Aquaculture Research, 1998, **29,** 211–224

Assessing culture fisheries practices in small waterbodies: a study of village fisheries in north-east Thailand

K Lorenzen
Renewable Resources Assessment Group, Imperial College, University of London, London, UK

J Juntana
Freshwater Fisheries Research and Development Centre, Department of Fisheries, Udon Thani, Thailand

J Bundit & D Tourongruang
Aquaculture Outreach Project, Asian Institute of Technology, Udon Thani, Thailand

Correspondence: K. Lorenzen, RRAG, Imperial College, 8 Princes Gardens, London SW7 1NA, UK

Abstract

Extensively managed culture fisheries systems in small, communal waterbodies in north-east Thailand were analysed using statistical methods and a simple population model. Villages stocked the waterbodies with a variable mixture of carp species and Nile tilapia, and held annual fishing days where individual fishing was allowed upon payment of a fee to the village. Yields ranged from 26 to 2881 (median 652) kg ha^{-1} year^{-1} and were strongly related to the trophic status of the waterbody and to stocking density (with an optimum at 9800 fish ha^{-1} year^{-1}). Stocking performance varied greatly between species and was also influenced by the trophic status of the waterbody. Catches were dominated by tilapia in the most fertile waterbodies and by carp species in all others, but catch species composition did not significantly influence yield when the effect of trophic status was accounted for. The optimization of stocking regimes is identified as the most promising option to improve village fisheries, on the basis of feasibility and predicted benefit (median increases in yield of 22–75%). Further empirical analyses, possibly combined with experimental management, are suggested to identify optimal stocking regimes.

Introduction

Culture fisheries or extensive aquaculture are practised in small waterbodies throughout the world (Welcomme 1996), and are particularly common in Asia where the practice is found in communal lakes and reservoirs as well as in private farm ponds (De Silva 1988; Ahmed 1992; Jhingran 1992; MC 1992). With the notable exception of China (Li & Xu 1995) and a number of projects elsewhere (Haigh 1994; Middendorp, Hasan & Apu 1996), culture fisheries in small waterbodies have received little research and extension support, and are often regarded merely as indicating failure to establish more intensive aquaculture practices. Consequently, their operators rely largely on personal experience and intuition when making management decisions.

In north-east Thailand (Esarn), culture fisheries have developed since the 1980s, following the expansion of government and private fish seed production, and various programmes to build village ponds and to promote aquaculture. Village ponds or reservoirs are built and maintained primarily to store water for domestic use and crop irrigation, but are also used for fishing or fish culture. Fish culture in communal ponds and reservoirs is being promoted by the Village Fisheries Programme (VFP) of the Department of Fisheries (DOF). Under the

© 1998 Blackwell Science Ltd.

programme, village fishery committees assume responsibility for pond management and are given some brief training in management techniques such as nursing, feeding, fertilization and integrated agriculture–aquaculture. However, recommendations are given only in broad terms, and all decisions are taken by the village committee. Various ways of using the pond have evolved, including harvesting by the village committee or renting out the pond to individuals. By far the most common regime, however, is to hold an annual fishing day where tickets are sold to individuals from within and outside the village, allowing them to fish with cast nets and lift nets. Such fishing days generate income for the village, and are also important social occasions (Chantarawarathit 1989; Garaway 1995).

In the present study, an exploratory analysis of village fisheries in north-east Thailand was conducted, focusing on the relationship between yields, natural conditions and management actions. A variety of statistical methods and a simple population model are used to identify management options likely to increase yields and financial benefits from village fisheries, and also estimate the potential magnitude of these increases. Finally, the cost effectiveness of the study and the potential for further empirical analyses and experimental management to resolve some remaining uncertainties is discussed.

Materials and methods

Data collection

Data collection took place between April 1994 and April 1996. A total of 16 active village ponds in Udon Thani province were selected at random to obtain an overview of management practice, trophic conditions and yields. Information on management practice (e.g. stocking, harvesting, feeding and fertilization, and access arrangements) was obtained through a questionnaire survey, additional semi-structured interviews and direct observation. Trophic status indicators [Secchi depth, conductivity, and the concentrations of total nitrogen, total phosphorus and chlorophyll (a)] were determined at least twice in each waterbody, always in the cold or dry season (late September to April). Water samples were analysed according to the APHA guidelines (APHA 1989). Stocking data (total numbers, broken down by species where possible) were obtained from village and DOF records. To account for the perennial nature of village fisheries, stocking numbers were averaged over the 2 years preceding a fishing day for which catch data were collected. Fishing day yields were estimated as the median catch (by weight) per ticket holder, multiplied by the number of tickets issued. The use of the median rather than the mean results in conservative estimates of total yield. The catch per ticket holder was estimated by direct measurement in nine villages, and by questionnaire surveys of at least 10 fishing day participants in the remaining seven villages. Questionnaire surveys were used when logistic reasons (such as several fishing days being held at the same date, or failure to notify fishing days in advance) made it impossible for field staff to attend the fishing day. Both direct catch sampling and the questionnaire survey covered total catch (weight) by species per ticket holder, and direct sampling also covered length distributions.

Three village ponds out of the total of 16 were stocked by the DOF as part of the study, and monitored for a period of 1.5 years through regular test fishing with seine nets. Stocking densities in all three ponds were about 10 000 ha^{-1}, comprising approximately 30% silver carp, 10% silver barb and 15% each of common carp, mrigal, rohu and tilapia. In all three fisheries, village committees decided to stock additional fish in the year following the DOF stocking, but not to hold fishing days until the second year. Fishing day yields from these ponds were divided by two to calculate the annual yields for use in the empirical yield analyses.

All data collection relied on the voluntary cooperation of the communities, and no attempt was made to influence management decisions. Project intervention was limited to the stocking of the three above mentioned ponds, but even in these ponds all other management decisions were left entirely to the village committee.

Analysis

An overview of management practices was obtained from summary statistics of the questionnaire survey. Regression methods were used to explore relationships between variables. All monetary figures are given in Thai Baht (B): 25 B equal US$1.00 at 1996 exchange rates.

The impact of natural conditions and management on yield was analysed using statistical methods and a simple population model. Statistical methods were used to analyse the impact on yield of those variables

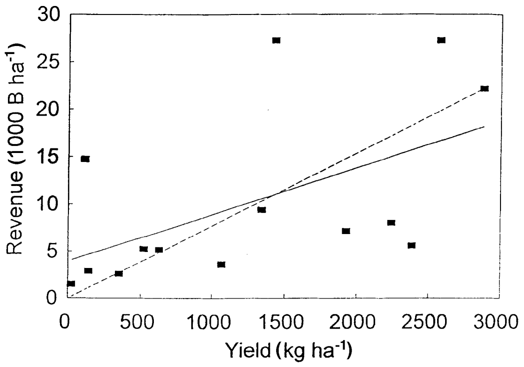

Figure 1 Relationship between fishing day yield and village revenue per unit area of pond. The solid line is a fitted linear regression model (the positive relationship is significant at $P < 0.05$); the dashed line indicates the median revenue per unit weight of 7.7 B kg^{-1}.

(trophic status, stocking density, fishing effort and species composition of the catch) that displayed sufficient variation in the data to permit an empirical analysis. The population model was used to explore the possible effects of changes in the harvesting regime, which did not display sufficient variation in the data to permit an empirical analysis.

For correlation and regression analysis, all data were aggregated to one representative value per pond (the median of the individual observed values). A logarithmic transformation was applied to all variables prior to correlation and regression analysis, because most variables spanned more than an order of magnitude and showed visible heteroscedasticity. Simple yield predictive models were derived by linear and quadratic regression of the transformed variables. Approximate confidence limits for the optimal stocking density were derived by the delta method (Seber 1982).

The species composition of the catches was analysed by cluster analysis in order to identify natural groupings. Hierarchical and nonhierarchical cluster analyses (Manly 1994) were carried out on the proportional contribution of each species to the total catch in the pond. An analysis of covariance (ANCOVA) was used to evaluate the impact of species composition on yield while accounting for the effect trophic status. The stocking performance of different species was analysed in terms of yield per seed fish. This allowed the separation of species with good (albeit variable) returns per seed fish from species with consistently low returns. The necessary species-wise stocking data were available for only 10 ponds, and therefore, no attempt was made to test for interspecific interactions, or interactions between species performance and trophic status.

A simple population model was developed to explore the effects of different harvesting regimes on yield. The model describes the growth and abundance of stocked cohorts, and allows the calculation of the long-term average yields that will be achieved under different harvesting regimes. The model was applied to the three fisheries monitored by regular test fishing, where detailed data allowed the estimation of growth parameters and recapture rates for all stocked species. It was not possible to separate the effects of natural and fishing mortality on recapture rates, and therefore, the analysis was carried out for a range of different assumptions. The model does not account for density-dependent responses in fish growth or mortality, for which no specific data were available, and is used here as an exploratory rather than fully predictive tool. Details of the model are given in the appendix.

Results

Status and management practice

The ponds surveyed ranged in area from 1.8 to 20 ha (median 3.3 ha), and all had a similar depth of about 2.5 m in the wet season and 1.5 m in the dry season.

In general, ponds were stocked during the wet season in June–July, when carp seed are easily available. Fishing days were held during the dry season in March–April (9 months after stocking), when low water levels permit wading in the pond. All villages banned the use any fishing gear between stocking and the fishing day, but some villages allowed open access in the period between the fishing day and restocking. All ponds were managed extensively, i.e. without significant inputs of fertilizers or feeds.

Seed fish, usually of 2–3 cm length but occasionally larger, were stocked at total densities ranging from 2200 to 54 000 ha^{-1} (median 10 400 ha^{-1}). The main species stocked were the Chinese silver carp, *Hypophthalmichtys molitrix* (Cuvier & Valenciennes), and occasionally bighead carp, *Aristichthys nobilis* (Richardson), the Indian major carps mrigal, *Cirrhinus mrigala* (Hamilton), and rohu, *Labeo rohita* (Hamilton), common carp, *Cyprinus carpio* (L.), Thai silver barb, *Puntius gonionotus* (Bleeker), and Nile tilapia, *Oreochromis*

Table 1 Pearson correlation matrix of the village fisheries data. The variables are total nitrogen concentration (*TN*), total phosphorus concentration (*TP*), chlorophyll a concentration (*Chl*), Secchi depth (*Secchi*), conductivity (*Cond*), stocking density (*SD*), number of tickets (*NT*) and yield (*Y*)

	log(*TN*)	log(*TP*)	log(*Chl*)	log(*Secchi*)	log(*Cond*)	log(*SD*)	log(*NT*)
log(*TP*)	0.48[1]						
log(*Chl*)	0.73[1]	0.60[1]					
log(*Secchi*)	–0.45[1]	–0.34	0.13				
log(*Cond*)	0.56[1]	0.59[1]	0.76[1]	0.35			
log(*SD*)	–0.45[1]	–0.30	–0.16	0.25	–0.10		
log(*NT*)	0.25	0.28	0.25	–0.14	0.33	0.02	
log(*Y*)	0.65[1]	0.83[1]	0.53[1]	–0.48[1]	0.47[1]	–0.26	0.54[1]

[1]Significant correlation ($P < 0.05$).

niloticus (L.). Most villages (about 70%) purchased seed from private traders, while the remaining villages obtained wholly or partly subsidized seed from the DOF. Median unsubsidized seed costs were 0.1 B per fish.

Fishing day participation ranged from 150 to 1000 (median 500) ticket holders, resulting in fishing intensities of 20–440 (median 125) tickets ha^{-1}. Fishing day yields ranged from 26 to 2881 (median 654) kg ha^{-1} per year. Village revenue from the ticket sales ranged from 6600 to 60 000 B in total, or 1500 to 27 000 (median 5600) B ha^{-1}. Total revenue was unrelated to pond area, but there were significant positive relationships between revenue and yield on a total and per area basis. The relationship between revenue and yield per unit area is illustrated in Fig. 1, showing a significant positive relationship ($P < 0.05$) of low predictive power (regression model indicated by a solid line). The median revenue per unit of yield was 7.7 B kg^{-1} (indicated by a dashed line).

Impact of trophic status, stocking density and fishing effort on yield

The correlation matrix for the trophic status indicators, management variables and yield is shown in Table 1. Yield [log(*Y*)] was significantly correlated with all trophic status indicators, and most indicators were significantly correlated with each other. To avoid the use of correlated explanatory variables in multiple regression analysis, only total phosphorus [log(*TP*)], the indicator most strongly correlated with yield, was used in further analyses. Correlation plots of log(*Y*) with the trophic status indicator log(*TP*), and the management variables stocking density [log(*SD*)] and number of tickets [log(*NT*)] are shown on the left hand side of Fig. 2. The plots show a clear linear relationship between log(*Y*) and log(*TP*), a possibly dome-shaped relationship between log(*Y*) and log(*SD*) (leading to the non-significant correlation indicated in Table 1), and a weak correlation between log(*Y*) and log(*NT*). Single and multiple regression models to predict log(*Y*) from log(*TP*), log(*SD*) and log(*NT*) are given in Table 2. In both single and multiple regressions, only linear terms were significant for log(*TP*) and log(*NT*). Only the combined linear and quadratic terms were significant for log(*SD*). (However, there was only one data point at low stocking density which exerted a strong influence on regression results: when this point was removed, a significant linear relationship with negative slope was estimated.) All terms included in the models were significant at $P < 0.05$, except for log(*NT*) in Model 6 with $P = 0.07$ (omission of this term nevertheless caused a conspicuous trend in residuals with *NT*). Interaction terms were not considered because of the limited data available. Trophic status as measured by log(*TP*) is the strongest single predictor of yield, followed by stocking density log(*SD*), while fishing effort log(*NT*) has least predictive value. Residuals of Model 6 using log(*TP*), log(*SD*) and log(*NT*) are plotted against the predictor variables on the right hand side of Fig. 2. Residuals show no systematic patterns in relation to any of the explanatory variables. The residuals of yield estimates based on questionnaire surveys (open squares) are generally larger than those of estimates based on direct sampling (solid squares), but do not show systematically different patterns.

The predicted yield as a function of total phosphorus concentration and stocking density

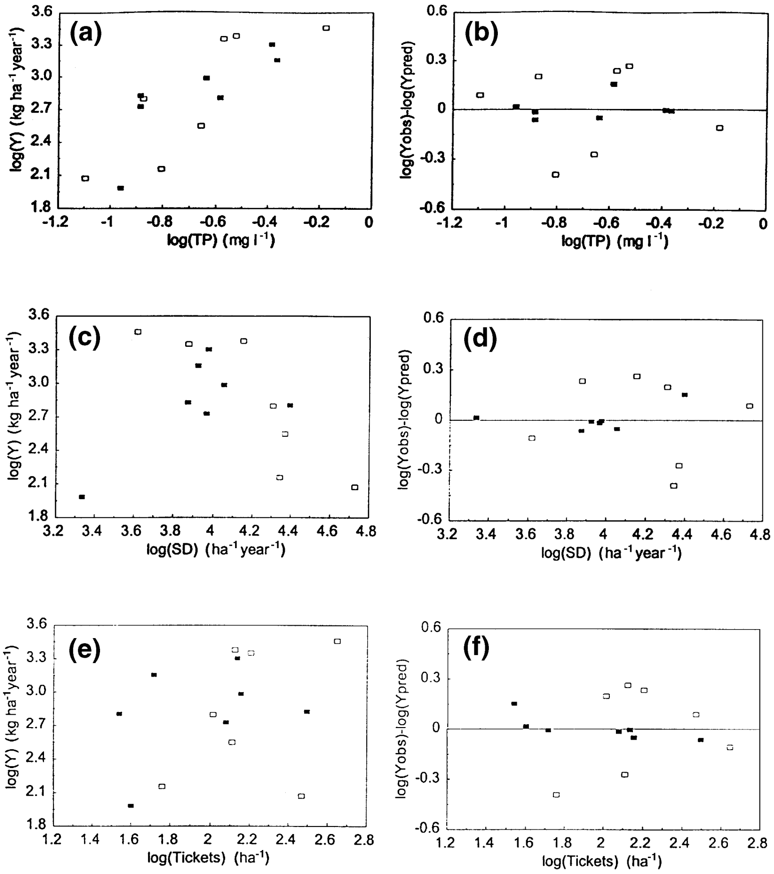

Figure 2 (Left column) Relationships between (a) yield and total phosphorus concentration (*TP*), (c), stocking density (*SD*) and (e) the number of tickets (*NT*). (Right column) Residuals of the yield predictive model (Model 6, Table 2) plotted against (b) *TP*, (d), *SD* and (f) *NT.* Solid squares indicate yield estimates based on direct sampling of catches; open squares indicate estimates based on interviews.

(Model 4, Table 2) is shown in Fig. 3. The highest yields are predicted for a stocking density of 9800 [95% confidence interval (CI) (7530, 12 740)] fish ha^{-1}. Interaction effects between trophic status and stocking density have not been estimated, and consequently, the predicted optimal stocking density is independent of trophic status. As mentioned before, omission of the influential data point at low stocking density would give rise to a linear relationship of negative slope between log(Y) and log(SD), and this would imply that yield may be maximized at a lower stocking density than predicted by Model 4. The impact of trophic status on the revenue obtained from fishing days and the relative cost of stocking is illustrated in Fig. 4. Figure 4a shows the relationship between *TP* and the village revenue (from ticket sales) that can be expected from a fishery stocked at the optimal density of 9800 ha^{-1}, assuming that a revenue per unit of yield of 7.7 B kg^{-1} (the median observed value) is realized. Figure 4b shows the predicted optimal stocking densities with respect to yield (and gross revenue) and with respect to the gross margin of revenue over seed cost, assuming a seed price of 0.1 B fish^{-1}. In ponds of low trophic status, the gross margin of revenue over seed costs is maximized at a substantially lower stocking density than yield. Seed costs take up a high proportion of gross revenue in ponds of low trophic status, but less than 10% in ponds of moderate to high trophic status (Fig. 4c).

Species composition and performance

Hierarchical cluster analysis of the catch species composition indicated two clusters of very high

Table 2 Yield predictive models for community fish culture in NE Thailand. Standard errors of regression parameters are given in brackets; (RMS) residual mean square

Variables

Y	Fishing day yield (kg ha^{-1} $year^{-1}$)
TP	Total phosphorus concentration (mg L^{-1})
SD	Stocking density (ha^{-1} $year^{-1}$)
NT	Number of tickets (ha^{-1} $year^{-1}$)

Models

Model (1): Yield from total phosphorus
$\log(Y) = 3.92\ (0.23) + 1.72\ (0.31) \log(TP)$
$n = 16, P < 0.001, r^2 = 0.690, RMS = 0.111$

Model (2): Yield from stocking density
$\log(Y) = -29.50\ (9.79) + 16.51\ (4.86) \log(SD) - 2.09\ (0.60) \log(SD)^2$
$n = 14, P = 0.012, r^2 = 0.555, RMS = 0.128$

Model (3): Yield from the number of tickets
$\log(Y) = 1.01\ (0.73) + 0.86\ (0.36) \log(NT)$
$n = 16, P = 0.031, r^2 = 0.291, RMS = 0.254$

Model (4): Yield from total phosphorus and stocking density
$\log(Y) = -15.76\ (8.05) + 1.14\ (0.33) \log(TP) + 9.78\ (3.98) \log(SD) - 1.23\ (0.50) \log(SD)^2$
$n = 14, P = 0.001, r^2 = 0.795, RMS = 0.065$

Model (5): Yield from total phosphorus and the number of tickets
$\log(Y) = 2.71(0.51) + 1.53\ (0.27) \log(TP) + 0.53(0.21)\log(NT)$
$n = 14, P < 0.001, r^2 = 0.793, RMS = 0.080$

Model (6): Yield from total phosphorus, stocking density and the number of tickets
$\log(Y) = -16.58(6.97) + 1.09\ (0.29) \log(TP) + 9.78\ (3.44) \log(SD) - 1.23\ (0.43) \log(SD)^2 + 0.39(0.19)\log(NT)$
$n = 14, P = 0.001, r^2 = 0.862, RMS = 0.048$

similarity, and a remaining set of fisheries of low similarity. Non-hierarchical clustering for two groups partitioned the fisheries into a tilapia-dominated and a carp-dominated group. Partitioning for three groups led to a subdivision of the carp group into a Chinese-carp-dominated group, and a mixed group which also included one of the fisheries classified as tilapia dominated in the two group clustering. Partitioning for higher numbers of groups led to further subdivisions of the mixed carp group.

The relationship of the catch species composition clusters to yield and trophic status (measured by *TP*) is shown in Fig. 5. The tilapia-dominated systems were found exclusively in ponds of high trophic status and high yield. Chinese carp-dominated and mixed carp systems occurred throughout the low and middle ranges of yield and trophic status.

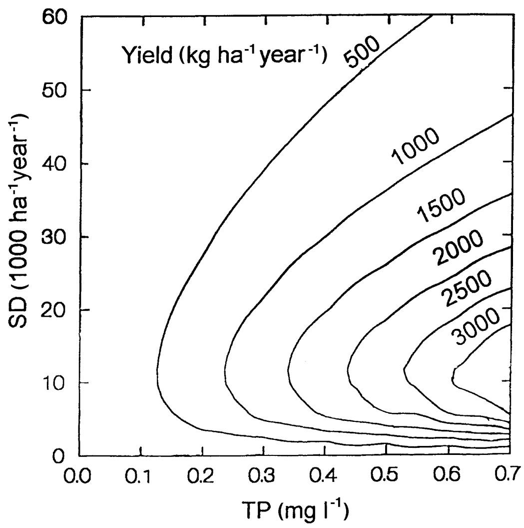

Figure 3 Predicted yield as a function of total phosphorus concentration (*TP*) and stocking density (*SD*), based on Model 4 (Table 2).

Comparison of yield and trophic status between groups showed that both were significantly higher in tilapia than in the combined carp systems, while no significant differences were found between Chinese-dominated and mixed carp systems. An ANCOVA showed that the catch composition had no significant effect on yield when the effect of trophic status was accounted for. The high yields in tilapia-dominated fisheries are related to their occurrence in waterbodies of high trophic status, and do not imply an inherent advantage of tilapia over carp dominated fisheries.

The yields per seed fish and stocking densities of the stocked species are shown in Fig. 6. Also indicated in Fig. 6a is the financial break-even level of 0.013 kg seed $fish^{-1}$, based on a seed price of 0.1 B $fish^{-1}$ and a revenue of 7.7 B kg^{-1}. Chinese carp give the most consistently high yields per seed fish, followed by mrigal and rohu. Tilapia, silver barb and common carp show median yields per fingerling at or below the financial break-even level. However, tilapia yields per fingerling span a very wide range, and can be substantially greater than the break-even level. A very high value of 0.83 kg seed $fish^{-1}$ was achieved in one of the tilapia-dominated ponds, and reflected the impact of natural reproduction. In the other two tilapia-dominated ponds, the species had not been stocked in the years preceding the study (i.e. tilapia production was based entirely on natural recruitment), and no yield per seed fish could be

 © 1998 Blackwell Science Ltd, *Aquaculture Research*, **29,** 211–224

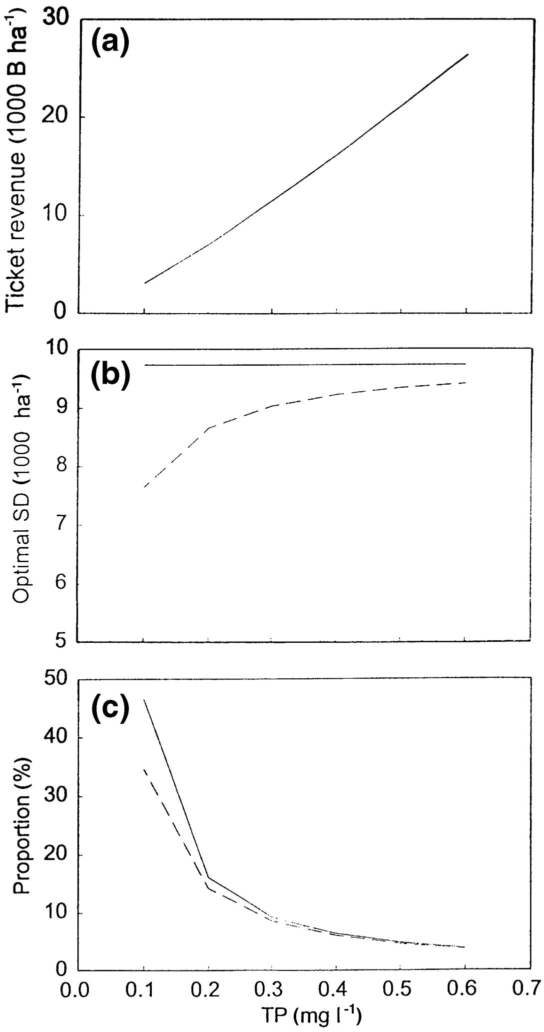

Figure 4 (a) Predicted village revenue from ticket sales, (b) optimal stocking density with respect to yield (solid line) and the gross margin of revenue over seed costs (dashed line), and (c) the corresponding seed costs as a proportion of gross revenue; predicted from Model 4 (Table 2).

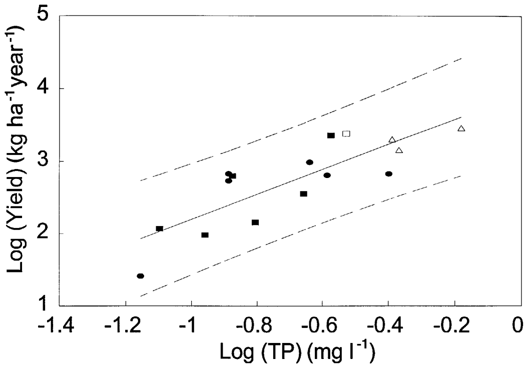

Figure 5 Yield and species composition of the catch in relation to trophic status measured by total phosphorus concentration (*TP*). The lines indicate the expected yield (solid line) and 95% prediction limits (dashed lines) of Model 1 (Table 2). Symbols denote the three cluster classification of ponds by species composition: Chinese-carp-dominated (black circles), mixed carp (black and open squares) and tilapia-dominated (open triangles). The pond marked with open squares was classified as tilapia-dominated in the two cluster classification, when all other Chinese and mixed carp ponds were joined in one class.

calculated. The stocking densities of the six species fell within similar ranges (Fig. 6b), indicating that there were no strong preferences for particular species, and that the differences in yield per fingerling are not attributable to differences in stocking densities.

Population dynamics

Catch length distributions obtained from village ponds that had been operational for more than one year usually showed more than one mode, indicating the presence of several cohorts (age-groups) in the catch. The older cohorts often accounted for only a small proportion of catch in numbers, but contributed substantially to yield (often more than 50%). Hence, the effective production cycle of villages fisheries is longer than one year. The mean gear selection length on fishing days (the length above which fish are retained by the fishing gear) was estimated as about 13 cm on the basis of aggregated length distributions.

The growth trajectories (estimated from the analysis of length frequency data, see 'Appendix') and recapture rates of stocked species in the three ponds monitored by regular test fishing are shown in Fig. 7. Pond committees in all three villages decided not to hold catching days in the first year after stocking, and therefore, recapture rates, relate to a 1.5-year culture period without harvesting. Ponds A and B were of similar trophic status (TP 0.13 mg L^{-1}), while pond C was of higher trophic status (TP 0.23 mg L^{-1}). All three ponds were classified as Chinese-carp-dominated in the cluster analysis. Chinese (silver) carp and common carp consistently showed the highest growth rates, followed by mrigal and rohu. Growth of silver barb and tilapia was poor in all three ponds. Mrigal and silver carp showed consistently high recapture rates, rohu and silver barb each showed high recapture in one out of the three ponds,

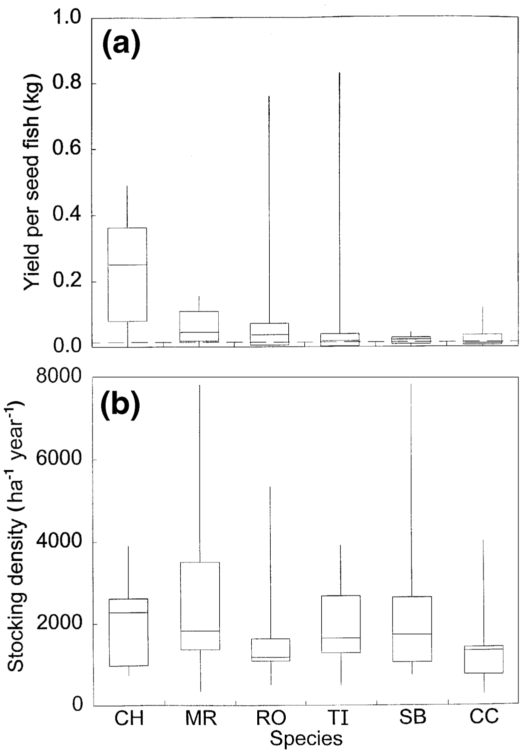

Figure 6 (a) Yield per fingerling and (b) stocking density for the stocked species. Vertical bars indicate ranges, boxes contain the middle 50% of the data, and horizontal bars indicate the median. The species are CH (Chinese carp), MR (mrigal), RO (rohu), TI (tilapia), SB (silver barb) and CC (common carp). The dashed line in (a) denotes the financial break-even level of yield per fingerling. Data for 10 ponds.

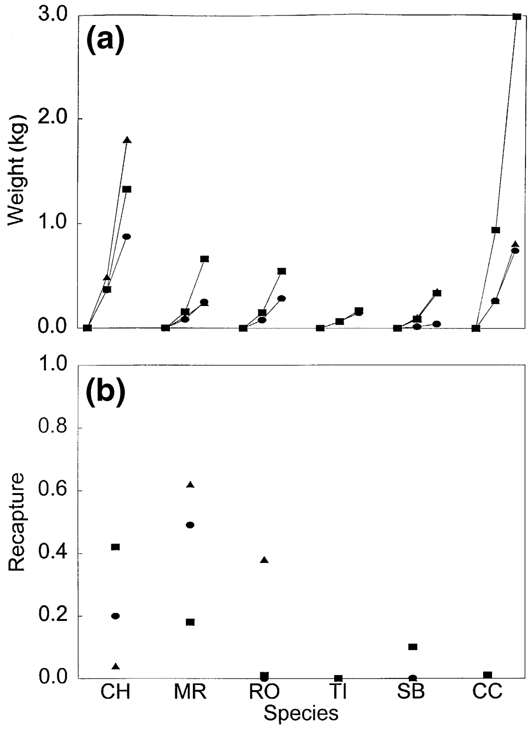

Figure 7 (a) Growth trajectories over 2 years and (b) recapture rates of different species stocked in the three village ponds monitored by regular test fishing. The species are CH (Chinese carp), MR (mrigal), RO (rohu), TI (tilapia), SB (silver barb) and CC (common carp). Ponds A (black circle) and B (black triangle) are of similar trophic status (*TP* 0.13 mg L^{-1}), while pond C (black square) is of higher trophic status (*TP* 0.23 mg L^{-1}). All three ponds were classified as Chinese-carp-dominated in the cluster analysis.

while recapture of common carp and tilapia was always poor. Chinese and Indian major carp combined good growth with high recapture rates, and consequently, showed the highest yields per fingerling (cf. Fig 6a). Silver barb and tilapia were poor on both growth and recapture, while common carp combined very good growth with poor recapture.

Figure 8 shows the predicted impact of different harvesting regimes on the equilibrium (long-term) yield from the three fisheries. Predictions are shown for three different values of the unknown harvest rate (the proportion of fish being harvested on the fishing day), and the corresponding values of natural mortality (see 'Appendix' for details). For each pond and value of the harvesting rate, predicted yields are given relative to the maximum achieved over the range of options considered. The optimal harvest rate (Fig. 4a) is predicted to be about 0.4, but any rate between 0.2 and 0.6 is likely to produce yields within 80% of the maximum, and this result is insensitive to the actual value of the harvest rate in the monitored fisheries. The timing of the fishing day relative to stocking (Fig. 4b) has little impact on yield if the harvest rate is low. If the harvest rate is high, the best yields are achieved if the fishing day is held about 3 months after stocking. At about 5–6 months after stocking, yields are most sensitive to the harvest rate and may be very low if the rate is high. During this period, the youngest cohorts become susceptible to the fishing gear and are prevented from achieving their production potential if a large proportion is harvested. The optimal gear selection length is predicted to be larger than the

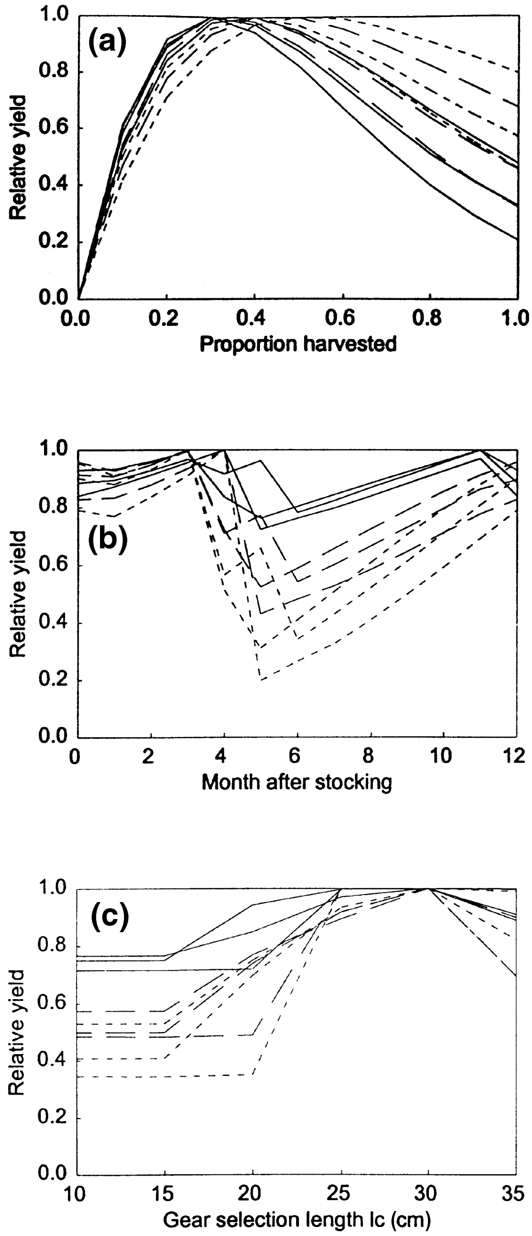

Figure 8 Impact of (a) the harvest rate, (b) timing of the fishing day and (c) gear selection length on yield. All predictions are given for the three ponds and for three mortality parameter sets assuming harvest rates of 0.33 (solid lines), 0.67 (dashed lines) and 1.0 (dotted lines). Default parameter values are: harvesting months after stocking; gear selection length 13 cm.

present value of about 13 cm (Fig. 4c). This result is not sensitive to the actual harvest rate, although the predicted benefits of increasing the gear selection length are largest if harvest rates are high.

Discussion

Status of village fisheries and options to improve extensive management

All the village fisheries surveyed were managed extensively, with no significant inputs of fertilizers or feed, and consequently, their yields were strongly influenced by the trophic status of the waterbody. Stocking density also had a significant effect on yield, with an optimum at about 9800 ha^{-1} for the given, variable mix of species. The median observed stocking density was 10 400 ha^{-1}, close to the predicted optimum, but a number of fisheries were heavily overstocked (cf. Fig. 2c). The costs of stocking at the optimal density account for a substantial proportion of fishing day revenue in waterbodies of low trophic status, but are insignificant in the more fertile waterbodies. An empirical model incorporating interaction terms would allow the optimization of stocking density with respect to trophic status. The estimation of interaction terms would require a larger set of data, comprising ponds for which trophic status and stocking density vary sufficiently to provide contrast, and are not correlated.

Yield was not significantly related to the species composition of the catch when the effect of trophic status was accounted for. Tilapia dominated the catches from the most fertile waterbodies, while carp dominated the catches from all others. This indicates that the relative performance of different species is related to trophic status, either directly or indirectly through trophic status effects on competitive interactions. Chinese and Indian major carp yielded the best returns per seed fish, while returns of silver barb and common carp were very low. Tilapia returns were also low, except in the most fertile waterbodies, where the species developed dominant breeding populations. Differences in species performance were attributable to differences in both growth and recapture. Overall, these results suggest that adjustments to the species composition of seed fish can be expected to increase yield and/or reduce stocking costs, and that the optimal combination of species may depend on the trophic status of the waterbody.

The population model indicates that a wide range of harvest rates (0.2–0.6) will result in yields within 80% of the maximum, but does not provide specific recommendations for the fisheries analysed because their actual harvest rate is unknown. Empirical Model 6 shows a weak positive relationship between fishing effort and yield for the observed range of effort, indicating that most fisheries could sustain higher harvesting rates. This does not necessarily imply that actual harvesting rates are below the optimum of about 0.4 predicted from the population model. The data set used in empirical modelling includes fisheries classified as mixed carp- or tilapia-dominated, and some of these may be able to sustain higher harvest rates than the three Chinese-carp-dominated systems analysed using the population model. Also, density-dependent responses in fish growth or mortality, which are not accounted for in the population model, would shift the predicted optimal harvest rate towards higher values.

Predictions from the population model also indicate a potential for improving the harvesting regimes of village fisheries by changing the time period between stocking and harvesting, or by increasing the mesh size of the fishing gear. Both options are predicted to increase yields substantially when harvest rates are high, but to have only a limited effect when harvest rates are low. Again, density-dependent responses would reduce the expected benefits from changes in the timing of management actions or gear selectivity, and could, in extreme cases, even result in negative effects.

The analysis has indicated a variety of management options that might improve the yields, or reduce the production costs in extensively managed village fisheries. Most of these options are still subject to considerable uncertainty, and therefore, require further investigation before specific recommendations can be given. Such investigations should be concentrated on options that are both feasible to implement, and expected to result in substantial improvements.

To identify such options, the potential increases in yield that can be expected from adopting them were predicted as follows. The effects of optimizing the stocking density, and of increasing fishing effort in all fisheries to the maximum observed value, were predicted using the empirical yield models. The effect of adjusting the species composition was predicted by assuming a yield per seed fish equivalent to the median of the three 'best' species in each pond, at the observed total stocking densities. The effects of improvements in the timing of management actions and in gear selectivity were predicted using the population model. The improvements in yield predicted for changes in the species composition, the timing of management actions, and gear selectivity do not account for density-dependent responses in growth or mortality, and therefore, are likely to overestimate the actual benefits. Table 3 provides an overview of the management parameters considered, the factors determining management practice with regards to these parameters (as identified by Chantarawarathit 1989; Garaway 1995; and in the present study), the feasibility of changing the parameters and the expected benefit of doing so (the median relative increase in yield predicted as outlined above). The various improvements are expected to result in median increases in yield of 22 and 124%. Adjustments of stocking density and species composition appear the most feasible options to implement, given that both are controlled by the village committees and the required seed are easily available (Purba 1990). Improvements in the stocking regime are expected to result in median increases in yield of 22–75%, and/or to reduce stocking costs. This suggests that the stocking regime is the most promising target for further research and extension efforts.

Is more intensive management feasible?

Intensification of village fisheries through feeding and fertilization has been widely promoted, but was not actually observed in any of the fisheries covered by the present study. Therefore, it is important to investigate whether intensification is likely to be beneficial in the context of a village fishery (and hence, should be promoted further) or whether extensive management is more appropriate (and hence, should be supported by specific research and extension efforts).

Because all of the village fisheries surveyed were managed extensively, the present study does not provide information relating to intensive management. However, some indication can be obtained from a comparison of the inputs required and outputs achieved in extensively managed village fisheries with those of semi-intensive farmer pond culture following locally appropriate management recommendations. The comparison is conducted from the point of view of the village and assumes that the waterbody is maintained primarily for purposes other than fish culture, therefore neglecting construction or opportunity costs. Table 4 details the average physical inputs and outputs of village fisheries under extensive and semi-intensive management, together with their costs and prices. Data for semi-intensive management (involving fry nursing, feeding and fertilization) are based on a study by AIT (1993). Also given are several

 © 1998 Blackwell Science Ltd,

Table 3 Feasibility and potential benefit of changing technical parameters in extensively managed village fisheries. Figures in brackets are subject to density-dependent responses of unknown magnitude, and are most likely to be overestimates

Management parameter	Determined by	Feasibility of change	Potential increase in yield (%)
Total stocking density	Advice from seed suppliers, experience	High	22
Species composition of seed fish	Advice from seed suppliers, experience	High	(< 75)
Number of tickets	Reputation and accessibility of pond, ticket price	Medium	61
Timing of stocking and harvesting	Seasonality in seed availability, water levels and agricultural labour demand	Low	(< 36)
Gear selectivity (mesh size)	Use of gear outside fishing day	Medium	(< 124)

performance indicators, the margin of village revenue over costs, the village return on communal labour (the margin divided by the total input of communal labour) and the village return on costs (the margin divided by total costs). These performance indicators are given for two management scenarios: a village fishery where revenue is obtained from the sale of fishing rights (i.e. tickets) to individuals; and a village aquaculture enterprise with communal harvesting where revenue is obtained from the sale of fish. For both scenarios, two sets of performance indicators are given, assuming free or paid communal labour. In a village fishery, extensive management provides a margin of 3452 or 2812 B ha^{-1}, depending on whether communal labour is provided free or is paid for by the village. Semi-intensive management would result in negative margins, and therefore, is not economically viable. The revenue realized from the sale of fishing rights (assuming the empirical average revenue per unit of yield of 7.7 B kg^{-1}) is insufficient to cover the costs of inputs required for semi-intensive management. A village aquaculture enterprise achieving normal market prices for produce (25 B kg^{-1}) would provide much higher margins than the village fishery, regardless of whether communal labour (including that needed for harvesting) is paid or not. In an aquaculture enterprise, semi-intensive management of the waterbody would be viable and produce higher margins, but lower returns on labour and costs than extensive management. Given that labour and finance may be difficult to raise for a marginal community activity like the village fishery, returns on labour and costs may be more important factors in village decision making than the gross margin. Hence, it is possible that villages would opt for extensive management, even under conditions where intensification would provide a higher margin of revenue over costs. A change in management from a fishery to an aquaculture enterprise would increase net village income, regardless of the intensity of production. However, villagers place a high value on the fishing day as a social occasion (Chantarawarathit 1989; Garaway 1995) and may wish to retain the fishery even though an aquaculture enterprise would produce a higher net income.

Research and extension to improve the management of village fisheries

The present study has provided an overview of management practice in village fisheries, identified relationships between natural conditions, management and yield, and indicated a number of ways in which management could be improved. The costs of collecting and analysing the data used in the study are estimated at about 150 000 B (US$ 6000), which given a total area of the 16 waterbodies of about 100 ha, is equivalent to 1500 B ha^{-1}. This is less than 30% of the median annual revenue per hectare from the fisheries, and about equal to the improvement in revenue expected from the optimization of stocking density alone. This suggests that empirical analyses of operational village fisheries and the use of simple models provide a cost-effective way of identifying management regimes that may significantly improve the performance of these systems. Related empirical modelling approaches have been used to evaluate management regimes in Chinese culture-based reservoir fisheries (De Silva, Lin & Tang 1992),

Table 4 Comparison of village fisheries and aquaculture enterprises under extensive (Ext) and semi-intensive (S-int) management in terms of physical inputs and outputs, and financial performance indicators. Data for semi-intensive management are based on an analysis of recommendations for farmer pond culture (AIT 1993)

	Physical units			**Monetary units Village fishery**		**Village aquaculture**	
	Ext	**S-int**	**Value (B unit^{-1})**	**Ext (B ha^{-1})**	**S-int (B ha^{-1})**	**Ext (B ha^{-1})**	**S-int (B ha^{-1})**
Inputs							
Materials:							
seed (1 ha^{-1})	9700	18 750	0.1	970	1875	970	1875
manure (kg ha^{-1})	0	12 625	0.05	0	631	0	631
urea (kg ha^{-1})	0	1263	5	0	6315	0	6315
hapa (1 ha^{-1})	0	6	184	0	1104	0	1104
ipomea (kg ha^{-1})	0	2856	0	0	0	0	0
duck layer conc. (kg ha^{-1})	0	181	15	0	2715	0	2715
rice bran (kg ha^{-1})	0	81	5	0	405	0	405
tickets, etc. (1 ha^{-1})	1	1	614	614	614		
Labour:							
nursing (days ha^{-1})	0	16	40	0	640	0	640
ipomea coll. (days ha^{-1})	0	42	40	0	1680	0	1680
manure coll. (days ha^{-1})	0	26	40	0	1040	0	1040
maintenance (days ha^{-1})	16	16	40	640	640	640	640
fish harvest (days ha^{-1})	60	60	40			2400	2400
Outputs							
Yield (kg ha^{-1})	654		1563				
Ticket revenue (B ha^{-1})				7.7	5036	12 035	
Market value (B ha^{-1})				25		16 350	39 075
Performance indicators							
Communal labour demand		(days)		16	100	76	160
Communal labour (free):							
gross margin of revenue over costs		(B ha^{-1})		3452	–1624	15 380	26 030
village return on communal labour		(B day^{-1})		216	–16	202	163
village return on cost		(%)		218	–12	1586	200
Communal labour (paid):							
gross margin of revenue over costs		(B ha^{-1})		2812	–5624	12 340	19 630
village return on communal labour		(B day^{-1})		176	–56	162	123
village return on costs		(%)		126	–32	308	101

tilapia pond culture (Prein, Hulata & Pauly 1993), Israeli commercial polyculture systems (Milstein 1995) and culture fisheries in oxbow lakes in Bangladesh (Middendorp *et al.* 1996).

Empirical analyses to identify beneficial management options rely on the presence of sufficient contrast (i.e. variation) in management practices to generate significant responses in the variables of interest (e.g. yield). In the present study, for example, the optimal stocking density for village fisheries could be estimated only because the survey covered fisheries that had been stocked at widely different densities. When planning further research and extension efforts to improve village fisheries, it is important to consider the trade-off between achieving immediate improvements through the implementation of specific recommendations, thereby reducing variation in management, and the potential for identifying better recommendations if variation is maintained or actively enhanced. Results from the present study suggest that stocking at a density of about 9800 ha^{-1}, combined perhaps with a shift in species composition towards high performing species, is likely to improve yields in

 © 1998 Blackwell Science Ltd, *Aquaculture Research*, **29,** 211–224

most village fisheries. However, large uncertainties remain regarding the optimal species composition and its relation to trophic status, and the potential for resolving these uncertainties would be reduced if all villages adopted the recommendations outlined above.

Two different approaches could be taken to resolve the remaining uncertainties. One approach is simply not to issue recommendations for the time being, but to conduct a more extensive survey, relying on the existing level of variation in stocking regimes to yield the desired information. Alternatively, an explicitly experimental approach could be adopted. For example, the DOF could treat its programme of providing free seed fish in the first years of village fisheries operation as a large-scale experiment, stocking systematically different species combinations and total densities in different waterbodies to enhance contrast in a way most likely to yield the information required. Both approaches would, of course, require the systematic collection of data on stocking, catches and trophic status from a set of village fisheries. The expected benefits of the different strategies outlined, i.e. the immediate implementation of recommendations, further empirical analyses based on existing levels of variation in management parameters, or active experimentation should be analysed carefully before embarking on large-scale research and extension efforts. It may also be possible to devise mixed strategies, such as actively experimenting with a limited set of fisheries while issuing uniform preliminary recommendations for all others. Walters (1986, Chapter 10) outlines some of the considerations involved in evaluating adaptive learning strategies for replicated systems such as the village fisheries. Further research is urgently required to provide specific guidance on adaptive learning approaches to the development of culture fisheries systems in small waterbodies.

Acknowledgments

This work was supported by the Department for International Development of the United Kingdom, through the Fisheries Management Science Programme.

References

Ahmed M. (1992) *Status and potential of aquaculture in small waterbodies (ponds and ditches) in Bangladesh.* ICLARM Technical Report 37. ICLARM, Manila.

Asian Institute of Technology (AIT) (1993) *An economic comparison of aquaculture with cropping options for small-scale farmers in Northeast Thailand.* AIT Aquaculture Outreach Project, Working Paper No. 5. AIT, Bangkok.

American Public Health Association (APHA) (1989) *Standard Methods for the Examination of Water and Wastewater,* 17th edn. APHA, Washington, DC.

Chantarawarathit N. (1989) *The DOF village fisheries project: an analysis of its problems and impact on Udonthani Province, Thailand.* M.Sc. thesis, Asian Institute of Technology, Bangkok.

De Silva S.S. (1988) *Reservoirs of Sri Lanka and their fisheries.* FAO Fisheries Technical Paper 298. FAO, Rome.

De Silva S.S., Lin Y. & Tang G. (1992) Possible yield-predictive models based on morphometric characteristics and stocking rates for three groups of Chinese reservoirs. *Fisheries Research* **13**, 369–380.

Garaway C.J. (1995) *Communal ponds in NE Thailand under different use-rights systems: a participatory rural appraisal of their differing roles in peoples' livelihoods.* Technical Report. MRAG Ltd, London.

Haigh B.A. (1994) *Report on the Technical Consultation on the Enhancement of Small Water Body Fisheries in Southern Africa.* ALCOM, Harare, Zimbabwe.

Jhingran A.G. (1992) Fisheries status of aquaculture-based open water systems in India. In: *Aquaculture Productivity* (ed. by V.R.P. Sinha & H.C. Srivastava), pp. 295–306. Oxford and IBH Publishing, New Delhi.

Li S. & Xu S. (1995) *Culture and Capture of Fish in Chinese Reservoirs.* International Development Research Centre, Ottawa.

Lorenzen K. (1996) The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. *Journal of Fish Biology* **49**, 627–647.

Manly B.F.J. (1994) *Multivariate Statistical Methods: A Primer,* 2nd edn. Chapman & Hall, London.

Mekong Committee (MC) (1992) *Fisheries in the lower Mekong River.* Interim Committee for Coordination of Investigations of the Lower Mekong Basin, Bangkok.

Middendorp A.J., Hasan M.R. & Apu N.A. (1996) Community fisheries management in freshwater lakes in Bangladesh. *NAGA, The ICLARM Quarterly,* April-June, 4–6.

Milstein A. (1995) Fish-management relationships in Israeli commercial fish farming. *Aquaculture International* **3**, 292–314.

Marine Resources Assessment Group (MRAG) (1992) *Length Frequency Data Analysis (LFDA).* Software Package. MRAG Ltd, London.

Pauly D. (1987) A review of the ELEFAN system for analysis of length frequency data in fish and aquatic invertebrates. In: *Length-based Methods in Fisheries Research* (ed. by D. Pauly & G.R. Morgan), pp. 7–34. ICLARM, Manila.

Prein M., Hulata G. & Pauly D. (1993) Multivariate methods in aquaculture research: case studies of tilapias in experimental and commercial systems. *ICLARM Studies and Reviews* 20. ICLARM, Manila.

Purba S. (1990) *An economic study of fry production systems in Northeast Thailand.* M.Sc. thesis. Asian Institute of Technology, Bangkok.

Seber G.A.F. (1982) *The Estimation of Animal Abundance and Related Parameters*. Griffin, London.

Shepherd J.G. (1987) Towards a method for short-term forecasting of catch rates based on length compositions. In: *Length-Based Methods in Fisheries Research* (ed. by D. Pauly & G.R. Morgan), pp. 113–120. ICLARM, Manila.

Walters C.J. (1986) *Adaptive Management of Renewable Resources*. Wiley, New York, NY.

Welcomme R.L. (1996) Aquaculture and world aquatic resources. In: *Aquaculture and Water Resource Management* (ed. by D.J. Baird, M.C.M. Beveridge, L.A. Kelly & J.F. Muir), pp. 1–18. Blackwell, London.

Appendix

A simple harvesting model for village fisheries

The following model was used to evaluate the impact of different harvesting regimes, defined by the time t at harvesting, the harvest rate H and the gear selection length l_c on the equilibrium yield of village fisheries. Fish growth is described by a von Bertalanffy growth function (VBGF):

$$W_{t,s} = [(W_{\infty,s}^{1/3} - (W_{\infty,s}^{1/3} - W_{0,s}^{1/3}) \exp(-K_s\, t)]^3 \quad (1)$$

where $W_{t,s}$ is the body weight at time t after stocking, $W_{\infty,s}$ and K_s are the von Bertalanffy growth parameters, and $W_{0,s}$ is the weight at stocking for species s.

Fishing days are held annually at the same time, i.e. cohorts are subject to successive harvesting events separated by one year. Cohort abundance prior to harvesting at time t is given by

$$N_{t,s} = (N_{t-1,s}\, C_{t-1,\,s}) \exp\left[-M_{u,s} \left(\frac{W_{t-1,s}^{1/3} + W_{t,s}^{1/3}}{2} \right)^{3b} \right] \quad (2)$$

where $N_{t,s}$ is the cohort abundance at time t, $N_{t\text{-}1,s}$ and $C_{t\text{-}1,s}$ are the cohort abundance and the catch at the previous fishing day (t – 1), and $M_{u,s}$ and b are the parameters of a size-dependent mortality model (Lorenzen 1996). On the first fishing day, $N_{t\text{-}1,s}$ equals the stocking density $N_{0,s}$ and $C_{t\text{-}1,s}$ equals 0. Catch on the fishing day at time t is given by

$$C_{t,s} = \begin{cases} N_{t,s}\, H & \text{if } W_{t,s} \geqslant W_{c,s} \\ 0 & \text{if } W_{t,s} < W_{c,s} \end{cases} \quad (3)$$

where H is the harvest rate and $W_{c,s}$ is the weight corresponding to the gear section length l_c. Both the harvest rate H and gear selection length l_c were assumed to be the same for all species.

Total equilibrium yield is the sum of the yields of all species and age groups over the lifetime of the cohorts:

$$Y = \sum_{t=0,\, s=1}^{t_{\max,S}} C_{t,s}\, W_{t,s} \quad (4)$$

where $t_{\max}$ is the maximum age considered (here 5 years) and S is the number of species (here six).

Estimation of parameters

Model parameters were estimated for all species stocked in the three village fisheries for which complete stocking, test fishing and harvest data were available. Von Bertalanffy growth parameters were estimated from length frequency distributions, using the ELEFAN (Pauly 1987) and projection matrix (Shepherd 1987) methods as implemented in the LFDA software package (MRAG 1992). The mean gear selection length was estimated from aggregated length distributions of the fishing day catches. Mortality rates were estimated from the recapture rates of stocked fish. The natural mortality rate during the period t from stocking to harvesting is given by

$$M_s = -\ln \left(\frac{C_s}{N_{0,s}\, H} \right) \frac{1}{t} \quad (5)$$

where C is the catch (recapture) from the cohort, N_0 is the stocking number and H is the harvest rate. The natural mortality rate $M_{u,s}$ at unit weight is then given by

$$M_{u,s} = M_s \left(\frac{W_{t-1,s}^{1/3} + W_{t,s}^{1/3}}{2} \right)^{-3b} \quad (6)$$

The allometric scaling factor of natural mortality b was assumed to be –0.3, in accordance with the empirical study of Lorenzen (1996). The harvest rate on the fishing day could not be estimated from the available data, and therefore, natural mortality rates were determined for different assumed harvest rates of 0.33, 0.66 and 1.