country, due to historical, climatic, geographical and socio-economic differences. For example, in Jiangsu and Zhejiang provinces, pond fish culture dates back to its original formulation by Fan Li in the 5th Century BC (Hu & Zhou 1989). With the people in these areas having accumulated a rich body of experience and strong culturing skills, fish culture has come to dominate the utilization of available water resources. On the other hand in many other areas, particularly in northern China, pond fish culture is relatively new, with a considerable proportion of existing ponds having been constructed since 1978.

With respect to climate and geography, variations occur particularly from north to south, and from coastal to inland areas. For example, in the southerly

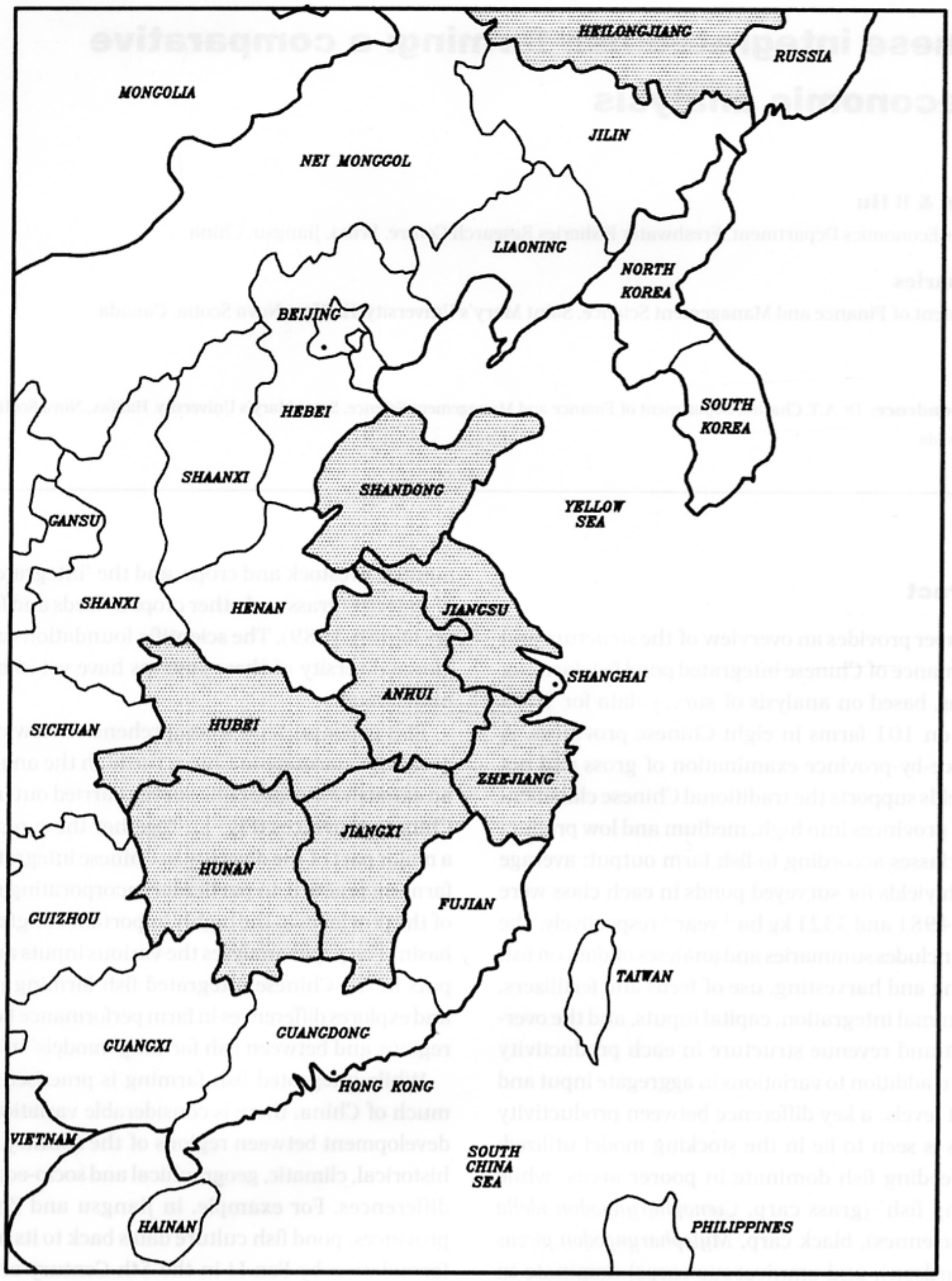

Figure 1 Map of eastern China, highlighting the eight provinces in which the fish farm survey was carried out.

Yangtze River and Pearl River basins, climatic conditions (temperature and rainfall) are conducive to high fish growth rates, in contrast to relatively cold and dry northern areas such as Heilongjiang province, where the frost-free season lasts for less than half of the year. From a topographical perspective, the much higher availability of water resources in coastal and lower reaches of major river systems contributes to a higher density of fish ponds in those regions.

The nature of fish farming also depends on socioeconomic factors, notably the farmer's access to capital and variable inputs, and the level of technological knowledge and management skill. In turn, these depend on overall local development and the provision

Table 1 Provinces, ponds and productivity classes

Productivity class	Province	No. of ponds surveyed	% of ponds	Avg. gross fish yield (kg ha^{-1} year^{-1})	Avg. net fish yield (kg ha^{-1} year^{-1})
Low	Anhui	22	2.2	3 621	3 033
	Heilongjiang	41	4.0	3 116	2 652
	Jiangxi	78	7.7	4 089	3 627
	Shandong	87	8.6	3 816	3 434
	Overall	228	22.5	3 765	3 321
Medium	Hunan	210	20.7	5 672	4 981
	Overall	210	20.7	3 765	4 981
High	Jiangsu	238	23.5	10 608	8 796
	Zhejiang	247	24.4	8 313	7 150
	Overall	485	47.9	9 439	7 958
Subtotal		923	91.1	7 180	6 135
	Hubei (2 farms)	90	8.9	9 764	7 860
Total		1 013	1 00.0		

of infrastructure, which vary greatly across China's provinces. For example, the relatively advanced regional infrastructure and higher income levels available in Jiangsu and Zhejiang provinces have produced numerous aquaculture research institutes, a relatively high level of education, and access by farmers to the inputs required for intensive pond culture. In contrast, integrated fish farming in Jiangxi province is affected by poorer infrastructure in the province, a lack of modern fish farming techniques and a lower overall education level.

Finally, there is considerable diversity across China in consumer demand for the various species of carp and other fishes, depending on inherent preferences and on income levels (purchasing power). The relatively high average incomes per capita found in provinces such as Jiangsu and Zhejiang produce correspondingly large market demands, which in turn promote more intensive pond culture as well as rotary stocking and harvesting, to meet the high demand. On the other hand, relatively low-income provinces have lower market-based demand, which acts as a constraint on production and leads to very different stocking structures.

Research on integrated fish farming has focused on four principal themes: (a) 'biological processes', such as the effect of feeding and manuring rates on fish growth (e.g. Zhu, Yang, Wan, Hua & Mathias 1990), (b) 'ecological systems', including examination of energy flows and multispecies stocking ratios (e.g. Engle 1987; Li 1987; Yan & Yao 1989), (c) 'farming systems' approaches, such as the development of participatory extension methods (e.g. Lightfoot 1990) and (d) studies of production economics, socio-economics and financial elements of farm operation. This paper emphasizes the latter category of research, which has received relatively little attention in the literature to date (IDRC 1982; Shang & Costa–Pierce 1983; Hu & Yang 1984; Pinnoi 1986; Hatch & Engle 1987; Ruddle & Zhong 1988; Vasanthakumar & Selvaraj 1988).

The following section describes aspects of the survey methodology and the analytic methods. Survey data are then utilized in subsequent sections to examine key fish farming inputs (fish stocking, feeds, fertilizers, capital and fish–animal integration), the yield and profit structure, and the primary determinants of profitability and productivity in integrated fish farming.

Methodology

This paper presents the results of a cross-sectional bioeconomic survey of 1013 fish ponds on 101 fish farms, chosen from those in eight Chinese provinces (Fig. 1, Table 1). The survey, based on data for the 12-month period from February 1985 to February 1986, was conducted by staff of the Fisheries Economics Department at China's Freshwater Fisheries Research

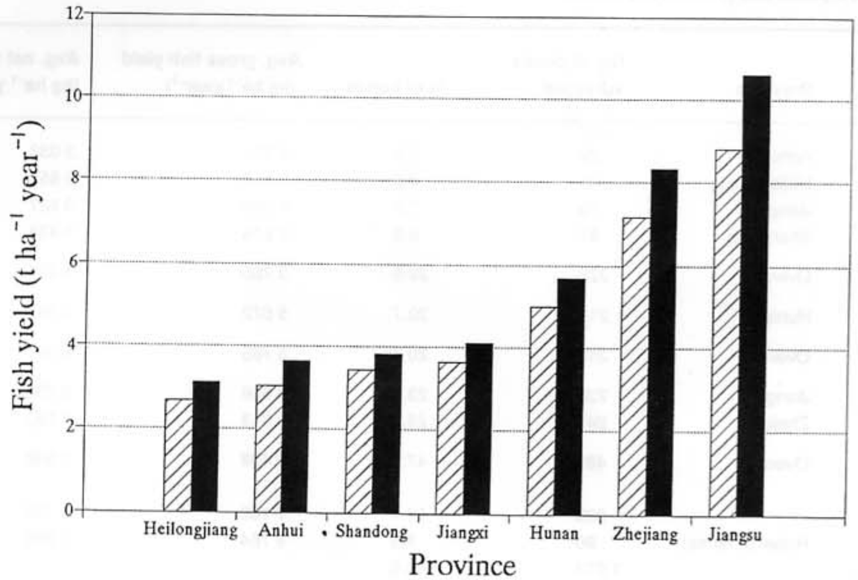

Figure 2 Gross and net fish yields (black and hatched columns, respectively) for each of the seven Chinese provinces for which suitable data were obtained. Yields (in tonnes) are aggregated over all species involved, and net yield equals gross yield minus stocking weight.

Table 2 Stocking densities, costs and composition

		Stocking weight (kg ha^{-1} year^{-1})				Stocking cost (Yuan ha^{-1} year^{-1})[a]			
Species group	Stocking size (g)	Low[b]	Medium	High	Overall	Low	Medium	High	Overall
Grass carp	100–615	133	208	547	368	545	737	2007	1357
Filter feeders	23–100	233	349	390	342	690	727	807	760
Black carp	125–625	0.4	7	168	90	2	27	736	393
Omnivores	4–38	78	127	376	246	360	412	1218	822
Total		444	691	1481	1046	1597	1903	4768	3332
		Composition by weight (%)				**Composition by cost (%)**			
		Low	Medium	High	Overall	Low	Medium	High	Overall
Grass carp		30	30	37	35	34	39	42	41
Filter feeders		52	51	26	33	43	38	17	23
Black carp		0	1	11	9	0	1	15	12
Omnivores		18	18	25	24	23	22	26	25
Total		100	100	100	100	100	100	100	100

[a] Approximate conversion, 3.75 Yuan = 1 US$ (1985 values).
[b] In Tables 2–5, headings low, medium, high and overall refer to productivity classes as depicted in Table 1.

Centre in Wuxi. A one-page questionnaire was administered, with data recorded on actual inputs, outputs (yields) and overall economic performance of each pond.

In the original survey design, an effort was made to select proportionately more fish ponds in those provinces (and those counties within any given province) where total fish production was greatest. However, it should be noted that the survey does not constitute a random sample of fish farms in the eight provinces of China, since (a) no definitive figures are available on the total number of integrated fish farms in each province, (b) criteria for selection of farms varied from province to province (with selection carried out jointly by the survey team in conjunction with local fishery experts), and (c) typically, the survey involved more than one, but not all, the fish ponds on any given fish farm.

Nevertheless, available information suggests that a reasonably representative sample was obtained in all but one of the provinces surveyed. The exception is Hubei province, where the survey was restricted to a set of 90 ponds located on two modern government-owned 'model' farms, known to have among the highest productivity levels in the province (having benefited from outside aid in their development). Since these ponds are clearly not representative of those in Hubei as a whole, they have been omitted from most of the analysis, to enable more accurate province-by-province comparisons. However, a specific discussion is included on their significance as high-yielding ponds in a lower-productivity environment.

In light of the above, the analysis in this paper focuses on the 923 ponds surveyed in the remaining seven provinces. These provinces were allocated into high, medium and low productivity classes, according to their average provincial gross and net fish yields per unit area, as derived from the survey data (Fig. 2, Table 1). In addition to reflecting clear differences in the data, use of these classes also permits (a) a better understanding of the variability in aggregate of stocking levels and fish yields among the ponds surveyed (Fig. 3) and (b) the examination of climatic, geographical and socio-economic effects on integrated fish farming, as discussed earlier.

A wide variety of fish species, feeds and fertilizers is utilized in Chinese integrated fish farming. To facilitate data analysis and interpretation of the results, this diversity of inputs has been suitably categorized. With respect to the fish stocks, the relevant species have been aggregated into four categories.

1 Herbivores: grass carp, *Ctenopharyngodon idella* (Valenciennes)
2 Filtering: silver carp, *Hypophthalmichthys molitrix* (Valenciennes)
bighead carp, *H. nobilis* (Richardson)
3 Carnivores: black carp, *Mylopharyngodon piceus* (Richardson)
4 Omnivores: common carp, *Cyprinus carpio* (L.)
crucian carp, *Carassius auratus* (L.)
Chinese bream, *Megalobrama amblycephala* (Yih)
tilapia, *Oreochromis niloticus, O. mossambicus* (and any other species not included in other categories)

While certainly a simplification of real-world complexity, this aggregation reflects commonly utilized species groupings and the ecological relationships between them. In particular, the above categories highlight the predominance of carp species in Chinese integrated fish farming, and contrast the filter-feeding silver and bighead carp with the other carp species (referred to as 'feeding fish' to indicate their capability to consume external feeds added by farmers to the ponds).

The other key inputs to the integrated fish farming system, feeds and fertilizers, have also been placed in appropriate categories, as follows: Feeds: (1) grasses and green fodder, (2) grains and cakes ('high-quality feed'), (3) husks and brans ('low-quality feed'), (4) snails and other feeds for carnivores, (5) artificial pellets. Fertilizers: (1) livestock (pig and cattle) manure, (2) poultry (chicken and duck) manure, (3) nightsoil (human waste), (4) chemical fertilizers.

Finally, with respect to aggregation of animal stocking and production data on integrated fish farms, two groupings were used: livestock (pigs and cattle) and poultry (chickens and ducks).

Data for both stocking and yield were initially recorded in Chinese units of 'Jin' (= 0.5 kg) but were converted to kilograms; these were then subsequently transformed to a per-hectare basis, through division by the total pond area. Feed and fertilizer inputs were also transformed into kg ha^{-1}. Hence, the results presented here are typically given as kg ha^{-1} $year^{-1}$, representing actual inputs or outputs per unit area over the 12-month survey period.

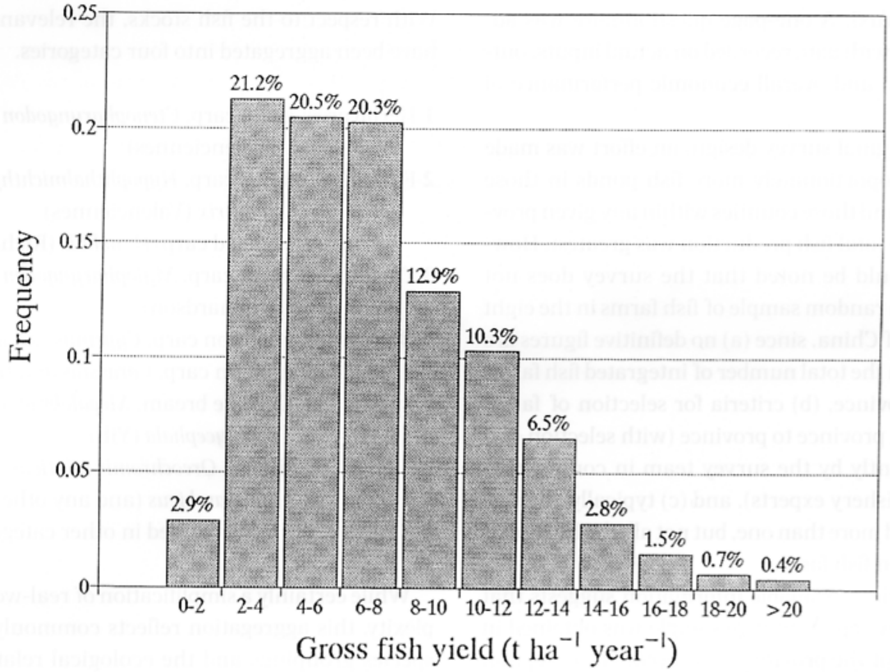

Figure 3 Percentage distribution of aggregate gross fish yields (tonnes ha^{-1} $year^{-1}$).

Fish stocking

The annual schedule for stocking varies across productivity classes, depending on climatic conditions and various other factors described earlier. In low-productivity provinces, the traditional pattern involves stocking in the spring, using fingerlings all of approximately the same size within each species; harvesting is traditionally carried out annually at the end of each year. In medium-productivity areas, stocking again takes place at the start of each year, but for some species, fingerlings of two different sizes are used to allow more than one harvest during the year; harvesting occurs over the summer months as well as at the end of the year. For high-productivity regions, such 'rotary harvesting' is widespread, combining multiple stockings through the year, use of multi-sized fingerlings, and (as in the medium-productivity case) harvests both over the summer and at the end of the year.

Given these timing variations in stocking and harvesting, for purposes of this aggregate analysis the total annual stocking of each species in each pond, and the corresponding stocking cost, were determined by summing over all stocking activity recorded in the survey questionnaire for that pond. Similarly, the total annual fish harvest, and its total value, for each species in each pond were determined by summing over all harvests.

Table 2 indicates the stocking densities and stocking costs for each productivity class, and for the surveyed provinces as a whole. Also indicated are ranges of fingerling stocking sizes, in grams, for each species group (Zhang 1992). The latter enable approximate conversions between stocking weights and the actual numbers of fingerlings involved, although it should be noted that since stocking involves fingerlings of various different sizes, such aggregate conversions are not necessarily meaningful.

Stocking levels vary significantly across regions, with the average density for high-productivity areas (1481 kg ha^{-1} $year^{-1}$) being approximately 3.3 times that of low-productivity provinces (444 kg ha^{-1} $year^{-1}$). In fact, stocking densities in the ponds surveyed in high–productivity areas reached up to 6588 kg ha^{-1} $year^{-1}$.

Table 2 also indicates the average stocking weight and stocking proportion (fraction of total stocking, by weight) for each species grouping within each productivity class. For the surveyed ponds overall, average stocking proportions for grass carp, filter feeders, black carp and omnivorous fish are 35%, 33%, 9% and 24% respectively. In low- and medium-productivity areas, filter-feeding fish (silver and bighead

Table 3 Feed and fertilizer inputs: weights and costs

	Composition by weight (t ha^{-1} $year^{-1}$)				Composition by cost (%)			
Input	**Low**	**Medium**	**High**	**Overall**	**Low**	**Medium**	**High**	**Overall**
Feeds								
Grasses	20.91	35.24	59.65	44.53	22	18	18	18
High quality	3.09	3.95	12.18	8.06	45	37	63	58
Low quality	2.45	7.04	4.61	4.63	15	24	4	7
Pellet feed	1.04	2.43	3.34	2.57	18	21	9	11
Snails	0.00	0.03	16.55	8.71	0	0	7	5
Cost[a]					1889	2112	6388	4303
Fertilizers								
Nightsoil	1.36	2.27	6.98	4.52	7	5	19	12
Livestock manure	7.91	14.47	8.23	9.57	33	20	32	28
Poultry manure	0.77	0.00	1.65	1.06	2	0	8	4
Total manure	10.04	16.74	16.86	15.15	42	26	59	44
Chemicals	0.84	1.93	0.53	0.92	58	74	41	56
Cost[a]					359	520	298	364

[a] In Yuan ha^{-1} $year^{-1}$.

carp) are the principal species stocked, representing just over half of the total stocking weight (52% and 51% respectively). This is twice the proportion (26%) utilized in high-productivity areas, where grass carp is the principal species (37%), with omnivorous species (principally crucian carp and Chinese bream) also important (25%). The high-valued carnivorous black carp (for which snails constitute the typical feed) represents 11% of stocking (by weight) in high-productivity provinces, but is almost absent from low and medium areas.

These results highlight the differences between two key stocking patterns in integrated fish farming. In low- and medium-productivity provinces, total densities are relatively low and filter-feeding fish dominate, while in high-productivity provinces, densities are high and 'feeding fish' dominate. These differences between stocking models will be considered in more detail below.

Feed and fertilizer inputs

In Chinese integrated fish farming, grass as a feed source and animal manure as a fertilizer have traditional importance. Indeed, farmers on a stereotypical farm grow grass on the dykes surrounding their fish ponds and rear animals beside the ponds, with the grass and manure deposited directly into the ponds as appropriate. The importance of grass as a feed is indicated in the survey analysis, which shows that grass is used as a feed on 92%, 99% and 80% of ponds in high-, medium- and low-productivity classes respectively, giving an overall 90% rate of use amongst the ponds surveyed. The role of animal manure in integrated fish farming will be discussed below, within the context of fish–animal integration.

Feeds and fertilizers represent the principal input costs for Chinese integrated fish farming, averaging 46% of total non-labour costs in the survey data. the average utilization of feeds and fertilizers, for each productivity class and for the surveyed provinces overall, is shown in Table 3, and is indicated relative to other input costs in Fig. 4. It should be noted that manure weights are in the form of 'wet weights'; these represent the 'raw' physical input in the production process. Since the focus here is on the costs of the various inputs, these weights will not be analysed further, but the reader is referred to Fang, Guo, Wang, Fang & Liu (1986) for a discussion of conversions between wet and dry manure weights.

While grasses represented the major feeds as measured by weight, 'high-quality' grains and cakes dominated feed costs (60%). In a similar manner, manures

Table 4 Fish–animal integration

Productivity class	% ponds with animal rearing	% ponds with cow or pig manure	% ponds with poultry manure	% ponds with any manure used
Low	15.8	65.4	7.5	81.1
Medium	73.3	84.8	2.9	91.9
High	2.7	53.4	22.3	70.7
Overall	22.0	63.5	14.2	78.1

were the most heavily utilized fertilizers as measured by quantity, while chemical fertilizers represented the majority (56%) of costs.

There are significant differences in feed and fertilizer use between regions, reflecting both the substantially higher total stocking density in high-productivity provinces and the difference in stocking patterns. In particular, the average combined cost of feed and fertilizer in high-productivity areas (6686 Yuan ha^{-1} $year^{-1}$) is approximately 2.5 times that in medium-productivity provinces (2632 Yuan ha^{-1} $year^{-1}$), and three times that in low–productivity areas (2248 Yuan ha^{-1} $year^{-1}$) (3.75 Yuan = 1US$ in 1985 values; source : Bank of China).

Feed costs increase with productivity level, from an average of 1888 Yuan ha^{-1} $year^{-1}$ in low-productivity areas, to 2106 Yuan ha^{-1} $year^{-1}$ in medium-productivity areas, to 6243 Yuan ha^{-1} $year^{-1}$ in high-productivity provinces. On the other hand, fertilizer costs follow the reverse trend, being highest in the low- and medium-productivity provinces (359 and 520 Yuan ha^{-1} $year^{-1}$ respectively) and declining to only 298 Yuan ha^{-1} $year^{-1}$ in high-productivity areas. These results reflect the different models of integrated fish farming alluded to above. The average proportion of feeding fish (grass carp, black carp and omnivores) is highest in high-productivity provinces; this 'feeding fish model' requires high inputs of feed. In poorer provinces, where filter-feeding fish dominate, fertilizer use is relatively more important (although still contributing much less to total costs than do feeds). This difference is demonstrated by examining the relative use of feeds and fertilizers in the data; feed costs average 95% of the combined total cost of feeds and fertilizers in high-productivity areas, but this drops to 84% and 80% in low- and medium-productivity zones respectively.

Fish–animal integration

Three forms of fish–animal integration can be envisioned for any given fish pond: (i) rearing of animals together with fish, in and around the fish pond, (ii) rearing of animals elsewhere on the farm in which the pond is situated, and use in the pond of the manure thus generated, or (iii) purchase or other 'importation' of animal manure from off-farm to fertilize the pond. All of these are forms of fish–animal integration, in that natural fertilizers generated in animal production are cycled into fish production; the difference lies in the scale of the cycling, whether on a pond, farm, or community level.

Table 4 shows, for each productivity class and for the survey data overall, the proportion of ponds in which animals (livestock and/or poultry) were stocked and/or harvested in conjunction with fish, and the proportions of ponds that utilized (a) livestock manure, (b) poultry manure, and (c) manure of any kind (including nightsoil). It is notable that a widespread utilization of manure holds across productivity classes, with some form of manuring used in 81% of ponds in low-productivity provinces, 92% of those in medium-productivity provinces and 71% of ponds in high-productivity areas. In particular, significant majorities (53–85%) of ponds reported use of livestock (pig and cattle) manure.

Overall, the rearing of animals side-by-side with fish culture was less common than the simple use of animal manure in fish ponds, with the former occurring at 22% of all ponds in the seven provinces analysed and the latter at 78% of the ponds. In the medium-productivity Hunan province, a substantial majority (73%) of ponds surveyed had animal rearing in conjunction with fish culture, while this appears to have been a relatively rare situation (3%) in high-produc-

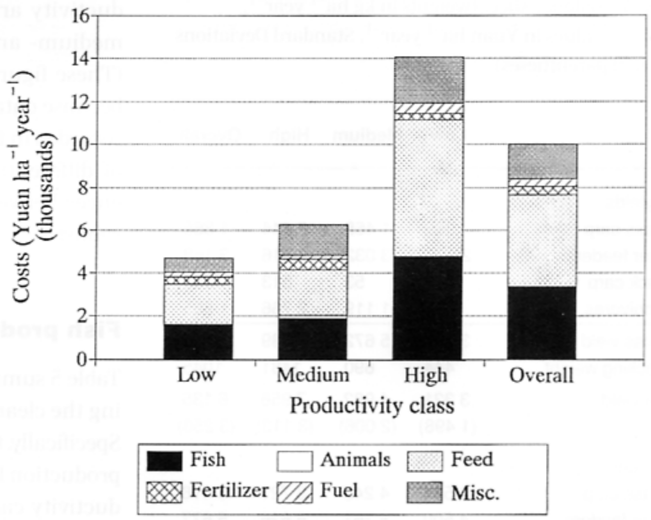

Figure 4 Average costs of fish farming inputs (fish stocking, animal stocking, feeds, fertilizers, fuel, other costs) by productivity class and for the survey data overall.

tivity provinces. This likely reflects the generally greater emphasis on livestock rearing in Hunan province, but it should be noted that in all cases, the joint rearing of fish and animals at the farm level may be greater than our results indicate, since the survey focused primarily on fish production, and was conducted at the pond level of analysis (with animal rearing elsewhere on the farm unrecorded).

Overall, these results indicate the importance of fish–animal integration in fish farming throughout the provinces studied (and particularly in Hunan). The results here indicate the major role of animal manure in the fish farming system, while also showing that the manure was often brought from elsewhere to the pond site, rather than being generated through rearing of animals alongside the pond. This latter result, and the relatively low number of animals involved relative to fish stocking levels, help to explain why animal stocking costs represent a small fraction of total input costs in the survey results (Fig. 4, Table 5).

Capital and infrastructure inputs

Among the principal fixed inputs to integrated fish farming operation for which survey data are available are the pond itself (measured in particular by its area and depth), irrigation pumps, aerators, transportation equipment and processing machinery. (Note that the corresponding land and the buildings on it are also important, but the survey provides no information on these costs.)

There appears to be little difference in average pond area or depth across productivity classes. The average fish pond surveyed was 0.93 ha in area, with an average depth of 1.95 m. However, there was considerable variation in both of these quantities; for example, of the 923 ponds surveyed (excluding the 90 in Hubei province), distribution of pond areas was as follows:

Pond area (ha)	Number of ponds	Percentage of ponds
Under 0.25	144	15.6
0.25 – 0.50	237	25.7
0.50 – 0.75	257	27.8
0.75 – 1.00	141	15.3
1.00 – 1.25	87	9.4
1.25 – 1.50	19	2.1
1.50 – 1.75	21	2.3
1.75 – 2.00	3	0.3
Over 2.00	14	1.5
Total	923	100.0

The availability of on-farm equipment, notably aerators and irrigation pumps, is considered to be of importance in achieving a high level of productivity. Without irrigation pumps, water levels cannot be maintained fully, while in the absence of aerators, dissolved oxygen levels are insufficient to maintain high stocking levels. For example, in the high-productivity

Table 5 Balance sheet (weights in kg ha^{-1} year^{-1}, monetary values in Yuan ha^{-1} year^{-1}, Standard Deviations shown in parentheses)

	Low	Medium	High	Overall
Fish yields				
Grass carp	999	1 468	2 444	1 865
Filter feeders	2 125	3 032	3 716	3 168
Black carp	3	53	513	282
Omnivores	638	1 119	2 766	1 865
Gross yield	3 765	5 672	9 439	7 180
Stocking weight	444	690	1481	1045
Net yield	3 321	4 982	7 958	6 135
	(1 498)	(2 006)	(3 113)	(3 250)
Revenues				
Grass carp	3 514	4 245	8 721	6 416
Filter feeders	4 500	4 761	6 626	5 677
Black carp	6	134	2 808	1 508
Omnivores	2 057	2 926	7 901	5 325
Animal production	101	591	30	175
Other income	16	221	121	118
Total income	10 194	12 878	26 207	19 219
	(5 852)	(5 142)	(13 117)	(12 638)
Costs				
Fish stocking	1 597	1 903	4 768	3 332
Animal stocking	27	179	11	53
Feed	1 889	2 112	6 388	4 303
Fertilizer	359	520	298	364
Fuel	218	195	516	369
Miscellaneous	664	1468	2154	1630
	4 754	6 377	14 135	10 051
Total costs [non labour]	(2 692)	(2 881)	(7 903)	(7 432)
Net income	5 440	6 501	12 072	9 168
	(4 397)	(3 769)	(7 586)	(6 905)
Labour payment	1 252	3 851	4 004	3 289
	(697)	(3 021)	(3 887)	(3 390)
Profit	4 188	2 650	8 068	5 879
	(4 482)	(3 871)	(7 323)	(6 488)

provinces of Jiangsu and Zhejiang the survey data indicate that on the average pond without aeration, a combined stocking of 1261 kg ha^{-1} year^{-1} produced a resulting gross fish yield of 8366 kg ha^{-1} year^{-1}. On the other hand, for ponds with aeration, the average stocking density was 2065 kg ha^{-1} year^{-1}, and the gross yield was 47% higher than in the absence of aeration, at 12 279 kg ha^{-1} year^{-1}.

The presence of capital equipment is much greater in the wealthier high-productivity provinces than it is elsewhere. The survey data indicate that aerators were present on 27% of surveyed ponds in high-productivity areas, but only 7% and 6% of ponds in medium- and low-productivity areas respectively. (These figures may underestimate the true values, because data on capital inputs were not always fully recorded in the survey. However, there is no evidence of differential recording across provinces, so differences between productivity classes are likely to be robust.)

Fish production and income analysis

Table 5 summarizes gross and net fish yields, indicating the clear distinctions across productivity classes. Specifically, the survey data show that average net fish production levels in the high-, medium- and low-productivity categories were 7958, 4982 and 3321 kg ha^{-1} year^{-1} respectively. The average net fish yield in high-productivity ponds was approximately 2.5 times the respective value in low-productivity ponds; this can be compared with stocking levels, which were 3.3 times higher in the high-productivity areas. The composition of the fish harvest reflects, in broad terms, the stocking ratios discussed above.

Average incomes also varied greatly between productivity classes, as indicated in Table 5 and Fig. 5. Average income ranged from an average of 10 194 Yuan ha^{-1} year^{-1} for low-productivity ponds to 12 878 Yuan ha^{-1} year^{-1} in medium-productivity Hunan province, to 26 207 Yuan ha^{-1} year^{-1} in high-productivity areas. Based on the survey results, revenues from animal production and 'other income' are small in all areas, although of somewhat greater importance in Hunan province (at 6% of total income).

It is clear from Fig. 5 that grass carp provides the greatest contribution to revenues of any single species, providing approximately one-third of total income in each productivity class. (Although filter feeders and omnivores are also important, these groupings each involve more than one species.) The greatest contrast in income sources between productivity classes is due to black carp, which provides 11% of total income in high-productivity provinces but which is almost absent (providing 1% or less of income) in low- and medium-productivity areas. This difference seems to reflect differing consumer preferences and income levels, as well as a lack of suitable traditional technology for raising black carp in the latter areas.

Figure 6 and Table 5 indicate considerable variation in both the absolute levels of net income, profits

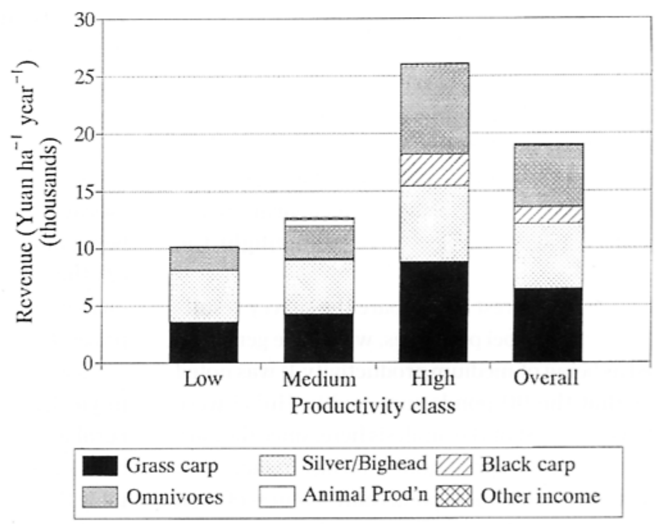

Figure 5 Average income (revenue) from integrated fish farming (grass carp, silver and bighead carp, black carp, omnivores, animal production, other income) by productivity class and for the surveyed ponds overall.

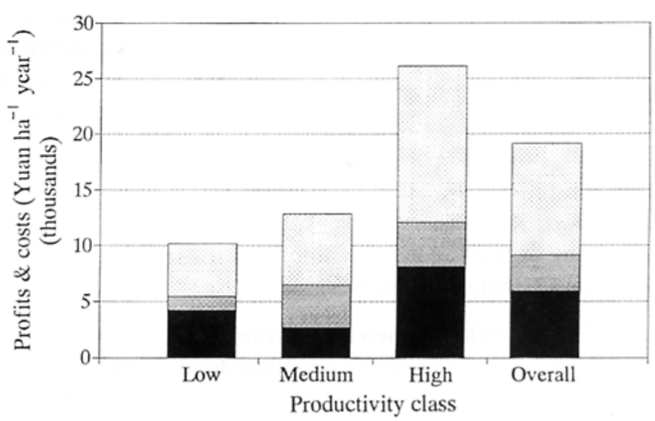

Figure 6 Average income (revenue) for each productivity class and overall, subdivided into profits, (black segments), labour payments (dark stippling) and non–labour costs (light stippling).

and labour payments, and their relative magnitudes, across productivity classes. Comparing total income and net income levels, one can observe that costs are a somewhat greater fraction of gross earnings in high-productivity than in low-productivity provinces (54% vs. 47%). This is why total income is 2.5 times higher in the former relative to the latter, but net income is only 2.2 times higher.

From Table 5, it can be seen that labour payments comprise 23% of net income in low-productivity provinces, 59% in Hunan, and 33% in high-productivity provinces, with the remainder representing profits in each case. The relatively high level of labour payments in Hunan may simply reflect data unreliability due to uncertainties amongst farmers in allocating income between labour payments and profits. This reflects the fact that in China, whether on communes, cooperatives or 'family' farms, the distinction has not been great between these two.

Finally, while clear differences exist in Chinese integrated fish farming across productivity classes, variability also occurs within each class. Indeed, a distribution of fish yields can be envisioned within any single class, with some overlap occurring between classes. The within-class variation can be seen through an examination of standard deviations in Table 5. For example, the coefficient of variation for total (gross) income is 57%, 40% and 50% for low-, medium- and high-productivity classes respectively, while corresponding figures for net income are 81%, 58% and 63%. Aspects of this heterogeneity will be examined in greater detail in the following section.

Yield and income heterogeneity

As noted above, differences exist in Chinese integrated fish farming both across productivity classes and within each class. These latter occur between provinces within a given productivity class, between counties in any given province, and between farms in any given area. Two examples serve to highlight the differences.

First, it is of interest to compare the survey results for Hunan and Hubei provinces, which are generally viewed as being of medium productivity. It was noted earlier that the 90 ponds surveyed in Hubei were omitted from most of the analysis here, since they are located on two unrepresentative farms. In fact, with respect to fish yields, these ponds have features of both the high- and medium-productivity classes;

1 the average total stocking density for the two farms surveyed in Hubei was very high at 1904 kg ha^{-1} year^{-1}, compared with 690 kg ha^{-1} year^{-1} in Hunan, or even the 1481 kg ha^{-1} year^{-1} average in high-productivity provinces;
2 the stocking proportion of grass carp on the two farms surveyed in Hubei was 37%, the same as that in high-productivity areas;
3 the stocking of filter feeders on those farms was 51%, the same as that in Hunan province.

The two farms are relatively new and have received substantial financial and technical assistance from outside the province, resulting in capital and infrastructure superior to that elsewhere in Hubei province. The farms have increased their stocking levels substantially above those common elsewhere in Hubei and Hunan provinces, and have modified the traditional stocking pattern by increasing the proportion of grass carp.

The average gross fish yield was 9764 kg ha^{-1} year^{-1} across the 90 ponds surveyed on these two Hubei farms; this is 72% higher than the 5672 kg ha^{-1} year^{-1} average obtained on the Hunan farms surveyed. The clear difference in performance suggests that in at least some circumstances, fish farms in areas of low- or medium-productivity can increase their average yields through suitable technology transfer, capital availability and socio-economic development.

Although yields on the two surveyed farms in Hubei are very high relative to others in medium-productivity areas, this difference diminishes considerably when economic aspects are addressed. In particular, average net income for ponds on the two Hubei farms was 7191 Yuan ha^{-1} year^{-1}, which is only 10% higher than the 6501 Yuan ha^{-1} year^{-1} average net income for ponds in Hunan province. This similarity, occurring despite 72% higher yields in the former case, can be ascribed to two factors: (1) high yields on the two Hubei farms required high levels of inputs, with an average total input cost of 13 540 Yuan ha^{-1} year^{-1} being more than twice that of Hunan province, and (2) the farms surveyed in Hubei are government-owned, and sold their production at below-market prices directly to the government.

As a second example of intra-regional variations in yields, in high-productivity Jiangsu province the rural areas around Nanjing and Wuxi cities differ in both socio-economic and geographic conditions (notably the level of infrastructure development and the availability of water resources). As a result, surveyed fish ponds in the Nanjing area had a relatively low average net fish yield of 5543 kg ha^{-1} year^{-1}, compared with an average of 12570 kg ha^{-1} year^{-1} in the Wuxi area. The latter appears to rank amongst the highest yields in China, while the former is similar to that of medium-productivity regions despite Nanjing's location in a high-productivity province.

Discussion

This paper has attempted to present a comprehensive overview of structural and economic aspects of integrated fish farming in China, emphasizing differences between three productivity classes and two stocking models within the country.

It has been suggested that differences between productivity classes can be traced to variations in both (i) micro factors controllable at the farm level, particularly the levels of inputs, including capital and management skill, and (ii) macro aspects of the broader environment, including climate, topography, culturing tradition, technological facilities, infrastructure, average income levels and the resulting consumer demand. These various on-farm and macro differences must be kept clearly in mind when considering the potential for the technology transfer of high-productivity techniques to low- and medium-productivity provinces, and in designing research activities (see also the related discussion in Edwards, Pullin & Gartner 1988).

Developmental issues differ notably between productivity classes, influenced in part by local climatic and socio-economic conditions. For example, in more socio-economically advanced high-productivity regions, farmers tend to utilize higher input levels, so as to increase output levels in response to relatively high market demand. In such cases, stress has been laid on sustaining high production levels while increasing the value of output; this is done by improving land and labour productivity, increasing feed conversion rates and reducing feed costs.

On the other hand, in low- and medium-productivity provinces, where the available land area per capita is relatively high, but average income levels are low, extensive (rather than intensive) fish culture remains the norm. To a limited extent, there is a trend in these areas toward more integrated fish farming methods, with key strategies being (a) to combine relatively plentiful water resources with the capital and technology provided by richer regions, (b) to promote production by expanding the market for fish, and (c) to emphasize the integration of animals and crops with fish production. To this end, there has been some technology transfer; for example, fish farming specialists from the Freshwater Fisheries Research Centre in Jiangsu province have been invited as advisors to provinces with lower farm productivity.

The survey analysis also highlights the existence of two clear fish stocking models in Chinese integrated fish farming. Farms in provinces with low to medium productivity tend to use relatively low stocking densities, and to emphasize the rearing of filter-feeding silver and bighead carp, which comprise approximately 50% of total stocking by weight and 40% by cost. On the other hand, in provinces with relatively high productivity, and high stocking densities, filter feeders comprise only 26% of stocking by weight and 17% by cost. In these areas, 'feeding fish' – grass carp, black carp and omnivores – are of greater importance, comprising 74% of stocking by weight and 83% by cost.

Differences in overall stocking densities between regions may be due to climatic effects (varying from north to south) and/or socio-economic conditions, including consumer demand and access to capital (as indicated earlier in comparing Jiangxi and Jiangsu). Variations in stocking proportions reflect both (a) the relative desirability in poorer provinces of raising fish species that require relatively low input costs (with relatively greater use of fertilizers over feeds), and (b) inherent regional differences in consumer preferences. For example, in northern China, common carp is favoured by consumers, while in Jiangsu province, increasing income levels over time have shifted demand away from filter-feeding fish (silver and bighead carp) toward the more desirable grass carp and black carp. The quantitative impact of these various 'external' factors will be examined in detail in a subsequent paper.

China's economic system is currently undergoing a major shift away from a totally planned economy towards a market orientation. This is producing fundamental changes in fish farming practices, as farmers base their decision making more on market prices and less on production quotas and government requirements. In contrast to past practices of selling fish directly to the government, a new private distribution system is becoming established, complete with fish buyers and other intermediaries. For example, in Wuxi (Jiangsu province), large fish farms may transport their production directly to urban wholesale centres, while fish buyers may travel to smaller rural farms to buy fish for resale in the city.

These practices, while common in many nations, are rather new to China. The analysis reported here can be viewed as providing a baseline, reflecting the economics of traditional integrated fish farming, for comparison with fish farm operation and performance under newer economic regimes. The latter will be examined in future research at the Freshwater Fisheries Research Centre.

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