DEVELOPING SUSTAINABLE AQUACULTURE SYSTEMS IN VIETNAM*

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ABSTRACT

A bioeconomic model of reservoir aquaculture in northern Vietnam, called BRAVO, is presented. The biological model is based on a conventional von Bertalanffy growth function and the economic model is a net revenue function. The greatest source of costs for the operation are restocking costs (75 percent) and contract labour costs (18 percent). The net revenue of the operations is approximately 9.7 million VND (approximately US$615). The greatest area of uncertainty in the model is harvesting efficiency, which is very low (ranging between 5 and 26 percent). The harvesting efficiency, along with the length of time between stocking and harvest, has a large impact on net revenue. Reservoir aquaculture has developed in an *ad hoc* way in Vietnam. Including reservoir aquaculture into government fisheries development plans with research focused on development of fingerling production, preparation of flooded land for aquaculture production and strengthening institutional arrangements for reservoir leasing and credit arrangements, is likely to lead to capitalisation, increased investment and therefore greater revenues for local fishing populations.

Keywords: bioeconomic modelling, fisheries, aquaculture, Vietnam,

Paper presented at the 49th Annual Conference of the Australian Agricultural and Resource Economics Society, 9-11 February 2005, Coffs Harbour, New South Wales, Australia

* The authors gratefully acknowledge the generous financial support of the Australian Centre for International Agricultural Research in funding the project - The economics of developing reservoir aquaculture in Vietnam ADP/2000/018. The biological and economic information provided by Nguyen Hai Son of Research Institute for Aquaculture No 1 (Vietnam); Le Thanh Hung, Thai Anh Hoa and Le Quang Thong of the University of Agriculture and Forestry (Vietnam); and Phung Giang Hai of the Institute for Fisheries Economics and Policy (Vietnam) is also appreciated.

1. Introduction

Over the last ten years, the Vietnamese Government has developed the hydroelectric and irrigation potential of the country through damming rivers. These dams have flooded large tracts of previously cultivated land, both in the north and in the south, and new dams and reservoirs are planned throughout the country in the next 20 years. The reservoirs have led to increased energy and water supply, the latter for irrigation crops. They have also developed the potential for enhanced, culture-based fisheries for fish food production - a partial compensating revenue source for landless or land-poor people who were forced to abandon their land with the damming of the rivers.

Culture-based fisheries are widely practiced in Asia and other developing countries (Welcommme and Bartley 1998, de Silva 2001). They involve regular stocking of suitable species and recapture at marketable size. Hence, they fall within the realm of aquaculture, as defined by the United Nations Food and Agriculture Organization (FAO 1997).[1] This form of culture is considered to have the potential to significantly and increasingly contribute to fish production, fisher income and food security in developing countries (de Silva and Amarasinghe 1997, Cowx 1998, Lorenzen *et al.* 1998, Welcomme and Barltey 1998, Quiros and Mari 1999). Unfortunately, there is a general lack of information on reservoir fisheries in Vietnam compared with other Asian countries. Yields obtained from Vietnamese reservoir aquaculture operations are relatively low compared with similar water bodies elsewhere in Asia, possibly due to incorrect species combinations, inappropriate stocking densities, incomplete harvesting and ineffective management practices. Moreover, the major time of harvesting in a given region is dictated by the hydrology of the water bodies, often resulting in excess supply of fish in a given village within a short time period.

This paper is a part of a larger project funded by the Australian Centre for International Agricultural Research (ACIAR). The ACIAR project is aimed at identifying ways to help the Government of Vietnam increase the economic value of culture-based reservoir fisheries for the benefit of local fishing populations. One strategy in pursuit of this goal is the development of a bioeconomic model of reservoir aquaculture to identify the significant input factors contributing to economic performance, harvest levels and species mix given current costs and prices. The purpose of this paper is to present the bioeconomic model, analyse the sensitivity of the model results to variations in model assumptions, and to comment on the implications of model results for fisheries policy and research prioritization in Vietnam. The bioeconomic model is named BRAVO: Bioeconomic model of Reservoir Aquaculture for Vietnamese Operations. Currently, the model is calibrated for small reservoirs in northern Vietnam only, as accurate and reliable data is not yet available in the south. A southern application will be conducted when such data becomes available.

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[1] "Aquaculture is the farming of aquatic organisms, including fish, mollusks, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture, while aquatic organisms which are exploitable by the public as a common property resource, with or without appropriate licenses, are the harvest of fisheries." (FAO 1997)

The paper proceeds as follows. Section 2 is a description of northern Vietnam reservoir aquaculture. The theory of the bioeconomic model is presented in Section 3 (the biological model is presented in Section 3.1 and the economic model is presented in Section 3.2). Numerical analysis and validation of the theoretical model for northern Vietnam reservoir aquaculture systems is presented in Section 4 (analysis and validation of the biological and economic components are provided in Sections 4.1 and 4.2, respectively). A sensitivity analysis on key model parameters is presented in Section 5. The paper concludes in Section 6 with comments on the implication of the model results for fisheries policy and research funding prioritisation.

2. Description of northern Vietnam reservoir aquaculture

The size of small reservoirs for capture-based fisheries in northern Vietnam range from very small - around 1 hectare (ha) - to approximately 80ha, with an average reservoir size of approximately 20ha. The reservoirs are generally leased by the provincial fishery authorities, an arm of the Department of Agriculture and Rural Development of the Provincial Government, to farmer cooperatives or collectives of at least two households. The duration of the leases range from 3 to 8 years and are determined on an *ad-hoc* basis. The primary function of the reservoirs are for irrigation, hence the reservoir culture practices have to comply with the downstream water needs (mainly for rice paddies), which is controlled by the provincial authorities.

Stocking is carried out from late March to mid April, with species stocked largely determined by the price and availability of fingerlings. The major stocked species include grass carp (*Ctenopharyngodon idella* Cuv. Et Van.), silver carp (*Hypophthalmichthys molitrix* Cuv. Et Val.), bighead carp (*Aristichthus nobilis* Richardson), common carp (*Cyprinus carpio* L.) and mrigal (*Cirrihinus mrigala* Hamilton).

After stocking, there is no particular management regime used until harvest, except for the vigilant guarding of fish stocks against poachers (occasionally requiring the construction of watch huts), and the irregular provision of supplementary feed. When grass carp are stocked, they are fed grass collected from adjoining land at no cost. Occasionally, tender cassava leaves, and in the smaller reservoirs (less than 5ha) rice bran and fermented cassava tuber, are also used to supplement the natural feed sources in the water body. This occasional feeding is not included in the standard version of BRAVO. There is no evidence of mixing ingredients into other forms such as a paste.

Harvesting takes place once a year in late February to late April when the water level is at a minimum, just prior to re-stocking. It is generally conducted daily over a one to two week period by seining - using a large drag net (150m x 2m) of fin mesh. Harvesting is a communal activity, using village labour. This labour may be paid for by reciprocated services provided in time by the lessees. Each net requires an average of 10 to 15 persons to operate. Fish are sold to known vendors who are engaged by the lessees prior to harvest. All returns from the harvest accrue to the lessee households in proportion to their input provided in terms of purchases and labour.

3. The theoretical model

BRAVO provides an annual enterprise gross margin, not including the wider impacts of institutional structures. For example, leasing fees to the reservoir are not included, and the rate of interest included is the formal, rather than informal rate. Analysis of the effects of different institutional arrangements on the fishing enterprise is considered to be a topic for further research. The biological model is presented in sub-section 3.1, and the economic model is presented in sub-section 3.2.

3.1 The biological model

It is assumed that carp growth conforms to the von Bertalanffy growth model, a model that defines growth as the net result of the processes of anabolism (tissue production) and catabolism (tissue dissipation) (von Bertalanffy 1938):

$$L_t = L_\infty (1 - \exp[-K(t - t_0)]) \qquad (1)$$

where: L_t = fish length (in cm) at time, t;

K = a growth coefficient that measures catabolic activity (year^{-1});

t_0 = a theoretical age at zero length; and

L_∞ = the theoretical maximum (asymptotic) length of the fish (in cm) that measures anabolism. It is the maximum length that a species of fish could potentially reach given the available food resources and productivity of the water body.

The von Bertalanffy growth model can be reformulated to measure growth through time at any age or fish length through the Gulland-Holt method (Gulland and Holt 1959):

$$\frac{dL}{dt} = -K(L - L_\infty) \qquad (2)$$

Note that K and L_∞ are interrelated, and often one of these variables needs to be fixed to estimate the other. In the numerical analysis (see Section 4.1), K is fixed and L_∞ is estimated for each species.

The von Bertalanffy growth function measures growth in terms of length, while output prices are a per weight measure. Hence, it is necessary to understand the relationship between length and weight. LeCren (1951) proposes that length (*L)* is exponentially related to weight (*W*) as follows:

$$W = aL^b \qquad (3)$$

where *a* and *b* are coefficients that differ between species, populations and seasons. Fish species that exhibit this relationship are considered to have isometric growth

(growth that occurs at the same rate for all parts of an organism so that its shape is consistent throughout development).

Supplementary feeding is not included in BRAVO as it is only occasionally used in north Vietnamese operations (although its use is increasing and, hence, could be included as an extension to the standard model). The carp species dominant in Vietnamese reservoirs, in general, do not share overlapping ecological niches. Hence, it is assumed that there will be no inter-specific competition for food. Density-dependent growth (as formulated by Lorenzen (1996)) was not specifically modelled due to lack of data. If density-dependence was modelled, equation (2) would be replaced by:

$$\frac{dL_t}{dt} = -K\left(L_t - L_{\infty L} + dB_t\right)$$

where: $L_{\infty L}$ = the theoretical maximum (asymptotic) weight of the fish (in kg) in the absence of density dependence (a measure of the productivity of the water body); and

dB_t = change in biomass density (biomass per unit of area or volume), *B*, through time.

Lorenzen (1996) notes that for mixed-age populations with constant biomass density, *B*, growth curves follow a conventional von Bertalanffy growth pattern. However, for single cohorts, density increases as the fish grow, and hence, the density-dependent model predicts growth curves that are mathematically different from the conventional von Bertalanffy growth curve. However, Lorenzen also shows that predicted single-cohort growth curves can always be approximated very closely by a conventional von Bertalanffy curve.

3.2 The economic model

The economic model is a simple net revenue function as shown in equation (4):

$$NR = TR - TC \tag{4}$$

where: *NR* = net revenue (in Vietnamese Dong, VND);
TR = total revenue (VND); and
TC = total costs (VND).

Total revenue is a function of harvest weight and prices:

$$TR = \sum_{i=1}^{5}\sum_{j=1}^{3}(W_{H_{ij}} * P_{H_i}) \tag{5}$$

where: $W_{H_{ij}}$ = the weight of each species, *i*, at harvest, *j* (kilograms, kg); and
P_{H_i} = the price of each species, *i* (VND/kg).

There is evidence that market prices of sold fish change significantly through time and depend on fish weight. Fishers stagger their harvest over a one to two week period to minimise flooding the market causing prices to be depressed. BRAVO allows for three different harvest times, j = 1, 2 and 3.

Total costs are a function of restocking costs and a number of miscellaneous fixed costs as shown in equation (6):

$$TC = (1+r)*(1+c)*\left(\sum_{i=1}^{5}(RC_i) + C_{NR} + C_{BR} + C_L\right) \tag{6}$$

where: TC = total costs (VND);
r = yearly interest rate;
c = contingency rate for miscellaneous costs;
RC_i = restocking costs for each species, i (VND);
C_{NR} = cost of net replacement (VND);
$C_{BR\&M}$ = cost of boat replacement (VND); and
C_L = cost of contract labour (VND).

Note that BRAVO assumes a annual steady-state aquacultural system. Nets and boats (non-motorised) need to be replaced approximately every five years, hence, the costs of purchasing one-fifth of a net and one-fifth of a boat are included in BRAVO. Also note that interest costs are assumed to accrue over a 12-month period for restocking costs, and over a 6-month period for all other costs.

Restocking costs are a function of the price of fingerings, the weight of fingerlings, and the number of fingerlings stocked:

$$RC_i = P_{F_i} * W_{F_i} * N_{F\,i} \tag{7}$$

where: P_{F_i} = Price of fingerlings of species, i (VND/kg);
W_{F_i} = Weight of fingerlings of species, i (kg); and
$N_{F\,i}$ = Number of fingerlings of species, i.

4. Numerical analysis and validation

4.1 Numerical analysis and validation of the biological model

BRAVO relies on biological data published in Nguyen *et al.* (2001), which provides data on the number of fish stocked, stocking biomass (kg/ha), the proportion of each species stocked (by number), harvest biomass (kg/ha), and stocking efficiency (defined as the ratio of yield of fish (kg/ha) to the weight of stocked fish (kg/ha) (Li 1987)). This data is presented for 13 reservoirs in the Yen Bai province, and 8 reservoirs in the Thai Nguyen provinces, over three production cycles, 1997/98, 1998/99 and 1999/2000.

Estimates for fingerling length and weight data for carp in northern Vietnam were taken from Nguyen *et al.* (2001) and unpublished survey data. *K* was assumed to be held constant at a value of 0.3, a value consistent with estimates in the relevant literature, and *a*, *b* and L_∞ values were estimated for each species from the literature (predominantly FishBase a relational database of a wide variety of fisheries data - www.fishbase.org). The standard model parameter estimates are displayed in Table 1. Note that the LeCren length-weight relationship was not used on fingerling data as it is generally not considered to be accurate for juvenile fish stocks. Hence, separate length-weight estimates were used for fingerlings.

Table 1: Standard model parameter estimates for the biological model

	K	Fingerling length (cm)	Fingerling weight (kg)	L_∞ (cm)	*a*	*b*
Common carp	0.3	8	20	63	0.0299	3.1230
Silver carp	0.3	10	15	80	0.0274	3.1540
Grass carp	0.3	8	30	110	0.0254	3.0550
Bighead carp	0.3	10	25	130	0.0289	2.9360
Mrigal	0.3	12	10	100	0.0086	3.0468

Source: Unpublished survey data and www.fishbase.org

Figure 1 and 2 present the change in individual fish length and weight, respectively, over time by species. Harvesting generally occurs within a 12 month period (generally at 11.5 months), hence the stocked fish are not allowed to grow over a 10 year period. However, the long-term growth curves are included to show how the biological function performs over time. Over the 10 year period, each species growth tends towards L_∞ for that species, with bighead carp being the longest and common carp being the shortest over time (Figure 1). Individual fish weight follows a signmoidal growth function, with bighead carp being the heaviest and mrigal being the lightest over time (Figure 2).

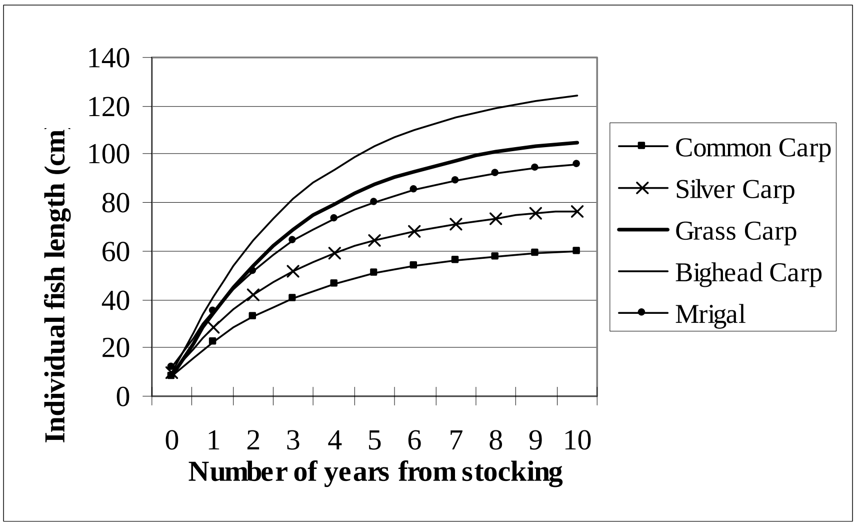

Figure 1: Change in individual fish length over time by species

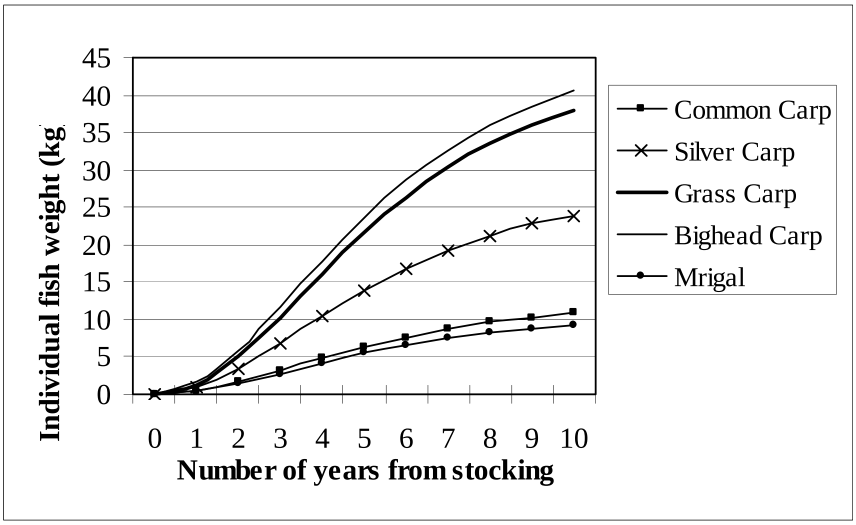

Figure 2: Change in individual fish weight over time by species

Nguyen *et al.* (2001) reports that yields vary widely between years and reservoirs. Table 2 present average yield data from Nguyen *et al.* (2001), and results from the bioeconomic model, based on an average production cycle length of 11.5 months.

Table 2: Mean harvest weight of individual fish by species - comparing published data and model results

Species	Mean size at harvest (kg)[a]	Results from model (kg)
Common carp	0.3 - 0.7	0.4
Silver carp	0.5 - 1.0	0.9
Grass carp	1.0 - 1.5	1.1
Bighead carp	1.2 - 2.0	1.4
Mrigal	0.3 - 0.6	0.4

[a] Source: Nguyen *et al.* (2001)

Data from Nguyen *et al.* (2001) on stocking density was used to derive a stocking density function (with reservoir size as the independent variable). This functional form is shown in Equation 8 and is graphed against the data in Figure 3. The percentage of each species stocked in the model (Table 3) is average data taken from Nguyen *et al.* (2001).

$$SD = 230.23 * RS^{-0.7476} \tag{8}$$

where: *SD* = Stocking density (kg/ha); and
RS = Reservoir size (ha).

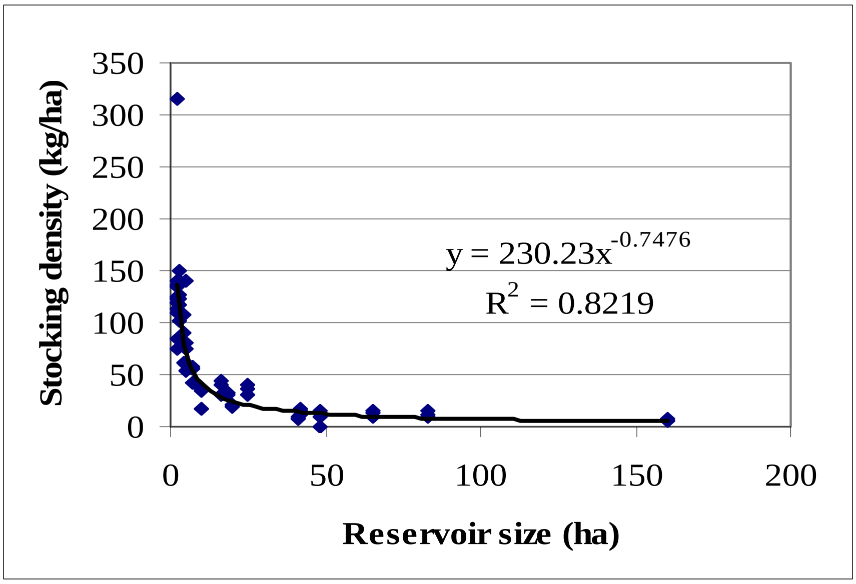

Figure 3: Stocking density by reservoir size - functional form derived from Nguyen *et al.* (2001) data

Table 3: Percentage of each species stocked

Species	% stocked
Common carp	6
Silver carp	38
Grass carp	21
Bighead carp	6
Mrigal	29

Source: Nguyen *et al.* (2001)

Harvest rates were derived by adjusting the proportion of fish harvested to match Nguyen *et al.* (2001) data on stocking efficiency. A functional form for harvest efficiency was created from the data (Equation 9), and is graphed against the data in Figure 4. Harvesting rates varied considerable for different reservoir sizes. Moreover, only a small proportion of fish are harvested (5-25 percent), even though attempts are made to collect all fish in the reservoir. This is partly due to mortality of fingerlings. Also, before damming, there is no attempt to prepare the reservoirs for aquaculture, and hence there is often much debris (including tree material and stumps) in the bottom of ponds which provides ample hiding space for the fish. Given these low harvesting rates, it is apparent that fish stocks are not a single cohort, rather they are a mixed cohort of stocked fish from the present year and fish not harvested from previous years. However, given that there is no information provided in Nguyen *et al.* (2001) on the age structure of harvested fish, stocks are modeled as a single cohort. Given the variability in data, sensitivity analysis will be conducted to analyse the impact of variability in harvest efficiency on model results.

$$H\% = 0.0163 * \mathrm{RS} + 12.213 \quad (9)$$

where: *H%* = Percent of stocked fish harvested.

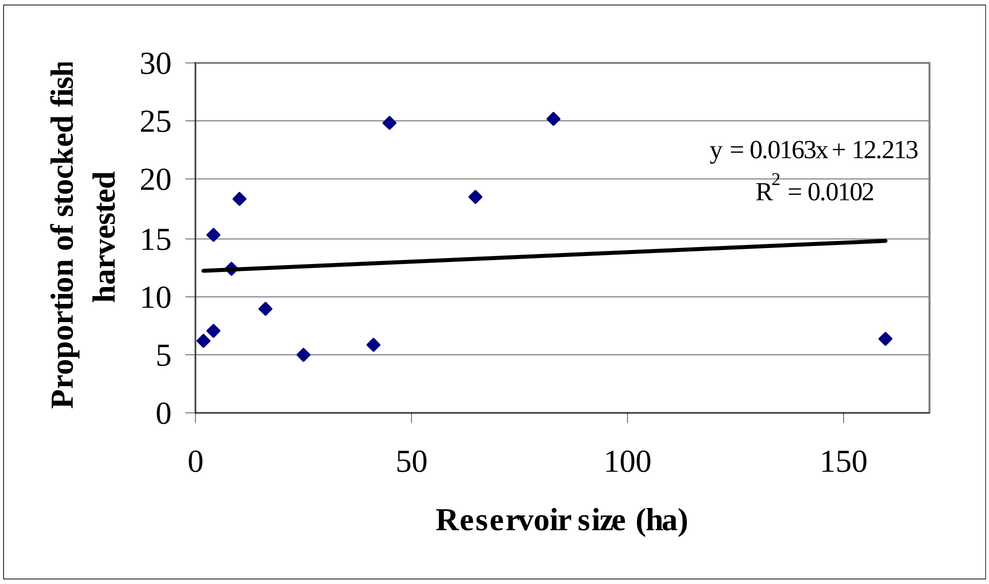

Figure 4: Harvest efficiency by reservoir size - functional form derived from Nguyen *et al.* (2001) data.

The resulting yield curve for different reservoir size is compared in Figure 5 with Nguyen *et al.* (2001) results for the two sampled reservoirs - Yen Bai and Thai Nguyen. The model predicts a yield curve that is of similar shape to the published data, with yields greater than those experienced in the Yen Bai province, but lower than those experienced in the Thai Nguyen province. Model results are closer to the Yen Bai growth function than the Thai Nugyen growth function reflecting the larger number of reservoirs in Yen Bai (13) compared with Thai Ngueyn (8) for which Nguyen *et al.* (2001) provide data.

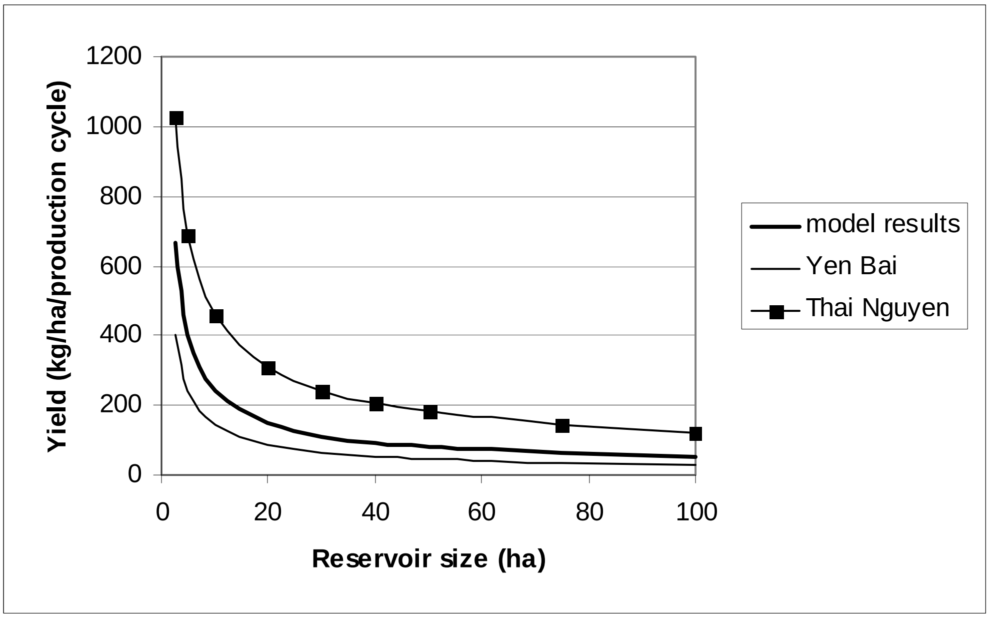

Figure 5: Model results for yields across reservoir sizes compared with Nguyen *et al.* (2001) data for the Yen Bai and Thai Nguyen provinces.

Model results for total harvest weight and biomass by species for an average reservoir size of 20ha is shown in Table 4. The harvest is dominated by silver carp, which contributes 50 percent of total harvest. Silver carp is the species stocked at the highest rate but also has the highest stocking efficiency. Mrigal (24 percent) and grass carp (17 percent) make smaller but significant contributions to harvest biomass. They are the second and third largest proportion stocked but have lower stocking efficiencies than bighead carp.

Table 4: Model results for total harvest weight and biomass by species for an average reservoir size (20ha).

	Total harvest weight (kg)	Harvest biomass (kg/ha)	Stocking efficiency
Common Carp	82	4 (3)	2.8
Silver Carp	1465	73 (50)	7.9
Grass Carp	493	25 (17)	4.8
Bighead Carp	213	11 (7)	7.3
Mrigal	704	35 (24)	5.0
Total	*2958*	*148 (100)*	*6.5*

Note: Numbers in parentheses indicate proportion of total harvest biomass.

4.2 Numerical analysis using the economic model

Fingerling prices were averaged from data on the Yen Bai and Thai Nguyen provinces collected by colleagues at the Vietnamese Research Institute for Aquaculture No 1. (RIA1) (Table 5). Grass carp and common carp fingerlings are significantly more expensive than the other carp species. Restocking costs by species are presented in Table 6. Mrigal, silver carp and grass carp represent 71 percent of restocking costs. The yearly interest rate was assumed to be 13.2 percent (Marsh *et al.* 2004), and contingency costs were estimated as 10 percent of total costs minus interest.

Other costs are presented in Table 7. It is assumed that one net is required for each reservoir (the number of nets does not depend on reservoir size for reservoirs less than approximately 80ha) and it needs replacing every 5 years at a cost of 2,000,000VND.[2] It is assumed that four non-motorised boats are required for a similar range of reservoir sizes, and they need replacing every 5 years at a cost of 200,000VND.[2] Watch-huts are not required as the guards are assumed to stay on the boats.

Contract labour is required to supplement the family labour for the tasks of guarding the reservoirs against fish poachers, harvesting and miscellaneous husbandry jobs. The labour cost for guarding is assumed to be 800VND/hour and 780 hours are required per year.[3] The labour cost for harvesting and other miscellaneous tasks is assumed to be 2300VND/hour and 820 hours are required per year.[3] Family labour is not costed as it is assumed to have an opportunity cost of zero. Contract labour costs contribute 70 percent of non-restocking costs.

Total costs equate to 14.1 million VND. Restocking costs contribute to 75 percent of the total enterprise costs.

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[2] Personal communication, Mr Nguyen Hai Son, Research Institute for Aquaculture No 1, Vietnam.
[3] Survey data, Mr Nguyen Hai Son, Research Institute for Aquaculture No 1, Vietnam.

Table 5: Assumptions on fingerling price for different fingerling sizes (VND/kg)

	Common carp	Silver carp	Grass carp	Bighead carp	Mrgial
Percent stocked	6	38	21	6	29
Fingerling size (g)	Prices				
< 15	30,000	17,000	31,000	18,000	19,000
15 - 20	20,000	14,000	25,000	13,500	16,000
20 - 35	18,000	11,000	22,000	13,000	12,000
> 35	15,000	8,000	18,000	10,000	9,000

Table 6: Restocking costs by species

Restocking item	Cost (VND)	% of restocking costs	% of total costs
Common Carp	530,000	5	4
Silver Carp	2,609,000	25	18
Grass Carp	2,266,000	21	16
Bighead Carp	383,000	4	3
Mrigal	2,702,000	25	19
Contingency (10% of non-interest variable costs)	849,000	8	6
Interest on restocking costs (assumed to accrue over 12 months)	1,233,000	12	9
Total restocking costs	*10,570,000*	*100*	*75*

Table 7: Costs other than restocking costs

Cost item	Cost (VND)	% of other costs	% of total costs
Net replacement costs	400,000	11	3
Boat replacement costs	160,000	4	1
Contract labour costs	2,510,000	70	18
Contingency (10% of fixed costs)	307,000	9	2
Interest on other costs (assumed to accrue over 6 months)	203,000	6	1
Total Fixed Costs	*3,580,000*	*100*	*25*

Harvest prices were provided by colleagues at RIA1 and are presented in Table 8. Grass carp, common carp and mrigal receive the highest prices at harvest compared with silver and bighead carps. Revenue per species for a 20ha reservoir is presented in Table 9. Silver carp, grass carp and mrigal contribute most to income flows. Silver carp receives the lowest market price but is stocked at the highest proportion. Grass carp and mrigal receive relatively high prices and are stocked at relatively high proportions.

Table 8: Assumptions on harvest price for different fish sizes (VND/kg)

Fish size at harvest (kg)	Common carp	Silver carp	Grass carp	Bighead carp	Mrgial
< 0.4	10,500	4,500	11,000	5,500	9,000
0.4 - 0.5	10,500	4,500	11,000	5,500	12,500
0.5 - 0.8	14,000	6,000	11,000	5,500	12,500
0.8 - 1.0	14,000	6,000	11,000	5,500	14,000
1.0 - 1.2	15,000	6,000	13,500	5,500	14,000
1.2 - 1.5	15,000	6,000	15,000	5,500	14,000
> 1.5	15,000	6,000	16,000	6,500	14,000

Table 9: Total revenue by species

Species	Total revenue (VND)	Percentage of total revenue (%)
Common Carp	862,000	4
Silver Carp	8,791,000	37
Grass Carp	6,659,000	28
Bighead Carp	1,174,000	5
Mrigal	3,640,000	27
Total revenue	*23,826,000*	*100*

A summary of the economic and social returns from the enterprise are presented in Table 10. Net revenue is approximately 9.7 million VND (approximately US$615). The benefit cost ratio is 1.7:1.

Table 10: Summary of economic and financial returns for an average reservoir size (27ha).

NET REVENUE (VND)	*9,676,000*
Total revenue (VND)	23,826,000
Total costs (VND)	14,150,000
Benefit cost ratio	1.7:1
Return on variable costs (%)	92
Return on total costs (%)	68
Marginal return (VND/kg)	4,481
Total revenue per ha (VND/ha)	1,191,000
Total costs per ha (VND/ha)	707,000
Net revenue per ha (VND/ha)	484,000

5. Sensitivity analysis

Sensitivity analysis on the von Bertalanffy growth parameters are presented in Figures 6 to 10. Each of the parameters are varied within a range that is considered possible. K, L_∞, L of fingerlings, a and b are varied by 33, 25, 20, 9 and 5 percent respectively, and so each figure cannot be compared directly. Given the range of likely sensitivity it can be seen that fingerling length and *a* are not very sensitive, *K* is moderately sensitive, while L_∞ and *b* are extremely sensitive. This indicates the importance of gathering accurate information on the latter two parameters.

Figure 11 shows model results for net revenue per hectare given a range of reservoir sizes. The curve is exponential and mirrors the stocking density curve of Figure 3. Figures 12 to 18 show the impact of stocking density, the length of the production cycle, fingerling weight, proportion harvested, fingerling price, fish price at harvest and contract labour costs on net revenue given an average reservoir size of 20 hectares. Each of these parameters are decreased and increased by 10 and 20 percent, so their sensitivity can be directly compared. The most sensitive variable is the length of the production cycle. The fish grow relatively slowly at first, but increase rapidly towards the end of the first year of stocking (see Figure 2). Hence, net revenue increases significantly with increased length of the production cycle. This is largely dictated by the hydrology of the water bodies. When water levels are high, the reservoir is restocked. When the reservoirs are partially drained for irrigation, water levels are low allowing ease of harvest. However, the longer the fishers can wait before harvesting, the greater the yield and hence the greater the net revenue. These results indicate that any scope to delay the harvesting time, say through combining reservoir aquaculture with cage culture (the latter could be used when the reservoir is drained) may have significant economic pay-offs. The least sensitive variable is contract labour costs.

Figure 6: Individual fish weight with different condition factors (*K*)

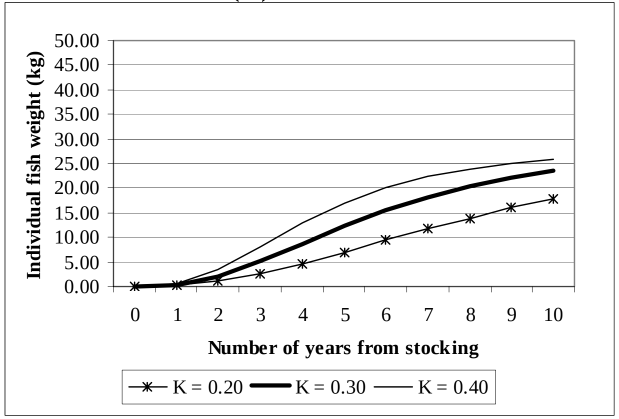


Figure 8: Individual fish weight with different lengths of fingerlings (cm)

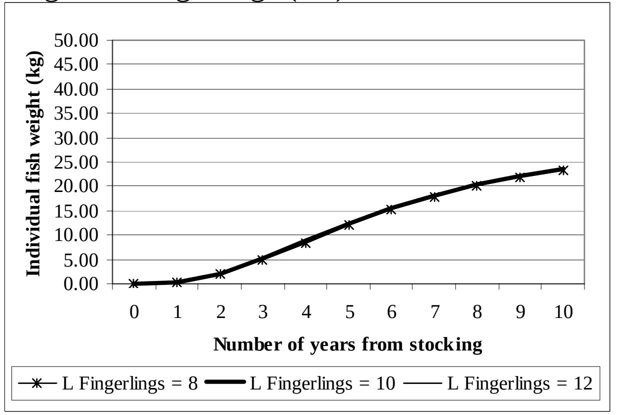


Figure 10: Individual fish weight with different values for *b*

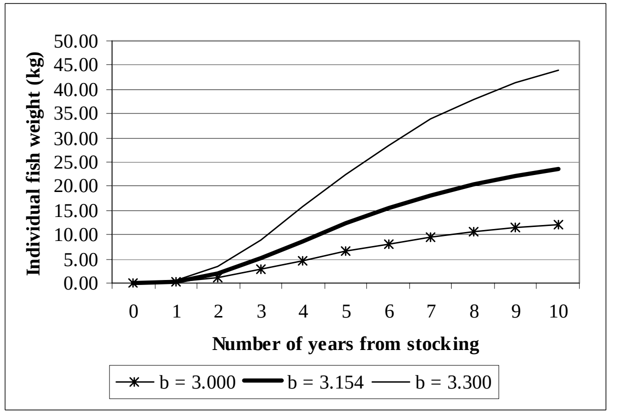


Figure 7: Individual fish weight with different asymptotic lengths (cm)

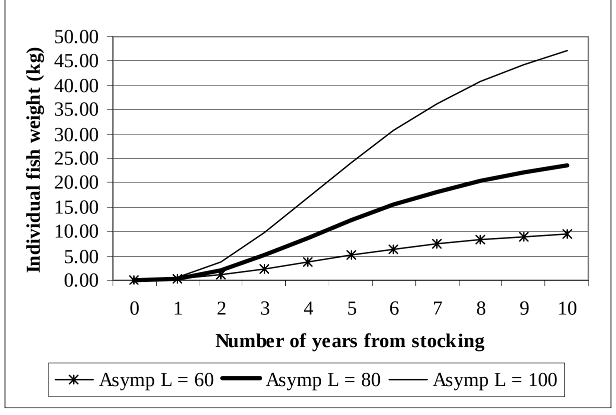
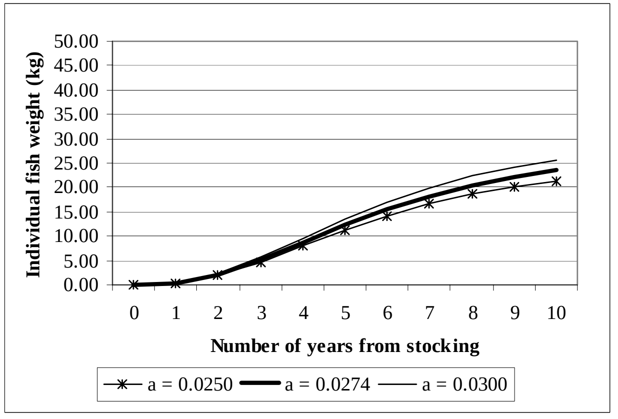


Figure 9: Individual fish weight with different values for *a*



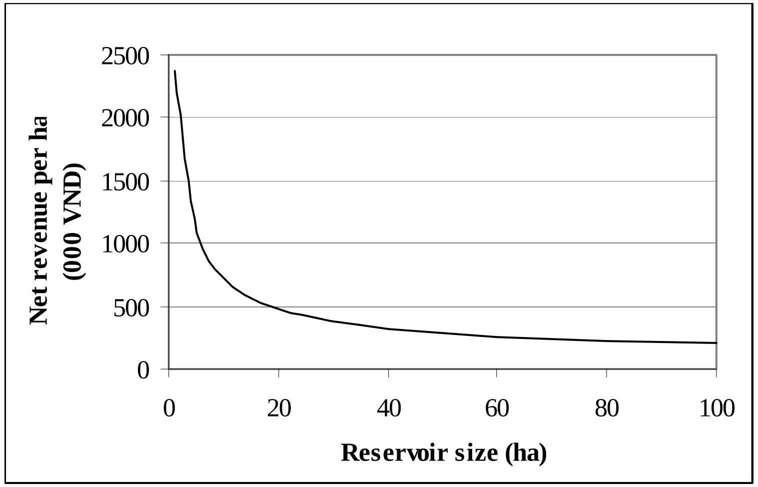


Figure 11: The effect of reservoir size on net revenue

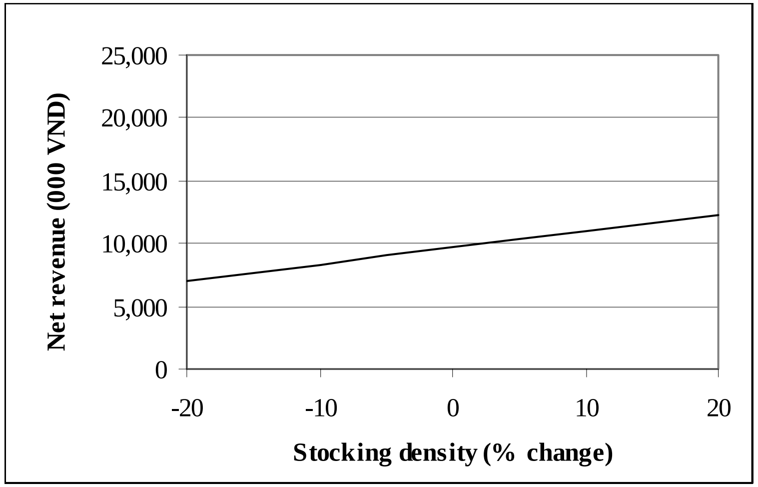


Figure 12: The effect of stocking density on net revenue

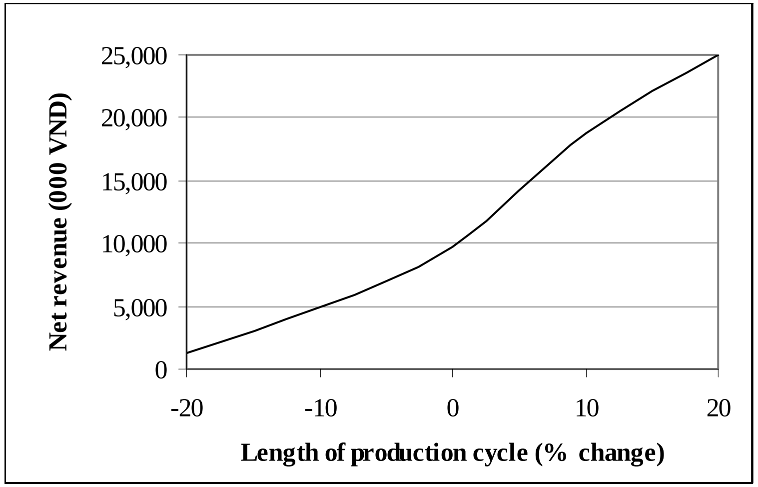


Figure 13: The effect of length of production cycle on net revenue

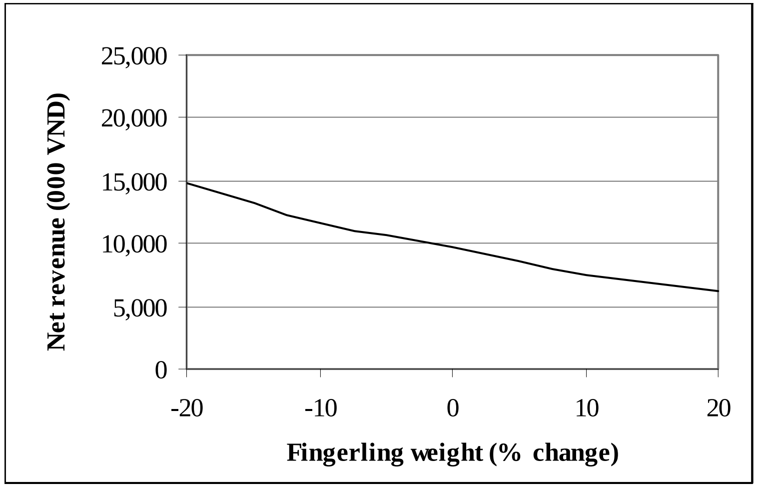


Figure 14: The effect of fingerling weight on net revenue

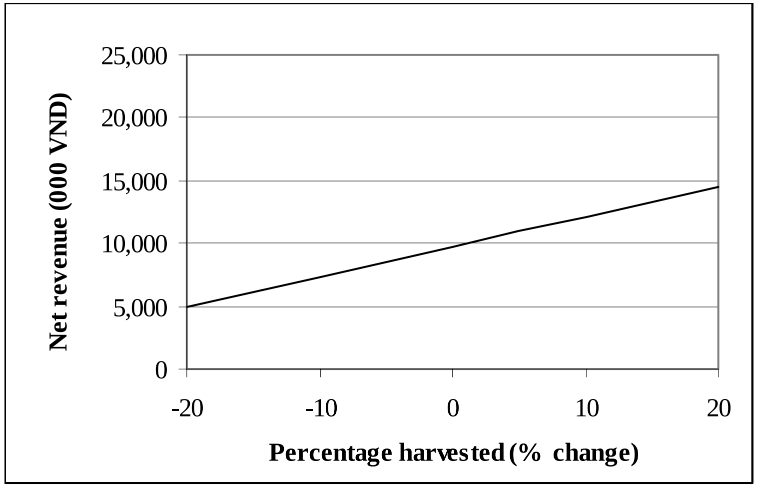


Figure 15: The effect of percentage harvested on net revenue

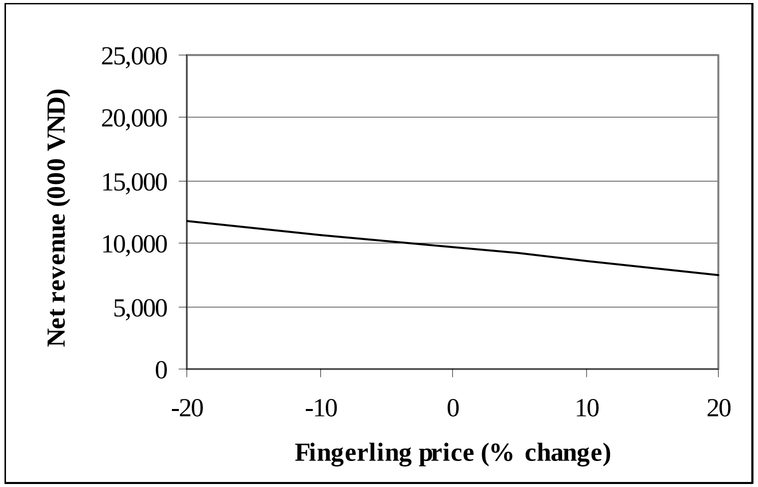


Figure 16: The effect of fingerling price on net revenue

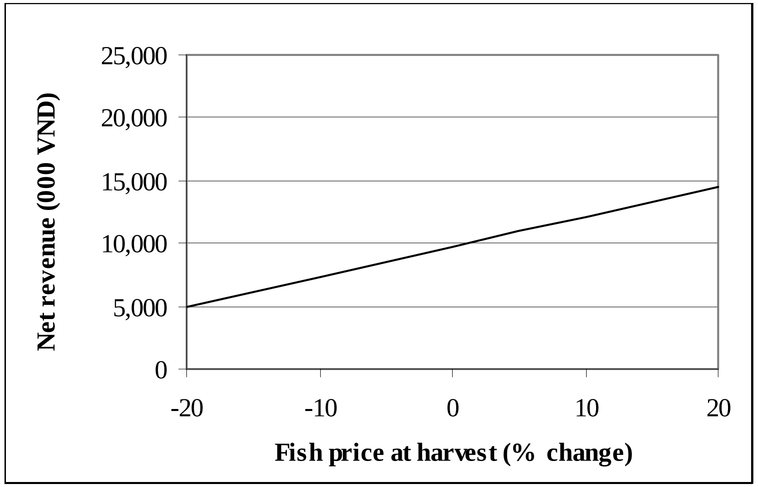


Figure 17: The effect of fish price at harvest on net revenue

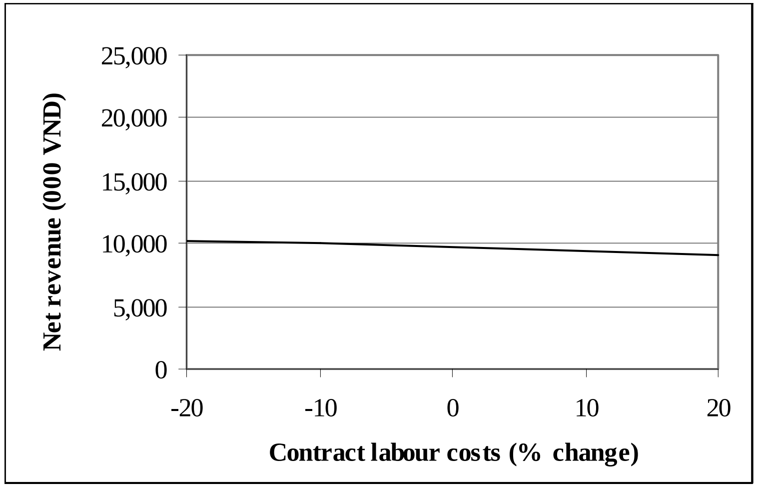


Figure 18: The effect of contract labour costs on net revenue

6. Conclusions - implications for policy and further research

Reservoir aquaculture is an infant industry in Vietnam. The industry's development has progressed in an *ad-hoc* nature, without a clear strategy from the Vietnamese government. Reservoir aquaculture is not included in fisheries development plans and consequently little in-country funds have been allocated to associated research. As a result, yields are low in Vietnam compared with similar fisheries elsewhere in Asia.

Bioeconomic results presented in this paper highlight two areas of uncertainty which have significant impacts on the gross margins of the aquaculture systems. The first is fingerling production. Good quality fingerlings are in short supply. Reservoir lessees purchase fingerlings on availability, rather than choosing species and quantities to optimise economic returns. Hence, species combinations and stocking densities are inefficient. Moreover, mortality of fingerlings is high due to poor quality fingerlings and transportation problems. Further research on constraints to fingerling production is likely to yield significant benefits to the aquaculture industry.

A second area of uncertainty and sensitivity is harvest efficiency. Currently, harvest efficiency is very low and variable (5-25 percent) due to fingerling mortality and inefficient harvest technologies. When the river systems are dammed to construct the reservoirs, little attention is given to preparing the flooded land for aquaculture purposes. Trees and other vegetation within the reservoirs provide ample hiding spaces for fish stocks, creating problems in harvesting. A government policy of preparing land (in an environmental appropriate manner) before creating the reservoirs is likely to lead to large increases in harvesting efficiencies and therefore large increases in financial returns to local fishing populations.

A further result of this analysis is that there is significant potential for capitalisation, and therefore rationalisation, of the industry. Costs are dominated by restocking (75 percent) and contract labour (18 percent) costs. The strengthening of institutional arrangements to securitise leasing arrangement is likely to improve incentives for capitalisation and investment in the fishing operations.

Lastly, further research into the fish marketing chain to highlight potential improvements in market chain performance, and to provide information on consumer preferences and consumption levels, is also likely to lead to higher prices and therefore higher revenues received by local fishing populations.

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