
Culture Fisheries Assessment Methodology



Final Report
Fisheries Management Science Programme
Overseas Development Administration

MRAG Ltd. July 1996

RNRRS PROJECT COMPLETION REPORT

Culture Fisheries Assessment Methodology

R5958

RNRRS: Fisheries Management Science Programme

PROGRAMME MANAGER: MRAG Ltd

SUB-CONTRACTORS: Asian Institute of Technology Aquaculture Outreach Project, Udon Thani, Thailand

Fisheries College, University of Agricultural Sciences, Mangalore, India

Freshwater Fisheries Research and Development Centre, Royal Thai Department of Fisheries, Udon Thani, Thailand

Zhejiang Institute of Freshwater Fisheries, Huzhou, Zhejiang, China

RNRRS PROGRAMME PURPOSE: Yields from enhanced fisheries increased by optimising strategies for stocking and harvesting

PRODUCTION SYSTEM: Land/water interface

COMMODITY BASE: Floodplain and lacustrine finfish

BENEFICIARIES: Artisanal and subsistence full and part-time fishermen, communities and cooperatives

TARGET INSTITUTIONS: Fisheries departments at various levels, reservoir authorities, and research institutions

GEOGRAPHIC FOCUS: South, Southeast and East Asia

	<u>PLANNED</u>	<u>ACTUAL</u>
START DATES	01.04.94	01.04.94
FINISH DATES:	31.03.96	30.06.96
TOTAL COST:	£ 83,520	£ 84,692

1. Project purpose

Development of methodology for the assessment of culture fisheries, in particular:

- (i) Quantitative assessment of technical management options
- (ii) Quantitative bio-economic analysis
- (iii) Socio-economic assessment of management options
- (iv) Integrated framework for the appraisal of culture fisheries development options

2. Outputs

Quantitative methods for the biological/technical assessment of culture fisheries have been developed. A comparative, empirical analysis has been carried out of mortality-size relationships in natural ecosystems and in aquaculture. The results provide a basis for the optimisation of seed size in culture fisheries, and

in are also of wider relevance to the design of aquaculture systems. A transparent modelling technique for culture fisheries assessment has been developed. All analyses, from parameter estimation to yield prediction, are carried out in computer spreadsheets. The models are easily adapted to take account of culture system specifics and data availability. A prototype software package for the analysis of stocking in seasonal water bodies has also been designed, and the feasibility of developing an expert system for Chinese reservoir culture explored.

For the bio-economic analysis of culture fisheries, technical/biological system models have been integrated with economic techniques of profitability, activity and investment analysis. Bio-economic analyses have been employed to assess stocking and harvesting patterns in operational culture fisheries, to appraise the benefits and costs of integrating culture fisheries with seed production, and to evaluate stocking and effort control options in developing culture fisheries.

Rapid and participatory appraisal (RRAP/PRA) methods were adapted for the assessment of resource use conflicts and the distribution of benefits from culture fisheries. An RRA sequence has been developed to facilitate the rapid appraisal of key issues in culture fisheries, without compromising the flexible and adaptive nature of the RRA and PRA approach. Rapid appraisal methods were also adapted to obtain detailed information for the technical and bio-economic assessment of culture fisheries and other aquatic resource uses.

The methodology developed has been integrated into a framework for the appraisal of culture fisheries development options. A checklist of key issues that should be addressed in such an appraisal has also been developed.

The methodology developed has been applied to three case studies in China, India and Thailand. In China, highly developed extensive culture systems were analysed with respect to their technical and economic efficiency. In India, development options in an artisanal, moderately enhanced fishery were analysed with respect to stocking and effort control. In Thailand, village fisheries managed for community income were studied with respect to stocking and harvesting patterns, prediction of yield from limnological characteristics, use conflicts, and distribution of benefits.

3. Contribution of outputs to project goals

The project purpose has been achieved: a methodology for the technical, bio-economic and socio-economic assessment of culture fisheries has been developed. The project contributes significantly to RNRRS-FMSP Purpose 2, "yield from enhanced fisheries increased by optimising strategies for stocking and harvesting", in that it provides methodology for the evaluation of stocking and harvesting strategies in culture fisheries. Project methodology is also applicable to the analysis of extensive aquaculture systems, and therefore makes a contribution to RNRRS Aquaculture Research Programme Purpose 2, "sustainable yields from small-scale, semi-intensive and extensive aquaculture systems increased through improved management".

There has already been significant uptake of project results in India, Thailand, and Laos, where the new assessment methodology is being applied in various projects. Results have also been taken up internationally by FAO, who have invited contributions on the methodology for their forthcoming Expert Consultation on Fisheries Enhancements. Hence project outputs are already contributing to the achievement of developmental goals.

4. Publications in press

Lorenzen, K. (in press) The relationship between body weight and natural mortality in juvenile and adult fish, a comparison of natural ecosystems and aquaculture. *Journal of Fish Biology*.

Lorenzen, K. (in press) Culture-based fisheries in Asian reservoirs and lakes: Key issues for sustainability. In: *Network of Aquaculture Centers in Asia-Pacific (Ed.) Aquaculture Sustainability and the Environment*. Bangkok/Manila: ADB/NACA.

5. Internal reports and manuscripts submitted or in preparation

Publications submitted

Lorenzen, K., Xu, G., Cau, F., Ye, J., & Hu, T. (subm.) Extensive fish culture in Chinese reservoirs: analysis of management options by transparent population modelling. Submitted to *Aquaculture Research*

Internal reports

Chevalier, C. (1995) Culture fisheries: Programme and user's guide DAA Agro-Informatique, INP-ENSA Toulouse, and MRAG Ltd.

Cowan, V.J. (1995) A participatory rural appraisal of the exploitation and ecology of snakehead (*Channa striata*) in Kumpawapee District, Northeast Thailand MRAG/AIT Aquaculture Outreach Research Report.

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. MRAG/AIT Aquaculture Outreach Research Report

Lorenzen, K. (1994) Dynamics and management of Asian culture-based reservoir fisheries. *Aquaculture News* 18, 20.

Lorenzen, K. (1996) A draft framework for the appraisal of culture fisheries development. Discussion Paper

Zhang, S. (1995) Knowledge-based decision making support system for culture-based fisheries management. MSc Thesis (Knowledge Engineering), University of Westminster.

Publications and reports in preparation

Lorenzen, K., Juntana, J. & Bundit, J. (in prep.) Communal pond fisheries in Northeast Thailand: status and management options. Research Report.

Lorenzen, K., Mohan, C.V. & Bhatta, R. (in prep.) Assessing the potential for culture fisheries development: a case study of Vanivilas Sagar reservoir, India. To be submitted to *Fisheries Research*.

Lorenzen, K., Xu, G., Cau, F., Ye, J., & Hu, T. (in prep.) Bio-economic analysis of extensive fish culture in Chinese reservoirs: a case study of Siming reservoir, Zhejiang. To be submitted to *Aquaculture*.

6. Other dissemination of results

Oral presentations at conferences and seminars

The Seventh International Conference on Natural Resource Modelling and Analysis, London, August 1994 (Lorenzen)

Mekong River Commission Regional Workshop on Reservoir Fisheries Development, Ubon Ratchathani, Thailand, February 1995. (Garaway, Lorenzen presented by Garaway)

Seminar at the Institute of Aquaculture, Stirling University, November 1995 (Garaway, Lorenzen)

Fourth Asian Fisheries Forum, Beijing, China, October 1995 (Lorenzen, 2 presentations)

Asian Development Bank/Network of Aquaculture Centers in Asia-Pacific Workshop on Aquaculture Sustainability and the Environment. Beijing, China, October 1995 (Lorenzen)

Third World Fisheries Congress, Brisbane, Australia July 1996 (Beddington)

Workshops and training courses organised:

Project workshop on the assessment of Chinese culture-based reservoir fisheries, London, February 1996.

Training course on "The Assessment of Culture-Based Reservoir Fisheries" for Biologists of the Thai Department of Fisheries, Udon Thani, Thailand, March 1995

Workshop on the biological and socio-economic assessment of culture-based reservoir fisheries, London, May 1995. (Workshop was organized on the occasion of the visit of Dr V.V. Sugunan, FAO Andre Mayer Research Fellow on small reservoir fisheries.

Workshop on management and development options for Vanivilas Sagar reservoir, Mangalore, Karnataka, India, June 1996

7. Follow-up indicated/planned

The design of suitable training materials and courses is essential to promote wider uptake of project results. Courses delivered as part of the collaborative agreements under the project have shown very promising results in terms of uptake, facilitated in particular by the transparent spreadsheet modelling approach.

An adaptive project applying the methodology developed in the present project is already operational in Laos. Further adaptive projects are envisaged, with funding from ODA as well as other donors.

Further strategic research is indicated in the following areas:

- (i) Meta-analysis and adaptive management of culture fisheries.
- (ii) Geographic information systems to support culture fisheries development.
- (iii) Economic analysis of the wider costs and benefits of culture fisheries development and their distribution.
- (iv) Analysis of institutional requirements in culture fisheries
- (v) Comprehensive management of small water bodies for fish production.

Concept notes addressing areas (i) and (ii) have been developed and accepted by the PAC. The other areas have been included in the FMSP strategy, and concept notes will be developed in due course.

8. Name and signature of the author of this final report

K Lorenzen

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- II **The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture,** by K. Lorenzen. *Journal of Fish Biology*, in press.
- III **Extensive fish culture in Chinese reservoirs: analysis of management options by transparent population modelling,** by K. Lorenzen, G. Xu, F. Cau, J. Ye & T. Hu. Submitted to *Aquaculture Research*.
- IV **Culture-based fisheries in Asian reservoirs and lakes: key issues for sustainability,** by K. Lorenzen. In: *Aquaculture Sustainability and the Environment* NACA/ADB.
- V **Communal ponds in NE Thailand under different use-rights systems: a participatory rural appraisal of their differing role in people's livelihoods,** by C.J. Garaway. Research report
- VI **A framework for the analysis of culture fisheries development.** by K. Lorenzen. Discussion Paper.

1. Executive Summary

- (1) Culture fisheries utilise the natural productivity of aquatic ecosystems for fish production based on the stocking and recapture of farm produced seed fish. Successful development of culture fisheries production systems relies on the design of stocking and harvesting regimes that are appropriate for the particular natural and socio-economic conditions under which they operate. Culture fisheries may be divided on the basis of resource ownership into fisheries and aquaculture systems, and this distinction has important implications for economic analysis. On the other hand, both forms of culture fisheries share a common biological and technical basis with strong implications for management and development options. This project was aimed at developing methods for the assessment of culture fisheries, integrating technical assessment with economic and socio-economic analysis.
- (2) The relationship between body weight and natural mortality in fish was investigated in order to provide a basis for the quantitative assessment of optimal seed size for stocking. The mortality-weight relationship found in natural ecosystems was consistent across ecosystems (lakes, rivers, and the ocean), as well as across taxonomic or ecological groups from the community down to the population level. The mortality-weight relationship in aquaculture differed systematically from that found in natural ecosystems.
- (3) Transparent population models for the analysis of management options in culture fisheries have been developed. The analyses are carried out in computer spreadsheets, are easily adapted to particular culture systems, and can make use of variety of data sources. The analyses cover all fundamental technical management issues in culture fisheries, the size and density of seed fish, and the gear selectivity and effort of harvesting.
- (4) For the bio-economic analysis of culture fisheries, biological/technical models were combined with methods of economic assessment. Bio-economic analyses were carried out of effort control and cost recovery in publicly owned culture fisheries, and to the efficient management of privately owned culture fisheries with particular reference to vertical integration.
- (5) Rapid and participatory appraisal (RRA/PRA) methods were adapted to obtain key technical and economic information, and for the assessment of resource use conflicts and the distribution of benefits from culture fisheries. An RRA sequence has been developed to facilitate the rapid appraisal of key issues in culture fisheries, without compromising the flexible and adaptive nature of the RRA and PRA approach.
- (6) The methodology developed has been applied to three case studies of culture fisheries in China, India and Thailand. In China, highly developed extensive culture systems were analysed with respect to their technical and economic efficiency. In India, development options in an artisanal, moderately enhanced fishery were analysed with respect to stocking and effort control. In Thailand, village fisheries managed for community income were studied with respect to the relationship between yield and community benefits, impact of natural conditions and stocking regime on yield, use conflicts, and distribution of benefits.
- (7) The biological/technical, bio-economic and socio-economic assessment methodology and the experiences from the case studies have been integrated into a framework for the appraisal of culture fisheries development. The framework is presently in draft form, and will be finalised following consultation with other specialists and practitioners.

2. Background

Culture-based fisheries are defined as fisheries based partly or entirely on the recapture of farm-produced seed fish. Culture-based fisheries are fish production systems at the interface of aquaculture and capture fisheries. They can be considered the most extensive form of aquaculture, or the most intensive way of managing a capture fishery. The FAO definition of aquaculture and fisheries is based on the notion of resource ownership: aquaculture implies individual or corporate ownership of the resource, while fisheries use common property resources with or without access regulation. In this sense, the present project deals with both culture-based fisheries and extensive aquaculture, and distinguishes between them where this is relevant. In practice it is not uncommon for ownership patterns in culture fisheries to change repeatedly between individual licenses, exclusive rights for a corporate entity, and open access. Consequently, the aquaculture-fisheries distinction is among the less stable attributes of culture fisheries systems.

Culture fisheries can increase productivity where the natural recruitment of resource populations is insufficient to fully utilise the production potential of a water body. This is often the case in modified inland water bodies such as reservoirs or flood control schemes, or where overfishing has drastically reduced the spawning stock. Culture fisheries have the potential to benefit resource poor sections of the population for whom more intensive fish culture is out of reach, but they may also disadvantage certain users of aquatic resources.

Commercial culture-based fisheries and extensive aquaculture of finfish are estimated to contribute about one million tons to the world's fish production, accounting for about 1 % of the total, or 5 % of aquaculture production. By far the largest part of this production is achieved in Asia, where China alone is estimated to produce 360,000-600,000 t/year in extensive fish culture in reservoirs and lakes (Lu 1992, Wang & Yi 1995). This is substantially more than the yield from salmon ranching (about 200 000 t per year), the second largest and by far the best studied culture fishery. Precise figures on culture fisheries are difficult to obtain, because the yields from this production system tend to be assimilated into the statistics of either aquaculture or capture fisheries. The productivity of culture fisheries varies greatly within Asia. The average productivity of Chinese reservoirs is very high, estimated at about 370 kg/ha/year (Li & Xu 1995). By contrast India, probably the second largest culture-based fisheries producer in Asia, is characterized by low productivity of 20 kg/ha/year, regarded as well below its potential (Sugunan 1995). Asian culture-based inland fisheries are dominated by carp species, and are estimated to account for about 5 to 10 % of total carp production in countries like China, India or Thailand. Hence culture fisheries are a relatively minor production system at the national or regional level, but may be of far greater local importance in the resource poor areas where they tend to operate. Moreover, the present culture fisheries production in many countries is regarded as well below its potential.

Many Asian governments and NGOs, as well as international donors, support culture-based fisheries through seed production and stocking. In spite of such investment, culture-based fisheries have received comparatively little attention in research, extension and policy formulation. Some projects have attempted to establish culture-based fisheries at unsuitable sites, or paid insufficient attention to the development of appropriate management regimes. Consequently, the benefits from culture-based fisheries have sometimes fallen short of expectations. Other culture-based fisheries and extensive culture systems have operated successfully for a long time, and have generated substantial benefits for their stakeholders. Such contrasting evidence indicates the need for a comprehensive methodology to assess the suitability of potential sites for the development of culture fisheries, and to devise appropriate management systems for new and established culture fisheries.

3. Project Purpose

This project was conceived to address the identified need for a methodology to assess management regimes of culture fisheries, and to appraise the suitability of potential sites for culture fisheries development. In recognising the diversity of natural and socio-economic conditions under which culture fisheries operate and upon which they depend, the project aimed to develop methods for site-specific assessments as opposed to technology packages.

Specifically, the purpose of the project was to develop methods for the

- (i) Quantitative assessment of technical management options.
- (ii) Quantitative bio-economic analysis.
- (iii) Socio-economic assessment of management options.
- (iv) Integrated appraisal of culture fisheries development.

4. Research Activities

A wide range of research activities were carried out in London and at the project's field sites in China, India and Thailand. Project staff comprised one full-time scientist, and a large number of local collaborators who carried out project work on a part-time basis. Three MSc students were supported and temporarily employed by the project, and have contributed significantly to project outputs. A full list of staff is given below.

MRAG Ltd.

Prof John Beddington (Principal Investigator, advising)
Mr Kai Lorenzen (Principal Investigator, full time)
Mr Christophe Chevalier (ERASMUS Student/temporary Research Assistant)
Ms Vicki Cowan (MSc Candidate/temporary Research Assistant)
Ms Caroline Garaway (MSc Candidate/temporary Research Assistant)

AIT Aquaculture Outreach, Udon Thani, Thailand

Mr Danai Tourongruang (Outreach Manager)
Ms Jatuporn Bundit (Project Research Assistant)

Fisheries College, Mangalore, India

Dr C.V. Mohan (Associate Professor)
Dr Ramachandra Bhatta (Associate Professor)

Freshwater Fisheries Research and Development Centre, DOF, Udon Thani, Thailand

Mr Keeree Kohanantakul (Director until 1995)
Mr Charinchai (Director from 1995)
Mr Jirachai Juntana (Fisheries Scientist)

Zhejiang Institute of Freshwater Fisheries, Huzhou, Zhejiang, China

Mr Xu Guxing (Director until 1995)
Mr Ye Jinyun (Director from 1995)
Mr Cao Fukang (Director of Aquatic Resource Laboratory)
Mr Hu T (Scientist)

The research activities carried out in the project can be divided into two areas: the development of methodology aimed at the specific needs of culture fisheries assessment and management, and the application of this methodology to case studies of particular fisheries.

4.1 Development of methodology

Development of methodology focussed on four aspects: mortality-weight relationships as an important aspect of the biological basis of culture fisheries, population models for the practical assessment of culture fisheries, tools for bio-economic analysis, rapid appraisal of socio-economic aspects, and the integration of the technical, economic and social aspects into a framework for appraisal

4.1.1 Mortality-weight relationship

A large set of empirical data on natural mortality and weight in fish in different natural ecosystems and aquaculture systems has been compiled. The relationship between body weight and natural mortality was analysed for lakes, rivers, and the ocean, as well as pond, cage and tank aquaculture systems.

4.1.2 Population modelling for assessment

The population model for culture fisheries developed in Project R5023 (Lorenzen 1995, 1996) has been reformulated in various ways to facilitate its practical application to a wide range of culture-based fisheries and extensive culture systems. The length-based version has been expanded to include natural recruitment, and the algorithm used for constructing the growth projection matrix has been revised to increase computational efficiency. An age-based version of the model has been devised and implemented in computer spreadsheets, to allow a transparent and flexible analysis. Spreadsheet-based approaches to the estimation of model parameters from stocking and catch data have also been devised and tested.

An interactive computer package has been developed for the analysis of stocking and catch data from seasonal reservoirs. The feasibility of developing an expert system for the management of Chinese culture-based reservoir fisheries has been assessed.

4.1.3 Bio-economic analysis

The population models for culture-based fisheries and extensive aquaculture systems have been linked with established tools of economic analysis, in order to allow a bio-economic assessment of culture fisheries. Management and development options in a Chinese reservoir culture system have been analysed using cost and activity analysis. The potential for developing a culture-enhanced fishery in an Indian reservoir under various stocking and effort control options has been analysed using a bio-economic model with investment appraisal methods.

4.1.4 Rapid appraisal methods

Rapid and participatory rural appraisal (RRA/PRA) methods have been adapted to explore the wider socio-economic context of culture fisheries and their interaction with other aquatic resource uses, and to obtain crucial technical and economic information for assessment. The methods were used most extensively in Thailand, but also in India and in reduced form in China.

4.1.5 Integrated framework for appraisal

An integrated framework for the appraisal of culture fisheries development has been drafted. Key issues were identified from the project case studies, theoretical considerations, and a review of the relevant literature. Guidelines for the investigation of these issues were developed and a checklist of key aspects in the appraisal of culture fisheries was compiled.

4.2 Case studies

Case study sites were selected to cover some of the major culture fisheries systems in Asia, with a diversity of assessment and appraisal needs.

4.2.1 China

This case study aimed to provide a detailed analysis of large-scale extensive fish culture in Chinese reservoirs, the most developed culture fisheries system. Long-term records of stocking and catch data for two reservoirs of 100 and 760 ha have been compiled and analysed using age-based spreadsheet population models. Detailed economic data for the larger reservoir was collected during a field visit. An assessment of management options in economic terms was carried out by combining the population models with economic analyses.

4.2.2 India

The Indian case study aimed to assess the potential for culture fisheries development in a large reservoir exploited by an artisanal fishery. Routine data collection in India was conducted in collaboration with, and funded by ODA-FMSP Project R4822 (Effects of parasitism on the yield of small reservoir fisheries). Data on the species and size composition of landings from the large Vanivilas Sagar reservoir have been collected over 18 months from the major fish marketing centre. A rapid rural appraisal was conducted to gain baseline information on fishing activities and their economics. Market sampling and RRA data were used to estimate the total yield of the reservoir, and growth and mortality of the major carp species. The major carp fishery including the possible contribution from past stocking was assessed using the length-based population model. The potential for more intensive enhancement of the major carp fishery under different management regimes was evaluated, based on the data collected from the reservoir and comparative information.

4.2.3 Thailand

This case study aimed to assess management options in communal culture fisheries run primarily to generate village income from the sale of fishing tickets. A baseline survey of communal pond fisheries was conducted in a district of Udon Thani province, a mini-watershed covering a variety of agroecological zones. Information on a wide range of management issues was collected by means of structured interviews with village headmen or elders. Data on total catches and catch composition were collected by sampling on fishing days, and by interviewing randomly selected villagers about their catches as part of the baseline survey. Information on fishing effort (number of tickets) and stocking density was also collected, and limnological sampling was conducted to assess the trophic status of the water bodies. A stocking experiment was conducted in 6 communal ponds, which were monitored over a 1.5 year period to determine the growth and mortality of stocked fish as well as the seasonality of limnological parameters. Participatory rural appraisals were conducted to assess the impact of community fisheries on the utilisation of resources and the distribution of benefits from village water bodies. Participatory appraisals were also conducted to study the exploitation of the key wild fish resource at the village level, the migratory snakehead (*Channa striata*).

5. Project Outputs

5.1 Development of methodology

The development of methodology built upon the foundations laid in the previous project R5023 (Potential yield of South Asian small reservoir fisheries). The population model was developed into a practical assessment tool, integrated in the wider economic and socio-economic analysis of culture fisheries.

A brief overview of the quantitative methodology, aimed at a professional rather than academic readership, was provided in:

Lorenzen, K. (1994) Dynamics and management of Asian culture-based reservoir fisheries. *Aquaculture News* 18, 20. (Appendix I)

5.1.1 Mortality-weight relationship

The relationship between body weight and natural mortality in juvenile and adult fish was analysed for different aquatic ecosystems: lakes, rivers, the ocean, and pond, cage and tank aquaculture systems. Mortality was described as a power function of weight:

$$M_W = M_u W^b$$

The parameters b (exponent) and M_u (mortality at the unit weight of 1 g) were estimated by nonparametric regression. Parameters were estimated for fish in the six ecosystems, as well as within selected populations, species and families.

Empirical results

At the ecosystem level, no significant differences in parameters were found between lakes, rivers and the ocean. A joint mortality-weight relationship for all natural ecosystems was estimated with parameters $b = -0.288$ (90% CI [-0.315, -0.261]) and $M_u = 3.00$ (90% CI [2.70, 3.30]) y^{-1} . Among the culture systems, mortality-weight relationships in ponds and cages were not significantly different and a joint relationship was estimated. The weight exponents of mortality in ponds/cages and tanks were very similar at about $b = -0.43$, and significantly more negative than in natural ecosystems. Mortalities at unit weight were significantly lower in tanks (0.91 y^{-1}) than in ponds/cages (2.24 y^{-1}), and both were significantly lower than in natural ecosystems. The significantly different mortality-weight relationships are illustrated in Figure 1. No systematic differences were found between the mortality-weight relationships determined at different ecological/taxonomic levels, i.e. individual populations, species, families, and ecosystems.

Implications for culture fisheries assessment

The empirical study provides *a priori* estimates of the weight exponent of natural mortality that can be used to assess stocking size and density when population-specific data are not available. Similar mortality-weight relationships can be expected in fish in all natural aquatic ecosystems. Within-population weight exponents of mortality are unlikely to differ strongly from the overall fish community exponent of about -0.3. The estimates of the weight exponent obtained for individual populations, species and families suggest that for any particular group, the exponent is likely to be within the range of -0.5 to -0.2. More precise and population-specific estimates can be obtained from stocking experiments. The information derived from the present analysis allows an assessment of the likely benefits and costs of conducting stocking experiments.

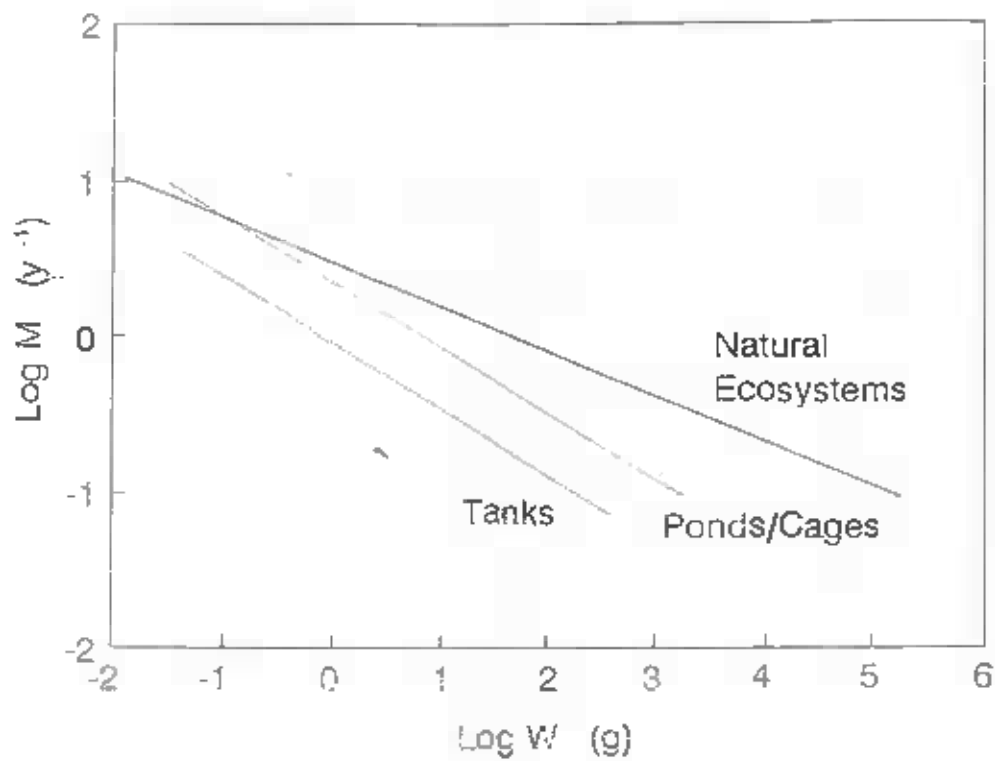


Figure 1 Comparison of the identified, significantly different mortality-weight relationships in fish in natural ecosystems, ponds/cages and tanks (from Lorenzen *in press a*).

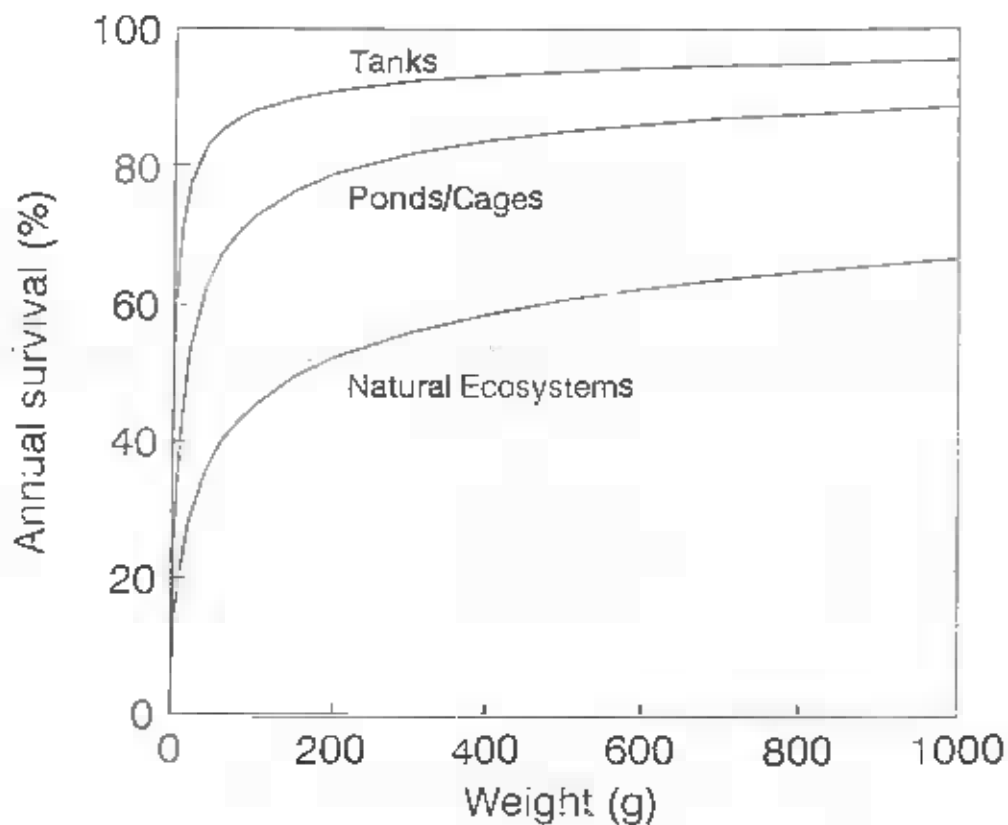


Figure 2 Average annual survival in fish in natural ecosystems, pond/cage and tank aquaculture in relation to body weight (from Lorenzen *in press a*).

Implications for the design of aquaculture systems

Expected survival is one of the criteria that must be considered in the design of aquaculture systems. The average annual survival in relation to weight in natural ecosystems, ponds/cages and tanks is shown in Figure 2. Both survival and weight are shown on a linear scale. This illustrates that survival increases rapidly with weight in small fish, but changes little once fish have reached a weight of about 200 g. The greatest differences in survival between unexploited natural ecosystems and pond/cage and tank aquaculture systems occur in small fish. At a body weight of 1 g for example, the average annual survival is 5% in natural ecosystems, 10% in ponds or cages, and 40% in tanks. At a weight of 1000 g, the average annual survival in unexploited natural ecosystems is 66%, as compared to 87% in ponds or cages, and 95% in tanks. The analysis of mortality-weight relationships suggests that on average, pond and cage systems can be expected to yield similar survival over the full weight range of farmed fish. Survival in tanks is higher on average than in ponds or cages. The improvement in survival achieved in tanks over ponds or cages is substantial in small fish (300 % at 1 g), but only moderate in large fish (less than 10 % at 1000 g). Given that investment and operating costs of tank systems are likely to be higher than those of pond or cage farms, and other things being equal, this suggests that small fish are best nursed in tanks, and transferred to ponds or cages for grow-out. Such a pattern of transfer from tanks into ponds or cages as fish grow is borne out in many established aquaculture systems, and the analysis of mortality-size relationships thus corroborates the conventional wisdom of aquaculturalists.

The quantitative relationships established here can aid the design of and production planning in aquaculture systems if more specific data are not available. It is important to remember, however, that the estimated mortality-weight relationships describe average mortality. There is considerable variation around these relationships and the ranges of observed mortality at weight in the different aquaculture systems overlap completely. Part of the observed variation is likely to be explicable in terms of the species cultivated, and details in the design and management of particular facilities. In practice, management capability for example may have a greater bearing on survival rates than the fundamental choice of facility (i.e. tank, pond or cage).

Ecological implications

The comparison of mortality-weight relationships between natural ecosystems and aquaculture also provide and interesting ecological insight. Predation is generally regarded as the major cause of mortality in natural ecosystems, but is very much reduced in aquaculture. Aquaculture mortality-weight relationships indicate the allometric scaling of non-predation mortality, which is therefore more strongly size-dependent than predation mortality. If non-predation mortality in natural ecosystems shows a similar scaling with body weight, then the allometric exponent of predation mortality must be less negative than that observed for total natural mortality. This implies that the relative importance of non-predation mortality in natural ecosystems is highest in small fish and juvenile fish.

Conclusion

The empirical analysis of mortality-weight relationships provides a basis for the quantitative assessment of stocking size in culture fisheries, and also contributes to the design criteria for aquaculture systems.

These results are presented in:

Lorenzen, K. (in press) The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. *Journal of Fish Biology*. (Appendix II)

5.1.2 Population modelling for assessment

Extensions to the length-structured model

Three extensions to the length-structured population model for culture fisheries (Lorenzen 1995) have been implemented. simple terms for natural reproduction and fishing effort dynamics, and a new algorithm for the construction of the growth projection matrix. Different terms for natural reproduction in the cultured fish population have been formulated, based on the contrasting assumptions that natural fingerling production is either limited to a low absolute level due to lack of spawning or nursery habitat, or is linearly related to

spawning stock biomass. The latter assumption implies that the natural population is regulated primarily through the density-dependent growth response and its impact on spawning stock biomass. The two assumptions represent the most extreme possibilities, any degree of density-dependent regulation at the pre-fingerling stage would result in recruitment intermediate between the two. The natural recruitment terms have been applied in the analysis of development options in an Indian reservoir where the natural recruitment to the major carp fishery was evident. A second extension to the model allows for dynamic adjustment of fishing effort to changing yield. The fishing effort dynamics term has also been used in the assessment of the Indian reservoir, which is exploited by an extremely mobile group of fishers. A new algorithm for the construction of the density-dependent growth projection matrix has been devised to increase computational efficiency. The length of time steps in the model is now limited so that the maximum growth during the step does not exceed the width of a length class. This allows a much more efficient construction of the matrix (which needs to be re-constructed at every step), and short time steps are in themselves desirable to limit the errors associated with discretization. The new algorithm has cut the computation time required to run the model by more than 50%.

Transparent modelling in computer spreadsheets

An age-based population model has been developed for the transparent analysis of culture fisheries in computer spreadsheets. Analysis of the data is conducted in three steps. At first, virtual population analysis (VPA) or a statistical catch at age model are used to estimate natural and fishing mortality rates, and to reconstruct the cultured population. In a second step, body weight data are analysed in relation to the reconstructed population biomass dynamics, in order to estimate density-dependent growth parameters. Finally, the growth and mortality models are combined in a yield predictive model for the evaluation of management options.

Different versions of the model have been implemented in spreadsheets and their advantages and disadvantages assessed. In the first step, the estimation of mortality and reconstruction of the population, the basic choice is between VPA and a statistical catch at age model. The statistical catch at age model is preferred on theoretical grounds because it involves less subjective intervention by the user and readily yields confidence limits for the estimated mortality rates. In practice, however, statistical catch at age models are difficult to fit if data are sparse and fishing patterns variable. In such situations, VPA is technically easier to use and while some judgement may be needed in VPA tuning, the impact of different assumptions on the reconstructed biomass is limited and can easily be assessed. Hence VPA has emerged as the preferred method for mortality estimation and biomass reconstruction in an interactive spreadsheet setup.

Yield predictive models can be formulated as equilibrium or as time-variant models. An example of a spreadsheet layout for an equilibrium yield model is shown in Figure 3. Predicted population numbers, body weight, biomass, catch and yield are shown together with the assumed parameter values. The overall model is broken down into individual cell formulae which are easily modified to account for specific aspects of a culture system or to test different assumptions. The equilibrium solution of the model is found using the spreadsheet SOLVE or OPTIMISER facilities. Equilibrium models give steady state solutions which are, by definition, independent of the length of the time steps used to calculate successive states of the system. The same is true for time-variant models framed in differential equations. Discrete-time approximations to models with continuous density-dependence may result in prediction errors and show peculiar behaviour if time-steps are too long or the system is very dynamic. Discrete-time models are useful nevertheless because they are far easier to implement in spreadsheets than differential equation models. The errors introduced by such models are small if the change in biomass from one time-step to the next is sufficiently small. In practice, if discrete time models provide a good description of past data series, they are likely also to provide reasonable predictions of future behaviour unless management is changed much more drastically than in the past. However, the models may exhibit unrealistic dynamic behaviour if extreme assumptions (parameter values) or changes in management are explored. In these cases, either an equilibrium model or continuous-time differential equation model should be used in predictions.

	A	B	C	D	E	F	G	H	I
1	Equilibrium yield model								
2									
3	Growth parameters			Mortality parameters			Fishing parameters		
4									
5	Winfr =	7503 g		b =	-0.3		F =	2.1 /year	
6	K =	0.2 /year		Mr =	0.27 /year		Wc =	880 g	
7	c =	0.012 g ^{1/3} ha/kg					p =	0.0048 /g	
8	Br =	909 kg/ha		Wr =	1000 g				
9									
10	Age [years]		0	1	2	3	4	5	
11									
12	W [g]		15	173	533	1057	1680	2343	
13	F [/year]		0.033	0.068	0.334	1.471	2.056	2.098	
14	N [/ha]		1700	891	569	304	55	6	
15	B {kg/ha}		26	154	303	322	92	13	
16	C [/ha]		54	59	162	234	48	5	
17	Y [kg/ha]		1	10	86	248	80	12	
18									
19	Biomass		Summary						
20									
21	Assumed =		909 kg/ha		Yield =		436 kg/ha		
22	Calculated =		909 kg/ha		Mean weight =		777 g		
23	Abs. difference =		0 kg/ha						
24									
25	WinfB =		7503						
26									

Figure 3 Spreadsheet layout of an equilibrium yield model for culture fisheries. Population numbers, catch, and body weight at age are predicted subject to the parameters defined in the upper rows of the spreadsheet and the stocking density and size of seed fish. The equilibrium solution is found using the spreadsheet "SOLVE" facility, by adjusting the biomass assumed in the calculation of body weight until it equals the biomass predicted by the model (from Lorenzen, Xu, Cao, Ye & Hu *subm.*).

Parameter estimation from heterogeneous data

A key parameter in all culture fisheries models is the density-dependent growth response. This parameter can be estimated only if stocking and catch data are available for a range of biomass densities, which in most cases implies a long period of time. Other model parameters can be estimated only from detailed data on the age or length structure of catches. Stocking, total catch and effort data are often available for longer periods, while catch structure data may only have been collected recently. Such heterogeneous sets of data may be analysed together using a mixed estimation approach, where parameters are estimated by simultaneous or consecutive fitting of the model to several data sets. In practice, a step-by-step approach is followed. Mortality and density-independent growth parameters are first estimated from catch structure data. The density-dependent parameter is then estimated by fitting observed to predicted historical catches, subject to the previously estimated parameters and historical stocking and effort patterns. Finally, a joint estimation of all parameters may be carried out, using the estimates from the step-by-step method as initial values.

Mixed estimation enables the utilisation of all available data for the assessment of the culture fishery. An example of a spreadsheet layout for mixed estimation is shown in Figure 4. Parameter values are defined at the top of the spreadsheet. The three graphs show the observed and predicted catch at age and weight at age in two years, and total yield over a 28-year period. The sums of squared differences between the observed and predicted values are calculated for each data set separately, and may be combined in a weighted total sum of squares. Estimation can be carried out for all parameters from all data sets

simultaneously, or for any suitable combination of parameters (while keeping the other parameters constant) and set of data. The mixed estimation method has been applied to the bio-economic analysis of extensive culture in a large Chinese reservoir.

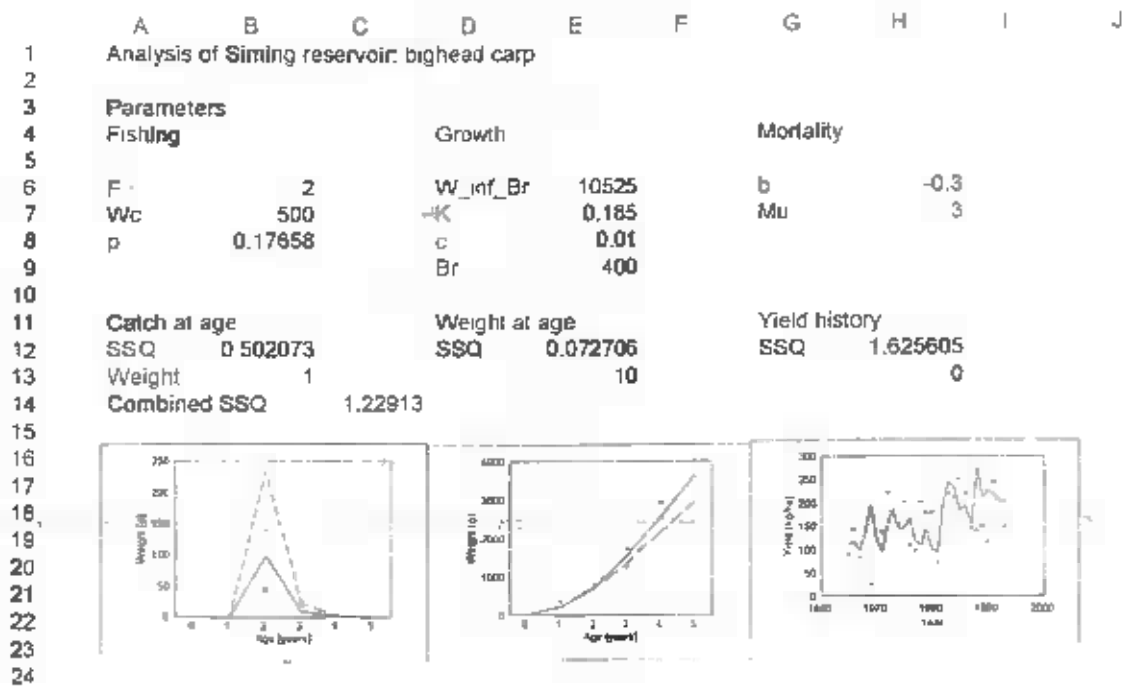


Figure 4 Spreadsheet layout for the estimation of model parameters from a mixed set of data. The upper part of the spreadsheet contains the parameter values used in model predictions. The graphs show the observed and predicted catch and body weight at age in two years for which such data are available, and the historical record of total yield. The sums of squared differences between the observed and expected values for all data sets are shown, together with the weighted, combined sum of squares. The model shown here has been only partially fitted to the age structured data. It also gives a reasonably good description of the long term yield data, which may be improved further by fitting the model to all three sets of data.

Software package for the assessment of culture fisheries in seasonal water bodies

A prototype software package for the analysis of stocking and catch data from seasonal reservoirs has been developed. The package offers sophisticated facilities for data handling and graphics, but analyses are presently limited to the fitting of the density-dependent growth and size-dependent mortality models to single-cohort stocking and catch data, and to yield predictions using the same models. Naturally, a dedicated package is less easily adaptable to different culture systems and data sets than a spreadsheet-based model, and substantial further development and field-testing would be necessary before the package could be released for general use. At present the package may be used in parallel with the spreadsheet models in workshops, in order to evaluate the user acceptance of the different models and to identify the best option to promote the wide use of quantitative methods in culture fisheries assessment.

Feasibility study of an expert system

First steps towards the design of an expert system for the management of culture fisheries in Chinese reservoirs have been undertaken. The basic structure of a possible expert system has been devised, and the expertise acquired from both Chinese and London-based project staff has been structured using the Knowledge Acquisition and Design Support (KADS) system. The study has shown the feasibility of

developing an expert system for Chinese culture fisheries based on project methodology. However, wider experience with the application of the methodology is desirable before an expert system can be implemented.

Conclusion

A wide range of methods and tools for the quantitative assessment of culture fisheries have been developed in the project. In the short and medium term, the transparent and flexible spreadsheet population models provide the most appropriate tools for practical assessment work. In the longer term, dedicated software packages including expert systems could make sophisticated assessment tools available to users with limited technical expertise.

These outputs are described in:

Lorenzen, K., Xu, G., Cau, F., Ye, J., & Hu, T. (subm.) Extensive fish culture in Chinese reservoirs: analysis of management options by transparent population modelling. Submitted to *Aquaculture Research*. (Appendix III)

Lorenzen, K. Mohan, C.V. & Bhatta, R. (in prep.) Assessing the potential for culture-based fisheries development: a case study of Vanivilas Sagar reservoir, India. To be submitted to *Fisheries Research*

Chevalier, C. (1995) *Culture fisheries: Programme and user's guide*. DAA Agro-Informatique, INP-ENSA Toulouse, and MRAG Ltd.

Zhang, S. (1995) *Knowledge-based decision making support system for culture-based fisheries management*. MSc Thesis (Knowledge Engineering), University of Westminster.

5.1.3 Bio-economic analysis

Bio-economic analyses were closely linked to the case studies, and were geared towards addressing key problems in the particular systems as opposed to providing insights of great generality. Accordingly, results are reported mainly in the case study section (5.2).

Implications of ownership patterns for bio-economic analysis

A point of general importance, however, is the pervasive role of ownership patterns in the management of culture fisheries, and in their economic analysis. In the widely used FAO classification of fish production systems, aquatic resources held in private (individual or corporate) ownership are defined as aquaculture systems, while resources held in public ownership with or without access regulations are defined as fisheries. Aquaculture systems can be managed comprehensively to produce fish in an economically efficient manner. Key issues in economic analysis are the relationships between inputs and outputs, and the profitability of alternative system designs including for example the integration or separation of seed production and on-growing. In fisheries, the focus is on regulating the activity of individual economic units exploiting a public or communal resource, to achieve goals such as employment, improvement of the socio-economic status of fishers, or provision of government or community revenue. While questions of overall economic efficiency are just as valid as in aquaculture systems, they are of less immediate concern to management than the problems of controlling effort and recovering seed costs from beneficiaries.

The crucial role of effort regulation

The impact of effort control options on the outcome of stocking in a culture-based fishery is illustrated in an analysis conducted as part of the Vaovilas Sagar case study (Section 5.2.2). Predictions of total yield, number of boats, catch value per boat, and cost of stocking per boat are shown in Figure 5, for a range of enhancement levels and effort control options. The effort control options explored are:

- (1) limiting the number of boats to the present level through restrictive licensing or monetary measures (taxes or license fees),
- (2) no direct control of effort or recovery of stocking costs; and
- (3) effort limitation through the collection of license fees or taxes at a level that recovers the costs of stocking.

In the example shown here, total yield is predicted to increase continuously over the range of stocking densities considered (Figure 5 a). The impact of the effort control regime on total yield is small, but one point is noteworthy: At lower stocking densities, the highest total yield is achieved in the most restrictive regime. At higher stocking densities, the less restrictive regimes lead to higher total yield because higher fishing effort reduces density and its effect on production. The number of boats (Figure 5 b) will remain constant in the most restrictive regime, but may increase drastically if access is open or restricted by monetary measures to an extent that purely recovers seed costs. The catch value per boat (Figure 5 c) is predicted to increase substantially if effort is fixed at pre-enhancement levels. Under open access, catches per boat are likely to remain constant, independent of the enhancement level as new boats are attracted into the fishery. Hence enhancement will not benefit the established fishermen and the costs of stocking must be borne by the public or community. If monetary measures are introduced to recover seed costs, this will prevent the least efficient units from fishing and raise the average catch value per boat by the amount charged as license fee or tax. Again, there would be no benefit to established fishers (in fact, some may be driven out), but the costs of stocking would be recovered from the fishery. The costs of stocking per boat are shown in Figure 5 d. Substantial costs per boat would be incurred at high levels of enhancement and very restrictive effort regulation. Less restrictive effort regulation allows to spread the costs of enhancement over a larger number of boats. Although the high costs per boat in restrictive regimes are offset by large gains in catch value, the introduction of very high fees is likely to meet with strong political opposition. Less restrictive regimes may be a more feasible way of expanding overall production, but even moderate increases in fees are likely to face opposition unless there is a clear benefit to individuals.

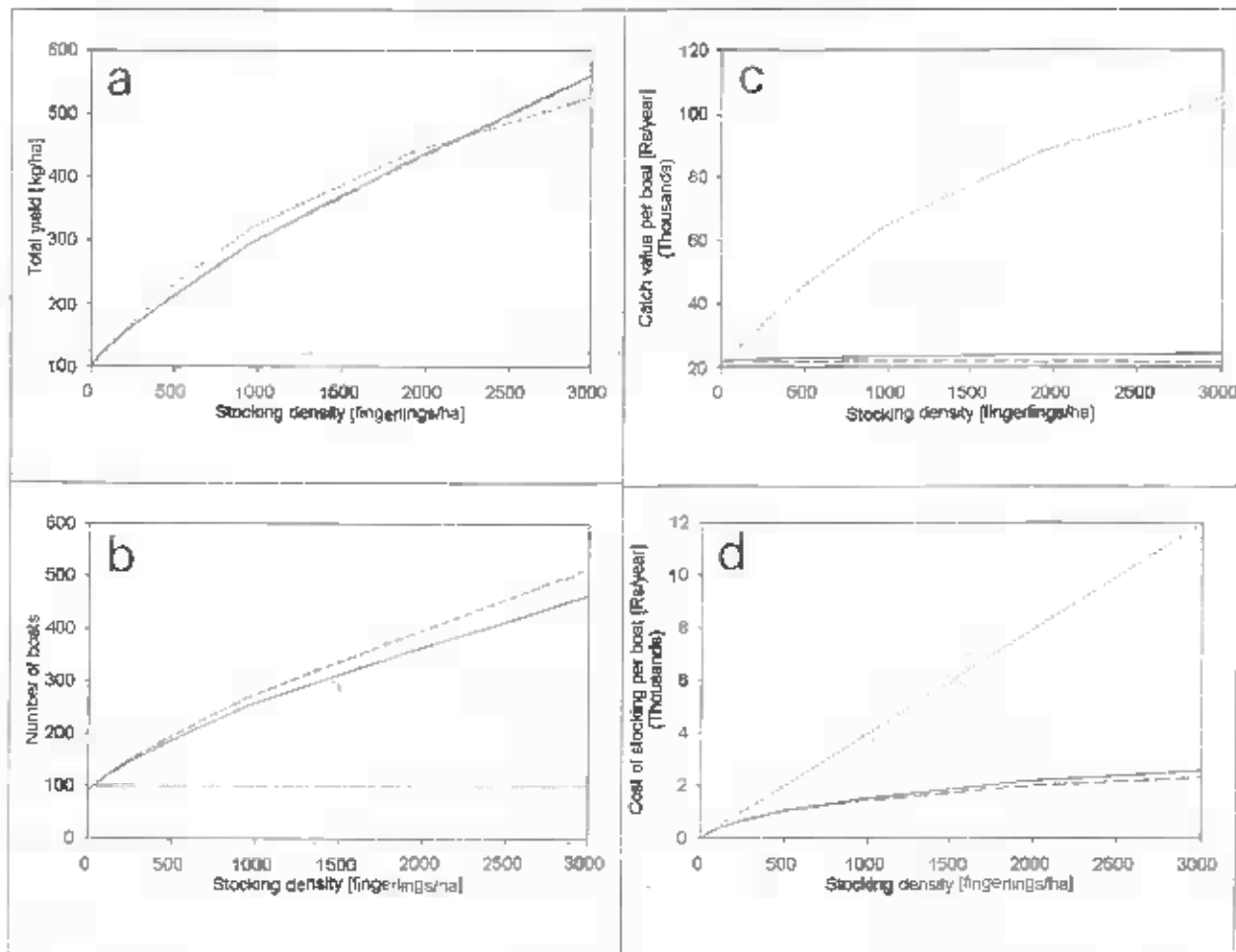


Figure 5 Impact of different fishery access regulations on the outcome of culture-enhancement. Graphs show total yield (a), number of boats (b), catch value per boat (c) and costs of stocking per boat (d) in relation to stocking density. The different access regimes considered are: number of boats limited to the pre-enhancement level (dotted line), open access (dashed line), and access limited by license fees or taxes sufficient to recover seed costs (solid line)

Conclusions

The focus of bio-economic analysis in culture fisheries is determined by the prevailing pattern of resource ownership. In fisheries that are publicly or communally owned, access regulation is crucial to sustainable development. Bio-economic analysis allows the quantitative evaluation of different access regimes, and should be complemented by participatory approaches to yield relevant guidance.

The bio-economic analyses are being finalized and reported as:

Lorenzen, K., Mohan, C.V. & Bhatta, R. (in prep.) Assessing the potential for culture-based fisheries development: a case study of Vanivilas Sagar reservoir, India. To be submitted to *Fisheries Research*.

Lorenzen, K., Xu, G., Cau, F., Ye, J. & Hu, T. (in prep.) Bioeconomic analysis of extensive fish culture in Chinese reservoirs: a case study of Siming reservoir, Zhejiang. To be submitted to *Aquaculture*.

5.1.4 Rapid appraisal methods

Rapid and participatory rural appraisal methods (RRA/PRA), originally developed in the context of farmer agriculture (Chambers 1992), have been successfully adapted to the study of culture fisheries. The methods were used to study socio-economic aspects of culture fisheries and related aquatic resource uses, and to supplement more formal methods of obtaining technical and economic data.

Gathering baseline information on aquatic resource use

Rapid appraisal methods are characterized by their open structure and adaptability, so that there is no "standard" procedure to follow. Nevertheless, a methods sequence has emerged that has been found to suit the basic information needs of many culture fisheries appraisals (Figure 6). At the beginning of the appraisal, village maps and/or water body maps are drawn by local villagers or fishers. These maps provide a first overview of villages and water bodies, and are used for later reference. Drawing the maps also provides a first opportunity for village participation and usually "breaks the ice" for further, more relaxed interaction. Participatory mapping may be followed by transect walks or boat tours to further explore the village or water body, and to check the information given in the map. Semi-structured interviews with key informants, as well as persons selected at random from particular groups, are used throughout the appraisal process.

The management of particular aquatic resources is studied in detail using graphical methods such as resource maps, trend matrices, seasonality matrices etc. Historical changes in management are explored using timelines. In order to evaluate differences in resource use by socio-economic status, a wealth ranking exercise may be carried out of the village population or fisher community. Community members are asked to identify wealth groups in the community, and the criteria that characterize these groups. A random subsample of households in the community is then ranked by wealth, i.e. assigned to the different wealth classes by a group of community members. Households from each wealth group are selected at random to study their use of aquatic resources and related issues. Where appropriate, a similar exercise may be carried out for structuring criteria other than wealth, for example ethnic group or caste. Information credibility is judged primarily on the basis of triangulation, i.e. information on the same topic is collected in at least three different ways and/or from at least three different sources.

Fishing practices and their social and environmental determinants

Rapid and participatory appraisal methods were also used to gain information on the fishing practices in artisanal culture and capture fisheries. The methods were found extremely efficient in eliciting information on the complex exploitation patterns of such fisheries and their relation to ecological and socio-economic factors. An example is given in Figure 7, where a seasonality matrix is shown for snakehead fishing by a farmer in Northeast Thailand. The matrix was constructed during an interview with the farmer, who then scored rainfall, total snakehead catch, and snakehead catch with various gear type over the seasons. The farmer also indicated the snakehead habitat (location of fishing), and his on and off-farm activities. In this example (Figure 7), the highest catches are taken in winter (December/January), in the dry season (April)

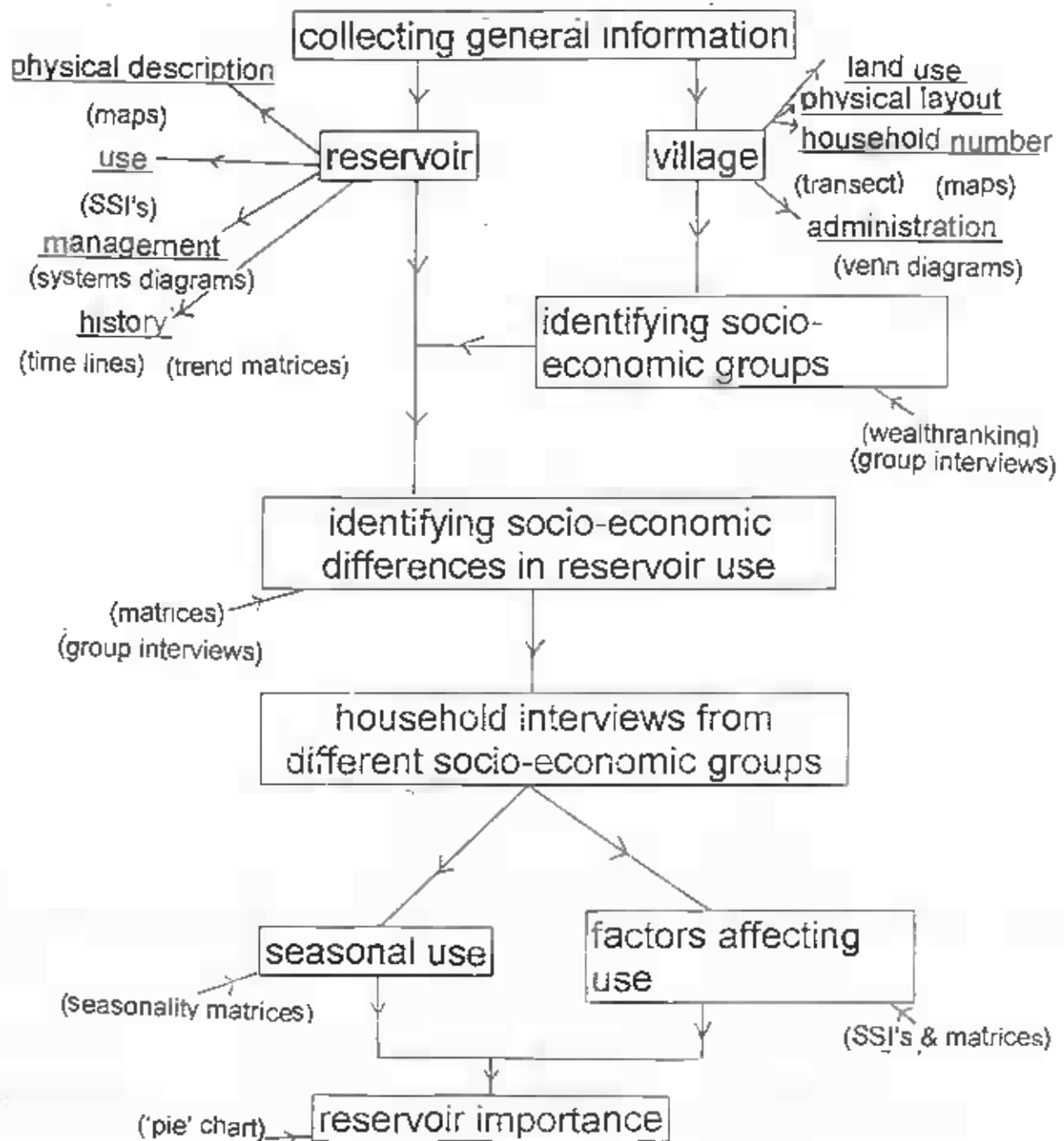


Figure 6 Sequence of participatory/rapid appraisal methods used to investigate the use of communal water bodies in Northeast Thailand (by Garaway)

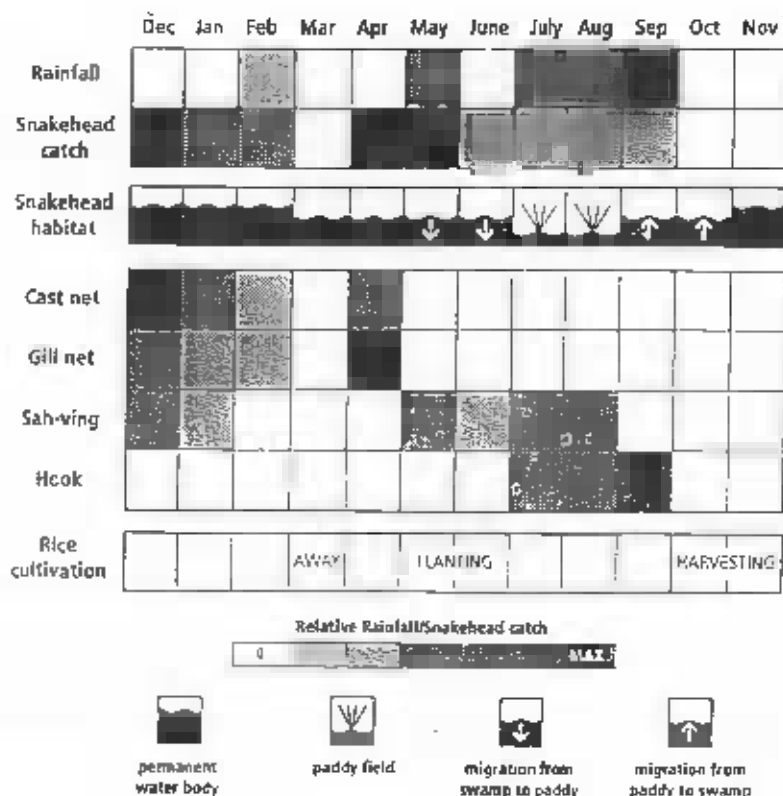


Figure 7 Seasonality matrix of snakehead fishing by one farmer in relation to environmental factors and the demand for on and off-farm labour. The diagram has been redrawn from a matrix constructed in a participatory appraisal in NE Thailand (from Cowan 1995).

and the early wet season (June). No fishing takes place in March when the farmer works off-farm, or during the rice harvest in October/November. Four different gear types are used, with the active gear (cast net and gill net used with active driving of fish) restricted to the period when farm labour demand is low (December to April). Significant catches are taken from a permanent water body (open access village reservoir) as well as from the farmer's paddies. If the village reservoir was developed into a communal fishery with restricted access (see Section 5.2.3), this farmer would lose a significant part of his subsistence fish catch. Similar matrices constructed with a number of other farmers showed a considerable diversity individual fishing patterns, but confirmed the regular use of both permanent water bodies and paddies.

Conclusion

Rapid appraisal methods were found to be extremely efficient in gaining detailed and relevant information for the socio-economic and technical assessment of culture fisheries. The main role of PRARRA is in the assessment of particular systems, while more formal approaches may be necessary where results of greater generality are sought.

The participatory appraisal studies in Thailand are reported in:

Cowan, V.J. (1995) A participatory rural appraisal of the exploitation and ecology of snakehead (*Channa striata*) in Kumpawapee District, Northeast Thailand. MRAG/AIT Aquaculture Outreach Research Report.

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. MRAG/AIT Aquaculture Outreach Research Report (Appendix VI)

5.1.5 Integrated framework for appraisal

An integrated framework is necessary for the appraisal of culture fisheries development options in terms of the suitability of sites and the development of appropriate management regimes for new and existing system. The role of the framework is to guide the appraisal process and to ensure that no important issues are overlooked. A draft framework has been produced, consisting of the following components:

- (1) Identification of issues relevant to the sustainable development of culture fisheries, based on theoretical considerations, results of the case studies, and a review of the relevant literature.
- (2) A brief guide to investigating key issues in particular fisheries, based largely on the assessment methodology developed in the project.
- (3) A checklist that may be used by an appraisal team or individual to ensure that all potentially important issues are being covered.

The framework is focused on concerns directly related to culture fisheries and covers technical, economic, socio-economic and institutions aspects. It is intended to complement the broader disciplinary guides to appraisal procedures such as "Appraisal of Projects in Developing Countries: A Guide for Economists" (ODA 1988), "Values for the Environment: A Guide to Economic Appraisal" (Winnepenny 1991), and "Guide to Social Analysis for Projects in Developing Countries" (ODA 1995). The framework is at present in draft form, and will be amended and completed following consultation with other scientists and practitioners.

Conclusions

The development of an integrated framework for the appraisal of culture fisheries has been initiated with the production of a draft discussion paper. This framework is expected to evolve in further consultation with scientists and practitioners.

Work on the integrated framework is reported in:

Lorenzen, K. (in press) Culture-based fisheries in Asian reservoirs and lakes: Key issues for sustainability. In: Network of Aquaculture Centers in Asia-Pacific (Ed.) *Aquaculture Sustainability and the Environment*. Bangkok/Manila: ADB/NACA. (Appendix IV)

Lorenzen, K. (1996) A framework for the appraisal of culture fisheries development. Discussion Paper, MRAG Ltd. (Appendix VI)