Farmers’ Decision-making on Integrating Aquaculture into Agriculture Systems in the Vietnamese Mekong Basin

IAAS in Vietnam (Article proposed for NJAS special INREF issue)

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Abstract

Contrary to the global trend of specialisation within agriculture, the rice-based Vietnamese production systems have diversified: into integrated aquaculture–agriculture systems. Economic liberalization in 1986 resulted in an explosive increase in rice production and a rapid diversification. This paper describes the history and dynamics of these systems in the Vietnamese Mekong Basin, and the farmers’ decision-making about integrating an aquaculture component. Fuzzy logic is used to simulate farmers’ decisions to opt for no aquaculture or one of four fish production systems: waste fed, pellet-fed, rice–fish, and ditch–dike, i.e. fish–fruit. The decision-making was simulated in a two-level hierarchy decision-tree. The first layer handles the farmer’s production preferences for rice, fruit and fish, with composed variables for land, water, labour, capital and market. The second layer simulated the choice between five options: no fish, and the four alternative fish-farming systems. The model allowed a farmer to practise different aquaculture systems at the same time. The fuzzy model simulation predicted the frequency distribution of fish production systems fairly accurately, but performed poorly when classifying individual farmers. To improve the accuracy of the simulation, additional rules can be specified and more factors considered for each product by adding a third layer to the decision-tree and replacing the composed variables with fuzzy rules.

Additional key words: fish, fuzzy logic, motives, change, diversification.

Introduction

Integrated aquaculture–agriculture farming systems (IAAS) are expected to make farmers’ livelihoods more sustainable, as with such systems, the components in the farm’s nutrient cycle are used more efficiently (Prein et al., 1998); (Jamu, 2003); nutrient losses are reduced, as manure and other farm waste are used to fertilise the pond and the pond sediments are subsequently used to fertilise crops whose residues can in turn be used as fodder for the livestock. Globally, agricultural research and development focus primarily on high-input technologies requiring high capital investments; e.g. most new breeds only perform well under optimal conditions. However, the financial capital available to small-scale farmers, for example in the Vietnamese part of the Mekong Basin (VMB), is insufficient to enable them to adopt such technologies. And if the farm components are not in equilibrium, even if farmers do adopt the technology there may be significant nutrient losses, thus reducing ecological and financial sustainability (Prein et al., 1998). To enlarge the potential of IAAS’s contribution to sustainable livelihoods the
INREF Program for Optimisation of Nutrient Dynamics (POND) studied: (1) breeding of fish that perform well in low-cost production environments and (2) optimising the nutrient recycling at farm level (INREF= Interdisciplinary Research and Education Fund of Wageningen University). The results of the first INREF experiments on the interaction between genotype and environment suggest that the context in which the fish are cultured does indeed dictate their growth performance (Charo-Karisa et al., 2004). Moreover, the growth rates of fish in the low-cost environment (ponds fertilised with poultry manure), nearly matched those of fish fed with high-cost pellets (Muendo et al., 2004).

The two innovations mentioned above can increase IAAS’s potential contribution to sustainable farmer livelihoods. Whether this potential is achieved depends on what options are available and what decisions individual farmers make. In order to analyse the decisions farmers make about changing and adopting technologies it may be necessary not only to assess the resource utilisation context (Hebinck, 2001) but also to run model simulations (e.g. Batz et al., 1999; Caswell et al., 2001), because used individually, neither method can entirely elucidate and quantify the process. Most current modelling methods are unsatisfactory because they assume that farmers’ decisions are based solely upon utility (Scoones & Toulmin, 1998). These models do not match the new constructivist sociological approach towards rural development, which places the individual farmer at the centre of agricultural innovations (Long, 2001). Therefore, we propose an alternative approach based on fuzzy logic modelling that can deal with subjective farmer utterances. The models also cope with non-probabilistic forms of uncertainty, and incorporate expert (i.e. farmer’s) knowledge (Zadeh, 1965, cited in (Jang et al., 1997). Moreover, they can generate a range of solutions (Silvert, 1997), similar to the process by which farmers shape one technology into various techniques (Hebinck, 2001). In this paper we describe how we tested the applicability of our approach using fuzzy systems for simulating farmers’ decision-making.

Vietnam is a good example of a country in which farming systems have tended to diversify instead of specialise. Within the past 3 decades, many farming systems in Vietnam have emerged from the state-controlled monoculture of rice for the market and other complementary produce destined for subsistence use. A range of new rice-based integrated systems has evolved, with many variations in terms of crop/fish/livestock integration and market orientation (Prein, 2002; Sanh et al., 1998). Because increased diversification in Vietnam has happened relatively recently, we collected the data to build a decision-making model by asking farmers to recount their practices (Bosma et al., in preparation). In this paper we attempt to elucidate farmers’ motives for diversifying into IAAS by (i) describing the history and changes of the IAAS in the Vietnamese Mekong Basin, (ii) establishing which factors account for farmers’ decisions to integrate aquaculture in the delta and surrounding hills, and using the known frequency distribution of the fish production systems (iii) applying fuzzy logic modelling to simulate farmer decision-making about these production systems.

**Methodology**

**Choosing the case study sites**

The Vietnamese part of the Mekong Basin can be divided into 7 agro-ecological zones (Figure 1). In order to assess the factors influencing the increased integration of farming components, we identified the zones where IAAS was appropriate. Livestock–fish–crop systems are found mostly in the freshwater alluvial zone (delta) and to a lesser extent in the upland and hill zones, where rain-fed agriculture predominates over irrigated cropping. In the other zones, crop and/or livestock farming is governed mainly by periodic flooding.
The predominant ethnic group in the delta lowlands is the Kinh, who practise Buddhism. In this area, the official land-use policy promotes the integration of fruit, fish, pigs and poultry into farming systems dominated by rice. The uplands are inhabited by the Kinh and a Khmer group of Cambodian origin. Some of the upland people practise a particular form of Buddhism prohibiting them from feeding faeces to animals and fish. The official land-use policy for the upland region focuses on the production of fruit, timber and cattle and this has led to the neglect of aquaculture’s potential. Recently, however, in response to the increasing number of farmers starting fish production, the ‘People’s Committee’ has started support programmes on aquaculture.

Data collection and processing

In 2004, farmers’ motives for implementing IAAS were assessed through semi-open interviews in the delta (February) and uplands (March). The reason for including the uplands was to capture the dramatic differences between the two farming systems. In the upland districts, three hamlets with predominantly rain-fed farms were selected: Le Tri, Phu Hiep, and Phu Hoa. In the delta, three hamlets in the villages studied by Phong et al. (2004) were selected: My Hung, Phu Dien and Thoi My. In that study, Participatory Community Appraisal (PCA) tools and structured questionnaires were used for recording an oral history and analysing the IAAS situation. The PCA involved timelines, seasonal calendars, food consumption patterns, village transects, bio-resource flows and production activities. The data for the timelines had been collected since 1970.

For the present study, we interviewed 144 farmers in 6 hamlets; in each hamlet 24 were selected through stratified random sampling based on wealth rankings of poor, intermediate and well-off. The classification was abstracted from existing lists or rankings provided by three knowledgeable local experts (Bosma et al., in preparation). In the interviews data were collected on family and farm characteristics, present farming systems, past changes and the causes or reasons for not changing. The data consisted of quantitative data on the household and farm, descriptive information, and “if then” statements. We classified children contributing to farm activities as youngsters (10 to 18 years) and their grandparents still working on the farm as elders; for the calculation of labour availability, elders not participating in work and young children were both classified as non-working. The “if then” statements, representing the linguistic expression of the conditions under which farmers implement a change or innovation, were based upon farmers’ motives for modifying their farming system and practices. These data and statements were used to build the fuzzy model.

Constructing the fuzzy model

A fuzzy system (also called a fuzzy inference system) consists of a number of “if then” rules, which describe the overall behaviour of a system. A reasoning mechanism determines the output of the fuzzy system, given its input and the behaviour described by the rules. A fuzzy “if then” rule is composed as follows: “If \( x \) is \( A \) and \( y \) is \( B \) then \( z \) is \( C \)”. In such a rule “\( x \) is \( A \)” is an antecedent, “and” is a connective, and “\( z \) is \( C \)” is called the consequence. The antecedent is composed of the variable \( x \) having one linguistic value \( A \) from a so-called “term set” of linguistic values (e.g. bad, average, good). The fuzzy linguistic values associated with each variable are represented as overlapping membership functions (MF) that completely cover the universe of discourse (see e.g. figure 4). Using the Matlab 6.1 software, release 13.1 we analysed the fuzzy model of the decision to integrate a fish component in the farming system.

The fuzzy inference system (FIS) was built in seven steps (adapted from Jang et al., 1997):
The decision-making process was represented in a two-level decision tree (Figure 2), in which the first layer consisted of three FISs for estimating the probabilities of a given farmer producing rice, fruit and fish respectively. The outputs of this layer, together with another variable termed the “Farmer’s reference frame”, are fed into the fourth FIS, which forms the second layer of the hierarchy.

When defining the input variables we used the factors the farmers considered to be central to the decisions they made (see Results section 2).

Data from the structured part of the semi-open interviews generated inputs for the fuzzifier (Figure 3) and supported the formulation of the linguistic value sets and the related MFs for each variable.

The farmer motives and utterances collected during the interviews guided the composition of the fuzzy “if-then” rules. We began by composing an extensive rule base for each FIS, including all possible combinations of the variables and linguistic values (e.g. 5 variables, each with 3 values, yielding 125 rules). Taking “don’t care” rules into account reduced the rule explosion. An example of a “don’t care” rule is “If Water is bad then No fish”; so, if the water is bad the rule chain is terminated.

The degree to which the rules were fulfilled was computed using the minimum operator. All fuzzy inference systems used max-min reasoning. The outputs of the first-layer fuzzy systems are not defuzzified (= transposed into crisp decisions), but used directly as input for the second layer.

The output from the second layer is a fuzzy set connecting the membership to each of the production systems considered. The farmer is assumed to adopt a particular production system if the membership for that output is larger than 0.5. Note that the layer-2 rule base contains multiple rules with the same antecedent and different consequences, which implies that farmers can adopt several different fish systems simultaneously.

The model was fine-tuned and calibrated by comparing the preliminary output with the real situation, and by manually adjusting the rules and the MFs parameters to obtain optimal fit between the observed systems and the model estimates.

Initially, the parameters for the membership functions (MFs) of the linguistic values for the input variables were set at quartile values calculated from the dataset, e.g. 1st quartile = low; 2nd and 3rd quartiles = acceptable and 4th quartile = good. For the fine-tuning, the magnitude of the five output variables was compared with the individual cases with the fish production system as practised on-farm. After identifying inconsistencies, the fine-tuning was done by shifting the thresholds of bad, acceptable and good for the MFs of the first-layer FIS input variables for the products (Figure 10). This change resulted in a larger or smaller centre value in the output, thereby increasing or reducing the probability of a specific system being implemented.

We will report the details of the membership functions for the input variables in the second part of the Results section, after presenting the dynamics of the IAAS. The model was validated through a comparative simulation of the fish production systems practised in the VMB uplands and delta. We then analysed the resulting set of rules.

Results

Dynamics of IAAS in the Mekong delta.

Historical background
Human recent settlement in the lower reaches of the Mekong river was favoured by the construction of a network of waterways from 1840 onwards. Later, the French colonial administration improved road access into the delta and people constructed linear settlements on the raised borders of the waterways (Sanh et al., 1998). Rural life on and around the waterways is still dominated by the diurnal tides from the South China Sea (Bosma et al., in preparation). The annual monsoon flood lasts between 2 and 6 months and may inundate the land by up to 3 m, depending on the particular year and location (Xuan&Matsui, 1998).

The livelihood of the people living in the delta centres on fish culture and irrigated, rainfed and/or floating rice crops. In the second half of the 20th century the economic development and livelihood patterns of the local people were strongly affected by wars and a centralised economic system. Between 1945 and 1976 the rural population followed a survival strategy, but the construction and dredging of waterways continued, laying the foundations for new development.

Changes since 1976
In all three delta districts studied the timeline showed the same major events (Figure 5). However, chronological differences in the key events caused technologies to have different impacts in districts and their hamlets (Phong et al., 2004). In some areas, major state investments in dikes and dams preceded the application of double or triple rice-cropping technologies.

Household production activities were strongly affected by the introduction of new technologies, the construction of canals and dikes, and the “Doi Moi” market reforms and wide commodity price fluctuations. From 1976 to 1992, farm households were stimulated to achieve self-sufficiency within cooperative units comprising 10 to 12 family farms, and the marketing of most products was either restricted to the local area (e.g. perishables, such as vegetables) or regulated by the state (e.g. pork, rice and clothing). The “Doi Moi” was a legal reform of the centrally planned economy, liberating trade, industry and services. It laid the foundations for land reform in which collective agriculture was abandoned. After 1992, land tenure was individualised and the land was designated either for agricultural by awarding a ‘red certificate’ or for forestry by a ‘green certificate’. These certificates not only conferred on the user the right to use the land as collateral, but also aimed to bring land use within a regulatory framework governed by land use policies. Farmers with a green certificate for forest plots had the obligation to bring their land use practices in line with regulations. Gradually, as the land market liberalised, land prices rose and access to land became dependent on the market.

Farmers’ reference frame.
Rice is the main staple crop in Vietnam and in the Mekong Basin in particular. Surplus production is sold to pay for farm inputs and support household needs. Elsewhere (Bosma et al., in preparation) we have reported that the adoption of water management practices, rice varieties, and rice technologies that allowed two – and later three – crops/year, improved the household’s food security, affected the market price of rice, and made land available for other uses. The improved food security achieved through rice production plus the low, but stable prices and liberalised market for rice influenced the farmers’ decision-making (some of them became less fixated on growing rice to ensure household food security. The motives for making changes to the farming system were also related to the farm household labour cycle and availability of labour. The desire to improve income and/or the availability of food for the household, especially to ensure the well-being of the children, was important. Older couples with no offspring to take over the farm tended to produce labour-saving fruit and fish instead of rice. Most farmers were aware of the
potential benefits of IAAS: risk spreading, a more even distribution of cash-generating opportunities, and more efficient resource use (Figure 6).

A low level of know-how sometimes hampered the inclusion of a new component in the farm, as shown in the fish-raising example (figure 7). In our survey, however, the only way we scored farmers’ knowledge was by recording the formal education they had completed. However, we found that the farmers’ propensity to try new technologies did not correlate solely with education level (Nhan et al., in preparation; Bosma et al., in preparation). In the villages, most of the transfer of know-how on feeding fish and new fish species for aquaculture was via the extension services and television. Poorer farmers’ access to media was limited, but those who travelled – sometimes for government (military) service – picked up ideas, could visit friends and acquire specific knowledge. Farmers rarely said that “lack of knowledge” was one of the top two major constraints to the adoption of a fish-farming system.

Farm characteristics
The village transects in the delta mostly showed homesteads with a pigsty and poultry pen, surrounded by fishponds, orchards, a vegetable garden and rice field (Phong et al., 2004). The average farm area was 1.0 ha in the delta (SD 1.8) and 2.1 ha in the uplands (SD 2.3). Most of the rice fields were at some distance from the homestead. The rice field was a source of food and cash for the family and of crop residues that could be used as livestock fodder. Other feed sources for pigs, poultry and fish came from the garden: weeds, and vegetable and fruit waste. After the fish had been harvested, the enriched sediment was removed from the pond bottom and applied as a topdressing around the trees in the orchard. In addition, the fishpond could supply water to irrigate the fruit trees and feed for pigs and poultry, such as water spinach, snails, or crabs. Most wastes and excreta were recycled on-farm (Phong et al., 2004). Farmers optimised the use of their resources by using the pig manure to fertilise the fishpond. In the uplands the homesteads tended to be further away from the fields, paddies, forests and orchards, making it more difficult to integrate the farm components effectively (Bosma et al., submitted).

In the delta, aquaculture started off with the existing ponds, canals and ditches and the self-recruited natural fish left after floods had receded. These fish were abundant until about a decade ago and were mostly raised without any inputs, but now almost all farmers have enhanced production by stocking with cultured fish and giving supplementary feeding (ibid.). In the delta, 97% of the farmers interviewed raised fish, compared with only 25% in the uplands. The pond or ditch area varied from 6 m² to 3,000 m² with an average of nearly 350 m². In the delta, at least 30% of the farms had more than one pond. The sample did not include farmers raising fish in netted enclosures or on boats in canals. In the delta about 40% of the farms were raising fish in ponds originally not meant for that purpose; in the uplands this figure was 25%. In the uplands, some ponds were used mainly to store water for livestock and orchards. In the lowlands of the delta, the ponds are the depressions left after soil was removed to raise the ground level for a house or for farming. In swampy areas it was traditional to build homesteads on raised mounds, not only to avoid flooding but also because of the scarcity of wood for houses with a raised floor. Fruit trees also need to be grown on raised land, to prevent them suffering from waterlogging.

Development of IAAS
When rice cropping was no longer remunerative, the farmers turned to substitution and/or complementary activities i.e. fish farming, fruit orchards, vegetable growing and livestock rearing. They increased the number of farm components to optimise the use of their limited resources and diversify production for the market. Phong et al. (2004) recorded 16 different rice-based systems in combination with horticulture,
upland crops, livestock, fishpond, and biogas. Almost 60% of the farms in the delta contained the four main components: garden, livestock, fish and rice; over 90% contained at least two (Figure 8). Some of the rice fields were converted directly into fishponds; sometimes, farmers gradually built a network of dikes and ditches, using the dikes for upland crops or trees and the ditches for raising fish (Linh, 2001; Prein, 2002; Sanh et al., 1998).

In the delta, over half of the farmers who started to raise fish concurrently developed land for fruit orchards; one third of them did so using ditch–dike or “raised bed” systems. In some cases the transition was related to neighbours’ land-use practices, not only because of the diffusion pattern of the innovation, but also because of the changes in water management resulting from local decisions to abandon paddy rice. In the uplands, the major reason for not having a fishpond was related to the unavailability of water during the dry season and/or inappropriate conditions: sandy or shallow soils (Figure 7). Other main reasons for not having a fishpond were insufficient assets, e.g. capital, and insufficient access to the land (the risk of theft and bird predation increased with the distance between homestead and fishpond).

The vast majority of fishponds recycled farm wastes: household and market waste, rice bran and excreta from humans, pigs, chickens and ducks. In the delta 77% of the fishponds recycled residues, compared with 65% in the uplands (Figure 9). Four major types of fish feeding systems could be distinguished: extensive low-input systems, farm-waste feeding systems, systems supplemented by external inputs of feed (e.g. pellets or market waste), and rice–fish systems. Feed regimes were not mutually exclusive: for example, fish wastes could be used in conjunction with pellets. Latrine ponds and manure-fertilised ponds were more popular in the delta, not only because of the water level in the delta but also because of the dominant religion in the uplands (Bosma et al., in preparation). In all three districts, the fish farming could be based on high, moderate, or low input levels, depending on market demand and level of technology. The practice was related to landuse differences, but distance to market was also important: 6.6 km for O Mon, 13.8 km for Tam Binh and 15.6 km for Cai Beh (Phong et al., 2004). For the model we retained 4 main fish production systems: ponds with waste- or pellet-fed fish, and fish raised in the ditches of fruit-oriented IAAS or of rice–fish systems.

**Fuzzy Logic Modelling**

The first step in the fuzzy logic modelling of farmers’ decision-making was to build a fuzzy simulation model based on a set of input variables reflecting farmers’ reasoning and output variables representing the causality of farmers’ decisions. This preliminary model was limited to simulating the frequency distribution of fish production systems in the delta and the uplands of the VMB. Five alternative modelled outputs were considered: no fish, waste-fed fish, ditch–dike, rice–fish, and intensive fish production systems (partially pellet-fed).

**The input variables**
The potential constraints to the expansion of aquaculture mentioned by the farmers were water, capital, labour, knowledge and three land-related factors (Figure 7). The farmers’ knowledge base was coupled to an index representing the farmers’ reference frame (Paassen, 2004). All five constraints are dependent upon several variables. The model assumes these constraints are represented by one parameter calculated from several variables, as explained below for the farmers’ reference frame.

For this study, we assumed that the determinants of the farmer’ decisions are the psychological attachment to the rice field, educational level, number of children, and age. From these four variables (constraints) an index was composed for the farmers’ reference
frame. The preoccupation with rice as a key to food security was represented by a value of -1 when the farmers had expressed interest in increasing rice production for domestic consumption or had already done so, and by +1 if they had not. Education was ranked from 0 to 5, where 0 represents no schooling and 5 a college education. The two variables most determining changes in the IAAS during the four stages of the household life-cycle were the number of children and age (ibid.). The number of youngsters was counted as real numbers and age implemented as: (10/age).

The availability of water for a pond depends on proximity to a waterway or source of water or groundwater, the soil water retention quality, and water level management options. These factors were also reflected in farmers’ land use, as improved water management possibilities enhanced multi-cropping and high-value fruit orchards (Bosma et al., in preparation). The index for water was derived from a land quality index (LQI). The land suitability was classified into nine classes, with land suitable for the most intensive production being assigned to class 1 and the extremely acid sulphate soils being assigned to class 9. Acid sulphate soils also make fish production difficult if drainage possibilities are limited. Homesteads consisting solely of an area with a house and farm buildings were consistently classed as 10. In practice this means that the linguistic value for Water is good if water was easily available all year after pond excavation, acceptable if water was available most of the year after excavation, and poor if water was difficult to access, even in the wet season.

The availability of land for a fishpond was related to the homestead area and upland fields where LQI<6, and to the number of lowland irrigated rice crops per year near the homestead. The irrigated land was taken into account only if the distance to the homestead was < 400 m and if LQI < 3.

Regarding labour, farmers most frequently mentioned that what determined production changes or innovations was the availability of family labour in a specific age category (Bosma et al., in preparation). The index for labour was derived from the weighted number of family members in the age categories: adult -0.25*non-working + 0.5*youngster + 0.75*elder.

In the model the availability of capital was assumed to depend on the capacity to save and the access to credit. The capacity to accumulate savings depends partly on income, which was related to the total area of land (rho= 0.43, Bosma et al., in preparation). Access to bank credit depends on the area of land with a red or green certificate and family-owned equipment/assets. The index for capital availability was derived from the area of land with red and green certificates, with the area with a green certificate counting for half. This ignores the frequent accessing of credit from relatives (for which no collateral was required) and from traders for inputs like fertiliser and feed.

The farm-gate prices of fish, fruit and rice were expressed as price indices with a value ranging from 0 to 1. A value of 0.1 was assigned when a low relative price was an argument for changing the farming system, 0.9 when a high price level was an argument for changing practices, and 0.5 when the product was stable during the period of the change. When the product price was not important enough to induce changes in the farming system, a neutral value in the fuzzy inference system was used; 1 was applied as the minimum operator to calculate the degree of fulfilment.

Performance and analysis of the fuzzy model

The preliminary fuzzy model for farmers’ decision-making predicted the number of farmers raising fish reasonably accurately, but the simulation of the frequency distribution of fish production systems in the VMB was less satisfactory (Figure 10). The fuzzy simulation predicted that 62 of 144 farmers would not raise fish; the actual number was 57. The mean accuracy of prediction for a specific fish production system was 91%.
In calculating the error, 4% were missed positives, i.e. farmers who were implementing the system but were not identified and 5% were the potential positives, i.e. farmers who did were not implementers but could have been according to the rules. The simulation underestimated the number of waste-fed ponds in the delta by about 15% and overestimated their number in the uplands by about 40%. The number of ponds in ditch–dike systems was overestimated in general by about 50%, mostly due to a large overestimation for uplands. The frequency of pellet-fed ponds was generally overestimated by 40%; the underestimation for the upland was smaller than the overestimation for the delta.

The model’s success rate in classifying individual farmers according to their fish production system was below 50% (Table 2). The model specifically failed to predict the few individual farmers who adopted rice–fish or intensive pellet-fed fish production systems. This indicates that the rules predicting rice–fish and pellet-fed systems should be evaluated further in order to improve the model’s performance.

The numbers of rules in the FISs for estimating the production levels of fish, fruit and rice were respectively 27, 21, compared with 34 rules for the fish production system (see e.g. the rule base for fish in Table 1). An analysis of the rules revealed that for raising fish or planting fruit trees, low capital availability was a constraint and an acceptable market price was a condition. However, these factors did not prove important for decisions to crop rice. Poor availability of water was a constraint to starting fish or fruit activities, but poor access to land did not restrict fish farming, though it did limit the farming of rice or fruit.

In order to elicit the farmers’ reasons for integrating complementary production components into their farming system and further develop IAAS, the model needs to be extended. We recommend at least four adjustments.

1. The number of waste-fed ponds in the uplands was overestimated because the religious taboo on using manure as feed was not considered. Both the underestimation of waste-fed ponds in the delta and the overestimation of pellet-fed ponds might be explained by farmer preference for pig-fattening concentrates and subsequent use of the manure to fertilise the ponds. These three aspects can probably be accounted for by inserting a variable *Farmers’ reference frame* in the FIS for each product separately.

2. The use of a three-level scale for subsistence rice production preferences hardly affected the variable for the farmers’ reference frame. It would be better to rank farmers’ preferences on a scale of 1-5: very high, high, medium, low, very low.

3. The price index for changes in the fish production system apparently performed well. However, it strongly influenced the simulation results and did not capture commodity market price fluctuations. To address this, the model simulations could be repeated with different price levels.

4. The fuzzy model overestimated the likelihood of ditch–dike systems in the uplands, possibly because of the favourable conditions there for fruit production. In fact, most farmers raising fish in the uplands have insufficient water to create ditch–dike systems and do not need ditches for draining water nor dikes to prevent the waterlogging of the soil in which fruit trees are grown. The fruit crops varied between the uplands and the delta: mango trees predominated in the upland, but longan and citrus were common in the delta (Phong, in preparation). To address this discrepancy, different factor demands related to the type of product should be included in the model.

**Discussion and conclusion**
Fuzzy logic modelling enabled us to satisfactorily simulate the frequency distribution of fish production systems in the VMB. However, for some systems the individual classification rate of farmers and the frequency distribution in delta or uplands were unsatisfactory. The simulation of the spatial dynamics of land use, Verburg et al. (2002) yielded a satisfactory fit, varying between 65 and 85%. We obtained a general fit of 91% for the frequency distribution, but an error of about 400% for the ditch–dike system in the hills. The error is less critical, however, given that Nhan et al. (submitted) have estimated that only one quarter of the available ditch–dike systems in the delta are effectively used for raising fish. Psychologists consider that people’s decisions are the outcome of complex and unobservable mental processes that researchers are still trying to elucidate (Johnson-Laird & Eldar Shafir, 1993). This is probably also reflected in the low individual classification rate for e.g. the infrequent rice–fish system: many farmers may have conditions suitable for the rice–fish system but only a few are actually using it, and we were unable to simulate their reasoning with the present rule-base and decision model. The rule base and the data sets used were rudimentary and have scope for improvement in terms of individual farmer knowledge and experience; this should reduce errors and increase the classification rate. Moreover, though using composed variables allowed a simple simulation model to be developed, this may have dramatically decreased the fuzzy character of the reasoning.

Most farmers in the VMB produced fish to improve their livelihoods and to diversify their sources of food and cash income. In view of the abundant rice production, with low and stable prices, and guaranteed family food security, rural households engaged in other farm activities to earn cash. In the delta, where ponds were often available for other reasons and ditches became available if farmers started growing fruit, fish make efficient use of resources and wastes from other land-use components for the family farm. This is reflected in the high frequency of waste-fed systems. Those promoting aquaculture improvements in Vietnam through the widespread adoption of innovations need to appreciate the role of fish in recycling waste (Brummett & Haight, 1996). The overestimation of the frequency for the ditch–dike and waste-fed systems in the hills shows that aquaculture has the potential for further expansion. While farmers in the uplands of Northern Vietnam cope with temporal water shortages by producing fish in short seasonal rain-fed cycles (Bosma et al., 2002), many of the upland farmers in our sample still believe that aquaculture is only feasible in the delta where water is available all year round. In Vietnam, small scale IAAS seem a logical entry point for the development of a socially, ecologically and financially sustainable agriculture, on family farms lacking resources or few opportunities outside agriculture.

Using fuzzy logic modelling of composed variables we have satisfactorily simulated farmer decision-making about adopting four aquaculture systems in the Vietnamese part of the Mekong Basin. Whether a fuzzy logic model can be used to explore the possibilities of fish production in other regions can be discussed only after the simulation has been refined by replacing the composed variables with a third level of FISs, including more factors for each product, and specifying additional rules for the farmers’ reference frame.

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**Figure 1. The agro-ecological zones of the Mekong Delta, Vietnam.**

Adapted from Sanh NV, Xuan V-T, Phong TA, 1998
Figure 2. Simulation architecture for farmer decision-making: on the left, the inputs for the first layer of three Fuzzy Inference Systems (FIS); in the centre, their respective outputs, i.e. the inputs for the second-layer FIS; and on the right-hand side, the output from the second-layer FIS.

Figure 3: General architecture of a Fuzzy Inference System (FIS): crisp inputs (I) are transformed into crisp outputs (O) using fuzzification, fuzzy inference and defuzzification. The fuzzifier transforms a crisp database in a fuzzy set, while the defuzzifier transposes the fuzzy output into a crisp solution or decision.

Figure 4: The adjusted membership functions of the input variables water for the Fuzzy Inference Systems of rice, fish, and fruit, respectively. The vertical axis gives the degree of membership while the values on the horizontal axis represent water availability (1/LQI).
Figure 5. A timeline of trends in agriculture for Cai Bè, Tam Binh and O-Mon districts in the VMB

Figure 6. The frequency distribution of the first two reasons the farmers in the delta and upland areas of the Vietnamese part of the Mekong Basin gave for the excavation of a pond.

Figure 7. First and second constraints to the integration of a fishpond in the IAAS of the VMD, mentioned by farmers; distance between the probable pond location and the homestead (Bosma et al. 2004).
Figure 8: Frequency distribution of farms according to the number of components in the farming systems in 3 districts of the freshwater alluvial zone in the Vietnamese Mekong Delta in 2002. The components were either rice, garden, upland crop, livestock, fishpond and biogas (based on data from Phong et al., in preparation).

Figure 9. Main feed resources of fish production systems practised in the alluvial freshwater delta and the uplands of the VMD (Bosma et al., 2004).

Figure 10: Number of farmers with various fish-raising systems from field study and model prediction. (Sample size: 144 farmers of whom 57 raised no fish and the others had 115 ponds).
Table 1. The list of consistent rules for the Fuzzy Inference Systems in the first layer of the decision model determining the likelihood that farmers are fish farming.

<table>
<thead>
<tr>
<th>Rule Description</th>
<th>Fish Farm Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>'if $W$ is bad, then fish farm is bad';</td>
<td>bad</td>
</tr>
<tr>
<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is low, then fish farm is bad';</td>
<td>bad</td>
</tr>
<tr>
<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is acceptable and $M$ is acceptable and $P$ is acceptable, then fish farm is acceptable';</td>
<td>acceptable</td>
</tr>
<tr>
<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is acceptable and $M$ is acceptable and $P$ is good, then fish farm is good';</td>
<td>good</td>
</tr>
<tr>
<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is acceptable and $M$ is good and $P$ is acceptable, then fish farm is acceptable';</td>
<td>acceptable</td>
</tr>
<tr>
<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is good and $M$ is acceptable and $P$ is acceptable, then fish farm is acceptable';</td>
<td>acceptable</td>
</tr>
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<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is good and $M$ is acceptable and $P$ is good, then fish farm is good';</td>
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</tr>
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<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is good and $M$ is good and $P$ is acceptable, then fish farm is acceptable';</td>
<td>acceptable</td>
</tr>
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<td>'if $W$ is acceptable and $L$ is acceptable and $C$ is good and $M$ is good and $P$ is good, then fish farm is good';</td>
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</tr>
<tr>
<td>'if $W$ is acceptable and $L$ is bad and $C$ is good, then fish farm is acceptable';</td>
<td>acceptable</td>
</tr>
<tr>
<td>'if $W$ is good and $L$ is bad, then fish farm is good';</td>
<td>good</td>
</tr>
<tr>
<td>'if $W$ is good and $L$ is acceptable and $C$ is acceptable, then fish farm is good';</td>
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</tr>
<tr>
<td>'if $W$ is good and $L$ is good, then fish farm is good';</td>
<td>good</td>
</tr>
</tbody>
</table>

Key: $W$=water; $L$=land; $C$=capital; $M$=labour; $P$=fish market.

Table 2: Cross-tabulation rates in percentages for individual cases of observed and estimated fish production systems.

<table>
<thead>
<tr>
<th></th>
<th>Estimated</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>No fish</td>
<td>Other</td>
</tr>
<tr>
<td>No fish</td>
<td>37</td>
<td>3</td>
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<tr>
<td>Other</td>
<td>7</td>
<td>53</td>
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<tr>
<td>Total</td>
<td>43</td>
<td>57</td>
</tr>
<tr>
<td>Waste-fed</td>
<td></td>
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<tr>
<td></td>
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</tr>
<tr>
<td>Waste-fed</td>
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<td>16</td>
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<tr>
<td>Other</td>
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<td>42</td>
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<tr>
<td>Total</td>
<td>42</td>
<td>58</td>
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<tr>
<td>Ditch–dike</td>
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</tr>
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<td></td>
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<td></td>
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<tr>
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<td>10</td>
</tr>
<tr>
<td>Other</td>
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<td>74</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>84</td>
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