The University of Reading

Assessing the sustainability of brackish-water aquaculture systems in the Philippines

Final report on DFID/AFGRP research project R8288

Xavier Irz and James R. Stevenson
University of Reading, Department of Agricultural & Food Economics

Contributors:

Rose-Glenda Alcade
Philippine Council for Aquatic and Marine Research and Development (PCAMRD), Los Banos, Philippines

Pierre Morissens
Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Equipe Aquaculture, Montpellier, France

Jean Petit
INRA, UMR Sol, Agronomie et Spatialisation de Rennes-Quimper, Rennes, France

Arnold Tanoy

Portia Villarante

Other Collaborators: Rafael D. Guerrero III (PCAMRD-DOST); Jurgenne Primavera (SEAFDEC-AQD); Clarissa Rubio (UP Diliman)

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DISCLAIMER

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EXECUTIVE SUMMARY

1- The project comprises five separate papers investigating different aspects of brackish water aquaculture in the Philippines. Papers 1 to 3 form the core of the project and progress towards the establishment of a ranking of different farming systems in terms of their relative sustainability. Paper 4 represents an extension of the original project proposal, as agreed with James Muir, which investigates in detail the role that aquaculture plays in the lives of poor people in the coastal areas of the Philippines. Finally, paper 5 investigates whether an efficiency case can be made for land reform in brackish water aquaculture in the Philippines. Hence, it is somewhat peripheral to the project but relates to the socio-economic analysis presented in paper 2, and in this regard was deemed worth including.

Paper number	Title	Aim
1	A typology of brackish-water pond aquaculture systems in the Philippines	Identify a small number of farming systems for comparative analysis of sustainability
2	Indicators of economic, ecological and socio-economic performance of aquaculture systems	Establish the relative performance of farming systems in economic, ecological and social dimensions
3	Analysing trade-offs among indicators of sustainability: a multi-criteria approach	Rank the farming systems identified in paper 2 in terms of their relative sustainability
4	Aquaculture and poverty – A case study of five coastal communities in the Philippines	Analyse the contributions that aquaculture makes to the livelihoods of poor people in coastal areas
5	Is there an efficiency case for land redistribution in Philippine brackish water aquaculture?	Test for the presence of an inverse relationship between farm size and efficiency, which would provide an efficiency rationale for land redistribution

2- We start by presenting the findings of the project and continue by formulating a number of recommendations.

AQUACULTURE FARMING SYSTEMS (Paper 1)

3- The construction of typologies of farming systems using multivariate datasets is increasingly perceived in the agriculture and, to a lesser extent, aquaculture literatures as being an important first step in comparative analysis.

4- A survey of brackish-water pond aquaculture farms was carried out in Regions III and VI – the two regions that account for the bulk of brackish-water aquaculture production in the Philippines. This yielded a net dataset (after removing inconsistent respondents) of 136 farms. Based on eight variables related to the use of labour, land and intermediate inputs (fertiliser, feed, fry), we identify three underlying latent variables (components) that explain 68% of the total variance in the original data by carrying out a principal components analysis. These three components (specialisation, land vs. labour intensity, and feed intensity) are used in a cluster analysis to establish five farm types.

5- The five farm types are labelled as follows: extensive polyculture (type 1, n=54); semi-intensive prawn polyculture (type 2, n=15); low-input labour-intensive systems (type 3, n=37); large, milkfish-oriented systems (type 4, n=11); and semi-intensive milkfish monoculture (type 5, n=19). These represent different combinations of production factors and characterise the full complexity of production systems in the Philippines, where traditional practices are mixed with new technologies and techniques.

6- This kind of typology offers greater realism than artificially imposed uni-dimensional classifications. For example, the concept of "intensity" can only refer to a specific input (e.g. land, labour, feed) even though the common division into extensive, semi-intensive and intensive systems requires a consideration of combinations of inputs.

SUSTAINABILITY OF AQUACULTURE FARMING SYSTEMS (Paper 2)

7- Aquaculture in the Philippines provides important livelihood opportunities directly (i.e, on-farm) as well as indirectly through multiplier employment effects that spread throughout the rural economy. Further, it represents a potential net source of dietary protein for Filipinos, although it may actually reduce the stock of protein because of inefficient farm management or a focus on culturing species situated high on the aquatic food-web. There are also environmental issues associated with brackish-water aquaculture, particularly nutrient enrichment of surrounding waters, and the appropriation of coastal resources in form of wild fry and broodstock, and wild-caught feeds. Finally, aquaculture development has sometimes been accused of increasing social inequity and the deprivation of coastal communities. Altogether, the sector faces economic, social and environmental problems that may challenge its long-term sustainability and provide the motivation for this research.

8- Sustainability, as conceived under the common "three pillars" or "weak sustainability" frameworks, is considered to be achievable through the attainment of economic, social and ecological objectives in an appropriate balance. In this context, comparative sustainability at the farm level can be analysed using a number of indicators for specific objectives. We follow this approach to study farm-level sustainability by comparing indicator results for each of the five farm types established in paper 1.

9- Indicators are developed for six farm-level objectives: profit maximisation, risk minimisation, maximisation of technical efficiency, maximisation of employment effects, maximisation of net protein production, and minimisation of nutrient loss.

10- Mean gross margin per hectare per year is used as an indicator of farm-level profit. We find that all farm types are profitable on average, but with considerable heterogeneity. Semi-intensive prawn-oriented polyculture (farm type 2) returns the highest level of profit on average at 59,100 pesos per hectare per year. Extensive polyculture (farm type 1) has the second highest with 51,200 pesos per hectare per year. The lowest level of profit per unit area is found for very large farms (farm type 4, 27,800 pesos per hectare per year).

11- Risk is measured by the standard error of the mean gross margin for a given farm type, divided by the mean gross margin. This measure conflates price and production risks and would ideally be measured from panel data from different farms over a time-series. However, such data is not available and we are restricted to considering variability in one time period only. As might be expected, the farm type that returns the highest level of profit is also the most variable – semi-intensive prawn-oriented polyculture (farm type 2). It would seem that operators of this kind of farming system attempt to mitigate their production and price risks by diversifying revenue streams across four species (prawns, milkfish, tilapia and crab) because revenue diversity, as measured by a Shannon index, is highest for this farm type.

12- Technical efficiency is estimated using a stochastic production frontier analysis. A favoured model is specified and the technical efficiency effects of particular farm-level characteristics are identified. We find that the following factors all reduce technical inefficiency: the operator lives on the farm; uses a traditional *lagum-lagum* pattern of stock movement as well as probiotics; and tests the pH of the soil. Of the five farm types, the semi-intensive prawn-oriented polyculture systems (type 2) are the most inefficient at less than 50%, which means that they could potentially double their output without increasing inputs. The other four farm types all fall in the 55% to 75% average efficient range.

13- The impact of aquaculture systems on employment is measured using an indicator that combines the on-farm employment per unit area and the employment in associated industries immediately upstream and downstream from the farm. This link is quantified using an assumed fixed technical coefficient for labour in each of these industries, and we use interviews with a number of businesses to generate the required data. We find that 80% of the employment effect of aquaculture is through on-farm labour use, although the downstream linkages are underrepresented in the analysis. On average, the total employment effect is 260 person days per hectare per year. However, there is heterogeneity that can be strongly linked to farm type. Low-input labour-intensive systems (farm type 3) provide the most employment with an average of 410 person days per hectare per year; extensive polyculture systems provide the lowest with 150 person days per hectare per year.

14- Food security impacts of aquaculture are measured by two indicators – the net dietary protein production (in kg per hectare per year) and the protein conversion ratio (ratio of inputs to outputs). The latter indicator shows that a majority of the farms produce more protein than they use as observable feed inputs, and thus are exploiting the natural productivity of the pond environment. However, there is considerable within-type heterogeneity for both these indicators, and some farms use considerable quantities of protein-rich feed to achieve relatively low yields. The highest net protein production per unit area comes from low-input labour-intensive systems (farm type 3). If we consider both this result and the high employment effect that these systems have on the local economy, we conclude that they can be considered relatively socially equitable. There is thus a possible tension between social equity and economic performance from the sector because low-input labour-intensive systems also perform relatively poorly when judged by economic indicators.

15- Nutrient loss to receiving waters is measured simply by the difference between the observable nutrient inputs and the nutrients embodied in the harvest. The fate of these excess nutrients are not known, but might be expected to correlate with the amount of nitrogen released into the water, hence contributing to nutrient enrichment of the coastal areas. All farm types present positive values for this indicator and therefore generate nutrient losses. However, there is considerable heterogeneity across types. Semi-intensive prawn-oriented polyculture farms lose, on average, 230 kg N per hectare per year - compared to only 20 kg N per hectare per year for extensive polyculture and 50 kg N per hectare per year for low-input labour-intensive systems.

16- Pesticides are applied to most farms, in fairly consistent quantities of between two and five kilograms per hectare per year. However, the kind of pesticides used varies significantly in terms of toxicity. Sodium cyanide is favoured in region III, whereas Brestan is more commonly used in region VI. Both of these chemicals are highly toxic and their status with regards to national and municipal laws is confused.

17- The ecological footprint method was applied in a partial manner by focusing on two inputs to the farming systems: small bivalve and univalve shells used as feeds, and prawn fry. Both of these inputs are dependent on the same areas that are occupied by the farms themselves – i.e. the inter-tidal coastal areas. Using secondary data from other ecological studies and data on the use of these inputs from the farm-level survey, we estimate that approximately nine hectares of inter-tidal areas are indirectly appropriated to provide small shells and fry to one hectare of semi-intensive prawn-oriented polyculture farm (farm type 2). The equivalent estimate for extensive polyculture is two hectares per hectare, whereas the areas for the other farm types are negligible / zero. These are only very partial estimates of the full ecosystem support required by brackish-water pond aquaculture in the Philippines. However, they are useful to highlight the paradox that has often been at the heart of criticisms directed at coastal aquaculture: while one of the rationales for aquaculture is that it can provide a solution to the problem of stagnating or declining wild fisheries yields, the mobilisation of many of the inputs consumed by aquaculture can add to the stresses faced by capture fisheries.

ANALYSIS OF TRADE-OFFS AMONG SUSTAINABILITY OBJECTIVES (Paper 3)

18- Farm-level trade-offs among sustainability objectives are analysed using a discrete- choice multi-criteria decision-making model. Central to the model is the concept of the utopian point – where all objectives are maximised simultaneously. Of course, such a point is exactly that, utopian, and thus we must be content with minimising the distant to such a point. Thus, the utopian concept of sustainability is made operational for modelling purposes.

19- While we find that there are important trade-offs between some pairs of indicators (e.g. profit and net protein production; profit and employment), there are other pairs of indicators for which a “nearly optimal” solution in one provides a good level of achievement in the other.

20- The measures of six indicators for five farm types are used as the basis of the analysis. The relative importance of each indicator in determining the distance to the utopian point is determined locally, and four case-studies in two barangays are used in applying the model. These weights are elicited from focus group exercises using the technique of matrix scoring.

21- For most sets of weights chosen by the groups, extensive polyculture (farm type 1) is the preferred farm type. It scores highly (but not maximally) for profit and has a relatively weak score only for employment effect. Large milkfish-oriented systems (farm type 4) perform poorly in all scenarios, and are the least preferred of the five farm types. The other three farm types are intermediate between these two.

AQUACULTURE AND THE LIVELIHOODS OF THE POOR (Paper 4)

22- The analysis of the social effects of aquaculture is extended by investigating the relationship between aquaculture and poverty based on a household-level survey of five coastal communities (or ‘barangays’) in the Philippines.

23- A review of the literature reveals that, at a conceptual level, the relationship between aquaculture and poverty is relatively straightforward. The arguments supporting the pro-poor nature of aquaculture rely on the income stream, employment and nutritional benefits that it can potentially generate. However, the empirical evidence regarding the ability of aquaculture to reduce poverty is rather limited and, altogether, mixed at best. Hence, there is room for additional empirical enquiry, which this study aims to fill.

24- Five communities were chosen in Regions III and VI. These communities were purposefully selected in order to capture a variety of contexts in terms of remoteness, relative importance of fishing and aquaculture as economic activities, geographic location and proportion of land area covered by mangroves. Altogether, qualitative and quantitative data on the socio-economic conditions and perceptions of 148 randomly selected households in the five communities was collected.

25- The results reveal a high, but also variable, incidence of poverty in the five studied communities. The quantitative analysis establishes that 59% of the surveyed households fall below the official poverty line, while 43% do not even reach the ‘food threshold’, which we interpret as an absolute poverty line. Meanwhile, a self-assessment exercise indicates that more than two thirds of respondents consider themselves to be poor. These figures compare unfavourably to a Head Count index of 37% for the country as a whole, confirming the received wisdom that coastal communities tend to be particularly deprived – and, hence, leaving room for a potentially large poverty alleviating effect of aquaculture.

26- There is clear evidence that both poor and non-poor households benefit from aquaculture, but that the poor benefit more in relative terms. The quantitative analysis indicates that a poor household derives, on average, PhP23,863, or 44% of its income, from aquaculture, as compared to PhP30,809, or 23%, for a non-poor household. Further, the extreme poor in the selected communities derive, on average, more than half their income from aquaculture. Aquaculture can therefore be considered pro-poor in the sense that its relative importance in income generation is larger for the poor than the non-poor. Confirming the analysis of income data, a very large majority of respondents expressed the view that aquaculture is mutually beneficial to the poor and non-poor.

27- A Gini decomposition exercise was carried out to investigate the influence of aquaculture on income inequality. The results establish unambiguously that aquaculture represents an inequality-reducing source of income in the studied communities. In particular, while aquaculture accounts for an average 30% of household income, it contributes to only 8% of overall inequality as measured by the Gini coefficient.

The inequality-reducing effect is even more pronounced at the margin, with a one percent increase in aquacultural income estimated to reduce the Gini coefficient by 0.08. This result is explained primarily by the lack of correlation between household income and aquacultural income - in other words, by the fact that the non-poor are not much more likely to derive large incomes from aquaculture than poor households. Further, the finding that aquaculture has an inequality-reducing effect appears robust in the sense that it applies to both the whole sample and the individual communities taken individually.

28- A minority of respondents (30%) believe that aquaculture may have a negative impact on the poor, mainly because it generates externalities (water pollution) from which poor fisher-folks suffer. However, these negative effects are clearly not thought to exceed the benefits from the industry, because an overwhelming majority (95%) expressed an overall positive view of aquaculture. Hence, it is clear that in these communities, aquaculture is seen as a potential solution to the poverty problem – and certainly not its cause.

29- The main benefit from aquaculture to the poor lies with the employment that it generates in labour-surplus communities where the lack of jobs is perceived as the main cause of poverty. The supervision of ponds (‘caretaking’) provides stable jobs to almost a quarter of households in the sample, which is usually sufficient to keep them out of poverty. The hiring of daily labourers and harvesters by fishpond operators is also important because it allows for a broad sharing of the value added generated by the sector. Hence, almost half of the households derive some income from the sale of wage labour to aquaculture farms, while one in five participates in the harvesting of fishponds. Additional employment is created through linkages, although its importance appears limited, as mentioned previously with reference to paper 2. Finally, in the two barangays where aquaculture is the most developed, only six households out of 62 do not derive any income from fish farming-related activities.

30- The analysis establishes that the poor themselves do not operate fish farms, although the causality of this relationship appears difficult to establish. On the one hand, and contrary to expectations, more than half of the respondents expressed the view that some poor people manage to establish themselves as aquaculture producers. Hence, there appears to be some degree of social mobility within the studied communities, and aquaculture itself may be regarded as an instrument of that mobility. On the other hand, respondents acknowledged that there are important barriers preventing entry into the sector by the poor, with access to credit representing the main one.

31- Although difficult to quantify, there appears to be important nutritional benefits to the studied communities from aquaculture, which materialize through a variety of non-market mechanisms. For instance, the practice of allowing the collection of ‘free fish’ from ponds, i.e. any residual fish or crustaceans left after the main harvest, represents a source of fish for a large number of households.

AQUACULTURE AND LAND DISTRIBUTION (Paper 5)

32- The tidally inundated brackish-water land supporting fish ponds has so far been exempted from the Comprehensive Agrarian Reform Laws in spite of being unequally distributed, as indicated by a large Gini coefficient of pond ownership (0.72), as well as the existence of very large farms (with sizes in excess of 100 hectares).

33- Beyond obvious equity issues, this unequal distribution raises the possibility that brackish water land may be used inefficiently if large farms are less productive than small farms, as is usually believed to be the case in the agricultural sector of developing countries. We investigate this question formally by testing for the presence of an inverse relationship between farm size and technical efficiency.

34- The econometric results provide evidence of an inverse relationship of only limited strength. Hence, it is estimated that, on average, a 10 percent increase in farm size raises the level of technical efficiency by only 1.4 percent. Further, farm size explains only 13 percent of the variation in production not accounted for by inputs.

35- The analysis also reveals that brackish water fish farms are very inefficient, confirming the conclusions reached in paper 2 with a different methodology. However, it is unlikely that land reallocation holds the key to unlocking the productive potential of brackish water aquaculture in the Philippines.

CONCLUSIONS AND RECOMMENDATIONS

36- Two factors suggest that extensive aquaculture is sustainable in the Philippines. Firstly, it would appear to be resilient in the face of a number of perturbations, such as disease outbreaks and the eruption of Mount Pinatubo. Secondly, from the results in the multi-criteria decision-making model in paper 3, we find that extensive polyculture and low-input labour-intensive systems are those preferred under sets of weights chosen by stakeholder groups in our study regions. Thus, these feed-extensive systems perform the best relative to the other farm types in the regions.

37- However, there are problem areas away from farm-level issues. Prime amongst these must be the reliance of the sector on wild broodstock and/or fry as well as on wild-harvested live feeds (small bivalve and univalve shells); and the conversion of mangrove areas to make way for more fishponds. All of these issues should be considered relevant areas for further research and possible government action.

38- An overall ranking of farming systems from the analysis in paper 3 is: extensive polyculture – top; low-input labour-intensive systems, semi-intensive milkfish monoculture, semi-intensive prawn-oriented polyculture – middle rankings; large milkfish-oriented systems – bottom.

39- The poor performance of a small number of very large farms that occupy almost half of the area of our sample farms provides motivation for including brackish-water fishponds under the Comprehensive Agrarian Reform Law. Powerful operators in the sector have thus far successfully lobbied for exemptions from the law, but this would appear to have no support in economic, social or ecological terms from the findings in this project.

40- The evidence presented here suggests that intensification of either prawn-oriented polyculture or milkfish monoculture would result in: a higher level of profit on average; a more variable level of profit; reduced nutrient and protein efficiency; reduced technical efficiency; and would likely have little effect on employment. In terms of choices of output, polycultures would appear to be preferred to monocultures on every level.

41- The ability of the poor to partake in aquaculture production should be facilitated by reducing barriers to entry into the sector, which means primarily improving their access to financial capital. If that is not possible, ensuring that caretakers do obtain a share of total revenue or profit, as stipulated in their verbal contracts, would improve entry into the sector by relatively poor households.

42- The research (papers 2 and 5) establishes that fish farmers exhibit high levels of technical inefficiency, which simply means that they could, on average, increase output by a considerable amount with the available technology and the input quantities currently used. While it is recognised that brackish-water farms operate in a difficult and changing environment, it appears that best practices are not shared among farmers, leading to a high level of heterogeneity in terms of technical performance. This suggests that there is considerable room for improvement in farm management, which could be brought about by public R&D investments specifically targeted at brackish-water aquaculture. Such investments are almost non-existent currently, which reinforces the idea that they might deliver high returns.

43- Further, it is clear from the results of paper 4 that, altogether, aquaculture makes a positive contribution to the livelihoods of the poor. Hence, the afore-mentioned investments appear desirable from both efficiency and equity points of view, because aquaculture development is likely to generate large benefits to the poor. At that level, the research found little support for the contention that aquaculture increases the deprivation of rural coastal communities.

44- However, our results also imply that technological progress in the sector does not automatically yield benefits to the poor, who are unlikely to use those technology themselves. It is really the employment-generating potential of new technologies that should be considered when assessing their contributions to poverty alleviation, rather than their potential to increase yield or profitability (which, of course, are important as well in ensuring that the new technology is adopted by farm operators).

BACKGROUND TO THE PROJECT

The Philippines is a country in which a *laissez-faire* government policy to aquaculture development over the previous two decades has been replaced with an official commitment to the principles of sustainability in its National Policy on Fisheries, embedded in the Philippines Fisheries Code of 1998. The crash of the intensive prawn industry in the early 1990s and public anxiety after numerous fish kills reported in the press have acted as drivers to bring about this change. However, in developing a strategy for sustainable development of the aquaculture sector, the Philippine government is constrained by the lack of an inter-disciplinary study on the specific farm-level impacts of different types of production systems. A suitable framework is required in which the trade-offs between the triple objectives of maximising economic performance, maximising social acceptability and maximising ecological sustainability, can be made explicit.

PROJECT PURPOSE

The primary purpose of the project is to improve knowledge of the interactions among the economic, social and ecological properties of pond aquaculture systems in the Philippines. This should in turn increase the coherence of the policies aimed at addressing the problems of the sector and thereby increase its sustainability. The project also intends to demonstrate the utility of a systems-thinking approach to the analysis of aquaculture.

In addition, following discussions with the program manager, it was decided to extend the scope of the project as defined in the original proposal to analyse the role that aquaculture plays in the livelihoods of the poor in the coastal areas of the Philippines.

RESEARCH ACTIVITIES

- Review of the literature on typologies, sustainability indicators, and multi-criteria decision making (MCDM) methods.
- Farm-level survey of a sample of 150 operators in regions III and VI of the Philippines.
- Principal component and cluster analyses of the farm-level data.
- Selection of sustainability indicators in economic, social and ecological dimensions.
- Collection of the primary and secondary data necessary to measure the selected indicators.
- Elicitation of preference weights for MCDM modelling through focus group discussions with stakeholders.
- Construction of a variety of MCDM models.

- Workshop on the theme ‘Aquaculture and poverty’ organized in the Philippines.
- Household survey of five coastal communities in the Philippines.
- Poverty and inequality analysis of the household survey.

- Analysis of the relationship between the technical efficiency of farms and their size.

RESEARCH OUTPUTS

- The literature reviewed is weaved into the five papers included in this report.
- A farm-level data set that represents an important and unique source of information on brackish water aquaculture in the Philippines.
- A typology of brackish-water farms that forms a concise summary of the diversity of production systems in Philippine aquaculture. The analysis identifies five farm types: extensive polyculture; semi-intensive prawn production; low-input labour-intensive systems; large, milkfish-oriented systems; and semi-intensive milkfish monoculture (paper 1).

- A comparative analysis of the five farm types identified in the typology based on the following sustainability indicators: farm profit; production and price risk; technical efficiency; employment generation; net protein production; nutrient loss; and (partial) ecological footprint (paper 2).
- A trade-off analysis of a selection of sustainability indicators (paper 3).
- A ranking of the five farm types derived from MCDM models. In most cases, extensive polyculture represents the preferred farm type. It scores highly (but not maximally) for profit and has a relatively weak score only for employment effect. By contrast, large milkfish-oriented systems perform poorly in all scenarios, and are the least preferred of the five farm types. The other three farm types are intermediate between these two (paper 3).

- A characterisation of the poor in the selected communities with regard to their relationship to aquaculture. We establish that aquaculture is clearly 'pro-poor' in the sense that the poor derive a relatively larger share of their income from aquaculture than the non-poor. We also find that aquaculture is perceived very positively by the poor and non-poor alike (paper 4).
- A Gini decomposition exercise on household income establishes that aquaculture reduces inequality in the selected communities (paper 4).
- An explanation for the pro-poor nature of aquaculture in the Philippines that lies with the employment generated by the sector. Aquaculture provides jobs to a large number of unskilled workers in communities characterized by surplus labour (paper 4).

- Evidence of an inverse relationship between farm size and efficiency but of only limited strength. Hence, it is unlikely that land reform is the key to unlocking the productivity potential of brackish water aquaculture in the Philippines (paper 5).

CONTRIBUTION OF OUTPUTS TO DEVELOPMENTAL IMPACTS

Several policy implications, recommendations and methodological insights can be drawn from the research:

- From a sustainability point of view, polyculture and (relatively) extensive systems tend to perform better than intensive and monoculture systems. This simple statement can help select options available to the government to encourage the development of the sector.

- There are clear trade-offs among the economic, social and ecological properties of aquaculture systems. Policy options aimed at orientating the development of the sector should therefore not be evaluated based on a single criterion, such as yield or profit per unit area.

- The poor performance of a small number of very large farms that occupy almost half of the area of our sample farms provides motivation for including brackish-water fishponds under the Comprehensive Agrarian Reform Law.

- Although the methodology appears ill-suited to evaluate the sustainability of aquaculture systems in absolute (rather than relative) terms, the research identifies the key areas of concern as: the reliance of the sector on wild broodstock and/or fry as well as on wild-harvested live feeds (small bivalve and univalve shells); and the conversion of mangrove areas to make way for more fishponds.

- Public R&D investments aimed at improving farm management in brackish water areas are likely to deliver high returns.

- Aquaculture development appears desirable from both efficiency and equity points of view because, in addition to high returns, it generates large benefits to the poor. The research found little support for the contention that aquaculture increases the deprivation of rural coastal communities.

- Improving access to financial capital by the poor would remove the main barrier to entry by the poor into aquaculture. If it is possible to bring about such an improvement, ensuring that caretakers obtain a share of total revenue or profit would improve entry into the sector by relatively poor households.

- If concerned with the contribution of aquaculture development to poverty alleviation, it is primarily the employment-generating potential of new technologies that should be considered in the Philippines.

The development impacts of the project can only be indirect through the adoption of some of the recommendations detailed above by policy makers and researchers involved in aquaculture development. At that level, it might be worth pointing out that the project was developed in collaboration with institutions in the Philippines – for instance, the poverty workshop was co-organized by PCAMRD and the University of Reading – and that the project report, when finalised, will be disseminated to all partner institutions.

LIST OF OUTPUTS

WORKSHOPS

Aquaculture and Poverty, co-convened by the University of Reading and PCAMRD, organized in Los Banos, Philippines on 22 April 2004.

List of speakers:

- Edwards, P., Emeritus Professor, AIT, Thailand
- Guerrero, R., Director, PCAMRD, Philippines
- Hejdova, E., Doctoral student, CIRAD, France
- Irz, X., Lecturer, The University of Reading, UK
- Morrisens, P., Scientist, CIRAD, France
- Primavera, J. H., Senior Scientist, SEAFDEC, Philippines
- Stevenson, J., Research Officer, The University of Reading, UK

Other participants:

- Barrios, E., University of the Philippines in Diliman
- Ong, D., BFAR Region VI
- Edra, R., PCAMRD
- Darvin, L.C. , PCAMRD
- Bondoc, L.V., PCAMRD
- Piscano, J., Independent
- Natividad, J., University of the Philippines in Diliman
- Pullin, R., Independent
- Rubio, C., University of the Philippines in Diliman
- Tanoy, A., Independent
- Villarante, P., Independent

PUBLICATIONS

Stevenson, J. R. (2005). Sustainability of brackish-water pond aquaculture systems: A farm level analysis of economic, social and ecological dimensions in the Philippines. PhD dissertation (first version submitted July 2005), University of Reading, Department of Agricultural and Food Economics.

CAB International (forthcoming, 2005). Aquaculture and poverty – A case study of five coastal communities in the Philippines [original text by Irz, X. and Stevenson, J. R.]. In: Aquaculture Compendium. Wallingford, UK: CAB International.

CAB International (forthcoming, 2005). Typology of farming systems in brackish water ponds, Philippines [original text by Stevenson, J. R. and Irz, X.]. In: Aquaculture Compendium. Wallingford, UK: CAB International.

Stevenson, J. R., X. Irz, J. H. Primavera, G. Sepulveda (2003). Costal aquaculture system in the Philippines: social equity, property rights and disregarded duties. Proceedings of the conference on rights and duties in the coastal zone, 12-14 June, Stockholm, Sweden.

ARTICLES UNDER REVIEW

Irz, X. and J. R. Stevenson. Is there an efficiency case for land redistribution in Philippine brackishwater aquaculture? Analysis in a ray production framework, submitted to Applied Economics.

PAPERS UNDER PREPARATION FOR SUBMISSION

Stevenson, J., X. Irz, R. Alcalde, J. Petit and P. Morrisens, A typology of brackish-water aquaculture systems in the Philippines.

Irz, X., J. Stevenson, A. Tanoy and P. Villarante. Aquaculture and poverty – A case study of five coastal communities in the Philippines, working paper posted on project website http://www.dfid.stir.ac.uk/Afgrp/report14.htm#R8288.

CONFERENCES AND SEMINARS

Irz, X. (2004). Déterminants des différents systèmes de production aquacoles aux Philippines – Mesure, déterminants et implications, invited seminar at the French Agricultural Academy, 07 April 2004, paper available at http://www.academie-agriculture.fr/seances/?dir=current.

Stevenson, J.R. (2004) Indicators of Sustainability for Philippine Aquaculture. Invited presentation to a roundtable organised by INRA-IFREMER as part of *Bordeaux Aquaculture 2004*, Bordeaux Exhibition Centre, Bordeaux, France, 22nd -24th Sept 2004.

Stevenson, J.R. (2003) Coastal Aquaculture Systems in the Philippines: Social Equity, Property Rights and Disregarded Duties. Presentation to the multidisciplinary scientific conference on Rights and Duties in the Coastal Zone, Royal Swedish Academy of Sciences, Stockholm, Sweden, 12-14 June 2003.

OTHER PRESENTATIONS

Stevenson, J.R. (2003, November). Invited presentation at a one-day workshop on sustainable aquaculture in the Philippines and Brazil organized by INRA-ENSAR, Rennes, France.

Stevenson, J.R. (2003, November). Presentation at the Development Studies Association workshop for postgraduate research students, Overseas Development Institute, London.

Stenvenson, J. R. (2003, March). Project presentation at the University of the Philippines, Department of Sociology.

Stevenson, J. R. (2003, April). Sustainability as compromise: brackish water pond systems in the Philippines. Presentation at SEAFDEC, Department of Aquaculture, Ioilo, Philippines.

APPENDICES

PROJECT LOGICAL FRAMEWORK

Hierarchy of Objectives	Objectively verifiable indicators	Means of Verification	Important Assumptions
Goal Improved policies for development of aquaculture in an economically viable, socially acceptable and environmentally sustainable way.	Growth of the sector and contribution to gross value added at national, regional and local levels. Increased productivity. Reduced opposition to aquaculture development. Creation of formal livelihood opportunities, in particular for the rural poor.	National statistics National and farm-level statistics. Local surveys, local news Local surveys	Political will to use results of the research as an input into policy making. Political stability End-user links can be maintained over the course of the project Co-operation of PCMARD and SEAFDEC
Purposes Improved knowledge of the economic, social and ecological properties of existing farming systems. Improved understanding of the necessary trade-offs among the economic, social and environmental impacts of aquaculture. Tools for planning and management developed through inter-disciplinary research.	See Outputs	See outputs	See outputs
Outputs Description of farming systems in terms of their technical and managerial characteristics. Measurement of the economic, social and environmental impacts of main farming systems. Improved understanding of the trade-offs among economic, social ad environmental impacts of aquaculture. Preferences (weights) of stakeholders for economic, social and environmental properties of aquaculture.	Farm-level data set from a representative sample of brackish water farms Typology of brackish-water pond aquaculture systems Data set of sustainability indicators for brackish-water pond aquaculture systems Trade-off analysis of indicator data. Multi-Criteria Decision Making (MCDM) model of brackish-water pond aquaculture systems and associated rankings.	Extended literature review on the economic, social and ecological impacts of aquaculture. Working papers for each stage of the research: - WP1: typology of farming systems - WP2: sustainability indicators and trade-off analysis - WP3: MCDM modelling exercise Final report will summarise the findings and draw conclusions on the usefulness of the approach. Final workshop will	Co-operation of farmers Quality and consistency of data Local institutions maintain co-operation

Ranking of production systems. Relevance of MCDM for policy making in aquaculture assessed.		disseminate outputs to local partners/stakeholders. Peer reviewed publications. Stakeholders consultation and participation.	

Activities	**Cost (% of total budget)**
Literature review	5%
Farm-level survey of technical, physical and attitudinal characteristics	20%
Factor and Cluster analysis of farm-level technical and managerial data	10%
Developing sustainability indicators for brackish-water pond aquaculture systems	10%
Data collection on Sustainability Indicators	15%
Stakeholder Analysis with policy-makers and community groups	10%
MCDM modelling	20%
Workshops	10%

RESEARCH PROPOSAL

SECTION A: KEY INFORMATION

1. Project Title

Assessing the sustainability of brackish-water pond aquaculture systems in the Philippines: A multi-criteria approach

Abbreviated Title:

Sustainability of brackish-water aquaculture

2. **Is the research strategic?** (delete as appropriate)

3. **Project Summary** (maximum 100 words)

Aquaculture in the Philippines has experienced fast growth in recent decades but recent problems have brought this growth to a halt. If the sector is to play an important role in the development of the country, there is a need to devise new ways of expanding the sector in an economically viable, socially acceptable and environmentally sustainable manner. The project seeks to contribute towards that aim by establishing the economic, social and environmental properties of existing aquaculture systems and by shedding light on the trade-offs among these properties that constrains the choice of a strategy for the sector. After establishing a typology of brackish water farms, sustainability indicators will be measured for each farm type and a multi-criteria decision making model developed to produce a ranking of farming systems. The project will make policy recommendations and determine the relevance of a multi-criteria approach to policy making in aquaculture.

4. Keywords (including subject, species, countries etc.)

Sustainability, Philippines, Brackish-water, Aquaculture, Penaeus sp., Chanos chanos, Equity, Multi-Criteria Decision Making

5. **RNRRS Programme**

Aquaculture and Fish Genetics Research

6. **RNRRS Production System**

Coastal Aquaculture

7. Project Goal (include RNRRS Programme Purpose where appropriate)

Practical policy options for the development of aquaculture in the Philippines in an economically viable, socially acceptable and environmentally sustainable way.

8. **Geographic Focus**

Philippines / S.E. Asia

9. **Commodity Base**

Fish and crustaceans

SECTION A: KEY INFORMATION Continued

10. Applicant's full name, title, post held and department

Dr Xavier Irz, Lecturer, Department of Agricultural and Food Economics

Name, address, telephone and fax of applicant's institution

Department of Agricultural and Food Economics University of Reading PO Box 237 Reading RG6 6AR Phone: 0118 931 8970 Fax: 0118 975 6467 Email: x.t.irz@rdg.ac.uk

11. **Name and address of any collaborators**

James Stevenson, Department of Agricultural and Food Economics, University of Reading, Address as above Dr Rafael Guerrero III, Philippine Council for Aquatic and Marine Research and Development (PCMARD), Los Banos, Philippines Pierre Morissens, Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement (CIRAD), Visiting Scientist in PCMARD, Los Banos, Philippines Dr Tahir Rehman, Department of Agriculture, University of Reading, Address as above Dr Jurgenne Primavera, South-East Asian Fisheries Development Centre (SEAFDEC), Tigbauan, Iloilo, Philippines Dr Clarissa Rubio, Department of Sociology, University of the Philippines, Diliman, Quezon City, Philippines

12. **Project Location**

University of Reading Republic of the Philippines: Pangasinan, Pampanga and other coastal fieldwork sites.

13. **If the project is located overseas or if there is an overseas collaborator, has the approval of the overseas government been obtained? If so, provide details**.

The Philippine Council for Aquatic and Marine Research and Development (PCMARD) are an agency of the Department of Science and Technology (DOST) and have significant policy influence in the areas of aquaculture and fisheries in the Philippine government. The head of PCMARD, Dr Raphael Guerrero is a collaborator in the project, as is Pierre Morissens, a visiting scientist at PCMARD. A letter of support from Dr Guerrero is attached.

14. **Starting and finishing dates**

1st April 2003	31st March 2005

SECTION B: DEMAND, UPTAKE AND GEOGRAPHICAL FOCUS

15a. **What is the project's purpose** (maximum 50 words)?

Knowledge of the interactions between economic, social and ecological properties of pond aquaculture systems increased. Encouraging coherence in addressing the problems of the sector. The utility of a systems-thinking approach to aquaculture promoted among Philippine institutions.

15b. **What developmental problems or needs is the project aimed at?**

The project aims to address the multiple environmental and social impacts of aquaculture that have not been subjected to systematic treatment in relation to the performance of specific aquaculture systems. The Philippines is a country in which a *laissez-faire* government policy to aquaculture development over the previous two decades has been replaced with an official commitment to the principles of the sustainability in its National Policy on Fisheries, embedded in the Philippines Fisheries Code of 1998 (Guerrero, 2001). The crash of the intensive prawn industry in the early 1990s and public anxiety after numerous fish kills reported in the press have acted as drivers to bring about this change.

However, in developing a strategy for sustainable development of the aquaculture sector, the Philippine government is constrained by the lack of an inter-disciplinary study on the specific farm-level impacts of different types of production system. A suitable framework is required in which the trade-offs between the triple objectives of maximising economic performance, maximising social acceptability and maximising ecological sustainability, can be made explicit.

15c. **What is the evidence for the demand for the research?**

There is policy-driven demand for the research as evidenced by the government policy on sustainable aquaculture (The National Policy on Fisheries, including aquaculture, embedded in the Philippines Fisheries Code 1998) which states:
the policy of the state is "*to ensure the rational and sustainable development, management and conservation of the fisheries and aquatic resources in Philippine waters including the Exclusive Economic Zone and in the adjacent high seas consistent with the primordial objective of maintaining a sound ecological balance, protecting and enhancing the quality of the environment.*" Moreover, the objective of the fisheries sector is the "*improvement of productivity of aquaculture within ecological limits*".

The main body for delivering initiatives towards achievement of this policy is the Philippine Council for Aquatic and Marine Research and Development (PCAMRD) whose mission statement is:
"*Enhance the productivity, global competitiveness and ecological sustainability of Philippine aquatic and marine resources through appropriate, strategic and people-oriented R & D programs".*

Equally important, there is bottom-up demand from aquaculture operators as evidenced from participatory rural appraisal (PRA) exercises carried out in April/May 2002 in the province of Pampanga (James Stevenson, pers. comm.). Aquaculturists see the need for government intervention to address the problems of water quality and disease that affect the performance of their farms.

15d. **What will the project contribute to resolving these problems or needs and over what time-scale?**

PCMARD researchers will collaborate in the project over the course of the two years, becoming familiar with the methods proposed by the team. It is expected that the findings will have significant policy influence in the Department of Science and Technology and the Bureau of Fisheries and Aquatic Resources (BFAR). By highlighting the trade-offs between ecological, social and economic properties of the systems, the project will help target interventions in areas of particular need.

The timescale for positive impacts from the implementation of the project findings are likely to be of the order of 2 -10 years.

15e. **What is the geographical focus of the project?**

- The literature review will attempt to draw on experience from across South-East Asia.
- The coastal areas of the Republic of the Philippines will be the focus of the fieldwork.
- The findings will be of interest in all countries in South-East Asia with significant areas of brackish-water pond production.
- The methodological aspects of the project (application of MCDM techniques for the evaluation of strategies and projects in aquaculture) will have general relevance.

15f. **Which are the identified target institutions?**

The primary target institutions are the Philippine Council for Marine and Aquatic Research and Development (PCMARD) and the Bureau of Fisheries and Aquatic Resources (BFAR). The Executive Director of PCAMRD is a member of the research team and will serve in an advisory role to ensure the policy relevance of the project at all stages.

The secondary target institutions are research institutions in the Philippines and in the region, namely the University of the Philippines (UP), South-East Asian Fisheries Development Centre (SEAFDEC), International Centre for Living Aquatic Resource Management (ICLARM) and the Asian Institute for Technology (AIT).

15g. **What are the proposed promotion pathways for the uptake of the project outputs?**

Promotion of the results in these specifically targeted institutions will be carried out throughout the length of the project and beyond. Workshops with interested parties will take place at an early stage to ensure that there is the opportunity for input to influence the research process.

The secondary target institutions will not necessarily feel a sense of ownership of the results but, in the case of SEAFDEC and UP, have members on the research team who can promote the findings from within the organisations.

15h. **Who will the beneficiaries be and are there any groups who will be disadvantaged by the application of the research findings?**

The indirect beneficiaries of the project will be rural coastal communities through improved management of aquaculture and it is hoped that the rural poor will benefit disproportionately. The project aims to ease the decision-making process and will have an impact if the research findings are taken into account in policy making. Consequently, as with any policy exercise, there is the possibility of some agents being made worse off as the result of a particular policy being implemented. However, part of the project is aimed at quantifying the social impacts of alternative forms of aquaculture so that the costs to any group of agents will be explicit. In this context, a group of agents will only suffer from the policies derived from the project if that is consistent with the dominant value judgements expressed through participatory research by policy-makers and other stakeholders.

16. **Is this proposal a continuation or extension of work already funded by DFID?**

This proposal is not a direct extension of any work funded by DFID but it will build on past research funded as part of DFID's Renewable Natural Resource Strategy. In aquaculture, the most relevant project is entitled 'Coastal Aquaculture and Environment: Strategies for Sustainability' (Reference Number - R6011) that investigates alternative strategies for sustainable aquaculture management in developing countries with a particular emphasis on shrimp farming in Thailand. That project described some of the economic, social and environmental impacts of aquaculture but did not attempt to formalise their interactions nor to provide a comprehensive analytical framework to support the policy making process. Furthermore, our proposal will not be limited to the analysis of a single production

(shrimps) but will consider a much wider range of options since there are important alternatives to shrimp farming in the Philippines.
The second DFID project that is worth mentioning is entitled 'The effects of policy and institutional environment on natural resource management and investment by farmers and rural households in east and southern Africa' (Reference Number – R7076CA). The project, although focusing on agriculture rather than aquaculture, presents many methodological similarities with our proposal. In particular, it presents the literature on sustainability indicators and discusses its relevance for applied research in developing countries (see for instance the working paper series e.g. "*A Review of Indicators of Agricultural and Rural Livelihood Sustainability*").

SECTION C: SCIENTIFIC BACKGROUND

17. **What work has previously been done or is currently being pursued towards the purpose, outputs and activities of the project? (A review of literature should be attached)**

Literature review is attached separately.

SECTION D: OUTPUTS AND ACTIVITIES

18a. **What are the outputs of the project?**

1- An appreciation of the diversity of production systems in Philippine aquaculture and a characterisation of these systems in terms of their technical and managerial characteristics.
2- Increased knowledge of the economic, social and environmental impacts of brackish water aquaculture in the Philippines.
3- Improved understanding of the necessary trade-offs between economic efficiency, social acceptability and ecological sustainability that are implicit in the choice of production systems in aquaculture.
4- A set of explicit weights that are attributed to the economic, social and ecological impacts of aquaculture by policy makers and other stakeholders in the Philippines.
5- Given this set of weights, an explicit ranking of the different production systems
6- An evaluation of the usefulness of MCDM methods in informing the policy making process in developing country aquaculture

18b. **What are the objective verifiable indicators for the outputs?**

1) A set of farm-level data on technical and managerial characteristics from a representative sample of brackish water farms.
2) From these data, a typology of brackish-water pond aquaculture systems established through cluster analysis and other types of multivariate analysis.
3) A data set of sustainability indicators for brackish-water pond aquaculture systems. These indicators will measure the economic, social and ecological impacts of the different production systems.
4) A trade-off analysis of indicator data.
5) A Multi-Criteria Decision Making (MCDM) model of brackish-water pond aquaculture systems and the rankings obtained as an output of the model.

18c. **What are the means of verification of the outputs?**

1- An extended literature review will place the research in the context of the existing scientific knowledge on the economic, social and ecological impacts of aquaculture.
2- Working papers will be produced at each stage of the research:

- WP1 will present the typology of farming systems
- WP2 will present the sustainability indicators and the trade-off analysis
- WP3 will present the result of the MCDM modelling exercise

3- The final report will summarise the findings and draw conclusions on the usefulness of the approach.
4- The final workshop will provide a way of disseminating these outputs to the local partners and stakeholders.
5- The relevance of the approach and validity of the results will be assessed by submission of articles for publication in peer reviewed journals.

18d. **What are the expected environmental impacts? (beneficial, harmful, neutral)**

i) Direct

None.

ii) Indirect

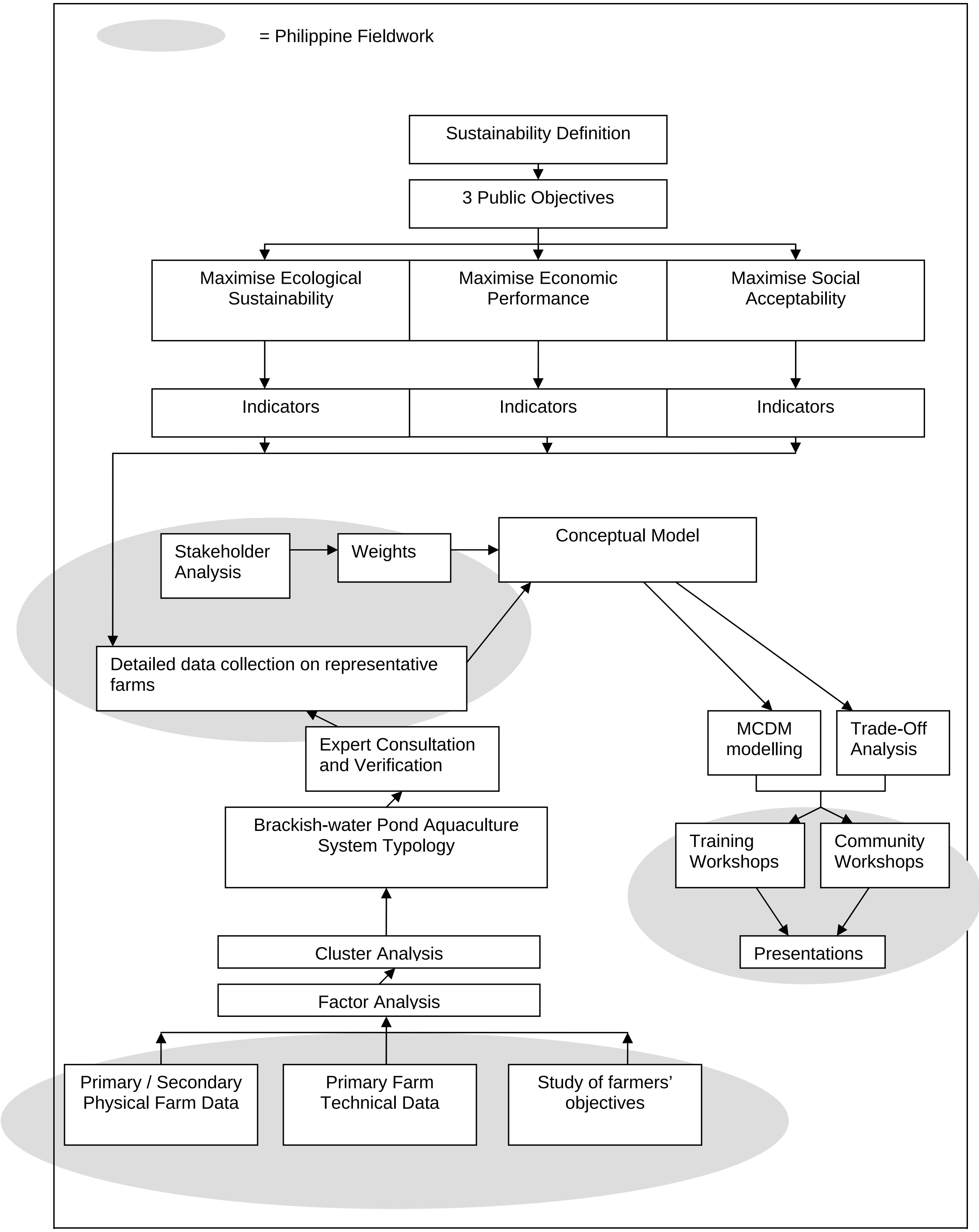
Implementation of the project findings should have a significant beneficial impact on the environment of the coastal zone. Improvements could take the form of targeted promotion of environmental innovations, greater understanding of environmental impacts in the government bureaus and the possibility of local community resource management in the medium-term. However, the overall impact

of the project will depend on its influence on the policy process in the aquaculture sector.
The project will contribute to environmental sustainability by:

- Generating new knowledge about the ecological impacts of alternative forms of aquaculture in the Philippines.
- Identifying the production systems that have the least negative impacts on the environment for similar levels of economic efficiency and social acceptability.
- Making explicit the trade-off between environmental quality and socio-economic performance inherent in the policy-making process.
- Providing a new tool (MCDM) for the assessment of projects and strategies in the aquaculture sector that takes explicit account of environmental impacts

19a**. Describe the project activities**

The flow chart below shows the interaction of the various project activities.


= Philippine Fieldwork
Sustainability Definition
3 Public Objectives
Maximise Ecological Sustainability
Maximise Economic Performance
Maximise Social Acceptability
Indicators
Indicators
Indicators
Stakeholder Analysis
Weights
Conceptual Model
Detailed data collection on representative farms
Expert Consultation and Verification
MCDM modelling
Trade-Off Analysis
Brackish-water Pond Aquaculture System Typology
Training Workshops
Community Workshops
Cluster Analysis
Presentations
Factor Analysis
Primary / Secondary Physical Farm Data
Primary Farm Technical Data
Study of farmers' objectives

Literature review (April - August 2003)
This task involves building on existing experience. The literature review will focus on issues specific to the Philippines as well as wider issues in aquaculture in South-East Asia. There will be a strong methodological component in order to situate the use of sustainability indicators and MCDM modelling in a wider academic tradition. The peer-reviewed and "grey literature" will receive equal attention and we also intend to carry out extensive email and personal networking with the main researchers in the field. This review will lead to an interim review report.

Farm-level survey of technical, physical and attitudinal characteristics (April – June 2003) and **Factor and Cluster analysis of farm-level technical and managerial data (July – Aug 2003)**
This farm-level survey is the gathering of data in order to produce a typology of farms according to their structure and function, and an attitudinal survey of farmers, to judge which objectives are important to them in carrying out aquaculture. Such a survey will help identify relationships between types of farmers and their farms and highlight differences across farm types. It is a necessary prior step in carrying out an appraisal of the performance of representative farms. This is a continuation of work due to start in the field in February 2003, with initial pilots being carried out by James Stevenson, prior to the start of the project.

Factor analysis will be used to reduce the dimensionality of a multivariate data set comprising data such as farm size, species cultured, feeding rates, owner or tenant managed and the objectives of the manager. Cluster Analysis is a multivariate data analysis method that groups individuals from a population according to their degree of similarity. In this context, 'similarity' can take a number of specific quantitative definitions but most widespread is the use of distance measures (technically a measure of *dissimilarity*). The clusters emerging from this analysis are considered specific "types" and representative farms from each cluster selected for re-visiting for data collection on the sustainability indicators.

Developing sustainability indicators for brackish-water pond aquaculture systems (April – June '03)
Sustainability indicators are measurable properties of systems that are used to compare between systems in the current time period (state indicators) and to analyse the performance of a system over time (rate indicators). Given the absence of time-series data sets in the current context, a state indicator method is proposed.

Indicators from the three spheres of sustainability (economic, ecological and social) will be developed for the purposes of assessing the trade-offs at the farm-level (see the attached literature review for a more extensive treatment). The final list for measuring on representative farms will be produced after consultation with a number of researchers in the disciplines of aquaculture, ecology, sociology and agricultural/aquaculture economics and guided by leading researchers in the use of sustainability indicators and MCDM modelling.

Data collection on Sustainability Indicators (November '03 – May '04)
This survey will be on representative farms (and in their neighbouring villages and communities) from each of the clusters identified in the cluster analysis. The indicators will be measured over the course of a number of days visit to the area of the farm, allowing a detailed picture of the network of livelihoods around the farm to build up. Participatory methods used at this stage include seasonal calendars, matrix scoring with a number of stakeholder groups and flow and venn diagramming. Ecological impacts will be largely inferred from the on-farm activities rather than measured directly (e.g. nitrogen budgets calculated using the patterns of inputs and outputs). Economic properties will be gathered from farmer testament relating to profits and risks.

Stakeholder Analysis (August – Sept '04)
Workshops will be held with different stakeholder groups and with policy-makers in the competent government departments, to establish what weighting they place on the different objectives. How important are the social impacts of aquaculture in comparison to economic advantages and ecological costs? How do different groups place different weights on different objectives and why? How committed are the policy-makers to the principles of sustainability in aquaculture? All of these issues will be explored in detail which, as well as a constituting an end in itself, is a requirement of the kinds of modelling that will be carried out in the later stages.

Multi-Criteria Decision Making (MCDM) Modelling (November '03 – July '04)
Explicit weights from the stakeholder analysis and the results from the typology and indicator measurement are to be combined in a model to show the trade-offs at the farm-level between economic performance, social acceptability and ecological sustainability. The methods of Multi-Objective Programming and Compromise Programming will most likely be used in the analysis of these trade-offs and in determining rankings of the farming system types.

Sensitivity Analysis (December '04 – February '05)
The sensitivity of rankings to changes in the weights will be tested, producing alternative rankings according to different sets of weights. This can be used to show how technical changes in different regions will affect different stakeholder groups. This will involve manipulating the MCDM model with different sets of weights from different stakeholder workshops.

Workshops, Training and Presentations (January '05 – February '05)
The dissemination of the findings will be via the mechanisms of workshops, training days at research institutions and presentations. Workshops will be held with members of all stakeholder groups. Training days at target institutions (PCAMRD, UP, SEAFDEC) will begin by introducing systems thinking and sustainability and following on to the specific elements of the research. Presentations will be made at relevant conferences. Project working papers will be posted on the Internet and appropriate publication in development and scientific journals will be pursued.

19b. **What factors could prevent the attainment of:**
i) Planned activities

Security concerns in the Philippines have been heightened following recent attacks on Western targets. If the security situation deteriorates, some members of the research team may be forced to evacuate. This is not anticipated but a contingency plan of activity whereby Filipino enumerators are trained to carry out fieldwork is available and can be implemented at any stage.

Fall in the value of the UK pound (or, conversely, a surge in strength of the Philippine peso) erodes the budget.

Lack of co-operation and participation by various stakeholders in fieldwork and in workshops.

ii) Outputs

The quality of the data and the consistency of the responses are reliant on the concentration of the farmers in responding to a series of questions. Data consistency checks will be built into the project design where appropriate (e.g. to ensure transitivity conditions are not violated). The surveys will be carried out on the farm to allow for visual inspection and qualitative data collection to support quantitative replies.

There are several points at which consultation between the project team and wider academic and governmental institutions will be sought, in order to verify that the findings are consistent with established local expert opinion. Reaching a consensus during this period cannot be guaranteed and where discrepancies and disagreements emerge, they will be documented carefully.

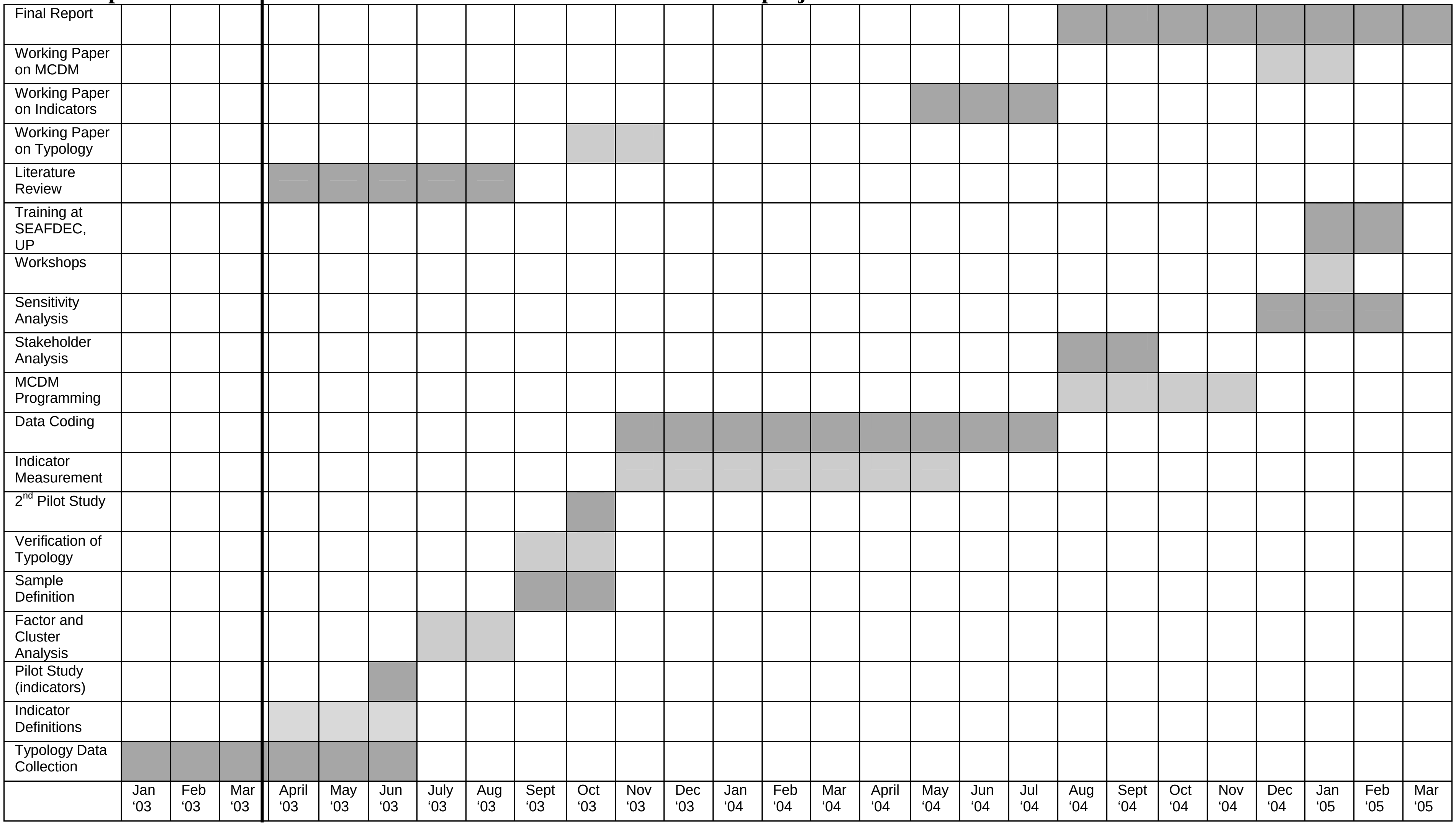
iii) Project Purpose

If the partner institutions do not develop or maintain an enabling environment for innovative extension or policy changes in promoting the outputs from the project, then the project purpose will not be achieved.

iv) Project Goal

N / A

20. **Complete a bar chart or attach milestone charts over the life of the project.**



Research project R8288: Assessing the sustainability of brackish-water aquaculture systems in the Philippines – Paper 1/5

A typology of brackish-water pond aquaculture systems in the Philippines

Abstract: *Aquaculture in the Philippines is a long-standing activity but has witnessed relatively recent, rapid, technical change with the introduction of hatchery technology and commercial feed-mills changing the production possibilities for a fishpond operator. We are confronted with a diversity of aquaculture practices in the coastal areas of the Philippines, with new technologies being incorporated into more traditional systems. As a first step to understanding the sector, we therefore present a typology of farming systems with the motivation of generating domains (farm "types") over which we can compare performance on a number of indicators. Our typology, restricted to brackish-water pond systems, is constructed using multivariate methods (principal components analysis, cluster analysis). Eight variables are used relating to the management of the farm across all the major factors of production. A stratified net sample of 136 observations provides the data for the analysis, from a farm-level survey carried out between January and June 2003 in the two main brackish-water production regions in the Philippines. We define five farm types from this analysis. In later work we will show how the use of this typology can be used for comparative study of economic, social and ecological performance at the farm-level.*

Contents

1. Introduction

The central proposition underlying work on typologies of farming systems is that farms are similar or identical to other farms of the same type (according to particular characteristics of interest) and that they are dissimilar to farms of other types. This follows from Derek Byerlee's idea (Byerlee *et al*, 1980) of "recommendation domains", such that policy statements made regarding one member of a domain are likely to hold for the other members of the domain. While interesting as an end in itself, a typology increases the likelihood that analysis of, for example, productivity (within domain) or comparative study (between domains) will be conducted properly (Shang, 1981).

For example, we might expect technical efficiency (or any other indicator of performance) "within domain" to be explained in the most part by managerial competence. In contrast, differences in the level of technical efficiency "across domains" might be accounted for by underlying differences in the nature of the technology. The conclusions for policy of determining differences within domain, as opposed to differences across domains, are very different. A lack of managerial competence might be addressed by increased investment in government extension services with respect to particular production techniques within domain. Alternatively, apparent differences in technical efficiency that are actually driven by inherent differences (e.g. in production risk) in the nature of the techniques used across domains.

There are numerous sets of criteria that can be used to classify aquaculture systems, drawn from technical, geographical, economic, ecological and social perspectives. Shang (1981) identifies ten criteria by which aquaculture systems could be conceptually divided. Some of Shang's criteria are nominal (e.g. nature of enclosure). Highlighted in bold are the categories of specific nominal criteria that serve to define the scope of the present study; i.e. *only aquaculture systems producing human food products in ponds filled with standing brackish-water of a tropical temperature are included in our survey*. In the Philippines however, this apparently already narrow sub-set of aquaculture systems contains a great heterogeneity in Shang's other categories.

We argue here that some of Shang's other criteria are not qualitative but quantitative. Shang has produced quasi-qualitative criteria by either imposing categories on a quantitative scale (e.g. monoculture/polyculture, water temperature) or by simplifying a complex combination of quantitative data in different dimensions (e.g. level of management intensity[1]). In these cases there are not the same fundamental shifts between categories as for truly qualitative criteria.

The objective of the typology work here is to tackle this heterogeneity using multivariate statistical methods. Most fundamentally however, we are interested in representing the current range of techniques employed in the Philippines. In later work we will consider the "farm types" established here as possible options for the use of the brackish-water land area and use them in the construction of models of the farm-level trade-offs between different policy objectives. Examples of these

[1] We use the term production intensity from hereon, in the same way Shang uses management intensity. This is to avoid confusion with the level of managerial or supervisional input the farm requires, which might also be considered "management intensity".

objectives are to maximise economic efficiency, maximise social acceptability and to minimise ecological impact.

The structure of this paper is as follows: in section 2 we further highlight the need for clarity with respect to production techniques under appraisal and why a typology is necessary; in section 3 we outline the methods we will employ in analysing our data, and refer to the literature on related studies; in section 4 we describe our data and the analyses; section 5 has our results and interpretations; section 6 examines the geographical distribution of farm types within our study regions; section 7 concludes.

Table 1 – List of criteria by which aquaculture grow-out systems might be classified (from Shang, 1981).

Criteria	Category
Purpose of Culture	**Human food**
	Improvement of natural stock
	Sports and recreation
	Ornamental fish
	Bait
	Industrial products
Nature of enclosure	**Pond culture**
	Cage and pen culture
	Raceway culture
	Raft culture
	Closed high-density culture
	Sea ranching
Sources of fry	Natural waters
	Captured gravid females
	Hatching
Level of management intensity	Extensive
	Semi-intensive
	Intensive
Number of species stocked	Monoculture (single species)
	Polyculture (more than one species)
Water salinity	Fresh water
	Brackish water
	Marine water
Water movement	Running water
	Standing water
Water temperature	Cold water
	Warm water
Food habit	Herbivorous species culture
	Omnivorous species culture
	Carnivorous species culture
Combination with agriculture production	Rice-fish farming
	Poultry-fish farming
	Pig-fish farming

2. Highlighting the Problem – Measuring Production Intensity

> *"'Intensity' relates to resource utilization (land, water, capital, labour, seed, feed, fertilizer and fuel) and different systems may be more or less intensive depending on which resource is considered. It is important to understand the use of all these resources if a thorough assessment of the sustainability of different kinds of shrimp culture is to be made."* (World Bank, 2002)

There are many studies that classify aquaculture systems using a measure of production intensity. However, the choice of variable or combination of variables with which to represent the concept of production intensity is not a trivial issue. The most important variables are perhaps stocking density, feeding rate and fertilizer application rate.

For monoculture of tiger prawn *Penaeus monodon*, Clay suggests stocking densities of greater than 200,000 pieces/ha for intensive systems, 25,000 – 200,000 pieces/ha for semi-intensive systems and less than 25,000 pieces/ha for extensive systems (Clay 1997 - cited in World Bank, 2002). However, the use of stocking densities alone makes comparison between polyculture systems, or between monocultures of different species, problematic. This is because different species have different habits of feeding, different body sizes at stocking and at maturity, different survival rates and patterns of natural behaviours. Given that the brackish-water pond production in the Philippines is a long-standing activity (Primavera 1995) that has evolved from traditional systems of polyculture with natural recruitment, there is a need to move away from reliance on the use of stocking density to characterize systems.

Using the feeding rate to describe the systems has distinct advantages as Ravagnan (1981) advocates:

> *"If we accept the concept that it is not the degree of crowding, but rather the energy derivation from the feed, i.e. the feed regime, which distinguishes the various methods of farming (Ravagnan, 1980), we consider: extensive the farm that takes its feed exclusively from the environment; intensive the one that instead takes it exclusively from outside sources; and semi-intensive the one that exploits the environment but integrates it with feed coming from outside sources. The production technologies available to us range around these three methods".* Ravagnan (1981, p.65).

This is an ecological classification and is an appealing approach from theoretical and practical viewpoints. The overall energy balance of the system gives important insights for those examining the food security implications of aquaculture and for ecologists studying the effect of nutrient enrichment on coastal waters. From a practical viewpoint, the problem of equivalence across species is lost and so feeding rate can be used for monoculture or polyculture systems.

In generating a measure of "farming" (or "production") intensity, there are both definitional and measurement issues. The most accurate definition probably comes from an economic perspective and argues that intensity is the use of variable inputs (e.g. fry, feeds, fertilizers) in relation to land. However, as with economic measures of partial productivity, the inputs can be substituted for one another to some extent, so that measuring one input cannot be totally satisfactory. It is therefore important to employ a multivariate approach to classification, which allows us to look at the particular sets of combinations of inputs that currently define production practices.

3. A Multivariate Approach to Classification

3.1 Factor Analysis

Factor analysis belongs to a group of models known as latent variable models. A latent variable is a concept that cannot be directly measured such as human "intelligence" or farming "intensity", that theory suggests is correlated to a number of specific tests (in psychology) or measurable features of systems (in farming systems research). Factor analysis is actually a group name for a range of specific statistical techniques used on multivariate datasets to explain either patterns of covariance or correlation in a set of observed variables, as function of a limited number of underlying factors.

In factor analysis there are no dependent and independent variables. Rather a matrix of covariance scores (for the specific method of "Principal Axis Factoring") or correlation coefficients (for "Principal Components Analysis") is used as the basis to explore how all the variables are related to underlying factors. Factor analysis yields interesting information as an end in itself – it gives us information on variables that are not directly observable. However, its purpose is also commonly to transform a multivariate dataset with many variables and correlations between the variables (multi-colinearity), to a new smaller set of underlying factors. It is considered a "data reduction" technique in this regard. Useful properties of these factors are that they are orthogonal to each other in factor space and are linear combinations of the original variables[2].

If the data set is well suited to factor analysis, and the original variables are well chosen, the construction of factors will occur without significant loss of information. Following this, factor scores for the individual observations (farms), showing the position of the observation in factor space (which can be positive or negative) can be calculated. Factor scores should then be used as a new dataset for carrying out cluster analysis. It would be inappropriate to carry out cluster analysis on the original dataset due to multi-colinearity in the original variables, which would effectively create weights in any clustering algorithm. Factors are orthogonal and therefore this problem is resolved. We can use cluster analysis to calculate the degree of similarity or dissimilarity between individual farms, in terms of their scores on the underlying factors.

3.2 Cluster Analysis

Cluster analysis is another exploratory technique where we do not have *a priori* hypotheses (in this case, with respect to the number or properties of the farm types) but are examining the structure of the data. It is a multivariate technique for classifying observations into groups (clusters). In the case of farming systems, ultimately each farm is unique in some respect. However, by using the factor scores

[2] Detailed treatments of this technique can be found in Comrey and Lee (1992). A more accessible introduction is provided by Kline (1994).

we obtain in carrying out principal components analysis, we can see how similar each farm system is to the other individual farming systems in our sample.

The objective of cluster analysis in the present case is to generate solutions that maximize similarity within groups of farms so that we might label each group as a particular farm "type". The term cluster analysis actually covers a number of different algorithms and measures of distance that can be employed in generating a typology. We employ Ward's method (Ward, 1963) and use squared Euclidean distance in multidimensional space.

The geometric distance in multidimensional space (in this case 3 components – see section 5.1 below) is known as Euclidean distance. However, we employ squared Euclidean distance so that progressively greater weight will be placed on farming systems that are further apart. Squared Euclidean distance is computed as:

$\text{distance}(x,y) = \Sigma_i (x_i - y_i)^2$
where x and y are two observations (farms) and *i* relates to each of the dimensions.

Ward's method of cluster analysis is one of a family of specific algorithms known as hierarchical (agglomerative) cluster analysis. These algorithms start with a set of individuals[3] (in our case farms), and begins by attempting to identify the two individuals with most similar scores. At this step in the analysis, these two individuals are merged to form a cluster. This cluster is treated as a single individual in the next step in the analysis, thereby reducing the number of individuals to be considered in the second step of the analysis by one. This process continues, with the number of individuals decreasing, and the number of clusters increasing. Therefore, as the analysis proceeds, the statistical software merges clusters rather than just individuals at each step (Stevenson, 1989).

Algorithms differ in the way in which the clusters are formed at each stage. Ward's method operates by testing which merger at each stage produces the least reduction in the overall *within* cluster squared distances. The output from any hierarchical cluster analysis is in the form of a dendrogram, showing the history of the cluster mergers from all individuals in the sample (i.e. all farms unique), up to a single cluster (i.e. all farms of the same "type"). The point at which we 'cut' the dendrogram will determine the number of clusters (i.e. farm "types") produced.

3.3 Previous Applications to Agriculture and Aquaculture
Kobrich, Rehman and Kahn (2003) report on two applications of multivariate techniques to the problem of classifying agricultural system types; one for Chilean peasant farming systems and one for wheat-rice farms in Pakistani Punjab. Both of these typologies were based on primary data collection surveys in their study regions.

Within aquaculture research, Coche (1982) and Muir (1995) present uni-dimensional guides for classification of different aquaculture systems, using production intensity – a variable that is itself multidimensional as we have outlined. Therefore, Michielsens *et al* (2002) represents the first application of factor analysis and cluster analysis to

[3] Cluster analysis, as well as factor analysis, both have strong traditions in the psychometric literature. It is only relatively recently that these methods have been adopted by the farming systems research community.

yield an empirical typology of aquaculture systems. In classifying carp farming systems across Asia, Michielsens *et al* (2002) used the following 12 variables: Area of the aquaculture facility (ha); Ratio of aquaculture facility to total farm area (%); Water added during the culture period (cm / month); Purchased inorganic fertiliser (kg / ha /yr); Total organic fertiliser (10^3 kg / ha / yr); Ratio of organic fertiliser collected (on or off-farm) to total organic fertiliser used (%); Total feed added (10^3 kg /ha /yr); Number of fish species cultivated; Stocking density (10^4 fishes / ha); Total labour (10^2 days / ha /yr); Ratio of family labour to total labour (%). Data came from a NACA/ADB farm-level survey.

Michelsens *et al*'s analysis suggests six "types" of carp farming system in Asia, which they name: Super-intensive, Intensive, Specialised semi-intensive, Specialised semi-extensive, Integrated semi-intensive, Integrated semi-extensive. The typology is put to use to examine the resource-use efficiencies of different farm types. We follow the lead shown by Michelsens *et al* by applying the multivariate techniques factor analysis and cluster analysis to data collected from a farm-level survey in the Philippines.

4. Farm-level Survey

4.1 Sampling

The two top regions for brackish water pond aquaculture production, regions 3 (Pampanga, Bulacan, Bataan and Zambales) and 6 (Iloilo, Capiz, Negros Occidental and Aklan), were chosen as study areas. The sample was stratified by farm size and by province, based on census data from 1997 provided by the Philippine Bureau of Agricultural Statistics (BAS). A breakdown of the net samples used in the analysis is given in appendices 1a and 1b.

Interviews with fishpond "operators" (those who invest capital, take the financial risks and gain the profits) and "caretakers" (salaried supervisors for those farms where the operator does not live on the farm)[4] were carried out on representative samples of fish farms from regions 3 and 6 between January and May 2003.

A net dataset comprising 11 variables and 137 observations (farms) was initially compiled after processing the farm-level interview data was complete. One farm observation was subsequently dropped from the dataset after test runs with principal components analysis and subsequent cluster analysis found it to be an outlier[5]. 136 farms were retained in the final dataset.

4.2 Motivations for choosing the variable set

The typology is based on technical aspects of the farming systems. The choice of the final list of variables, from a large dataset compiled during the farm-level survey, was motivated by experience gained in carrying out the interviews. Most of the farms are polyculture systems, but different priorities dominate on different farms. Operators are generally either orientated towards *prawn production* or towards *milkfish*

[4] For a treatment of the nature of this relationship, see Stevenson *et al* (2003)

[5] The farm represented a unique cluster with anomalously large Euclidean distance in the cluster solution from all other farms. This is likely to be due to the fact that it is a small farm (0.17 ha) and so any accuracy problems in the data for that farm are magnified when units/ha/yr are calculated.

production. This is supported by farmer testimonies and by Pierre Morissens, a researcher with CIRAD (Cooperation Internationale en Recherche Agronomique pour le Developpmente) with more than six years experience of working with farmers in the study area. Crabs and tilapia will sometimes be added as secondary species, for the purposes of aeration, or opportunisitically if the market and environmental (i.e. salinity) conditions are good, but these are not of fundamental importance to the operators and are not given "special treatment" on the farm.

None of the farms in the sample operated at a sufficiently high level of intensity to require mechanised aeration, in the form of paddlewheels, and in general the level of capital investment on the farm is relatively low. Therefore, the main differences between farms in terms of the use of factors of production (land, labour, capital) would seem to be *the relative importance of land and labour*. A degree of substitutability between these two factors might be expected in the production function for these farms.

With these key ideas in mind, the following 8 variables were chosen for principal components analysis:

farmsize	Farm size (ha)
inorg	Total inorganic fertiliser applied (kg/ha/yr)
organic	Total organic fertiliser applied (kg/ha/yr)
totlabor	Total labour input (man days/ha/yr)
commfeed	Ratio of commercial feeds to total feeds added (%)
sugposd	Stocking density of tiger prawn (Fry/m^2)
bangussd	Stocking density of milkfish (Fry/m^2)
totfeeds	Total feeds added (kg/ha/yr)

The raw data reported by farmers were in a variety of local units and over different periods. The emphasis in the data collection was placed on getting credible data, rather than on convenience for analysis. Therefore a lengthy process of sorting and coding the data was required.

4.3 Factor Model - Testing for appropriateness

The underlying assumption of a factor model (the existence of a few factors that underlie variability in the data) in carrying out a Principal Components Analysis (PCA) may be more or less appropriate depending on the nature of the data. Two widely used statistics to determine the validity of using a factor model on a data are the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The results of both of these tests for the current data set are given in table 2 below.

Table 2 – KMO and Bartlett's statistics for the factor model data set

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.671
Bartlett's Test of Sphericity	Approx. Chi-Square	118.223
	df	28
	Sig.	.000

Bartlett's test is used to test the null hypothesis that the variables are uncorrelated in the population (Hair *et al*, 1998). For this test, the population correlation matrix is an identity matrix. Bartlett's test uses a chi-square transformation of the determinant of the correlation matrix and, with the current dataset the null hypothesis can be rejected, thereby giving no reason to question the validity of using a factor model on the data.

The KMO statistic compares the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients. While there is no absolute cut-off or statistical tests for the value of the KMO statistic, a value of 0.7 and above is desirable, but values of 0.5 and above are tolerable. Essentially, a small value for the KMO would suggest that the correlations between pairs of variables cannot be explained by other variables (Sharma, 1996).

In addition to statistical tests outlined above, the inspection of the correlation matrix for the dataset should show a significant number of correlated pairs of variables of around 0.3. This final rule of thumb for the appropriateness of the dataset to factoring is less satisfactorily resolved in this case than the formal statistical tests. There are many pairs of correlations but usually in the range 0.2 to 0.25. It is therefore important that all the variables show high communality after the extraction (the amount of variance in each variable explained by the factor model) and that the components are easily interpretable. The correlation matrix for the 8 variables is given in appendix 2.

5. Results

5.1 Factor Extraction

A PCA extraction was carried out on the dataset in SPSS using the correlation matrix and standardised variables (i.e. with mean = 0 and standard deviation = 1). Communalities for the 8 variables are sufficient (the extraction accounts for at least half of the original variance for most of the variables) and are shown in table 4 below.

There is a degree of subjectivity with regard to the number of factors that should be extracted. Common stopping rules are: to stop when eigenvalues go below 1 (see table 3 below); and the scree test (to extract at a noticeable step change in the scree plot – see appendix 3). Of these, the scree test is inconclusive (3, 4 or 5 components could be defended) and so the eigenvalue rule is used, which suggests that 3 components should be extracted.

Table 3 – Variance explained by the 3 principal components

Component	Eigenvalue	% of Variance	Cumulative %
1	**2.235**	**27.941**	**27.941**
2	**1.328**	**16.606**	**44.546**
3	**1.067**	**13.341**	**57.887**
4	.810	10.121	68.008
5	.781	9.759	77.768
6	.659	8.233	86.001
7	.632	7.897	93.898
8	.488	6.102	100.000

Table 4 – Communalities, the % variance each of the 8 original variables explained by the 3 component extraction

	Initial	Extraction
Zscore(FARMSIZE)	1.000	.585
Zscore(INORG)	1.000	.436
Zscore(ORGANIC)	1.000	.557
Zscore(TOTLABOR)	1.000	.598
Zscore(COMMFEED)	1.000	.459
Zscore(SUGPOSD)	1.000	.599
Zscore(BANGUSSD)	1.000	.630
Zscore(TOTFEEDS)	1.000	.767

Table 5 – Component solution matrix

	Component		
	1	2	3
Zscore(FARMSIZE)	.250	**-.668**	.275
Zscore(INORG)	**.617**	.187	-.144
Zscore(ORGANIC)	**.690**	-8.104E-02	.273
Zscore(TOTLABOR)	-.198	**.668**	-.334
Zscore(COMMFEED)	**.568**	.326	.174
Zscore(SUGPOSD)	**-.638**	3.538E-02	.437
Zscore(BANGUSSD)	**.642**	.352	.307
Zscore(TOTFEEDS)	-.367	.403	**.685**

5.2 Interpreting the Component Loadings

The correlations between the observed variables and the underlying factor model are called the component loadings. Any given variable should only load significantly on one or possibly two components, but any given component may have several variables that load on it. The components should be interpretable in line with hypotheses held prior to the analysis. Table 6 below (from Hair *et al*, 1998) gives the guidelines for identifying significant component loadings based on sample size. In this analysis, significance is based on: α=0.05, a power level of 80 percent, and standard errors that are assumed to be twice those of conventional correlation coefficients. With our sample size of 136, we can consider factor loadings of around 0.48 and above to be significant.

Factor Loading	Sample Size Needed for Significance
30	350
.35	250
.40	200
.45	**150**
.50	**120**
.55	100
.60	85
.65	70
.70	60
.75	50

Table 6 - Guidelines from Hair et al (1998) for identifying significant factor loadings based on sample size.

Referring to the factor loadings in the solution in table 5, we can interpret and name the components according to those variables that load significantly on that component[6]. Statistically significant loadings are marked in bold.

5.2.1 Component 1 – "Specialisation"

This component describes the orientation of the production system towards either of the two main crops: prawns or milkfish. The stocking density of milkfish fry (BANGUSSD) is positively loaded on this component. In addition, however,

[6] The solution given is unrotated. Rotations, such as Kaiser's varimax rotation (Kaiser, 1958), are sometimes used in interpreting component loadings. However, rotations represent a simplification of the underlying component structure that in our case is not required – the results are interpretable as they are.

variables for both kinds of fertilizer (INORG and ORGANIC) load significantly positively on this component. This is because inorganic and organic fertilizers are used to culture natural food in the grow-out ponds ("lab-lab"[7] and "lumot"[8]) and milkfish can feed on this natural productivity throughout their life-cycle. In the cases where the operator wishes to fatten the fish prior to harvest ("finishing") or increase their growth rate due to low water temperature or low density of lab-lab, then commercial feeds are added. This explains the significant loading for the ratio of commercial feeds to total feed added in the year (COMMFEED), because only high quality commercial feeds are used to supplement the natural productivity of the pond ecosystem.

Commercial feeds are used much more sparingly in prawn polyculture systems. Commercial feeds are expensive, and increasingly so. For an operator to use commercial formulated prawn feeds in polyculture would make little economic sense. The feed would tend to be eaten by the secondary species in the pond, the prices of which attract only a fraction of the price of the prawn.

Commercial feeds are often employed by prawn polyculture operators during the critical nursing period (usually up to a month in duration), where the recently hatched prawn fry are separated from the rest of the species on the farm to avoid mortality from predation. However, the quantities of commercial feeds used in this period ("Fry Mash") are small, due to the minute size of the fry.

Additionally, milkfish experience relatively low rates of mortality once they have brought through their nursing period, whereas prawns tend to be much more prone to shocks in the pond ecosystem. They are more sensitive to salinity changes, temperature changes and viral outbreaks (Kautsky, Ronnback *et al.* 2000). Operators can make the decision to add commercial feeds for milkfish during later periods of grow-out, relatively safe in the knowledge that the production risk is low. In many cases, the important component of risk in milkfish monoculture is the fluctuation in price due to the multiple sources of milkfish in the market (i.e. pond culture, pen and cage culture). Operators will often keep the fish at market size until they have agreed a good price in the market before harvesting.

As a corollary, prawn stocking density (SUGPOSD) loads significantly negatively on this component, suggesting that farms that are specialized in prawn production do not stock milkfish at high densities or use large quantities or commercial feeds or fertilizers. Farms with a neutral score for this component are those with no specialization for either milkfish or prawns and are likely to be particularly extensive (i.e. with low stocking densities).

Overall, the component "Specialisation" accounts for 27.9% of the original variance in the set of eight variables.

5.2.2 Component 2 – "Labour vs Land Intensity"

The second component to be extracted has farm size (FARMSIZE) as a significant negative loading and total labour (TOTLABOUR) as a significant positive loading.

[7] Lab-lab is the Filipino term for a dense mat of microbenthic organism communities, composed of algae and diatoms, that rests on the pond floor (Sumagaysay-Chavoso & San Diego-McGlone, 2003).
[8] Lumot is the Filipino term for filamentous algae.

The component has been named the "Land vs Labour Intensity" because conceptually, farms may lie anywhere on a continuum where land is the major factor of production at one end (those with a negative component score), and labour is used in attempted compensation for lack of land at the other end (farms with a positive component score). This would suggest the possibility of some degree of input substitution between labour and land in the production function.

Overall, the component "Labour vs Land Intensity" accounts for 16.6% of the original variance in the set of eight variables.

5.2.3 Component 3 – "Feed Intensity"

Only one variable loads positively on this component: the total feeding rate (kg feeds / ha /yr "TOTFEEDS"). Prawn stocking density loads positively on this component, but at a level that is not significant at the level $\alpha = 5\%$. The interviews carried out during the survey showed that some farms, particularly prawn-oriented systems, used large quantities of low-quality feeds, particularly small molluscs collected from nearby riverbeds ("gasang", "suso" "agiis"; Cruz, 1997). The major explanation for the evolution of this method of production is the converse of the details given above in relation to milkfish culture. By using low quality feeds of low cost (P1-2 / kg in comparison to P12-20 / kg for commercial feeds) it is possible to minimize the costs of rearing prawns as a strategy to minimize the production risk associated with a given production cycle. The lower growth rates associated with low quality feeds, thereby lengthening the production cycle and extending the possibility of exposure to disease and other shocks, would appear to be more than compensated for by the reduced loss in the case of high mortality.

In these systems, it would appear that a survival rate to adult size of only 2 or 3% would result in a positive gross margin. 5% survival would result in a healthy profit, thus making the polyculture of prawn based on low quality feeds a very economically resilient system in the short to medium term. Longer term, there could be a problem with excessive harvesting of shells from the riverbed. If the cost of these natural resource-based supplemental feeds were to rise significantly, the economic feasibility of these systems would be under threat, in the same way milkfish intensification is under threat from rising commercial feed prices.

The component "Feed Intensity" accounts for 13.3% of the original variance in the set of eight variables.

5.3 Cluster Analysis

The principal components analysis has given us 3 dimensions along which the farms are distributed according to their technical and management characteristics. We can visualise the distribution of the 136 farms in 3 dimensions but the picture is somewhat complex. By carrying out a cluster analysis, we can identify groups of farms that similar to each other and different from farms of other groups. Ward's method (Ward, 1963) allows us to work with distance functions in any number of dimensions.

A cluster analysis was carried out using the factor scores from the 3 principal components over the 136 farms using Ward's algorithm in SPSS. The dendrogram showing a possible cutting line is shown in appendix 4. The number of clusters to choose (i.e. at which point to "cut") depends largely on the purposes of the exercises.

In the absence of any a priori expectations as to a “true” number of farm types, we choose the 5 cluster solution. We think that this gives a range of solutions with sufficient level of disaggregation to illustrate the complexity in how fishponds operate. Too much disaggregation, and the farm types would become too numerous, too complicated to understand and too difficult to communicate effectively.

5.4 Cluster solution x Principal Component Scores: “Farm Types”

The next stage is to interpret the results of the cluster analysis. To do this, we cross the cluster solution with the factor scores to see which factors are important in defining each “farm type”. Figure 1 below shows the 5 cluster solution in a 3-dimensional scatterplot where the axes are each of the three principal components.

Illustrated in figures 2a-c, are factor scores for the 3 principal components for each of the clusters. This allows us to examine the factors that characterise the farm types. Statistically significant differences between the mean factor scores for each farm type are tested in appendix 5. In addition, we can examine the five farm types according to the original set of 8 variables in shown in table 7 below. From this we can identify the features that define each farm type and name them. This will be the focus of the next section.

Figure 1 – Distribution of farm types in the three principal components.

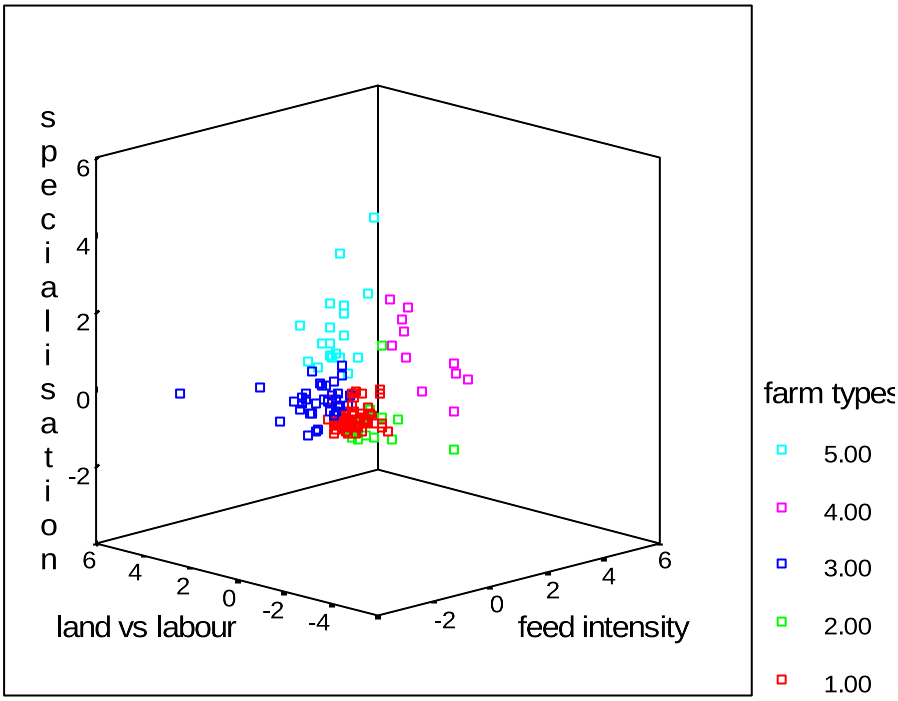


Figure 2a – 5-cluster solution with scores for "specialisation" by farm type

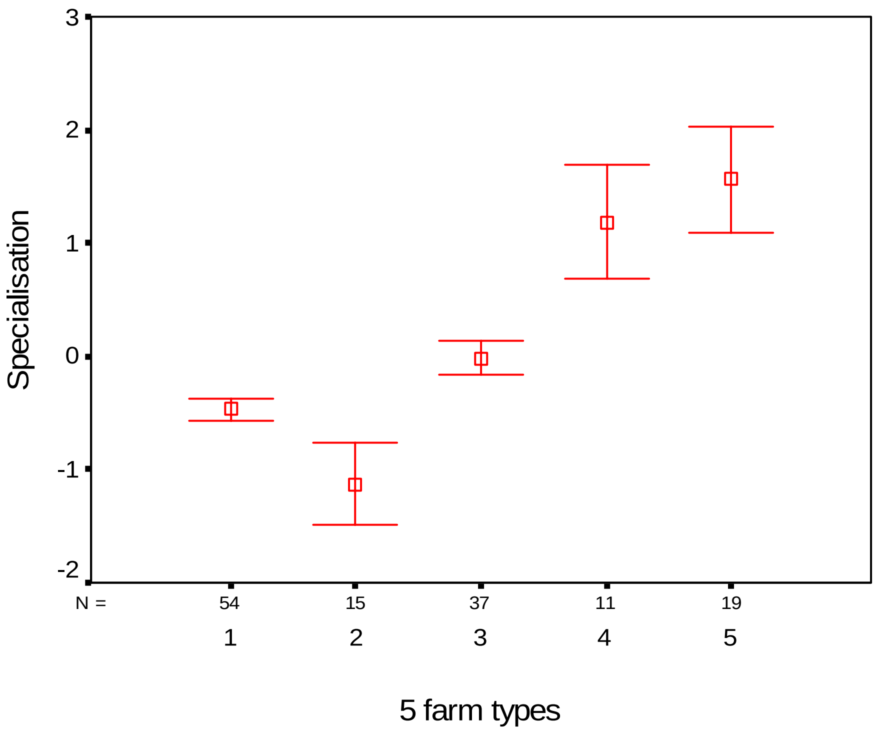


Figure 2b – 5-cluster solution with scores for "land vs labour" by farm type

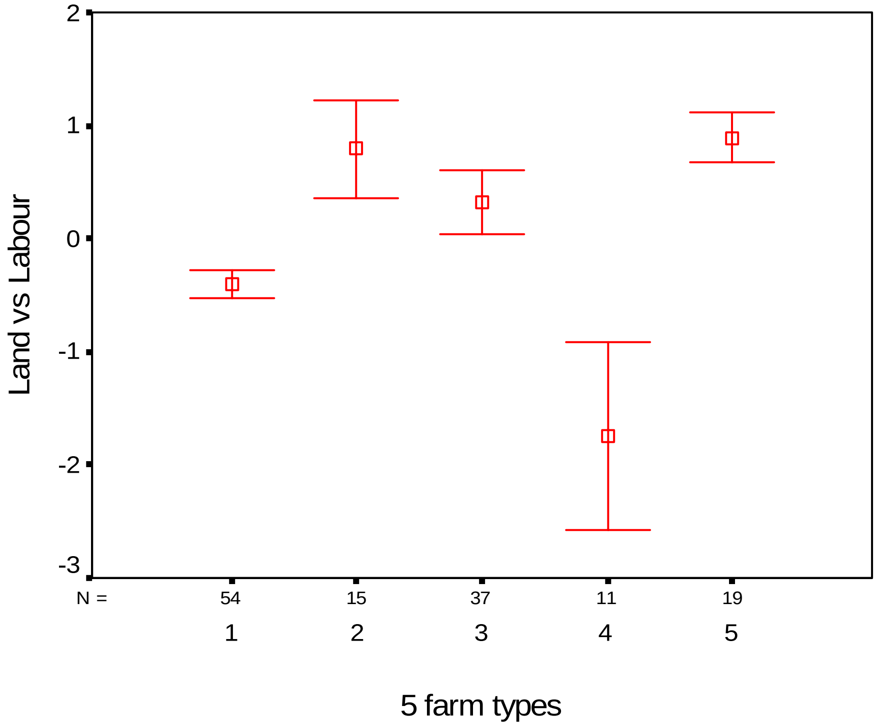


Figure 2c – 5-cluster solution with scores for "feed intensity" by farm type

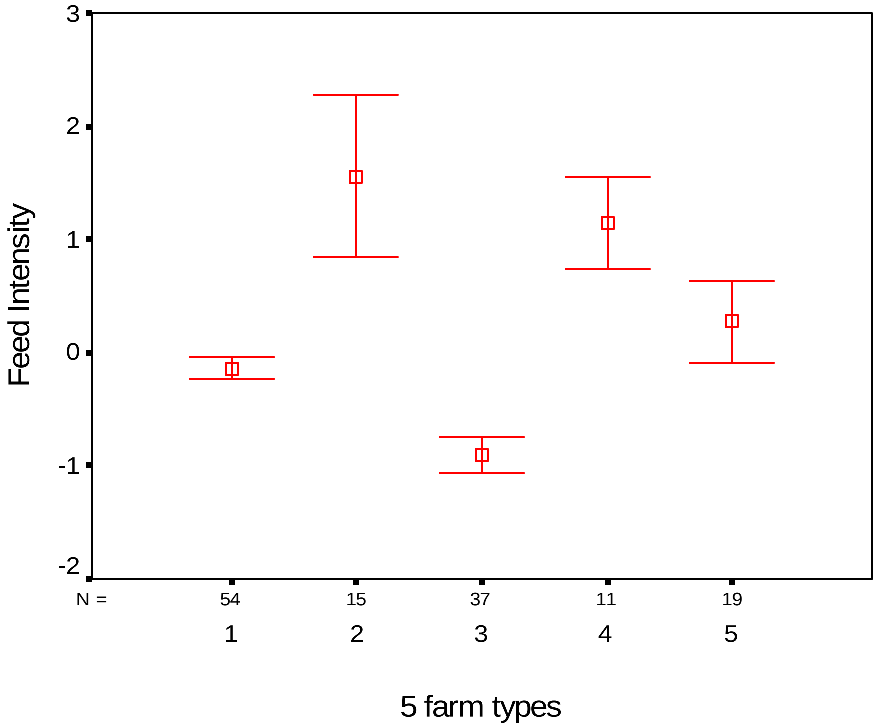


Table 7 – Details of a 5-cluster solution, giving rise to 5 farm types

		FARM SIZE (ha)	INORG FERT (kg/ha/yr)	ORGANIC FERT (kg/ha/yr)	TOTAL LABOUR (person days/ha/yr)	COMM. FEED (%)	PRAWN S.D. (fry/m^2)	MILKFISH S.D. (fry/m^2)	TOTAL FEEDS (kg/ha/yr)
1	N = 54								
	Mean	9.24	35.65	52.65	235.52	1.28	4.47	0.09	1908.55
	SE Mean	*1.09*	*11.71*	*24.24*	*20.20*	*0.77*	*0.45*	*0.01*	*308.14*
2	N = 15								
	Mean	2.88	31.40	0.00	370.41	6.71	**9.42**	0.18	**16248.34**
	SE Mean	*0.77*	*14.08*	*0.00*	*35.85*	*5.69*	*1.76*	*0.11*	*3429.52*
3	N = 37								
	Mean	3.97	189.33	214.80	**501.00**	8.44	1.20	0.16	559.96
	SE Mean	*0.85*	*35.55*	*69.33*	*65.28*	*4.05*	*0.36*	*0.02*	*270.91*
4	N = 11								
	Mean	**63.73**	136.03	**2750.48**	119.81	11.31	1.63	0.39	1251.60
	SE Mean	*13.66*	*40.39*	*713.00*	*38.84*	*9.14*	*0.82*	*0.12*	*705.15*
5	N = 19								
	Mean	6.13	**407.08**	**1113.36**	272.05	**76.93**	**0.00**	**0.71**	1858.59
	SE Mean	*1.46*	*115.60*	*379.81*	*35.28*	*8.53*	*0.00*	*0.12*	*872.66*
All	N = 136								
	Mean	11.08	137.00	457.35	318.37	15.20	3.27	0.23	3063.13
	SE Mean	*1.80*	*22.23*	*102.67*	*23.13*	*2.86*	*0.37*	*0.03*	*577.81*

5.5 Identifying the Farm Types

One-way Analysis of Variance (ANOVA) were carried out to determine statistically significant differences between the farm types. Important results from Scheffe's Post-Hoc tests are reported in the descriptions below, with full details given in appendix 6.

5.5.1 Type 1 – "Generalists" (n = 54, or 39.7% of sample)

Roughly neutral to all factors; Average size, no specialisation.

When carrying out a typology exercise, it is normal for a certain proportion of the sample to be average with regards to the variables of interest. By describing farms of this type as "Generalists", we observe that they show no degree of specialization in terms of production practices for either milkfish or prawn, and may therefore flexibly switch between these two species depending on supply of fry or market conditions.

Given that these are farms with no distinguishing features with regard to the dataset used in this exercise, it is possible that other variables are more important in identifying their characteristics. An example is the level of economic diversification on the farm between prawn, milkfish, crab and tilapia which are the four crops found to be cultured in our sample. Diversification of the farm between these crops has the benefit of spreading production risk and possible disease control via biological interactions between the crops.

Reporting the number of species cultured on the farm is one way of describing the diversity of the farm. However, this does not give information regarding the relative importance of each species to the revenue stream of the farm. Metzel and Ateng (1993), and Irz and Fatch (2004) use Simpson's Index to report crop diversity on farms in Bangladesh and Malawi respectively. Here we use the closely related Shannon Index, a more widely used index that has the attractive property of being bound between 0 (no diversification - the farm produces only one crop) and 1 (perfect diversification – the farm produces all possible crops, in our case 4, in equal proportions according to revenue).

The formula for the Shannon Index (H') is:

$$H' = -\Sigma\, p_i * \ln(p_i)$$

where p is the proportion of total revenue from species i.

$$H_{max} = \log(S)$$

where S is the number of species. Equitability (E), the measure reported here is given by H'/H_{max} and produces the index bound between 0 and 1 (Shaw, 2003, p.34).

From the results shown graphically in figure 3, we can observe that farm types 1 and 2 are economically diverse, whereas 3, 4 and 5 are less so. The differences between farms 1 and 2 in comparison with 3, 4 and 5 are statistically significant at the 5% level (see table 8 below).

Figure 3 – Revenue diversity indices by farm type

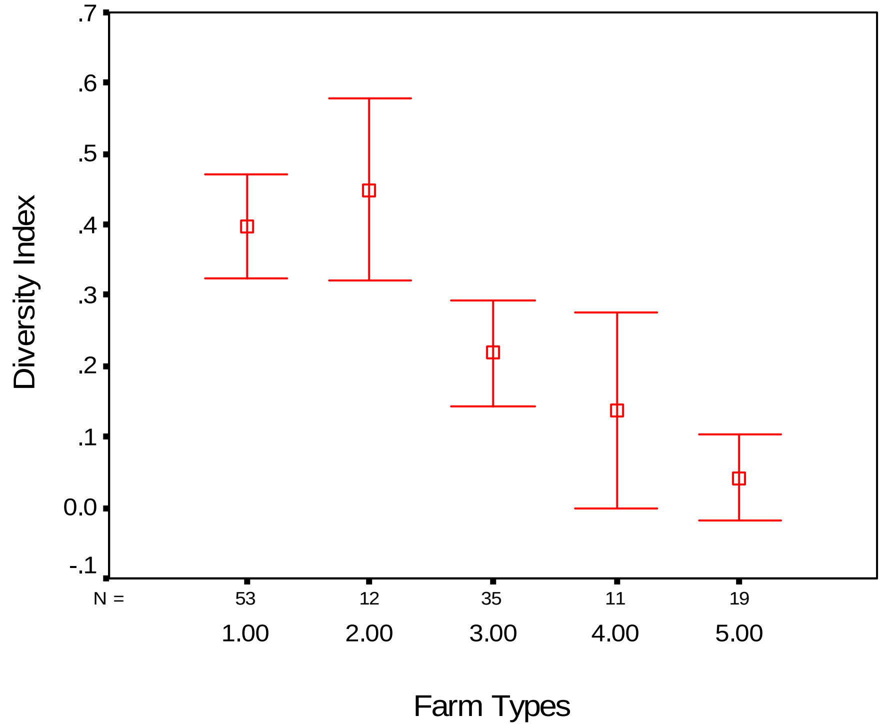


Table 8 – One-way ANOVA with Scheffe's Post-Hoc test for differences in mean diversity index between farm types

(I) Farm Type	(J) Farm Type	Mean Difference (I-J)	Std. Error	Sig.
1	2	-0.052	0.073	0.974
	3	0.179	0.050	0.015

	4	0.259	0.076	0.024
	5	0.355	0.061	0.000
2	1	0.052	0.073	0.974
	3	0.231	0.077	0.066
	4	0.311	0.096	0.037
	5	0.406	0.085	0.000

Therefore, we can conclude that "Generalist" is a good term to describe farm type 1, not just in terms of the production practices outlined in the typology, but when referenced to the level of economic diversification across possible crops.

5.5.2 Type 2 – "Prawn-Oriented Polyculture" (n = 15, or 11.0%)

Farms of this type have negative scores for factor 1, and are therefore oriented towards the production of prawns. Relative to the sample, labour is more important than land as a factor of production, as can be seen from small farm size and above-average labour intensity.

Farms of this type also have high total feeding rate, but with a low percentage of commercial feeds in the diet (6.7% by weight). From carrying out a one-way ANOVA, we can see that feeding rates are higher than those of all other farm types (significant at the 1% level) and that there are higher stocking densities of prawn fry on these farms than on all other farm types (significant at the 1% level). We therefore name this type as "Prawn-oriented polyculture".

By referring to the results of the diversity index shown in figure 3, we can see that these farms, whilst oriented in their production towards prawns, actually are most successful in spreading their revenue most evenly across the candidate species for culture. This would suggest that the farmers attempt to ameliorate the risk associated with the prawns themselves, in the knowledge of how variable returns from prawn production can be. This means that while these farms are specialised in prawn production relative to the sample as a whole, they are not so in absolute terms (i.e. they are not prawn monoculture systems).

5.5.3 Type 3 – "Low Input, Labour Intensive Farms" (n = 37, or 27.2%)

Farms of this type are neutral to factor 1, and are therefore not specialized with respect to either prawn or milkfish production. They have positive scores for factor 2 and so labour is much more important as a factor of production than land. From the results of a one-way ANOVA, we observe that these farms have higher labour use than farm types 1 and 4 (significant at the 1% level) and farm type 5 (significant at the 5% level). They have negative scores for factor 3 and are very feed-extensive. They have lower feed-intensities than all other farm types.

The amount of fertiliser used in these systems is moderate and low stocking densities are used. These really are very extensive farms and there could be interesting issues to do with access to credit for poor fish farmers for these systems. Alternatively, it may be that these farms are under-utilised because the motivations of the operator do not relate to maximising levels of production or profit but to some other objective (e.g. to have control of land in the area; for leisure as a break from another activity). These are hypotheses that can be explored.

5.5.4 Type 4 – "Large, Milkfish-Oriented Systems" (n = 11, or 8.1%)

Farms of this type are positive for factor 1 and are therefore specialized in milkfish production. They have negative scores for factor 2 and therefore land is more important than labour as a factor of production. Feeding rates are approximately average for the sample.

From the results of a one-way ANOVA, we observe that these farms are larger in size than farms belonging to all other farm types (significant at the 1% level). It is their size that defines them primarily, but there is a tendency for milkfish-orientation on these farms. Large ponds, fertilized with large amounts of manure are used on this farm type. Labour intensity is lower than for any other farm type and stocking densities are low.

These farms tend to be operated by local elites and the income from the fish farms, despite their size, is unlikely to be the main one for the operator. As mentioned previously, the motivation for entering fish farming may not be production-related and control of the land may be important for local political objectives held by the operator. There are a number of social issues relating to these farm types, notably the potential for land reform.

5.5.5 Type 5 – "Small Milkfish Monoculture Farms" (n = 19, or 14.0%)

Positive scores for factor 1 suggest that these farms are milkfish-specialised. They are positive for factor 2 and therefore labour is more important than land as a factor of production. From the results of a number of one-way ANOVA test, we find that these farms have higher use of commercial feeds than all other farm types (significant at the 1%); have higher stocking densities of milkfish fry than all other farm types (significant at the 5% level); and have higher use of inorganic fertilizers than all other farm types (significant at at least the 5% level).

No other species are stocked in these systems and therefore they are entirely dependent on milkfish for their income. There has been a large increase in the production of milkfish from non-pond aquaculture (e.g. pens, cages) recently in the Philippines and so these systems are suffering from lower prices and their margins are being squeezed. It will be interesting to follow whether diversification into the other candidate species will follow (along the lines of the "Generalist" farm type) or whether these operators, whose production practices are entirely set up for milkfish culture, will try and stick it out in the hope of an increase again in the market price.

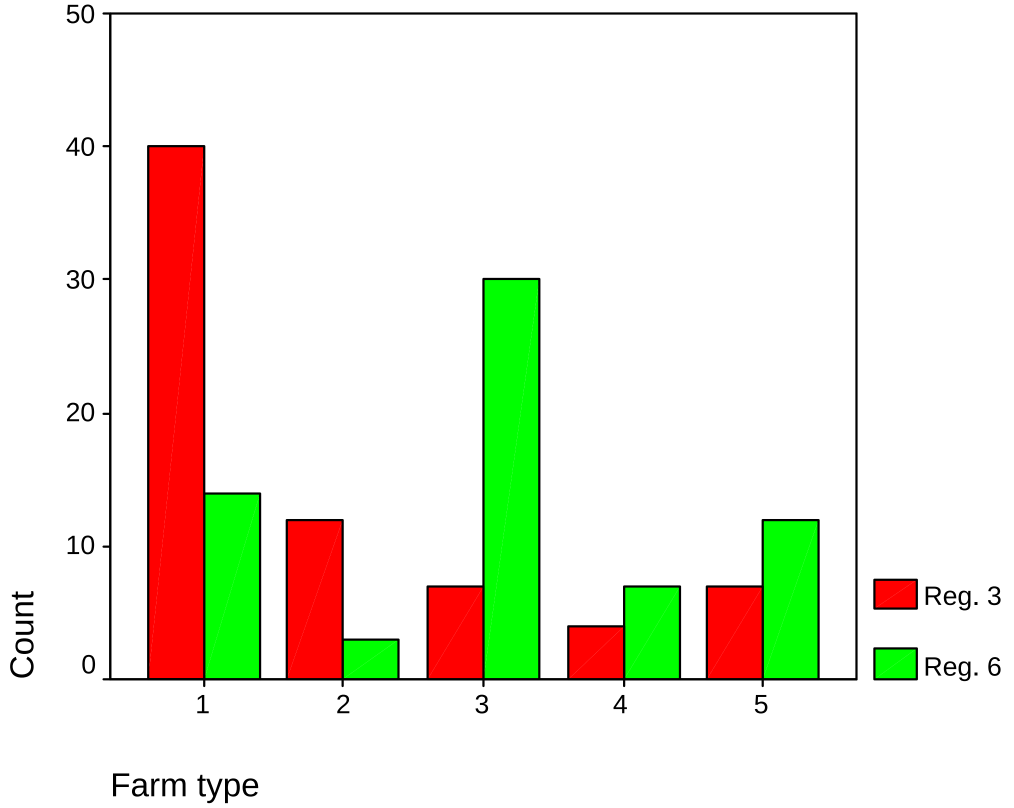
6. Geographic Distribution

We can observe that there is a geographically biased distribution for farm types in our sample. As previously outlined in section 4.1, sampling effort was split almost equally between two regions – 49% in Central Luzon (region 3) and 51% in Western Visayas (region 6). As table 9 and figure 4 show below, most prawn-oriented farms are found in region 3 (80%). Generalists are also somewhat concentrated in region 3 (74%). On the other hand, low-input high-labour systems are particularly strongly concentrated in region 6.

Table 9 – Values for regional dummy variables

Farm Type	% in Region 6
1 – Generalist	0.26
2 – Prawn-oriented polyculture	0.20
3 – Low input systems, labour intensive	0.81
4 – Large, milkfish oriented-systems	0.64
5 – Small milkfish monoculture farms	0.63
Total sample (all farm types)	0.49

Figure 4 – Geographic distribution by farm type



7. Conclusion

The results of the principal components analysis are easily interpreted and are in line with expectations held *ex-ante* with regard to possible latent variable structure. One possible cluster solution containing five farm types has been outlined and their defining characteristics highlighted.

What we have effectively generated with this analysis is a survey of the current farming systems in the Philippines. While this is useful as an end in itself, we see it primarily as a means to aid comparative study in policy. For instance, in the case of a single objective (such as increase food security), we can then study protein budgets for each of the clusters to identify the 'best' production system for this objective. However, we believe that policy regarding sustainable development of the aquaculture sector requires a multiple-criteria approach to appraisal, as the following two quotes should help illustrate:

> *"The super-intensive cage farms are inefficient in nutrient and labour use….but provide very high returns to land and capital investment. Clearly there are trade-offs between the use efficiencies of different resources, and local demand for these resources has implications for the relative merits of alternative systems."* Michielsens *et al* (2002, p. 412).

> *"The extensive farming method finds its validity but also its limits in its link with natural productivity. It is characterized by a favourable energy balance, but by rather low production per surface unit."* Ravagnan (1981, p.66)

In complex cases where there are a number of competing objectives (e.g. maximize economic performance, minimize ecological impact, maximize social equity) then we can explore the trade-offs at the farm-level between ecological, social and economic properties of the farming systems. In addition, we can examine the determinants of geographical biases in the adoption of particular farming systems. These topics will be the subject of subsequent papers in this report.

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Appendix 1a – *Stratification of a net sample size of 70 farms for region 3*

Total Farms in Sample	**Bataan**	**Bulacan**	**Pampanga**	**Zambales**
# Farms > 10 ha	**2** (2)	**4** (4)	**9** (8)	**0** (1)
# Farms 2 – 10 ha	**6** (5)	**7** (7)	**21** (19)	**0** (3)
# Farms < 2 ha	**3** (3)	**5** (3)	**11** (10)	**2** (4)
Total	**11** (10)	**16** (14)	**41** (38)	**2** (8)

The table above shows the stratification of the net sample of 70 farms in region 3. The figures in bold represent the stratification of the actual net sample collected during fieldwork. The figures in parentheses represent the number that would be completely representative of the region, according to the Bureau of Agricultural Statistics (BAS) inventory from 1997. Zambales is deliberately under-represented because, in carrying out work in that province it was found that most of the farms were actually only nursery systems ("kawagan") that supply fingerlings to the grow-out systems in Bataan, Bulacan and Pampanga. They are not directly comparable in our analysis as they are not aquaculture grow-out systems and so have been omitted from the net sample.

Appendix 1b - *Stratification of a net sample size of 67 farms for region 6*

Total Farms in Sample	**Aklan**	**Antique**	**Capiz**	**Guimaras**	**Iloilo**	**Negros Occ.**
# Farms > 10 ha	**2** (2)	**0** (0)	**5** (5)	**0** (0)	**5** (5)	**7** (3)
# Farms 2 - 10 ha	**8** (7)	**0** (1)	**10** (10)	**0** (1)	**4** (5)	**7** (8)
# Farms < 2 ha	**7** (7)	**0** (1)	**3** (5)	**0** (1)	**4** (4)	**5** (4)
Total	**17** (16)	**0** (2)	**18** (19)	**0** (2)	**13** (14)	**19** (16)

The table above shows the stratification of the net sample of 67 farms in region 6. Antique and Guimaras provinces have limited suitable area for fishponds and are only marginal in the regional production, so were not included in the fieldwork. As before, the figures in bold represent the stratification of the actual net sample collected during fieldwork. The figures in parentheses represent the number that would be completely representative of the region, according to the BAS inventory from 1997.

Appendix 2 – *Correlation matrix for the 8 variables*

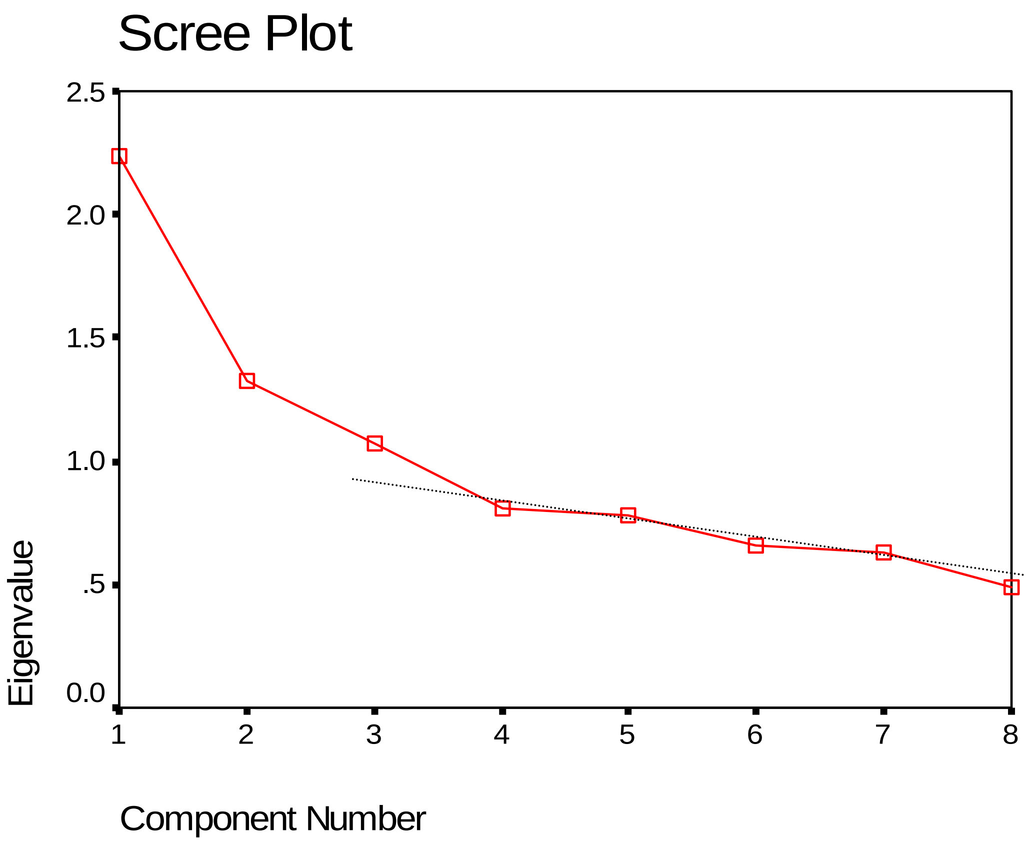
a) Correlation Matrix

	FARMSIZE	INORG	ORGANIC	TOTAL LABOUR	SUGPO S.D.	BANGUS S.D.	TOTAL FEEDS	COMM. FEED
FARMSIZE	1.000	.001	.182	-.248	-.102	.054	-.120	-.018
INORG	.001	1.000	.330	-.015	-.292	.245	-.138	.241
ORGANIC	.182	.330	1.000	-.166	-.233	.363	-.134	.245
TOTLABOR	-.248	-.015	-.166	1.000	.031	.027	.106	-.031
SUGPOSD	-.102	-.292	-.233	.031	1.000	-.295	.312	-.196
BANGUSSD	.054	.245	.363	.027	-.295	1.000	.025	.360
TOTFEEDS	-.120	-.138	-.134	.106	.312	.025	1.000	-.074
COMMFEED	-.018	.241	.245	-.031	-.196	.360	-.074	1.000

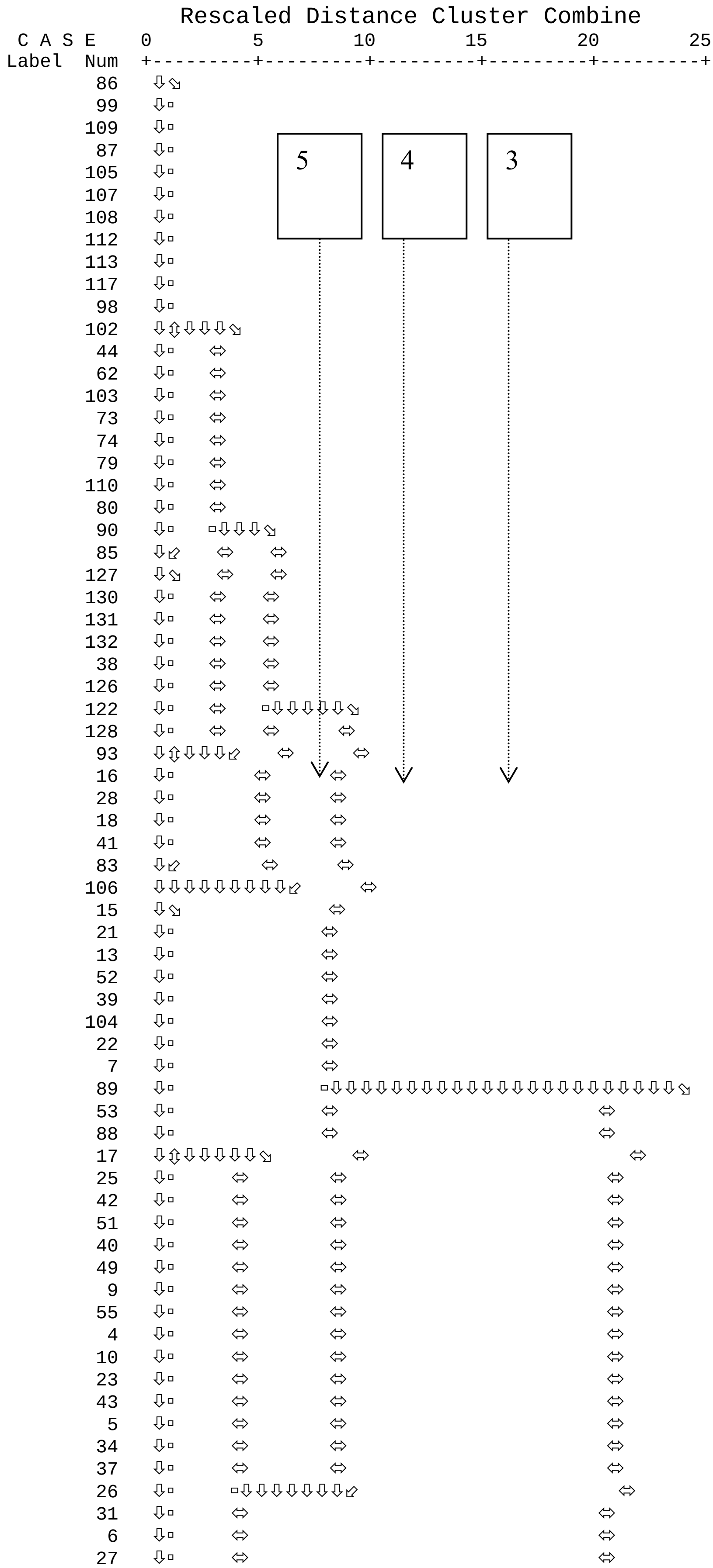
b) Significance of correlations

	FARMSIZE	INORG	ORGANIC	TOTAL LABOUR	SUGPO S.D.	BANGUS S.D.	TOTAL FEEDS	COMM. FEED
FARMSIZE		.497	.017	.002	.118	.267	.081	.417
INORG	.497		.000	.432	.000	.002	.054	.002
ORGANIC	.017	.000		.026	.003	.000	.060	.002
TOTLABOR	.002	.432	.026		.360	.379	.109	.361
SUGPOSD	.118	.000	.003	.360		.000	.000	.011
BANGUSSD	.267	.002	.000	.379	.000		.385	.000
TOTFEEDS	.081	.054	.060	.109	.000	.385		.198
COMMFEED	.417	.002	.002	.361	.011	.000	.198	

Appendix 3 – *Scree Plot showing extraction of principal components*



Appendix 4 – *Dendrogram of Cluster Analysis output*



```
  8    ⇩⬃    ⇔                       ⇔
 14    ⇩⬂    ⇔                       ⇔
134    ⇩▫   ⇔                       ⇔
  3    ⇩▫   ⇔                       ⇔
  1    ⇩▫   ⇔                       ⇔
 30    ⇩▫   ⇔                       ⇔
 63    ⇩⇳⇩⬂   ⇔                      ▫⇩⇩⇩⇩⇩⇩⇩⇩⇩⬂
  2    ⇩▫ ⇔  ⇔                       ⇔       ⇔
 54    ⇩▫ ⇔  ⇔                       ⇔       ⇔
 57    ⇩▫ ⇔  ⇔                       ⇔       ⇔
 33    ⇩▫ ⇔  ⇔                       ⇔       ⇔
 97    ⇩▫ ⇔  ⇔                       ⇔       ⇔
135    ⇩⬃ ▫⇩⇩⇩⬃                      ⇔       ⇔
 68    ⇩⬂ ⇔                          ⇔       ⇔
118    ⇩▫ ⇔                         ⇔       ⇔
 29    ⇩▫ ⇔                         ⇔       ⇔
114    ⇩▫ ⇔                         ⇔       ⇔
101    ⇩▫ ⇔                         ⇔       ⇔
124    ⇩▫ ⇔                         ⇔       ⇔
 92    ⇩⇳⇩⬃                          ⇔       ⇔
 96    ⇩▫                          ⇔        ⇔
115    ⇩▫                          ⇔        ⇔
116    ⇩▫                          ⇔        ⇔
 75    ⇩⬃                           ⇔       ⇔
 48    ⇩⬂                           ⇔       ⇔
 56    ⇩▫                          ⇔        ⇔
 32    ⇩▫                          ⇔        ⇔
 11    ⇩⇳⇩⇩⇩⬂                        ⇔       ⇔
 36    ⇩▫  ⇔                        ⇔       ⇔
 19    ⇩▫  ⇔                        ⇔       ⇔
 35    ⇩▫  ⇔                        ⇔       ⇔
 58    ⇩▫  ▫⇩⇩⇩⇩⇩⇩⇩⬂                  ⇔       ⇔
 84    ⇩⬃   ⇔     ⇔                  ⇔        ⇔
 12    ⇩⬂   ⇔     ⇔                  ⇔        ⇔
111    ⇩▫  ⇔     ▫⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⬃      ⇔
 20    ⇩▫  ⇔     ⇔                          ⇔
 77    ⇩⇳⇩⇩⇩⬃     ⇔                          ⇔
 47    ⇩⬃        ⇔                          ⇔
 24    ⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⬃                          ⇔
 61    ⇩✖⇩⇩⇩⇩⇩⬂                              ⇔
 72    ⇩⬃    ⇔                              ⇔
 81    ⇩⬂    ⇔                              ⇔
 94    ⇩▫   ⇔                               ⇔
 69    ⇩▫   ⇔                               ⇔
 59    ⇩▫   ▫⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⬂              ⇔
125    ⇩▫   ⇔                ⇔              ⇔
 70    ⇩⇳⇩⬂   ⇔               ⇔              ⇔
 64    ⇩▫ ⇔  ⇔                ⇔              ⇔
 71    ⇩▫ ⇔  ⇔                ⇔              ⇔
 82    ⇩⬃ ⇔   ⇔               ⇔              ⇔
 65    ⇩⬂ ▫⇩⇩⇩⬃               ⇔              ⇔
 67    ⇩▫ ⇔                  ⇔              ⇔
 95    ⇩▫ ⇔                  ⇔              ⇔
 46    ⇩▫ ⇔                  ▫⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⬃
 60    ⇩⇳⇩⬃                   ⇔
 66    ⇩▫                    ⇔
129    ⇩▫                    ⇔
123    ⇩⬃                    ⇔
 78    ⇩⬂                    ⇔
119    ⇩⇳⇩⇩⇩⇩⇩⇩⇩⬂              ⇔
121    ⇩▫     ⇔              ⇔
133    ⇩⬃      ⇔              ⇔
 50    ⇩⬂     ▫⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⇩⬃
 76    ⇩▫     ⇔
 91    ⇩▫     ⇔
100    ⇩⇳⇩⇩⇩⇩⇩⇩⇩⬃
120    ⇩▫
 45    ⇩▫
136    ⇩⬃
```

Appendix 5 – *Analysis of variance (ANOVA)of the differences in mean factor scores for five farm types using Scheffe's Post-Hoc Test*

Dependent Variable	Grouping Variables (I) Farm Type	(J) Farm Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Factor 1 - Specialism	1	2	0.656	0.165	0.005*	0.140	1.172
		3	-0.457	0.121	0.008*	-0.834	-0.079
		4	-1.658	0.187	0.000*	-2.243	-1.073
		5	-2.035	0.151	0.000*	-2.507	-1.563
	2	1	-0.656	0.165	0.005*	-1.172	-0.140
		3	-1.113	0.173	0.000*	-1.654	-0.571
		4	-2.314	0.225	0.000*	-3.016	-1.612
		5	-2.691	0.196	0.000*	-3.302	-2.080
	3	1	0.457	0.121	0.008*	0.079	0.834
		2	1.113	0.173	0.000*	0.571	1.654
		4	-1.201	0.194	0.000*	-1.809	-0.594
		5	-1.578	0.160	0.000*	-2.077	-1.079
	4	1	1.658	0.187	0.000*	1.073	2.243
		2	2.314	0.225	0.000*	1.612	3.016
		3	1.201	0.194	0.000*	0.594	1.809
		5	-0.377	0.214	0.545	-1.047	0.293
	5	1	2.035	0.151	0.000*	1.563	2.507
		2	2.691	0.196	0.000*	2.080	3.302
		3	1.578	0.160	0.000*	1.079	2.077
		4	0.377	0.214	0.545	-0.293	1.047
Factor 2 - Land vs Labour	1	2	-1.191	0.204	0.000*	-1.830	-0.552
		3	-0.726	0.149	0.000*	-1.193	-0.259
		4	1.346	0.232	0.000*	0.623	2.070
		5	-1.296	0.187	0.000*	-1.880	-0.713
	2	1	1.191	0.204	0.000*	0.552	1.830
		3	0.465	0.214	0.324	-0.205	1.135
		4	2.537	0.278	0.000*	1.669	3.406
		5	-0.105	0.242	0.996	-0.861	0.650
	3	1	0.726	0.149	0.000*	0.259	1.193
		2	-0.465	0.214	0.324	-1.135	0.205
		4	2.072	0.240	0.000*	1.321	2.824
		5	-0.570	0.198	0.087***	-1.188	0.047
	4	1	-1.346	0.232	0.000*	-2.070	-0.623
		2	-2.537	0.278	0.000*	-3.406	-1.669
		3	-2.072	0.240	0.000*	-2.824	-1.321
		5	-2.643	0.265	0.000*	-3.472	-1.814
	5	1	1.296	0.187	0.000*	0.713	1.880
		2	0.105	0.242	0.996	-0.650	0.861
		3	0.570	0.198	0.087***	-0.047	1.188
		4	2.643	0.265	0.000*	1.814	3.472

Dependent Variable	(I)	(J)	Difference (I-J)	Std. Error	Sig.	95% C.I. Lower Bound	95% C.I. Upper Bound
Factor 3 - Feed Intensity	1	2	-1.696	0.183	0.000*	-2.269	-1.123
		3	0.760	0.134	0.000*	0.341	1.178
		4	-1.290	0.208	0.000*	-1.940	-0.641
		5	-0.413	0.168	0.200	-0.937	0.110
	2	1	1.696	0.183	0.000*	1.123	2.269
		3	2.456	0.192	0.000*	1.855	3.057
		4	0.406	0.249	0.619	-0.373	1.185
		5	1.283	0.217	0.000*	0.605	1.961
	3	1	-0.760	0.134	0.000*	-1.178	-0.341
		2	-2.456	0.192	0.000*	-3.057	-1.855
		4	-2.050	0.216	0.000*	-2.724	-1.376
		5	-1.173	0.177	0.000*	-1.727	-0.619
	4	1	1.290	0.208	0.000*	0.641	1.940
		2	-0.406	0.249	0.619	-1.185	0.373
		3	2.050	0.216	0.000*	1.376	2.724
		5	0.877	0.238	0.011**	0.133	1.621
	5	1	0.413	0.168	0.200	-0.110	0.937
		2	-1.283	0.217	0.000*	-1.961	-0.605
		3	1.173	0.177	0.000*	0.619	1.727
		4	-0.877	0.238	0.011**	-1.621	-0.133

where (*) denotes significant at the 1% level

where (**) denotes significant at the 5% level

where (***) denotes significant at the 10% level

Appendix 6 - *Analysis of variance (ANOVA) of the differences in mean values for the original set of 8 variables for five farm types using Scheffe's Post-Hoc Test*

	(I) Farm Type	(J) Farm Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
FARMSIZE	1	2	6.366	4.094	0.660	-6.425	19.157
		3	5.271	2.993	0.543	-4.082	14.625
		4	-54.485	4.640	0.000	-68.982	-39.987
		5	3.116	3.741	0.952	-8.574	14.806
	2	1	-6.366	4.094	0.660	-19.157	6.425
		3	-1.095	4.293	0.999	-14.509	12.320
		4	-60.851	5.568	0.000	-78.248	-43.453
		5	-3.250	4.845	0.978	-18.387	11.888
	3	1	-5.271	2.993	0.543	-14.625	4.082
		2	1.095	4.293	0.999	-12.320	14.509
		4	-59.756	4.817	0.000	-74.807	-44.705
		5	-2.155	3.959	0.990	-14.525	10.214
	4	1	54.485	4.640	0.000	39.987	68.982
		2	60.851	5.568	0.000	43.453	78.248
		3	59.756	4.817	0.000	44.705	74.807
		5	57.601	5.314	0.000	40.997	74.205
	5	1	-3.116	3.741	0.952	-14.806	8.574
		2	3.250	4.845	0.978	-11.888	18.387
		3	2.155	3.959	0.990	-10.214	14.525
		4	-57.601	5.314	0.000	-74.205	-40.997
INORG	1	2	4.248	66.822	1.000	-204.545	213.041
		3	-153.676	48.861	0.048	-306.347	-1.005
		4	-100.380	75.736	0.780	-337.024	136.265
		5	-371.430	61.069	0.000	-562.249	-180.612
	2	1	-4.248	66.822	1.000	-213.041	204.545
		3	-157.924	70.080	0.285	-376.896	61.048
		4	-104.628	90.883	0.856	-388.601	179.346
		5	-375.678	79.078	0.000	-622.766	-128.591
	3	1	153.676	48.861	0.048	1.005	306.347
		2	157.924	70.080	0.285	-61.048	376.896
		4	53.296	78.625	0.977	-192.377	298.969
		5	-217.755	64.618	0.027	-419.661	-15.848
	4	1	100.380	75.736	0.780	-136.265	337.024
		2	104.628	90.883	0.856	-179.346	388.601
		3	-53.296	78.625	0.977	-298.969	192.377
		5	-271.051	86.741	0.050	-542.083	-0.019
	5	1	371.430	61.069	0.000	180.612	562.249
		2	375.678	79.078	0.000	128.591	622.766
		3	217.755	64.618	0.027	15.848	419.661
		4	271.051	86.741	0.050	0.019	542.083
ORGANIC	1	2	52.650	271.480	1.000	-795.624	900.923
		3	-162.153	198.509	0.955	-782.417	458.111
		4	-2697.827	307.695	0.000	-3659.256	-1736.398
		5	-1060.715	248.110	0.002	-1835.964	-285.465
	2	1	-52.650	271.480	1.000	-900.923	795.624

		3	-214.802	284.716	0.966	-1104.431	674.827
		4	-2750.477	369.234	0.000	-3904.191	-1596.762
		5	-1113.364	321.273	0.021	-2117.219	-109.510
	3	1	162.153	198.509	0.955	-458.111	782.417
		2	214.802	284.716	0.966	-674.827	1104.431
		4	-2535.674	319.433	0.000	-3533.781	-1537.567
		5	-898.562	262.526	0.023	-1718.857	-78.267
	4	1	2697.827	307.695	0.000	1736.398	3659.256
		2	2750.477	369.234	0.000	1596.762	3904.191
		3	2535.674	319.433	0.000	1537.567	3533.781
		5	1637.112	352.407	0.000	535.976	2738.249
	5	1	1060.715	248.110	0.002	285.465	1835.964
		2	1113.364	321.273	0.021	109.510	2117.219
		3	898.562	262.526	0.023	78.267	1718.857
		4	-1637.112	352.407	0.000	-2738.249	-535.976
TOTLABOR	1	2	-134.881	70.787	0.462	-356.063	86.301
		3	-265.478	51.760	0.000	-427.208	-103.748
		4	115.713	80.230	0.721	-134.974	366.400
		5	-36.528	64.693	0.988	-238.670	165.614
	2	1	134.881	70.787	0.462	-86.301	356.063
		3	-130.597	74.238	0.544	-362.563	101.368
		4	250.594	96.275	0.155	-50.230	551.418
		5	98.353	83.770	0.847	-163.396	360.102
	3	1	265.478	51.760	0.000	103.748	427.208
		2	130.597	74.238	0.544	-101.368	362.563
		4	381.191	83.290	0.001	120.941	641.442
		5	228.950	68.452	0.029	15.063	442.837
	4	1	-115.713	80.230	0.721	-366.400	134.974
		2	-250.594	96.275	0.155	-551.418	50.230
		3	-381.191	83.290	0.001	-641.442	-120.941
		5	-152.241	91.888	0.603	-439.356	134.874
	5	1	36.528	64.693	0.988	-165.614	238.670
		2	-98.353	83.770	0.847	-360.102	163.396
		3	-228.950	68.452	0.029	-442.837	-15.063
		4	152.241	91.888	0.603	-134.874	439.356
COMMFEED	1	2	-5.431	6.469	0.950	-25.644	14.781
		3	-7.160	4.730	0.683	-21.939	7.620
		4	-10.033	7.332	0.759	-32.941	12.876
		5	-75.651	5.912	0.000	-94.123	-57.179
	2	1	5.431	6.469	0.950	-14.781	25.644
		3	-1.728	6.784	0.999	-22.926	19.469
		4	-4.601	8.798	0.991	-32.092	22.889
		5	-70.220	7.655	0.000	-94.139	-46.300
	3	1	7.160	4.730	0.683	-7.620	21.939
		2	1.728	6.784	0.999	-19.469	22.926
		4	-2.873	7.611	0.998	-26.656	20.909
		5	-68.491	6.255	0.000	-88.037	-48.946
	4	1	10.033	7.332	0.759	-12.876	32.941
		2	4.601	8.798	0.991	-22.889	32.092
		3	2.873	7.611	0.998	-20.909	26.656
		5	-65.618	8.397	0.000	-91.855	-39.381
	5	1	75.651	5.912	0.000	57.179	94.123

		2	70.220	7.655	0.000	46.300	94.139
		3	68.491	6.255	0.000	48.946	88.037
		4	65.618	8.397	0.000	39.381	91.855
SUGPOSD	1	2	-4.946	0.976	0.000	-7.997	-1.895
		3	3.270	0.714	0.001	1.039	5.501
		4	2.838	1.107	0.167	-0.619	6.296
		5	4.471	0.892	0.000	1.683	7.259
	2	1	4.946	0.976	0.000	1.895	7.997
		3	8.216	1.024	0.000	5.017	11.416
		4	7.785	1.328	0.000	3.635	11.934
		5	9.417	1.155	0.000	5.807	13.028
	3	1	-3.270	0.714	0.001	-5.501	-1.039
		2	-8.216	1.024	0.000	-11.416	-5.017
		4	-0.431	1.149	0.998	-4.021	3.158
		5	1.201	0.944	0.805	-1.749	4.151
	4	1	-2.838	1.107	0.167	-6.296	0.619
		2	-7.785	1.328	0.000	-11.934	-3.635
		3	0.431	1.149	0.998	-3.158	4.021
		5	1.633	1.267	0.798	-2.328	5.593
	5	1	-4.471	0.892	0.000	-7.259	-1.683
		2	-9.417	1.155	0.000	-13.028	-5.807
		3	-1.201	0.944	0.805	-4.151	1.749
		4	-1.633	1.267	0.798	-5.593	2.328
BANGUSSD	1	2	-0.092	0.080	0.862	-0.343	0.160
		3	-0.075	0.059	0.805	-0.259	0.109
		4	-0.296	0.091	0.038	-0.581	-0.011
		5	-0.622	0.074	0.000	-0.851	-0.392
	2	1	0.092	0.080	0.862	-0.160	0.343
		3	0.017	0.084	1.000	-0.247	0.280
		4	-0.204	0.109	0.484	-0.546	0.138
		5	-0.530	0.095	0.000	-0.828	-0.233
	3	1	0.075	0.059	0.805	-0.109	0.259
		2	-0.017	0.084	1.000	-0.280	0.247
		4	-0.221	0.095	0.252	-0.517	0.075
		5	-0.547	0.078	0.000	-0.790	-0.304
	4	1	0.296	0.091	0.038	0.011	0.581
		2	0.204	0.109	0.484	-0.138	0.546
		3	0.221	0.095	0.252	-0.075	0.517
		5	-0.326	0.104	0.050	-0.652	0.000
	5	1	0.622	0.074	0.000	0.392	0.851
		2	0.530	0.095	0.000	0.233	0.828
		3	0.547	0.078	0.000	0.304	0.790
		4	0.326	0.104	0.050	0.000	0.652
TOTFEEDS	1	2	-14339.789	1432.247	0.000	-18815.02	-9864.563
		3	1348.594	1047.270	0.798	-1923.727	4620.915
		4	656.947	1623.302	0.997	-4415.253	5729.148
		5	49.955	1308.951	1.000	-4040.021	4139.930
	2	1	14339.789	1432.247	0.000	9864.563	18815.015
		3	15688.383	1502.073	0.000	10994.977	20381.789
		4	14996.736	1947.962	0.000	8910.096	21083.376
		5	14389.743	1694.934	0.000	9093.719	19685.768
	3	1	-1348.594	1047.270	0.798	-4620.915	1923.727

		2	-15688.383	1502.073	0.000	-20381.79	-10994.977
		4	-691.647	1685.230	0.997	-5957.350	4574.056
		5	-1298.640	1385.008	0.927	-5626.262	3028.982
	4	1	-656.947	1623.302	0.997	-5729.148	4415.253
		2	-14996.736	1947.962	0.000	-21083.38	-8910.096
		3	691.647	1685.230	0.997	-4574.056	5957.350
		5	-606.993	1859.188	0.999	-6416.248	5202.262
	5	1	-49.955	1308.951	1.000	-4139.930	4040.021
		2	-14389.743	1694.934	0.000	-19685.77	-9093.719
		3	1298.640	1385.008	0.927	-3028.982	5626.262
		4	606.993	1859.188	0.999	-5202.262	6416.248

Research project R8288: Assessing the sustainability of brackish-water aquaculture systems in the Philippines – Paper 2/5

Sustainability indicators for brackish-water pond aquaculture in the Philippines: Economic, social and ecological dimensions

Abstract

The concept of sustainable development is commonly associated with a balance between economic viability, social equity, and ecological sustainability. In this paper we critically review these issues with respect to aquaculture in the Philippines and introduce specific objectives to characterise these properties: maximise profit; minimise risk; maximise technical efficiency; minimise nutrient loss; maximise net dietary protein production; and maximise employment.

We describe methodologies for generating specific indicators of these objectives for aquaculture at the farm level and present results for five farming system types in brackish-water ponds in the Philippines. We also consider some other related analyses (e.g. ecological footprints, mortality by different species, pesticide application) that help us build a picture of the complexity of the farming systems.

Overall, we find that semi-intensive prawn-oriented polyculture has the highest level of profit (gross margin per unit area) but at the cost of low achievement in other objectives – most notably nutrient loss, technical efficiency and risk. Extensive polyculture performs well with regard to most indicators except for employment effect, the highest values for which are seen in low-input labour-intensive systems. Semi-intensive milkfish monoculture systems and very large milkfish-oriented systems would seem to perform averagely or poorly for most indicators. The results for all indicators are summarised, but analysis of the implications is reserved for paper 3.

Contents

1. Introduction

Indicators are measurable properties of systems and are the most widely-used means through which broad notions of "social good" (following Milon, 1987) can be used for comparative study. Given the particular focus of this study, our choice of a set of indicators is more specifically grounded in the literature on sustainable development. There follows a partial review of studies that have used sustainability indicators in the analysis of farming systems, and, subsequently, a brief discussion of our own choice of indicators. The selected indicators are then presented in details and used for comparative analysis of the five farming systems identified in paper 1.

2. Review of sustainability indicators

Indicators are, in a general sense, used to provide information about a complex system (e.g., agroecosystem), or an unmeasurable concept, such as that of sustainability (Bockstaller and Girardin, 2003). Their use in the analysis of sustainability issues is justified by Bell and Morse (1999) as a way of giving a degree of rigour to the study of what are, ultimately, values held by people. However, it should be recognised from the outset that devising sustainability indicators is not an exact science, but, instead, represents a synthesis of different perspectives on a problem to give insight to decision-making. Hence, the approach is a paradigm in the Kuhnian sense – the paradigm of sustainability – combining the objective measurement of a subjective choice of indicators. Ultimately, selecting sustainability indicators is not inferior to more rigorous approaches in science, but merely different, and the subjectivity of the exercise is laid bare.

In practice, the process of developing indicators is itself a compromise integrating the scientific knowledge of the moment, the need for conciseness, simplicity of use, and the availability of data (Girardin *et al.* 1999). Conceptually, in the case of agriculture and related natural resource systems, there are two broad categories of indicators, which can be characterised as means-based and effect-based (van der Werf and Petit, 2002). Means-based measures relate to production practices, with an assumed link to the outcome of this practice. An example would be "amount of nitrogen fertiliser applied" with an assumed, but indirect, link to an objective that is to be minimised (e.g. eutrophication of a river). Effect-based measures relate to the direct outcomes of production practices and are to be preferred. An example would be "amount of nitrate lost to a river", which gives much more relevant and precise information to the decision-maker concerned with the river ecosystem than the equivalent means-based measure. However, effects-based measures are more data intensive, and the marginal value of the information gained over a means-based indicator has to be weighed up against the costs in extra data requirements.

Any given application of the sustainability indicator paradigm may invoke a single global indicator or, more commonly, a number of different indicators. We focus our review on applications that use a multiple-indicator approach, owing to the conceptual difficulties associated with single, global indicators. Such difficulties are primarily centred on the problem of incommensurability of values, both in technical terms (i.e. adding apples and oranges together) and in social terms (i.e. what is important in the decision problem).

Van der Werf and Petit (2002) review twelve applications of sustainability indicators to different agricultural systems. At a technical level, they find great diversity in the number of indicators selected (from 2 to 13), the manner with which interactions between indicators are treated, and whether scores (assigned by the researcher) or measured values are used. In terms of their broader aims, studies using sustainability indicators may assess environmental objectives only, or may include indicators for social and economic objectives as well. This choice of scope relates to whether or not the research team are interested in "environmental" or "ecological" sustainability as in the former case, or in "sustainability" or "sustainable development" as in the latter case. Beyond these general considerations, sustainability indicators are used to investigate a wide range of issues, as we now attempt to illustrate.

Nutrient disequilibrium is a common theme to many case-studies, and nutrient budgets then represent the preferred methodology for calculating a related indicator. Funge-Smith and Briggs (1998), for instance, compute complete nutrient budgets for intensive prawn aquaculture systems in Thailand. The limitation of this kind of total accounting of nutrient flows is, however, that it can usually only be carried out on a few experimental farms owing to heavy data requirements. In an attempt to address this issue, Islam *et al.* (2004) and Wijnhoud *et al.* (2003) provide methods for a less comprehensive accounting, which offers the possibility of application to a greater number of farms. Whatever the method used, nutrient loss, expressed in kilogram per hectare or unit of product, is the related indicator for these studies.

Energy-use is another objective for which indicators have been developed, and may be expressed as total energy used in the system, or energy used per unit of product or land (Bailey *et al.,* 2003). For instance, expression of an indicator per unit area of farming system is particularly useful in comparing agricultural practices. On the other hand, calculating energy requirements per unit of product is similar to what is done in Life-Cycle Assessment (LCA), where energy flows from the production, use, and disposal of a product are considered, and the focus is thus more on the impact of consumption trends (Heller and Keoleian, 2003) rather than that of different production practices. It is worth pointing out that LCA has seen recent application to commercial feeds for aquaculture (Papatryphon *et al.*, 2004), and that this type of analysis implicitly assumes technical homogeneity (i.e., that the impact of the use of one unit of feed is the same on all farms), which represents an obvious simplification of reality.

In an attempt to measure the sustainability impact of aquaculture, Prein *et al.* (1998) use four indicators to characterise farming systems before and after the integration of aquaculture into them. Their indicators are: net income, expressed as a monetary value; recycling and diversity, both expressed as scores; and production capacity, expressed as a quantity of product per unit area. The results are displayed in a kite diagram to visually demonstrate the Pareto dominance of integration. Along similar lines, another research team (Dalsgaard *et al.*, 1995; Dalsgaard and Oficial, 1997) base their approach on four key ecological properties of sustainable systems and suggest four related indicators: diversity, cycling, stability and capacity. Their analysis is connected to the ECOPATH II mass-balance modelling software for modelling ecosystems (Christensen and Pauly, 1992). ECOPATH models represent trophically linked biomass 'pools' and are parameterised by satisfying two master equations describing production and consumption within an ecosystem (or farm).

ECOPATH-based models have now seen hundreds of applications in the literature, mostly in capture fisheries. An important recent paper uses ECOPATH in association with a series of objective functions in economic, ecological and social dimensions (Christensen and Walters, 2004), to examine the consequences of alternative fisheries management policies. The authors find that the trade-offs between objectives are more significant than might have been expected, thereby showing the relevance of a multi-objective approach.

Particularly relevant to our own study, Rasul and Thapa (2003) compare ecological and conventional agricultural systems in Bangladesh by measuring sustainability indicators derived from a large farm-level survey. Their work is of interest because of its focus on a developing country and its coverage of economic, ecological and social objectives, as detailed in Table 1. The table shows the selection of profitability, an index of stability across farms, equity (in the form of employment per hectare) and food security – all important indicators for which specific methodologies are developed in this paper. In the end, the authors establish that the two farming systems differ significantly with respect to some indicators but not others, and that, overall, ecological agriculture is relatively more sustainable.

Table 1 – Objectives, indicators and specific methods of analysis used by Rasul and Thapa (2003)

Broad objective	Indicator	Specific method
Ecological sustainability	Land-use pattern	Proportion of land under field crops, homestead and orchard
	Cropping pattern	Cropping intensity, crop diversification, mixed cropping
	Soil fertility management	Proportion of farmers using inorganic and organic fertilizers, and area covered by each type
	Pest and disease management	Proportion of farmers using biological, mechanical, and chemical methods
	Soil fertility status	Chemical analysis of soil samples collected from both kinds of farms
Economic sustainability	Land productivity	Crop yields
	Yield stability	Index of yield trend across farms
	Profitability	Financial return, economic return and value added per unit of land
Social acceptability	Input self-sufficiency	Ratio of local inputs cost to total inputs cost
	Equity	Employment per ha
	Food security	Adequacy of food grain produced
	Risks and uncertainties	Index

Altogether, the generation of sustainability indicators has become an industry in itself (King *et al.*, 2000) so that the above review is far from exhaustive. However, and perhaps surprisingly, there is little consensus on the proper way in which indicators should be selected and used. This can be explained by the fact that sustainability is a multifaceted concept - something which has unfortunately not always been recognised in the literature. As a result, the definition and measurement of sustainability indicators draw on different literatures when used to compare different kinds of systems (e.g. an economy, a farm) at different scales (e.g. country-level, farm-level), and there has been little by way of a consistent underlying conceptual framework. The objective of the following section is to define the issues relevant to the selection of indicators for aquaculture in the Philippines.

3. Brackish-water aquaculture in the Philippines: A critical review of the economic, social and economic issues

This section reviews the economic, social and environmental issues that aquaculture in the Philippines is currently facing, based on the existing literature and, in some cases, data collected whilst carrying out a farm-level survey between January and June 2003[1]. In addition, semi-structured interviews, direct observation, personal participation in on-farm and off-farm activities, and life-history discussions with key informants are all used to develop a greater understanding of the issues. The emphasis is placed primarily on description but linkages to theories in the relevant literature are made wherever possible. Our choice as over-riding themes of "economic viability", "social equity" and "environmental sustainability" is influenced by the sustainability literature, in particular Adger, *et al*. (2003) and Brown *et al.* (2001).

3.1 Economic viability

The most comprehensive study of aquaculture economics is that based on the survey carried out by the Asian Development Bank (ADB) and the Network of Aquaculture Centres in Asia-Pacific (NACA). The related dataset is enormous, covering the ten prawn producing countries in the region (Thailand, Indonesia, China, Vietnam, Bangladesh, Philippines, India, Taiwan, Malaysia, Sri Lanka) and has led to a number of papers. Most important among these is that by Shang *et al.* (1998) on the comparative economics of prawn production and marketing in the ten Asian countries listed above, which we now attempt to review.

3.1.1 Relative economic performance of Philippine aquaculture

Using data from 1994, Shang *et al*. (1998) describe the cost and revenue structures of extensive, semi-intensive and intensive prawn grow-out operations in Asian countries, as summarized in Table 2 for extensive farms. In terms of profitability, the Philippines top the set of countries studied with a profit rate of US$4.67 per kilo for extensive systems. Semi-intensive farms also return a healthy level of profit of US$ 2.54 per kilo, which is at the upper end of the range for all Asian countries. However, for intensive farming systems, the level of profit in the Philippines is low, at US$ 0.29 per kilo, which ranks the country second bottom among the ten Asian countries. Hence, the results suggest that the Philippines are internationally competitive in prawn production for relatively extensive systems only. The evolution of the industry since Shang *et al*. (1998)'s study was published confirms that view as virtually all the farms currently in commercial operation in the Philippines can be described as semi-intensive or extensive (according to the definition adopted by these authors).

We now try to explain the profitability levels described above. Table 2 shows that, for extensive systems, the Philippines are characterized by a relatively low level of land productivity, an average total cost of production but the highest level of profit per unit output. These apparently paradoxical findings can be reconciled when output prices are considered, because the Philippines have the highest farm-gate price for extensively-raised prawn at US$ 7.28 per kilo. This relatively high price is likely due to the fact that extensive farms in the Philippines raise relatively large prawns, although Shang *et al.* (1998) do not report the average individual size for each country. The other production systems in the Philippines do not enjoy the same level of price advantage when compared to other countries. Hence, Philippine semi-intensive prawn farms obtain an average farm-gate price of US$ 6.55 per kilo and intensive farms achieve US$ 7.10 per kilo, which ranks fifth and fourth respectively among eight Asian countries.

Table 2 – Farm-level economics of extensive prawn production in Asia, from Shang et al. (1998)

FARM-LEVEL CHARACTERISTICS	Thailand	Indonesia	Philippines	Vietnam	India	Bangladesh	Sri Lanka	China
Total Number of farms	2002	24000	3029	22374	45040	6500	80	2681
Sample size	7	1024	68	296	744	163	17	117
% of total farms	0	4	2	1	2	3	21	4
Average farm size (ha)	12.2	5	10.8	10.3	1.2	16.6	5	39.5
Stocking density (PL/m2)	0	3.1	1.7	0.3	3.7	1.5	14.9	7.9
Feed Conversion Ratio	0	0.3	0.4	0.1	1.2	0.4	0.3	1.4
Number of crops / yr	2.4	2	1.7	1.3	1.3	1.2	1.7	1
Production (kg/ha/yr)	394	162	260	79	696	216	2944	421
COST STRUCTURE ($/kg)	**Thailand**	**Indonesia**	**Philippines**	**Vietnam**	**India**	**Bangladesh**	**Sri Lanka**	**China**
Fixed Costs	0.9	1.2	1.01	2.01	1.33	1.34	1.92	0.74
Overhead	0.68	0.4	0.18	1.07	0.28	0.99	1.33	0.13
Depreciation	0.22	0.8	0.83	0.93	0.99	0.35	0.59	0.54
Interest	0	0	0	0.01	0.07	0	0	0.06
Variable costs	0.84	2.66	1.6	1.04	3.08	2.73	1.52	0.88
Feed	0	0.22	0.49	0.17	1.39	0.13	0.31	0.29
Seed	0	1.26	0.53	0.42	0.99	1.77	0.76	0.13
Power	0.46	0.01	0.03	0.04	0.27	0.04	0.12	0.1
Labour	0.08	0.65	0.37	0.24	0.26	0.56	0.31	0.13
Other	0.3	0.52	0.19	0.16	0.18	0.23	0.02	0.23
Total Cost	1.74	3.86	2.61	3.04	4.42	4.07	3.45	1.62
Farm-gate price	3.63	6.84	7.28	2.73	7.19	6.9	7.05	3.05
Profit (US$ /kg)	1.89	2.98	4.67	-0.31	2.77	2.83	3.6	1.43
COST STRUCTURE (% Total Cost)	**Thailand**	**Indonesia**	**Philippines**	**Vietnam**	**India**	**Bangladesh**	**Sri Lanka**	**China**
Fixed Costs	51.8	31.1	38.5	66	30.2	32.9	55.8	45.4
Overhead	39.2	10.3	6.9	35.1	6.3	24.3	38.6	7.8
Depreciation	12.6	20.7	31.7	30.6	22.4	8.5	17.2	33.7
Interest	0	0.1	0	0.2	1.5	0	0	3.9
Variable costs	48.2	68.9	61.5	34	69.8	67.1	44.2	54.6
Feed	0	5.8	18.7	5.6	31.4	3.3	8.9	17.8
Seed	0	32.7	20.2	13.9	22.4	43.5	22.2	8.2
Power	26.3	0.2	1	1.3	6	1	3.5	6.2
Labour	4.6	16.7	14.4	8	6	13.8	9.1	8.1
Other	17.3	13.4	7.2	5.2	4.1	5.6	0.5	14.4

For intensive systems, the cost of production per kilo is second highest in the Philippines at US$ 6.81. and relates to the relatively high costs of variable inputs. Hence, Shang *et al*. (1998) establish that the costs of feed (US$ 2.61 per kilo of output), seed (US$ 1.27 per kilo) and labour (US$ 0.43 per kilo) are higher in the Philippines than in other countries for intensive farms, which is explained by high variable input prices, as well as, possibly, low levels of technical efficiency of the farms. This cost structure is responsible for the low level of profitability of intensive farms in the Philippines. Given the level of financial and production risk associated with intensive systems, this level of profit can be considered economically non-viable, as has been suggested by the continuing pattern of de-intensification or abandonment of formerly intensive shrimp farms in the Philippines.

The other production systems present more satisfactory cost structures. For semi-intensive farms, the Philippines have a middle-ranking production cost of US$ 4.01 per kilo. Feeds represent the main cost for all countries for these systems, but the Philippines report the highest cost share for this item (over 55%). For extensive systems, the Philippines produces at US$ 2.61 per kilo and seed is the most important variable cost. One can hypothesize that these more satisfactory cost structures, when compared to that of intensive systems, relates to the fact that non-intensive farms manage to substitute relatively expensive commercial feeds with other cheap sources of protein, such as small shells (as described in paper 1).

Altogether, we conclude from this review that the Republic of the Philippines appears internationally competitive in extensive and semi-intensive prawn production. However, the high costs of commercial feeds in the Philippines mean that the competitive position of the country is dependent on the availability of ‘natural feeds’,, so that one could argue that the continued success of exports from the Philippines depends on the health of the coastal ecosystem.

3.1.2 Within-Country Heterogeneity

There is a long history of brackish water aquaculture in the Philippines, and the techniques currently used represent combinations of traditional practices and modern technologies that are often not familiar to aquaculture technicians. As a rule, farmers adopt only partially, and to different degrees, the bundle of technical innovations that have been developed in the past few decades. These innovations, in terms of inputs, include commercial pellet feeds, hatchery-bred prawn fry, commercial inorganic fertilizers, hatchery-bred tilapia fry, and saline-tolerant tilapia fry. In addition, techniques for the management of pond conditions and stock growth come from innovations introduced by operators and from technicians at national and international research institutions. These include the use of nursery ponds (operator innovation), modular systems of production (improved traditional), salinometers to measure salinity of source water (private sector innovation), laboratory testing of fry for the presence of disease agents (innovation from Negros Prawn Producers Cooperative), green-water technology (innovation of SEAFDEC-UPV), closed-recycling systems (operator innovation and SEAFDEC tested). Aquaculture operators draw on these technologies and techniques in various combinations according to the constraints that they face (e.g. working capital, market access, environmental conditions).

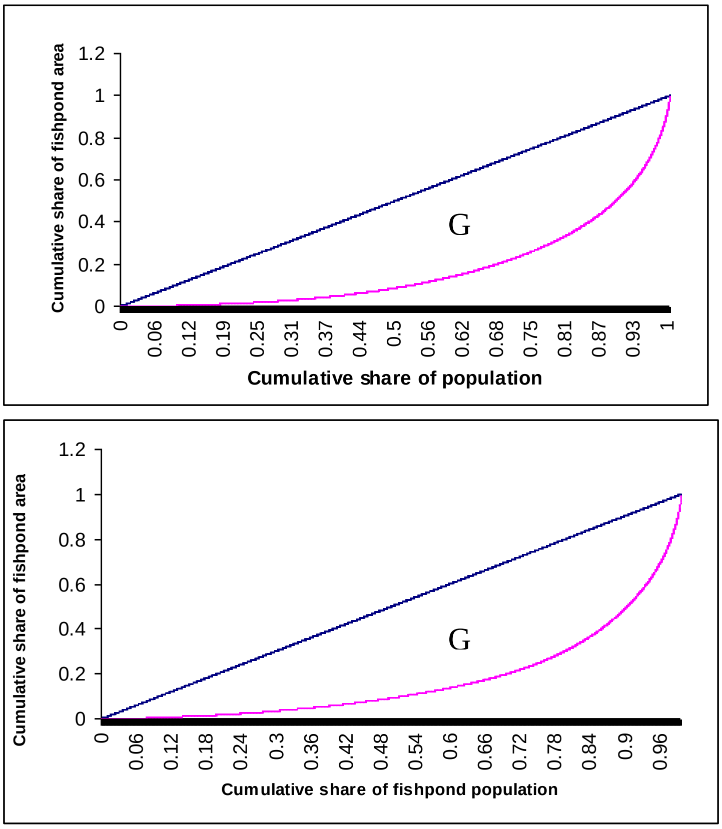
Thus, we have to recognize the complex combinations of strategies that fishpond operators employ to remain profitable. Intensive aquaculture is usually fairly standardized, but this is not the case for extensive and semi-intensive systems. This heterogeneity is partly historical (some current systems were adapted from traditional milkfish ponds, some newly built on mangrove acid-sulphate soils or on mudflats), and partly as a result of differences in the specific objectives and constraints faced by the operators.

3.2 Social Equity

3.2.1 Distribution of fishpond landholdings

The distribution of farm size is perhaps the most important factor in determining social equity for the general agricultural sector in developing countries and appears relevant in assessing the social impact of aquaculture in the Philippines. Using data from the Bureau of Agricultural Statistics (BAS) inventory of fishponds from 1997, we compare the distribution of land ownership in regions 3 and 6 by plotting Lorenz curves and calculating Gini coefficients (Figure 1)[2].

Figure 1 – Lorenz curves for regions 3 (top) and 6 (bottom)



The Gini coefficient is the ratio of the area enclosed by the Lorenz curve and the diagonal (G), and the area under the diagonal (i.e. Gini coefficient = G/0.5 = 2G). The greater the inequality in land distribution, the greater the value of the Gini coefficient up to a maximum of 1 where all the land is owned by one member of the population.

The two regions are almost identical in their distribution of fishpond unit sizes, as summarized by Gini coefficients of 0.715 for region 3 and 0.719 for region 6. This compares unfavourably with Thailand which had a Gini coefficient of 0.42 in 1988 for the distribution of land holdings in general. Further, it should be noted that the analysis is based on the total number of brackish water fishpond units, and so these results are an indication of the concentration of pond ownership only among those engaged in the industry. If data on family landholdings for the entire household population in these regions were available, the Gini coefficient for the distribution of all landholdings in general would approach unity for both regions. Altogether, it is clear that the land supporting brackish water pond aquaculture in the Philippines is very unequally distributed.

3.2.2 Absenteeism

It is well known that many operators do not live close to their fishponds, and this phenomenon has implications both for management and for social equity. The need for the operator to have a trusted caretaker can often take precedence over the desire for the caretaker to be technically competent. The central importance of trust in the caretaker-operator relationship means that operators that live outside the area where the fishpond is situated often bring their own employees from outside to be caretakers. This can be a cause for tension between absentee operators and the local communities.

Hence, while the rationale for aquaculture as a rural development strategy is often cited, the predominance of absentee operators lessens the potential benefits to the rural areas. Profits are spent outside the region, thus eliminating any potentially beneficial multiplier effects through consumption. Indeed, in the case of prawn aquaculture in Honduras, Stanley found that the farms operated as an enclave, separate from the community and the local economy, rather than as a stimulus to growth in the coastal regions (Stanley, 2003).

3.2.3 Impacts on the livelihoods of fishermen

Aquaculture has both positive and negative impacts on the livelihoods of the people dependent on the rivers and seas for their livelihood. The negative impacts are organic pollution and thus a deterioration in environmental quality; a loss of habitat for commercially important species; and loss of an open-access multi-functional resource in the case of conversion of mangroves to new fishponds. Positive impacts are primarily through employment in the aquaculture sector both directly (as caretakers, labourers) and indirectly (supplying inputs such as small shells, fry and by-catch for fishmeal).

The fisherfolk lobby in the Philippines is large in number but weak in representation and voice at high levels of governance. A number of non-governmental organizations (NGOs) represent the interests of fisherfolk with the rationale that they are among the poorest members of society. In addition, the activity of municipal fishing is seen by many as culturally important and worthy of support.

3.2.4 Impacts on food security

There is an equivocal literature on the benefits of aquaculture to food security. Prawns and crabs are recognised as serving no food security purpose at the national level, as they are luxury products and may actually reduce global protein supply significantly (Naylor, Goldburg et al., 2000). Conversely, milkfish and tilapia are an important part of the daily diet for most social classes in the Philippines. When prices of these fish fall during periods of local market saturation (harvests from fishponds often occur in clusters around the full moon where the tidal range is greatest) they may even be affordable to the poor. In addition, immediately following harvests, people are often allowed to enter the drained pond to collect any fish left behind by the harvest labourers. This represents a possibility for free fish for the poor, although it merely mimics the *de facto* harvesting-rights for local people that would operate under open-access to mangroves and other inter-tidal habitats.

3.2.5 Increased vulnerability of coastal villages to typhoons and flooding

Fishpond areas do not provide protection to coastal villages from strong winds, tidal waves and tsunamis. The shearing effect of a mangrove in the same area dissipates the force of incoming water. Villagers in Lat-Asan, Capiz, Philippines experienced this first hand and shared their experiences during key-informant interviews in April 2004. Mangroves were the only structures to survive in their village when a tidal wave struck in the 1980s. Most of the residents that survived were those that had managed to climb the mangrove and coconut trees in sufficient time.

In the aftermath of the tsunami that engulfed areas of Indonesia, India, Thailand and Sri Lanka on 26th December 2004, questions are being raised as to whether the development of the coastline in these areas contributed to the extent of the devastation. Aquaculture is not the only driver of change in land-use in the coastal areas of these countries, but it is certainly a significant one. The issue of coastal resilience to such events is likely to now become more widely understood and hold higher priority than was previously the case in countries pursuing aquaculture development.

3.3 Environmental Sustainability

3.3.1 Initial land clearance for the ponds

Built on inter-tidal lands usually cleared of its cover of saline-adapted vegetation (e.g. mangroves, *nipa* palms), fishponds alter the functioning of the coastal ecosystem. A typical tropical inter-tidal zone covered in mangroves provides a number of extractable goods (e.g. firewood, crabs that can be collected from the mud, honey, tannins - Kaplowitz, 2001), but it is the ecological and hydrological services that represent their most important sources of value (Gilbert and Janssen, 1998; Nickerson, 1999; Barbier, 2000; Janssen, Gilbert *et al.*, 2000; Ronnback and Primavera, 2000; Janssen, Gilbert *et al.*, 2001). When these habitats are destroyed to make way for fishponds, these services are lost. Therefore the mere presence of fishponds in an area is disruptive and has a negative impact on the functioning of the coastal ecosystem. The resultant loss of mangroves from the Philippines represents a feature of aquaculture development over the past 50 years that is alarming to some (Primavera, 1995).

3.3.2 Environmental externalities during operation

3.3.2.1 Exogenous to aquaculture
(i.e. from fishpond to environment in general)

The release of organic pollution from the farms, and subsequent nutrient enrichment of surrounding waters has been documented in a number of cases (Funge-Smith and Briggs, 1998; Tovar *et al.*, 2000; Islam *et al.*, 2004). Nutrient enrichment occurs when the nutrient input to the pond (in the form of feeds and fertilisers primarily) exceeds the rate at which the fish assimilate the nutrients (directly through feed or indirectly through fertilisers, via primary production in the pond). Therefore, when water exchange occurs, the nutrients are released into the surrounding water bodies and can cause excessive primary production.

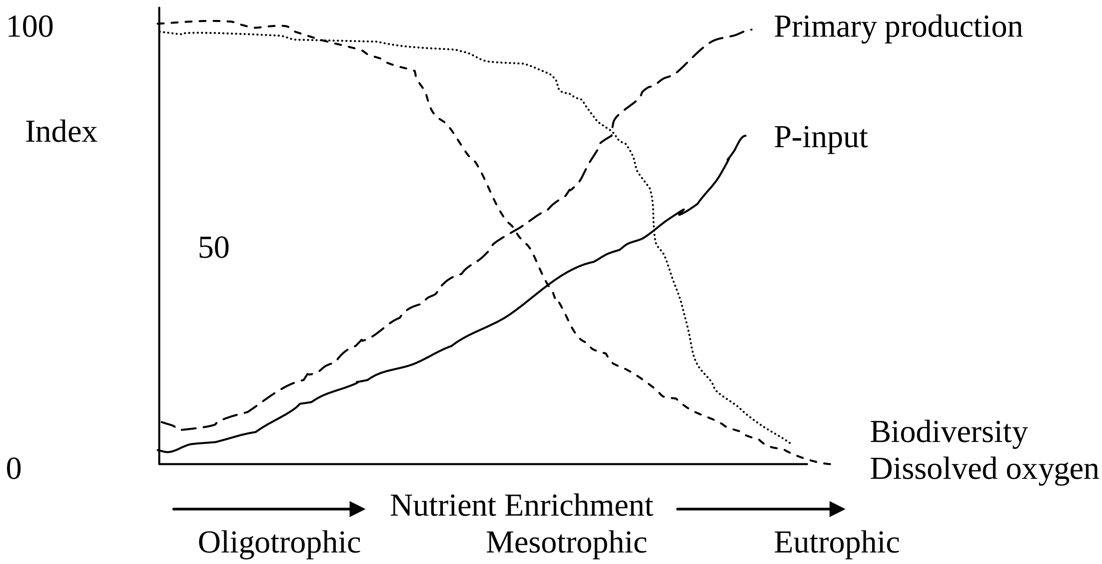
It is not easy to assess complete nutrient flows, particularly in low-data environments (Janssen, 1999). However, in an example of a complete nitrogen budget in aquaculture, Funge-Smith and Briggs (1998) analyse experimental pond systems for production of shrimp in Thailand. Their results show that in intensive shrimp ponds, the majority of the total nitrogen input (78%) to the farming system is introduced in the form of pelleted feed. Erosion of the pond bottom provides 16 per cent of N input, with negligible inputs from all other sources.

The composition of nitrogen outflows is more diverse. Nitrogen embodied in harvested shrimps accounts for only 18 percent of all outputs. The fate of the remaining nitogen produced by these systems can be summarized as follows: denitrification and ammonia volatilisation (30%); sedimentation (24%); loss to surrounding waters during water exchange (17%); and loss to surrounding waters during harvest drainage (10%). Nitrogen therefore becomes loaded in the effluent (27% of the total), which can potentially seriously enrich the receiving waters (Funge-Smith and Briggs, 1998). This conclusion seems relevant in the context of the study areas as it is supported by casual observation of local management practices. In particular, the "pulse" of effluent emission when the harvest takes place is well-known to fish farmers in the Philippines, who respond by avoiding as much as possible water exchanges in the days following a neighbours' harvest. Of course, we acknowledge that the farms in our sample do not operate at the same level of intensity as those investigated by Funge-Smith and Briggs, but they still have high levels of external inputs, which gives relevance to the study of nutrient flows presented later in this paper.

In an attempt to address the problems created by nutrient disequilibrium in aquaculture, new technologies have recently been developed. For instance, in a closed-recycling water system, intensive aquaculture can proceed without the daily water exchange that causes chronic environmental stress. However, in an experimental study (Thakur and Lin, 2003), the water drained from ponds (during harvest) of this kind still contained between 14 and 28 percent of total N input. The "pulse" effect of this emission to the environment remains a problem, although closed-recycling clearly delivers some environmental benefits and should help decrease inter-farm transmission of diseases.

We now turn to the evidence regarding the link between nutrient enrichment and environmental damage. Figure 2 illustrates the relationship between Phosphorus input and biodiversity that Merrington *et al*. (2002) established for freshwater systems. If, as suggested by the literature, this relationship is a general one that applies to brackish waters as well, it must have important consequences for the health of the ecosystems supporting the fish ponds in the Philippines.

Figure 2 – Relationship between nutrient enrichment, biodiversity, dissolved oxygen and primary production (redrawn from Merrington, Winder et al., 2002).



Ranges for the 3 states are as follows:

Oligotrophic – Total P<0.01 mg l^{-1}
Total N<0.2 mg l^{-1}
Hypolimnetic dissolved oxygen (% saturation) > 80
Phytoplankton production (g C $m^{-2}d^{-1}$) 7-25

Mesotrophic – Total P = 0.01 – 0.02 mg l^{-1}
Total N = 0.2 – 0.5 mg l^{-1}
Hypolimnetic dissolved oxygen (% saturation) =10-80
Phytoplankton production (g C $m^{-2}d^{-1}$) = 75-250

Eutrophic – Total P > 0.02 mg l^{-1}
Total N > 500 mg l^{-1}
Hypolimnetic dissolved oxygen (% saturation) <10
Phytoplankton production (g C $m^{-2}d^{-1}$) 350-700

The final externality generated by aquaculture relates to its use of pesticides, which represents a source of pollution to the surrounding waters with dramatic short-term consequences. The toxicity of sodium cyanide (a widely used piscicide) in particular represents a significant human health risk.

3.3.2.2 Endogenous to aquaculture
(i.e. fishpond to environment to fishpond)

Aquaculture is dependent on the coastal environment. In the language of systems ecology we can consider fishponds as open systems within the coastal ecosystem. What makes aquaculture such a unique natural resource system is that the success of individual fishponds is dependent on the conditions of the immediate natural environment (for clean, disease-free water with good oxygen content) as well as on the coastal environment at a higher spatial scale. At the level of the region, aquaculture is dependent on the creeks, rivers and lakes for supplying small shells to feed to the prawns. At the national level, the fishponds are reliant on the availability of broodstock for prawn and milkfish for hatching, both of which have the coastal environment as an important habitat in their life-cycle.

It follows that there are negative feedbacks to the fishponds that result from either over-intensification on individual farms or from too many fishponds being constructed. These may be immediate and dramatic such as when over-crowding of ponds in an area results in wide scale mortality from oxygen depletion or disease (Holmer *et al.*, 2003). That explains why the concept of carrying capacity is seen as a central component to planning for sustainable aquaculture (World Bank, 2002) but it is a concept that is very difficult to operationalise owing to large data requirements, as explained below.

Carrying capacity represents the maximum number of fishponds that could be supported by an ecosystem, in terms of the environmental support services provided by that ecosystem and the use of these services at any one time by the fishponds. When the carrying capacity is exceeded, there is an emergent environmental event such as a phytoplankton bloom (as occurred in Bolinao in February 2002 that led to a fish kill in over 500 fish cages in municipal waters - Siar, 2002) or a disease outbreak (as occurred frequently in the province of Negros in the mid-1990s, leading to the abandonment of numerous intensive prawn farms - Yap *et al.*, 2003). The difficulty is that carrying capacity is difficult to determine prior to an environmental event. Predictive work to this end is currently being undertaken (e.g. TROPECA project headed by John Hambrey).

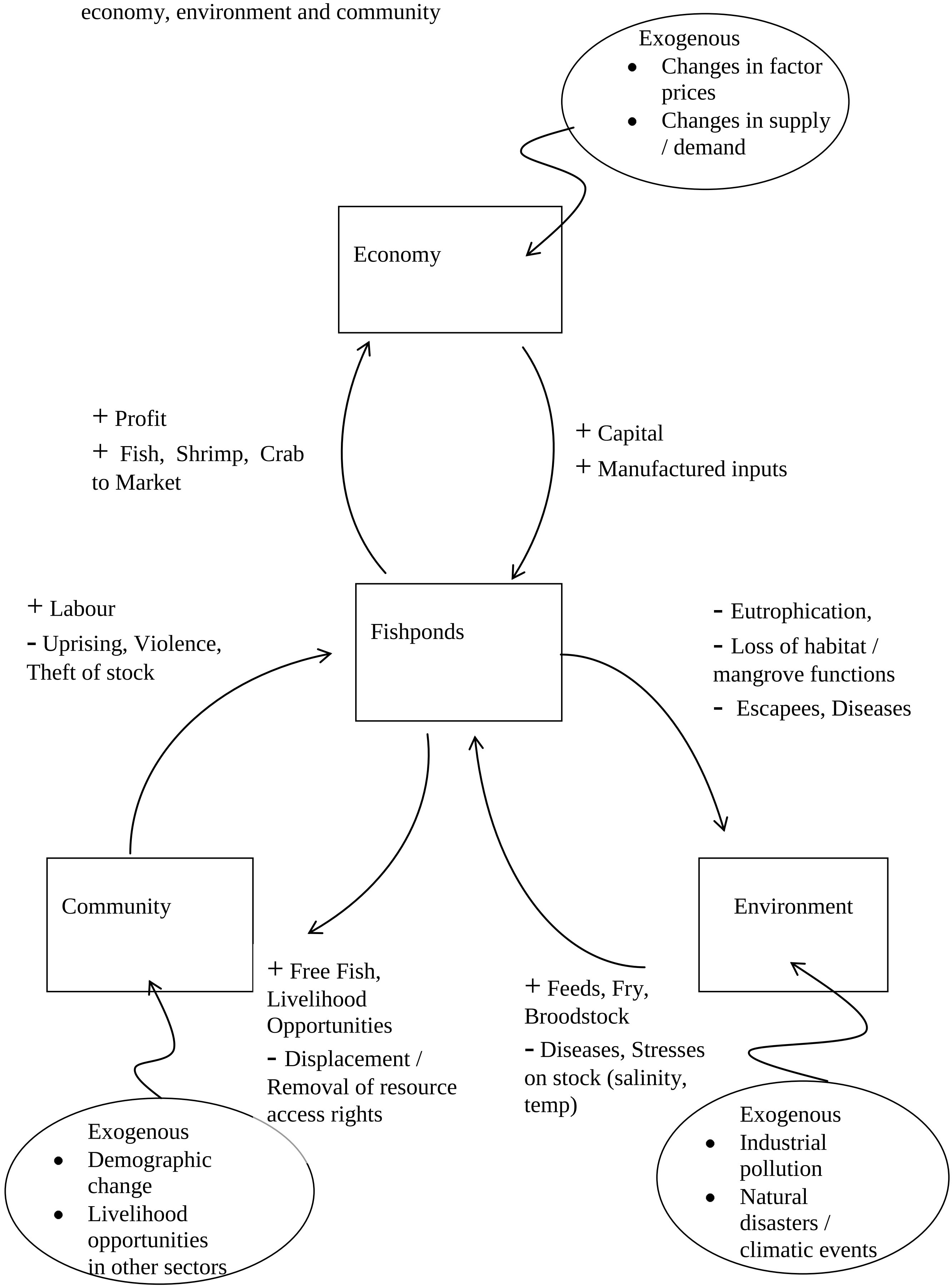
More long-term feedbacks are also undeniably present owing to the pressure put on the finite wild fishery on which aquaculture is dependent for inputs, by sometimes demanding more than the environment can supply (Ahmed *et al.*, 2001) and by indirect damage to the stocks of these fisheries. Indirect damage to the fishery may occur through: disruption to the life-cycle of wild prawn and milkfish through loss of coastal habitat – a habitat that is used for spawning and juvenile stages of both species (Bagarinao, 1994; Primavera, 1998); harvesting of wild fry for grow-out that reduces wild adult / juvenile populations as well as resulting in extremely high levels of by-catch (Ahmed *et al.*, 2001; Frankenberger, 2002); genetic interactions between wild and cultured stocks of the same or similar species, that may result in a loss of evolutionary fitness in the wild population through loss of adaptive traits (Xu, *et al.*, 2001); and through the introduction of non-native pathogens or escapee populations (Bartley *et al.*, 2000). As can be seen from this list there are a significant number of endogenous environmental problems with coastal aquaculture.

4. Issues of Scale

The multiple problems facing the aquaculture industry are manifest at different spatial scales: farm-level, regional, and national. The current study is both modest and ambitious. It is modest as it deals mostly with the farm-level effects of aquaculture, in recognition that the task of addressing multiple scales in analysis often entails complexity beyond our means (see Clayton and Radcliffe, 1996 and Giampietro, 2004 for examples of first attempts at multi-scale modelling for sustainability). However, this study remains ambitious in scope in that we attempt a degree of holism at the farm level by attempting to measure indicators of economic, ecological and social performance. The interactions between the farms and the economy, society and environment are outlined in figure 3. Fishponds exert pressure on the environment and cause undesirable social problems (marked with '-' signs) but have positive economic benefits and some social benefits (marked with '+' signs). The fishponds also rely on the economy, community and ecosystems for inputs.

Changes that are marked as exogenous in this scheme are not accounted for, and may change the opportunity costs and trade-offs in ways that are not taken into account in our model. However, the positive and negative interactions between economy, environment, community and the fishponds will now be analysed using indicators.

Figure 3 – Positive and negative relationships between fishponds and the regional economy, environment and community



5. Sustainability - Operationalising a utopian concept

The central concept employed in this paper is that the sustainability of a farming system is found in an appropriate balance between economic, ecological and social objectives. In this respect, we can consider a farming system that maximises economic performance, but with poor ecological and/or social performance, to be unsustainable. Conversely, a farm that achieves a sufficient level of performance across all three objectives can be thought of as sustainable.

In this regard, the concept of sustainability is fundamentally a rhetorical device, and one that a number of people are unwilling to lose from their vocabulary because, although it is used in a number of different ways, the term has a substantive and important meaning. In moving from the **rhetoric** of sustainability, to actually measuring its constituent elements (i.e. sustainability indicators), one has to pass through **theory**. In the case of the sustainability of aquaculture systems in the Philippines, the relevant literatures are those related to production economics, agroecology, socio-economics, and sociology.

Underlying these literatures are a number of principle normative ideas or concepts. That is, we can formulate maximisation or minimisation statements that, *ceteris paribus*, would be uncontroversial. Of course, the central point underlying our thesis is that the *ceteris paribus* clause in that statement doesn't usually apply – thus, there are trade-offs to be made among objectives, defined in part by the technology.

It then follows that the choice of indicators becomes a matter of choosing specific, measurable, units of account for these objectives. It is this process that we describe as the **operationalisation** of sustainability. As Pannell and Glenn state, criteria for choosing between indicators might be:

"High uncertainty about the level of the indicator to be monitored (desirable)
Low uncertainty about links between the indicator, management practices and production (highly desirable)
The indicator can be measured reliably and accurately (desirable)
Low cost of monitoring the indicator over the necessary scale (desirable)"
Pannell and Glenn (2000, p.148)

Thus, the principles governing the operationalisation phase of developing sustainability indicators is not one that is determined solely by theoretical or methodological dogma. Rather, it becomes a real-world problem, constrained by data availability, time and expertise, and with the intention of being outcome-oriented and influential over policy. Hence, the approach is primarily a pragmatic one.

Following this review, there are a number of objectives for which indicators are relevant, as discussed next.

5.1 Economic Objectives

For aquaculture to contribute to economic growth, it should give a sufficient return on investment in order to attract economy-wide resources, notably capital, into the sector. However, the variability of returns (i.e. the riskiness of the investment) is also important because agents are usually thought to be risk averse. Intuitively, variability of returns to investment in aquaculture allows for the possibility of bankruptcies, abandonment of ponds, and, ultimately, capital flight from the sector. In this context, it is reasonable to posit that, *ceteris paribus*, an aquaculture system should, **maximise profit**; and, with regards to the second idea, that, *ceteris paribus*, an aquaculture system should **minimise the risk** associated with investment, or at least be **resilient in the face of risks.**

The general principle of efficiency, (i.e. of minimising the throughput associated with production, that is, producing on the production possibility frontier), also finds validity in the sustainability concept. In particular, the principle of **maximising technical efficiency**, such that a given level of output is achieved with the minimum possible use of inputs[3], is important. It prevents waste of resources and allows for a higher level of profit than when systems are inefficient.

5.2 Socio-economic / Social Objectives

Given the aquatic resource-dependence of the economy in coastal areas of the Philippines, aquaculture is associated with social equity issues. Reducing poverty is always a central theme of government rhetoric and the link between aquaculture and poverty, explored further in paper 4, should therefore be a relevant area of study. Put simply, it is important to establish whether aquaculture benefits the poor.

In terms of livelihood benefits, in the ideal case poor people would be able to become operators, and a suitable objective would be to **maximise accessibility of the sector** to the poor. An alternative would be to **maximise the employment possibilities** generated by the sector. Further, given the importance of fish in the diet of nearly all Filipinos, an indirect benefit of aquaculture might be achieved by **maximising food security** objectives relating to the farming system.

5.3 Ecological Objectives

Brackish-water aquaculture is generally sited in the ecologically sensitive inter-tidal zone. The ponds appropriate aquatic natural resources (e.g. water, wild-harvested feeds, wild-caught broodstock for hatching to fry, wild-caught fry) and the coastal waters receive pollution in the form of effluent and undigested feeds from the ponds. *Ceteris paribus,* aquaculture should therefore aim to **minimise natural resource appropriation** and to **minimise pollution of receiving waters**.

The normative component to this statement cuts across time and spatial scales. There are intra-industry issues relating to externalities of production, with costs for environmental damage being passed from pond to pond; inter-industry issues relating to aquaculture's effects on the capture fisheries sector - a social equity concern, given the poverty of municipal fishermen; and long-term ecological issues regarding the loss of natural capital and its impacts on future generations.

We thus consider a number of objectives as representing components of sustainable aquaculture, as summarized in Table 3. Were these objectives to be studied in isolation, without data constraints, we might consider a particular approach as described in the 'ideal-world' column of the table. In a comparative study where all these objectives are measured for the same systems, and with limitations regarding data collection and availability, we consider a practical approach that generates information on each objective under these constraints, as described in the 'feasible' column of the table.

Table 3 – "Ideal-world" and "feasible" approaches to studying the objectives associated with sustainable aquaculture

Objective	Ideal-world	Feasible
Maximise profit	Full economic profit	Gross margin
Minimise risk	Variation in output over time (panel data)	Variation in output on similar farms (cross-section)
Maximise technical efficiency	Stochastic multi-output distance function	Stochastic frontier with single output (i.e. revenue)
Maximise food security	Dietary protein balance	Dietary protein balance
Maximise regional employment	Social accounting matrix or full input-output analysis	Employment multiplier analysis
Minimise coastal resource appropriation	Full ecological footprint with all primary data for inputs and outputs	Partial ecological footprint with some primary and some secondary data for inputs only
Minimise eutrophication potential	Full nutrient balance	Partial nutrient balance

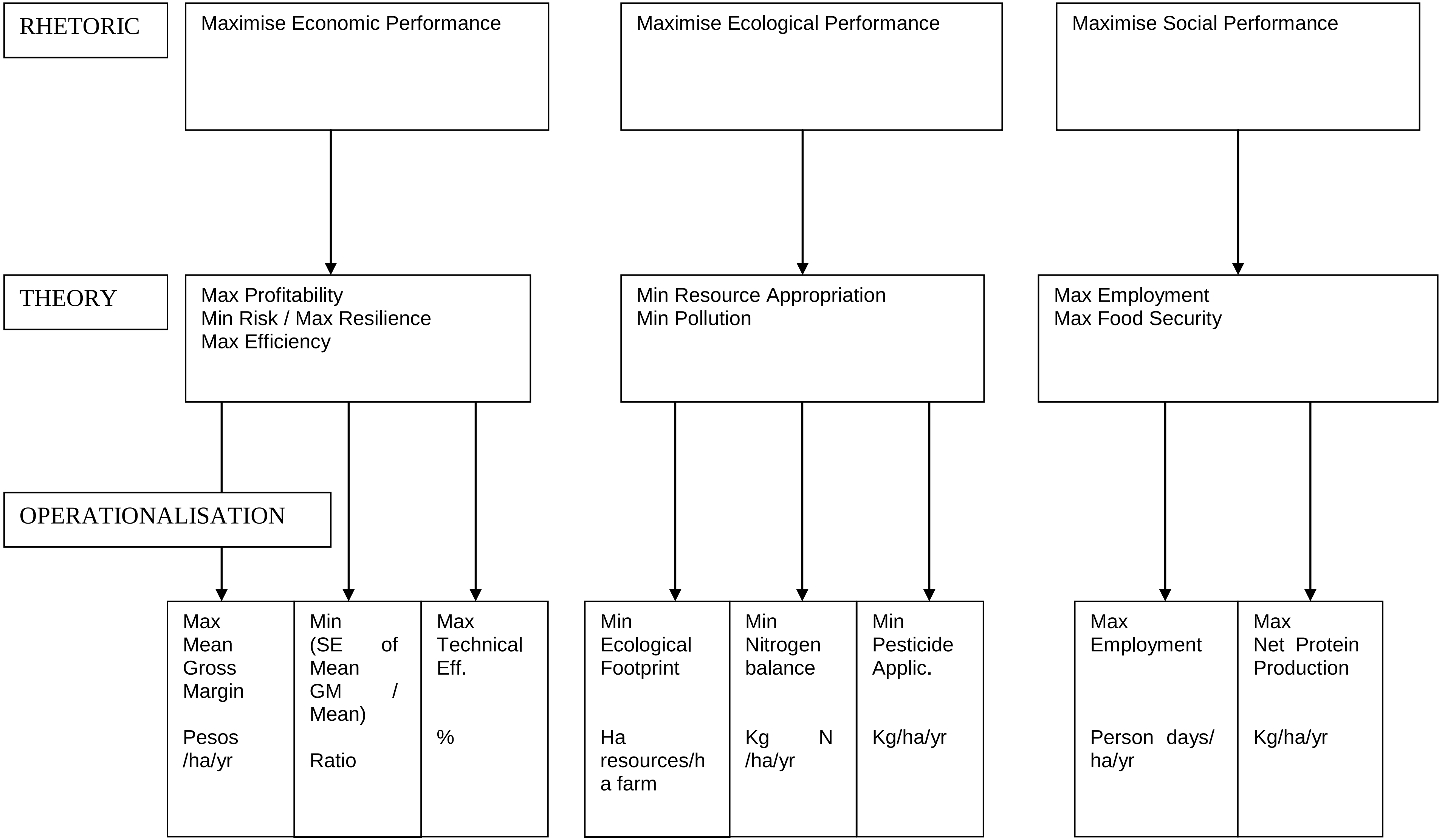
5.4 Sustainability Indicators

In light of the previous discussion, there follows a report of the ten selected sustainability indicators for brackish-water pond aquaculture systems in the Philippines. Each indicator is treated identically to cover:

- The rationale behind its choice
- The theory behind its definition and measurement
- The methods used to measure it
- The empirical results

The objects of the analysis are the five farm types that were described in the typology in paper 1. A diagram summarising this introduction is given in figure 4.

Figure 4 – Summary of the framework for sustainability indicators



6. Economic Indicators

In this section, we examine how the five farm types (extensive polyculture; semi-intensive prawn polyculture; labour-intensive low-input systems; large, extensive milkfish-oriented farms; and semi-intensive milkfish monoculture) differ according to three main measures of economic performance: profit; risk; and technical efficiency. Explanations for the results and their implications are then explored.

6.1 Profit

There are a number of definitions and measures of profit. Full economic profit would take into account all production factors, including land and family labour, while **gross margin** considers only the variable costs of production. Calculating full economic profit in our case would require much more comprehensive data than would be available from caretakers. Thus, either the sample would be restricted to those operators that live on the farm and are available for interview, or the sampling process would be significantly lengthened to incorporate visits to the homes or other businesses of absentee operators, solutions that were both deemed unsatisfactory. Besides, it is believed that gross margins best capture differences in production practices across farming systems. Formally, they are calculated using the following formula:

$$GM = (TR - C_{Feed} - C_{Fert} - C_{Seed} - C_{VarLab})/FS \qquad (1)$$

where GM is gross margin in PhP per hectare per year, *TR* is total revenue from all sales at mean prices for one year, C_{Feed} is the total cost of feeds in one year, C_{Fert} is the cost of fertilisers for one year, C_{Seed} is the cost of fry and fingerlings for one year, C_{VarLab} is the cost of seasonal or variable labour and *FS* is the farm size, expressed in hectares. We now review the components of the gross margin for each of the five farming systems under study.

6.1.1 Cost profiles

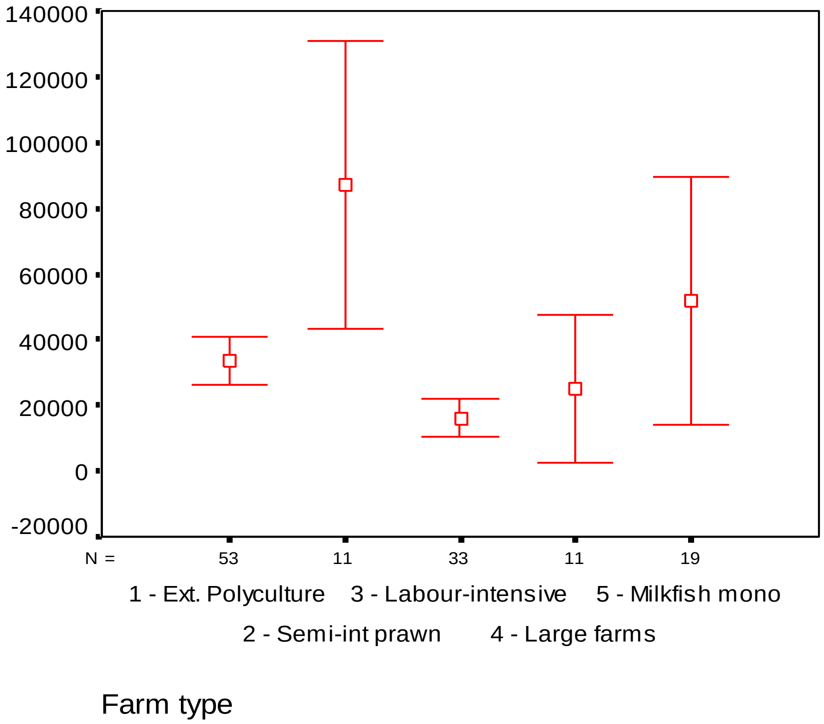
The absolute level of variable costs per unit area, shown in the final column of table 4 as well as in figure 5, vary greatly across farm types. As expected, the semi-intensive systems (types 2 and 5) have relatively higher variable costs than the other farm types. Looking at the composition of variable cost, it is also evident that there is a great deal of heterogeneity in the relative importance of inputs across farm types. However, focusing on the average values across all farm types (last row of table 4), it is evident that seeds represent a very important cost item, while feeds do not, which is indicative of the relatively low degree on intensity of the farming systems under study. Seeds account for a particularly large share of variable cost item in the case of both kinds of prawn production (types 1 and 2), which can be explained as follows. The low individual unit cost of fry (roughly PhP 0.1 per piece) is as a result of the fry often having been rejected by capital-intensive operators in other parts of the Philippines, or from the fry not having been tested for diseases at all. Given the informational problems in the transaction, fry prices are low, but survival is also extremely low. This implies that the effective cost of fry is high because operators, expecting high mortalities, stock at high densities to compensate.

The importance of feeds in variable costs varies greatly across farming systems, from a minimum of 4.4% for the low-input system (type 3) to almost a third for semi-intensive milkfish monoculture (type 4). Table 4 also reveals that aquaculture production is relatively labour intensive as hired workers account, across all farm types, for more than a third of total variable cost. Finally, fertiliser accounts for a small share of variable cost in all but the most milkfish-oriented systems (types 4 and 5), which make heavy use of imported inorganic fertilizers.

Table 4 – Total variable cost and its composition (by farm type)

Farm type	feed share (%)	fertiliser share (%)	seed share (%)	hired labour share (%)	TOTAL Variable costs (PhP/ha/yr)
1 - Extensive polyculture	11.2	6.7	49.2	32.8	33440
2 - Semi-intensive Prawn-oriented polyculture	27.0	2.4	54.3	16.3	87136
3 - Low-input, labour intensive	4.4	12.3	27.9	55.3	16103
4 - Large, milkfish oriented	14.5	26.4	25.8	33.3	25055
5 - Semi-intensive Milkfish monoculture	30.0	17.6	25.8	26.6	51536
All types	14.0	11.1	38.7	36.2	35567

Figure 5 – Mean variable costs by farm type (PhP/ha/yr)



6.1.2 Revenue shares

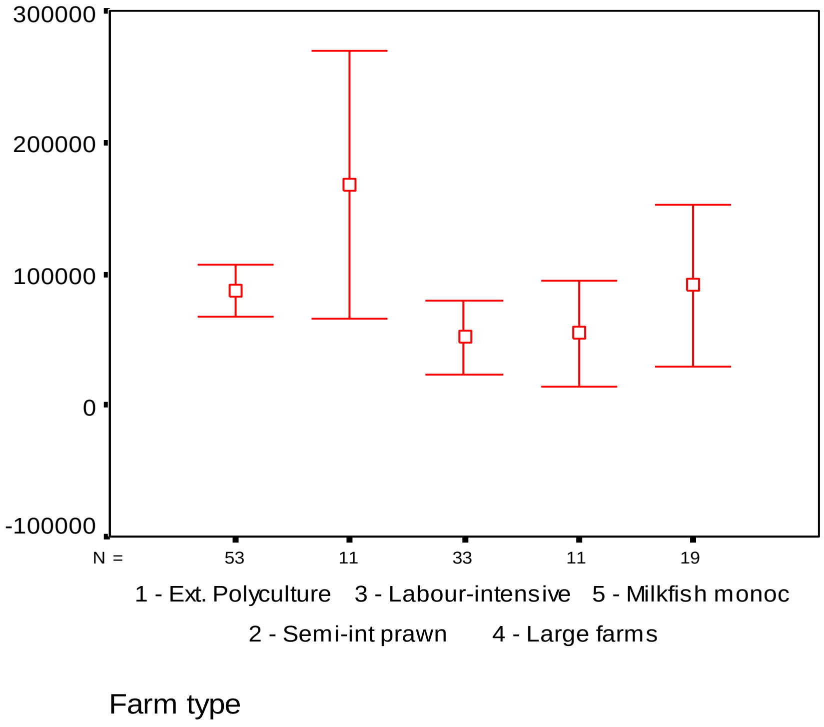
Revenue from aquaculture was calculated by using farm-level production and price data collected through a survey. During the survey, however, caretakers and operators could usually not state the "average" price achieved for each species in the last harvest, but were much more confident about the "highest" price and the "lowest" price achieved in that year. Therefore, we simply took the average of these two values when computing total revenue.

Table 5 reveals that the main species in terms of revenue are prawns for types 1 (extensive polyculture) and 2 (semi-intensive prawn-oriented polyculture), and milkfish for the others. Not surprisingly, overall revenue per unit area reflects the species orientation of each farming system as well as its degree of intensification. Semi-intensive prawn polyculture farms (type 2) have the highest (and most variable) revenue per unit area, with twice the revenue of extensive prawn farms (type 1) and semi-intensive milkfish monoculture (type 5). Low-input labour intensive farms (type 3) and large farms (type 4) have the lowest revenue per unit area. Analysis of the degree of revenue diversification across species is examined further in a later section, in the context of price risks.

Table 5 – Composition of total revenue by farm type

Farm type	Prawns	Milkfish	Crabs	Tilapia	TOTAL Revenue (PhP/ha/yr)
1 – Extensive polyculture	53.7	25.1	15.4	5.8	86854
2 – Semi-intensive prawn-oriented polyculture	57.0	14.6	22.6	5.8	168091
3 – Low-input, labour intensive	28.6	60.9	8.3	2.2	51430
4 – Large farms	20.0	79.3	0.0	0.7	55053
5 – Semi-intensive milkfish monoculture	0.0	90.0	3.7	6.4	90889
Mean	36.5	47.8	11.1	4.5	82535

Figure 6 – Mean revenue by farm type (PhP/ha/yr)



6.1.3 Mean gross margin by farm type

The gross margin, as defined previously, is a crude measure of profit, excluding payments made to credit, land rents, and the opportunity cost of family labour. However, it can be directly related to the factors that define farm "types" because of its link to inputs and associated production techniques. In economic terms, gross margins can be interpreted as the returns to land, family labour and other fixed farm assets. The distribution of gross margins for the sample is given in Figure 7 below, while Figure 8 presents a plot of the means by farm type. Clearly, farming systems integrating prawn production (types 1 and 2) are noticeably more profitable than the other farm types. Type 5 farms achieve intermediate gross margins, while types 3 and 4 stand out by their low levels of profitability. Further, Figure 8 indicates that the 95 percent confidence intervals of the mean are spread widely, most notably for type 2 farms. This intra-group variability will be discussed in the following section in relation to the concept of risk.

Figure 7 – Distribution of mean gross margin (PhP/ha/yr)

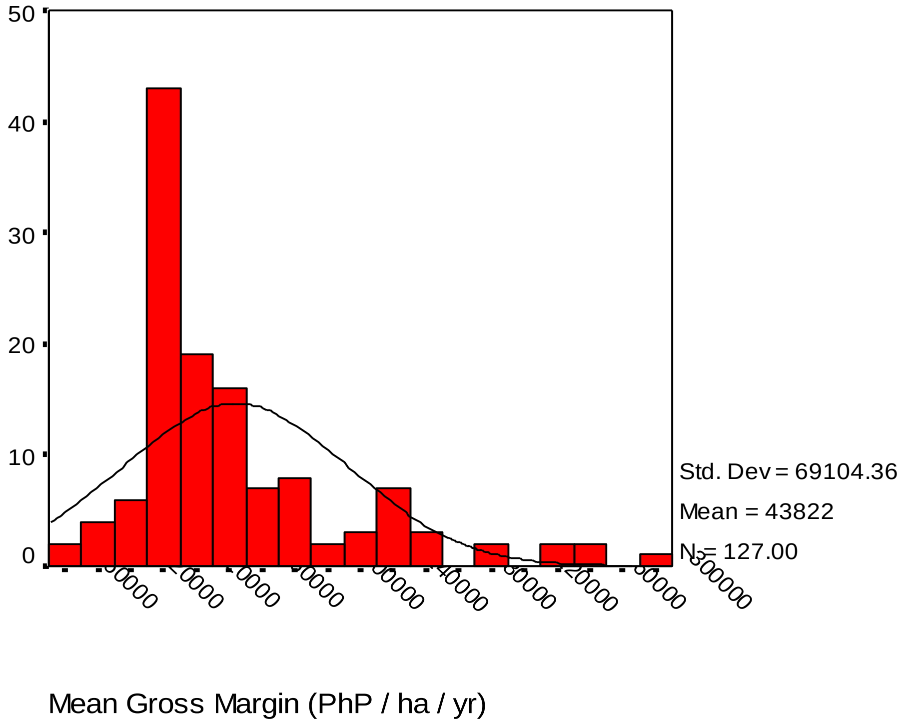
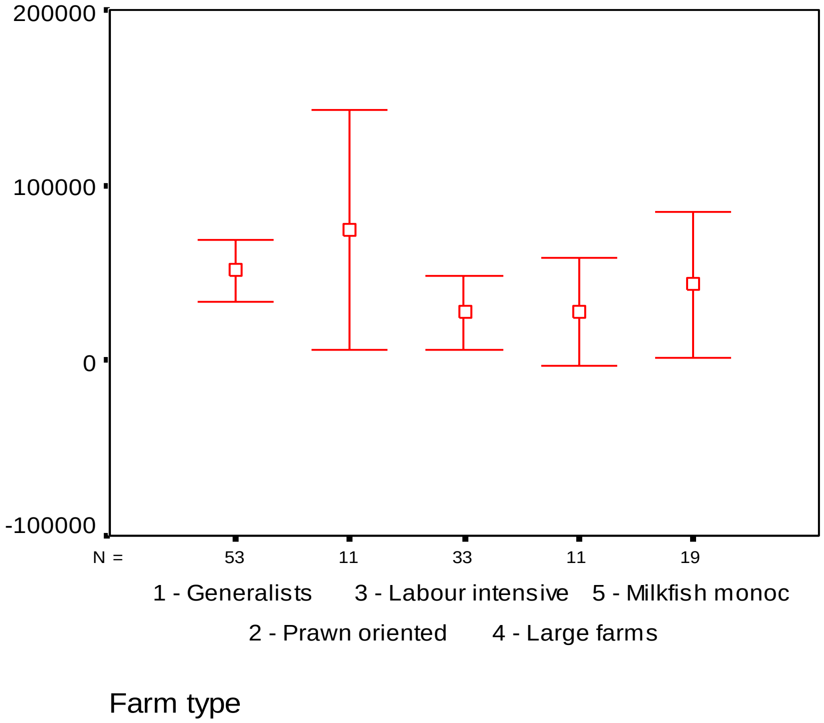


Figure 8 – Mean gross margin by farm type (PhP/ ha/yr)



6.2 Risk

6.2.1 Theory

Variation in output from a single farm over time is usually taken as a measure of the production risk (Just and Pope, 2001). However, time-series data are not available in our case so that a related measure of risk cannot be derived. There is some evidence from Figure 8 that the level of within-type variability (shown in the graph by the 95% confidence intervals of the mean) differs across farm types. We use this observation to define the ratio of the **standard error of the mean gross margin to the mean gross margin itself** as an indicator of overall risk for each farming system type. The underlying assumption is that variability in one growing year between farms of the same type gives us similar information to measuring trends over time on a single farm. It is therefore only a snapshot, and, unfortunately, the variability in gross margin may be attributable in part to farm-level characteristics that are not used in the typology exercise (e.g. farmer's experience), rather than the underlying risk profile of the techniques common to each farm type. The results for these calculations are given in the following section, followed by a decomposition into production risk and price risk.

6.2.2 Overall Risk – Results

Table 6 and Figure 8 (above) show that semi-intensive prawn-oriented polyculture (type 2) returns the highest mean gross margin, but with the highest level of risk. This stands in contrast to the situation for extensive polyculture (type 1), which returns the second highest mean gross margin but with the lowest level of risk. Hence, in this case, there exists a clear trade-off between overall profitability and riskiness of production systems, although that conclusion cannot be generalised to all five farming systems. Indeed, in terms of these two dimensions (profit and risk), farm types 3, 4 and 5 are 'Pareto dominated' by farm type 1. We now attempt to explain overall profit variability by dividing it into several sub-components.

Table 6 – Profit and risk indicators by farm type

Farm type	Average GM (pesos / ha /yr) PROFIT INDICATOR	N	Std. Error of Mean	SE Mean / Mean RISK INDICATOR
1	51220	53	8647	0.169
2	59065	12	32235	0.546
3	29769	35	10214	0.343
4	27845	11	13943	0.501
5	43252	19	19826	0.458
Average	43026	130		

6.2.3 Production Risk – Mortality by species and farm type

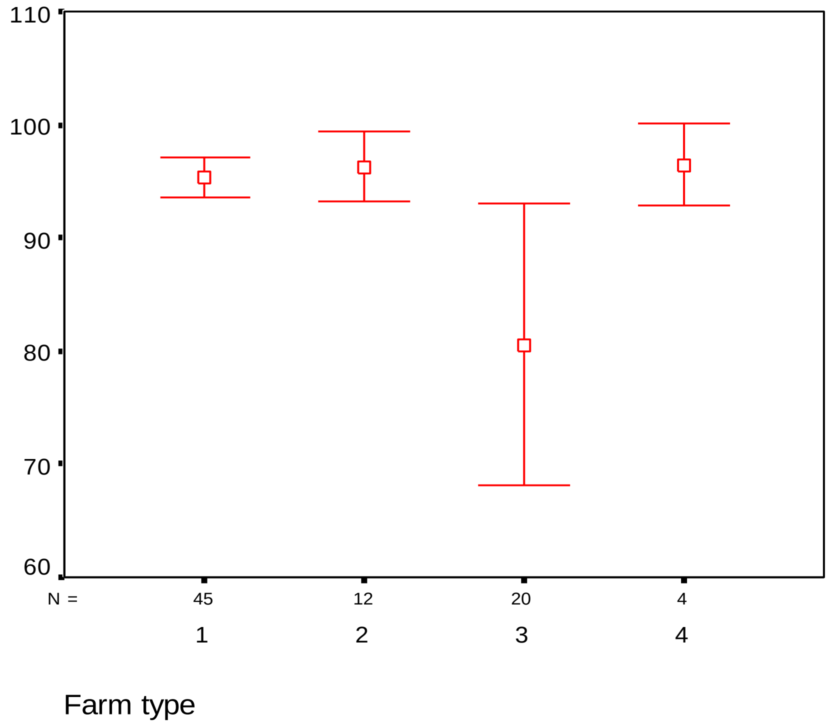
Comparing mortality rates in prawn production across farm types shows a surprising pattern (Table 7 and Figure 9). The small, labour-intensive, low-input system (farm type 3) displays a significantly lower rate of prawn mortality than the other farming systems that also stock prawns (types 1 and 2). This would suggest that a high use of labour per unit area can result in lower mortality rates, although the large standard deviations in Table 7 make this interpretation somewhat tentative. However, it is also intuitively appealing that a large input of supervisory labour should improve water and disease management.

That said, interpreting Table 7 in terms of the relative production riskiness of farming systems is not straightforward because the absolute levels of mortality rates might not be as informative as their variability from year to year. In this light, it may be that prawn production in extensive polyculture systems (type 1) is not considered risky in spite of extremely large mortality rates because operators simply expect one or two per cent survival of the prawn fry. If that is the case, then the low-input farming system can be characterised as being high risk, as indicated by the large standard deviation of the mortality rate (26.8). This could be explained by the fact that those farms lack access to risk-reducing inputs (apart from labour). The next section considers another source of risk associated with unanticipated variations in output prices.

Table 7 - Mortality rates by species and farm type

Farm type		Prawn (% mortality)	Milkfish (% mortality)	Tilapia (% mortality)	Crab (% mortality)
1	Mean	95.3	39.3	75.5	54.1
	N	45	45	18	28
	Std. Deviation	6.1	35.0	24.0	20.3
2	Mean	96.3	43.0	90.6	55.7
	N	12	9	2	8
	Std. Deviation	4.9	34.2	9.0	17.5
3	Mean	80.6	39.9	95.0	61.6
	N	20	31	1	8
	Std. Deviation	26.8	30.9		18.8
4	Mean	96.4	42.0	48.8	
	N	4	10	1	
	Std. Deviation	2.2	27.8		
5	Mean		40.8	49.5	20.0
	N		18	1	1
	Std. Deviation		32.6		
Total	Mean	91.8	40.2	75.4	55.0
	N	81	113	23	45
	Std. Deviation	15.4	32.3	23.4	19.9

Figure 9 – Mortality rates of prawns by farm type (%)



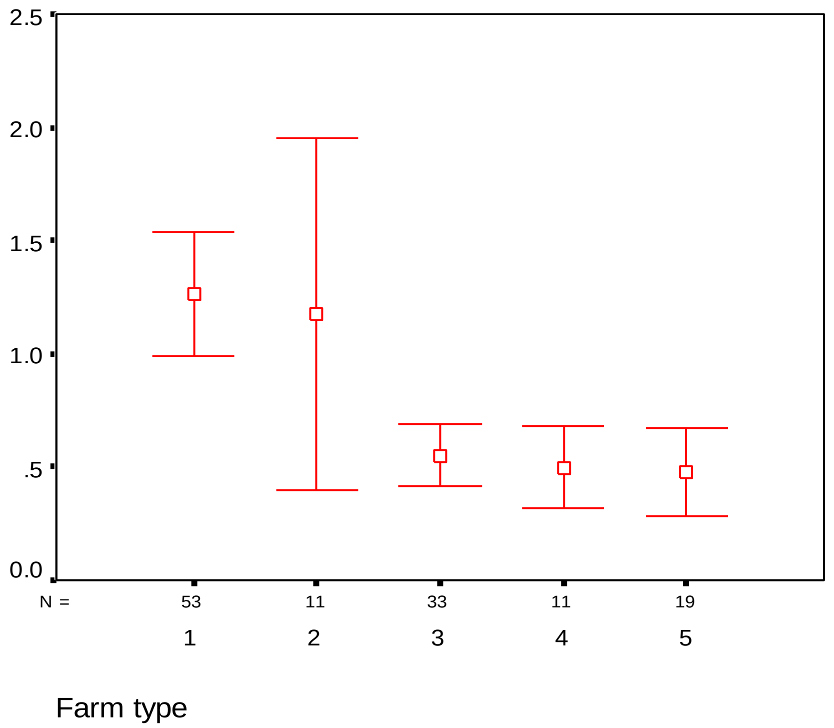
6.2.4 Price Risk

We define a measure of price risk for a particular farm type using the following formula:

$$\text{Price risk} = (TR_{MHP} - TR_{MLP}) / TR_{MLP} \qquad (2)$$

where TR is total revenue, and the subscripts MHP and MLP refer to Mean High Price and Mean Low Price respectively. MHP (MLP) is the mean of the highest (lowest) prices achieved in the year of study across all farms of a given type. Prawns and crabs, while being the high value species, are also the most variable in price. This is explained by volatility in the export market for prawns, as well as seasonality in the domestic demand for crabs, a luxury food consumed primarily during festivals and holidays. One could argue that as long as these price variations are anticipated, they do not generate risk. However, while the seasonality in domestic demand can be predicted to some extent (prices rise at Easter and Christmas), the random component to export markets for prawns is more difficult to predict. In order to pursue the analysis of price risk further, the price risk index defined above is calculated for each farm type and reported in Table 8 and Figure 10.

Figure 10 – Price risk index by farm type



We observe that farm types 1 and 2, which have a strong orientation towards prawn production, face the highest level of price risk. Rather surprisingly, the pattern across farm types in Figure 10 shares a great deal of similarity with that of the index of revenue diversity, detailed in paper 1 (section 5.5.1), and also reported in Table 8. In particular, we note that farm types 1 and 2 have diverse revenue sources, whereas types 3, 4 and 5 are more reliant on a single crop - milkfish. Further, Table 9 establishes that the differences between farms 1 and 2 in comparison with types 3, 4 and 5 are statistically significant. Hence, the mean score for equitability for farm types 1 and 2 are not significantly different from each other but are statistically different from the other farm types at the ten percent level. The mean of the price risk index follows a roughly similar pattern, although the high value of the standard error for the mean for farm type 2 results in low statistical power of the test.

The finding that relatively more specialised farming systems are exposed to less risk may seem counter-intuitive because diversification across enterprises is usually presented as a mechanism for reducing risk (Zenger and Schurle, 1981; Bhende and Venkataram, 1994). However, in the case where one enterprise is significantly more risky than others, the degree of risk simply reflects the importance of that enterprise in the production plan of the farm. Thus, operators producing prawns in combination will always face greater price risks than operators producing only milkfish. This interpretation is confirmed by the absence of prawn monoculture in the study area, probably because prawn production is simply too risky.

Table 8 – Revenue diversity and price risk by farm type

	Equitability (H') - REVENUE DIVERSITY INDICATOR	PRICE RISK INDICATOR
1 – Generalists	0.397	1.263
2 – Prawn-oriented	0.449	1.173
3 – Low-input, labour intensive	0.218	0.549
4 – Large farms	0.138	0.499
5 – Milkfish monoculture	0.043	0.478
Mean	0.280	0.886

Table 9 – Comparison of the mean level of equitability and price risk index using ANOVA and Scheffe's post-hoc test.

Dependent Variable	(I) Farm type	(J) Farm type	Mean Difference (I-J)	Std. Error	Sig.
Equitability	1	2	-0.052	0.073	0.974
		3	0.179	0.050	0.015
		4	0.259	0.076	0.024
		5	0.355	0.061	0.000
	2	1	0.052	0.073	0.974
		3	0.231	0.077	0.066
		4	0.311	0.096	0.037
		5	0.406	0.085	0.000
Price risk	1	2	0.090	0.259	0.998
		3	0.714	0.173	0.003
		4	0.765	0.259	0.075
		5	0.785	0.209	0.009
	2	1	-0.090	0.259	0.998
		3	0.624	0.272	0.268
		4	0.675	0.333	0.398
		5	0.695	0.296	0.246

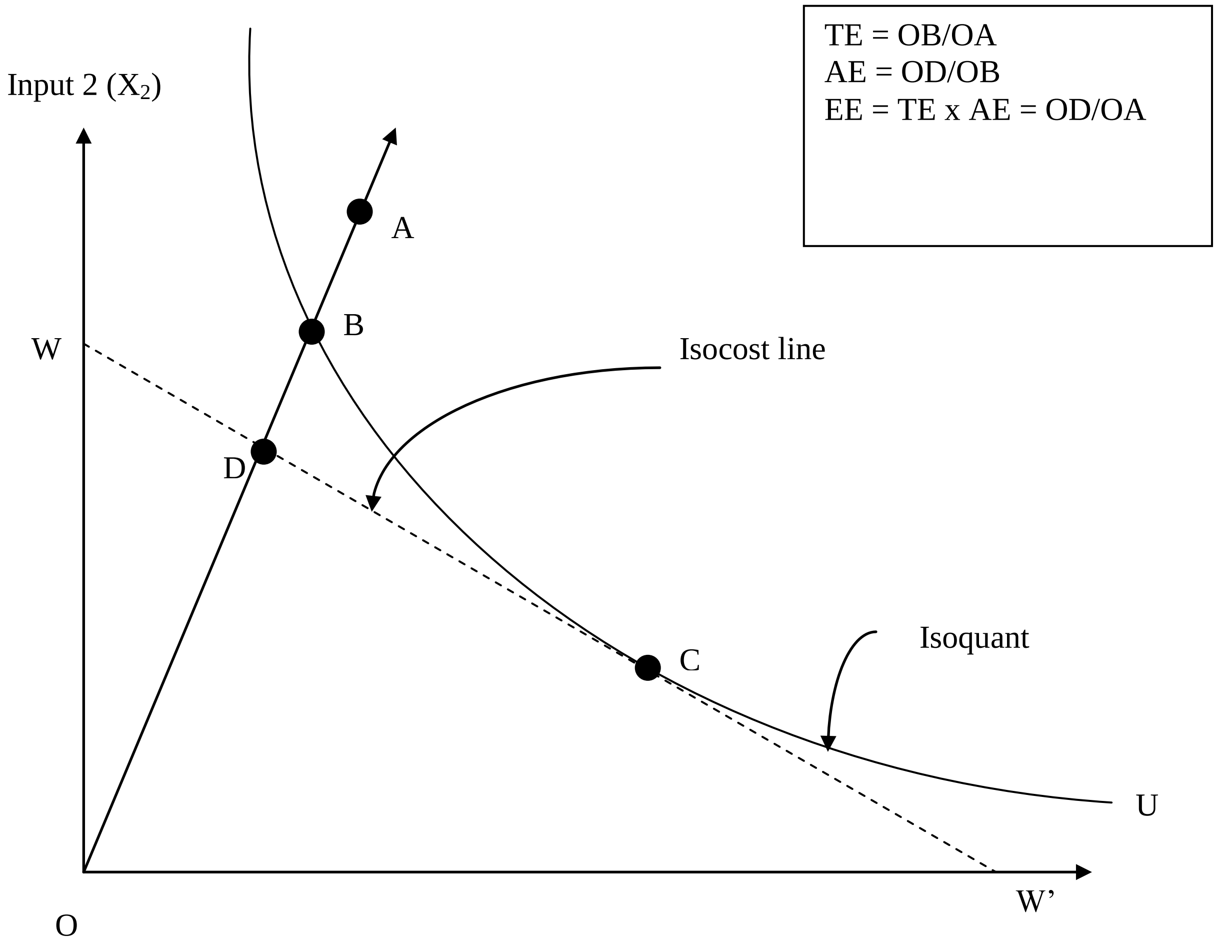
6.3 Technical efficiency and its determinants

6.3.1 Rationale

As Kumbhakar and Lovell (2003) note, not all producers are successful in solving the optimisation problems that underlie microeconomic theory. In particular, all producers do not succeed in utilising the minimum inputs required to produce the output levels that they choose, given the technology at their disposal, and, as a result, they exhibit some degree of technical inefficiency. Further even technically efficient producers may not succeed in allocating inputs in a cost-effective manner, in which case they are allocatively inefficient. Finally, allocative inefficiency can also occur if producers choose output combinations that do not maximise revenue. These various sources of inefficiency represent formidable informational and managerial challenges for fishpond operators, and, in this regard, assuming profit maximisation might seem somewhat heroic. Here, we limit ourselves to the analysis of technical efficiency because it requires the weakest behavioural assumption in a context where it is likely that producers pursue complex livelihoods strategies.

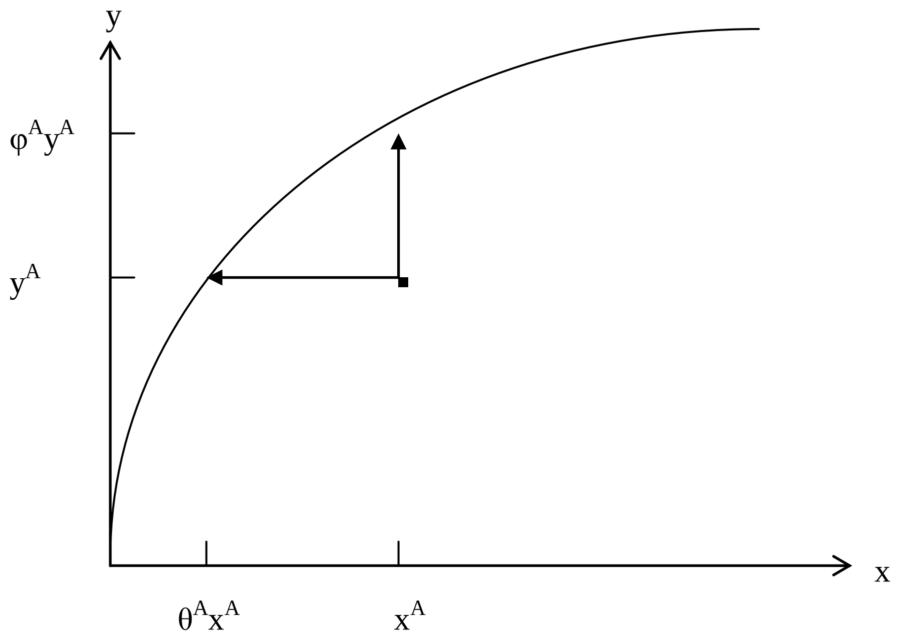
More formally, technical efficiency (TE) is defined as the ability of a firm to produce on the frontier isoquant (Farrell, 1957), as is the case for points B and C in Figure 11. Perhaps more intuitively, with an output orientation, technical efficiency corresponds to the ability to achieve maximum possible output from a given set of inputs; or, with an input orientation, to the ability to use least inputs to achieve a given level of output. Farrell showed how overall economic efficiency is the product of technical efficiency and allocative efficiency, where input-orientated allocative efficiency is defined as the ability to produce at a given level of output using the cost-minimising input ratios (Bravo-Ureta and Pinheiro, 1997). Technical inefficiency therefore defines the extent to which producers fail to produce on the frontier isoquant whereas allocative inefficiency relates to the extent to which producers do not choose the combination of inputs that would minimise their costs, or the combination of outputs that would maximise their revenue (in an output-based approach). Although efficiency analysis does not make any assumption regarding substitutability among inputs, it becomes rather meaningless if producers are unable to modify input proportions, in which case allocative efficiency is always achieved.

Figure 11 – A graphical illustration of different efficiency concepts. Technical efficiency is defined by the ratio OB/OA; allocative efficiency is defined by OD/OB; and overall economic efficiency is the product of these two ratios OD/OA. Adapted from Sharma and Leung (2003).



Alternatively, technical efficiency can be measured by the distance to a best production frontier rather than by distance to an isoquant as illustrated in figure 12 below.

Figure 12 – Production frontier approach to technical efficiency estimation (after Kumbhakar and Lovell, 2003, p. 47).



The production frontier f(x) illustrates the technically efficient relationship between an input (x) and a single output (y). A producer using x^A to produce y^A is technically inefficient as it operates beneath the frontier f(x). In an input-oriented approach, $TE(y^A,x^A)$ measures the maximum contraction of x^A that enables continued production of a level of output (i.e. y^A), where $TE(y^A,x^A) = \theta^A < 1$. In an output oriented approach, $TE(x^A,y^A)$ measures the reciprocal of the maximum expansion of y^A that is possible using x^A inputs, and $TE(x^A,y^A)=(\varphi^A)^{-1}<1$ (Kumbhakar and Lovell, 2003).

There are two families of approaches to the estimation of technical efficiency – parametric and non-parametric. In parametric approaches, a functional form for the technology is assumed (e.g. Cobb-Douglas). However, it is possible to introduce a stochastic term such that deviations below the frontier can be decomposed into random errors and technical inefficiency. In non-parametric approaches, no functional form for the technology is assumed but all deviations are assumed to be attributable to technical inefficiency. This latter assumption is particularly problematic for agriculture and aquaculture owing to the numerous weather, environmental and ecological effects that can influence production, and thus parametric approaches, such as the stochastic frontier production function method discussed in the next section, tend to be favoured over non-parametric approaches (such as data envelopment analysis – DEA).

Before developing the theory underlying efficiency measurement, it is worth emphasising the central importance of technical efficiency in a development strategy for aquaculture, as argued by Bravo-Ureta and Pinheiro (1997, p. 49):

> *"Many researchers and policymakers have focused their attention on the impact that the adoption of new technologies can have on increasing farm productivity and income (Hayami and Ruttan 1985; Kuznets 1966; Schultz 1964; Seligson 1982). However…. major technological gains stemming from the green revolution seem to have been largely exhausted across the developing world. This suggests that attention to productivity gains arising from a more efficient use of existing technology is justified* (Bravo-Ureta and Pinheiro 1993; Squires and Tabor 1991)*."*

In the case of aquaculture, new technologies, such as fry hatcheries (in particular for prawns), and the development of commercial feed pellets with optimal combinations of nutrients for growing fish, have shifted the production frontier up and to the left. However, these changes have occurred at a very fast rate, as they did with the Green Revolution. As a result, institutional innovations such as environmental regulation, land reform, and government extension provision, which would have allowed aquaculture to adjust to changes in the technical arena more comfortably, did not occur fast enough. Therefore, a number of questions remain regarding how well the sector has adapted to technical innovation. Diagnosing the extent of technical inefficiencies in the sector and examining their determinants is a useful tool in addressing some of these questions.

6.3.2 Stochastic production frontier models – General theory

The measurement of technical efficiency across all farms in the sample is based on their distance to a single stochastic production frontier that characterises "current best practice" in the sample. This kind of parametric methodology is now dominant in the production economics literature, owing to the problems of noisy data that make DEA less attractive.

In the original framework developed by Farrell (1957) and extended by Kopp (1981), we first consider a deterministic production frontier given by:

$$Y_i = f(X_i\,;\,\beta) - u_i \qquad (2)$$

where Y_i is the maximum achievable output of the i^{th} farm, X_i is the input vector that it uses, and β is a vector of unknown parameters. This deterministic approach suffers from the limiting assumption that all deviations from the frontier are attributed to technical inefficiency. However, efficiency measures obtained from these models are affected by statistical noise (Schmidt, 1985-86). As a way of addressing this problem, a stochastic production frontier can be rewritten as:

$$Y_i = f(X_i\,;\,\beta) + \varepsilon \qquad (3)$$

where ε is a "composed" error term (Aigner *et al.*, 1977) which can be written as:

$$\varepsilon_i = v_i - u_i \qquad (4)$$

The term v_i is a two-sided $(-\infty < v < \infty)$ normally distributed random error that, it is assumed, captures exogenous factors outside of the control of the producer. These might include weather shocks, natural disasters and good luck. It should be noted in passing that the suitability of this specification for aquaculture (of prawns in particular) has been questioned (Brennan *et al.*, 2000), given the number of downward shocks that can be experienced (e.g. disease, flooding, water pollution) compared to the possibility for beneficial stochastic events (i.e. good luck).

The term u_i is a one-sided ($u \geq 0$) random component that captures the technical inefficiency of the farmer. This is essentially the distance (i.e. the shortfall in output) of a given farm below the stochastic frontier given by $f(X_i ; \beta) + v_i$. The distribution of u can take several forms, including the half normal, truncated normal, exponential and gamma distributions. In what follows, we use the model developed by Battese and Coelli (1995), which assumes that the inefficiency term is a normal random variable $N(m_i ; \sigma_u^2)$ truncated at zero, where $m_i = z_i\delta$ and z_i is a vector of firm-specific variables which may influence the firms' efficiency

The most commonly used method for estimating stochastic production frontiers is maximum likelihood (Battese and Coelli, 1995; Coelli *et al*. 1998), which can easily be carried out using the program FRONTIER 4.1 (Coelli, 1996). The software operates the numerical maximisation of the likelihood function that is expressed in terms of two variance parameters $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$ (Battese and Corra, 1977). It is clear that parameter γ lies between zero and unit, with zero values indicating that deviations from the frontier are due entirely to noise, while values of one indicate that all deviations are due to technical inefficiencies. FRONTIER also predicts individual farm technical efficiencies by using the expression of the expected value of u_j conditional on the estimated value of ε_j, as first established by Jondrow et al. (1982).

6.3.3 Stochastic production frontier models – Previous applications to aquaculture

Applications of stochastic frontier production models were late to emerge in the aquaculture literature in comparison to agricultural economics. This initial lack of frontier studies in aquaculture can be attributed to the inherent bio-economic complexity in these systems, and the concomitant problems of obtaining appropriate production data (Sharma and Leung, 1998). However, after this slow start, there is currently a burgeoning literature on efficiency measurement in aquaculture which is summarized by Sharma and Leung (2003). The problems of bio-economic complexity remain, but it would seem that authors have perhaps become braver in asserting the assumptions necessary to carry out the analysis.

Sharma and Leung (1998) and Sharma (1999) present applications to carp polyculture systems in Nepal and Pakistan respectively. Owing to the similarities in value of the various carp species, these papers use fish production per unit area (kg / carps / ha) with all factor inputs also expressed per unit area. The overall level of technical efficiency in Nepal was 77 percent, with intensive farms more efficient that extensive farms. Lower estimates were derived for Pakistan, but the pattern of semi-intensive/intensive systems having higher technical efficiency than extensive systems held (67 percent for semi-intensive/intensive farms, versus 56 percent for extensive farms).

In terms of the technical efficiency effects investigated in the model, both papers specify three simple indices related to fish management, water management and feed management. These indices take a value between zero (no recommended management practices used in that area) and unity (all of the recommended management practices are used), with decimal values representing intermediate cases where some practices are employed and others are not. These indices, while crude, establish a clear link between the model and actual production practices and, hence, can help generate useful insights for, among others, extensionists..

With data from Nepal (Sharma and Leung, 1998), the t-ratios for the slope coefficients of these indices were insignificant individually under maximum likelihood estimation. However, under generalised likelihood ratio tests, both production intensity and the grouped indices for these regular management practices had a significant and positive effect on technical efficiency. With Pakistani data (Sharma, 1999), the water and feed management indices had significant and positive effects on technical efficiency for both semi-intensive/intensive and extensive production systems. Neither study finds a significant relationship between farm size and technical efficiency. Altogether, those two studies demonstrate that fish farmers often do not use the available technology in a technically optimal way, and that inefficiencies relate to a large extent from the failure of adopting recommended production practices.

In another context, Dey *et al.* (2000) analysed technical efficiency in freshwater tilapia aquaculture in the Philippines and reached very different conclusions. They found that experience and farm size both had a significant, positive effect on technical efficiency and that the overall level of technical efficiency in their sample was high (mean TE = 83%). On the basis of these findings, the authors recommend the introduction of new technologies to raise productivity, owing to the nearly fully technically efficient exploitation of the current technology. It should be noted that freshwater tilapia pond farming is a relatively new activity and tilapia is an exotic species to the Philippines. Culture techniques do not appear to differ from farm to farm as much as in brackish water ponds. There is also virtually no polyculture in fresh-water systems in the Philippines.

With regards to the species of interest in this study, two recent papers are particularly relevant. Irz and McKenzie (2003) compare the technical efficiency of intensive freshwater tilapia production systems with extensive brackish-water polyculture in Pampanga, Philippines. They find that technical efficiency in the brackish-water systems is low (53% on average), whereas the technical efficiency in intensive tilapia production is high (83% on average). From these results, the authors conclude that extension services for brackish-water systems would be a cost-effective way of increasing productivity, but, in accord with Dey *et al.* (2000), that technological change would be required to raise productivity in freshwater systems. These findings may provide helpful insights to the government agencies in the Philippines in their effort to coordinate research and development activities for aquaculture.

Chiang *et al.* (2004) analyse technical efficiency in milkfish production in Taiwan. Their study presents methodological problems associated with polyculture systems and these authors prefer to define output only as milkfish yield, leaving aside other productions, rather than aggregating across species. This is surely an unsatisfactory assumption as secondary species can represent an important percentage of the total yield – up to 40 per cent of total revenue in the case of farms in their sample.

The literature on technical efficiency in aquaculture has yet to see its potential realised, in terms of use in informing policy and improving management. The models presented in the literature thus far have mostly not laid out explicit mechanisms through which a (in some cases) low level of technical efficiency can be related to specific failures at policy or farm-management level. In addition, the econometrics behind the method makes the results difficult to communicate to policy-makers.

6.3.4 Model specification

We choose the translog functional form for the parametric represention of the production technology. Output is given by total annual revenue from aquaculture because alternatives, such as total weight of production or total revenue in average prices, are inappropriate. The difference in the nature of the four possible outputs makes summing them by weight meaningless, and substituting individual prices for average prices would not reflect any premium that the operator would achieve from producing higher quality products (e.g. prawns of an individual size large enough to be exported, larger milkfish for fillets etc).

Five inputs are used in the analysis: X_1 is land area of the farm in hectares, X_2 is labour in person-days per year, X_3 is feeds cost per year (in PhP), X_4 is fertilisers cost per year (in PhP), and X_5 is fry and fingerlings cost per year (in PhP). Data is taken for one year in a cross-section of 127 farms. To ease interpretation of the estimated parameters, each logged variable is mean-centred prior to estimation to ensure that the output elasticities at the sample mean are simply equal to the first-order coefficients.

We use the model of Battese and Coelli (1995) because it allows for the simultaneous estimation of technical efficiency levels and their determinants. Further, the appropriateness of alternative specifications can easily be investigated in this framework by carrying out a likelihood ratio test. The test compares a null hypothesis for restrictions on parameters (H_0) against an unrestricted alternative (H_1), based on the following ρ statistic:

$$\rho = -2\{L(H_0) - L(H_1)\} \quad (5)$$

where L(.) denotes the value of the log-likelihood function. The test statistic is then compared to a critical value obtained from a chi-squared distribution. This procedure makes it easy to test, for instance, the hypothesized influence of a number of farm-specific variables on technical (in)efficiency, or whether the technology exhibits increasing, constant, or decreasing returns to scale.

We initially consider three model specifications. Model 1 does not allow for technical inefficiencies by imposing the parametric restriction $\gamma = 0$. In this context, all deviations from the frontier are due to statistical noise and the frontier reduces to the average response function which is estimated by ordinary least squares (OLS). Model 2 allows for inefficiencies, but assumes that those are not explained by farm-specific variables (or technical efficiency effects). This second specification is referred to as the error components model. Model 3 adopts the most general specification, which allows for inefficiencies and introduces 15 technical efficiency effects ($\delta_{1\text{-}15}$) for which data are available. These relate to technical, managerial and socio-economic characteristics of the farm and are all dummy variables, taking the value one when a particular technique is used or when a particular management structure is in force, and zero otherwise. In addition, there are dummy variables for each of the farm types from the typology[4] and a regional dummy variable to allow for differences in natural resource endowment. Finally, a dummy variable is introduced that takes the value one when the operator reported an exogenous shock to their farming system. This follows from the critique of Brennan (2000) regarding the one-sided, downwards nature of the shocks experienced by prawn aquaculture, in conflict with the assumed normal distribution of the *v* term in the error that is introduced with the aim of capturing stochasticity. A preferred specification is now selected based on the results of likely-hood ratio tests.

Table 10 – Values of the log-likelihood function of alternative specifications

	MODEL 1 – No inefficiencies (ols regression)	MODEL 2 – Error components	MODEL 3 – Technical efficiency effects
Log-likelihood function	-157.43	-139.99	-126.40

Model 1 (H_0) vs Model 3 (H_1). The calculated value of the test statistic is $\rho = 62.06$, which is compared to a critical value of 40.11, itself derived from a mixed chi-squared distribution[5] at α=0.001 with 17 restrictions (i.e. $\gamma=\delta_0=\delta_1= \delta_2 \ldots \delta_{15}=0$). In this case, the null hypothesis of absence of inefficiencies is strongly rejected, and the analysis supports the view that many producers are not using the available technology in a technically optimal manner.

Model 2 (H_0) vs Model 3 (H_1). The test statistic $\rho = 27.18$ is compared to a critical value of 25.00 for the chi-squared distribution at $\alpha = 0.05$ with 15 restrictions (i.e. $\delta_1=\delta_2\ldots\delta_{15}=0$). Here again, the null hypothesis is rejected, implying that the farm-specific variables introduced in the model have some power in explaining inefficiencies..

Finally, a similar procedure was carried out to determine the appropriate functional form of the production function. More specifically, the trans-log specification was tested again the Cobb-Douglas by setting the final 15 cross-product terms equal to zero. This null hypothesis was again rejected. We therefore conclude from this series of tests that the full translog stochastic frontier with technical efficiency effects is the most appropriate specification of the model. The results derived from this preferred specification are now analysed.

6.3.5 Estimation Results

The coefficients in the production function, reported in Table 11, are somewhat disappointing with regards to expectations held *ex-ante*. Only feeds and fry return statistically significant and positive output elasticities. The results indicate that fry is the more important input, which is consistent with the extensive nature of the production process – mean output is therefore most constrained by a lack of fry input to the system. The output elasticities for land and fertilizers are positive, as would be expected, but also statistically insignificant. The most puzzling result is for labour input, which returns a negative output elasticity, although with a low degree of statistical significance.

However, there are a number of important factors to consider before dismissing these results as inappropriately representing the technology. Of course, we might expect labour input for activities such as monitoring the stock and ensuring optimal feeding patterns to be productive. However, these types of labour use are responsible for only a small percentage of the total labour demand in aquaculture. The majority of the labour input is used for maintenance of the dykes, harvesting the fish, and removing weeds from the pond – all important activities that are, however, not directly related to output. These activities are carried out with the aim of avoiding negative consequences, or what is referred to in the agricultural literature as 'damage control'. It is therefore perhaps more appropriate to consider the labour input used by these activities as being similar in essence to pesticides – an input that is not normally included in production functions as it is not directly productive. In fact, one could argue that use of large quantities of labour in maintaining the dykes and removing weeds is indicative of sub-optimal construction or positioning of the farm, which are characteristics for which data are not available. This issue is taken up in the later section entitled "Technical efficiency, stochasticity and the labour input problem".

Table 11 – Maximum likelihood estimates of model 3. Only the first five terms of the full trans-log specification are given here, for convenience.

Inputs	Name	Coefficient	Std Error	t-ratio
β0	Intercept	-0.636	0.590	-1.078
β1	Land	0.123	0.135	0.914
β2	Labour	-0.135	0.112	-1.213
β3	Feeds **	0.086	0.025	3.409
β4	Ferts	0.018	0.017	1.075
β5	Fry **	0.680	0.062	10.897
σ^2		2.753	0.993	2.774
ρ		0.941	0.030	31.665
Log-likelihood function		-126.40		
Mean % Technical efficiency		62.8%		
Technical Efficiency Effects	Name	Coefficient	Std. Error	t-ratio
δ0	Intercept	0.195	0.965	0.202
δ1	Region	-0.433	0.818	-0.529
δ2	Live on farm *	-2.683	1.416	-1.895
δ3	Main Income	-0.333	0.799	-0.417
δ4	Exog. Shock **	2.749	1.289	2.132
δ5	Lagum-Lagum *	-3.320	1.693	-1.961
δ6	Continuous	-0.911	0.830	-1.098
δ7	Record Keeping	-0.965	0.843	-1.145
δ8	Probiotics *	-2.561	1.479	-1.732
δ9	Salinometer	-1.102	0.878	-1.255
δ10	pH Test *	-3.678	2.013	-1.827
δ11	Farm type 1 *	-1.678	0.924	-1.815
δ12	Farm type 2 **	2.893	1.311	2.206
δ13	Farm type 3	0.529	0.874	0.605
δ14	Farm type 4 **	-4.997	2.429	-2.057
δ15	Owns land	-0.506	0.801	-0.632

Table 11 further establishes that farms in the sample exhibit high levels of inefficiency, with a mean of 63%. This value indicates that, on average, brackish water farms produce less than two thirds of the maximum achievable output, given the available technology and the recorded input uses. The result suggests that productivity of brackish water aquaculture in the Philippines could therefore increase substantially from improvements in farm management, which is consistent with the finding of Irz and McKenzie (2003). Further, the model allows for the identification of possible inefficiency effects (i.e, factors which tend to increase/decrease inefficiency). Any positive value for a parameter δ in Table 11 indicates that the related variable increases inefficiency. Only those determinants with a high level of statistical significance are now discussed in detail.

The dummy variable for membership of farm type 2 (semi-intensive prawn production) significantly increases technical inefficiency, as is confirmed by the mean efficiency scores plotted by farm type in Figure 13. With regard to the other farm types, the estimation results demonstrate that types 1 (polyculture) and type 4 (large farms) are relatively more technically efficient than the others, while types 3 and 5 (the reference) are comparable in terms of technical efficiency. Hence, our typology does capture differences across farms that have a significant influence on their technical performances.

Beyond this general statement, however, it is difficult to provide a definite explanation as to why a particular farming system might be more technically efficient than another, but the results might suggest that intensification reduces technical efficiency. This hypothesis is tested by a one-way ANOVA comparison of the means between types 1 and 2 (systems with prawn accounting for more than 50 percent of total revenue) and between types 4 and 5 (systems with milkfish accounting for more than 50 percent of total revenue). These paired comparisons are justified by the fact that farm types considered present large similarities apart from their degrees of intensification. Hence, the stocking density of prawns and feeding rate for type 2 farms is significantly greater than for type 1 farms, while the species revenue shares are similar; and the stocking density of milkfish and feeding rate for type 5 farms is significantly greater than for type 4, but both farming systems are oriented towards milkfish production.

Let us consider first the two polyculture systems, where type 1 farms can be considered extensive and type 2 farms semi-intensive. Table 12 shows that type 1 has a higher mean technical efficiency than type 2, and that the difference is significant at the one percent level. Similarly, for milkfish systems, the extensive farms (type 4) achieve, on average a level of efficiency which is sixteen percent greater than that of the intensive farms, although the difference is not statistically significant. Hence, this analysis provides support for the idea that intensification tends to reduces technical efficiency, and particularly so in the case of prawn polyculture. This might be explained by the fact that the strength of the polyculture system is that it enables species to exploit different trophic niches in the pond, but this effect is likely to be diminished with the increased densities associated with intensification.

Table 12 - Scheffe's Post-hoc tests on a one-way analysis of variance comparing mean technical efficiency between farm types 1 and 2, and between types 4 and 5.

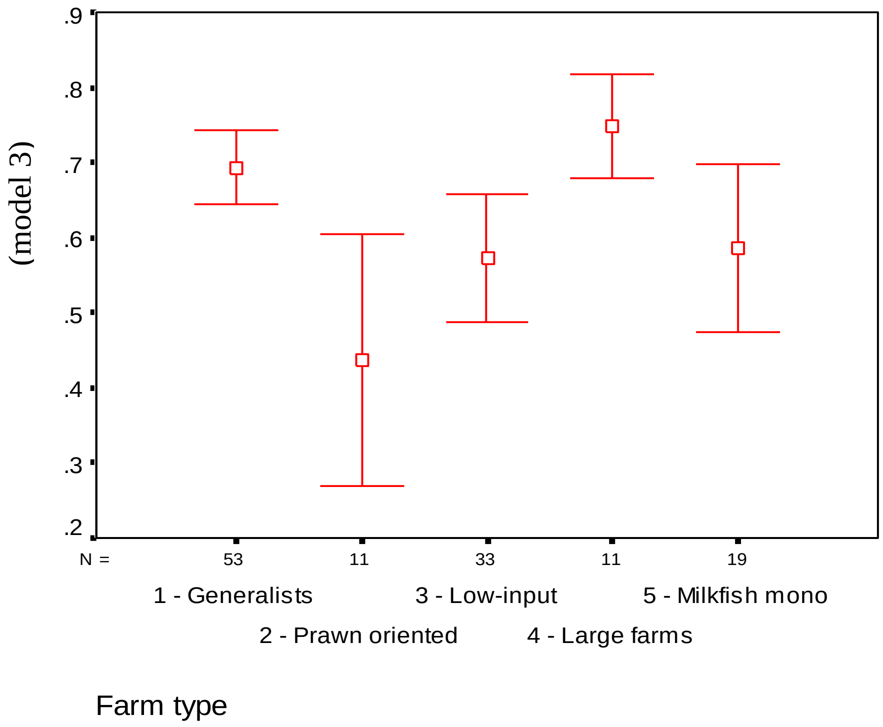
(I) Farm type	(J) Farm type	Mean Difference (I-J)	Std. Error	Significance
1	2	.2569	.06854	.009
4	5	.1619	.07838	.376

The analysis of inefficiency effects pursues by noting in Table 11 that, as intuitively expected, the dummy variable for negative exogenous shocks (related to parameter $\delta 4$) significantly increases inefficiency. Finally, parameters $\delta 2$, $\delta 5$, $\delta 8$ and $\delta 10$ all take statistically significant negative coefficients, indicating that the related variables have a positive influence on efficiency. In particular, an operator living on his farm ($\delta 2$), employing the traditional *lagum-lagum* system of production ($\delta 5$), using probiotics ($\delta 8$) and testing the pH of the soil ($\delta 10$) achieves higher levels of technical efficiency than otherwise.

These results, in part, support the traditional wisdom related to aquaculture. Hence, a saying reported by a number of operators asserts that the best inputs to the farming system are "the shadow of the operator across the pond and his footmarks on the dyke". In this regard, a producer living on his farm is likely to perform better than an absentee operator, as is confirmed by the econometric results . In addition, the *lagum-lagum* system of stock movements is a traditional one, dating back to a period when the construction of concrete sluice gates was not possible, and the much-researched modular (or continuous) systems of operation were therefore unavailable.

However, the use of probiotics, a relatively new technical innovation for strengthening the resilience of the culture medium with respect to bacterial diseases (Corre, Janeo et al., 1999), also improves technical efficiency. This conclusion, while intuitive, should be treated with caution because of the small proportion (7%) of farms that have adopted this innovation. Further, it would perhaps be more accurate to state that those farms using probiotics are more efficient that those that do not, because the use of probiotics may be indicative of unobserved heterogeneity among operators, possibly explained by characteristics such as a higher education level. The same cautious interpretation should be applied to the finding that pH testing of the soil ($\delta 10$) increases technical efficiency. We now return to a detailed discussion of why the labour elasticity of the estimated production function might be negative.

Figure 13 – Mean and 95 per cent confidence intervals of technical efficiency by farm type.



6.3.6 Technical efficiency, stochasticity and the labour input problem

The previous approach to efficiency measurement implicitly assumes that the firms have access to the same technology. However, it is unlikely that firms face exactly the same natural resource conditions, or other exogenous factors, such as weather, that can shock or bias production (Just and Pope, 2001). Therefore, Just and Pope (2001) emphasise the need for greater biological and physical realism in representing agricultural technologies. For instance, they stress the timing of input use as an important variable in determining output, a view that is strongly supported by the empirical literature in aquaculture. An illustration relates to temporary over-feeding, which damages the culture environment through the degradation of unused feeds (Sumagaysay-Chavoso and San Diego-McGlone, 2003).

In this context, with timing as an important variable, Just and Pope (2001) consider that production response dependent on local weather is represented by:

$$y = f(x^1, ...x^m, k, \varepsilon) \qquad (6)$$

where k represents all relevant capital inputs, ε is a vector of weather occurrences, and, for now, the issue of timing of input use is suppressed for convenience. Then, adding temporal details, the representation becomes:

$$y = \{f^*(f_1(x^1, y_0, z^1, \varepsilon^1), ... f_m(x^m, y_{m-1}, z^m, \varepsilon^m)) \; |z^i \le k\} \qquad (7)$$

describing an *m*-stage technically efficient input-output relationship using the smooth function *f*, where ε^i represents local weather events occurring during stage t_i of the production process, x^m is harvest inputs applied at harvest time t_m, and y_0 represents the initial conditions. Just and Pope (2001, p. 646) suggest that the possibility for weather events to cause significant variation in final or stage output is large:

> *"Weather can cause certain operations (stages) to be largely ineffective or consume excessive resources unless choices of timing are altered. For example, trying to cultivate a field that is too wet can cause tillage to be ineffective or consume excessive labour. Or trying to plant a crop before adequate rain can result in an inadequate stand of seedlings. The associated consequences for output can be dramatic….An important result following from the lags [in equation 5.6] is that realised output may not be monotonically increasing in input variables. For example, bad weather (pest infestations) can reduce yields while motivating managers to use more labour (pesticides). Thus a regression of output y_{tn} on some total input vector $x = \Sigma_i x^i$ may suggest a negative association for some variables even though $\delta E_i(y_{tn}) / \delta x^i$ is positive, where E_i is the expectation of y_{tn} taken at time t_i (using information available at time t_i). This has led some economists to model particular inputs as controlling the damage to normal growth (Feder, 1979)."*

While the idea that pesticides are a damage control input is familiar and well-established, the idea that labour should be modelled as such may be more controversial. However, there would seem to be a definite validity for considering this possibility in the case of aquaculture. This is because the weather and other exogenous events have a direct impact on the quality of the medium of culture (water), as explained below.

Excessive water temperature, salinity, nutrient content, and, thus, the presence of disease agents are largely out of the control of the operator but can be linked to weather events. Storm surges, flooding, organic pollution from unregulated industry and organic pollution from other fishponds are all environmental events that the fishpond operator has no control over. The main labour input into aquaculture ponds is supervision (i.e. caretaking). The importance of this role increases when conditions on the farm are bad, owing to poor water quality, and a careful watch on the stock is then needed. The second most significant use of labour involves reinforcing the dykes, which is also important when conditions are bad (e.g. there is the threat of a coming storm). Hence, in these two examples, it is conceivable that labour input has primarily a damage control function, which can explain the negative elasticity of labour in Table 11.

Kumbhakar (2002) takes a different, but related, approach to modelling the productive use of labour in aquaculture by formulating an alternative to the seminal stochastic frontier specification proposed by Aigner *et al.* (1977). His simultaneous estimation of production risks and technical inefficiency using data for salmon farms in Norway, establishes that "production risks are increasing with feed and decreasing with labour and capital" (Kumbhakar, 2002, p.20). He argues thus:

> *"Labour plays an important role in production risk management. Farm workers' main tasks are monitoring of the live fish in the pens, biophysical variables (sea temperature, salinity, oxygen concentration, algae concentrations etc) and the condition of the physical production equipment (pens, nets, feeding equipment etc). Thus workers ability to detect and diagnose abnormal fish behaviour, detect changes in biophysical variables and make prognoses on future development is crucial to mitigate adverse production conditions" (Kumbhakar, 2002, p.16).*

Kumbhakar uses this logic to support his findings that the quantity of labour decreases production risks. However, the argument put forward in the above passage seems to imply that the ability/quality of the supervisor may be more important to the production process than the quantity of supervision.

The previous discussion can be summarised as follows. First, labour input in aquaculture may be production risk-reducing (Kumbhakar, 2002). Second, labour may be considered a damage control input rather than a yield increasing input. This implies that, in the absence of a temporal specification of the technology, negative output elasticities for labour may result, owing to exogenous events that absorb labour and, simultaneously, reduce output (Just and Pope, 2001).In light of our finding of a negative output elasticity for labour (model 3), Just and Pope's argument seems attractive.

6.4 Summary

The results of the economic component of the analysis in this paper are summarized in a simplified manner in Table 13. At a first level, we find that there is considerable heterogeneity with regards to the economic performance of the five farming systems under study, as described below.

Extensive polyculture farms (type 1) achieve, on average, relatively average levels of profitability. One particular advantage of this farming system lies in its resilience. Although price risks are high, owing to the importance of prawns, the overall riskiness of this farming system is relatively low because revenue diversification across four species acts as a form of insurance. Finally, farms adopting this production system achieve relatively high levels of technical efficiency, in spite of very large mortality rates for prawns (in excess of 95%).

Table 13 – Summary of analysis of economic indicators

	Type 1 – Extensive polyculture	Type 2 – Semi-intensive prawn-oriented polyculture	Type 3 – Low-input labour-intensive systems	Type 4 – Large milkfish-oriented systems	Type 5 – Semi-intensive milkfish monoculture
Costs	Average	High	Low	Average	Average
Revenues	Average	High	Low	Low	Average
Gross margin	Average	High	Low	Low	Average
Price Risk	High	High	Low	Low	Low
Overall Risk	Low	High	Average	High	High
Revenue Diversity	High	High	Average	Low	Low
Prawn Mortality	High	High	Low	High	N/A
Technical Efficiency	High	Low	Average	High	Average

The strength of semi-intensive prawn-oriented polyculture systems (type 2) lies with their high profitability. The large production costs involved are more than compensated by the yield increases permitted by intensification, resulting in relatively large gross margins. However, the catch for these high economic returns is a high level of risk as well, due primarily to the importance of prawns in these systems. In fact, the high degree of revenue diversification in this group of farms demonstrates the importance of secondary species in mitigating risks. Average technical efficiency of type 2 farms is low (40%).

Not surprisingly, low-input labour-intensive farms (type 3) only achieve low profitability because of the restrictions on yields that this production system imposes. On a more positive note, price risks are also low, possibly owing to marketing strategies that do not depend on the export market. The analysis also suggests that type 3 farms perform reasonably at a technical level, as indicated, for instance, by prawn mortality rates that are low compared to the rest of the sample (although, with a mean of around 80 percent, there is still considerable room for improvement). Technical efficiency is average at just below 60 percent for this group of farms.

Relatively low profitability characterises large milkfish-oriented systems (type 4), which is explained by average costs but low revenues. Price risks are low but these production systems are nonetheless risky, because of the compound effect of high prawn mortalities and a low level of revenue diversification due to a strong orientation towards milkfish. However, technical efficiency is estimated to be higher than average for this farm type at around 80 percent.

Finally, the indicators reported in Table 13 suggest that semi-intensive milkfish monoculture systems (type 5) are fairly average in terms of their economic performance. In particular, compared to the other farm types, farms in this group exhibit average profitability and technical efficiency. Further, a relatively low price risk index is as expected for systems that do not produce prawns, but the overall level of risk is high, owing to the specialisation of these systems.

Altogether, it is clear that the five production systems investigated here achieve vastly different economic performances, although it is not possible to single out one farm type as being economically superior to the others. This is in part due to the apparent trade-off existing between profitability and riskiness of farming systems, which operators can influence primarily by adjusting the output mix and level of intensification of their production plans.

7. Social / socioeconomic indicators

7.1 Introduction

At a broad level, the Philippines can be characterised as a labour-surplus economy, and the only source of livelihood available to many poor Filipinos is often their labour. Thus, farming systems that require labour directly or indirectly can be considered to make a positive contribution to social equity by providing jobs to poor people. However, the social effect of aquaculture may be more complex than suggested above. As pointed out by Funge-Smith and Briggs (1998) for instance, social transformations accompanying the development of coastal areas for aquaculture "can be both positive and negative; the increased income into traditionally poor coastal areas must be balanced against loss of job diversity, loss of independence, rising prices and growing inequity between farmers and non-farmers " (Funge-Smith and Briggs, 1998 p.118). It is also important to consider the possibility that aquaculture development may make some people strictly worse off, and that these are likely to be among the poorest. Hence, if there are employment benefits that can compensate for the inevitable losses in municipal fisheries brought about by fishpond development, these have also to be balanced against the loss of independence and, possibly, of diversity that result from such a change. These changes are made all the more perilous and fragile by the quasi-irreversibility involved in aquaculture development, whereby the landscape of an entire region can be rapidly transformed.

The distribution of farm size is also a characteristic of aquaculture that impacts on social equity. The highly inequitable distribution of farm size within brackish-water aquaculture in the Philippines, and the exemption of brackish-water areas from agrarian reform legislation, have both served to concentrate the benefits of aquaculture. In addition to the distribution of farm size and employment linkages, we might consider a third level at which aquaculture affects social equity through its impact on nutrition. The Philippines, like many developing countries, pursues an agricultural strategy in which the objectives of price stabilisation and self-sufficiency figure prominently. As Coxhead's general equilibrium analysis of the effects of these interventions shows, there can be negative impacts on the environment (through incentives to cultivate marginal land), as well as a rise in food prices as a result of food security related policies. Thus, great caution is needed when making social equity claims made in connection with food security (Coxhead, 2000). For certain, it can be said that achievement of food security as an objective can come at the cost of other objectives, and that it is an important and often-used term in the policies of the Philippine Department of Agriculture (DA).

The following sections review the employment and food security impacts of aquaculture. We introduce the specific methodologies and present results for each farm type. The social equity impact of an inequitable distribution of farm size within aquaculture is not given treatment here as this is not a farm-level impact. Rather, it is a sector-level phenomenon. Evidence appraising an efficiency case for agrarian reform within aquaculture is given in paper 5.

7.2 Employment Generation

7.2.1 Background and methodological approach

Unemployment in the Philippines, particularly in the rural areas, is a persistent social problem. At the national level, the rate of unemployment rose between the years 1996 and 2003 from 7.4 percent to 10.1 percent (Anon, 2005). Further, unrelenting population growth in the Philippines, constant at the high rate of two to three percent per annum, suggests that the problem will not easily be resolved and makes employment creation in rural areas a policy imperative. In this context, aquaculture has been proposed as a means to increase rural employment possibilities, and prevent urban drift.

On-farm employment is part of the contribution of aquaculture to total employment. For example, in Thailand, direct employment in aquaculture in 1995 was estimated at 80,000 (ADB/NACA, 1995 – cited in World Bank, 2002). However, the impacts of aquaculture on employment are also felt through the multiplier effect, where aquaculture consumes inputs from other sectors (upstream) and provides outputs for processing and marketing sectors (downstream).

Multiplier effects in terms of economic activity in general, and employment in particular, follow Walrasian principles of general equilibrium and were originally developed by Leontief (1936, 1966). The main methodology, called input-output analysis, models the interactions among different sectors in the economy such that the impact of changes in one sector can be predicted. Although useful, input-output economic analysis is very data-intensive, and usually relies on government-generated "input-output" or "inter-industry transaction" tables that can often take years to compile. Hence, the most recent input-output dataset available for the Philippines is only for year 1994 (Anon, 2005).

In our case, although a full input-output analysis can not be carried out, we employ the underlying principles of the approach at a more local scale. Our aim is to distinguish between employment effects of different types of farming systems within the general agricultural sub-sector of aquaculture. This requires the following primary data:

- On-farm Employment
- Input 'consumption' by different farm types
- Labour use of input supply industries
- Output produced by different farm types
- Labour use per unit of output in processing and marketing industries

Data covering on-farm employment, input use and output are available from the farm-level survey. Data on labour use in downstream and upstream industries were collected from a number of interviews with business owners, employees and own-account individuals working in the input industries and output marketing sector.

7.2.2 On-farm Employment

The use of labour on-farm is important as an indicator of the possibilities for direct employment generation in aquaculture grow-out. It is clear that many people in coastal *barangays* in the Philippines rely on seasonal or full-time employment on fishponds for their livelihood (see paper 4), but quantifying the effect is difficult.

However, a socio-economic survey of the aquaculture industry in the Philippines, carried out in 1979 (Aspuria and Fabro, 1979, cited in Bailey, 1982), found that total labour demand, exclusive of guarding and supervising, to be less than 18 man days per hectare per year for milkfish monoculture, and 45 man days per hectare per year for polyculture prawn and milkfish. Another survey, (ADB/NACA, 1995), which covers 13 Asian countries, reports that the Philippines has the lowest labour use per unit area on extensive shrimp farms. It is calculated from the survey that on-farm labour use is only 1.5 person months per hectare per year for the Philippines, as compared to an average of 6.4 person months per hectare per year across all 13 countries. The previous estimate for the Philippines converts into roughly 45 person days per hectare per year, and so there would seem to have been little change in labour intensity over the period between these two studies. Further, these studies suggest that the employment generation potential of brackish water aquaculture in the Philippines is unlikely to be fully exploited.

By contrast, the average on-farm labour use across all farm types in our sample is approximately 200 person days per hectare per year, as detailed in Table 17. Unlike the studies mentioned previously, this figure includes the labour input of the caretaker and includes both family and hired labour. Our estimate of 200 person days per hectare per year is roughly equivalent to the Asian average in the ADB/NACA survey and calls into question the validity of the figure of 1.5 person months per hectare per year stated calculated from that same survey. The way in which on-farm labour demand varies across production systems will be discussed later.

7.2.3 Employment Effects

The main assumption of the input-output technique is that of a fixed relationship between the level of output of an industry and its use of inputs. Thus, by increasing demand for the output of an industry (e.g. feeds from feed mills), the use of particular inputs to that industry (e.g. labour) will increase in fixed proportions. The empirical approach starts by calculating a coefficient that measures the labour intensity in an industry that supplies inputs to aquaculture:

Backward link labour use coefficient = Labour use / Unit output (8)

In a similar fashion we calculate a coefficient that measures the labour intensity in an industry that demands the products of aquaculture (e.g. marketing and processing industries):

Forward link labour use coefficient = Labour use / Unit Input from aquaculture (9)

In the case of backward linkages from aquaculture, when calculating the coefficients one has to assume that there is zero final demand from all sectors other than aquaculture. We therefore restrict the analysis to commodities produced by businesses that state (during interview) that aquaculture represents near total demand for their output. Additional difficulties concerning forward linkages from aquaculture and the problem of multiple outputs will be considered in a later section.

7.2.4 Input (Backward) linkages

7.2.4.1 Employment in input-supply industries

Some of the industries delivering inputs to aquaculture also supply agriculture and capture fisheries. Hence, ice plants, transport service providers, artisanal gasoline stations, fertiliser/feed dealers and fishing supply stores all supply goods and services to the aquaculture sector, but not exclusively. Given the assumption underlying the input-output methodology that total demand from non-aquaculture activities should be zero, we omit certain items and sectors from the analysis. Those include: fertilisers (mostly imported and also used by agriculture); pesticides (mostly imported, mostly illegal); transport, gasoline and ice (all with significant demand from households and fisheries); and ‘recycled’ or joint products from other industries such as old bread and manure.

Figure 14 below sketches the supply chains for each input, and identifies, in bold, the inputs that are included in the employment effect analysis. The labour use coefficients for each of the included inputs are given in Table 14 and details of the calculations and assumptions underlying them are given in appendix 1. The coefficients for commercial feeds (1.17 person days per kilo) and small shell feeds (1.04 person days per kilo) are similar, which might suggest that the choice of feeding strategy has a broadly neutral impact on employment in the input-supply sector. However, this would be a false conclusion. Small shells are required in much greater quantities compared to commercial feeds, owing to their inferior nutrient content. As a result, adopting a feeding strategy based on small shells is likely to have a much greater positive impact on employment.

The three seed options included in the analysis (hatchery-reared prawn fry, wild milkfish fry or milkfish fingerlings) have very different coefficients. Prawn hatcheries produce fry by the million with only a handful of staff, whereas wild collection of milkfish fry is labour intensive (Ahmed *et al.*, 2001; Frankenberger, 2002). Milkfish fingerlings have a significantly greater coefficient because these fingerlings are cultured from fry size in specialised aquaculture ponds by operators that purchase wild fry during peak season and smooth the annual supply by stunting them in ponds before selling them on for grow-out. Each fingerling has thus been harvested from the wild (with a coefficient of 1.05 person days per thousand), and labour has been employed in tending to and feeding them, as well as maintaining the facilities in which they have been reared. Mortality of some the fry during this period increases the value of the coefficient because, obviously, only fry that survive the nursing period can be sold to operators.

Table 14 – Coefficients for the employment effects of input use

Input	Coefficient	Units	Source
Commercial Feeds	1.17	Person days * $tonne^{-1}$	1 Interview and site-visit to a feed production plant
Small shells	1.04	Person days * $tonne^{-1}$	4 Interviews and direct observation in the field
Milkfish Wild Fry	1.05	Person days * fry^{-3}	Ahmed, Magnayon-Umali et al., 2001
Prawn Hatchery Fry	0.045	Person days * fry^{-3}	1 Interview and site-visit to San Felipe, Zambales
Milkfish Fingerlings	9.23	Person days *fry^{-3}	3 Interviews and site-visits in Zambales

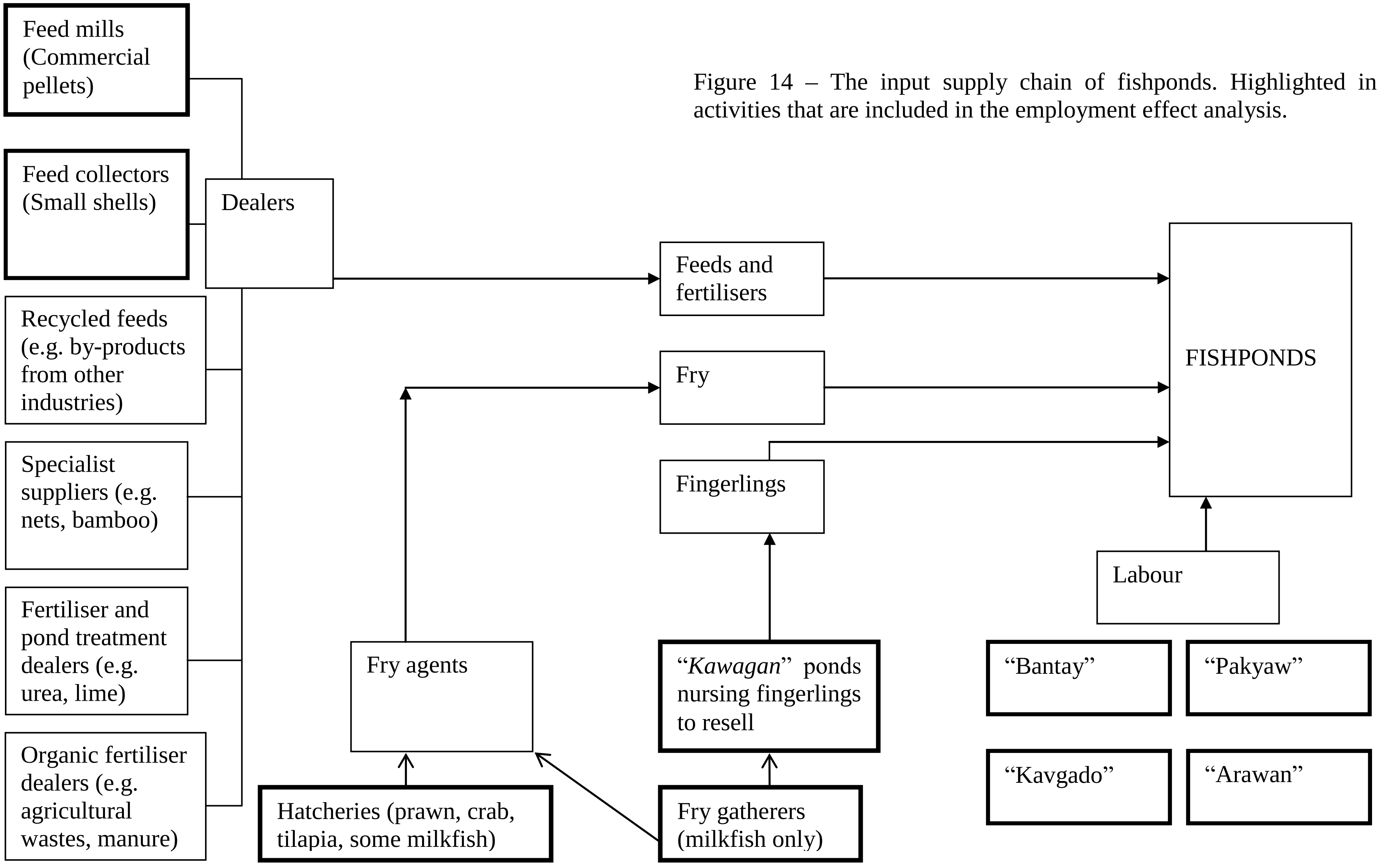


Figure 14 – The input supply chain of fishponds. Highlighted in bold are activities that are included in the employment effect analysis.

7.2.4.2 Input consumption by farm type

Table 15 presents the intensity of use, for each farm type, of the inputs included in the employment effect analysis. There is considerable heterogeneity, with large consumption of small shells and prawn fry by farm type 2 (semi-intensive prawn polyculture), and of commercial feeds and milkfish fry by farm type 5 (semi-intensive milkfish monoculture). Farm types 3 (low-input, labour intensive systems) and 4 (large milkfish-oriented systems) are extensive with respect to most of these inputs, while farm type 1 (extensive polyculture) represents an intermediate case. Although not directly interpretable, these figures suggest that there are important linkages of aquaculture to the rest of the local economy, and that the intensity of this linkage is likely to vary significantly by farm type.

Table 15 – Use of inputs included in the employment effect analysis, by farm type

Farm type		Small shells (kg/ha/yr)	Commercial feed (kg/ha/yr)	Milkfish fingerlings (#/ha/yr)	Wild milkfish fry (#/ha/yr)	Prawn fry (#/ha/yr)
1	Mean	2,057	62	1,518	88	102,293
	N	53	53	53	53	53
	Std. Dev.	4,498	386	1,857	431	88,470
2	Mean	10,780	164	4,737	0	253,526
	N	13	13	13	13	13
	Std. Dev.	13,637	402	11,211	0	207,352
3	Mean	395	21	2,202	611	21,700
	N	35	35	35	35	35
	Std. Dev.	1,412	52	2,409	1,554	38,385
4	Mean	234	283	3,198	1,724	38,970
	N	11	11	11	11	11
	Std. Dev.	521	672	4,796	3,536	77,190
5	Mean	0	1,772	3,050	7,084	0
	N	19	19	19	19	19
	Std. Dev.	0	3,809	4,101	10,935	0
Total	Mean	2,027	328	2,383	1,371	75,615
	N	131	131	131	131	131
	Std. Dev.	5,921	1,575	4,426	4,901	114,588

7.2.5 Output (Forward) linkages

7.2.5.1 Employment generated by the marketing and processing of aquaculture products

Employment is generated in the sorting, handling, dealing, transportation, processing (if any) and marketing of the output produced by aquaculture farming systems. The marketing chain for aquaculture products is described in further details in Figure 15. Though this supply chain appears reasonably simple, linking the output of aquaculture farms to the level of employment generated in each of the output-related industries is fraught with difficulties. One particular problem relates to the fact that fish dealers are very heterogeneous in terms of size of operation, clients (fish farmers and/or fishermen), and markets served. In view of this problem, we limit our quantitative exercise to the analysis of an activity known as *cha-cha*, which corresponds roughly to the sorting of harvest that takes place on the dockside. This activity involves men and women who wait by the *consignacions* (buying stations) to help sort the harvests by species and approximate size classes. They work in groups, and sit or crouch in a circle around the area where the fish are docked. The wages for the *cha-cha* are paid by the fishpond operator, through the *consignacion*, at a fixed rate per weight of each species.

In Sasmuan, Pampanga, we interviewed six *consignacion* owners. The terms under which the *cha-cha* operated in each one were almost identical. They are typically paid in nature or in cash at the following rates (for the group in total):

Prawn = 0.5 kg for every 40 kilo processed = PhP150 per 40.5 kilo[6]

Milkfish / Tilapia = PhP100 per 40 kilo processed = PhP100 per 40 kilo

Crabs = PhP2 per piece

Following interviews with *consignacion* owners and with *cha-cha* worker, we found that each individual earns around PhP100 per day. While the majority of the work is finished by early afternoon, the workers start early in the morning, and the job can thus be considered a full-time activity. In fact, few *cha-cha* workers had other sources of livelihood. The nature of the work is such that when there is a harvest, there is a pressure, from both the fishpond operator (who wishes for the sorting to be carried out as quickly as possible) and from the unemployed *cha-cha* workers on the dock, for more people to enter the group until the quantity of fish processed is such that each worker takes home around PhP100. It is therefore legitimate to calculate the employment contribution per unit of aquacultural product via the peso metric, as follows:

Prawns = 1.5 person day per 40.5 kilo

Milkfish / Tilapia = 1 person day per 40 kilo

Crabs = 1/50 person day per piece

7.2.5.2 Output produced by farm type

The sorting process that takes place in the *cha-cha* and in marketing is dependent, to a large extent, on the production from aquaculture. Hence, the more productive the fishponds are, the more work is available through these downstream linkages. Table 16 below gives the annual mean production of each species per unit area for each farm type. The mean values for farm types 1 and 2 are evenly spread across the four species, although with considerable variability across farms (indicated by the large standard deviations). Farm type 2, while characterized by an orientation towards prawn production (paper1), has mean productions of tilapia and milkfish that are higher, in weight, than that of prawn. These secondary species, although of relatively low value, generate large amounts of fish for the local markets, and, consequently, a lot of work for the *cha-cha*.

Farm types 3 and 4 have a low level of production for all species but milkfish, and farm type 5 produces milkfish and/or tilapia in large quantities. The levels of output for the semi-intensive systems (farm types 2 and 5) are approximately double that of the average for the whole sample.

Table 16 – Output produced by farm type

Farm type		Prawn (kg/ha/yr)	Milkfish (kg/ha/yr)	Crabs (kg/ha/yr)	Tilapia produced (kg/ha/yr)	TOTAL PRODUCTION (All species kg/ha/yr)
1	Mean	117	194	88	169	568
	N	53	53	53	53	
	Std. Deviation	121	308	160	272	
2	Mean	254	521	219	744	1738
	N	13	13	13	13	
	Std. Deviation	378	1199	272	2560	
3	Mean	50	320	60	20	450
	N	35	35	35	35	
	Std. Deviation	122	398	183	95	
4	Mean	33	793	0	23	849
	N	11	11	11	11	
	Std. Deviation	70	1247	0	77	
5	Mean	0	1030	35	673	1738
	N	19	19	19	19	
	Std. Deviation	0	805	153	2896	
Total	Mean	89	431	78	247	845
	N	131	131	131	131	
	Std. Deviation	168	716	179	1368	

Figure 15 - Output supply chains for fish, crabs and prawns produced in brackish-water fishponds. Highlighted in bold are activities that are carried out primarily by the poor.

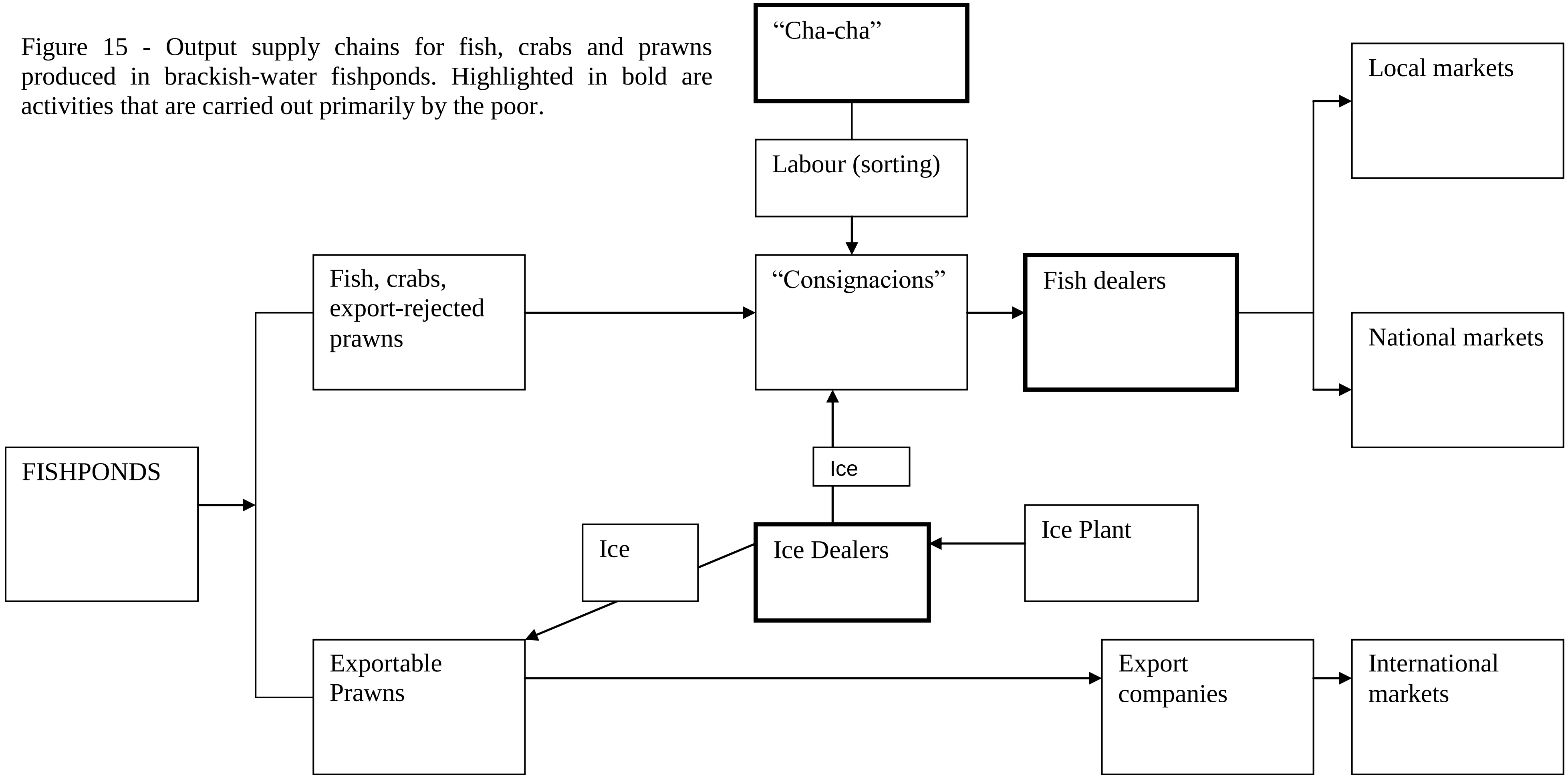


Table 17 – Employment generation by farming system and its break down by activity.

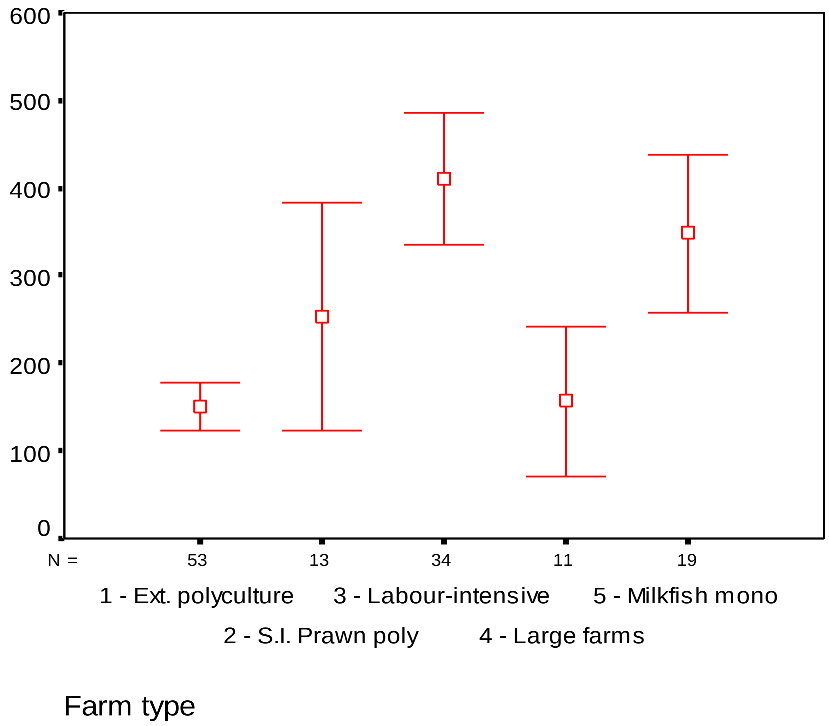
	Farm type	Input-use employment effect	Hired labour On-farm	Family Labour On-farm	"Cha cha"	Total employment effect
average (person days / ha /yr)	All	29.1	112.6	90.3	26.5	258.5
	1	20.9	79.4	30.9	19.5	150.7
	2	66.5	84.7	44.4	58.2	253.8
	3	20.9	211.5	163.3	15.6	411.2
	4	31.3	53.0	50.2	22.2	156.7
	5	39.9	82.2	180.3	46.0	348.3
% total employment	All	11.3	43.6	34.9	10.2	100.0
	1	13.9	52.7	20.5	13.0	100.0
	2	26.2	33.4	17.5	22.9	100.0
	3	5.1	51.4	39.7	3.8	100.0
	4	20.0	33.9	32.0	14.2	100.0
	5	11.4	23.6	51.7	13.2	100.0

7.2.6 Employment generation by farm type

Table 17 synthesizes the results of our partial input-output analysis. It establishes that on-farm activities generate the most employment from aquaculture. Hence, looking at the whole sample, on-farm labour demand accounts for over three-quarters of the estimated labour demand from the sector, the rest relating in almost equal measure to backward and forward linkages. However, Table 17 also reveals that there is some variability in the extent to which farming systems generate linkages and employment. In particular, farm types 2 and 5 are semi-intensive systems and, as a result, generate more off-farm employment through both backward and forward linkages than extensive systems. For example, a ten-hectare type-2 farm (semi-intensive prawn polyculture) generates 665 person days of employment in the sector supplying inputs to the farms and 582 person days of employment through the *cha-cha*. The generated employment corresponds to approximately four full-time equivalents (FTEs) and matches the labour-use on the farm (also approximately 4 FTEs, divided between hired and family labour). By contrast, the employment effect of type 3 farms (low-input labour-intensive systems) is predominantly on-farm.

We now turn to a comparison of the overall labour intensity of the five farming systems. Although type 3 farms (low-input labour-intensive farms) are only loosely linked to the broader economy, they generate the most employment (411 person days per hectare and year) due to their heavy on-farm labour requirements. By contrasts, it is the strong employment linkages for types 2 (semi-intensive prawn polyculture) and 5 (semi-intensive milkfish monoculture) that allow them to have intermediate employment impacts. Finally, types 1 (extensive polyculture) and 4 (large milkfish farms) stand out by the fact that they generate the least employment. Altogether, our empirical results establish that there is considerable heterogeneity in the extent to which farming systems create employment, with type 3 farms generating almost three times more labour demand than type 1 farms.

Figure 16 – Total employment generation from different farming systems



7.2.7 Indirect effects of aquaculture on the regional economy

The previous analysis is now extended by considering the broader effects of aquaculture development on the local economy. Barrow & Hall (1995, cited in Stanley, 2003) suggest that regional economic multiplier effects can be broken down into different categories, presented in Table 18 below. They describe "Growth Poles" and "Enclaves" as extremes of a continuum of various modes of export-driven development. Their application is to multinational corporations, whereas Stanley (2003) applies their framework to the case of shrimp aquaculture in Honduras. Growth-poles stimulate the local economy in the ways outlined in Table 18, whereas enclave-type development is vertically integrated with the economic benefits accruing primarily to investors outside the region.

Table 18 - Assessment of business impact on a local economy (Barrow and Hall, 1995, cited in Stanley, 2003)

	Growth pole multipliers	Enclave-type development
(1)Primary linkages: - Backward linkages and the purchase of input supplies - Forward linkages and the composition of demand	Large backward linkages (local input use) Large forward linkages (local processing)	Small backward linkages (high imported input content) Small forward linkages (export or consume primary product)
(2)Fiscal links	Sector pays substantial taxes to local and national government	Sector exonerated from taxes or exhibits tax avoidance
(3)Consumption links	Sector payroll is well-distributed to allow spending by lower-skilled employees on locally made goods	Sector payroll is concentrated among high-skilled, professional employees who purchase imported consumer goods
(4)Investment spillovers	Majority of shareholders local, majority of profits/dividends reinvested locally	Investment funds raised internationally, with profits remitted outside the region
(5)Employment skill spillovers	A range of employment opportunities available with extensive training in skills transferable to other sectors	Skilled labor imported to the region and most employment opportunities offered in unskilled, or highly specialized positions
(6)Secondary links	Sector interested in the broad development of the host economy; political participation and assistance to community in education, health efforts etc	Sector has little interest in community; staff establish few residency/political ties and provide few donations to community development efforts

The primary linkages outlined in the first row of Barrow and Hall's description have been given quantitative treatment, with regards to different farm types. However, the linkages numbered (2) – (6) in the table above are community, region or country-level phenomena that emerge at higher scales. Fiscal links are likely to be very low, given the widespread failure to tax in the Philippines. At the local level, the "municipal ticket" is charged when operators make sales through the *consignacions*. While this tax is collected, the rate in Sasmuan, Pampanga in April 2004 was 0.2 percent of sales, hence generating minimal revenue for the municipally funded institutions.

Consumption linkages for aquaculture in the Philippines fall more into the growth-pole column of Stanley's typology, with local labour hired seasonally and their wages spent in local markets. This is consistent with the findings in Irz *et al.* (2001) who review the relationship between agriculture and poverty, and stress the importance of consumption linkages to the poverty alleviating effect of agricultural growth.

Investment spill-overs are dependent to a great extent on where the operator lives with the positive impact decreasing with the distance between the operator's residence and his fishponds. Employment skill spill-overs are likely to be favourable, and paper 4 provides evidence from household data that suggest that the experience gained as caretakers and labourers does allow some people to become fishpond operators in their own right later in life. Philanthropic and community-minded initiatives, such as gifting secondary species from prawn ponds to the local community, that Stanley terms secondary links, are entirely dependent on the attitudes and motivations of the operators.

The potential for aquaculture to contribute indirectly to the regional economies of the Philippines lies in a more effective and systematic collection of revenue from aquaculture operators. In general, we can say that aquaculture is currently operating as something of a growth-pole in the Philippines, especially in comparison to other countries where industrial prawn aquaculture provides the archetypal enclave model in Stanley's typology. However, there is considerable potential for redistributive benefits through innovations in governance.

7.2.8 Aquaculture for rural development?

The impact of growth in the aquaculture sector is dependent on the technology used on the farms. Biased technical change that is labour-saving while raising productivity changes the balance of importance between on-farm employment and off-farm employment (in the input-supply and marketing sectors relating to aquaculture). Less labour is used on the farm per unit of output, and even possibly per unit area if the process of intensification involves some level of mechanization. However, the greater throughput of intensive systems results in more use of inputs per unit area, which creates employment in the input-supply sector, while greater output creates employment in sectors downstream from the farm. In view of the above, it is clear that the relationship between employment generation and technology/intensification can only be determined empirically.

In Philippine brackish water aquaculture, our results suggest that, due to the technologies currently used in the sector, employment generation occurs primarily through on-farm labour use. Further, although the forward linkages are clearly under-estimated in our analysis, this is unlikely to affect the quantitative results significantly owing to the short marketing chain and the lack of processing of aquaculture products. The result suggests that on-farm labour intensity of new technologies should therefore be of prime importance when assessing their social impact. However, marketing and processing activities offer livelihood opportunities primarily to women and, as such, are important in a qualitatively different manner. Hence, increased economic activity that adds value in forward linkages is likely to have a positive gender bias in favour of women (Siar and Caneba, 1998).

7.3 Aquaculture and food Security

7.3.1 Background

The net impact of aquaculture on protein production is ambiguous because most pond aquaculture farming systems use protein-rich feed inputs of some kind, although it is possible to raise stock up to a certain density without the need for supplemental feeding. Further, the overall protein productivity of the farm is difficult to establish as it depends on the managerial expertise of the operator (in avoiding mortality and achieving good stock growth), the species under culture, and the farming intensity. However, it is well established that more intensive farms (and managerially inefficient farms) will require higher levels of "throughput" (Giampietro, 1997), in the form of undigested feeds, in comparison to non- or low-feed systems. This will result in lower feed conversion efficiency and net protein production.

Hence, for farming systems that are both managerially inefficient and intensive, or those that grow species with high protein requirements, it is highly likely that the farm generates a net loss of global dietary protein (as famously discussed in Naylor, *et al.*, 2000). This is in contrast to the view that aquaculture has a significant role to play in providing food security in developing countries (Williams, 1997), as it has the potential to be an efficient provider of protein to developing nations. While rice and corn remain the staples of the Filipino, fish for protein is a crucial component to the nutritional health of the nation.

The previous observation is important in assessing the food security impact of aquaculture in the coastal areas of the Philippines because the tendency of the Filipino to "eat nearly every species of fish, even the very smallest fish, and nearly every part of every fish, including fins, heads and most of the entrails" (Bell and Canterbery, 1976) is mentioned in the literature and can be observed in all local food markets and homes at mealtimes[7]. In this light, the use of what the aquaculture industry refers to as "trash fish" as an input for feeding prawns becomes a social equity issue. In particular, it is possible that aquaculture development, while lowering the price of good quality fish for comfortably-off families, may also serve to increase the price of the poorest quality fish (i.e. feed manufacturers, or even the farms directly, add demand for poor quality fish alongside consumers), that has long been the staple protein of the coastal poor.

Casual observation of production practices in Philippine brackish water aquaculture reveals, however, that the potential for negative food security impact is likely to vary across farming systems. For instance, many farms culture filamentous algae ("*lumot*") and/or a cyanobacterial mat ("*lab-lab*") in their ponds that fish can use as feed. The protocol for this involves drying the soil until it cracks; allowing a little water into the pond (a few centimetres depth); and then filling the pond completely once plant growth has started. Farms using this practice well can raise fish (mainly milkfish) with little supplementary feeding and may, therefore, generate a positive net protein production. This stands in sharp contrast with the situation of intensive or semi-intensive prawn farms that use vast amounts of protein-rich feeds to produce only a small quantity of output. We now pursue this analysis further by calculating net protein production for each of the five farming systems. As a last point, however, it is worth emphasising that most forms of aquaculture compare favourably with livestock production in terms of protein balance, although there is considerable heterogeneity within the sector (Naylor *et al.* (2000) provide a critical appraisal).

7.3.2 Methods

Data on feed types and feeding rates were collected in the farm-level survey. Subsequently, the feeds used were categorised into three types: Wild Fisheries Products; Agricultural/Food Industry By-Products; and Commercial Feeds. Table 19 below details the composition of these feed categories as well as the number of farms in the sample on which each individual type of feed is used. The table clearly illustrates the diversity of feeds which are used in brackish water aquaculture. Further, data on the proximate analysis of each feed type were collected from secondary sources where available. For the small bivalve shells ("*gasang*" and "*agiis*") and the small univalve shell ("*suso*"), samples were donated for analysis by fishermen collecting them in the estuaries and lakes in Pampanga province. The fresh samples were roughly crushed, sun-dried and crushed again. These dry samples were then taken to the Central Analytical Laboratory of the South-East Asian Fisheries Development Center – Aquaculture Department (SEAFDEC - AQD). The crude protein content and nitrogen (N) content of all the feeds are given in Table 19.

Using this information, net dietary protein production (NDPP) for each farm was calculated as follows:

$$\text{Net dietary protein production (kg/ha/yr)} = \Sigma X_i - \Sigma Z_j \qquad (10)$$

where X_i denotes protein output per hectare and year of item *i*, while Z_j measures protein input per hectare and year corresponding to feed type *j*. Note that inputs include the fry or fingerlings, although the bulk of the protein input is in the form of feed. An alternative way of investigating the food security impact of aquaculture is through the calculation of a protein conversion ratio (PCR), defined simply as the ratio of feed inputs to fish production:

$$\text{PCR} = \text{Total protein in feed / (protein in output – protein in fry)} \qquad (11)$$

Thus, PCR takes a value of one when there is no overall loss of dietary protein as a result of the activity of a farming system, a value greater than one when there is a loss of dietary protein, and a value between zero and one for systems that use less protein in external inputs they produce. These latter systems thus generate a surplus of protein by using the natural productivity of the pond ecosystem.

Table 19 – Proximate analysis of the sample farms' feeds, fertilisers and outputs

Item	% Crude protein	% N	Source for proximate analysis	Number of farms in the sample using item (or producing output)
WILD FISHERY PRODUCTS				
Seaweed	10.64	1.70	Gerpacio & Castillo, 1979	1
"Alamang" (small shrimps, capture fishery)	67.23	10.76	Cruz 1997	21
Boiled Fish (usually low-value small fish or "trash fish", capture fishery)	32.18	5.15	Gerpacio & Castillo, 1979	22
"Suso" (univalve shell)	9.34	1.49	SEAFDEC-AQD	11
"Gasang" (small bivalve)	0.69	0.11	SEAFDEC-AQD	46
"Tahong" (mussel meat)	61.14	9.78	Cruz 1997	2
"Agiis" (small bivalve)	0.69	0.11	Assume the same as Gasang	5
AGRICULTURAL / FOOD INDUSTRY BYPRODUCTS				
Old Bread	7.64	1.22	USDA (2003)	13
Cracked Corn	8.76	1.40	Gerpacio & Castillo, 1979	3
Rice Bran	11.40	1.82	Gerpacio & Castillo, 1979	7
Expired Noodles	9.92	1.59	Gerpacio & Castillo, 1979	1
Egg Yolk	12.40	1.98	Gerpacio & Castillo, 1979	6
Boiled Squash	0.91	0.15	USDA (2003)	1
Chiz Curls (expired cheese-flavoured crisps)	6.67	1.07	Packet	6
Carabao skin		No data		1
Mudpress (from sugar fields)	2.86	0.46	Gerpacio & Castillo, 1979	2
COMMERCIAL FEEDS				
Fry Mash	35.20	5.63	Cruz 1997	10
Starter	33.44	5.35	Cruz 1997	22
Grower (prawn)	32.56	5.21	Cruz 1997	2
Grower (milkfish)	24.36	3.90	Cruz 1997	4
Crumble	33.44	5.35	Cruz 1997	2
Juvenile	24.36	3.90	Cruz 1997	1
Fattener	23.49	3.76	Cruz 1997	2
Finisher	23.49	3.76	Cruz 1997	10
Hog Mash		No data		1
FERTILISERS				
Carabao Manure	-	0.30	Cruz 1997	4
Chicken Manure	-	3.80	Cruz 1997	31
Commercial organic fertiliser	-	2.00	Cruz 1997	1
Ammonium sulphate	-	14.00	Cruz 1997	1
OUTPUTS				
Milkfish	20.53	3.28	USDA (2003)	115
Prawn	23.08	3.69		82
Tilapia	17.60	2.82	G&C, p. 6	26
Crab	18.50	2.96	USDA for Queen Crab	46

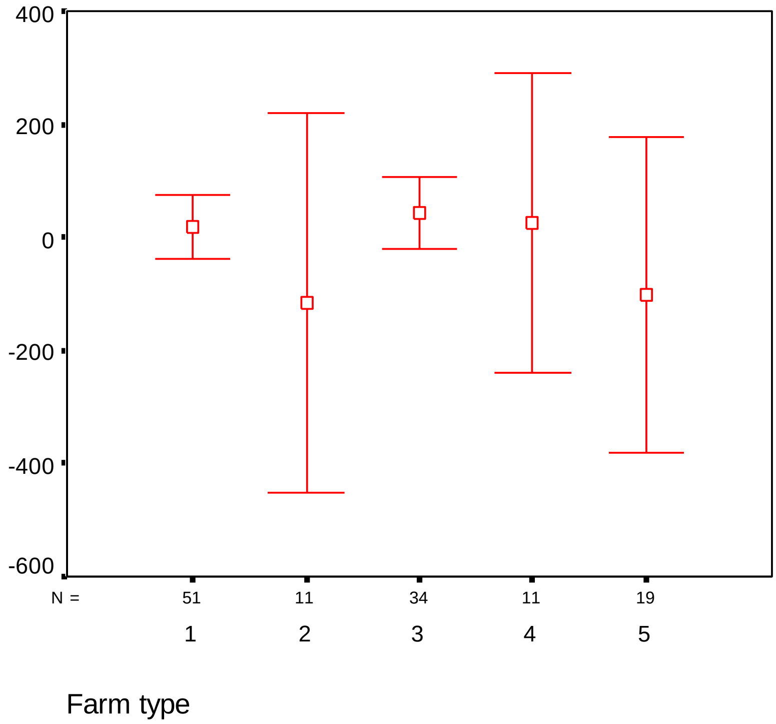
The NDPP indicator is useful as it accounts for the protein productivity per unit area of the farming system under study, but is difficult to interpret. The PCR indicator is more easily interpretable, but is a ratio and thus does not account for land productivity.

7.3.3 Results

7.3.3.1 Net dietary protein production

Five outliers were removed from the sample of 131 farms. There is still considerable within-type variability in these results but we can observe that farm types 1 (extensive polyculture) and 3 (low-input labour intensive) have marginally positive mean NDPP, suggesting that they make a positive contribution to net protein production. The other farm types have wide 95% confidence intervals so that it is difficult to reach definitive conclusions regarding their net impact on protein production. However, we note that, as expected, the more intensive farm types (2 and 5) have negative NDPP means with similar values and ranges, suggesting that these systems consume more proteins than they produce.

Figure 17 – Mean and 95% confidence intervals for NDDP by farm type



7.3.3.2 Protein conversion ratio

The sample mean of the protein conversion ratio, at 0.89, indicates that the sample farms, on average, produce more dietary protein than they use. However, Figures 18 (scores by farm type) and 19 (entire distribution) also establish that there is heterogeneity within the sample. As expected, the semi-intensive systems (farm types 2 and 5) have mean PCR values greater than unity, owing to the higher level of throughput in these systems. Operators of these farming systems cannot use the natural productivity of the water efficiently, due to the crowding of stock in the ponds, and therefore have to use external feeds.

Very high values (in excess of three) are explained by inefficiency in the feeding strategies of caretakers. Often these strategies are based on rules of thumb given to them by the operators (e.g. two sacks per pond per day), and thus are not adaptive in the sense that they do not respond to changes in the behaviour of the prawns/fish, the presence of undigested feeds, or an increase in stock mortality.

Figure 18 – Mean and 95% confidence intervals of PCR by farm type.

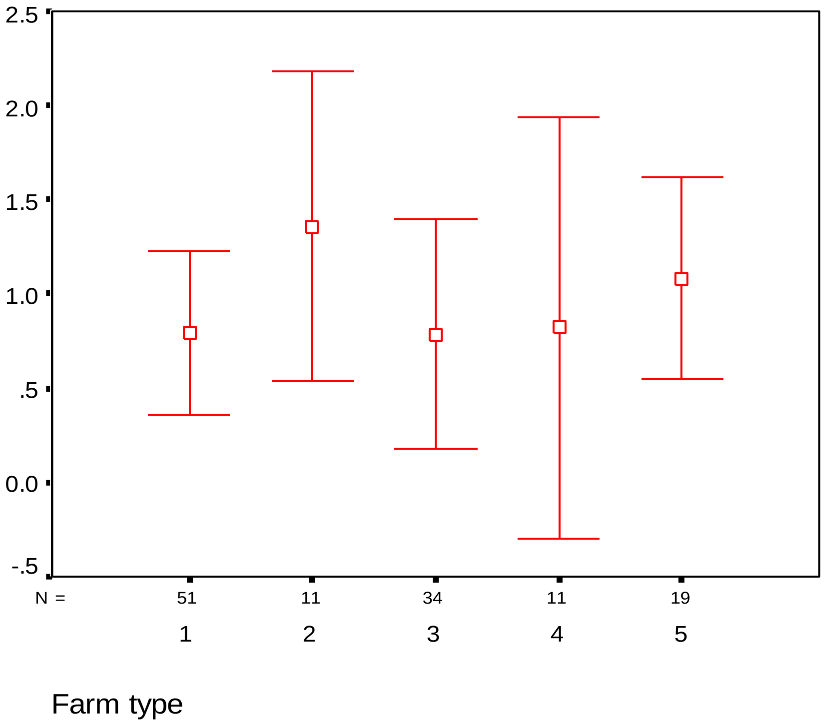
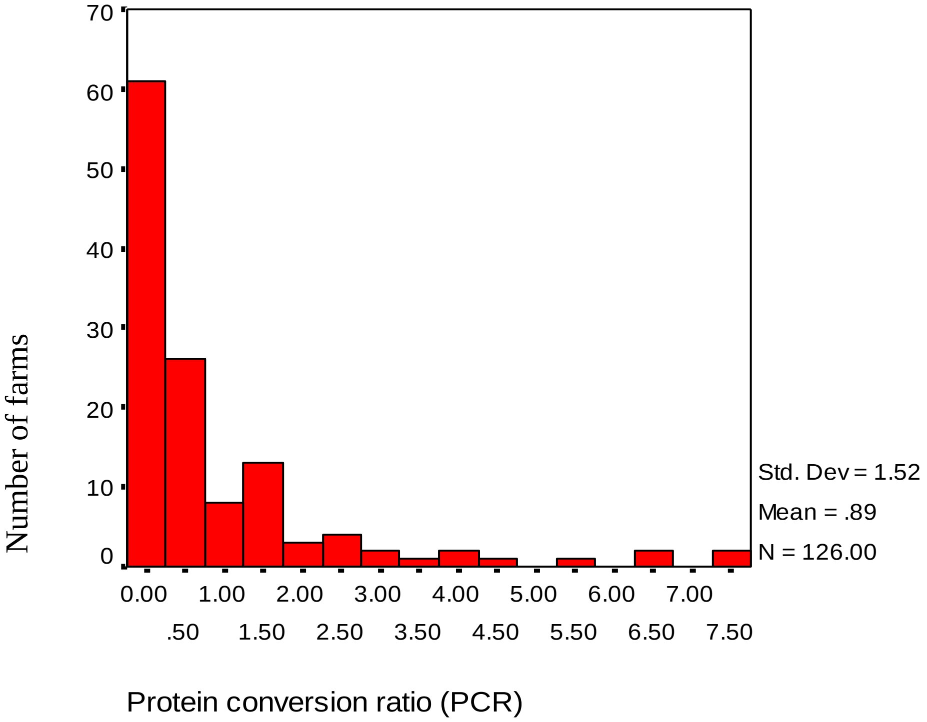


Figure 19 – Frequency chart of PCR



7.4 Summary

This section has established that the employment generating potential of aquaculture in the study area varies considerably by farm type – both in the composition of employment created (on or off the farm) and its volume. Altogether, we find that on-farm activities dominate the employment effect of aquaculture, and, consequently, that farm types that are directly labour-intensive are more likely to increase regional employment. It is worth noting, however, that in some cases, the on-farm labour for peak periods to carry out tasks such as harvesting or dyke maintenance is not provided by the local communities. Instead, it is brought in by absentee operators keen to use people they can trust. This serves to limit the positive regional benefits of aquaculture to rural coastal areas. With regard to food security, the results should be treated with caution as there is great variability across the sample that prevents us from reaching definite conclusions. However, it appears that aquaculture, altogether, makes a positive contribution to dietary protein production in the study area, and that extensive systems tend to outperform semi-intensive ones in this regard.

Although the results demonstrate that there is heterogeneity in various social indicators across farming systems, farm type 3 (low-input labour-intensive systems) stands out by performing well in several respects. For this group of farms, the average size is small (four hectares) and labour is the most important factor of production. While this farming system generates the smallest employment effect, the large on-farm labour use more than compensates so that type 3 farms generate the most employment. This farm type also accounts for the largest net surplus of dietary protein, owing to its limited use of external protein-rich feeds.

The favourable conclusions that we reach for this model of low-input aquaculture contrast with the results of the economic analysis in the previous section. There, it was shown that farm types 1 (extensive polyculture) and 2 (semi-intensive prawn-oriented polyculture) were achieving the highest levels of economic performance. Thus, there is a possible tension between the objectives of economic efficiency and social equity, which will be explored further in paper 3 by deriving compromise solutions. We now turn to the analysis of the ecological and environmental properties of the five farming systems under investigation.

8. Ecological indicators

8.1 Introduction

There is some evidence from the highly aggregated green accounting methods used by the United Nations statistical division that the Philippine economy grew between 1988 and 1994 in a manner that was environmentally sustainable (Bartelmus, 1999). Indicators that monitor an entire economy are helpful for monitoring general progress towards the ideal of sustainable development, and particularly when used to mitigate optimistic development diagnoses based on GDP. However, such indicators do not reveal the problems of specific sectors and, thus, can be of limited practical value in guiding policy.

In this context, this section introduces indicators of the three areas of environmental and ecological concern that can be linked to the management of fishponds in the Philippines. These correspond to: the issue of coastal natural resources appropriation, which we propose studying with ecological footprint analysis; the problem of eutrophication, which we approach by an analysis of the nutrient balance of the farms; and the issue of pesticide use. This section introduces each indicator in turn and includes the following: an introduction to the theory that motivates the choice and use of the indicator; a review of other studies that have employed the indicator (where appropriate); a detailed explanation of how the indicators are calculated; and, finally, the results, which are analysed across farming systems.

8.2 Ecological Footprint

8.2.1 Introduction

The ecological footprint is a biophysical accounting method of the appropriation of natural resources by different human enterprises that was initially introduced by Rees and Wackernagel (1992). The concept has huge intuitive appeal, largely through the strength of the imagery associated with the footprint metaphor, the size of which determines the degree of pressure that human beings impose on their environment.

The ecological footprint has found particularly wide usage in the study of aquaculture systems for a variety of reasons. Firstly, the use of natural resources and generation of wastes by aquaculture, particularly of prawn and salmon, have concerned ecologists for many years (Bilio, *et al.*, 1981; Brown, 1989; Primavera, et al., 1993; Primavera, 1995; Roberts and Muir, 1997; Naylor et al., 2000). Secondly, the natural resources used by aquaculture are generally appropriated from highly sensitive ecosystems in the coastal zone, where changes as a result of human pressure can be observed within short time horizons. This is in comparison to other human activities, such as car use, for which the impacts have longer gestation periods spread over wide areas, and, thus, entail greater degrees of complexity and uncertainty in their measurement. Thirdly, one of the rationales for aquaculture is that it can help ameliorate the plateau or decline in wild fisheries yields. However, many of the inputs required by, and undesirable joint products from, aquaculture can add to the stresses faced by the capture fisheries. The ecological footprint has been seen as a useful tool to highlight this paradox.

8.2.2 The ecological footprint method

The ecological footprint method begins with the identification of all the major direct and indirect material and energy inputs and outputs used and produced by a system of interest. These input and output flows are then quantified where possible, and the most complex stage of the method then involves their subsequent conversion into a commensurate unit: the ecosystem area. In particular, this last step requires ecological study to inform the conversion, based on average productivities for the inputs of interest from their source ecosystems (e.g. marine coastal shelf, agricultural field, mangrove stand). The subsequent summing of ecosystems areas gives an overall indicator of total ecosystem support to the system. Thus, the total supporting ecosystem area to a system needed to maintain ecological equilibrium is known as the ecological footprint. A number of important limitations and assumptions apply to the conversion and summing stages, which we discuss in the next section.

Ultimately, the ecological footprint can be expressed in two ways. Most studies have used the ratio of shadow ecosystem area to physical area of system (Larsson *et al.*, 1994; Wackernagel and Rees, 1996; Kautsky *et al.*, 1997; Folke, *et al.*, 1998; Ronnback, *et al.*, 2003). This places emphasis on the technologies involved in production. However, in the case of production systems for a single product, Bunting (2001) argues that shadow ecosystem area per unit of product is the most helpful measure for comparative analysis. This latter formulation creates similarities with life-cycle assessment (LCA), a broad methodology that treats the product as the object of analysis, and aims to incorporate the many different kinds of environmental impact involved in the production and consumption of the product 'from the cradle to the grave' (Heller and Keoleian, 2003; Papatryphon *et al.*, 2004).

Expressing the ecological footprint using the Bunting formulation allows for high levels of resource appropriation to be off-set by high levels of productivity. A farming system with low impact and low productivity would give similar results to a system with high impact and high productivity. Therefore the hectare per kilo formulation can be considered an indicator of ecological efficiency – a concept that is fundamentally different from that conveyed by the original ecological footprint (Stoorvogel, *et al.*, 2004 represents a recent example of a paper that measures ecological efficiency rather than absolute impact). Given the fact that we have accounted for the productivity of the production systems elsewhere, and, given the multiple-output nature of brackish water aquaculture, we favour the original formulation – thus ecological footprints are expressed as hectares of coastal ecosystem per hectare of fishpond.

In an ideal case, all inputs and waste products would be convertible into a corresponding ecosystem area, allowing full accounting. However, in practice, some are difficult, if not impossible, to incorporate. For example, mineral resources are conceptually difficult to footprint as are many types of wastes (Tyedmers, 2000). A careful examination of the limitations of the method is therefore in order.

8.2.3 Limitations and assumptions underlying the ecological footprint

Van den Bergh and Verbruggen (1999) offer a rigorous critique of the method. First, regarding the usefulness of the method, they object to the exaggerated claims made on behalf of the ecological footprint (EF) that it can reveal (un)sustainability on its own.

As they point out, “a single aggregate indicator like the EF does not allow for trade-offs among the three central dimensions of ecological economics’ evaluation, i.e. efficiency, equity and sustainability” (Van den Bergh and Verbruggen, 1999, p. 64). At a more practical level, they suggest that the hypothetical nature of the calculated land areas makes communicating the results of the analysis to the users difficult.

Second, implementation of the EF is fraught with practical and conceptual difficulties. Hence, the aggregation of different kinds of land-use inherent to the method is problematic, and often relies on weightings that are often not made explicit. Van den Bergh and Verbruggen (1999) also object to the treatment of energy in most applications of the EF (land areas are calculated to sequester carbon, in a manner completely incompatible with marginal thinking in economics), and the arbitrariness of the scales at which the EF is calculated (e.g. global, regional, national, cities). Finally, they argue that trade can, in principle, spatially distribute the environmental burden among the least sensitive natural systems and that the EF thus “has an anti-trade bias” (Van den Bergh and Verbruggen, 1999, p.67).

We share the concerns expressed above and propose the following in an attempt to limit their significance. The ecological footprint is only one indicator in our study, alongside economic, social and other ecological indicators, and does not support on its own any claims regarding the sustainability of alternative farming systems. Further, only one broad category of land is used in the analysis (mudflats / seabeds / mangroves), which, thus, justifies the implicit equal weighting of each hectare of land input in the calculations. Finally, what we attempt is only a partial calculation, but, hopefully, one that is free from many of the problems associated with more ambitious applications of the EF (e.g. Tyedmers, 2000).

8.2.4 Applications of the ecological footprint method to aquaculture – a review

The ecological footprint and its use for sustainability assessment are reviewed by Deutsch *et al.*, (2000), and, with a specific focus on seafood production, by Folke, *et al.* (1998). A study of particular relevance for this project is Larsson *et al.* (1994) who calculate the ecological footprint for the resources required to sustain production in semi-intensive shrimp farms in Columbia. Their findings are highlighted in Figure 20 below, which shows that the mangrove nursery function for the production of post-larvae creates the largest dependence of shrimp production on natural ecosystem. Illustrating the uncertainty and difficulties that surround the method, the authors give wide estimates corresponding to the upper and lower bounds for the abundance of gravid spawners and post-larvae, their dependence on the mangrove, and the efficacy of their capture by collectors. Establishing a functional relationship between mangroves and other inter-tidal habitats as nursery areas for fisheries appears particularly difficult, but critical to the results of the analysis. This challenge was tackled by many other authors who subsequently included the results in various kinds of ecological and economic appraisal (Primavera, 1998; Ley, *et al.*, 1999; Ronnback *et al.*, 1999; Barbier, 2000; Stevenson, 2002).

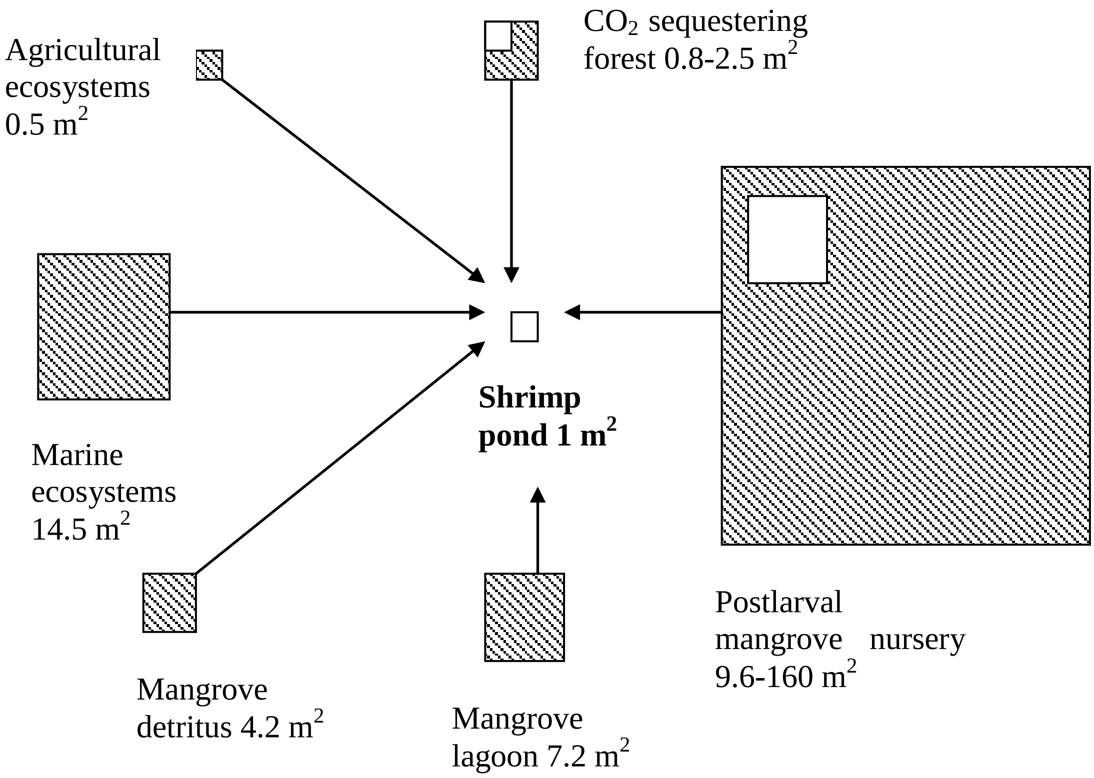


Figure 20 – Ecosystem areas appropriated for each square meter of semi-intensive shrimp farm in a coastal mangrove area, Bay of Barbacoas, Columbia (Larsson, *et al.*, 1994, redrawn in Folke *et al.*, 1998). Where the values are expressed as a range, the smaller white squares represent lower bounds for the estimated area, and the larger grey squares the upper bounds.

A related study establishes, based on a case-study in India, that each prawn hatchery is dependent on an estimated 455 hectares of mangroves for the supply of spawners (Ronnback *et al.,* 2003). The paradox is, of course, that the demand for spawners by the hatcheries is driven by coastal prawn aquaculture ponds that occupy the same mangrove areas on which the supply is dependent.

In a different context, Kautsky *et al.* (1997) compare two distinct farming systems for the production of tilapia in Lake Kariba, Zimbabwe: intensive cage culture and semi-intensive pond culture. Their calculations suggest that cage culture in the lake is appropriating resources at a much greater rate than pond culture in the areas around the lake, and suggest that the stress placed on the lake ecosystem by tilapia cage culture violates minimum conditions for sustainability.

Finally, Tyedmers (2000) employs the Bunting formulation of the ecological footprint to compare salmon production from aquaculture and wild fisheries. The results indicate that both farmed Atlantic and Chinook salmons have a larger total ecological footprint than any of the five commercially harvested species considered in the study. For instance, at over 12.5 and 16 hectares per tonne respectively, farmed Atlantic and Chinook salmons impose a much heavier pressure on the environment than wild caught Sockeye, Chub and Pink salmons – the footprints of which are all under 6 hectares per tonne (Tyedmers, 2000). Demonstrating the usefulness of the approach, the author simply concludes that the biophysical costs of production are greater for farmed salmon than for wild caught salmon.

Finally, this literature review establishes that there are currently no published studies on the ecological footprint of polyculture production systems – a gap that the current study aims to fill.

8.2.5 Footprint calculations

This section calculates the area of resource appropriation for prawn fry and for shell collections, in hectares of coastal ecosystem per hectare of farming system. Hence, this is only a partial calculation of the total ecological footprint of the farm, owing to the difficulty in obtaining data for footprinting other inputs, such as milkfish fry, crab fry, other feed inputs and fertilisers. However, this partial calculation is relevant as it indicates appropriation of coastal resources in the areas around the ponds. This local footprint is in contrast to some of the global calculations that have been carried out for aquaculture when impacts as diverse as greenhouse gas emissions and energy use in plastics, building materials, and other indirect inputs have been included in the calculation (Tyedmers, 2000). Conversion of all these diverse impacts into non-equivalent ecosystem areas and their subsequent aggregation make the interpretation of ecological footprint results difficult.

In addition, the local nature of the resources that are included in this analysis mean that the results can be interpreted as being strongly linked to local environmental carrying capacity – a concept that is becoming much more widely used in aquaculture as production sites proliferate (Kautsky *et al*., 2000; Ronnback *et al.*, 2003). As an informal indication of the relevance of this concept of local environmental capacity, one interview with a Municipal Agrarian in one of our study areas revealed that fishermen often complain about the effects of trawling for shells[8] on their fishing. The trawling has two main ecologically disruptive impacts: it directly disturbs the benthic ecosystem on the floor of the rivers and estuaries, and it generates large quantities of bycatch. A particularly important component of the bycatch is the fry of commercially important, low-value species on which the municipal fisheries are dependent. Hence, there is competition for alternative uses of the ecosystem, which creates social tensions. In fact, fishpond operators, being so dependent on the shells, often intimidate the fishermen and flout municipal ordinances banning the trawling for shells in particular waters, in a context where the Department of the Environment and Natural Resources (DENR) does not have the resources to enforce the ordinances. We now turn to the the analysis of the empirical results.

8.2.5.1 Prawn fry

We use the values calculated in the study by Ronnback *et al.* (2003) for the productivity of the *P. monodon* spawner collection industry in mangrove areas in Bangladesh, and for the productivity of hatcheries in producing viable postlarvae fry from the spawners. Their estimates are expressed as ranges between lower and upper bounds and are presented in Table 20 below.

Table 20 – Footprint of *P. monodon* postlarvae.

	Spawners per hectare of mangrove	Spawners required by hatcheries to produce 1 million post-larvae	Hectares of mangrove required per 1 million post-larvae
lower estimate	0.9	6.7	6.00
upper estimate	1.8	14.1	25.4

Source: Ronnback *et al.* (2003); Ecological field study and interviews with hatchery operators.

8.2.5.2 Small shells

Following Tyedmers (2000), we employ the methods of Pauly and Christensen (1995) to explore the relationship between primary productivity and fisheries yield. The unit of account for primary productivity is carbon, and the primary productivity required P to support the marine organisms consumed as feeds in aquaculture is given by:

$$P = (M/W)*10^{(T-1)} \qquad (12)$$

where P is expressed in grams of carbon fixed; M denotes the wet weight mass (g); W is the ratio between wet weight and carbon content; and T is the trophic level at which the organism feeds (where autotrophs are assigned a value of unity). This equation assumes an average transfer efficiency between trophic levels of ten percent

In the case of the small live shells fed to tiger prawns, all the organisms[9] are herbivorous and therefore have a trophic level of two. The percentage carbon for bivalve species is in the region of 40 to 50 percent of total weight, based on which we assume a value of two for W.

The shells feed on phytoplankton suspended in the water column, and reside on the bottom of the river, where they can be harvested using trawl gears. The area of ecosystem support required is calculated by dividing the value of P by an estimate of the average rate at which carbon is fixed (i.e. the net primary productivity - NPP) in the supporting coastal ecosystem (Tyedmers, 2000, p. 47). Following Tyedmers (2000), such an estimate is derived from Longhurst, *et al.* (1995) who list NPP estimates for 57 discrete biogeochemical provinces encompassing the oceans of the world. Complicating the analysis, the Philippines lie at the boundary of three of Longhurst's provinces, referred to as China Seas Coastal (CHIN); Western Pacific Warm Pool (WARM); and the Kuroshio current (KURO) that has its origin to the east of Luzon and flows up towards Japan. The primary production rates for these three provinces are presented in Table 21 below.

Table 21 – Primary productivity in oceanic provinces bordering the Philippines.

Domain	Province	Primary production rate (g carbon m^{-2} day^{-1})	Primary production rate (g carbon m^{-2} yr^{-1})
Coastal	CHIN	1.70	619
Westerlies	KURO	0.53	193
Trades	WARM	0.22	82

Source: Longhurst *et al*. (1995)

We use data for the CHIN province because the fisheries that supply the aquaculture sector with feeds are coastal or estuarine. There is uncertainty in identifying boundaries between provinces in the coastal domain because "the processes that force or constrain algal blooms are more diverse than in the open oceans: river plums, bathymetric features, bottom roughness, tidal fronts, tidal mixing, local (mountain gap) extreme wind stress, shelf break and coastal upwelling and downwelling. Even this list does not exhaust the possibilities." (Longhurst *et al*, 1995, p.1258). We are sure that the coastal waters of the Philippines are some of the most productive in the world, and therefore justify using the CHIN province data. This province is ranked 6th most productive out of 57 global provinces.

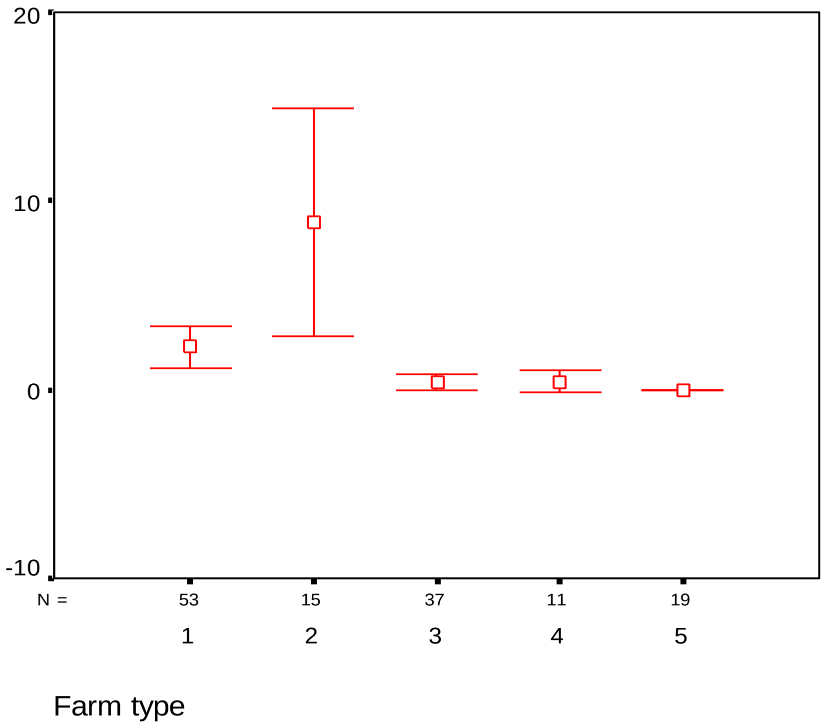
Thus, the ecosystem area to support the production of one kilo of small shells is calculated as:

Shells footprint = Productivity required (P) / Primary Production rate (CHIN)
$= (1000 / 2 * 10^{(2-1)}) / 619$
$= 8.08 \text{ m}^2 \text{ kg}^{-1}$ (13)

8.2.6 Results

The results of the ecological footprint calculations by farm type are given in Figure 21. They should be interpreted as conservative estimates, based on the use of generous figures for the primary production rate (i.e. the highest primary productivity of three possible coastal provinces was used in calculating the footprint for the harvested small shells), and the productivity of spawners from mangroves (i.e. the lower estimate from the paper by Ronnback *et al*. 2003).

Figure 21 – Ecological footprint estimates by farm type for two inputs: small shells and prawn fry



In central Luzon, the extent of brackish-water aquaculture development has led to a situation in which there are virtually no unexploited semi-natural areas in the inter-tidal zone. As Figure 21 shows, farm type 2 (semi-intensive prawn polyculture), depends on ecosystem support from these areas at the average rate of 8.9 hectares per hectare of farming system for feed and prawn fry inputs alone, with the ratio for some farms reaching 50. Thus farming systems of this type are forced to appropriate resources from areas outside of the region, owing to overexploitation in the region where the ponds are situated. This result seems plausible and has important, as well as practical implications, as illustrated by an anecdotal example. The recent development by a prominent local aquaculture entrepreneur of a business that "imports" shells from outside the region has recently been observed. These shells, harvested in the large freshwater lake Laguna de Bay and elsewhere, are transported by truck to Pampanga province, and finally distributed to caretakers working for the operator or sold to other fish farms. Thus, these systems are appropriating resources from other stressed ecosystems at low cost to the prawn aquaculture operators through vertical integration of the supply chain.

At another level, and although not directly related to our footprint analysis, there would also appear to be a critical shortage of gravid spawners in the wild, in part due to the appropriation of their nursery areas by aquaculture ponds. This endogenous feedback within the broad aquaculture system is perhaps obvious to an ecologist, but it has not been recognised to any significant extent by fish farmers themselves, or by the Philippine government. Further, the problem is unlikely to disappear in the future as complete domestication of the *P. monodon* life-cycle is not imminent.

Going back to the ecological footprint analysis summarised in Figure 21, the low / zero values of the indicator for farm types three to five indicate that fry and wild-caught feed requirements for these systems are met exogenously to the ecosystems where the ponds are situated. Thus, these production systems do not create the same endogeneity problem where the success of the ponds is dependent on the health of ecosystems that are destroyed to produce them. This is an important conclusion in planning new sites for aquaculture, although it does not mean that these apparently more environmentally friendly farming systems do not appropriate coastal or marine resources – rather, they do so in a diffuse manner (i.e, from seas across the nation, and, for the case of imported fish meal and milkfish fry, from other nations).

8.2.7 Summary

Owing to data constraints and its land-based orientation, the ecological footprint concept is difficult to operationalise for comparative study. In the current case this is particularly problematic for inputs relating to milkfish fry. Milkfish aquaculture depends on the same kinds of coastal resources as prawn-oriented systems, but calculating the ecological footprint for milkfish fry is difficult because the milkfish are not mangrove-dependent to the same extent as prawns, and thus cannot be intercepted for ecological study. Therefore, any comparison of farming systems with different milkfish and prawn orientations is likely to be biased against the prawn-oriented systems owing to the impossibility of calculating ecosystem support areas for milkfish production. However, the ecological footprint has been useful in the current study in highlighting the farming systems (particularly farm type 2) that have intensified to the point where their resource needs cannot be met by the local ecosystems.

8.3 Nitrogen Balance

8.3.1 Rationale

The nutrient balance of the farm is proposed here as a means-based measure of the likely contribution of the farming system to eutrophication in the coastal zone. In systems terms, nutrient balance represents an indicator of the pressure applied to the coastal ecosystem by the farming subsystem. However, it should be recognised at the outset that this indicator is likely to be particularly site-specific in its relevance and importance, because the effect of the release of nitrogen by a farm depends on the local context. That is why, as Sumagaysay-Chavoso and San Diego-McGlone (2003) note, discharge limits should not only be set per unit of output, but, instead, on the total amount of aquaculture production activity in a given area: “Even if stocking density is low for one farm, an increasing number of farms may exceed the environmental capacity of certain receiving water” (Sumagaysay-Chavoso and San Diego-McGlone, 2003, p.416).

Regarding the causes of nitrogen emissions from fish farms, Handy and Poxton (1993) suggest that excessive pollution may arise from poor farm management rather than the volume of metabolic output (i.e. faeces production). Poor farm management, in this instance, refers to an inability to adjust the diet regime in order to ameliorate the effects of post-feeding excretion . Applying this to the Philippine case, given the simple rules of thumb that constitute the management regime instructions passed on to the caretakers from the operators, it might be unrealistic to expect anything but “poor management” in the case of excretion and nutrient waste management. When combined with the degree of crowding of the ponds (there is little else but fishponds covering certain municipalities), and the numerous other sources of organic discharge (e.g. human houses, sugar and alcohol industry processing), nutrient enrichment (eutrophication) is likely to be a problem. Its consequences are described by Merrington *et al.* (2002, p.29) as follows:

- Changes in nutrient levels may affect the species composition of algal communities, with knock-on effects to other animals in the aquatic/marine food chain;
- Decomposing algae and weeds can deoxygenate water causing fish mortality;
- Algal blooms are often responsible for taints and problems with filtration in surface-drawn public water supplies, thereby increasing the cost of purification;
- Surface algal blooms detract from the appearance of waters and impair their amenity value;
- Some algal species produce ecologically-disruptive toxins which can also be hazardous to humans.

Phosphorus is the other nutrient, alongside nitrogen, that may be instrumental in the eutrophication of coastal waters as it is the stoichiometry (i.e. the ratio of abundances of the two chemical species) in particular that is the reason for changes in the algal communities. However, nitrogen is often used as the metric to measure the ecosystem disturbance resulting from agricultural and aquacultural practices (Martin, *et al.*, 1998; Janssen, 1999; Wijnhoud, *et al.*, 2003).

8.3.2 Method

Data on the proximate analysis of all feed inputs to and outputs from the farms in the sample were collected when possible from secondary sources, and were derived from primary analysis when necessary (for two species of small shells – see proximate analysis results in Table 19). For each farm in the sample, the following formula was then used to calculate the nutrient balance, which is self-explanatory:

$$(N_{feeds} + N_{ferts} + N_{fry} - N_{outputs}) \text{ / Farm size = Nutrient balance (kg N/ha/yr)} \qquad (14)$$

8.3.3 Results

The results of the analysis of the controllable nitrogen flows by farm type are given in Tables 22 and 23 as well as Figure 22. These results show that feed is the main source of nitrogen to the ponds for all farm types, with the exception of farm type 1, for which it is fertiliser. Further, a comparison of the means of the N-loss using ANOVA shows that there are statistically significant differences across the farm types. However, one-way ANOVA using Scheffe's post-hoc test does not yield statistically significant differences in multiple comparisons, except between farm types 1 and 2 (at the 10% level).

Semi-intensive prawn-oriented polyculture (farm type 2) shows particularly wide within-class variation, yielding a large 95 percent confidence intervals for the mean (Figure 22). Some individual farms even have zero or negative nutrient balances (i.e. they actually remove nutrients from the inflowing water), although the means are positive for all farm types. The within-type variability for farm types 1, 3, 4 and 5 is quite low, therefore suggesting a strong association between farming system and nutrient efficiency. Farm types 1 and 3 have the best results for this indicator with mean values just above zero, whereas farm type 2 (semi-intensive prawn polyculture) has the highest mean value but is highly variable within-type.

Table 22 - Descriptive statistics for the indicator of total nitrogen loss (kg N per ha per yr)

Farm type	N	Mean	Std. dev.	Std. error	95% C.I. for mean		Min	Max
					Lower bound	Upper bound		
1	53	20.0	66.9	9.2	1.6	38.5	-49.9	365.0
2	14	231.9	732.00	195.6	-190.8	654.6	-74.5	2760.7
3	35	49.9	54.9	9.3	31.0	68.8	-28.7	185.4
4	11	121.1	84.9	25.6	64.1	178.2	5.1	272.5
5	19	167.5	139.6	32.0	100.2	234.8	-37.4	483.4
Total	132	80.1	253.7	22.1	36.4	123.8	-74.5	2760.7

ANOVA

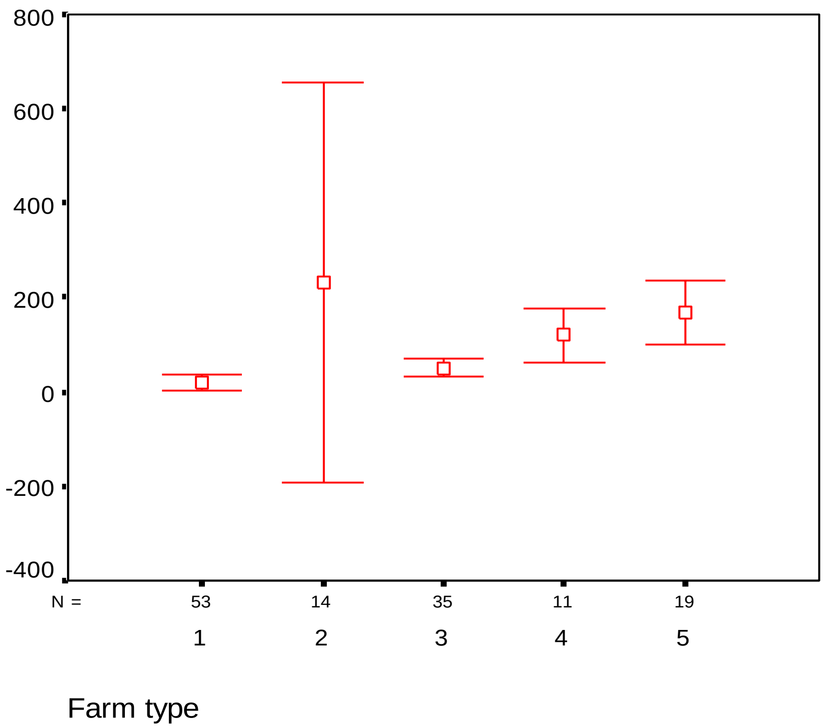
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	709417.1	4	177354.3	2.916	.024
Within Groups	7724105.7	127	60819.7		
Total	8433522.7	131			

Table 23 – Breakdown of the results of the nutrient balance indicators by farm type.

Farm type		N content feeds kg/yr	N content ferts kg/yr	N content fry kg/yr	N content of output kg/yr	total N loss (kg N / ha / yr) NITROGEN BALANCE INDICATOR
1	Mean	98.55	199.58	8.18	124.33	20.04
	Std. Error of Mean	27.44	76.28	1.34	18.68	9.18
2	Mean	492.66	32.02	5.03	70.34	231.90
	Std. Error of Mean	311.71	24.55	1.44	24.78	195.64
3	Mean	18.15	378.15	4.68	74.36	49.91
	Std. Error of Mean	6.85	110.09	1.92	22.49	9.28
4	Mean	1703.09	4251.59	66.32	1089.95	121.13
	Std. Error of Mean	1147.57	1140.70	40.18	293.14	25.61
5	Mean	509.47	1264.76	15.57	407.83	167.53
	Std. Error of Mean	282.33	528.97	8.24	161.94	32.03
Total	Mean	311.89	720.15	12.83	226.63	80.09
	Std. Error of	112.76	159.03	3.78	42.09	22.08

	Mean					

Figure 22 – Nitrogen balances for each farm type.



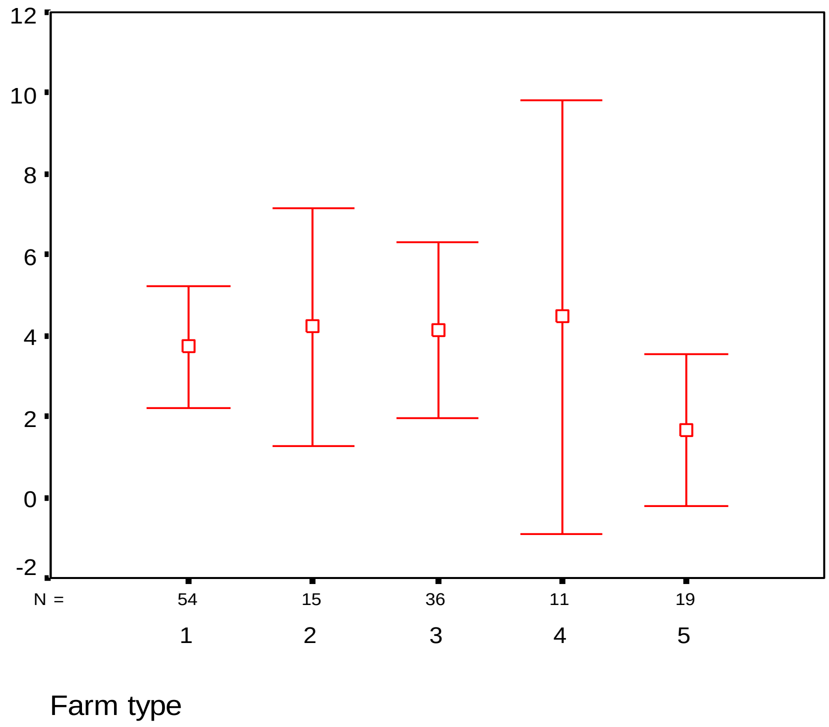
8.4 Pesticide Application

A number of different pesticides are used in aquaculture, ranging from extremely toxic chemical compounds, such as sodium cyanide or Brestan, to less toxic, semi-natural, plant-based compounds, such as tobacco dust. Figure 23 summarises the application rates derived from the farm-level survey. There would seem to be no clear technological basis for pesticide application, in the sense that the application rate is not explained by farm type, as indicated by wide confidence intervals and little differences in mean values across farm types.

This somewhat surprising result may be explained by a methodological problem. There is a major issue of commensurability with the calculated indicator because the products used on the farms differ greatly in terms of their toxicity. Using some kind of index of toxicity would provide a more satisfactory way of aggregating pesticides (as suggested in Maud *et al.* (2001)).

Although our analysis is limited, it is clear that there are potentially serious human health and environmental issues associated with the more toxic pesticides, which should be a source of concern because their legal status under municipal and national laws remains ambiguous. For instance, sodium cyanide application would seem to have been banned for use on fishponds but is freely available in local markets (imported from Taiwan or South Korea) and employed on 90 percent of farms in our Central Luzon sample. Brestan is also an illegal piscicide, but operators were open about its use, particularly in Western Visayas. It would seem as though laws designed to protect the marine environment and the workers on fishponds are not enforced in any meaningful way.

Figure 23 – Mean and 95% confidence intervals for pesticide application rate (kg/ha/yr) by farm type



8.5 Summary

The ecological footprint methodology was applied to two inputs to the farms: prawn fry and the small shells used as feed. We find that a conservative estimate of the coastal resource appropriation by semi-intensive prawn polyculture farms falls in the range of ten hectares of coastal ecosystem per hectare of fishpond. This highlights the pressures that these kinds of aquaculture systems place on the environment in other areas indirectly, and, often, some distance from the ponds. However, the use of the ecological footprint as a comparative indicator proved difficult owing to the conceptual challenge of footprinting milkfish fry inputs.

Pesticide use does not vary significantly by farming system, in contrast with the situation in agriculture where the rate of pesticide application is usually correlated to the choice of variety (high-yielding versus traditional) and overall intensification level.. Thus, pesticide application as calculated in this section is not a useful indicator for comparative analysis of sustainability in the current study.

It therefore seems that the nutrient loss to the environment, measured from partial nitrogen budgets, represents the most useful indicator for comparing the ecological impacts of different fish farming systems, as well as the trade-offs that might exist between ecological impact and socio-economic properties of these system. Applications examining these trade-offs, considered in paper 3, will thus only use this indicator to measure ecological performance.

From the results of the nutrient loss indicator, we find that farm types 1 (extensive polyculture) and 3 (low-input, labour-intensive systems) are the most environmentally sustainable.

9. Conclusion

We have built up a picture of the complexity of the brackish-water farming aquaculture systems defined in paper 1 through the use of indicators that provide information on specific economic, social and ecological objectives. Our findings are summarised in Table 24 below, that demonstrates that a number of trade-offs appear to exist at the farm-level among these objectives.

Table 24 – Summary table of results from all indicators

	Type 1 – Extensive polyculture	Type 2 – Semi-intensive prawn-oriented polyculture	Type 3 – Low-input labour-intensive systems	Type 4 – Large milkfish-oriented systems	Type 5 – Semi-intensive milkfish monoculture
Costs	Average	High	Low	Average	Average
Revenues	Average	High	Low	Low	Average
Gross margin	Average	High	Low	Low	Average
Price Risk	High	High	Low	Low	Low
Overall Risk	Low	High	Average	High	High
Revenue Diversity	High	High	Average	Low	Low
Prawn Mortality	High	High	Low	High	N/A
Technical Efficiency	High	Low	Average	High	Average
Total Employment Effect	Low	Average	High	Low	High
Net Dietary Protein Production	Positive	Negative	Positive	Zero	Negative
Protein Conversion Ratio (input:output)	<1	>1	<1	<1	Approx. = 1
Partial Ecological Footprint (ha ecosystem / ha fishpond)	Approx. = 2	Approx. = 9	<1	<1	Zero
Nitrogen loss	Low	High	Low	Average	High
Pesticide Application	Average	Average	Average	Average	Low

Such a trade-off can be illustrated by the properties of farming system 2 (semi-intensive prawn-oriented polyculture). These farms return high levels of profit on average (as indicated by high gross margins), and have a positive but fairly average potential on local employment. However, they perform poorly on a number of other indicators, including overall and price risks (high), technical efficiency (low), net dietary protein production (negative), ecological footprint (large), and rate of nutrient loss (high).

Another example corresponds to the low-input labour-intensive system (farm type 3). These farms have high positive employment effect, a positive dietary protein production, and low ecological footprints and nutrient loss, but return only low levels of profit. Altogether, it is not possible to identify a preferred farming system, which justifies the trade-off analysis developed in the next paper.

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Appendix 1

a) Wild-fry gatherers

Calculated using data from Ahmed et al (2001) from five gathering sites and from interviews with 42 gatherers. Thus n=42. The fry season is split into two periods – Peak season for 4 months March-June, and off-peak season for 8 months July-February.

	Number of gatherers	Hrs gathering / day	Daily production (fry per gatherer per day)	% survival	Live fry per hr
Peak	6	6.8	950	94	131.3
	10	5.5	960	98	171.1
	16	5.5	1136	96	198.3
	1	3	150	95	47.5
	9	6.3	1744	98	271.3
Off-peak	6	1.2	68	99	56.1
	10	1.2	67	99	55.3
	16	1	109	98	106.8
	9	1	90	98	88.2

Peak season mean productivity = 194 fry/hr

Off-peak season mean productivity = 83 fry/hr

Assuming an 8-hour working day, and allowing for the seasonal variation in productivity, we calculate (194*8*17/52)+(83*8*35/52) = 954 fry / person day

b) Small shells

From the results of interviews with four teams of collectors of small shells in Sasmuan, Pampanga, we estimated 40 “coolers” of shells per two-person team in a 5-hour collecting period. Each “cooler” (a large polystyrene container) contains 30 kilos of shells. Thus, an average of 600 kilos are produced per person per 5-hour working day, which is 960 kilos per 8-hour day, corresponding to 1.04 person days per metric tonne of shells.

c) Commercial feeds

A visit to a well-known commercial feed-mill in region 3 gathered the following data. The feed-mill operates 24 hrs, with workers on 3-shifts of 8 hours each. The number of people employed at the factory is 155, all full-time. Output is 5.5 tonnes per hour, therefore, we estimate:

155 / (5.5*24) = 1.17 person days / tonne

d) Hatchery fry

A visit to one of the hatcheries in Zambales province that provides fry to fishponds in region 3, gathered the data. The hatchery has 4 “runs” per year and each run produces an average of 10 million prawn fry. There are 6 full-time employees. Thus we estimate:

6 / 40 = 0.15 FTE / million fry.

Assuming 300 person days / year for FTE workers, we therefore estimate:

0.15*300/1000 = 0.45 person days per thousand fry.

e) Fingerlings

The coefficient for fingerlings were calculated by adding an additional labour-input to the hatchery fry estimates, to account for the period when the fry is nursed through the first few weeks of its life-cycle, and correcting for mortality. On the basis of three interviews with fingerling producers, we obtained the estimate of 7.1 person days / thousand fingerlings. However, this estimate has a high degree of error associated with it, owing to vastly different coefficients for the three operators.

Endnotes

[1] The details of the sampling procedure used in this survey are given in paper 1, but we draw on some summary statistics from this survey here.
[2] The Gini coefficient is the summary statistic most commonly reported to measure inequality at the country level (Stiglitz, 1993). Gini coefficients are bound between 1 and 0, where 1 represents perfect inequality (in this case, all the land is operated by one person) and 0 represents perfect equality (all farms are the same size).
[3] Alternatively, the technical efficiency relation can be described with respect to output, i.e. achieve the maximum possible output for a given level of inputs.
[4] Except for farm type 5, which is necessary in order to avoid singularity problems. Hence, farm type 5 is chosen as a reference to which efficiency levels of other farm types are compared.
[5] From Kodde and Palm (1986).
[6] This is an imputed value based on market prices.
[7] Personal observation; Jurgenne Primavera, personal communication.
[8] As should be clear from previous discussion, the collected shells are used as feed in aquaculture.
[9] Possible identifications include *Dosinia (Phacosoma) troschel* or *Katelysia hiatina* for "*Gasang*"; *Telescopium telescopium* or *Clypeomorus coralium* for "*Suso*" (Springsteen and Leobrera, 1986)

Research project R8288: Assessing the sustainability of brackish water aquaculture systems in the Philippines – Paper 3/5

Analysing trade-offs among indicators of sustainability: a multi-criteria approach

Abstract: *A number of recent papers in agricultural economics and related literatures have considered the trade-offs associated with particular development projects or programmes. We briefly review this literature and propose a methodological framework for analysing sustainability at the farm-level using subjective, local weights and objective, positive sustainability indicators. More specifically, this paper uses the measures of six sustainability indicators to examine the relative merits of five aquaculture pond farming systems in the Philippines. We employ a discrete-choice multi-criteria decision-making model that calculates the distance of alternative farming systems to a utopian point – an unfeasible but approachable point where all objective functions are maximised. We apply our analysis to a number of scenarios using sets of weights from two barangays elicited during a series of focus group discussions (FGDs) with particular stakeholder groups.*

We find that extensive polyculture is the preferred farming system under most conditions, and that very large milkfish-oriented systems perform poorly in our analyses. We interpret these findings with reference to qualitative data gathered during FGDs and examine the implications with regard to the inclusion of aquaculture under existing agrarian reform legislation – from which aquaculture has been exempted for over 15 years.

Contents

1. Introduction

We have thus far approached the analysis of sustainability, in papers 1 and 2, by defining specific objectives in economic, social and ecological realms. We have established that no single farming system maximizes all of these objectives. Thus, the normative problem of choosing one system over another necessarily involves trade-offs among objectives and this paper will present various ways of analysing such trade-offs in a discrete choice setting. We start by reviewing applications of trade-off analysis and multi-criteria decision making frameworks in agriculture, paying particular attention to a technique called compromise programming. We go on to describe participatory exercises in two case-study *barangays*, used to elicit the weights, or “importance coefficients” (following Munda, 2004) that are necessary for compromising among objectives. Rankings for the five farming systems are then established using each set of weights and the implications of the results are finally discussed.

2. Trade-off Analysis

2.1 General framework and previous applications to agriculture, natural resource management and aquaculture

The idea of trade-off analysis is simple and relates to the negotiation of competing objectives in a socio/political-economic manner. However, its translation into a practical methodology takes a variety of forms. For instance, some authors consider multiple values (in the societal sense), associated with achievement of each of the objectives (e.g. Brown *et al.*, 2001, Munda, 2004). That is, there is a recognition that different groups of people have different priorities. Other authors, whose work still falls under the general heading of trade-off analysis, present a purely technical analysis of the opportunity costs (to the other objectives in the problem) of achieving maximisation in any one objective (e.g. Bouman *et al.*, 1998; Lu and van Ittersum, 2004; Stoorvogel *et al.,* 2004). Another distinction relates to the general dichotomy in the literature between what can be described as “algorithmic” and “soft” approaches to conflict resolution (hereon compromising).

The algorithmic approach considers preferences to be modelled by the use of real-valued weights (that sum to unity) and are founded on substantive rationality. That is, the quality of the decision is the most important factor in determining the validity of the methodology. Applications of this method can be found in Kobrich (1997) for peasant farming systems in Chile, and El-Gayar and Leung (2001) who applied the method to aquaculture in Northern Egypt. This latter case is of particular relevance, and the authors considered three objectives in their model: total protein, foreign exchange, and employment generated by aquaculture. The authors found that freshwater supply and ricebran were limiting factors to the development of aquaculture in the region, although policy implications for their findings are unclear. The choice of an appropriate policy instrument to realise changes in the development of the industry requires further study to include a firm-level model.

Softer approaches to compromising are based on a procedural rationality where the quality of the process under which the decision is made is the most important factor by which a methodology should be judged (Martinez-Alier *et al.*, 1998; Roth, 1999). This approach is typically founded on a discursive ethics (O'Hara, 1996) where deliberation is held to be the ultimate democratic principle to which policies should abide (O'Neill, 1997). Applications of this softer form of multi-criteria approach include Brown *et al.* (2001) who sought compromises among stakeholders in the context of the establishment of a marine protected area, and Gregory and Wellman (2001) who consider alternative management plans for an estuary in Oregon, USA. In both of these successful applications, we find that a dual emphasis on deliberation and analysis provides significant benefits including generating a sense of local ownership of the results.

Our analysis in this paper is quantitative, and there is an overall positivist epistemology underlying it. However, in using focus groups and matrix scoring exercises in our case-study barangays, there is a degree of geographic specificity to the analysis. The results are thus not generalisable to the country-level, but in an important sense, this is the kind of philosophy required to usefully carry out work with the concept of sustainability. Local imperatives are important and we believe that the subjective assignment of weights to a positivist set of sustainability indicators combines the strengths of both algorithmic and soft approaches to trade-off analysis.

2.2 Discrete choice pay-off matrix

We now examine five models of aquaculture farming systems, based on the typology exercise presented in paper 1. The decision problem takes each of these farm types as discrete “options” for land-use in the brackish-water zones. Thus, we overlook the determinants of within-type heterogeneity and examine the differences in mean scores for each of six indicators[1]: profit, nutrient balance, employment, technical efficiency, risk and net protein production. Our analysis then aims at establishing the relative performance of these farming systems, as opposed to their absolute performance as would be measured with reference to standards or thresholds.

The first step of the analyses involves the definition of a pay-off matrix, which, in our discrete choice setting, is simply a 6x6 matrix of levels of the six indicators mentioned above. When a given objective is maximised (across the five options) the pay-off is the corresponding achievement of the other indicators for that farming system. Reading the matrix, in Table 1 below, each of the row elements are maximized in turn and the column elements correspond to the percentage achievement of each objective for that farm type. For example, reading the first row, when profit is maximized, nutrient balance achieves only 9 per cent of its maximum, employment 62 per cent and so on. Further, from the presence of ones on non-diagional positions in the table, it can be inferred that the nutrient balance and risk objectives are maximised for the same farming system. The same applies to the pairing of protein production and employment.

Table 1 – Pay-off matrix for six objectives

Pay-off when z is maximised (%)

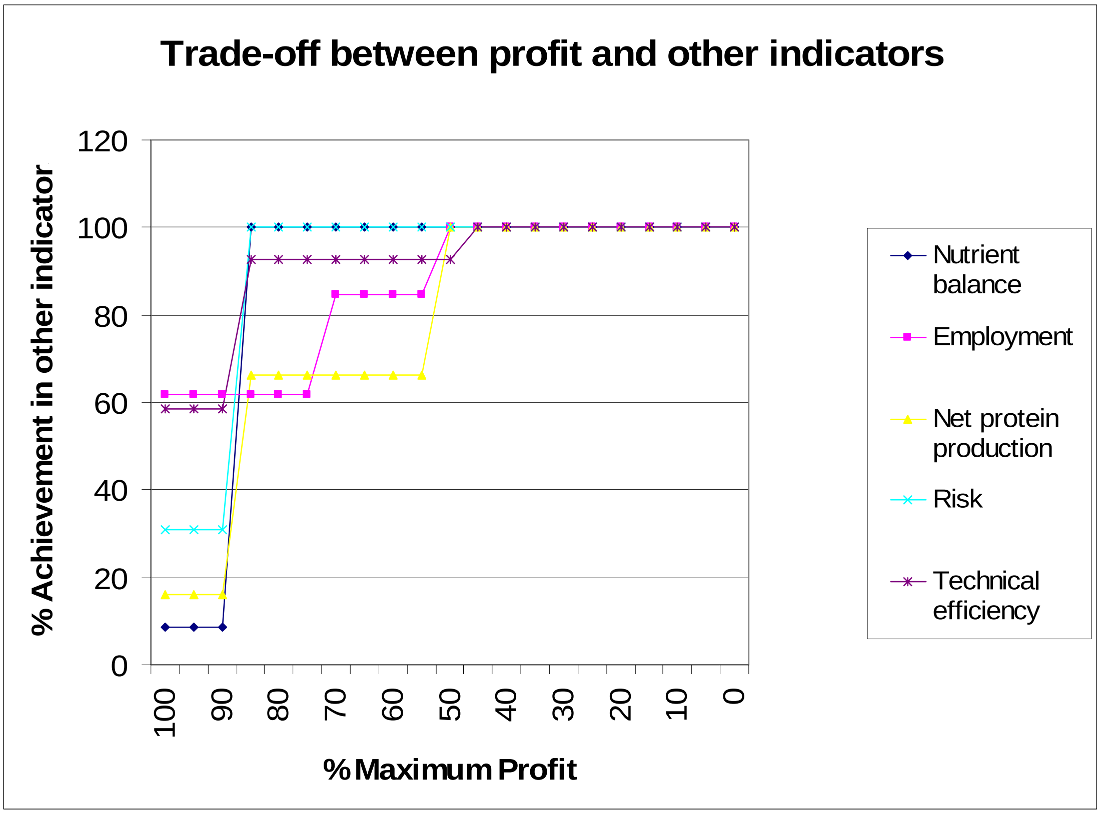
Objective to maximise (z)	Profit	Nut Balance	Employ-ment	T.E.	Risk	Protein Production
Profit	1.00	0.09	0.62	0.58	0.31	0.16
Nut balance	0.87	1.00	0.37	0.93	1.00	0.66
Employment	0.50	0.40	1.00	0.77	0.49	1.00
T.E.	0.47	0.17	0.38	1.00	0.34	0.48
Risk	0.87	1.00	0.37	0.93	1.00	0.66
Protein production	0.50	0.40	1.00	0.77	0.49	1.00

Thus, for nutrient balance versus risk (in row 2) and protein production versus employment (in row 6), there is no trade-off. However, for other objectives, it is clear that significant trade-offs exist. Of particular note is the relationship between profit (the major motivating factor of operators) and the other objectives (which are important to different stakeholder groups). This is the subject of the following section.

2.3 Trade-off analysis between profit and other objectives

The pay-off matrix suggests that there are significant opportunity costs (i.e, in terms of other objectives) to the maximisation of profit. In order to gain further insight into the relationship between profit and these other objectives, we gradually relax (in 5% intervals) the profit objective, from its maximum, as a constraint in the individual maximization of the other objectives. Figure 1 presents the results of these calculations.

Figure 1 – Trade-off analysis between profit and other indicators



As we move from left to right along the horizontal axis, acceptable profit, expressed as a percentage of maximum profit, decreases. For each five percent decrease in profit, the largest level of the other indicator, expressed as a percentage of its own maximum, is calculated. Thus, at 100 percent profit, the values for the other indicators in Figure 1 are the same as those reported in the top row of the pay-off matrix, which corresponds to the results for farm type 2 (semi-intensive prawn-oriented polyculture). As we reach 85 percent of maximum profit, there is a significant increase in the feasible achievement of several other objectives (risk, technical efficiency, nutrient balance, and protein production). These results are achieved by farm type 1 (extensive polyculture). Thus we find that a relatively marginal decrease in profit, from its maximum level, generates potentially significant benefits in terms of the other objectives.

The finding of relatively large non-economic benefits of "nearly optimal" economic solutions is consistent with that of Lu and van Ittersum (2004). Their application (to policy objectives on the Loess plateau, China) is based on a continuous choice problem, but the methodology is essentially the same – the discrete choice problem can be considered a special case of their continuous choice example. Figure 1 also shows that some indicators trade-off more significantly against profit than others – employment and net protein production achieve their maximum feasible values on a farming system (type 3, low-input labour-intensive systems) that has only 50 per cent of maximum profit.

These findings demonstrate the relevance of employing multiple criteria in a decision problem, as it shows the opportunity costs of a narrow focus on optimisation of a single criterion. Using compromise programming models as a means to reconcile the conflicting objectives, we can show how the relative merits of particular production systems are dependent on the weights placed on each of these objectives.

3. Compromise Programming Models

3.1 Introduction

Compromise Programming refers to a family of methods that seek compromise solutions to problems with multiple objectives. The central motif is an upper or lower reference point, which is unfeasible (owing to conflicts among objectives) but approachable. From this family of methods, the nomenclature of which lacks standardisation, we use a weighted distance function method, where alternatives are assessed according to their distance to an ideal or "utopian" point, where all objectives are maximised. The choice of a utopian point based method lies on the rationale that sustainable development is often considered a utopian concept, where economic, social and ecological objectives are not conflicting.

Central to the approach is Zeleny's axiom of choice which states that:
"Alternatives that are closer to the ideal are preferred to those that are farther away. To be as close as possible to the perceived ideal is the rationale of human choice." (Zeleny, 1982, p. 156). This axiom can be considered an alternative to the basic traditional structure underlying choice problems in economics, which can be described in a simplified setting by:

$$\underset{(x1,x2)}{Max}\, Z(x_1, x_2) \tag{1}$$
subject to $T(x_1,x_2) = k$

where (x_1,x_2) represents a vector of choice variables for the decision-maker. This can be a basket of commodities in consumer theory, or a vector of outputs in a joint production problem (Ballestero and Romero, 1998). $Z(x_1,x_2)$ is the utility function for the decision-maker, and $T \leq k$ represents the feasible set. Thus, economic rationality is usually defined in terms of maximising a consistent and transitive function such as $Z(x_1,x_2)$ subject to the satisfaction of the feasible set. The information required to carry out such an analysis is formidable for an individual, and, as a result, economists rarely deal with empirically elicited utility functions, and, even less frequently, with empirical social utility functions (Ballestero and Romero, 1998). The connections between the traditional utility paradigm and compromise programming are explored in Ballestero and Romero (1991, 1994).

The exposition of the basic compromise model that we now present is based on Glaser (2002). Note that the following two sections include continuous citations of selected passages from this work between pages 23 and 73.

3.2 The general vector-optimisation model

The decision-maker considers $K \geq 2$ objectives (criteria), with each individual objective function z_k having its own dimension $[d_k]$ $(\forall k \in \mathsf{K}:=\{1,\ldots,K\})$, where K is a so-called index set which contains the indices of all K objectives. Together they form the vector-value objective function z(x) which is to be maximized. Thus, K objectives are to be maximised simultaneously and we have the general vector optimisation model (VOM):

$$\max_x \{z(x) \mid x \in X\}$$

$$\text{with } z: \Re^N \rightarrow \Re^K;\ x \mapsto z(x) := \begin{pmatrix} z_1(x) \\ \vdots \\ z_K(x) \end{pmatrix} \tag{2}$$

The objective function now returns a vector for each alternative (x) from the set of feasible alternatives under consideration (X), and the feasible region of the objective space of the VOM,

$$Z^{(VOM)} := \{z(x) \mid x \in X\} \subset \Re^K \tag{3}$$

which is a K-dimensional subset of $\Re^K$. Whereas for each individual objective function z_k $(\forall k \in \mathsf{K})$ a total order of X is still given, and thus, the individually optimal objective-function value or individual optimum

$$z_k^{\otimes} := \max\{z_k(x) \mid x \in X\} \qquad (\forall k \in \mathsf{K}) \tag{4}$$

as well as the set of individually optimal solutions

$$X_k^{\otimes} := \{x \in X \mid z_k(x) = z_k^{\otimes}\} \neq \emptyset \qquad (\forall k \in \mathsf{K}) \tag{5}$$

exist for every objective, the same is generally not true for z, for it only implies a partial order of X on $\Re^K$. The definition of an ordered set is a binary relation which has certain properties (reflexivity, transitivity, anti-symmetry). In the case of a partially ordered set, there may be elements that are incomparable, which is the case with $Z^{(VOM)}$. Only in the rare case that at least one alternative x_{perf} exists which maximizes all objective functions at once[2], can the decision problem (VOM) be solved at this stage. All such alternatives

$$x_{perf} \in X_{perf} := \bigcap_{k=1}^{K} X_k^{\otimes} \quad (6)$$

are called perfect solutions, since they attain the ideal objective vector or utopian point

$$z^{\otimes} := (z_1^{\otimes}, \ldots, z_K^{\otimes})^T \quad (7)$$

Objectives partaking of this property are called complementary, because attaining the optimum of one objective does not diminish the objective function values of the others, i.e. there is no trade-off between objectives. However, the entire basis of the MCDM paradigm is that problems usually exhibit conflicting objectives, or, in other words, that they do not have any perfect solution ($X_{perf} = \emptyset$). In that situation, Glaser (2002) recommends the following two-stage procedure to derive a solution :

- Filter – A check is made for non-dominance among the alternatives. Any dominated alternative is simply discarded at this stage.

- Compromise – Reconcile the conflict in (VOM) by means of a compromise, with the aim of finding the best compromise solution among the alternatives.

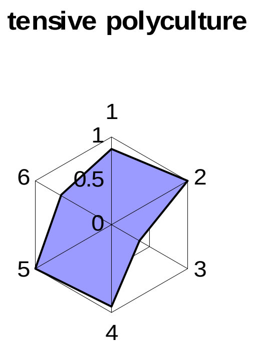
These two steps are explained in details and implemented to analyse the properties of our fish farming systems in the following sections.

3.3 Non-dominance filter

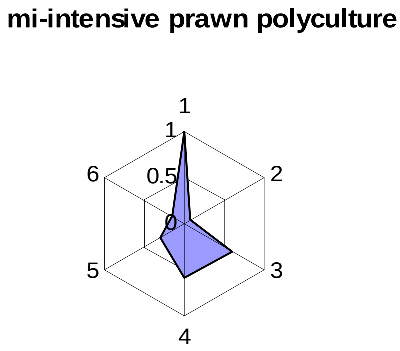
Some alternatives in the compromise programming model may be Pareto-dominated because the model does not feature any inherent efficiency component. Thus, in a first step, it is necessary to carry out an initial check to eliminate the alternatives that are dominated. In a discrete choice setting such as ours, this task is straightforward and best performed visually by drawing radar diagrams, as presented in Figure 2. The diagrams establish immediately that none of our alternatives is Pareto dominated by others. Hence, there is no obviously 'best' and 'worst' farming system among the five alternatives considered here. We note, in particular, that although type 5 (semi-intensive milkfish monoculture) provides no maximal element, it could potentially become an optimal choice under a particular combination of weights. Altogether, application of the non-dominance filter does not allow us to eliminate any of the alternatives, and Figure 2 makes clear that the choice of a particular farming system for the brackish waters of the Philippines involves some difficult trade-offs, which we analyse further through the use of a compromise model.

Figure 2 - Radar plots of the six sustainability indicators by farming system. Each of the six points measures one of the indicators, expressed as the percentage of the individual optimum for this indicator. The following notation is used: 1=Profit, 2=Nutrient loss, 3=Employment, 4=Technical efficiency, 5=Risk, 6=Net protein production

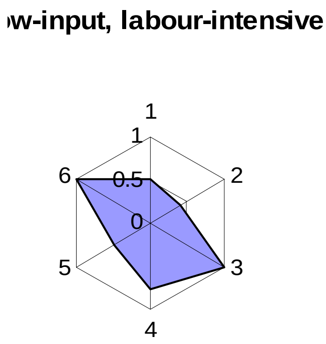
Type 1 -



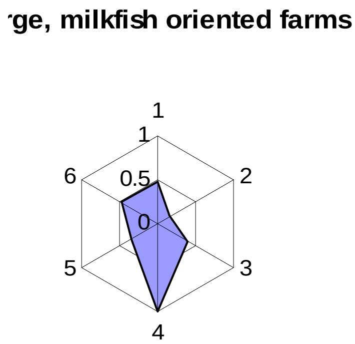
Type 2 -



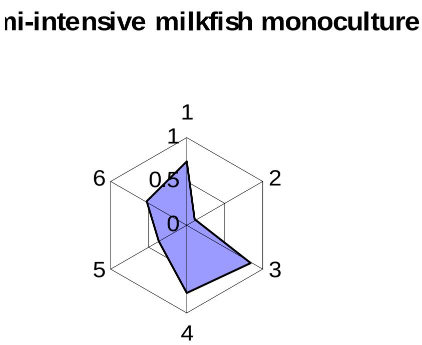
Type 3 -



Type 4 -



Type 5 -



3.4 Compromise model

A compromise model (CM) can simply be described by the following mathematical problem:

$$\max_x \{\psi(z(x)) \mid x \in X\} \qquad (8)$$

The transformation of the objective vector in (8) is referred to as scalarisation. The additional preference information with regard to the vector of objective functions *z*, as chosen by the decision maker, finds its expression in the scalar real-valued compromise functional, which is a function of functions:

$$\psi: \Re^K \to \Re; z(x) \mapsto \psi(z(x)) \qquad (9)$$

This compromise function is usually parametised. Our study uses methods that require the choice of a vector of weights *w* and parameter *p* to complete the specification of the distance function, as explained in details below. In that case, the specific compromise function (ψ) can be either a weighted objective function (otherwise known as weighted sum), or a weighted distance function, which is actually a family of specific functions that use different *p* metrics. If the compromise optimum $\psi* := \max\{\psi(z(x)) \mid x \in X\}$ exists, then an optimal solution of (CM) $x* \in \arg\max\{\psi(z(x)) \mid x \in X\}$ is called the best compromise solution with respect to (CM). Further, z*:=z(x*) is a compromise-optimal objective-function vector.

In the current study, we employ a distance function that minimizes the distance of objective-function vectors in $Z^{(VOM)}$ to the utopian point $z^{\otimes}$.

Next, we define a distance function d^{∇} that fulfils the axioms of non-negativity, identity, symmetry and sub-additivity. The L_p-norm with parameter $p \geq 1$ is employed to measure the distance of a vector z_k to the utopian point $z^{\otimes}$. It takes the following specific form:

$$d^{\nabla}_{p,w}(z^{\otimes}, z(x)) := \begin{cases} \left(\sum_{k=1}^{K} w_k((z_k^{\otimes} - z_k(x))/(z_k^{\otimes} - z_k^{\bullet}))^p\right)^{1/p} & 1 \leq p < \infty \\ \max_k \{w_k((z_k^{\otimes} - z_k(x))/(z_k^{\otimes} - z_k^{\bullet}))\} & p = \infty \end{cases} \qquad (10)$$

Expression $z_k^{\bullet}$ defines the opposite of the utopian point, or anti-ideal point, which is a vector of minimal elements. While some compromise methods use this anti-ideal point as a Lower Reference Point (LRP), and aim to maximise the surplus distance achieved above the LRP, here the argument ($z_k^{\otimes} - z_k^{\bullet}$) is merely used as a way of normalising distances. This is the normalisation procedure suggested in Ballestero and Romero (1998, p.20) and the result is a dimensionless distance that is not dependent on the unit of measurement. The method therefore overcomes the problem of incommensurability of individual attributes (Zeleny, 1982) through the use of relative, rather than absolute, deviations. Thus, apples and oranges are happily considered in the same problem.

When p=1, d^{∇} gives the weighted absolute differences (sometimes referred to as the Manhattan metric as it calculates distance in the same manner as someone navigating city blocks). When p=2, d^{∇} gives the familiar Euclidean distance. When p = ∞, d^{∇} gives the Tchebycheff norm, which is applied to the weighted absolute differences. In both forms of function d^{∇} in equation (10), $w \geq 0$ and $1^{T}w = 1$, and these weights *w* are used to express the importance of each objective in the decision problem.

3.5 Utopian and anti-ideal points for brackish-water aquaculture

The decision problem consists of x=5 alternatives (farming systems) and k=6 objectives (sustainability indicators), and the corresponding data can therefore be conveniently summarized in a 5x6 matrix. The weights (w_k) applied to each indicator come from participatory exercises carried out in two *barangays* in the Philippines between June and August, 2004. The process of eliciting these weights is detailed in the following section and a number of scenarios for (CM) are then modelled, based on the information gathered in these exercises.

The utopian and anti-ideal points are given in Table 2 below. The objectives which are to be minimised (i.e. N loss and Risk index) are used in their inverse form in the compromise model. Thus all objectives in the compromise model are to be maximised and all distances to the ideal point are to be minimised. As we can see, the utopian and anti-ideal points differ substantially, which gives meaning to the analysis.

Table 2– Utopian and anti-ideal points in the compromise model

	Mean Profit in PhP/ha/yr (max)	N loss in kg/ha/yr (min)	Total Employment effect in person days/ha/yr (max)	Net protein production in kg/ha/yr (max)	Risk index (min)	Technical efficiency estimate (max)
Utopian	59065	20.0	411.2	53.2	0.169	0.748
Anti-ideal	27845	231.9	150.7	8.6	0.546	0.437

4. Elicitation of the weights in the compromise programming model

4.1 Presentation of the communities

The Philippines has a highly devolved structure of governance. The first step on the governance ladder is that of the *barangay*, which is derived from a pre-Hispanic social unit of 30 to 100 families owing allegiance to one chief (McCoy and de Jesus, 1982). In contemporary Philippines, the *barangay* remains an important social construction and source of identity. Each *barangay* has an elected captain and council that meet to discuss issues such as policing, peace-keeping, and applications for infrastructure projects from the municipality and higher levels of government. Owing to population growth, this social entity is now often as large as 500 families, a register of which is kept in some form by the *barangay* secretary. When a *barangay* becomes unmanageably large in population terms, it may be split in two.

The *barangay* was chosen as the unit of analysis for the current study and two were selected for detailed study, one from region 3 (Barangay Sapang Kawayan, Masantol, Pampanga) and one from region 6 (Barangay Nanding Lopez, Dumangas, Iloilo). Both *barangays* are remote and their landscapes are dominated by fishponds. Brief descriptions of both *barangays* follow (see more details in paper 4):

- Barangay Sapang Kawayan (SK) is a rural community under the jurisdiction of the municipality of Masantol in the Pampanga province of Region 3. Masantol is classified as 'partially urban' and has 32,464 registered voters (National Statistical Coordination Board, 2004). The community of SK is located to the South of Masantol proper and is only accessible by boat (one hour from Masantol and 20 minutes from another town, Haganoy, in the nearby province of Bulacan). It is surrounded by fishponds and river systems and has a total land area of 265 hectares (Provincial Agriculturalist's Office), which supports a population of 2,676 individuals in 559 households (2000 National Statistics Census).

- Barangay Nanding Lopez (NL) is located in the municipality of Dumangas, province of Iloilo (Region 6). Three major rivers traverse the area and the *barangay* is almost bounded by water except for a strip of land that connects it to the rest of the municipality. About 97 per cent of the 797 hectares of land in the *barangay* are occupied by fish ponds and discussions with key informants suggested that aquaculture and fishing represented the two main sources of livelihood for the population of 1,359 individuals (as of 2003).

In paper 4, we estimate the extent of poverty in five coastal barangays in the Philippines, including those studied here. We find the extent of poverty as measured by the common head-count index to be high in both Sapang Kawayan (59%) and Nanding Lopez (44%) (see Table 3 below). The "poverty gap" measure, which considers the severity of poverty by taking into account the distance of each household to the poverty line, further indicates that the depth of poverty is fairly similar in the two communities. Finally, the head count index measured at the food threshold reveal a high incidence of extreme poverty in both barangays (35% in SK and 36% in NL).

Table 3 – Aggregate income per capita and poverty incidence in case-study barangays

	Income per capita (PhP/yr)			Poverty Incidence		
Barangay	Mean	Median	S.D.	Head Count	Poverty Gap	Head Count (Food)
SK	17,214	14,633	12,134	0.59	0.26	0.35
NL	18,381	17,974	11,639	0.44	0.21	0.36

4.2 Eliciting importance coefficients from focus group discussions

Members of the two *barangays* were invited as participants in a series of focus group discussions (FGDs). This was arranged informally through two research assistants staying in the *barangays* for an extended period (at least one month): Portia Villarante (with help from Maggie Babay) in Sapang Kawayan, and Arnold Tanoy in Nanding Lopez. It was possible for the research assistants to become familiar with the community and its members as a result of their stay and to gather additional information based on the anthropological nexus of immersion, participation and recording. Three groups were identified as being representative of a cross-section of the interests in each *barangay*:

- *Barangay* council
- A group of men, with various livelihoods
- A group of women, with various livelihoods

The *barangay* council are an elected body and thus have a remit to represent the interests of the community. However, the positions on the council may be disproportionately comprised of those from higher social classes, which provides the rationale for considering separate groups of men and women with diverse interests and no formal access to power. The genders were separated to allow for gendered perspectives to emerge and to prevent domination of the discussion by the men in the group. For Nanding Lopez, only the results of the *barangay* council FGD are available for inclusion in this analysis owing to a problem with the research assistant working in that community.

Each FGD was comprised of between 8 and 12 members, and had the following structure:

1. Introductions
2. Background information on the research project given to the group
3. Discussion of the positive and negative aspects of aquaculture in the area
4. Description of indicators by the research assistant to the group
5. Choice by the group of the 3 most important indicators
6. Matrix scoring of the chosen indicators by nominated representatives
7. Justification for the choice
8. Appeals / Changes by other members
9. Acceptance / Vote of the final result by the group
10. Snack and Soft Drinks
11. Thanks

The discussion in step (3) and throughout the course of the events were recorded and transcribed by the research assistants. Interesting quotes are used in the following sections to illustrate the group's rationale behind the choice of weights. The matrix scoring problem presented to the group in (5) and (6) consisted of first choosing which three indicators were most important, and then allocating 20 stones between 3 indicators to reflect their relative importance. This process is similar in spirit to the rapid rural appraisal (RRA) techniques pioneered by Robert Chambers (e.g. Chambers, 1997).

RRA is essentially applied common-sense in data collection, with the imperative of expression by the people of the full complexity of their situation. RRA is extractive, in the sense that an external research team are trying to understand a local situation and take the findings 'away' for analysis. This is in comparison to the recent development in the literature of what is described as a "participation imperative" (Sumberg *et al.*, 2003) whereby the expectation is for research groups to empower and facilitate action by local groups and individuals in directly improving their situtations. Thus RRA has evolved into PRA – participatory rural appraisal. Whatever their divergence may be in terms of epistemology, there is a shared, implicit code of conduct for research groups in carrying out what might be potentially divisive, intrusive activities. As Chambers writes:

"Empirically…the recurrent finding with PRA has been that if the initial behaviour and attitudes of outsiders are relaxed and right, and if the process can start, the methods of PRA themselves foster further rapport. Early actions by outsiders can include transparent honesty about who they are and what they are doing; and participation in local activities, especially being taught and performing local tasks. Personal demeanour counts, showing humility, respect, patience and interest in what people have to say and show; wandering around and not rushing; and paying attention, listening, watching and not interupting. Having confidence that 'they can do it' and transmitting that confidence, again and again enables local people to get started with activities like participatory mapping, diagramming or matrix scoring. Then they quickly lose themselves in the activity and are often pleased and proud of what they find they know and can do." (p.134 Chambers, 1997).

In most cases, the group immediately decided on the first one or two indicators that should be chosen, with some debate between members about the final choice. Different members were able to reallocate the stones to the three indicators if there was disagreement on the weights, and in some cases the issue was put to a vote. Given that $1^T w=1$ and $w_k \in [0,1]$, then each stone can be interpreted as representing a relative weight of 5 per cent.

4.3 Weights from the Barangay Council, Nanding Lopez

4.3.1 Focus Group Discussion

The group consisted of eight members of the *barangay* council: the *barangay* captain, six councillors and the *barangay* secretary. The main sources of livelihood for the participants, alongside stipends and privileges associated with their position on the council, were: the farming of a quarter hectare of ricefield; the operation of one hectare of fishpond; river fishing; the sale of medical supplies; tricycle driving (own vehicle); and '*sari-sari'* storekeeping (two instances). The group also included the housewife of a fisherman.

The initial discussion provided the following main insights:

- Absentee operators bring in their own labourers from the city (Iloilo) so that the benefits from aquaculture in those cases do not accrue locally. The group would like more family-oriented aquaculture in which the operator lives on the farm and uses family and local labour.

- Milkfish-oriented farming systems are favoured over prawn production because the group perceive more work to be available on milkfish ponds than on prawn-oriented ponds. They also know that it is possible to enter the milkfish ponds at the end of the harvest and gather stranded fish for their own consumption. Milkfish are left over after a harvest from a prawn polyculture pond, but in lesser numbers.

- Smaller landholdings would allow for local people to move into aquaculture, although the group believe that a minimum size of 10 hectares would be required to ensure the economically viability of a fish farm.

4.3.2 Matrix scoring

The group, in consensus, chose the following indicators: employment multiplier, technical efficiency, and ecological footprint. Employment was chosen immediately by all members. Technical efficiency was proposed by one member and the others agreed that to be technically competent was important, with the underlying motivation being that "outsiders" do not understand the local ecology in the same way and that absentee operators do not supervise their workers well. Ecological footprint was the last to be selected but was agreed upon, with reference to the local ecology.

Twenty stones were given to the group as markers to rank the three selected indicators. After the markers were placed by one nominated member, the group was asked again if they were satisfied with the ranking. The markers were re-allocated by another member, which changed the relative weight for each category but not the ranking. The rest of the group, however, did not agree and opted to return the markers to their original position. The member that changed the weights conceded and deferred to the "will of the group". The final distribution was as follows:

- employment multiplier 45%
- ecological footprint 30%
- technical efficiency 25%

In the modelling, the ecological footprint indicator is not used because it does not model the environmental impacts of milkfish farming owing to the problems in establishing appropriated areas (as described in paper 2). However, the group were reflecting environmental concern and the issues that they mentioned in justifying their choice of indicator centred around the impacts of the aquaculture systems on fishing. Pesticide application was perceived to be an issue, but none of the indicators address this issue as it has been shown that applications do not vary by farming system. Fish kills during periods when harvests occur were mentioned and these are likely to be due to oxygen depletion through nutrient enrichment from the effluent. Therefore, the nutrient balance is used in place of ecological footprint in this case, despite the group overlooking that indicator – most likely through not fully understanding the implications of nutrient enrichment and its links to ecological health. This is clearly a problem with participatory research and we recognise that the solution presented here is highly imperfect.

4.4 Weights from the Barangay Council, Sapang Kawayan

4.4.1 Focus Group Discussion

The group consisted of eleven members: the *barangay* captain, the youth council chairman, seven *barangay* councillors, the barangay treasurer and its secretary. Mostly composed of men, the group have diverse interests, with some of the members operatoring fish ponds, and others working as caretakers, labourers and fishermen.

The initial discussion yielded the following main insights:

- Family involvement in the operations of the fishponds is seen as very desirable. Some absentee operators do not trust local people to work as caretakers or even as hired labourers.
- The culture of milkfish is associated with the large farms in the area. The use of commercial feeds for the culture of milkfish is viewed negatively and is associated with deterioration in the local water quality. The following quotes illustrate this point, and are copied verbatim, with each group member identified by a number, rather than by name.

Group Member 1
Iyong mga noong araw, noong mga unang panahon natural feeding lang. Mga nilalagay lang lablab at lumot. Pero ngayon talagang gumagamit na ng feeds o feeding. Ang epekto naman ng feeding sa ilog papangit ito, ginagamit pa rin ito ng mga malalaking palaisdaan. Pinapatay talaga ng feeds ang mga isda na nasa labas ng fishpond, tulad ng mga nasa dagat. Naaapektuhan naman ang kabuhayan ng mga tao.
In the past, we have been using natural feeds for our farm, like the ‘lablab’ and ‘lumot’. At present, [fishponds] use commercial feeds. Although it is a fact that commercial feeds destroy the river, big fish farms continue to use them. As the polluted water, the effect of commercial feeds, descends to the nearby bodies of water, it affects our fish farms and kills fishes in the river and sea as well.

Group Member 2
Nakaksira talaga sa kalikasan.
It destroys the environment.

Group Member 3
Oo, sinisira talaga niyan kasi pinapatay ang mga isda ng tubig na mula sa labas – kahit nga pa pati ang dagat apektado na rin! Nababawasan ang kabuhayan namin.
Yes, it is true. The contaminated water wipes out the fishes – it even affects the sea! There is hardly any source of livelihood left for us.

Group Member 4
Apektado kami ng katas ng feeds supply.
We are affected by the overload of feeds supply.

and later…

Group Member 1
Malaki nga ang epekto ng feeds. Kaya nga kinausap ako ng Kaliwa noong araw na kailangan naming magtulong-tulong para diyan para matanggal ang feeds.
The use of commercial feeds has an enormous effect on the environment. There was a time that a Leftist group talked to me about abolishing commercial feeds in fish

farming. They told me that everybody had to help to stop the use of commercial feeds.

Group Member 5
Hindi na dapat nagpifeeds.
Totally stop the use of commercial feeds.

Group Member 6
Kasi sa panahon ngayon ay wala ng lablab. Lahat na lang nakadepende sa feeds. Kaya ang epekto sa ilog ay mas tumitindi dahil sa dami ng pakain.
At present, there isn't much lablab. Everybody depends on commercial feeds for their fishponds. The river suffers because of excessive use of feeds.

Group Member 7
Mas maraming feeds kasi mas maraming naghahanapbuhay parang mga mangingisda, pero ang dagat naman ang benta.
Most of us here depend on fishing for our livelihood, so more people use commercial feeds. But with this, we are taking the sea [nature] for granted.

- Rather surprisingly, technical knowledge, in the sense of formal education in fisheries or a related science, is seen as being unnecessary or even damaging:

Group Member 3
I want to discuss the technical knowledge of the fishpond operator. We experienced that some [operators] hired technicians to work in the fishponds years ago. Their income improved at first, but when the excessive use of pesticides caused pollution and eventually affected the quality of soil and water in [Sapang Kawayan], [we realized] that it's better for the fishpond to have caretakers instead of technicians. We have qualified caretakers [here]; they have years of experience and exposure to fish farming, which make them more qualified than technicians. Caretakers give the fishpond more income as well. The technicians know too much about pesticides, chemicals and commercial feeds, they apply it to fishponds. The quality of our soil was ruined because of too much use of chemicals. That is our experience here. The caretakers have intensive training on fish farming, they are in the fishpond come day and night; they are knowledgeable with the current of the water; they know the life cycle of the fishes. The water current [in this part] is different than the one in Batangas [a province in Southern Philippines] where it is more predictable. If it rains, water here become less salty, when high tide comes, salinity increases. The technicians are not well aware of that; they don't know that the salinity of water changes like that.

4.4.2 Matrix scoring

The group chose profit and employment immediately. The choice of the third indicator was between risk and ecological footprint. Risk was eventually chosen by the group following the rationale that variability in income affected the availability of work on the fishponds. The concerns regarding environmental and technical aspects of the farming system that were brought up in the discussion are not reflected in the choice of weights. The final distribution was as follows:

- profit 40%
- employment 25%

- risk index 35%

4.5 Weights from a group of men in Sapang Kawayan

4.5.1 Focus Group Discussion

The group consisted of six members of between 34 and 56 years of age: two fishpond operators, one man who collects small shells from the river to sell to fishpond operators and three labourers (whose work is mainly on fishponds). The initial discussion can be summarised as follows:

- The group believe that the amount of work available to them per hectare is the same regardless of the size of the pond.
- Prawns are favoured over milkfish because there is the perception that a lot of land is required to produce milkfish and that prawns offer the only possibility for smallholdings to profit.
- Fishpond operators and labourers alike seem to be reliant on the environment, particularly on the quality of the water in the rivers, for their livelihood. They recognise their dependency on this resource.

The following passages from the transcript are copied verbatim:

Group Member 1

Ako, maganda din ang #4, pero sa aming mga mahihirap, na umaasa na lang ng ikinabubuhay sa kalikasan, mas mahalaga ang #8. Kasi marami ang umaasa diyan, kung maganda ang lagay ng kalikasan, marami din ang magkakaroon ng pagkakakitaan.

The importance of #4 (technical efficiency) cannot be denied. But for poor people like us who depend on the environment for our livelihood, I think #8 (ecological footprint) is the most important of all. For me, the environment is really important because it is where many of us depend for our source of income.

Group Member 2

Sang-ayon na din ako diyan. Tutol din kasi ako sa mga ganyan na nakakasira sa kalikasan.

I agree with that. I strongly detest any [activity] that can harm the environment.

and later…

Group Member 3

Magbigay din sila ng puhunan. Kung kami ay may mauutangan, kahit ang mga maliliit na propitaryo, hindi naman sa lahat ng pagkakataon ay may kita. Kailangan na bigyan tayo ng puhunan ng gobyerno.

They should lend us money for capital. If we have [an institution] that will grant loan to small scale fishpond operators there will be more of us who will benefit from it. The government must provide us money for investment.

Group Member 1

Ang mga technical na kaalaman at magbigay ng atensiyon ang gobyerno sa #8 (kalikasan).

The government must help us increase our technical knowledge. They should give more attention to the effects of fish farming in our environment as well.

Group Member 4
Tama iyon. Dapat ay magbigay din sila ng mga seminar para mamulat ang mga tao dito sa epekto ng mga nilalagay sa fishpond sa ating kalikasan.
That's right. They should give seminars so people would be more aware of the effects on the environment of what they put in the fishpond.

Group Member 3
Bigyan ito ng atensiyon ng gobyerno, pagtuunang pansin ang pollution. Lalo na ang feeds sa mga bangus.
The government must give attention to water pollution, especially those which is caused by commercial feeds used in milkfish farming.

and later….
Group Member 3
Kasi ang #8 kapag hindi mo binigyan ng atensiyon at magpatuloy ang paggamit ng mga feeds at fertilizer masisira talaga ang kalikasan. Kawawa naman ang mga maliliit na namamalakaya na umaasa sa ilog.
If we give less importance to preserving the environment [as in #8 – ecological footprint] and continue to use commercial feeds and fertilizers, the environment will be destroyed and the fishermen who depend on the river for their livelihood will suffer.

Group Member 1
Lahat naman apektado diyan sa huli, hindi lang ang mga maliliit pati na rin ang mga may-ari ng malalaking palaisdaan apektado kung masira ang kalikasan dahil sa mga ginagamit nilang feeds.
All of us, not only those who rely on the river but also the big fishpond operators, will suffer if the pollution from commercial feeds destroys the environment.

4.5.2 Matrix scoring

The group, in consensus, chose profit, employment and ecological footprint. The allocation of stones to ecological footprint increased as the discussion continued to a final distribution as follows:

- profit 35%
- employment 15%
- ecological footprint 50%

As before, the issues discussed in relation to the ecological footprint were all on the subject of water quality and organic pollution – which are not covered by our analysis using the footprint indicator, but the translation of the word "ecological" was what the group were reacting to. The nutrient loss into the river was too technical a concept for them, but their concerns are in this area, rather than in resource appropriation (i.e. sink problems, rather than source problems). Therefore, nutrient loss is used for the scenario modelling.

4.6 Weights from a group of women in Sapang Kawayan

4.6.1 Focus Group Discussion

The group consisted of 10 women of between 26 and 50 years of age. All the women were only informally employed and some declared their husband's occupations (hired labourer on the fishponds or "Arawan"; caretaker on a fishpond; barangay captain). The initial discussions did not go well, as the women seemed unwilling or unable to abstract from the point of view of the operator to a wider societal perspective when it came to discuss feelings about the specific characteristics of farming systems (e.g. family orientation vs. absenteeism; milkfish vs. prawn orientation; large vs. small farm sizes). Most knew at least one fishpond operator, as part of their social network, and spoke on their behalf in relaying their experiences of these various characteristics.

However, the following insights were gained:

- Release of effluent as a result of high feeding rates was cited as a reason for the decline in fisheries yields from the rivers around the barangay.
- A negative feeling towards technical assistance from hired technicians from fisheries programmes predominates in the group, owing to the poor results achieved when a number of operators hired technicians (that is, fisheries graduates and / or consultants from SEAFDEC). Many operators hiring technicians went bankrupt, and the presence of technicians likely reflects an attempt to intensify production by the operators. It would seem as though the hiring of technicians coincided with the national crash in prawn production from Vibrio sp. diseases in 1994, and so the timing may have been unfortunate, but this is not recognised by the group. There is therefore a deep suspicion of anything other than local knowledge and experience in managing the ponds.
- Pesticides are perceived as being necessary and important in the functioning of the ponds. No mention is made of any health-related impacts of pesticides.
- Poor water quality is widely recognised within the group, with members of the group attributing it variously to fishpond effluents, factory pollution, and other upstream sources from neighbouring municipalities.

Regarding this last point, the following passage is copied verbatim from the transcript of the FGD:
Facilitator
Ano kaya ang pinakapangunahing dahilan ng water pollution? Ang factory ba na sinasabi nila na nakakaapekto sa mga tubig dito? O ang bangus feeds na nakakasira din?
What could be the major agent of pollution? The wastes from the factories that flows to the river or the feeds that the fishpond operators use?

Group Member 1
Yung feeds.
The feeds.

Group Member 2
Sabi ng iba yung factory.
Others say it’s the factory.

Group Member 1
Malayo naman sa atin yun. Kinakabahan nga ako sa polusyon. Basta hindi dito nagmumula ang polusyon.
The factory is far from here. I am worried with the pollution. It isn’t from here.

Group Member 3
Sa Apalit, doon nagmumula. Sa Hagonoy doon nagmumula.
Usually dirty water comes from Apalit or Haqonoy [neighbouring municipalities].

Facilitator
Pero nadoon karamihan ang masyadong nagfefeeds dito ng bangus?
Is that so because more fishpond operators there feed their milkfish? [These municipalities have a lot of semi-intensive milkfish monoculture in ponds and pens].

Group Member 1
Iyan siguro, dumadating na lang ang tubig dito na sa Sapang Kawayan.
That can be a reason - the water flows to Sapang Kawayan from there.

Facilitator
Dumadaloy lamang.
It flows from somewhere else.

Group Member 4
Hindi dito nagmumula ang polusyon.
The polluted water did not come from Sapang Kawayan.

Group Member 1
Dumadaloy.
It flowed from somewhere else.

Group Member 3
Kapag amoy dagat ay malinis.
If the water smells like salt, it's from the sea and it's clean.

Group Member 5
Naaamoy namin iyon.
We can smell that.

4.6.2 Matrix scoring

Profit and employment were considered the most important indicators. Ecological footprint was chosen by the group but their rationale was again based on nutrient balance issues, reflecting a misunderstanding of the meanings of the terms described. This situation is similar to that previously described in scenario 2. The markers were spread evenly across the 3 indicators, with 7 stones each to profit and employment and 6 stones to the environmental impact. Thus the distribution of weights is as follows:

- profit 35%
- employment 35%
- ecological footprint 30%

5. Compromise model results

5.1 All weights equal

The rationale behind using equal weights is that it is possible to establish a benchmark, where all criteria are considered. With the inclusion of profit, risk, and technical efficiency in the final list of six indicators, economic issues dominate in this scenario. The metric $p = \infty$ results in almost equal scores for all indicators as the maximisation operator considers the number of maximal elements (type 3 has two maximal elements, types 1, 2 and 4 have one each) and in the cases where there is one maximal element, the distance collapses to the weight attached to each indicator.

In this scenario, where six dimensions are considered, results for all three metrics are reported. Thus, in the scenarios when p =1 and p = 2, the rankings are the same, with farm type 1 (extensive polyculture) ranked highest by some distance. Farm type 3 (labour-intensive, low-input systems) ranks second, followed by semi-intensive milkfish monoculture, large milkfish oriented systems and, ranking last, semi-intensive prawn polyculture. As an overall balance of the six indicators used in the modelling exercises, farm type 1 would appear to be superior by some distance, and farm types 2 and 4 perform poorly.

Table 4 - Compromise model results when all indicators are given equal weights. The results under p values of the L_p metric of 1, 2 and ∞ are reported.

Indicator	Weight		
Profit	0.167		
N loss	0.167		
Employment	0.167		
Protein production	0.167		
Risk index	0.167		
TE	0.167		
	p=1	p=2	p=∞
Farm type 1 (distance)	0.304	0.105	0.167
Farm type 2 (distance)	0.767	0.364	0.167
Farm type 3 (distance)	0.482	0.180	0.156
Farm type 4 (distance)	0.745	0.341	0.167
Farm type 5 (distance)	0.617	0.222	0.161
Farm type 1 (rank)	1	1	3
Farm type 2 (rank)	5	5	3
Farm type 3 (rank)	2	2	1
Farm type 4 (rank)	4	4	3
Farm type 5 (rank)	3	3	2

As can be seen from these results, the distances (and subsequent rankings of farming systems) are sensitive to the *p* value in the L_p metric. In six dimensions, it is necessary to explore the range of possible metrics, as the properties of distances are not intuitive when the number of dimensions is greater than three. In the remaining four scenarios, only three indicators are chosen by each group, thus defining sets of weights in 3-dimensional space. The most intuitive *p* metric to use in this case is thus *p*=2, which defines the Euclidean distance (i.e. a straight line). Thus, in the remaining scenarios, only the results of the *p*=2 metric are reported.

5.2 Weights from the barangay council of Nanding Lopez

Farm type 3 (low-input, labour intensive systems) ranks highest. Smallholdings are not abundant in the areas around Nanding Lopez, where large landowning families dominate production. These large farms (farm type 4) rank poorly with the group. Employment is the most important consideration for the council when they think about aquaculture, as they know that for most of their constituents, the major benefit is being able to sell their labour to the pond operators. The issue of workers being brought in from outside the barangay by absentee operators is clearly one that upsets them. These results suggest that aquaculture as currently practiced in the area is not satisfactory to the group, and that other farming system types would be preferred.

Table 5 – Compromise model results from the weight set given by the barangay council, Nanding Lopez. Parameter p = 2.

Indicator	Weight	
Profit	0	
N loss	0.3	
Employment	0.45	
Protein production	0	
Risk index	0	
TE	0.25	
	Distance to utopian point	Rank
Farm type 1	0.229	3
Farm type 2	0.357	5
Farm type 3	0.104	1
Farm type 4	0.340	4
Farm type 5	0.186	2

5.3 Weights from the barangay council of Sapang Kawayan

Farm type 1 (extensive polyculture) is optimal and is considerably closer to the utopian point than any of the other alternatives. Of particular note is the very poor performance of farm type 4 (very large milkfish-oriented farms). In particular, the issue of absentee operators not trusting the local community to work as caretakers or labourers and instead bringing in their own workers “from outside”, was again prominent in the focus group discussion.

Table 6 – Compromise model results for the weight set given by the barangay council in Sapang Kawayan. Parameter p = 2.

Indicator	Weight	
Profit	0.4	
N loss	0	
Employment	0.25	
Protein production	0	
Risk index	0.35	
TE	0	
	Distance to utopian point	Rank
Farm type 1	0.138	1
Farm type 2	0.221	3
Farm type 3	0.271	4
Farm type 4	0.481	5
Farm type 5	0.205	2

5.4 Weights from the group of men in Sapang Kawayan

As in the previous case, Table 7 shows that farm type 1 (extensive polyculture) is optimal and very close to the utopian point (distance is only 0.086). Farm type 4 farms (large farms) are those that dominate the local area (there is a 130 hectare fishpond next to Sapang Kawayan) and these perform very poorly under this scenario. Environmental concerns are paramount in this group, as they are very aware of the impacts of intensification on the water quality locally and their dependence on the inter-tidal areas being in a fit state to support aquatic life. The group's expression of preference for prawn over milkfish as "the only possibility for smallholdings to profit" is also borne out in the rankings in Table 7.

Table 7 – Compromise model results for the weight set given by the focus group of men in Sapang Kawayan. Parameter p = 2.

Indicator	Weight	
Profit	0.35	
N loss	0.5	
Employment	0.15	
Protein production	0	
Risk index	0	
TE	0	
	Distance	Rank
Farm type 1	0.086	1
Farm type 2	0.277	3
Farm type 3	0.261	2
Farm type 4	0.455	5
Farm type 5	0.281	4

5.5 Weights from the group of women in Sapang Kawayan

While farm type 1 is ranked highest of the five farm types, farm types 1, 2, 3 and 5 all return distances to the utopian point in the range 0.18 – 0.22. Only farm type 4 (Very large milkfish-oriented farms) performs poorly.

Table 8 – Compromise model results for the weight set given by a group of women in Sapang Kawayan. Parameter p = 2.

Indicator	Weight	
Profit	0.35	
N loss	0.3	
Employment	0.35	
Protein production	0	
Risk index	0	
TE	0	
	Distance	Rank
Farm type 1	0.186	1
Farm type 2	0.214	3
Farm type 3	0.218	4
Farm type 4	0.467	5
Farm type 5	0.194	2

6. Overall findings

Fairly consistent patterns have emerged from the analysis. Either farm type 1 (extensive polyculture) or farm type 3 (low-input, labour intensive systems) are optimal under the weight sets considered here, (as modelled in tables 4 to 8, and as shown by the summary in table 9). These are both extensive farming systems and these findings suggest that for the communities that live in the area, relatively low external input aquaculture is the most appropriate. These farming systems are not significantly different from practices that fishpond operators in the Philippines would consider traditional. Thus, alongside the results of the compromise model, we might also consider these systems to be highly socially acceptable. They do not represent a recent break with tradition (as represented by farm types 2 and 5), nor do they dominate the landscape owing to their large size (farm type 4). Preferences for extensive polyculture and low-input labour-intensive systems are thus likely to have a significant socio-historical determinant.

Looking at the pattern of weights chosen in the four focus groups, we can see that each group fairly consistently chose one economic indicator, one socio-economic indicator and one environmental indicator. Net protein production was never chosen and risk and technical efficiency only once each. If we pool these weights to form a composite "average weight", then we can obtain an overall distance and overall ranking. Pooling the weights and then computing the distances, or computing the distances using each set of weights and then calculating the average distance gives the same results.

Table 9 - Different weights from each FGD

	Scenario 2 (NL council)	Scenario 3 (SK council)	Scenario 4 (SK men)	Scenario 5 (SK women)	AVERAGE WEIGHT
Profit	0	0.4	0.35	0.35	0.275
N loss	0.3	0	0.5	0.3	0.275
Employment	0.45	0.25	0.15	0.35	0.3
Protein production	0	0	0	0	0
Risk index	0	0.35	0	0	0.0875
TE	0.25	0	0	0	0.0625

Table 10 - Distances using these “average” weights and p=2

	Distance using average weights, p=2	Rank
Farm type 1	0.1596	1
Farm type 2	0.2673	4
Farm type 3	0.2136	2
Farm type 4	0.4357	5
Farm type 5	0.2167	3

Taking the mean distance across all four focus group-based scenarios, we find that, overall farm type 1 (extensive polyculture) performs the best in terms of local imperatives. It is the closest to the utopian point by some distance. Farm types 2, 3 and 5 are middle-ranking, with farm type 4 (very large milkfish-oriented farms) very far behind.

6.1 Implications – Local level

In terms of the multiple perspectives that are relevant when we consider the case of *barangay* Sapang Kawayan, we find that the *barangay* council, a group of randomly selected men, and a group of randomly selected women all choose sets of indicators and weights that suggest farm type 1 (extensive polyculture) to be the preferred model. This unexpected level of agreement implies that there are not significant social tensions within the community regarding aquaculture (i.e. there is social commensurability of values). While this may be true, there would seem to be an important issue with regards to the relationship between the communities and the operators of the very large farms that dominate much of the land-use in both Sapang Kawayan and Nanding Lopez.

Some members of one of the focus groups mentioned community agitation by leftist activists, in addition to the widely-held knowledge that the New People’s Army are active in extorting money with the threat of violence from large-scale operators. This suggests that land distribution is an important local political issue. Added to this, we find that the results of the compromise model for farm type 4 (large milkfish-oriented systems) are poor – it ranks last out of the five farm types in both Nanding Lopez and Sapang Kawayan – suggesting that these systems are performing relatively poorly in relation to the concerns of the communities. There is thus significant potential for social unrest and conflict.

6.2 Implications – National level

The top two ranking farm types (1 and 3) are also the most abundant in our sample. Of a total of 136 farms in the sample for the typology (paper 1), 54 were type 1 farms and 37 were type 3 farms. Thus, the highest ranking two categories represent 91 out of a sample of 136 (66.9%). This is encouraging – it suggests that a majority of the farming systems in regions 3 and 6 are performing well with regard to the sustainability indicators presented here.

The picture is different if we consider the individual farm sizes. If our sample stratification is a good representation of the actual distribution (and a significant amount of energy was put into the process of ensuring that it is), then we can examine the performance of the sector per unit area. Thus, farm types 1 and 3 represent only 42.9% of the total area in regions 3 and 6, whereas the very large farms that perform so poorly in the sustainability scenarios occupy 46.5%. There are implications here for the agrarian reform of the sector – almost half of the brackish-water pond area in regions 3 and 6 is occupied by very large farms that perform poorly relative to the other types.

Thus, it would seem that there is considerable potential for all-round improvement in the farm-level performance of the sector by including aquaculture under agrarian reform law. The rationale behind this statement is that agrarian reform would reduce the number of farms performing poorly (farm type 4) and, with appropriate institutional innovations, promote aquaculture farming systems of the kind that are performing well. Evidence of a possible win-win situation with regard to efficiency and equity objectives of such a change are considered in paper 4. The overall impression from the results presented in this paper is that, were the brackish-water areas in Central Luzon and Western Visayas covered in fishponds of a kind similar to farm types 1 and 3 (i.e. relatively low-input, $\leq$ 10 hectares), then there would be benefits to the sustainability of the sector.

Our approach to sustainability has shown the trade-offs at the farm level between the three objectives of maximising economic, social and ecological performance. These objectives may vary in their importance in different geographic localities, and among different groups of people in each geo-political unit. Our approach has helped answer questions regarding who benefits from aquculture as it is currently practiced, and where areas of tension or prospects for development may lie. Somewhere in the negotiation between objectives and values, we find sustainability.

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[1] Described in detail in paper 2.

[2] That is, the intersection of all individually optimal solutions is nonempty ($\bigcap_{k=1}^{K} X_k^{\otimes} \neq \emptyset$).

Research project R8288: Assessing the sustainability of brackish water aquaculture systems in the Philippines – Paper 4/5

Aquaculture & Poverty – A Case Study of Five Coastal Communities in the Philippines

Abstract: *After reviewing the rather thin literature on the subject, we investigate the relationship between aquaculture and poverty based on a case study of five coastal communities in the Philippines. The analysis relies on a data set collated through a questionnaire survey of 148 households randomly selected in these five communities. The methodological approach combines the qualitative analysis of how this relationship is perceived by the surveyed households and a quantitative analysis of the levels and determinants of poverty and inequality in these communities. There is overwhelming evidence that aquaculture benefits the poor in important ways and that it is perceived very positively by the poor and non-poor alike. In particular, the poor derive a relatively larger share of their income from aquaculture than the rich, and a lowering of the poverty line only reinforces this result. Further, a Gini decomposition exercise shows unambiguously that aquaculture represents an inequality-reducing source of income. We believe that the pro-poor character of brackish water aquaculture in the study areas is explained by the fact that the sector provides employment to a large number of unskilled workers in communities characterized by large surpluses of labour. Our results also suggest that the analysis of the relationship between aquaculture and poverty should not focus exclusively on the socio-economic status of the farm operator/owner, as has often been the case in the past.*

Contents

1. Introduction

Poverty in the Philippines remains a major problem, which represents a formidable barrier to the country's development. As will be discussed in the methodological section, there exists multiple ways of measuring poverty, which can explain some of the discrepancies found in the literature regarding its incidence in the Philippines as elsewhere. However, there is little doubt that poverty levels in the Philippines are high both in absolute and relative terms. According to the latest set of World Development Indicators (Table 1), more than one third (37%) of the Philippine population lives under the national poverty line, while 15% finds itself in absolute poverty as defined by the $1 a day criterion of the World Bank. Furthermore, these figures compare unfavourably to those of other countries of the South-East Asian region such as Indonesia, Malaysia and Thailand. This is explained by a relatively low level of income per capita (at least when compared with Malaysia and Thailand) and relatively large income inequalities (when compared with Indonesia). As a consequence, the incidence of poverty in the Philippines is as acute as in countries with much lower income levels, such as Cambodia. Its reduction ranks high on the agenda of the government and other international agencies.

Table 1: Incidence of Poverty in South-East Asia

Country	National Poverty Line			International Poverty Line		GNI per capita ($)
	National %	Rural %	Urban %	Population below $1/day	Population below $2/day	
Cambodia	36.1	40.1	21.1	NA	NA	310
Indonesia	27.1	NA	NA	7.5	52.4	810
Malaysia	15.5	NA	NA	<2	<0.5	3,780
Philippines	36.8	50.7	21.5	14.6	46.4	1,080
Thailand	13.1	15.5	10.2	<2	<0.5	2,190

Source: World Bank Development Indicators, 2003

How can poverty be reduced in the Philippines? The starting point to answer this question is a realisation that the international consensus on the achievement of poverty alleviation has changed over the last two decades. The view that economic growth represents a sufficient condition for poverty alleviation has proven wrong, and it is now clear that a satisfactory rate of poverty reduction cannot automatically be achieved through the mere trickle-down effect of growth to the poor. Instead, decision makers need to design policies with a clear pro-poor focus, i.e. policies that benefit the poor disproportionately. This thinking has also modified the way in which development agencies function, in particular with respect to the funding of research in/for developing countries. It is no longer sufficient for researchers to claim that their activities will lead to productivity gains and economic growth; instead, demonstrating the effect on the poor of particular projects has become paramount. This general statement is reflected in DFID's Renewable Natural Resources Research Strategy (RNRRS), which no longer focuses only on the generation of new knowledge in natural and social sciences, but also on the promotion of the use of this knowledge to improve the livelihoods of poor people. In this context, investment in aquaculture R&D for developing countries can only be justified to the extent that the resulting knowledge and technologies make a positive contribution to the livelihoods of the poor. This paper aims at testing whether this is actually the case based on a community-level analysis of poverty in several coastal areas of the Philippines where brackish water aquaculture is present. We start with a brief literature review of the relationship between aquaculture and poverty; move on to present an overview of the methodology and data collection; and, finally, present the qualitative and quantitative analysis of the relationship between aquaculture and poverty.

2. Aquaculture and Poverty: The State of Knowledge

At a conceptual level, the potential contributions of aquaculture to poverty reduction are relatively well understood (Edwards, 1999; Muir, 1999). Several opportunities can arise for the poor from the improved use of aquatic resources that aquaculture development permits. There are, first, the direct effects generated by this development, i.e. effects that can be directly related to the farm's activities. Aquaculture growth generates new income, calculated as production sales minus variable costs, which accrues to the owner(s) of the fixed factors of the fish farm (mainly the pond/land, family labour, management and other necessary equipment such as boats and nets). The impact on poverty of this additional income flow depends on the socio-economic status of the farm operator/owner and will only be significant if the poor themselves participate in aquaculture. Obstacles to this participation are potentially numerous and include the capital and skill intensity of the activity as well as its riskiness. At this level, it is usually thought that extensive or semi-intensive forms of aquaculture are relatively more pro-poor than intensive systems, due to the fact that the poor usually lack access to credit, which prevents them from purchasing the intermediate inputs used in large amounts in intensive systems.

Aquaculture development can also generate employment on the farm, either on a full-time basis when a 'caretaker' is responsible for the day-to-day farm operations, or on a more occasional basis for seasonal tasks, such as harvest. This is likely to benefit the poor in countries with large labour surpluses, such as the Philippines, because a poor person's labour often represents his main asset and, by the same token, his main source of livelihood. When comparing different forms of aquaculture, it is also likely that their relative labour intensities have an important bearing on their relative potentials for poverty reduction.

However, small direct effects would not necessarily imply that aquaculture is not 'pro-poor'. It is possible that the additional income stream and employment generated by aquaculture development trickles down to the poor through a series of linkages within rural communities. These include production links, both 'upstream' from the farm in demand for inputs and services for aquaculture, as well as 'downstream' from the farm in the demand for processing, storage, and transport of production. There are also consumption links as fish farmers and farm labourers spend their increased incomes on goods and services that are provided outside of aquaculture. While conceptually simple, these growth linkages are difficult to measure but, in agriculture at least, most empirical studies have estimated large multipliers, explained primarily by the strength of the consumption linkages (Irz et al., 2001)[1]. This implies that our study should not focus exclusively on the farm but, instead, should take a broader view of the relationship between aquaculture and poverty.

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[1] These ideas have been formalised in so-called agriculture-led industrialisation strategies that stress the importance of agriculture in creating a market for industrial products (Adelman, 1995).

Many authors also argue that aquaculture development can have a positive nutritional effect on the poor as a supplier of high quality animal proteins and essential nutrients (Prein and Ahmed, 2000). If the poor adopt aquaculture, own-consumption of fish by the farm household can increase its nutrition and food security. In addition, aquaculture growth increases the supply of fish, which reduces its price and makes it more affordable to the poor. Note, however, that the argument depends on the size of the market where production is sold as well as on the nature of the fish produced. If aquaculture production is sold locally on small and poorly integrated markets, it is likely that the price decrease resulting from additional supply will be large; on the other hand, if production is exported, the nutritional benefits to the country's poor will be non-existent. In a similar vein, these benefits will only materialise if the poor, either locally or nationally, do indeed consume the species produced by aquaculture and, in the case where only high-value species are farmed, no such nutritional benefits can be claimed. Sometimes, it can also be argued that aquaculture improves the nutrition of the poor through other channels. For instance, caretakers are sometimes allowed to catch fish in the ponds that they supervise to satisfy their family's consumption needs. A common practice in the Philippines is also to allow poor people to catch any residual production after the main harvest has taken place in large brackish water ponds.

Altogether, the arguments supporting the pro-poor nature of aquaculture rely on the income stream, employment and nutritional benefits that it can potentially generate. To some extent, these arguments apply to any agricultural enterprise as well as fishing, but aquaculture presents some advantages over these activities. First, it often represents the only option to farm land under saline conditions, which is precisely the case in the large areas of brackish water of the Philippines. Second, the productivity of fisheries is often limited by its open-access nature, which results in the well-known 'tragedy of the commons' that some identify as a cause of poverty (Hardin, 1968). By contrast, aquaculture development involves the creation of well-defined property rights that form, arguably, a pre-condition for productivity growth and represents an important developmental option for many coastal communities characterized by high levels of poverty. Finally, fish is a nutrient efficient protein source, in comparison to livestock, so there is an underlying biological reason for claiming that aquaculture represents a particularly attractive way of producing cheap proteins for the poor and the malnourished. In fact, so intuitive is the previous set of arguments that aquaculture generated massive enthusiasm in the last two decades, with some viewing its development as a 'blue revolution' with tremendous potential for fostering food security, generating economic growth in rural areas and alleviating poverty.

However, the empirical evidence regarding the ability of aquaculture to reduce poverty is mixed at best (Edwards and Demaine, 1997). The assessment of this potential is made all the more difficult that while there are many studies of poverty in farming communities and among the urban poor, few empirical studies have focused specifically on aquaculture (FAO, 2003). Yet, there is a general view in the literature that the promotion of aquaculture in Africa and Latin America has largely been unsuccessful (Edwards and Demaine, 1997). In Asia, while commercial scale aquaculture has recently experienced a spectacular expansion, it is households with better resource bases rather than the poor who have benefited. As a result, donor support for aquaculture development has declined in the past ten years (Hlwart et al., 2003). However, there is also anecdotal evidence that coastal aquaculture can represent an important source of employment for the rural poor, through the demand for labour input, seed and feed (Edwards, 1999; Tacon, 2001). On the other hand, several case studies have documented the fact that aquaculture development can, in some cases, have a detrimental effect on the poor due to its environmental impact or its role in triggering social conflicts. The shrimp industry, in particular, has been blamed for a whole series of problems that, it is argued, have sometimes made the poor strictly worse off (Stonich et al., 1997).

3. Methodology & Data

3.1 Methodological Overview

The literature review on the relationship between aquaculture and poverty reveals the need for further empirical inquiry. Several methodological approaches could be used to support this inquiry and these were discussed during a workshop organized by PCAMRD and the University of Reading on 22 April 2004 in Los Banõs, Philippines. Following the workshop that generated invaluable insights, the following methodological choices were made by the project leaders:

- The unit of analysis for this study should be the whole 'community'. It was felt that focusing solely on fish farms would be too restrictive in the sense that it would limit our understanding of poverty in the coastal areas of the Philippines. In particular, a farm-level analysis would make it very difficult to investigate how important aquaculture really is for the livelihoods of poor people in these communities, or to put into light any negative impact of aquaculture on the poor. By contrast, focusing on a few communities allows us to gain in depth understanding of the economic, institutional and social characteristics of these communities that are essential to investigate rural livelihoods and rural poverty in a holistic manner (Bebbington, 1999).

- The analysis adopts primarily a 'traditional' approach to poverty measurement and evaluation. By that, we simply mean that the identification of the poor relies on quantitative consumption and income data that are collected through a survey. Although this approach has undoubtedly some shortcomings, there is little evidence that the more qualitative alternatives that have been proposed in recent years are superior (Ravallion, 1996, p. 124). In short, the methodology aims at defining profiles of poor and non-poor households in the chosen communities, hence establishing how the two groups differ in terms of their involvement in aquaculture (or aquaculture-related activities).

- However, it is also clear that the acceptability and effectiveness of development and poverty policies depends in large part on the perceptions by the stakeholders themselves of poverty and poverty reducing measures. Hence, we also decided to investigate the subjective notion of poverty through participatory methods (see Hentschel and Waters (2003) for a recent application of that approach).

3.2. The Study Area and Data Collection

3.2.1. Regional Context

Brackish water aquaculture in the Philippines represents a traditional activity which has grown over the last few decades. Although uncertain, the total surface area of fishponds is large and has increased until recently through the conversion of mangroves and swamps. Yap (1999) suggests that there are 239,323 hectares of brackishwater fishponds in the Philippines, while the electronic data that we obtained from the Bureau of Agricultural Statistics (BAS) records a total harvested area of 415,272 hectares in year 2000, although this latter figure might be accounted for by joint or multiple owners of a single fishpond, each having featured in the survey separately. The ponds are distributed unequally across the country, with Region 3 covering the central part of the Northern island of Luzon and Region 6 in the Western Visayas (central Philippines) dominating the industry. Hence, Region 3 accounts for 28% of the total area of fish ponds and 39% of the national production in value terms, while the corresponding figures for Region 6 are 24% and 14% (BAS). We therefore decided to concentrate the study on these two regions where the economic importance of brackish water aquaculture is largest.

The situation with regard to poverty appears significantly different in the two selected regions. Figure 1 reveals that Central Luzon is characterized by the lowest incidence of regional poverty in the country at less than 20%. This can be related to the relative economic prosperity of the region due to the proximity of the national capital, Manila, and its many industries. By contrast, poverty incidence is high in the Western Visayas, with close to half of the population classified as poor ; only regions in Bicol and Mindanao fare worse in terms of poverty nationally.

The literature establishes that poverty is really a multi-dimensional concept and that it should therefore be evaluated from a variety of angles. One such angle is the prevalence of malnutrition among young children, presented in the second map (Figure 2). The indicator of malnutrition selected measures the proportion of children under the age of 59 months with a weight for age ratio smaller than the population average by at least two standard deviations. The national picture of poverty that emerges from this second map differs slightly from that described in Figure 1. Consistent with the previous results, the incidence of child malnutrition in Central Luzon appears relatively low, but in the Western Visayas region, more than one third of the children are seriously underweight. The ability of aquaculture to improve nutrition, as postulated in the literature, seems therefore particularly relevant in Region 6.

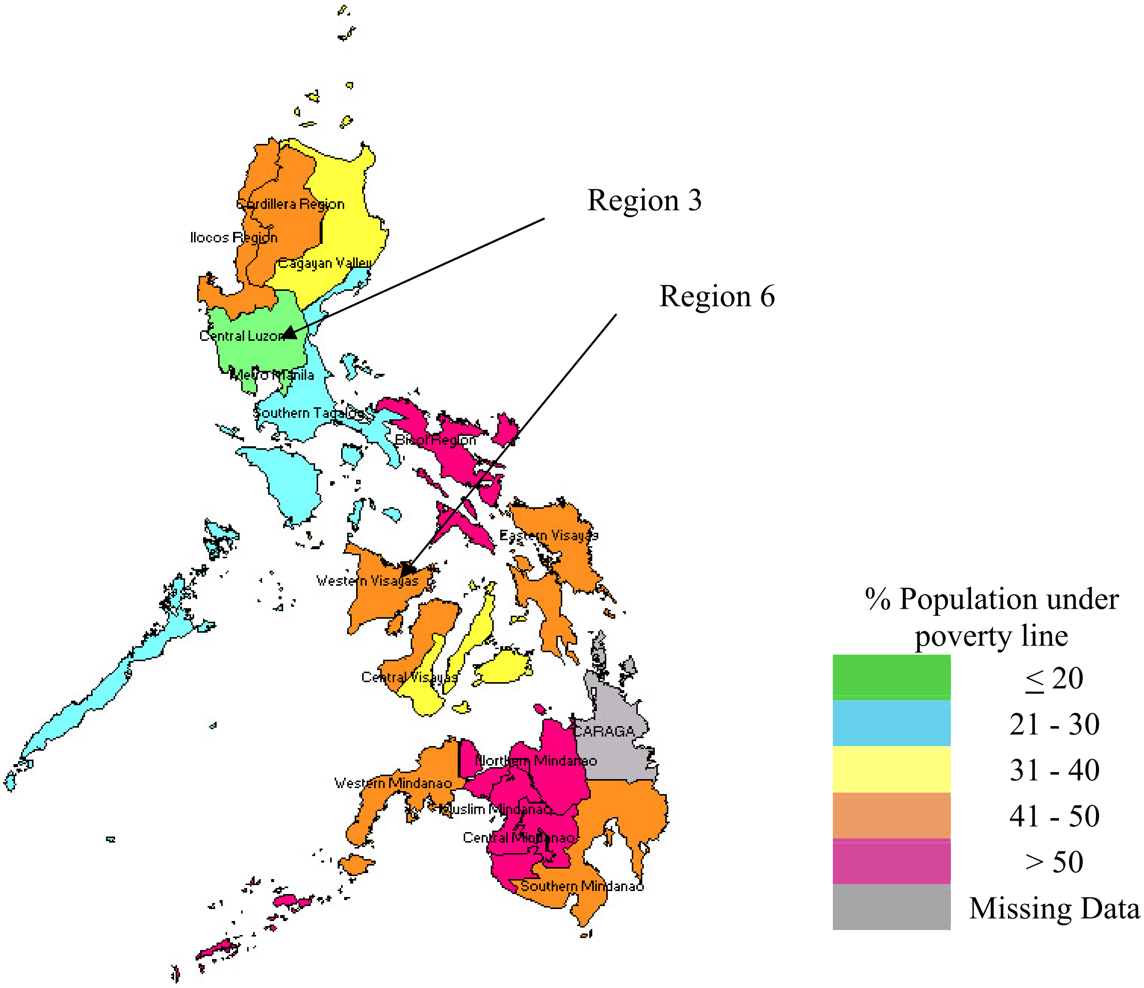

Figure 1: Poverty Map of the Philippines, 1997
Source: 1997 Philippine Poverty Estimates, NSCB 1998

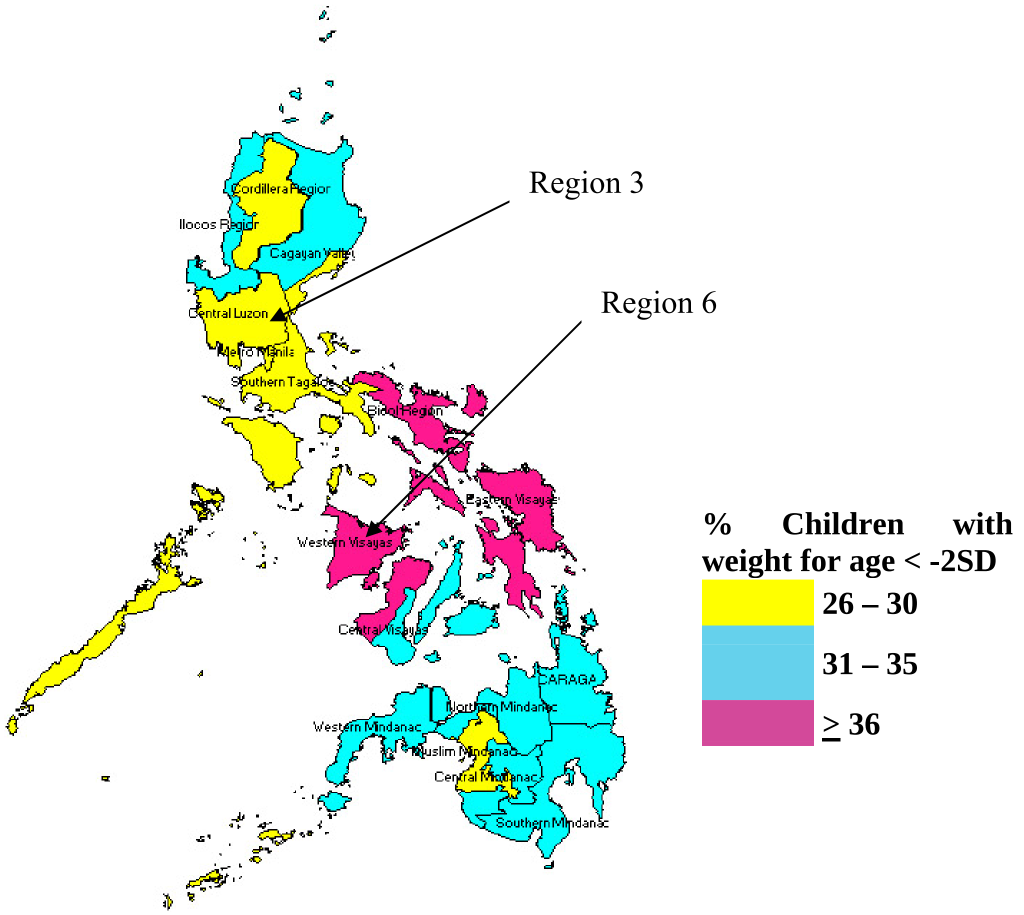

Figure 2: Proportion of Underweight Children (0-59 Months), 1998
Source: National Nutrition Survey of 1998, FNRI-DOST

3.2.2 Data collection and overview of selected communities

A survey collected household-level data based on a questionnaire presented in the Appendix. Its core was inspired by the questionnaire developed by the World Bank's Living Standards Measurement Survey (LSMS) team (Grosh & Glewwe, 2000) but we also had to make important adjustments because of specific objectives as well as time and financial constraints. The questionnaire is divided into ten sections that give a fairly comprehensive overview of a household's socio-economic situation (household composition, education, employment, land-based activities (aquaculture & agriculture), fishing activities, other sources of income (transfers, remittances, rental earnings), consumption, asset ownership, housing, access to healthcare and credit). In addition, it contains a whole section investigating how the respondent perceives poverty and its relationship to aquaculture. The questionnaire was piloted by the research team in May 2004, which led to major revisions, and the survey proper was carried out from June to October 2004 in the two selected regions. The data was collected by enumerators during two face-to-face interviews taking place at a week's interval, with all the recall data on consumption being collected during the second visit.

An important step in implementing the methodology involves specifying precisely what is understood by the term 'community'. For our purposes, we chose the smallest administrative unit in the Phillipines, called a barangay, which corresponds roughly to the borough of a municipality. Residents appear to have a real sense of belonging to their barangay, which has its own institutions (in particular, a barangay council and captain, who are elected) and social events (in particular, the annual fiesta which is organized on the day of the barangay's saint). Participants at the workshop confirmed that barangays represent appropriate communities for our study.

Sampling followed a three-stage strategy. The first stage, discussed previously, selected the two regions with the most developed aquaculture sectors (Regions 3 & 6). The second stage selected a few barangays in each region. Our initial intent was to select those randomly but discussions at the workshop made clear that a purposive strategy would in fact be preferable. There were several suggestions at the workshop that the impact of aquaculture on the poor probably depends on the type of community considered. Relevant characteristics include the remoteness of the community, its distance to the town/village centre, the level of urbanization of the barangay and its surroundings, the importance of fishing as an economic activity in that community, and the presence of mangroves. A brief description of the five selected communities follows:

- San Antonio (SA) is a barangay of the 'partially urban' municipality of Sasmuan, in the Pampanga province of Region 3 (NSCB Philippine Standard Geographic Codes, July 2004). It is part of the town centre, close to the market, municipal hall and other basic institutions of the municipality. However, its total land area of more than 800 hectares is occupied primarily by fishponds. The barangay has a total population of 1,603 individuals spread across 286 households (2000 National Statistics Census).

- Barangay Sapang Kawayan (SK) is a rural community under the jurisdiction of the municipality of Masantol in the Pampanga province of Region 3. Masantaol is classified as 'partially urban' and has 32,464 registered voters (National Statistical Coordination Board, 2004). The community of SK is located to the South of Masantol proper and is only accessible by boat (one hour from Masantol and 20 minutes from another town, Haganoy, in the nearby province of Bulacan). It is surrounded by fishponds and river systems and has a total land area of 265 hectares (Provincial Agriculturalist's Office), which supports a population of 2,676 individuals in 559 households (2000 National Statistics Census).

- Barangay Nandin Lopez (NL) is located in the province of Iloilo (Region 6), municipality of Dumangas. Three major rivers traverse the area and the barangay is almost bounded by water except for a strip of land that connects it to the rest of the municipality. About 97% of the 797 hectares of land in the barangay are occupied by fish ponds and discussions with key informants suggested that aquaculture and fishing represented the two main sources of livelihood for the population of 1,359 individuals (as of 2003).

- Barangay Lat-Asan (LA) is located in the province of Capiz (Region 6), municipality of Pan-ay. It is a small island (46 hectares) which can only be reached by boat from the barangay of Pawa. Most of the land (30 ha) is occupied by aquaculture ponds but there are also substantial mangrove areas in the barangay (15 ha). With a population of 680 spread in 139 households (1999 survey), this is by far the smallest community in our sample.

- Barangay New Buswang (NB) belongs to the municipality of Kalibo, Province of Aklan, Region 6. It differs from the other four barangays in the sense that the area has no major waterways (except for small creeks & man-made canals) and no fishponds. The ponds that used to border the barangay have been converted to residential lots for the most part following the collapse of the aquaculture sector due to diseases and lack of access to markets. There are, however, fishponds remaining in bordering barangays (Old Buswang in particular). The second particularity of the barangay is that it contains a 20 hectare area of natural and replanted mangroves, which is part of the Bhakawan project of SEAFDEC. The total population of 8,127 is spread over 223 hectares of land.

Altogether, these five barangays differ in terms of their geographical location, importance of aquaculture and fishing as economic activities, remoteness, level of urbanization, and share of area occupied by mangroves. Barangay NB serves as a reference to get some insights into the poverty situation of coastal communities with no fish farming industry that make alternative uses of the land (in particular, developing mangrove-related activities).

The last step of the sampling strategy selected households randomly from an exhaustive list compiled in each barangay from official records, which sometimes had to be amended to include recently settled households and households living in remote parts of the barangay (e.g., migrant caretaker families living in houses built on the dykes of fish ponds). In the end, 36 households were surveyed in SA, 37 in SK and 25 in each of the three remaining barangays (NL, LA, ND) , for a total of 148. If we exclude NB, which has no aquaculture, our sample accounts for roughly 10% of the population of households in barangays SA, SK, NL and LA on which most of our analysis focuses.

4. Poverty & aquaculture: perceptions

4.1 Defining the context: general perceptions of poverty

Our study reveals that a vast majority of households consider themselves to be poor, although the data indicates some regional differences. In the province of Pampanga, around two thirds of the respondents see themselves as poor (75% in SA and 62% in SK), while in the Visayas region this proportion is even larger (92% in NL and LA, 100% in NB). These regional differences are consistent with the poverty maps presented above, but the very high levels of perceived poverty incidence observed in both regions suggest that the coastal communities that we study are also much poorer than the regions to which they belong. Clearly, poverty is perceived as a major problem for all the coastal communities under scrutiny, which gives relevance to our investigation.

As the recent literature on poverty and livelihoods has moved away from single indicators of poverty to emphasize its multi-dimensional nature, the study attempted to identify how the respondents themselves would define the concept[2] and Table 2 summarizes the results[3]. The large number of answers to the question confirms that poverty is interpreted in very different ways by individuals, although it could also reflect the open-ended nature of the question. More than half of the respondents identified having an insufficient income as the key characteristic of poverty, followed by the inability to purchase enough food to meet the household's needs, the lack of a regular income, and, finally, the fact that one is unemployed. The emphasis on food consumption indicates that people in these communities face absolute, rather than relative, poverty. It also gives some relevance to the analysis of the potential nutritional benefits that the literature suggests can be associated with the development of aquaculture. In a similar vein, the fact that unemployment is identified as a key characteristic of the poor implies that the potential of aquaculture to reduce poverty is closely linked to its ability to create jobs in the communities studied here. The results also indicate, in line with the literature, that poverty should be analysed in a dynamic rather than static framework, because poor households are identified by their vulnerability to external shocks. Hence, income poverty is not only related to the low level of household earnings but also to their variability and the poor are identified by a substantial number of respondents as being unable to secure a stable/permanent job.

Table 2 suggests further that asset poverty, though present, does not represent the main dimension of poverty in these three communities. A few respondents associated household poverty with the inability to own a house, land or durable goods, and the issue of indebtedness of the poor was also mentioned. Similarly, the lack of social status of the poor, as indicated by their lack of influence in these communities and their dependence on others for their livelihoods, was rarely identified as a key characteristic of poverty. Altogether, the data indicates that in the coastal communities investigated here, it is the income and consumption dimensions of poverty that tend to dominate, as opposed to the concepts of asset and social poverty that have become very popular in the recent livelihoods literature. We also note that the perceived meaning of poverty seems fairly homogenous across communities.

Table 3 explores the vulnerability of the surveyed households. Weather shocks were reported by a substantial number of respondents as a cause of crisis but, given that some of these communities can be flooded for several weeks a year during the rainy season, it is rather surprising that typhoons and floods were not mentioned more frequently. It can therefore be postulated that these events are regarded as fairly normal by many in these communities, and that, as such, proper coping strategies are in place to overcome them. By contrast, illness or the loss of a job within the household are identified as much more important sources of vulnerability. This finding is consistent with the results reported previously in Table 2 and it appears that a key characteristic of the poor is their heavy dependence on their ability to work, even in the short term. However, the increased vulnerability resulting from the loss of a job is clearly more pronounced in Region 3 than Region 6. This could reflect the fact that salaried employment in region 3 is simply more widespread than in Region 6; alternatively, it could also be the case that, because wages are notoriously lower in Region 6 than in Region 3 (roughly PhP 100/day in Region 6 compared to PhP 150/day in Region 3), employment might not guarantee immunity from poverty in

[2] The exact question was: In your opinion, what does it mean for a household to be poor? What is the main characteristic of poverty?
[3] From hereon, all tables are presented at the end.

that region. The vulnerability to illnesses is easily understood as resulting from the combined effect of a loss of income due to the inability to work and the additional drain on household income associated with the cost of medicine and health care, which was repeatedly mentioned by respondents as an important problem.

The perceived causes of poverty are presented in Table 4 and, once again, confirm that the key problem for the poor is one of securing a stable job. Note also that low salaries are perceived as a much more important determinant of poverty in the three barangays of Region 6 than in SA and SK, which reflects the regional differences in wages mentioned previously. However, our results also indicate that almost a fifth of all respondents identified individual behaviour as an important explanatory factor of poverty, and that for more than half, these respondents considered themselves to be poor. The situation is therefore not one where only the rich perceive the poor as deserving their predicament. Personal indolence, laziness and flawed 'personal character' were mentioned most frequently as leading causes of poverty, and there were repeated suggestions that 'vices', meaning drinking and gambling, were rampant in all five communities. Hence several respondents indicated that expenditure on alcohol and gambling was often taking priority over the satisfaction of the household's basic needs. Overpopulation is regarded as an important cause of poverty only in SK and NB, which are also the barangays with the highest population densities. The respondents provided many other possible explanations for poverty, including the scarcity of fish in the wild and the lack of education of the population, but these explanations were not mentioned very frequently.

In the face of important shocks, households have developed a whole range of coping strategies that are summarized in Table 5. In all five communities, the main response to a crisis is to seek help from a large support network, corresponding primarily to the extended family, but which can also include friends, neighbours, local politicians and employers. Borrowing money forms the second most important coping strategy and was mentioned by more than 40% of respondents. This strategy relies almost exclusively on the informal credit market, with most of the loans originating from local money lenders, local stores, employers, and relatives. However, it is also worth noticing that close to a third of respondents simply do not have any coping mechanism, and are left to endure shocks by reducing consumption, which is certain to have a large negative effect on the welfare of their households. Again, this is interpreted as indicating the presence of absolute poverty in these communities. A substantial number of households also rely on their own industriousness to cope with crises, by simply working more, or, rather surprisingly, starting a small family business (such as a small food or retail store).

The respondents were also asked to identify potential means of reducing poverty within their communities, and the results are reported in Table 6. Rather disturbingly, almost a fifth of the respondents consider that such means simply do not exist and that poverty within their communities is all but inevitable. This fatalistic attitude is often supported by the argument that the situation of these communities has not improved in the recent past, with some respondents indicating that the younger generation is not better educated than the older one, that fish is becoming scarcer, while families are getting larger. This was interpreted by many as indicating that past measures taken to tackle poverty, such as investments in family planning and education, have not worked, and that there is little reason to assume that it will be any different in the future. On a more positive note, however, 39% of respondents consider that improving individual behaviour represents an important avenue to reduce poverty, which suggests that some of the solutions exist within these communities. In line with the discussion on the causes of poverty, 'improved behaviour' includes the reduction of vices, an increase in the number of hours worked, or more careful budgeting at household level (that would allow the accumulation of savings). Creating more job opportunities also ranks high as a method of reducing poverty within these communities, as might have been expected from answers to the other questions. It is interesting to note that the government is not perceived as being central to poverty reduction, although 14% of respondents mentioned its role. This could be interpreted in several ways, but might suggest that most in these communities consider the central state to be either weak or corrupt.

Altogether, we conclude that the communities under scrutiny consider poverty to be widespread and of major importance. Poverty, which is defined primarily in terms of its income and consumption dimensions by the respondents, is perceived as relating primarily to the issue of unemployment, but individual behaviour is also recognized as a major contributing factor. The main sources of vulnerability (illness & loss of job) are dealt with by mobilizing an extensive support network and borrowing from the informal credit market, although a substantial number of households simply have to reduce consumption. A majority of respondents believe that poverty can be reduced, primarily through job creation within the community, as well as improved individual behaviour. All of these characteristics define the context in which we now analyse the relationship between aquaculture and poverty.

4.2 Aquaculture & poverty: the views from five communities

Aquaculture development has often been criticised for the inequities that it apparently generates (Alauddin and Tisdell, 1998; Coull, 1993) and has even been blamed for the marginalisation of and increased unemployment in some coastal communities (Primavera, 1997). It therefore seems relevant to identify how aquaculture is perceived not only by those directly involved in it (i.e., the fish farmers) but by the entire community. The survey first asked respondents to evaluate whether, in their view, aquaculture benefited the rich and/or the poor in their community and the results are summarized in Table 7. A very large majority considers that aquaculture is mutually beneficial to the poor and the rich, but there is also a small minority (23%), particularly in Region 6, that believe that only the rich benefit. The regional difference could be explained by the fact that land ownership in the Visayas region is typically more inequitably distributed than in Central Luzon, and that the salaries offered to caretakers and daily workers are also noticeably lower in Region 6 (see section 5.5).

We then investigated what form the benefits from aquaculture to the poor might take by asking whether the poor themselves practiced fish farming. Informal discussions with aquaculture experts and local officials seemed to indicate that fish farming in the brackish water areas of the Philippines was mainly a rich-man activity, but this contention is not supported by the results of our survey. Indeed, Table 8 reveals that more than half of respondents consider that some poor people operate fish farms. The interviewees repeatedly mentioned examples of individuals who, having started as caretakers, managed to acquire small fishponds and, from thereon, developed profitable aquaculture operations. There is therefore some level of social mobility within the studied communities, and aquaculture might be regarded as an instrument of that mobility. Further, it seems that escape from poverty via aquaculture is only possible when the caretaker earns a substantial share of the farm's profit, as is often the case in Region 3, but much more rare in Region 6.

However, there are also some clear barriers to entry into the sector, as indicated by the fact that 82% of respondents consider that it would be impossible for them to start a fish farming operation (Table 9), although the problem seems more severe in Region 3 than in Region 6. When probed further about why the poor might not be able to start a fish farming operation, the third of respondents who had expressed that view overwhelmingly mentioned the lack of access to credit and financial capital as the key hurdle, while a few (8) also thought that access to land was a problem. The lack of access to credit is also by far the main reason given by the respondents who felt that they would be unable to start their own fish farm, although lack of knowledge or land were also mentioned. Hence, it appears that financial capital represents the scarce factor in these communities that limits entry into the fish farming industry. This is explained by the fact that the type of aquaculture practiced in these communities requires the purchase of large amounts of intermediate inputs (prawn fry and fingerlings in particular) and also by the level of risk involved. Flooding of fish ponds is a frequent occurrence, as is mass mortality (particularly of prawns), so that the returns to invested capital are highly uncertain (many respondents made a parallel between fish farming and gambling). As a consequence, only those in a strong financial position are willing to take the risk associated with brackish water aquaculture.

Because part of the literature suggests that aquaculture can be detrimental to some particularly vulnerable social groups, we did explicitly ask respondents whether, in their opinion, fish farming might have a negative impact on the poor (Table 10). More than two thirds of the interviewees thought that it was not the case. The large minority (30%) that disagreed usually believed that aquaculture had a negative impact on fishing, which represents an important source of livelihood for the poor. The blame was put primarily on the feeds used in large quantities to grow milkfish, and a few individuals, particularly in barangay Lat-Asan, also suggested that the chemicals employed to fight diseases as well as the pesticides used between cycles were responsible for the observed decline in wild fish stocks. Note, however, that perceptions of these negative impacts vary widely across communities, in a way that is consistent with the importance of fishing as an economic activity. In particular, aquaculture is perceived as being most detrimental to the poor in the two barangays supporting a large number of fishermen (SK and LA). Further, barangay SK was purposely selected on the outer edge of the Pampanga estuary, hence downstream from most fishponds and relatively more exposed to the negative externalities generated by aquaculture than the other barangays. This may explain why a majority of respondents in SK thought that aquaculture had a negative impact on the poor.

In view of the previous set of results, it is not surprising that aquaculture is perceived positively by an overwhelming majority (95%) within these five communities (Table 11). The number one perceived benefit is the creation of jobs that are crucially needed in these communities. More details about the employment generated by aquaculture will be presented in section 5.5. The second major perceived benefit from aquaculture for these communities is the provision of fish for human consumption. In particular, the practice of allowing the collection of ‘free fish’ from fish ponds, i.e. any residual fish or crustaceans left after the main harvest, was mentioned as an important benefit from aquaculture by a large number of respondents in Region 3. As the gains from such an activity are rather limited, it is mainly the young and the poor who partake in it, which is likely to substantially improve nutrition in their households. Many respondents also emphasized the importance of payments in fish that are made for various tasks (harvest for instance), as well as the traditional practice by farm operators to give fish as gifts at the time of harvest to neighbours, friends and family. Hence, there appears to be important nutritional benefits to these communities from aquaculture, which materialize through a variety of non-market mechanisms that make fish available to residents. Some other indirect benefits from aquaculture to these communities were mentioned but only infrequently, including the generation of local tax revenues, or the provision of credit by farm operators.

The last section of the questionnaire investigating perceptions of the relationship between aquaculture and poverty deepened the analysis by attempting to get a sense of the magnitude of the perceived benefits from aquaculture as well as related problems. This was achieved by asking respondents to choose a step on a ladder, presented to them on a piece of paper, after explaining that the first step was describing the worst possible situation and the highest step the best possible situation (see Questionnaire in Appendix)[4]. The ladder presenting ten steps, admissible answers range from 1 to 10, and Table 12 presents the mean scores together with their standard deviations for a series of question.

The first two questions were aimed at evaluating the potential nutritional benefits that aquaculture could generate in these communities. Respondents were asked to evaluate their overall food security situation by choosing a step on the ladder, where the first step was described as a situation where all household members barely have anything to eat, and the highest step as a situation where every member of the household eats three nutritious meals daily. The average score (5.05) indicates clearly that a majority of households feel far from fully food secure, and the table also indicates that the situation is worse in Region 6, as was expected from the poverty maps (Figure 2). Worryingly, the results also suggest that the food security situation of these three communities has slightly worsened over the last five years, but respondents expect this trend to be reversed in the near future. The second question[5] allows us to quantify the importance of fish in the diet of these communities and the relatively high average score (5.80) confirms that fish is an important food item in most households. Further, there is little indication that availability of fish in these communities has changed in the last five years, and respondents do not anticipate major changes at that level in the short future either. Altogether, we interpret this set of results as indicating that aquaculture could potentially make an important contribution to the improvement of nutrition in these communities, since most households are not fully food secure, while fish plays an important role in their diets.

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[4] We are thankful to Dr Peter Edwards for suggesting the use of this tool.

[5] The exact question is: ‘The first step on the ladder shows a situation where fish/seafood does not form part of your household’s diet at all, even if your household members wanted to eat fish. The highest step on the ladder represents a situation where your household members can eat as much fish as they want.’

Given the crucial role that employment plays for the poor, it is interesting to analyse how respondents judge the importance of aquaculture as a source of jobs for their household[6]. The average score of 3.88 establishes that aquaculture represents an important source of employment in these communities, although the situation varies across barangays. In region 3, households are much more dependent on aquaculture for employment in SK (average score of 7.53) than in SA (average score of 3.75). We believe that this simply reflects the relative remoteness of barangay SK compared to SA, which is located close to the city centre where various forms of employment are potentially available. In Region 6, aquaculture is a significant source of employment in barangay NL (average score of 5.96) but appears unimportant in the two other barangays. This was expected in NB, which was selected as a reference community with no fish farming industry, but not in LA, where we thought that the community's economy would be equally divided between fishing and aquaculture.

The data also reveals that in barangays SK and NL, very few households (6 out of 62) replied that none of their employment was related to aquaculture, while almost half of respondents gave that answer in SA. Hence, in three of the barangays under study, involvement of the household in aquaculture represents the rule rather than the exception. Finally, the last question was aimed at measuring the overall importance of aquaculture as a source of household cash income and the results closely mirror those obtained with regard to employment. This gives a final confirmation that in these communities, income and employment are closely related to each other.

Altogether, this part of the survey draws a fairly clear picture of poverty in these communities and how it relates to aquaculture. There is little doubt that most households are poor, a situation that is defined primarily by low and variable income and consumption, as well as some degree of food insecurity. The main coping mechanism during crises consists in requesting help from an extensive support network and taking loans from the informal credit market. Although unemployment is identified as the main cause of poverty, many respondents also consider that its reduction requires improvement in individual behaviour. In this context, aquaculture is perceived overwhelmingly as being beneficial to the entire community and, more specifically, to the poor. Although ownership of fish farms might be very concentrated in the communities under scrutiny, most households derive some employment from aquaculture and the sector is identified as a key source of income. In addition, distribution of 'free fish', which is a by-product of the farming activity, is important to a large number of respondents and one can logically suggest that this benefit is particularly pro-poor. Contradicting a large volume of recent literature, few negative effects of aquaculture on these communities are identified by their residents. There are suggestions that the industry imposes some negative externalities on the fishing industry, but these costs are judged to be largely outweighed by the benefits of increased employment and increased availability of fish from aquaculture. However, there are important barriers to the adoption of aquaculture by the poor, most notably the lack of access to credit, but the study also reveals some level of social mobility within these communities, sometimes facilitated by aquaculture itself.

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[6] The exact question is: 'The first step on the ladder describes a situation where no household member earns from any aquaculture-related activity. The highest step on the ladder represents a situation where members of your household obtain all their earnings from various aquaculture-related activities (production, marketing, harvesting, processing, input supply etc.).'

5. Levels and Determinants of Poverty and Inequality in the Selected Communities

5.1 Approach to Poverty Measurement

The steps involved in measuring and explaining poverty are well understood. In a first step, an indicator of household welfare or well-being is constructed, and that indicator can then be compared to a poverty line to identify the poor (Ravallion, 1996). Once the poor and the non-poor are distinguished, the correlates of poverty are analysed in an attempt to explain why some households are poor, and draw policy conclusions on how to facilitate escape from poverty.

Although the underlying logic is straightforward, each step of the methodology is unfortunately fraught with problems. A fundamental issue arises from the fact that well-being is not directly observable, so that a proxy needs to be defined to measure household welfare. Total current income is a popular choice in poverty studies, but it is also recognised that it suffers from important theoretical shortcomings (Balisacan, 1999). Most importantly, current income does not constrain consumption when households can borrow or use savings, which is the rule even in low-income countries where financial markets fail. In fact, the previous section identified borrowing as a key coping mechanism of households in the study areas and Fafchamps and Gubert (2003) showed how most informal loans within social networks in the Philippines attract no interest rate, thus making a debt trap impossible. It follows that consumption is theoretically a better welfare indicator than income. A more fundamental critique of the standard approach to poverty measurement, which was first formulated by Sen (1985), considers that income and consumption indicators are too limited as concepts of welfare, and that it would therefore be more appropriate to replace them with various social indicators, such as life expectancy, literacy and infant mortality. In a similar vein, the recent livelihoods literature emphasizes the multi-dimensional nature of poverty and the need to analyse it at a disaggregated level.

For this particular study, we note the previous set of limitations and choose to adopt a traditional approach to poverty measurement that we complement with additional indicators of household welfare, such as access to non-market goods, as suggested by Ravallion (1996). Our initial intention was to derive a consumption-based index of welfare, but the pilot survey revealed numerous difficulties in collecting the necessary data: respondents were often unable to recall what they had consumed or were getting impatient/annoyed with the dozens of questions on consumption of individual items. By contrast, and contrary to what the literature suggests (Ravallion and Chen, 1997; Lipton, 1997), it proved much easier to obtain information on household income, which most respondents were happy to share. We therefore rely for this particular study on an income-based poverty measure. Although practical considerations drove this methodological choice, we feel warranted in our approach by the results in Section 4.1, which established that income represents the main dimension of poverty in the eyes of a large majority of respondents in all five communities.

Our income measure includes earnings accruing to all household members from salaried employment, self-employment in activities such as fishing or retailing, rents of physical assets (land, houses, tri-cycles, boats etc.) as well as transfers from the state and individuals. A common practice in the study areas consists of making payments in nature (principally in the form of rice or fish), and their values were imputed on the basis of the prevailing market prices for these commodities. Further, it is clear that a household's needs depend on its demographic composition so that total household income should be adjusted accordingly. Conceptually, the construction of so-called equivalence scales is relatively simple as it should mainly take into account two key factors: first, the number of children in the household, because a child's needs are likely to be substantially less than an adult's[7]; and second, overall household size, because the presence of fixed household costs is likely to cause economies of scale in consumption. Empirically, however, the problem is complex and has generated an extensive literature (Banks & Johnson, 1994; Coulter *et al.*, 1992) from which no consensus emerges (Balisacan, 1999). In this context, we simply define our welfare measure as household income per capita, which is clearly preferable to the use of unadjusted household income.

The next step in the analysis consists in comparing the income-based welfare indicator to a reference level in order to identify poor households, but, here again, the construction of a poverty line raises a number of additional issues[8]. A common practice involves setting the poverty line as a constant proportion of the mean income, but, because the analysis then loses meaning in terms of absolute standards of living, it is unlikely to be of much relevance to anti-poverty policies (Ravallion, 1996). Clearly, in a country such as the Philippines, it is absolute poverty that matters, and it is preferable to build a poverty line interpretable in terms of the subsistence needs of the population. In the present context, we simply rely on the official poverty line, reported online by the Philippines National Statistics Office (PNSO) for individual regions in year 2000[9], which we adjust for inflation by using the national Consumer Price Index (CPI) also reported on the PNSO website. The poverty line is defined by the National Statistical Coordination Board (NSCB)[10] as the annual per capita food threshold plus the cost of other basic non-food requirements, and hence clearly relates to absolute poverty. For Central Luzon, the poverty line in year 2000 was PhP14,200, and the CPI increased from 152.1 in July 2000 to 183.3 in July 04, when the survey took place. The adjusted poverty line for Region 3 is therefore set at PhP17,113, or $305 at the current exchange rate. The corresponding value in Region 6 is PhP14,703, or $262 at the current exchange rate. The PNSO also reports a food threshold, defined by the NSCB as the annual per capita cost of basic food requirements which meet 100% adequacy of the recommended dietary allowance for protein and energy and 80% of all other nutrients. This measure of survival needs was PhP9,183 nationally in 2000, which translates to PhP11,067 in 2004 after taking into account the effect of inflation.

5.2 Levels of Poverty

Table 13 presents summary measures of income levels in the five communities under scrutiny. Mean household income in our sample, expressed on an annual and per capita basis, is equal to PhP18,889, while the median amounts to PhP12,925, and the

[7] Balisacan (1992) establishes for the Philippines that a rural couple with one child needs 20% more income than a childless household to achieve the same welfare level. However, it is also true that food need per unit of body weight is higher for children than adults; and that children need food of higher quality (in terms of energy density and protein balance) than adults. We are grateful to Dr Peter Edwards for that last point.

[8] In fact, some authors consider that the exercise introduces so much arbitrariness into the analysis that the poverty line should simply be set to plus infinity (Deaton, 1996).

[9] The address is www.census.gov.ph/data/sectordata/2000/ie00pftx.html.

[10] http://www.nscb.gov.ph/ru8/default.asp

standard deviation to PhP21,892. These figures do not describe the entire distribution of income very well but, nonetheless, suggest, when compared to the poverty lines calculated for each region, that poverty levels in the studied communities are substantial and that inequalities within these communities are relatively large as well. The table also reveals some differences across barangays. While the three communities SK, SA and NL appear relatively similar in terms of income levels, barangay LA is much poorer (mean income of only PhP9,379) and NB stands out from its particularly unequal distribution of income, as revealed by a relatively large mean (PhP23,673) but a very low median (PhP11,742) and an extremely large standard deviation (PhP40,344).

Going further in our assessment requires the choice of an aggregate poverty measure and the most popular one is the headcount index, defined as the percentage of the population below the poverty line. The index is used mainly because of its simplicity of interpretation but suffers from severe theoretical shortcomings (Ravallion, 1996), the main issue relating to its invariance with respect to a change in the distribution of income among the poor. For instance, a clearly undesirable evolution where all poor people become poorer while the non-poor maintain their income levels does not result in any change in the headcount index. The issue has also relevance when evaluating policies because, for instance, if a project manages to raise the income of the extremely poor, but not enough to lift them above the poverty line, success will not be reflected in the head-count measure of poverty.

These problems led researchers to develop alternative 'distribution-sensitive' poverty indicators, such as the poverty gap, which is the mean distance separating the population from the poverty line, with the non-poor being given a distance of zero. It measures the poverty deficit or depth of poverty of the population, i.e. the resources that would be needed to lift all the poor out of poverty through perfectly targeted cash transfers. Mathematically, it is defined as:

$$PG = \frac{1}{n}\sum_{i=1}^{q}\left[\frac{z - y_i}{z}\right] \qquad (1)$$

where n denotes the size of the population, y_i the income of individual i, q the number of poor people and z the poverty line. Even though this measure represents an improvement over the headcount index, it has some restrictive properties, in particular the fact that, when judging the impact of an increase in income of a poor person, the distance of that poor person's income from the poverty line is not taken into account (i.e., it does not matter how poor that person is). If it is believed that society or policy makers should place a larger weight on the welfare of extremely poor people, the squared poverty gap, which is often described as a measure of the severity of poverty, might be preferable. It is defined mathematically as:

$$P2 = \frac{1}{n}\sum_{i=1}^{q}\left[\frac{z - y_i}{z}\right]^2 \qquad (2)$$

Hence, it can simply be interpreted as a weighted poverty gap, where the weights are calculated as the distance of each poor person's income to the poverty line. We note in passing that all three aggregate measures of poverty relate to each other in the sense that they represent special cases of a class of indicators first proposed by Foster et al. (1984) defined as[11]:

$$P(\alpha) = \frac{1}{n}\sum_{i=1}^{q}\left[\frac{z - y_i}{z}\right]^{\alpha} \qquad (3)$$

The aggregate poverty measures are reported in Table 13, which indicates that 59% of the sample population falls below the poverty line. Hence, the incidence of poverty in the five communities is clearly high and exceeds by far the national average, as the headcount reported in Table 1 for the whole of the rural areas of the Philippines is only 40.1%. It was expected to find a higher poverty incidence in Region 6 than in Region 3, but that is not the case. In fact, barangay NL has the lowest poverty headcount, while barangay LA has the highest one, and both are located in Region 6. More relevant than regional differences might be the remoteness of the communities, because barangays SK and LA, which are both relatively difficult to access, have a relatively high poverty incidence. Table 13 also presents estimates of the poverty gap and squared poverty gap for each community and the whole sample. It is reassuring to find that the ranking of the five barangays does not depend on the choice of aggregate poverty measure . Poverty is the least prevalent in barangay NL, followed by barangay SA, barangay SK, barangay NB, and, finally, barangay LA. The poverty gap for the whole sample (0.28) indicates that the depth of poverty is relatively large among our sample households as it means that eliminating poverty completely in these communities would require cash transfers amounting to 28% of the poverty line for every individual. Finally, Table 13 presents a measure of extreme poverty, which is simply the headcount index calculated not with respect to the poverty line, but, instead, the food threshold. The sample average of 0.43% confirms that absolute poverty represents a major problem for these coastal communities. Comparison of the five barangays once again confirms that poverty is worst in LA, but the ranking is slightly modified for the three communities with the lowest poverty incidence (SK, SA and NL).

In conclusion, these aggregate figures indicate clearly that all five communities are poor, with a high incidence of extreme poverty defined as a situation where households are unable to satisfy even their most basic needs for food. Barangays LA and NB stand out as being particularly poor, while no clear regional differences regarding the incidence of poverty can be established from our sample.

5.3 Is Aquaculture Pro-poor?

Our analysis of the relationship between aquaculture and poverty starts by evaluating the quantitative importance of fish-farming related activities in generating income in the three barangays (SK, SA, and NL) where the industry is present[12]. Table 14 reports total income from aquaculture for each barangay and the whole sample, expressed per household and per capita, as well as the aggregate and average shares of

[11] The head count index is obtained for α=0, the poverty gap for α=1, and the squared poverty gap for α=2.

[12] Barangay Lat-asan was selected to represent a community where only part of the land was occupied by fishponds. However, we found that only a negligible income stream was attributable to aquaculture in that community, in part due to the small area of ponds, and could therefore not include the barangay in this analysis.

aquaculture in household income[13]. It is clear that aquaculture represents a quantitatively important economic activity in all three communities, as the table reveals that aquaculture generates an income of, on average, PhP27,194 per household or PhP5,038 per capita. This income stream represents 29% of total income accruing to the sample households, while the average income share from aquaculture amounts to 39%. On the other hand, these figures indicate that households in these communities are also able to diversify their sources of income, and the previous percentages can be compared to an average non-farm share of rural household income of 42% in the whole of the Philippines (FAO, 1998). Hence, aquaculture is economically significant in these coastal communities, but it is one of many important activities, including fishing, retailing and construction. The table further reveals that fish-farming is much more important in barangay SK than in the other two areas. This is explained by the fact that barangay SA is close to the relatively urban centre of Sasmuan, which offers job opportunities, while workers from barangay NL can find jobs in agriculture as the barangay is connected to the mainland. By contrast, barangay SK is relatively remote so that fishing and aquaculture represent the main economic activities. Indeed, the share of income from aquaculture in SK is on average 58%, so that the activity is obviously an essential source of livelihood in that community. These results also confirm that the economic environments of the three barangays differ substantially, which was deemed desirable when setting up the survey and suggests that our purposive sampling strategy was, from that point of view, relatively successful.

Next, we investigate the pro-poor nature of aquaculture by distinguishing the income generated by aquaculture that accrues to the poor and the non-poor. Table 14 establishes clearly that both groups benefit substantially from the activity: a poor household derives, on average, an income of PhP23,863 from aquaculture, which translates into PhP3,951 per capita, or roughly a quarter of the poverty line. A non-poor household benefits even more, with an average income of PhP30,809, or PhP6,552 in per capita terms. These results are consistent with the opinions expressed by respondents about the distributional properties of aquaculture (see section 4.2): clearly, both the poor and the rich[14] benefit from the activity. Furthermore, while the poor benefit less from fish-farming in absolute terms, they benefit a lot more in relative terms. Thus, Table 14 reveals that aquaculture accounts for 44% of income for the poor, but only half as much (23%) for the rich. This is a key result of our analysis that gives strong empirical support to the idea that brackish water aquaculture is indeed pro-poor in the Philippines. Further, this conclusion appears robust to the choice of community and poverty line and can therefore be stated with confidence. First, with regard to the choice of barangay, the aggregate shares of income from aquaculture for the poor and non-poor are 34% and 11% respectively in SA, 31% and 12% in NL, while both are equal to 57% in SK. Then, the pro-poor character of aquaculture becomes even more evident when focusing on the subset of extremely poor households, i.e. those with an income below the food threshold. For the whole sample, these extremely poor households derive more than half their income (54%) from aquaculture, as opposed to only 25% for the remaining households and, here

[13] The aggregate share is the sum of aquacultural incomes divided by the sum of household incomes for the group of households considered. The average share is the arithmetic average of the ratio aquaculture income/household income for each household in the group.

[14] We take 'rich' as simply meaning non-poor. Most households in that category are in fact far from being rich by any standards.

again, the same pattern emerges within each barangay. In particular, in SK where aquaculture benefits the poor and the rich equally in relative terms, the activity accounts for a massive 71% of income of the extremely poor, as opposed to only 53% for the remaining households. The corresponding percentages in SA are 43% versus 13%, while they are 42% and 12% in NL.

We pursue this investigation by carrying out a simple experiment that assesses by how much poverty would increase if the sample households were not receiving any income from aquaculture. That is, we reproduce the poverty evaluation of section 5.2 by replacing total household income by non-aquacultural income and the results are presented in aggregate form in Table 15. Concentrating on the poverty measures, it is clear that poverty would increase substantially to reach very high levels in all three communities, and that this conclusion does not hinge on the choice of index or poverty line. The headcount is simulated to rise from 54% to a massive 70%, indicating that more than two thirds of households would be poor in the absence of aquaculture. The poverty gap almost doubles from 24% to 47%, which means that eliminating poverty in the absence of aquaculture would require perfectly targeted cash transfers amounting to almost half of the poverty line for every member of these three communities. Finally, the squared poverty gap would almost triple from 0.14 to 0.39. The fact that the relative increase in the squared poverty gap exceeds that of the poverty gap, which is itself larger than that of the headcount index, reveals that eliminating aquacultural income would represent a particularly regressive change, or, in other words, that it would have a particularly detrimental impact on the extremely poor. This interpretation is confirmed by the observation that the increase in the head count index is larger when calculated at the food threshold (19%) than when calculated at the poverty line (16%). Of course, the above simulation represents an over-simplification of reality because, if aquaculture was to disappear from a particular community, individuals deriving income from the sector would be able to reallocate labour and assets to other sectors to generate alternative income. Hence, the above figures represent upper bounds of the likely impact of the disappearance of aquaculture on poverty. Yet, we believe that in reality there would be major obstacles to such a reallocation of household resources, as the Philippines are usually described as a 'labour surplus economy' where unemployment and under-employment represent important problems. This view was also shared by most of the respondents, as they identified the lack of jobs as the main cause of poverty in their communities. Further, the previous simulation reinforces the conclusion that aquaculture benefits the poor and the extremely poor disproportionately.

5.4 Measuring and Explaining Income Inequality

The extent of poverty in a particular group of households is simply a function of mean income and the distribution of income within that group. Hence, there is an obvious relationship between income inequality and poverty, and the pro-poor nature of aquaculture depends in large part on how the income generated by the sector is distributed among households. This motivates our investigation of inequality in the three study areas and how it relates to aquaculture. For this purpose, we rely on a large literature that has developed adequate measures of inequality as well as ways of attributing total inequality to different income sources. The analysis starts with the Lorenz curve, which plots the cumulative percentage of the population to the cumulative share of income they control and hence provides a complete geometric characterization of the distribution of income (Sadoulet & de Janvry, 1995). For the

98 households in barangays SA, SK and NL, the Lorenz curve is depicted by the blue line in Figure 3. The Gini coefficient, which represents the most popular summary measure of income inequality, is then defined as the area between the Lorenz curve and the first diagonal (pink line in Figure 3), expressed as a percentage of the total area below the first diagonal. Admissible values therefore range from zero to unity, with larger values of the coefficient indicating larger levels of income inequality.

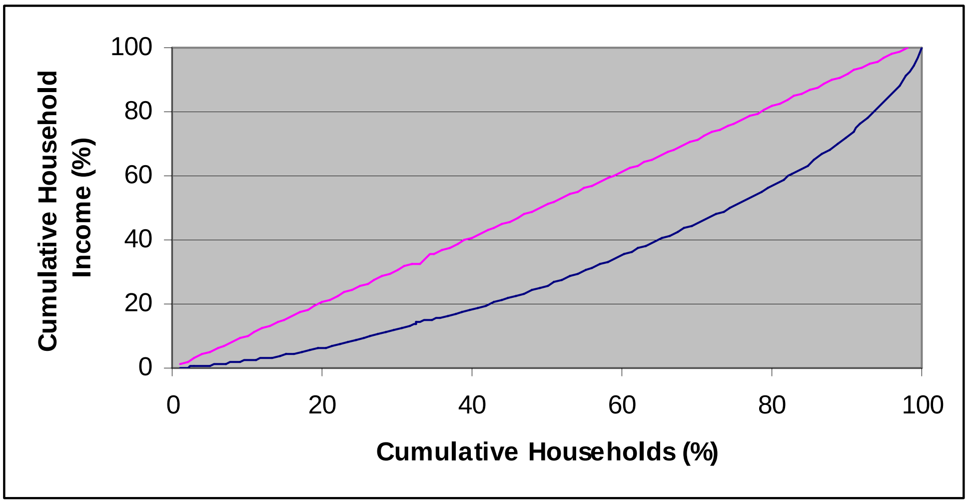

Figure 3: Lorenz Curve

The Gini coefficient takes different mathematical expressions and we opt for that proposed by Pyatt, Chen and Fei (1980):

$$G = \frac{2}{n\bar{y}} \operatorname{cov}(y, r) \qquad (4)$$

where y_i and r_i denote the income and rank of household i when the population is ordered by increasing income, n is the total number of households, $\bar{y}$ is the mean population income, and cov(.) denotes the covariance operator. In the case of our 98 households, the Gini coefficient takes a value of 0.36, which is indicative of significant but modest inequalities. However, when this level of inequality is applied to a mean income that is marginally larger than the poverty line (Table 13), it results in a large number of households being poor.

A very useful property of the Gini coefficient is that it can be broken down according to each particular source of income, which can then be compared in equity terms. The approach was pioneered by Stark, Taylor and Yitzhaki (1986), who investigated the effect of remittances on inequality in two Mexican villages, and derived the following expressions (Sadoulet and de Janvry, 1995, p. 22):

$$G = \sum_s S_s R_s G_s \qquad (5)$$

where S_s denotes the share of source s in total income, G_s is the Gini coefficient of the sth source of income, and R_s denotes the Gini correlation coefficient between income source s and total income expressed as[15]:

[15] By analogy with the previous notations, r_s is the rank of household i when the population is ordered by increasing income from source s, denoted y_s.

$$R_s = \frac{\text{cov}(y^s, r)}{\text{cov}(y^s, r^s)} \qquad (6)$$

Expression (5) is fairly intuitive as it states that the effect of income source *s* on the level of inequality is a function of three factors:

- The relative importance of income source *s* in total income S_s. Clearly, a source of income accounting for a very small share of total income can only have a minor impact on overall inequality.
- The distribution of income from source *s* among all households, as measured by G_s. If only a few households derive a large income from source *s* (large value of G_s), that source of income will tend to increase overall inequality in the community.
- The correlation between income from source *s* and total income across households. A low level of correlation indicates that households deriving a relatively large (small) income from source *s* are not necessarily rich (poor), which therefore tends to reduce overall inequality.

The analysis can be pursued to investigate whether a particular source of income increases or decreases inequality in a group of households. First, it is important to notice that quantities S_s and G_s are both positive and smaller than unity, while R_s can take values in the *-1* to *+1* range. It is therefore clear from equation (5) that a negative Gini correlation coefficient R_s implies that income source *s* unambiguously reduces inequality. To determine the overall effect of income source *s* on inequality when R_s is positive, it is useful to re-write the Gini decomposition as (Sadoulet & de Janvry, 1995):

$$\sum_s S_s \frac{R_s G_s}{G} = 1 \qquad (7)$$

This expression can be interpreted as a weighted average of each source of income's 'concentration coefficient' $R_s G_s / G$ and indicates that a source of income is inequality increasing (decreasing) if and only if this coefficient is greater (smaller) than unity.

The above formulae help characterize the overall inequality effect of a particular income source, but it is also interesting to determine the marginal effect, i.e. whether a small change in income source *s* would increase or decrease inequality. This is motivated by the observation that most policies aim at changing the magnitude of an income source rather than removing it completely or creating it where it did not previously exist. Stark, Taylor and Yitzhaki (1986) derived the change in the Gini coefficient as a result of one percent increase in income from source *s* as:

$$\frac{\partial G}{\partial \ln y_s} = S_s (R_s G_s - G) \qquad (8)$$

or, in relative terms:

$$\frac{\partial \ln G}{\partial \ln y_s} = S_s (\frac{R_s G_s}{G} - 1) \qquad (9)$$

These expressions imply that, at the margin, income source *s* is inequality increasing (decreasing) if and only if the concentration coefficient for that income source is greater (smaller) than unity.

The Gini decomposition was used to investigate the impact of aquacultural income on inequality in each barangay as well as the whole sample (Table 16). Focusing on the aggregate results first, while aquaculture represents almost a third of household income, it accounts for less than 3% of the total Gini coefficient of 36%, with non-aquaculture therefore accounting for more than 33%. In other words, only 8% of overall inequality is attributable to aquaculture, while 92% is attributable to other income sources. This limited impact of aquaculture on inequality occurs in spite of the fact that aquacultural income is, on the whole, relatively unequally distributed: its Gini coefficient is 66%, as compared to 57% for income unrelated to fish farming. However, consistent with expression (5), the result is explained primarily by the fact that the Gini correlation coefficient for aquaculture is positive but very small, at 5%, as compared to 90% for non-aquaculture.

This decomposition is therefore extremely useful in understanding the impact of aquaculture in these coastal communities. First, the relatively large Gini coefficient for aquaculture simply reflects the fact that a substantial number of households derive no income from this activity. However, the key result relates to the Gini correlation coefficient, which indicates that there is little relation between total household income and aquacultural income. This means that relatively rich (poor) households are not much more likely to derive large (small) incomes from aquaculture than poor (rich) households. We are therefore left, once again, with the conclusion that both poor and rich people benefit substantially from aquaculture in these communities.

From the previous set of results, it should come as no surprise that the overall effect of aquaculture is to decrease inequality in these communities, as indicated by a concentration coefficient of 0.11, which is clearly smaller than unity (see equation (7)). Hence, aquaculture is a more equitable source of income than the available alternatives taken together. The inequality reducing nature of aquaculture is also apparent at the margin: a one percent increase in aquacultural income in these communities results in a decrease in the Gini coefficient of 0.08, or more than 21% when expressed in relative terms. This supports the view that aquacultural growth has a strong levelling effect on the distribution of income in these communities.

The previous set of conclusions applies broadly to each barangay taken individually, although some interesting nuances are also evident. Most remarkably, in all three communities the decomposition establishes that aquaculture reduces inequality both overall and at the margin, which is an indication of the robustness of our results. Hence, the three concentration coefficients are smaller than unity at 0.11 in SA, 0.81 in SK and -0.41 in NL. In all three communities, the inequality reducing impact of aquaculture is explained primarily by the low or negative correlation between total household income and fish-farming income. Barangay NL stands out in this regard because of its negative Gini correlation coefficient for aquaculture, which indicates that, on average, the poorer a household in that community, the larger the income that it derives from fish-farming activities. It follows that aquaculture is particularly pro-poor in NL, which is consistent with the observation reported in Table 16 that a one percent change in fish-farming income in that community decreases the Gini coefficient by a massive 9% (the corresponding values in SA and SK are 6% and 3% respectively). Finally, the table also reveals that the distribution of aquacultural income varies substantially in the three communities: the Gini coefficient for that source of income is larger than that for other sources of income in SA and NL but smaller in SK. We believe that this simply confirms our interpretation, stated above, that the main determinant of the Gini coefficient for aquacultural income is the number of households deriving no income from the sector. In SA and NL, this number is relatively large, hence justifying the large Gini coefficients.

5.5 Discussion

The quantitative analysis presented in this section suggests that aquaculture in the study areas represents a source of income which is both pro-poor and inequality-reducing. This result deserves an explanation which we now seek through an investigation of how the sample households derive income from aquaculture. The data reveals first that very few owners (or operators) of fish farms are represented in our random sample and we interpret this finding as indicating that the industry is concentrated in the hands of a few individuals who tend to live away from the communities where production takes place. In spite of this feature, aquaculture in the coastal areas of the Philippines represents an important source of employment through the direct and indirect demand for labour that it generates. Hence, more than half of the households in barangays SK, SA and NL are involved in at least one aquaculture-related activity. Table 17 gives additional details about the income and employment generated by aquaculture in the three barangay and shows that a large number of economic activities are related to the operation of fish farms:

- Labourers are hired on a daily basis for a wage of approximately PhP150 in Region 3 and PhP100 in Region 6. They usually carry out maintenance tasks related to the fishponds, and most importantly the consolidation of dykes, which involves taking mud by hand from the bottom of the pond and applying it where the dykes need reinforcement[16]. This operation appears particularly labour intensive in Region 3, where the dykes need to be high and strong to resist tides and seasonal floods. Hired workers in Region 3 are also used in large numbers to remove an invasive weed (local name 'digman'), which is thought to be detrimental to the survival of prawns. Table 17 indicates that 46% of the sample households derive some income from the sale of wage labour, which accounts for more than a quarter of the total aquacultural income accruing to the three barangays. Hence, the demand for wage labour generated by aquaculture appears particularly pro-poor because most households can apparently benefit from it.

- Harvests, which take place two to three times a year, also mobilize a large number of workers (usually ten to twenty for a ten-hectare pond) for a full day, at a wage rate of approximately PhP250 in Region 3 and PhP150 in Region 6, which is, sometime, supplemented by a small quantity a fish. Almost one in five households in our sample participates in that activity, but the related income is limited (PhP4,499) because harvests provide at best a few weeks of employment annually for any given individual.

[16] In recent years, mechanical diggers have been introduced but their use remains rare.

- ‘Caretaking’, which corresponds to the supervision of aquaculture ponds, provides employment to 23% of households in our sample. The task is usually carried out by a permanent employee who lives on the dykes of the fish pond together with his family. The remuneration of caretakers has several components, including a base monthly salary (around P4,000 in Region 3 and P3,000 in Region 6), incentive payments in the form of a percentage of the harvest, as well as payments in nature (provision of free housing, rice and fish) but arrangements vary from farm to farm and region to region. For instance, incentive payments range from zero to 20% of the harvest and are a lot more frequent in Region 3 than in Region 6. Caretaking is important for the three studied communities because it provides permanent employment to a significant number of workers, a rule of thumb being that one caretaker is usually hired to manage ten hectares of fish ponds. The mean income of participating households is relatively large (PhP51,354) and the activity accounts for 44% of total aquacultural income in the three communities. Notice however that a family of four earning the mean caretaking income would still fall below the poverty line.

- The data reveals that the collection of shells and molluscs which are used as feeds in fish ponds represents another important activity directly related to aquaculture, in which 14% of households partake. It is usually carried out as an own-account activity but large farms sometime hire full-time workers solely for the purpose of collecting these ‘natural feeds’. Further, the activity appears relatively lucrative with the mean income of participating households amounting to PhP26,621. The importance of this type of feeds is a reflection of the polyculture and extensive nature of the production systems considered here, which often makes it uneconomical to use high quality feeds to, say, grow prawns, when most of the feeds are actually consumed by other species.

- The collection of ‘free fish’, i.e. left-overs after the harvest, appears qualitatively unimportant as a source of income but it might generate substantial nutritional benefits to poor households.

- The survey finally reveals that there is a whole range of other activities related to aquaculture, directly or indirectly, which provide income and employment to the coastal areas of the Philippines, although they are not listed individually in Table 17. They include the marketing of feeds, seeds (‘fingerling agents’), fish, prawns and crabs; the collection of wild fry and fingerlings; boat transportation of workers, inputs and outputs; and even the construction and maintenance of boats used in the operation of fish ponds. It is likely that Table 17 underestimates the income stream generated by aquaculture through these activities because it is often difficult to attribute a particular activity, such as transportation, solely to aquaculture.

6. Conclusion

This paper has investigated the relationship between aquaculture and poverty from several perspectives based on a household survey of five costal communities. We started by examining how this relationship was perceived by the residents of these communities themselves and pursued with a quantitative assessment of the determinants of poverty and inequality. The findings can be summarized as follows:

- Aquaculture in the studied communities generates a substantial income stream that benefits both the poor and the rich. This quantitative result confirms the view expressed by a large majority of households, and the perception of aquaculture in the five barangays is overwhelmingly positive.

- While the rich benefit slightly more in absolute terms, the poor benefit a lot more in relative terms and it is in that sense that aquaculture can be considered pro-poor. Further, the pro-poor nature of aquaculture is evident in different economic environments and only increases when the poverty line is lowered. In particular, the group of extremely poor households that struggles to meet even its basic food needs derives more than half of its income from aquaculture.

- A Gini decomposition exercise established unambiguously that aquaculture represents an inequality-reducing source of income in these communities. This is explained primarily by a low level of correlation between total income and aquaculture income. In other words, it is not necessarily richer households that derive large incomes from fish farming in these communities.

- Our study does not support the view, present in the literature, that aquaculture contributes to the marginalisation of the poor. Some residents in coastal communities are aware of possible negative impacts of aquaculture, most notably on fishing, but consider them to be more than offset by job creation in aquaculture.

This set of results might seem surprising at first as brackish water aquaculture in the Philippines is usually considered a rich-man activity. We believe that it is explained primarily by the fact that, while the industry remains relatively concentrated in the hands of rich owners/operators, it is still generating a large demand for relatively unskilled labour. In the context of communities where the primary cause of poverty is the lack of employment opportunities, the jobs directly or indirectly related to fish farming represent an essential source of livelihood for the poor. This also means that policy makers concerned with developing the sector, if aiming to have an impact on poverty, should pay attention to the employment effects of new policies and technologies. While intuitive, this recommendation contrasts with the emphasis that is usually put on production and land productivity growth in the debate about aquaculture development in developing countries.

Table 2: Meaning of Poverty - Number of occurrences of each answer and related percentages

Barangay	Insufficient Income	Irregular Income	No Job	No permanent Job	Unable to purchase enough food	No durable goods	No own house	To be landless	No Savings	No access to education/ health care	No influence in the community	To be dependent on others	To be indebted/ have to borrow to get by	Too many children
SK	17	13	3	8	15	0	3	2	6	1	0	1	2	3
	46%	35%	8%	22%	41%	0%	8%	5%	16%	3%	0%	3%	5%	8%
SA	18	5	11	4	14	5	2	6	1	2	1	2	1	0
	50%	14%	31%	11%	39%	14%	6%	17%	3%	6%	3%	6%	3%	0%
NL	15	7	1	3	6	2	0	1	0	1	1	2	0	1
	60%	28%	4%	12%	24%	8%	0%	4%	0%	4%	4%	8%	0%	4%
LA	17	7	0	1	3	1	0	0	1	0	0	0	0	0
	68%	28%	0%	4%	12%	4%	0%	0%	4%	0%	0%	0%	0%	0%
NB	12	3	3	6	3	1	1	2	1	2	0	1	0	0
	48%	12%	12%	24%	12%	4%	4%	8%	4%	8%	0%	4%	0%	0%
Total	79	35	18	22	41	9	6	11	9	6	2	6	3	4
	53%	24%	12%	15%	28%	6%	4%	7%	6%	4%	1%	4%	2%	3%

Table 3: Sources of Vulnerability

	Flood	Drought	Typhon	Illness	Death	Job loss	Other
SK	3	1	1	17	1	17	5
	8%	3%	3%	46%	3%	46%	14%
SA	2	0	4	10	1	11	2
	6%	0%	11%	28%	3%	31%	6%
NL	5	0	3	11	1	0	1
	20%	0%	12%	44%	4%	0%	4%
LA	4	0	1	8	1	0	0
	16%	0%	4%	32%	4%	0%	0%
NB	5	0	0	9	4	0	0
	20%	0%	0%	36%	16%	0%	0%
Total	19	1	9	55	8	28	8
	13%	1%	6%	37%	5%	19%	5%

Table 4: Perceived causes of poverty

Barangay	Low Salaries	Unemployment/ No stable jobs	Hig Prices of Necessities	Lack of Education	Lack of Physical Assets	Scarcity of Fish	Dependence on Fishing/ Farming	Over-population/ Too Many Children	Vices/ Laziness/ Irresponsible Behaviour
SK	5	24	6	4	3	3	1	13	12
	14%	65%	16%	11%	8%	8%	3%	35%	32%
SA	0	25	1	5	3	7	7	1	6
	0%	69%	3%	14%	8%	19%	19%	3%	17%
NL	5	19	0	0	2	0	2	1	5
	20%	76%	0%	0%	8%	0%	8%	4%	20%
LA	4	11	2	0	8	9	14	1	0
	16%	44%	8%	0%	32%	36%	56%	4%	0%
NB	10	15	2	5	1	0	0	5	5
	40%	60%	8%	20%	4%	0%	0%	20%	20%
Total	24	94	11	14	17	19	24	21	28
	16%	64%	7%	9%	11%	13%	16%	14%	19%

Table 5: Coping Strategies

Barangay	Work More	Borrow	Sell Assets	Help from Support Network	Help from Government	Reduce Consumption/ no coping mechanism	Rely on Own Savings	Start Family Business
SK	5	22	7	24	0	6	2	4
	14%	59%	19%	65%	0%	16%	5%	11%
SA	5	15	1	18	3	6	1	0
	14%	42%	3%	50%	8%	3%	3%	0%
NL	1	6	1	12	2	12	0	0
	4%	24%	4%	48%	8%	8%	0%	0%
LA	1	7	2	9	2	11	0	0
	4%	28%	8%	36%	8%	44%	0%	0%
NB	0	10	2	12	2	13	0	0
	0%	40%	8%	48%	8%	52%	0%	0%
Total	12	60	13	75	9	48	3	4
	8%	41%	9%	51%	6%	32%	2%	3%

Table 6: How Can Poverty Be Reduced?

Barangay	Create More Job Opportunities	Create Livelihood Opportunities for Women	Improve Individual Behaviour	More Investment/ credit	Government Help	Improve Access to Education	Improve Family Planning	Develop Aquaculture	None
SK	10	4	11	0	2	0	1	4	14
	27%	11%	30%	0%	5%	0%	3%	11%	38%
SA	11	0	10	7	2	3	3	0	9
	31%	0%	28%	19%	6%	8%	8%	0%	25%
NL	6	0	16	2	6	0	0	1	0
	24%	0%	64%	8%	24%	0%	0%	4%	0%
LA	4	0	7	4	6	0	0	0	5
	16%	0%	28%	16%	24%	0%	0%	0%	20%
NB	9	0	14	2	4	1	1	0	0
	36%	0%	56%	8%	16%	4%	4%	0%	0%
Total	40	4	58	15	20	4	5	5	28
	27%	3%	39%	10%	14%	3%	3%	3%	19%

Table 7: Does Aquaculture Benefit the Poor and/or the Rich?

Barangay	Neither	The Rich, Not the poor	The Poor, not the Rich	Both
SK	0	0	0	37
	0%	0%	0%	100%
SA	0	1	4	31
	0%	1%	11%	86%
NL	0	12	0	13
	0%	48%	0%	52%
LA	1	14	1	8
	4%	56%	4%	32%
NB	0	7	1	16
	0%	28%	4%	64%
Total	1	34	6	105
	1%	23%	4%	71%

Table 8: Do the poor practice fish farming?

Barangay	Yes	No
SK	31	6
	84%	16%
SA	18	18
	50%	50%
NL	16	9
	64%	36%
LA	10	15
	40%	60%
NB	6	18
	24%	72%
Total	81	66
	55%	45%

Table 9: Could You Start Fish Farming?

Barangay	Yes	No
SK	2	35
	5%	95%
SA	5	31
	14%	86%
NL	10	15
	40%	60%
LA	4	21
	16%	84%
NB	6	19
	24%	76%
Total	27	121
	18%	82%

Table 10: Does Fish Farming Have Any negative Impact on the Poor?

Barangay	No	Yes				
		Total	Negative Impact on fishing	Exploitation of the Poor	Arduous work	Irregular Income
SK	12	25	24	1	1	0
	32%	68%	65%	3%	3%	0%
SA	27	9	3	1	0	4
	75%	25%	8%	3%	0%	11%
NL	23	2	1	1	1	0
	92%	8%	4%	4%	4%	0%
LA	18	7	7	0	0	0
	72%	28%	28%	0%	0%	0%
NB	24	1	0	1	0	0
	96%	4%	0%	4%	0%	0%
Total	104	44	35	4	2	4
	70%	30%	24%	3%	1%	3%

Table 11: Overall, Is Aquaculture a Good Thing in Your Community?

Barangay	No	Yes				
			Main benefit from aquaculture			
		Total	Employment	Income	Fish/Food	Indirect
SK	4	33	26	4	14	1
	11%	89%	70%	11%	38%	3%
SA	0	36	32	4	17	3
	0%	100%	89%	11%	47%	8%
NL	0	25	19	14	5	2
	0%	100%	76%	56%	20%	8%
LA	3	22	3	10	8	1
	12%	88%	12%	40%	32%	4%
NB	0	25	16	2	15	0
	0%	100%	64%	8%	60%	0%
Total	7	141	96	34	59	7
	5%	95%	65%	23%	40%	5%

Table 12: Ladder Diagram

Barangay		Food			Fish			Employment	Cash
		-5 years	Now	+ 5 years	-5 years	Now	+ 5 years		
SK	Average	6.55	6.09	6.46	7.88	7.26	7.00	7.53	7.69
	SD	2.11	1.91	1.84	2.19	2.26	2.22	3.14	3.11
SA	Average	7.11	6.44	7.45	7.19	7.28	7.91	3.75	3.72
	SD	1.75	1.81	2.06	2.07	1.86	2.13	3.59	3.57
NL	Average	4.46	4.17	4.71	5.21	4.42	4.71	5.96	5.42
	SD	2.15	1.24	1.55	1.74	1.47	1.52	3.24	3.08
LA	Average	3.60	3.44	3.24	4.16	4.16	3.52	0.60	0.52
	SD	1.29	1.23	1.20	1.52	1.37	1.16	2.08	1.71
NB	Average	4.12	4.08	4.48	4.72	4.64	4.72	0.40	0.32
	SD	1.76	1.66	1.83	1.51	1.47	1.51	2.00	1.60
Total	Average	5.40	5.05	5.43	6.06	5.80	5.74	3.88	3.80
	SD	2.32	2.03	2.31	2.36	2.27	2.43	4.05	3.98

Table 13: Aggregate Income & Poverty in the Five Communities

Barangay	Income			Poverty			
	Mean	Median	SD	HC	PG	P2	HC (Food)
SK	17,214	14,633	12,134	0.59	0.26	0.15	0.35
SA	24,242	17,182	21,555	0.50	0.22	0.12	0.31
NL	18,383	17,974	11,638	0.44	0.21	0.12	0.36
LA	9,379	5,600	10,413	0.84	0.50	0.33	0.76
NB	23,673	11,742	40,344	0.60	0.28	0.17	0.44
Total	18,889	12,925	21,892	0.59	0.28	0.17	0.43

Table 14: Aquaculture and Income Generation

Barangay	Households	Income From Aquaculture (PhP) Per Household	Per Capita	Average Share of household Income	Aggregate Share of Household Income
SK	All	43,927	8,167	0.58	0.57
	Poor	32,535	5,342	0.58	0.57
	Non-Poor	60,636	13,993	0.58	0.57
	Extremely Poor	30,872	4,778	0.65	0.71
	Non-Extremely Poor	50,999	10,643	0.54	0.53
SA	All	19,282	3,403	0.23	0.17
	Poor	18,877	2,763	0.31	0.34
	Non-Poor	19,686	3,730	0.16	0.11
	Extremely Poor	21,072	3,175	0.35	0.43
	Non-Extremely Poor	18,494	4,203	0.18	0.13
NL	All	13,823	2,743	0.33	0.17
	Poor	14,676	2,484	0.41	0.31
	Non-Poor	13,153	3,019	0.26	0.12
	Extremely Poor	16,056	2,779	0.48	0.42
	Non-Extremely Poor	12,567	2,717	0.24	0.12
All	All	27,194	5,038	0.39	0.29
	Poor	23,863	3,951	0.45	0.44
	Non-Poor	30,809	6,552	0.32	0.23
	Extremely Poor	23,564	3,721	0.51	0.54
	Non-Extremely Poor	29,037	5,898	0.33	0.25

Table 15: Simulated Poverty Levels (No Aquaculture)

Barangay	Income			Poverty			
	Mean	Median	SD	HC	PG	P2	HC (Food)
SK	7,869	2,833	10,778	0.86	0.64	0.54	0.70
SA	20,698	13,555	22,878	0.58	0.35	0.27	0.44
NL	12,631	11,667	11,522	0.64	0.41	0.34	0.48
Total	13,796	8,179	17,212	0.70	0.47	0.39	0.55

Table 16: Gini Decomposition

Barangay		Source of Income *s*: Aquaculture	Non-Aquaculture	Total
SA	Gini Decomposition			
	Income share (S_s)	0.166	0.834	1.000
	Gini coefficient (G_s)	0.928	0.519	0.397
	Gini correlation coefficient (R_s)	0.047	0.900	1.000
	Overall contribution to Gini coefficient ($S_sG_sR_s$)	0.007	0.389	0.397
	Share of Gini coefficient ($S_sG_sR_s/G$)	0.018	0.982	1.000
	Concentration coefficient (G_sR_s/G)	0.111	1.178	1.000
	Response of Gini coefficient to a change in income source *s*			
	Absolute change ($S_s(R_sG_s\text{-}G)$)	-0.059	0.059	0.000
	Percentage change ($S_s(G_sR_s/G\text{-}1)$)	-0.148	0.148	0.000
SK	Gini Decomposition			
	Income share (S_s)	0.570	0.430	1.000
	Gini coefficient (G_s)	0.402	0.516	0.235
	Gini correlation coefficient (R_s)	0.475	0.569	1.000
	Overall contribution to Gini coefficient ($S_sG_sR_s$)	0.109	0.126	0.235
	Share of Gini coefficient ($S_sG_sR_s/G$)	0.463	0.537	1.000
	Concentration coefficient (G_sR_s/G)	0.812	1.249	1.000
	Response of Gini coefficient to a change in income source *s*			
	Absolute change ($S_s(R_sG_s\text{-}G)$)	-0.025	0.025	0.000
	Percentage change ($S_s(G_sR_s/G\text{-}1)$)	-0.107	0.107	0.000
NL	Gini Decomposition			
	Income share (S_s)	0.172	0.828	1.000
	Gini coefficient (G_s)	0.606	0.491	0.357
	Gini correlation coefficient (R_s)	-0.244	0.941	1.000
	Overall contribution to Gini coefficient ($S_sG_sR_s$)	-0.025	0.383	0.357
	Share of Gini coefficient ($S_sG_sR_s/G$)	-0.071	1.071	1.000
	Concentration coefficient (G_sR_s/G)	-0.414	1.293	1.000
	Response of Gini coefficient to a change in income source *s*			
	Absolute change ($S_s(R_sG_s\text{-}G)$)	-0.087	0.087	0.000
	Percentage change ($S_s(G_sR_s/G\text{-}1)$)	-0.243	0.243	0.000
All	Gini Decomposition			
	Income share (S_s)	0.295	0.705	1.000
	Gini coefficient (G_s)	0.662	0.574	0.359
	Gini correlation coefficient (R_s)	0.149	0.816	1.000
	Overall contribution to Gini coefficient ($S_sG_sR_s$)	0.029	0.330	0.359
	Share of Gini coefficient ($S_sG_sR_s/G$)	0.081	0.919	1.000
	Concentration coefficient (G_sR_s/G)	0.275	1.303	1.000
	Response of Gini coefficient to a change in income source *s*			
	Absolute change ($S_s(R_sG_s\text{-}G)$)	-0.077	0.077	0.000
	Percentage change ($S_s(G_sR_s/G\text{-}1)$)	-0.214	0.214	0.000

Table 17: Decomposition of Aquacultural Income

Barangay		Wage Labourer	Harvester	Caretaker	'Free fish' Collector	Shell Collector	Other
		Type of Activity					
SK	**Share of HHs participating**	0.57	0.03	0.27	0.16	0.30	0.11
	Mean Income (participating HHs)	18,109	3,900	64,571	4,850	32,779	51,583
	Mean Income (all HHs)	10,278	105	17,452	786	9,745	5,577
	Share of Aquacultural Income	0.23	0.00	0.40	0.02	0.22	0.13
SA	**Share of HHs participating**	0.28	0.14	0.19	0.03	0.00	0.14
	Mean Income (participating HHs)	18,579	10,410	50,914	1,800	0	19,970
	Mean Income (all HHs)	5,161	1,446	9,900	50	0	2,774
	Share of Aquacultural Income	0.27	0.07	0.51	0.00	0.00	0.14
NL	**Share of HHs participating**	0.56	0.52	0.24	0	0.12	0.12
	Mean Income (participating HHs)	8,345	2,272	29,839	0	4,043	2,900
	Mean Income (all HHs)	4,673	1,181	7,161	0	485	348
	Share of Aquacultural Income	0.34	0.09	0.52	0.00	0.04	0.03
All	**Share of HHs participating**	0.46	0.19	0.23	0.07	0.14	0.12
	Mean Income (participating HHs)	15,175	4,499	51,354	4,414	26,621	26,240
	Mean Income (all HHs)	6,968	872	12,053	315	3,803	3,213
	Share of Aquacultural Income	0.26	0.03	0.44	0.01	0.14	0.12

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Appendix: Questionnaire Survey

SURVEY OF HOUSEHOLDS IN THE COASTAL AREAS OF THE PHILIPPINES

Municipality: Barangay:

Date of first visit:

Date of second visit:

Part 1. HOUSEHOLD ROSTER

PERSON INTERVIEWED: PREFERABLY THE HEAD OF THE HOUSEHOLD. IF HE/SHE IS NOT AVAILABLE, FIND A "PRINCIPAL RESPONDENT" TO ANSWER THE QUESTIONS IN HIS/HER PLACE. THE PERSON SELECTED MUST BE A MEMBER OF THE HOUSEHOLD WHO IS ABLE TO GIVE INFORMATION ON THE OTHER HOUSEHOLD MEMBERS.

A person is considered part of the household:
- If he/she normally lives and eats his/her meals in the household's dwelling
- If he/she is not away from the household more than 9 months a year

ID CODE	1. MAKE A COMPLETE LIST OF ALL CONCERNED BEFORE GOING TO QUESTIONS 2-6 **NAME**	2. SEX **MALE.1** **FEMALE 2**	3. RELATIONSHIP TO HEAD: **HEAD.................1** **WIFE/HUSBAND.........2** **CHILD/ADOPTED CHILD..3** **GRANDCHILD...........4** **NIECE/NEPHEW.........5** **FATHER/MOTHER........6** **SISTER/BROTHER.......7** **SON/DAUGHT.-IN-LAW...8** **BROTHER/SISTER-IN-LAW..................9** **GRANDFATHER/MOTHER..10** **FATHER/MOTHER-IN-LAW.11** **OTHER RELATIVE......12** **SERVANT OR SERVANT'S RELATIVE...........13** **TENANT OR TENANT'S RELATIVE...........14** **OTHER(SPECIFY_____).15**	4. AGE **YEARS**	5. What is the present marital status of [NAME]? **MARRIED..1** **DIVORCED.2** **SEPARATED.3** **WIDOW OR WIDOWER..4** **NEVER MARRIED..5**	6. Religion **CATHOLIC..1** **PROTESTANT...2** **MUSLIM....3** **OTHER....4**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

PART 2. EDUCATION

ID CODE	1. Are you currently enrolled in school? YES..1(»3-7) NO..0	2. What is the highest level you have completed in school? ***Codes: Elementary: 1-6 High school: 7-10 College: 11-16 Vocational: V1-V3*** *>>next person*	3. In what grade are you currently enrolled in school? Use same codes as for Q2.	4. Is the school you are currently enrolled in public or private? **PUBLIC.1 PRIVATE SECULAR..2 PRIVATE RELIGIOUS..3**	5. How far away from your home is the school you have been attending in the last 12 months? **DISTANCE**	6. How do you go to school? **WALK.1 BICYCLE.....2 CAR...3 Public Transport....4 BOAT..5 OTHER (SPECIFY).6**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

Do you face any major problem to send your children to school? ☐

No…………………………………………………………………………..1
Yes, fees are too high..2
Yes, costs (textbooks, uniforms, etc.) other than fees are too high…………...3
Yes, transportation to school…………………………………………………..4
Other (Specify)……………...………………………………………………5

PART 3: EMPLOYMENT

I would like to ask each household member questions about the work that he/she did the last 12 months, whether work on a farm, on his/her own account, in a household business enterprise, or for someone else.

ID CODE	1. What did you do?	2. For what type of business were you working? **Household/own account enterprise………....... 1** **Business owned by a family member outside the household .2** **Business owned by non-household/non-family member……3**	3. For how many weeks in the last 12 months did you do this work?	4. During these weeks, how many hours per week did you usually do this work?	5. How much was your last payment? If respondent has not been paid, ask: What payment do you expect? What period of time did this payment cover?	6. If you received fish as a form of payment, how much did you receive? Over what time interval?	7. If you received a non-monetary payment for this work other than fish, what was the value of this payment?
	WRITTEN DESCRIPTION		**WEEKS/ YEAR**	**HOURS/ WEEK**	**Pesos (Specify time period)**	**Kg (Specify time period)**	**Pesos (Specify time period)**

For own-account fish-farming, farming and fishing, do not ask questions on payments (i.e., stop at column 5 (included)).

PART 4. LAND-BASED ACTIVITIES
4.1. ACCESS TO LAND

PLOT CODE	1. Please tell me about each plot of land owned, rented or leased by your household? **NAME OF PLOT**	2. What is the area of the plot? **(Ha)**	3. What kind of land is this? **Brackish water Fish Pond..1** **Fresh water fishpond….2** **Non-irrigated agricultural land……....3** **Irrigated agricultural land…………………4** **OTHER(SPE-CIFY_)....5**	4. Is this land owned and used by your household, rented/leased in or rented out? **Owned and used…….1** **Owned and rented out……….2** **Leased under FLA…..3** **Rented in from private owner…………….4**	5. How did your household acquire this land? **INHERITED...1** **CLEARED.....2** **PURCHASED...3** **(SPECIFY__).4**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

7. Is it difficult to have access to a fish pond to practice aquaculture?
   - Very difficult……………1
   - Rather difficult…………..2
   - Relatively easy…………...3
   - Very easy ………………...4

   ☐

If difficult, why? ____

Sections 4.2 and 4.3 should only be completed if the household includes a fish pond operator or a farm operator

4.2. Agricultural productions

4.2.1 Outputs

Cropping	Name of crop:		Name of crop:		Name of crop:		Name of crop:	
	Production (Kg)	Farm gate price (Pesos)	Production (Kg)	Farm gate price (Pesos)	Production (Kg)	Farm gate price (Pesos)	Production (Kg)	Farm gate price (Pesos)
1st Crop								
2nd Crop								
3rd Crop								
Annual total								

	ANIMAL	How many [animals] does your household currently own? NUMBER
1	Pigs	
2	Poultry	
3	Goats	
4	Water Buffalo	
5	Cows	
6	Others (specify)	

4.2.2 Operating expenses

Cropping	Seeds		Fertilisers		Land Rent		Hired labour		Other Expenses
	Quantity	Price	Quantity	Price	Area	Price	Quantity	Price	(Pesos)
1st Crop									
2nd Crop									
3rd Crop									
Annual total									

4.2.3 Livestock

4.3. Aquaculture productions

4.3.1 Output

Harvests	Name of fish:		Name of fish:		Name of fish:		Name of fish:	
	Production (Kg)	Farm gate price (Pesos)	Production (Kg)	Farm gate price (Pesos)	Production (Kg)	Farm gate price (Pesos)	Production (Kg)	Farm gate price (Pesos)
1st Harvest								
2nd Harvest								
3rd Harvest								
Annual total								

4.3.2 Operating expenses

Cropping	Fry/fingerlings		Feeds		Fertilsers		Land		Fertilsers		Land Rent		Hired labour		Other Expenses
	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Area	Price	Quantity	Price	(Pesos)
1st Crop															
2nd Crop															
3rd Crop															
Annual total															

4.3.3 Extension

1. How many times during the last 12 months did members of your household visit an aquacultural extension agent or an agricultural extension center to discuss fish/prawn/crab production? Times ☐

2. How many times in the last 12 months did any aquacultural cultural extension agent visit? Times ☐

Part 5. FISHING

1. How many months a year can do you fish (as a professional activity reported in Part3)? (Note: answer should be consistent with answer in the ‘employment’ table)

2. If there are months when you cannot fish, why is that? (No fish, bad weather etc.)

3. In the months when you fish, how much do you typically catch in a week/day?

4. What is the sale price of each product?

5. What are the costs involved in fishing? Specify time period over which those apply.

- Boat rental
- Boat maintenance
- Fuel cost
- Fishing gear replacement
- Hired labour
- Other (specify)

Part 6. OTHER SOURCES OF INCOME

1. During the past 12 months has your household or any of its members received any money or goods from persons who are not members of your household? For example for relatives living elsewhere, child support or alimony, or from friends or neighbours?

Yes=1, No=0 [ ]

2. If answer to Q.1 was positive, fill out the table below:

1. DONOR	2. What is the relationship of donor to this household? 1=spouse 2=sibling 3=son/daughter 4=parent/s 5=other	3. How much money have members of the household received from[DONOR] in the past 12 months? Pesos	4. Where does the donor earn his/her money? Place
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

3. Other sources of income over the last 12 months

	SOURCE	How much did your household receive in the last 12 months from [SOURCE] including the value of any payment in the form of goods? PESOS
1	Transfers from the state	
	Pension	
	Illness/disability Payment	
	Social assistance payment	
	Other (specify)	
2	Rental income:	
	Land	
	House	
	Car	
	Boat	
	Tricycle	
	Other (specify)	
3	Revenue from sale of assets:	
	Source 1(Specify)	
	Source 2	
	Source 3	
	Etc..	
4	Other Income:	
	Private pension	
	Source 2	
	Source 3	
	Etc.	
5	Other: (Specify)	

7. Perception of poverty and coping strategies:

1- Do you consider that your household is poor? [ ]
   a. Yes……………………………………….1
   b. No………………………………………..0
2- In your opinion, what does it mean for a household to be poor/what is the main characteristic of poverty? (To be landless? To be unable to purchase enough food for the household? To have no influence within the community? Etc.)

3- What type of crisis have you experienced in the last 12 months?

Crisis	**Yes=1**
Flood	
Drought	
Typhoon	
Illness in the family	
Death of a household member	
Loss of job	
Eviction	
Others (specify)	

4- How did you cope with the crisis? (Loan, sale of livestock/land/other assets, support network, migration etc.)

5- In your opinion, what is the main cause of poverty in your community?

6- In your opinion, could poverty be reduced in your community? If so, how?

Aquaculture and poverty:

7- Does fish farming benefit the poor and/or the rich?

8- Do the poor practice fish farming? If not, why? (lack of information; financial resources; suitable land etc.)

9- Could you yourself start fish farming if you wished to do so? If not, why?

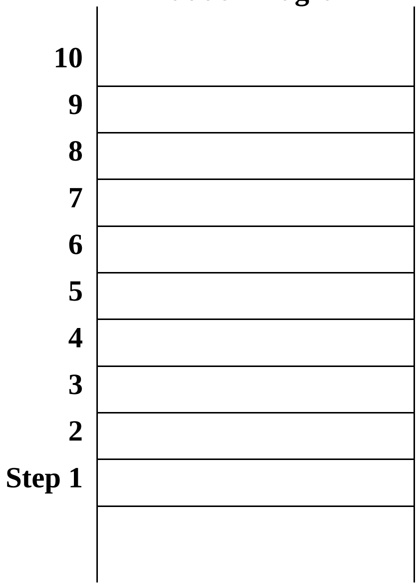
10- Does fish farming have any negative impact on the poor? If so, which ones?

11- In your opinion, is fish farming altogether a good thing for this community and why?

12- Should the government do more in your area to develop fish farming?

I will now show you a ladder diagram. Please choose a step on the ladder that realistically describes your situation. The first step on the ladder describes the worst possible situation. As the step goes higher, the situation gets better. Thus, the highest step on the ladder represents the best situation that you can have.

Ladder Diagram



13- Overall food consumption.
The first step on the ladder represents a situation where all household members barely have anything to eat. You hardly know where the next meal is coming from. The highest step indicates a situation where every member of your household eats three nutritious meals daily.
Five years ago ______ At present_____ Five years from now_____

13- Fish consumption
The first step on the ladder shows a situation where fish/seafood does not form part of you household's diet at all, even if your household members wanted to eat fish. The highest step on the ladder represents a situation where your household members can eat as much fish as they want.
Five years ago ______ At present_____ Five years from now_____

14- Employment
The first step on the ladder describes a situation where no household member earns from any aquaculture-related activity. The highest step on the ladder represents a situation where members of your household obtain all their earnings from various aquaculture-related activities (production, marketing, harvesting, processing, input supply etc.).
At present_____

15- Cash income from aquaculture
The first step shows no cash income from aquaculture for your household. The highest step on the ladder shows cash income from aquaculture-related activities that is more than adequate to provide for you household's needs
At present_____

PART 8: CONSUMPTION
8.1 FOOD CONSUMPTION EXCLUDING FISH - MOST KNOWLEDGEABLE MEMBER

Number of days since last visit:

In the following questions, I want to ask about all purchases made for your household, regardless of which person made them. **Q1. Has your household consumed [FOOD] since my last visit?** Please exclude from your answer any [FOOD] purchased for processing or resale in a household enterprise.

				PURCHASE SINCE LAST VISIT		HOME PRODUCTION	GIFTS
	1. PUT AN X (X) IN THE APPROPRIATE BOX FOR EACH FOOD ITEM. IF THE ANSWER TO Q.1 IS YES, ASK Q.2-5.			2. How much of [FOOD] have you or any other member of the household bought since my last visit, that is since []**?**	3. What was the total value of your purchase?	4. Since my last visit, how much [FOOD] did your household consume that you grew or produced at home?	5. Since my last visit, how much [FOOD] did your household consume that you received as a gift?
		NO	**YES**	**Quantity (Specify unit)**	**Value (Pesos)**	**Quantity (Specify Unit)**	**Quantity (Specify Unit)**
1	Rice						
2	Other cereals						
3	Roots/tubers						
4	Fruits						
5	Vegetables						
6	Poultry						
7	Pork						
8	Beef						
9	Other meats and meat products						
10	Dairy products and eggs						
11	Coffee/cocoa/tea						
12	Non-alcoholic beverages						
13	Other foods						
14	Alcoholic beverages						

8.2. FISH CONSUMPTION - MOST KNOWLEDGEABLE MEMBER

In the following questions, I want to ask about all purchases made for your household, regardless of which person made them. **Q1. Has your household consumed [FISH] since my last visit?** Please exclude from your answer any [FISH] purchased for processing or resale in a household enterprise.

				PURCHASE SINCE LAST VISIT		AQUACULTURE	FISHING	GIFTS
	1. PUT AN X (X) IN THE APPROPRIATE BOX FOR EACH FOOD ITEM. IF THE ANSWER TO Q.1 IS YES, ASK Q.2-5.			2. How much of [FISH] have you or any other member of the household bought since my last visit, that is since**?**	3. What was the total value of your purchase?	4. Since my last visit, how much [FISH] did your household consume that you produced 'at home' through aquaculture?	5. Since my last visit, how much [FISH] did your household consume that was obtained by fishing?	6. Since my last visit, how much [FISH] did your household consume that you received as a gift?
		NO	YES	Quantity (Specify unit)	Value (Pesos)	Quantity (Specify Unit)	Quantity (Specify unit)	Quantity (Specify Unit)
1	Tilapia							
2	Bangus							
3	Crabs							
4	Shrimps							
5	Prawns							
6	Round scad							
7								
8								
9								
10								
11								
12								
13								
14								

8.3. OTHER

1. Total consumption – Please refer back to the ladder diagram.

The first step on the ladder represents the (unrealistic) situation where your household would not spend any of its cash-income on food (including fish). The highest step indicates a situation, unrealistic as well, where all cash income would be spent on food. Please characterize your current situation

At present_____

2. Over the last 12 months, in what month was it most difficult to provide adequate food for your household? Why?

8.4. CONSUMER DURABLES – MOST KNOWLEDGEABLE PERSON

1.	2. LIST OF ITEMS	3. Do you own [ITEM]
	DESCRIPTION	**Yes..1 No…0**
1	Stove	
2	Refrigerator	
3	Washing Machine	
4	Sewing/knitting machine	
5	Fan	
6	Television	
7	Radio	
8	Tape player/CD player	
9	Camera, video camera	
10	Bicycle	
11	Motorcycle/scooter	
12	Tricycle	
13	Car	
14	Truck	
15	Water pump/tube well	
16	Fish pond equipment	
17	Farm equipment	
18	Non-motorized boat	
19	Motorized boat	
20	Phone/cell phone	

Part 9. HOUSING MODULE – SHORT -- PART A. DESCRIPTION OF THE DWELLING

Now I would like to ask you about your housing conditions. I mean by housing all the rooms and all separate buildings used by your household members. What buildings or rooms do the members of your household occupy?

1. WHAT IS THE MAJOR CONSTRUCTION MATERIAL OF THE EXTERNAL WALLS?

   BRICK 1
   CONCRETE BLOCKS 2
   WOOD, LOGS..3
   TIN, ZINC, GI SHEETING..4
   BAMBOO 5
   SACS/PLASTIC ………………………………………..6
   OTHER (SPECIFY____________________)............7

2. WHAT IS THE MAJOR MATERIAL OF THE ROOF?

   CONCRETE 1
   METAL SHEETS..2
   WOOD...3
   NIPA 4
   OTHER (SPECIFY ___________________)........... 5

3. WHAT IS THE PRIMARY MATERIAL OF THE FLOOR?

   WOOD...1
   TILE...2
   CONCRETE 3
   CLAY/EARTHEN FLOOR 4
   BAMBOO 5
   LINOLEUM..6
   OTHERS(SPECIFY ___________________) 7

4. How many rooms do the members of your household occupy, including bedrooms, living rooms and rooms used for household enterprises?

DO NOT COUNT BATHROOMS, KITCHENS, BALCONIES AND CORRIDORS

NUMBER OF ROOMS

5. What is the space of your dwelling including living and accessory rooms?

SQUARE METERS

6.. In approximately what year was this dwelling built?
ASK THE RESPONDENT TO PROVIDE AN ESTIMATE IF UNSURE OF THE EXACT YEAR

YEAR BUILT

7. Do you own or rent this house?

   OWN 1
   RENT 2
   OTHER (SPECIFY)..3

PART B. HOUSING SERVICES

1 What is the main source of water for drinking and cooking for your household?

   PRIVATE CONNECTION TO PIPELINE 1
   PRIVATE WELL.. 2
   PUBLIC TAPS/ STANDPIPE 3
   PUBLIC WELL 4
   NEIGHBORS 5
   WATER VENDOR 6
   OTHER (SPECIFY _____________________) 7

2. How do you usually treat your drinking water?

   NO TREATMENT………………………………………….1
   BOIL IT... 2
   FILTER IT (ONLY) 3
   OTHER (SPECIFY)……………………………………….4

3. What is the main source of water for bathing and washing for your household?

PRIVATE CONNECTION TO PIPELINE 1
PRIVATE WELL 2
PUBLIC TAPS/ STANDPIPE 3
PUBLIC WELL 4
NEIGHBORS... 5
WATER VENDOR 6
RIVER, SEA, POND………………………………….7
OTHER (SPECIFY ______________________)…….8

4. What is the type of toilet that is used in your household?

FLUSH TOILET 1
WATER SEALED……………………………………………..2
OUT HOUSE OVER PIT 3
OUT HOUSE CONNECTED TO SEWAGE 4
OTHER (SPECIFY _______________________)..........5
NO TOILET 6

5. What is the main source of lighting in your dwelling ?

ELECTRICITY...1
KEROSENE, OIL OR GAS LAMPS 2
CANDLES OR BATTERY FLASHLIGHTS..................3
OTHER (SPECIFY_____________________)............4

6. What fuel do you use most often for cooking?

GAS..1
ELECTRICITY...2
WOOD...3
CHARCOAL 4
KEROSENE 5
OTHER (SPECIFY ______________________)..........7

Part 10. HEALTH

1. During the last four weeks, how many days of primary activity did you miss due to poor health?

ID Code	Number of days

2. How far away is the closest surgery/hospital/health station? ☐ Km

3. Is medical care easily available to your family members?

Yes……. 1
No... 2 ☐

4. If not, why?

Part 11. CREDIT

1. Can you borrow money if you need it?

Yes……. 1
No... 2 ☐

2. If your answer is positive, from which sources?

Source of credit	Yes=1 No=0
Cooperative	
Agricultural Bank	
Other Bank	
Money lender	
Savers' group	
Viillage Fund	
Family	
Friends	
Other (specify)	

3. How far is the closest bank? ☐ km

Research project R8288: Assessing the sustainability of brackish-water aquaculture systems in the Philippines – Paper 5/5

Is there an efficiency case for land redistribution in Philippine brackish-water aquaculture? Analysis in a ray production frontier framework

Abstract: *We investigate the possible existence of an inverse relationship (IR) between farm size and productivity in Philippine brackishwater pond aquaculture. The study is motivated by the fact that fish ponds have so far been exempted from the Comprehensive Agrarian Reform Laws and suggestions in the literature of inefficient management of fish farms. The analysis of technical efficiency is based on the estimation of a multi-product ray production function estimated in a stochastic frontier framework. There is some evidence of an IR but of only limited strength. Hence, it is unlikely that agrarian reform is the key to unlocking the productivity potential of brackishwater aquaculture in the Philippines.*

Contents

1. Introduction

While global production of capture fisheries stagnated over the last decade, output from aquaculture expanded steadily.[1] The FAO (2002) reports that global catch from capture fisheries barely returned in year 2000 to the level observed in the early 1990s at roughly 78 million tonnes. Meanwhile, production growth in aquaculture took place at an average annual rate of 7.1% in the 1980s and 5.1% in the 1990s, which makes aquaculture one of the fastest growing food-producing sub-sectors (Ahmed and Lorica, 2002). This spectacular development has sometimes been described as a 'blue revolution', with the underlying idea that aquaculture could potentially solve some aspects of the world's chronic hunger and malnutrition problems (Coull, 1993). While there is no arguing with the increase in aquaculture production, it is however necessary to acknowledge that this development has generated a number of social, environmental and economic problems. Hence, questions have been raised about the ecological impact of aquaculture, in particular with regard to biodiversity (Jana and Webster, 2003; Tisdell, 2003) and mangrove destruction (Primavera, 2000); about the equity of its development (Primavera, 1997; Alauddin and Tisdell, 1998; Coull, 1993) and about its food security benefits (Naylor et al., 2000; Primavera, 1997).

The Philippines conform to these general trends. Yap (1999) reports that aquaculture output in the country has grown at the average annual rate of 5.4% in the 1990s and that its share of total fisheries production keeps increasing. Yet, its development has had a detrimental effect on mangroves, resulted in the salinisation of previously productive agricultural land, generated conflicts over the use of natural resources (Yap, 1999) and some have even argued that it has been responsible for the marginalisation of some coastal communities and an increase in the rate of unemployment (Primavera, 1997). Against this background, the aim of this article consists in addressing one equity aspect of aquaculture development in the Philippines that relates to the distribution of fishpond holdings[2]. We investigate whether there is any evidence of an inverse relationship (IR) between farm size and productivity in brackishwater aquaculture in order to evaluate the case, on efficiency ground, for reform of the existing tenurial system, land redistribution, or other policies aimed at improving the functioning of the land market.

The study is motivated first by a common perception that the vast areas of Philippine brackishwaters[3] represent a valuable resource that is not exploited optimally and is not contributing fully to the development process of coastal areas. We believe that it will make a contribution to an important and ongoing policy debate that emerges from the fact that, while the Philippines adopted several land reform laws in the late 1980s, aquaculture ponds have so far been exempted[4]. As a result, the distribution of holdings in brackishwater aquaculture remains very unequal as indicated by a Gini coefficient of 0.72 for the two regions that form the focus of our study[5] and it is well-known that fish farms of more than a hundred hectares are not uncommon. Naturally,

[1] As there is increasing doubts regarding the validity of Chinese fisheries statistics, our statements refer to the world excluding China. See FAO (2002) for a discussion of this issue.

[2] Although it is not always specified, our study relates only to brackishwater pond aquaculture.

[3] Yap (1999) reports that there are 239,323 hectares of brackiswater fishponds in the Philippines. The electronic data that we obtained from the Bureau of Agricultural Statistics gives a total harvested area of 415,272 hectares in year 2000.

[4] The most recent one is the Comprehensive Agrarian Reform Law (CARL) of 1988 that imposes land redistribution with a five hectare retention limit set on all agricultural land.

[5] Source of data: Bureau of Agricultural Statistics' inventory of fishponds from 1997.

large fishpond owners and leaseholders believe that agrarian reform would, if anything, only worsen the severe problems of poverty and inequality in the communities where fish farming represents an important activity. Yap (1999) cites a telling extract from the newsletter of Negros Prawn Producers and Marketing Cooperative:

> *"The implementation of the (land reform) law is liable to cause widespread strife among the landowners…. There is no showing that land reform will enliven the plight of the poor. Without undermining their capabilities, it is also doubtful whether they (the farmers) can put up the necessary capital to maximize land use. Having been used to having a landlord on whom to call in times of need, this plunge to independence may have a crippling effect."*

This view stands in sharp contrast with the common belief in agriculture that small farmers tend to achieve higher productivity and efficiency levels than large farmers, i.e. that there usually is an IR, as demonstrated in Sen's seminal paper (Sen, 1962)[6]. Besides, the experience of Thailand, where the extremely dynamic prawn industry is supported by relatively small farmers (Yap, 1999), suggests that there is no particular impediment to the development of a competitive aquaculture sector based on smallholders. We therefore believe that testing the IR in Philippine brackishwater aquaculture will generate important policy insights; in particular, a strong IR would suggest that institutional changes leading to a more equal size distribution of holdings could increase both equity and efficiency.

Our analysis is based on the analysis of a sample of 127 farms in two of the three main regions for brackishwater aquaculture in the Philippines and investigates the level and determinants, including farm size, of their technical efficiency. From a methodological standpoint, we believe that the article makes three contributions to the agricultural economics literature. First, we represent the technology by a ray production function first proposed by Löthgren (1997), which, to the best of our knowledge, has not been previously attempted on farming data. This approach presents several advantages that we explain in the next two sections. Second, we explore the properties of the output ray function which arise from its duality with both the minimum cost and maximum revenue functions. This is important in interpreting our estimations results, and could be useful in the future to use the model to analyse issues of allocative efficiency. Finally, we propose two approaches to quantify the explanatory power of the inefficiency effect variables in the Battese and Coelli (1995) stochastic frontier model. This is extremely useful in the empirical section to measure, in a way that is entirely consistent with the underlying frontier model, the strength of the IR relationship.

The paper is organised as follows. The section presents the different approaches to the measurement of efficiency in polyculture systems, insisting on the advantages and properties of the ray production function. Section three presents the estimation strategy and proposes an approach to quantify the explanatory power of the inefficiency effect variables of the econometric model. The remaining sections

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[6] A recent review of the IR literature is Fan and Chan-Kang (2003). It concludes to the lack of consensus on the validity of the IR hypothesis.

discuss the data and empirical model, present the empirical results, and offer conclusions.

2. Measuring the productivity/efficiency of polyculture farms

2.1 A review of alternative approaches

The IR literature started with the simple observation that yields, defined as output per unit of surface area, differed according to the size of farms. In this context, output is measured either in quantity or value terms and the negative relationship seemingly implies that reallocating land from large to small farms would result in a net increase in production. However, output per hectare is only a partial productivity indicator which cannot satisfactorily measure overall farm productivity (Jha, Chitkara and Gupta, 2000). Hence, farm A can achieve a higher yield than farm B not because it is more efficient in transforming inputs into outputs but simply because it uses more fertilisers or pesticides. Furthermore, any introductory economics textbook makes it clear that economic optimality usually differs from yield maximisation. To address this concern, albeit only partially, one can investigate the relationship between gross margin and farm size, but this again fails to account for the input of primary factors, such as labour and machinery services, in comparing farm performance. There is also a concern that gross margins do not only reflect the productive ability of farm managers but also the price environment in which they operate (Coelli, Rahman and Thirtle, 2002). Hence, a farm can generate a high gross margin per hectare due to its proximity to a particular market rather than its productive performance. There is therefore a strong case to investigate the IR relationship within the confines of production economics, which can accommodate the multi-dimensional aspect of farm production.

Aquaculture production in the study area involves the polyculture of prawns, fish (tilapia and/or milkfish) and crabs, which are produced simultaneously in the same ponds. This raises a number of interesting modelling issues that we now attempt to tackle. Obviously, all of the inputs, with the exception of the fry and fingerlings, are largely non-allocable, i.e. it is not possible to determine the amount of each input used in the production process of each individual output. Hence, land cannot be allocated to different productions, and neither can the feeds or the labour input used to exchange the pond water or maintain the mud dykes. This introduces a first linkage among the different outputs of the aquaculture farm. Second, it is necessary to recognize the possible jointness of production as it is likely that the different species interact with each other in the aquaculture pond. For instance, biologists and aquaculture experts often consider that the association prawn/tilapia in ponds tends to reduce the rate of prawn mortality because tilapias, through their filtering activity and consumption of organic matter lying at the bottom of the pond, improve the bacteriological quality of the pond water (Corre et al., 1999). If that is so, output of any single species depends not only on the inputs used in the production process of that species but also on the quantities of other species grown simultaneously in the pond. We therefore conclude that the production process relies on a truly multiple-output technology, and that it is not possible to specify different production functions for each output.

There exist several possible avenues to measure efficiency in a multiple-output context. Maybe the most common approach involves the estimation of dual cost, revenue or profit functions (Löthgren, 2000). However, this group of methods relies on relatively restrictive behavioural assumptions of economic optimization, such as that of profit maximisation, which might not be expected to hold in developing country aquaculture as farmers are likely to adopt complex livelihood strategies in the face of multiple market failures. For instance, in addition to expected returns, it is likely that the riskiness of alternative enterprises is taken into account by farm operators when formulating production plans because perfect insurance markets simply do not exist. Furthermore, estimation of these dual functions requires data on prices of inputs and/or outputs that present sufficient variability to allow the use of regression techniques. However, such variability is unfortunately often not present in cross-sectional data because input and output markets are relatively well integrated within regions. We therefore believe that a primal approach is better suited to the analysis of efficiency and productivity for this particular study.

In a primal setting, a straightforward method of productivity/efficiency measurement consists in aggregating all outputs into a single index, which can in turn be used in the estimation of a production function/frontier. The method, suggested by Mundlak (1963) in the agricultural economics literature, has frequently been used in the study of efficiency in aquaculture (e.g., Karagianis, Katranidis & Tzouvelekas (2002) analyse seabass and sea bream production in Greece; Irz and McKenzie (2003) study polyculture systems in the Philippines; and Sharma and Leung (1998) as well as Sharma (1999) investigate the efficiency of carp polyculture systems in Nepal and Pakistan respectively). The single output index is usually obtained as the total weight of production, which, although not theoretically sound, seems acceptable for relatively similar products[7].

When the products are not close substitutes, however, it is necessary to use output prices to aggregate them. The simplest method consists in expressing output in value terms, but there is a concern that in that case the resulting index reflects not only output quantities but also the prices at which the farm products are sold. This general index number problem is partially circumvented by the use of superlative output indices, such as the Fischer index or Tornqvist-Theil index, first proposed by Caves, Christensen and Diewert (1982) and presented in details in Coelli, Rao and Battese (1998) (chapters 4 and 5). However, even superlative indices measure output in a satisfactorily manner only under a number of restrictive assumptions, most notably that output markets are perfectly competitive. Also, estimating an aggregate production function implicitly imposes restrictions on the form of the underlying multi-product technology. The very existence of an aggregate output index that can be built from output quantities and prices depends on the technology being separable in outputs and inputs (Orea, Alvarez and Morrison Paul, 2002). Hence, we believe that, given the complexity of the input-output relationship in aquaculture, it is desirable to use a framework of analysis that offers more flexibility in the representation of the multi-product technology.

Fortunately, such a framework has recently become available with different ways of representing the technology. An intuitive idea consists in re-writing the transformation function so as to express one particular output as a function of the input vector and the quantities of all other outputs. There are two difficulties with this

[7] That is how all of the studies mentioned above proceeded, with the exception of Irz and McKenzie (2003).

approach. First, the choice of output that is used as dependent variable in the regression analysis is arbitrary and this introduces an artificial asymmetry in the method. Second, and most problematic, is the fact that not only the technology parameters but also the efficiency scores depend on the particular output that is chosen as dependent variable. The efficiency scores are therefore output specific and there is no guarantee that the rankings obtained from alternative formulations of the model be consistent with each other, as is easily demonstrated in Figure 1 for the two-output case. The technology is represented by the production possibility frontier PP'. Farm A is clearly closer to the frontier than farm B when efficiency is measured according to a 'fish' orientation, but the reverse is true when a 'prawn' orientation to efficiency measurement is adopted. Furthermore, when a farm is not producing the output used as dependent variable in the regression, the interpretation of the efficiency scores becomes difficult[8].

For these reasons, the efficiency literature has moved away from the estimation of transformation functions. A first alternative that has become popular in recent years corresponds to the estimation of input or output distance functions (Coelli and Perelman, 2000; Morrison Paul, Johnston and Frengley, 2000; Brümmer, Glauben and Thijssen, 2002; Irz and Hadley, 2003). The output distance function introduced by Shephard (1970) is defined formally from the output set $P(x)$ by:

$$D_o(x,y)=Min\{\theta>0: y/\theta \in P(x)\} \qquad (1)$$

It measures the fraction of maximum achievable output y/θ that the firm produces, given a vector of inputs x and the technology, and assuming that any increase in production would involve a proportional increase in all individual outputs. For any input-output combination (x,y) belonging to the technology set, the distance function takes a value no larger than unity, with a value of unity indicating technical efficiency. For instance, in Figure 1, farm C is clearly inefficient as its output vector does not lie on the border of the output set, and the resulting value of the distance function is equal to ratio OC/OC^d. The output distance function gives directly the well-known Farrell (1957) output-based index of technical efficiency (Brummer, Glauben and Thijssen, 2002). The output distance function is always homogenous of degree one in outputs and inherits properties from the parent technology as detailed in Färe and Primont (1995).[9]

The last set of techniques available to investigate the efficiency of multi-output firms relies on the estimation of a ray frontier production function, first proposed by Lothgren (1997). His basic insight consists in expressing the output vector in polar coordinates, which makes it possible to represent the technology by a function relating the Euclidian norm of the output vector to the inputs and output mix, represented by the output polar coordinates. Formally, the output vector y of dimension M is expressed as:

$$y = \|y\| m(\theta(y)) \qquad (2)$$

[8] This is a problem for the empirical application presented here as there is great heterogeneity within our sample with regard to the subset of the four species actually produced on the farm, as discussed in detail in the data section.

[9] In particular, as described in Lovell et al. (1994), the output distance function is non-decreasing, positively linearly homogeneous and convex in y, and decreasing in x.

where $\|y\|$ denotes the Euclidian norm of vector y ($\|y\| = \sqrt{\sum_{i=1}^{M} y_i^2}$), $\theta(y)$ is an (M-1) vector of polar coordinate angles of the output vector y, and the M functions m_i: $[0, \pi/2]^{M-1} \rightarrow [0,1]$ define the coordinates of the normalized output vector. This is illustrated in the two-output case in Figure 1. The output vector of farm C is expressed in terms of its norm, OC/OC^r, and a single angle θ^c measuring the relative proportions of fish and prawn outputs, i.e. the output mix. The two functions m_f and m_p of the polar-coordinate angle θ^c simply define the (regular) coordinates of the normalized output vector OC^r obtained by radial projection of vector OC on the circle of radius 1. Formally, the *(M-1)* polar coordinate angles are obtained by applying recursively the following formulae (Löthgren, 1997):

$$\theta_i(y) = \cos^{-1}\left(\frac{y_i}{\|y\| \prod_{j=0}^{i-1} \sin\theta_j(y)}\right), i = 1,....,M-1 \qquad (3)$$

where $\sin\theta_0 = \cos\theta_M = 1$. Hence, the first angle θ_1 is equal to $\cos^{-1}(y_1/\|y\|)$; the second angle θ_2 is equal to $\cos^{-1}(y_2/\|y\|\sin\theta_1)$ and so on. Note that all *(M-1)* functions $\theta(y)$ are homogenous of degree zero in outputs, which simply reflects that they capture only the proportions of outputs in vector y. The coordinates of the normalized output vector are also easily recovered as:

$$m_i(\theta(y)) = \cos\theta_i(y) \prod_{j=0}^{i-1} \sin\theta_j(y) \qquad (4)$$

This set up allows us to represent any technology by a multi-output ray production function $f(x,\theta(y))$ as follows:

$$f(x,\theta(y)) = \max\{\rho > 0 : \rho.m(\theta(y)) \in P(x)\} \qquad (5)$$

This function gives the maximum norm of the output vector that the firm can produce, given a vector of inputs x and the existing technology, and assuming that any increase in production would involve a proportional increase in all individual outputs. Hence, any technology feasible input-output combination *(x, y)* is defined by the inequality $f(x,\theta(y)) \geq \|y\|$. In terms of Figure 1, the value of the ray production function is simply equal for farm C to the ratio OC^d/OC^r. Under the assumption of strong input disposability, the ray function is positively monotonic in inputs (Löthgren, 2000).

In order to understand how the ray production function can be used to measure efficiency, it suffices to recognize that the ray production and output distance functions are closely related to each other. It follows from equation (5) that, for any observed output vector y, the radial frontier output vector is simply defined by $f(x,\theta(y)).m(\theta(y))$ so that the distance function is recovered as:

$$D_o(x,y) = \frac{\|y\|}{f(x,\theta(y))} \qquad (6)$$

This is indeed observed in our graphical example, as ratio OC/OC^d is obviously equal to OC/OC^r divided by OC^d/OC^r. This relationship is most important because we know that virtually all the properties of a multi-output technology can be recovered from the distance function. For instance, Brummer, Glauben and Thijssen (2002) and Irz and Hadley (2003) use it to characterize technological change and productivity growth, while Kim (2000) derives measures of output substitutability from it. Equation (6) therefore implies that the same can be done from the ray production function. For our purpose, it is sufficient to recognize that output elasticities are easily derived from the ray production function as:

$$\varepsilon_{y,x_j} = \frac{\partial \ln\|y\|}{\partial \ln x_j} = \frac{\partial f(x;\theta(y))}{\partial x_j} . \frac{x_j}{f(x,\theta(y))} \qquad (7)$$

This expression gives the percentage change in all outputs resulting from a one percent change in input *j* and is expected to take a positive value (Fousekis, 2000). Alternatively, the appendix demonstrates that because the ray production function entertains some duality with both the maximum revenue and minimum cost functions, this elasticity can be interpreted as the revenue elasticity or the scale-adjusted cost share of input *j*. The scale elasticity follows immediately (Löthgren, 2000):

$$\varepsilon_{scale} = \frac{\nabla_x f(x;\theta(y)).x}{f(x,\theta(y))} \qquad (8)$$

This elasticity should be compared to unity to establish whether the firm operates under decreasing, constant or increasing returns to scale. Finally, the derivatives with respect to the coordinate angles reflect the change in output norm when the output mix is changed along the production frontier. They therefore relate to the degree of substitutability of the different outputs, but in a rather indirect way as demonstrated in the appendix, where the expression for the marginal rate of transformation between any two outputs *i* and *j* is derived as:

$$\frac{p_j}{p_i} = \frac{y_j\left(\sum_{m=1}^{M-1} \frac{\partial \ln f}{\partial \ln \theta_m} \frac{\partial \ln \theta_m}{\partial \ln y_j} - 1\right)}{y_i\left(\sum_{m=1}^{M-1} \frac{\partial \ln f}{\partial \ln \theta_m} \frac{\partial \ln \theta_m}{\partial \ln y_i} - 1\right)} \qquad (9)$$

We note, however, that these derivatives are simultaneously equal to zero if and only if the PPF is, at the point of approximation, a perfect sphere in output space. Furthermore, this expression could easily be used to derive to Morishima-like elasticities of output substitution.

We conclude from this analysis that, from a theoretical point of view, the ray production function and the output distance function are superior, as a basis for efficiency measurement of aquaculture farms, to the alternatives presented in the literature (dual functions, aggregate production functions and transformation functions).

2.2 Implementation issues

While from a theoretical point of view the output distance function and ray production function appear equally satisfactory for our purpose of measuring efficiency in aquaculture, the same does not hold from an empirical/econometric point of view[10]. A first issue relates to the fact that the distance function is linear homogenous in outputs. Imposing this property globally requires the use of a logarithmic functional form that cannot accommodate zero values on either inputs or outputs. In fact, all of the

[10] Note that distance functions can be used in a non-parametric setting in order to measure technical efficiency, as is the case for instance in Data Envelopment Analysis. Because these techniques do not account for noise, and production shocks seem important in aquaculture as indicated for instance by the levels and variability of mortality rates of prawns, we do not think that they are suitable for our purpose. We therefore focus our discussion on parametric techniques.

published papers on distance functions of which we are aware use a transcendental logarithmic functional form, in order to impose homogeneity while conferring sufficient flexibility to the parametric function. A common practice consists then in replacing zero values by 'small numbers' (see Morrison-Paul, Johnston and Frengley (2000) and Fousekis (2002) for two recent examples) but this seems highly unsatisfactory as the logarithmic function goes asymptotically to minus infinity at zero. In fact, Battese (1997) explores this problem in the context of a Cobb-Douglas production function to conclude that replacement of zero values by small numbers can seriously bias the parameter estimates. Given that most farms in our sample do not produce all four outputs, this problem represents a major obstacle to the estimation of an output distance function on our data.

The second issue arises from the fact that the value of the distance function is unobservable so that an expression of the form $D=f(x,y)$ is not estimable directly by standard regression techniques. Following Lovell et al. (1994), this problem is usually circumvented by modifying the regression equation based on the homogeneity properties of the distance function. However, it is feared that this clever transformation of the estimable equation might lead to possible endogeneity of the regressors (Grosskopf et al., 1997; Löthgren, 2000).

By contrast, no homogeneity restriction needs be imposed on the ray production function, which can therefore be represented by non-logarithmic functional forms and hence accommodate zero values. Furthermore, it is also believed that the endogeneity problem highlighted above for the distance function does not apply to the ray production function (Löthgren, 2000). Hence, we choose to pursue our investigation of efficiency of aquaculture farms in the Philippines based on the estimation of a ray production function.

3. Estimation Strategy

The estimation of firm-level efficiency scores from a ray production function follows the stochastic frontier methodology initially proposed by Aigner, Lovell and Schmidt (1977). Accordingly, a scalar-valued composed error term is introduced in the empirical ray production function[11]:

$$\|y\| = f(x,\theta(y);\beta) + v - u \qquad (10)$$

where β is a vector of parameters to be estimated; v is a symmetric random variable that is independently and identically distributed across individuals; and u is a non-negative random variable. This specification recognizes the fact that production is first affected by random shocks and measurement errors, which are captured by the disturbance term v. However, the productive performance of farms is also determined by the quality of managerial decisions and it is likely that some farmers make mistakes, i.e., that they are technically inefficient. This is formally captured by the random variable u that describes the deviation of the norm of the observed output vector y from the maximum achievable norm $f(x,\theta(y);\beta)e^{v}$, which is conditional on the exogenous shock v.

Given a parameterisation of the ray production function and distributional assumptions on the random terms, equation (10) can be estimated by the maximum

[11] Notice that the error term is introduced in an additive rather than multiplicative way because, as explained earlier, we do not want to use a logarithmic functional form due to the 'zero value' problem.

likelihood methods that have now become commonplace in the stochastic frontier literature[12]. All models consider that the random error term v follows a normal distribution $N(0,\sigma^2_v)$ but differ with respect to the distribution of inefficiencies u. A first generation of models considers that this term is identically and independently distributed, following a half-normal distribution (Aigner, Lovell and Schmidt, 1977), truncated normal (Stevenson, 1980) or gamma (Greene, 1990) distribution. However, by assuming that inefficiencies are identically distributed, all of these models implicitly assume that there is no relationship between efficiency and farm-specific characteristics, as was first noted by Kumbhakar, Gush and McGuckin (1991). Consequently, they are obviously ill-suited to the analysis of the inverse relationship.

Fortunately, several models have been developed to simultaneously measure inefficiencies and identify their farm-level determinants. We adopt the formulation of Battese and Coelli (1995) who relax the assumption of identically distributed inefficiency terms by considering that u_i is obtained by truncation at zero of a normal variable $N(\mu_i; \sigma_u^2)$ where:[13]

$$\mu_i = z_i\delta \qquad (11)$$

The term z_i denotes a vector of potential determinants of inefficiencies, including farm size, while δ is a vector of parameters to be estimated. Note that because the inefficiency effects enter the model in a highly non-linear way, there is no identification problem when using the same variable in the specification of the ray production function and as an inefficiency effect[14]. The likelihood function is derived algebraically as in Battese in Coelli (1993) and it can then be maximised numerically to produce estimates of both the ray production function and the vector of parameters δ. Further, while the individual inefficiency levels are not directly observable, the method allows for calculation of their predictors by applying the procedure first proposed by Jondrow et al. (1982). As the expressions for these predictors are presented in Battese and Coelli (1993) only for the multiplicative model, while ours is additive, they are worth reporting here. First, the conditional expectation of the inefficiency term u given a total residual $e=v-u$ is derived from the expression of the conditional density function of u given e derived in full in Battese and Coelli (1993):

$$E(u|e) = \mu_* + \sigma_* \frac{\phi(\mu_* / \sigma_*)}{\Phi(\mu_* / \sigma_*)} \qquad (12)$$

where:

$$\mu_* = \frac{\sigma_v^2 z\delta - \sigma_u^2 e}{\sigma_u^2 + \sigma_v^2}$$
$$\sigma_*^2 = \frac{\sigma_v^2 \sigma_u^2}{\sigma_u^2 + \sigma_v^2} \qquad (13\text{ a \& b})$$

These expressions express mathematically that the random variable u, conditional on e, is simply obtained by truncation at zero of the normal variable $N(\mu_*,\sigma_*^2)$. The Farell output-oriented efficiency score follows immediately:

[12] See Coelli, Rao and Battese (1998) for an introductory presentation of this literature and Kumbhakar and Lovell (2000) for a more detailed and technical one.
[13] The individual subscript i was ignored up to this point for notational clarity.
[14] An example of a stochastic production frontier where land appears both as an input and as an inefficiency effect is Ngwenya, Battese and Fleming (1997), cited on page 212 of Coelli, Rao and Battese (1998). The issue of identification is also discussed in Battese and Coelli (1995) where a time trend is used to capture both technological change and inefficiency change over time.

$$\hat{TE} = \frac{\hat{y} - E(u|\hat{e})}{\hat{y}} \quad (14)$$

where $\hat{y}$ denotes the fitted output norm $f(x,\theta(y);\hat{\beta})$ and $\hat{e}$ is the estimated residual.

Next we turn to the issue of quantifying the explanatory power of the inefficiency effects introduced in vector z, which is motivated by our primary aim of exploring the robustness of any potential IR in Philippine aquaculture. This problem has been largely ignored in the literature, as the only attempt at tackling it of which we are aware is Pascoe and Coglan (2002) who, on a fisheries model, develop a procedure to isolate the variation in inefficiencies attributable to the inefficient effect variables. The procedure simply involves regressing the estimated technical efficiency scores against the variables introduced as inefficiency effects by ordinary least squares. This approach is ad hoc and seems unsatisfactory because it fails to recognize the highly non-linear way in which the inefficiency effects enter our model. From equation (11), it is evident that the mean of the normal variable truncated at zero to model inefficiencies is a linear function of the z variables but this implies that the relationship between predicted efficiencies (14) and the z variables takes a complex non-linear form. We therefore prefer to investigate this question differently.

A first approach compares the full specification of the model to a restricted one where this variable is dropped from vector z in equation (11). The comparison is based on the decomposition of the total variance term e into its random shock and inefficiency components u and v. Coelli (1995) establishes that the relative contribution of inefficiency to the variance of the error is given by:

$$\gamma^* = \gamma / [\gamma + (1-\gamma)\pi/(\pi-2)] \quad (15)$$

where parameter $\gamma = \sigma_u^2/(\sigma_u^2+\sigma_v^2)$. This quantity captures the variation in production not accounted for by physical factors that is attributed to inefficiencies rather than random shocks. Hence, the difference between this quantity for the full model and the restricted model gives us directly a measure, in percentage terms, of the explanatory power of the inefficiency effect z_i.

We would also like to be able to measure the strength of the relationship between any z_i variable and technical efficiency by calculating a standard elasticity but once again, the literature seems to have ignored this issue. From equations (12) and (13), one can derive the responsiveness of the conditional predictor of u to a change in any inefficiency effect variable:

$$\frac{\partial E(u|e)}{\partial \ln z_i} = \frac{z_i \delta_i (1-\gamma)}{(\Phi(\mu^*/\sigma^*))^2}[\Phi(\mu^*/\sigma^*)(\Phi(\mu^*/\sigma^*) - \frac{\mu^*}{\sigma^*}\phi(\mu^*/\sigma^*)) - \phi^2(\mu^*/\sigma^*)] \quad (16)$$

Using this expression in equation (14) defining the efficiency score, one obtains:

$$\frac{\partial TE}{\partial \ln z_i} = -\frac{z_i \delta_i (1-\gamma)}{\hat{y}(\Phi(\mu^*/\sigma^*))^2}[\Phi(\mu^*/\sigma^*)(\Phi(\mu^*/\sigma^*) - \frac{\mu^*}{\sigma^*}\phi(\mu^*/\sigma^*)) - \phi^2(\mu^*/\sigma^*)] \quad (17)$$

This elasticity gives the percentage change in efficiency resulting from a unit percentage change in the inefficiency effect variable z_i. Note that it depends not only on the parameter estimates but also on the data so that it can be estimated at any sample point or at the sample mean. The empirical section of the paper uses this expression to derive what we call the technical efficiency elasticity of farm size. Alternatively, Kumbhakar and Lovell (2002) propose to use the mode of the distribution of *u* given *e* as predictor of the inefficiency variable, which gives for our model:

$$M(u|e) = \begin{cases} \mu^* \text{ if } \mu^* \geq 0 \\ 0 \text{ otherwise} \end{cases} \quad (18)$$

The resulting elasticity of technical efficiency with respect to any inefficiency effect variable follows immediately:

$$\frac{\partial TE}{\partial \ln z_i} = \begin{cases} -\frac{z_i \delta_i (1-\gamma)}{\hat{y}} \text{ if } \mu^* \geq 0 \\ 0 \text{ otherwise} \end{cases} \quad (19)$$

4. Data and estimable model

The two main regions of the Philippines for brackishwater pond aquaculture were selected for this particular study. Region three covers the central part of the northern island of Luzon and has brackishwater fish ponds in the four provinces of Pampanga, Bulacan, Bataan and Zambales. Region six is located in the Western Visayas, central Philippines, and includes the provinces of Iloilo, Capiz, Negros Occidental and Aklan. The sample was stratified by farm size and by province, based on census data from 1997 provided by the Bureau of Agricultural Statistics. Production and socio-economic data were then collected by interviews with farm operators and caretakers (salaried supervisors). A total of more than 150 farms were initially surveyed but several observations were dropped because of inconsistencies and/or missing values, so that our analysis is based on a sample of 127 individuals.

Table 1 presents the summary statistics of the production variables. Starting with the land input, it is apparent from our data that the farms in the study area are relatively large, with an average surface area of more than eleven hectares[15]. Further, land is also unequally distributed, ranging from one tenth of a hectare for the smallest farm to 130 hectares for the largest, and the Gini coefficient of land concentration for our sample is equal to 0.67. This heterogeneity in farm size gives some relevance to the investigation of the IR pursued in this paper. Table 1 also informs us about the type of aquaculture practiced by the farms in the sample. First, in monetary terms, the main intermediate input corresponds to the seeds ("fry" for prawns, "juveniles" for crabs and "fingerlings" for milkfish and tilapia), followed by the feeds and, finally, fertilisers. This simple fact reflects the extensive nature of brackishwater aquaculture in the Philippines, as even in semi-intensive production systems, the feeds account for the major share of cash costs. Also, the substantial cost of fertilisers reveals that farm operators attempt to bolster the natural productivity of aquaculture ponds, while the production process in intensive aquaculture relies solely on the provision of feeds from an external source for the growth of the cultivated species. Finally, the summary statistics also suggest that labour represents an important cost of production, as the wage rate for farm labour is approximately 150 PhP/day in region 3 and 100 PhP/day

[15] This can be compared to an average size of prawn farms in Thailand of only 2.16 hectares (Yap, 1999).

in region 6, so that the total wage bills exceeds, on average, the cost of any individual intermediate input.

With respect to outputs, milkfish is the dominant production in volume. This is not surprising as the polyculture production system described here represents a recent evolution of the traditional milkfish monoculture system (Chong et al., 1984). The average milkfish yield of less than 500kg per hectare confirms the extensive nature of the production process. The volumes produced of the other species appear relatively small compared to that of milkfish but the relative importance of the species is different in value terms. Given that prawns fetch a price nearly ten times as high as that of milkfish per weight unit, they actually represent the dominant production in terms of revenue share[16]. This price differential is explained in part by the fact that milkfish and tilapia are consumed domestically, while an important proportion of the prawns are exported to the high-income markets of Japan and the United States. However, notice that crabs, which are also exclusively sold on domestic markets, also receive high prices and are therefore important productions in economic terms.

Finally, Table 1 also suggests that the farms in the sample choose different associations of species, as average output for each species differs whether it is computed on the whole sample of farms or on the sub-sample with a strictly positive output for that particular species. Figure 2 represents the distribution of the number of species grown on the farm and brings two valuable insights. First, a large majority of farms do indeed practice the polyculture of at least two species, hence justifying our earlier discussion on multi-product technologies. And second, the association of all four species is only adopted by a relatively small fraction of the sample farms, implying that there is a large number of zero output values in the sample.

We choose a quadratic functional form as a first step in estimating the output ray function defined in equation (7):

$$\|y\| = \alpha_0 + \sum_{j=1}^{M+K-1} \alpha_j w_j + \sum_{j \le k} \sum_{k=1}^{M+K-1} \beta_{jk} w_j w_k + D - u + v \qquad (20)$$

where the vector w includes each of the *(M-1)* polar coordinate angles $\theta(y)$ and the K inputs, and D is a regional dummy taking a value of unity for the farms located in region 6.[17] The quadratic production function is a flexible functional form in the sense that it can serve as a local second-order approximation to any unknown production function. This specification therefore gives flexibility to the model which can accommodate zero values on both inputs and outputs.

The empirical specification includes the three following inputs: land and labour, defined as in Table 1 as the total surface area of the aquaculture farm and the number of man days of labour used on the farm; and intermediate inputs, expressed in value terms, and hence representing an aggregate of the feed, fry/fingerling and fertiliser inputs. On the output side, all four productions were used to define the three polar coordinate angles for tilapia, crabs and prawns. The last step in specifying the model consists of choosing the inefficiency effects that enter equation (11). The literature

[16] The average prices per kilogram for our sample are 45PhP for milkfish, 31PhP for tilapia, 412PhP for prawns and 210 PhP for crabs.
[17] We introduce the regional dummy because the preliminary OLS regressions discussed below suggest that there might be technological differences between the two regions.

suggests at that level that one should choose variables susceptible of influencing the adoption of particular management practices or the determinants of their adoption (Irz and McKenzie, 2003). Given the focus of this paper on the IR relationship, farm size is included as it is our aim to establish whether small and large farms adopt different management practices that lead to differences in efficiency. It is also possible that management differs across regions, and we therefore include the regional dummy as well as inefficiency effect. Other variables, such as training and experience of the operator, probably have an influence on efficiency but our data unfortunately does not allow for their inclusion.

5. Empirical Results

5. 1 Partial productivity indicators

We start our analysis of the IR relationship by investigating the relationship between farm size and land productivity. Although imperfect as outlined earlier, partial productivity indicators have played an important role in the development of the IR literature and are therefore worth reporting. Table 2 presents the results of three OLS regressions relating a measure of land productivity to farm size and, in order to account for possible regional effects, a regional dummy taking a value of unity for the farms located in region 6. The first regression uses the crudest possible measure of land productivity, i.e. harvest weight per hectare, and the results seemingly indicate a significant and **positive** relationship between farm size and productivity.

However, it makes little sense to add weights of species that fetch widely different prices and the second regression tackles this problem by measuring land productivity in terms of revenue per hectare. The regression, which represents the equivalent of those presented in the influential paper of Berry and Cline (1979), has a surprisingly large explanatory power, as indicated by a R-square value of 0.42. Further, it reveals a **significant and negative** relationship between farm size and revenue per hectare. The coefficient of the farm size variable is easily interpreted as an elasticity and indicates that a 10% increase in farm size results in a 2.2% decrease in revenue per hectare. Finally, the coefficient of the regional dummy is also negative and significant, indicating that farms tend to be substantially less productive in region 6 than in region 3.

The last regression accounts for differences in use of intermediate inputs when comparing farms as it measures land productivity by gross margin per hectare[18]. It does confirm to some extent the results of the previous regression but in a much weaker way. In particular, the negative relationship land productivity-farm size persists, with an elasticity of -0.18, but with only a modest level of statistical significance; the explanatory power of the regression declines to a mere 13%; and it transpires once again that land productivity in region 3 is significantly higher than in region 6.

The difference in results between the two first regressions imply that, on a per hectare basis, larger farms tend to produce more in weight but less in value terms than smaller ones. Hence, it is likely that larger farms tend to choose output combinations with greater emphasis on lower value species (tilapia, milkfish). The difference in results

[18] Note that for this regression, the dependent variable is the level of the gross margin and not its logarithm. This is so because some farms have negative gross margins which prohibits the use of a log-log functional form for this regression.

between the two last regressions indicates that the higher revenue per hectare achieved by smaller farms, is, to a large extent, explained by a more intensive use of intermediate inputs. All in all, we conclude from this simple analysis that there is clear evidence of a negative relationship between intensity of land use and farm size but only weak evidence of an inverse relationship between land productivity and farm size.

5.2 Specification tests and the structure of the technology

The general specification of the stochastic frontier described above was tested against a number of simpler alternatives in order to gain some insights into the structure of the technology and inefficiencies. A second objective is to define a more parsimonious specification as the full model requires estimation of a relatively large number of parameters given the sample size[19]. The results of likelihood ratio tests are presented in Table 3[20].

First, we test the composed error specification against the hypothesis of absence of inefficiencies by comparing the log-likelihood of our model against that obtained by standard OLS regression. The likelihood ratio statistic of 39.2 exceeds by far its critical value and we therefore conclude to the presence of substantial inefficiencies across our sample farms[21]. From a methodological angle, this result implies that the modelling of the technological relationship between inputs and outputs as a stochastic ray production function rather than a deterministic one is strongly supported by our data.

The second test investigates the explanatory power of the two variables introduced as inefficiency effects in our specification. It is also strongly rejected, implying that the regional dummy and farm size variables have, jointly, a statistically significant influence on efficiency. The third test considers the null hypothesis that the regional effects, introduced into the model through the regional dummy in the ray production function and in the inefficiency effect component of the model (11), are inexistent. The hypothesis is accepted as dropping these two variables from the model results in a decrease in the likelihood function of only 0.8, which is marginal. This absence of regional effects in the ray production function stands in sharp contrast to the results obtained earlier based on partial productivity indicators. There is no inconsistency here, however, because the ray production function can accommodate possible differences in output mix across regions, while partial productivity indicators fail to do so[22]. Next, the explanatory power of farm size on inefficiencies is tested and the null hypothesis of no farm-size effect is strongly rejected. We therefore conclude from these four tests that the regional dummy variable can be dropped from the specification of the model, while farm size as an inefficient effect should be retained.

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[19] The total number of parameters in specification (20) is equal to 34, for a sample size of 127.

[20] The test statistic is $LR=-2*\{ln(L(H_0))-ln(L(H_1))\}$, where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null and alternative hypotheses (Battese and Coelli, 1998).

[21] Note that the null hypothesis includes the restriction $\sigma_u=0$. As this parameter is necessarily positive, the test statistic follows a mixed chi-square distribution, the critical values of which are found in Kodde and Palm (1986).

[22] In terms of figure 1, the efficiency of farm C is measured radially, which means that this farm is implicitly compared to farms with a similar output mix. By contrast, gross margin or revenue per hectare measures fail to account for possible differences in output combinations when comparing farms.

The last two tests investigate the structure of the technology. Most interesting is the question of whether inputs and outputs are separable, which is tested by comparing our model to a restricted version where the parameters of all cross-terms between inputs and polar coordinates angles in (20) are set equal to zero. The null hypothesis is rejected at any sensible level of significance, which implies that it would not be possible to aggregate consistently the four outputs into a single index. This is why the ray production frontier is used rather than a frontier production function, which requires output aggregation prior to estimation. Finally, the last test considers the null hypothesis that the parameters associated with all the cross-terms among inputs and among polar coordinate angles are equal to zero. It is strongly rejected.

Altogether, we conclude from this series of tests that there are substantial inefficiencies among the sample farms, which are partially explained by farm size. However, regional effects are not present, and the regional dummy is therefore dropped from the model's specification. Further simplification of the specification is not possible as the tests indicate that the technology is truly multi-product and the relationship among inputs and outputs is a complex one.

The results of the maximum likelihood estimation for our preferred specification are presented in Table 4. We note that many of the coefficients present relatively low levels of statistical significance but this should be expected as there is a high level of collinearity among the covariates[23]. The individual parameters of the technology are not directly interpretable and we therefore compute in Table 5 the elasticities of the production ray function at the sample mean, together with their standard errors. Most straightforward to interpret are the input elasticities described in equation (7). First, there is a significant and positive relationship between land input and production, as a one percent increase in farm size results in a 0.58% increase in all outputs. Hence, land stands out as a key production factor which can be explained by the extensive nature of the technology. Second, the elasticity with respect to intermediate inputs is also highly significant, with a one percent increase in that aggregate resulting in a 0.36% increase in production. Finally, the elasticity with respect to labour is very small, negative and not statistically significant, which means that the model fails to capture a positive relationship between labour input and production. There are several possible explanations for this negative result. One relates to the difficulty of measuring labour input properly, in particular as far as farm operators are concerned. We had to make sometimes crude assumptions in building the labour variable[24], which might explain in part this statistically insignificant elasticity. Second, the labour variable presents a high degree of collinearity with the other inputs, which can be explained by the fact that most farm operators seem to adhere to the rule of thumb 'one care taker for ten hectares'. Finally, we note that the finding of a negative and/or insignificant labour elasticity, although paradoxical, represents an empirical regularity (Whiteman, 1999). The scale elasticity (8) is obtained by summation of all three input elasticities to give a value of 0.92, with a standard error of 0.11. Hence, the

[23] This is not unusual when using flexible functional forms. For instance, in the full translog specification of his model, Löthgren (2000) reports only five significant coefficients (5%) from a total of 21 in the specification of the technology.

[24] For instance, we had to assume that the operator was either working full time or half-time on the farm, which probably does not reflect the heterogeneity of situations regarding the labour contribution of the operator.

technology exhibits slightly decreasing returns to scale at the sample mean but the hypothesis of constant returns to scale cannot be rejected.

On the output side, the elasticities of the ray function with respect to the polar coordinate angles are more difficult to interpret. We note, however, that the last elasticity is large and strongly significant, which implies that the PPF, at the sample mean, differs significantly from a perfect sphere. We conclude that the representation of the technology that we obtain appears reasonably consistent with theoretical expectations and provides an ex-post justification for the ray production function approach that was chosen over the standard estimation of an aggregate production function.

5.3 Inefficiencies and the inverse relationship

The likelihood ratio tests established that inefficiencies in our sample were statistically significant, and that is confirmed by the fact that parameter γ in Table 4 has a large t-ratio. The mean efficiency score for the sample is equal to 0.37,[25] which is very low and implies that the sample farms could potentially increase production 2.7 times without any increase in inputs or change in technology. This finding confirms that of Irz and McKenzie (2003) and suggests that there is considerable room for managerial improvement of the farms in the study area. It represents an empirical validation of Yap's contention that many brackishwater ponds are 'underdeveloped and under-productive' (Yap, 1999). It can also be explained by the fact that extensive production systems have not been the focus of much research and extension activity in the Philippines, which stands in sharp contrast with the situation of the semi-intensive systems of tilapia production in fresh water that have benefited from large R&D investment. The interviews carried out with farmers confirmed that formal extension services are simply not regarded as an important source of technical information by the operators of extensive farms. Finally, it is also necessary to recognize that the extensive production systems considered here are intrinsically complex and offer numerous opportunities for farmers to make mistakes. This is so because these systems are open, due to the frequent exchange of the pond's water, which limits the farmer's control of the production process. Furthermore, the production process depends on the natural productivity of the pond, which itself relates to the populations of various plankton and filamentous algae species that are difficult to manage and sensitive to temperature, salinity, soil conditions and the chemical and nutrient composition of the culture water (Arfi and Guiral, 1994).[26] The situation is very different in intensive production where the growth of the target species depends primarily on the feeds brought from outside of the farm and the pond has little biological function beyond the provision of oxygen to the fish/crustaceans (Kautsky et al., 2000)[27].

Figure 3 presents the frequency distribution of efficiency scores and indicates a high level of heterogeneity within the sample. The distribution is very flat, as reflected by a

[25] In the additive model presented here, the predicted efficiency scores can take negative values, which is theoretically impossible. We therefore replaced negative values by zeros when that occurred (in only a few cases) prior to calculating this average.
[26] We are thankful to Pierre Morrisens for this idea.
[27] An analogy with agriculture might be useful here. Extensive aquaculture, like organic farming, seems to be management intensive while intensive aquaculture, like conventional farming, tends to rely on the application of standard technological packages that leave little initiative to the farmer.

standard error of 0.26, and is spread over the whole possible range, from a minimum of zero to a maximum of 0.97. We now turn to the direct analysis of the IR relationship by investigating whether these large variations in technical efficiency scores are related to farm size. The likelihood ratio tests already demonstrated the existence of a significant relationship between farm size and efficiency, which can also be seen in Table 4 by the large t-ratio of parameter δ_a. Furthermore, note that this parameter takes a strictly positive sign, indicating that *larger farms in our sample are less efficient than smaller ones*. Hence, we conclude to the existence of a statistically significant IR in Philippine brackishwater aquaculture. We would like, however, to go further in identifying the strength of this relationship, which cannot be established directly from the parameter estimates and we now implement for that purpose the two approaches discussed in the methodological section.

Our first contention was that a natural way of investigating the explanatory power of farm size as an inefficiency effect consists of comparing the full model to a restricted version where farm size is dropped as an inefficiency effect. We find that for the full specification, inefficiencies account for 86% of the total variance term, implying that the bulk of the variation in production not accounted for by physical factors is attributed to inefficiencies rather than random shocks (i.e., what Pascoe and Coglan (2002) referred to as luck). For the restricted model, where farm size is dropped from the *z* vector, inefficiencies account for only 73% of the total variance term. It is therefore logical to conclude that variations in production not accounted for by inputs are attributable to random shocks for 14%; farm size for 13%; and unexplained inefficiencies for 73%. This implies that the IR, although statistically significant, appears to be of only limited quantitative importance.

Next, we compute the efficiency elasticity of farm size corresponding to equation (17) and obtain a value of -0.137 at the sample mean. This indicates that a 10% increase in farm size decreases the level of farm-level efficiency by a modest 1.4% for the average farm and confirms the previous result of an IR of only limited strength. When farm-level efficiency is predicted by the mode of the distribution of *u* given *e*, as in equation (18), the efficiency elasticity at the sample mean takes the same value at the three-digit level. The results are therefore robust to the choice of predictor used to infer farm-level efficiency scores.

From a methodological point of view, it is also interesting to compare our results to those obtained by application of the procedure suggested by Pascoe and Coglan (2002) to quantify the explanatory power of the inefficiency effect variables. When regressing by OLS the efficiency scores against the logarithm of farm size, we obtain results that are simply inconsistent with the first-stage maximum-likelihood estimation. The estimated efficiency elasticity of farm size at the sample mean is 0.24, with a t-ratio of 3.52, and the R-square for this regression is only 9%. Clearly, the sign of the elasticity is inconsistent with that of parameter δ_a in Table 4. Furthermore, these results suggest that farm size explains only 7.7% (=0.09*0.86) of the variation in outputs not accounted for by physical inputs, while we find a value almost twice as large. Hence, we conclude that this procedure, which is not consistent with the underlying model of efficiency measurement, can lead to erroneous conclusions regarding both the direction and the strength of the relationship between inefficiency effect variables and efficiency scores. We therefore believe that our methodological contribution is important in deriving the policy implications of the popular Battese and Coelli (1995) model.

6. Discussion and conclusion

This paper uses a stochastic ray production function in order to investigate a potential inverse relationship in Philippines brackishwater aquaculture, based on a cross-section of 127 farms. The novelty of our approach is threefold: at a theoretical level, we derive the dual properties of the ray production function, which are useful in interpreting the parameter estimates; at an econometric level, we offer two different approaches to quantity the explanatory power of the inefficiency effects, including farm size, that are introduced in the model; and at an empirical level, ours is the first attempt to model a farming technology by a ray production function.

The estimated multi-product technology is not separable in inputs and outputs, implying that our approach is superior to the estimation of a stochastic production function, which requires the aggregation of outputs into a single index. Returns to scale are slightly decreasing at the sample mean but the CRS hypothesis cannot be rejected. The distribution of efficiency score is spread out over the whole possible range with an average value of 0.37, which is extremely low. Large potential productivity gains are therefore achievable in the study area, without any change in the technology, output mix or input combination. Is land redistribution or an improvement in the functioning of the land market a key to achieving these efficiency gains? Our analysis reveals that it is probably not the case. We find that there clearly exists a significant inverse relationship between farm size and productivity, but that the strength of this relationship is limited. Farm size explains only 13% of the variability in outputs not accounted for by physical inputs, against 73% for unidentified factors, and 14% for random shocks. The elasticities that we derive indicate that when farm size doubles, efficiency decreases only by a modest 14%. It is therefore likely that application of the land reform laws to brackishwater fish ponds, which so far have secured exemptions via intense political lobbying by the pond owners and lease holders, does not constitute a panacea to unlock the productive potential of these areas. There might be legitimate reasons, on equity grounds, to call for the removal of these exemptions, but the efficiency case for this policy carries only limited weight. We know that the cost of implementing land redistribution programs is always high, and that is likely to be particularly so in the Philippines where issues of corruption, weak law enforcement and slow-moving bureaucracy in coastal areas are well documented (Primavera, 2000).

Although this is an important result for policy formulation, it is unfortunately a negative one as we are left with the conclusion that variations in efficiency relate to unexplained factors. The best we can do at this level is therefore to speculate on the underlying reasons leading to the poor average technical performance of the farms. Here, we believe that the lack of R&D investment in brackishwater aquaculture is a key constraint to the production and productivity growth of the sector. Even aquaculture specialists recognize the difficulty to manage these systems, and it therefore seems that there is a need to generate knowledge before even considering investment in extension services. It remains to be shown that such investments are economically desirable, but our results suggest that the potential gains from improved farm management are very large.

Figure 1: Alternative representations of a multi-output technology.

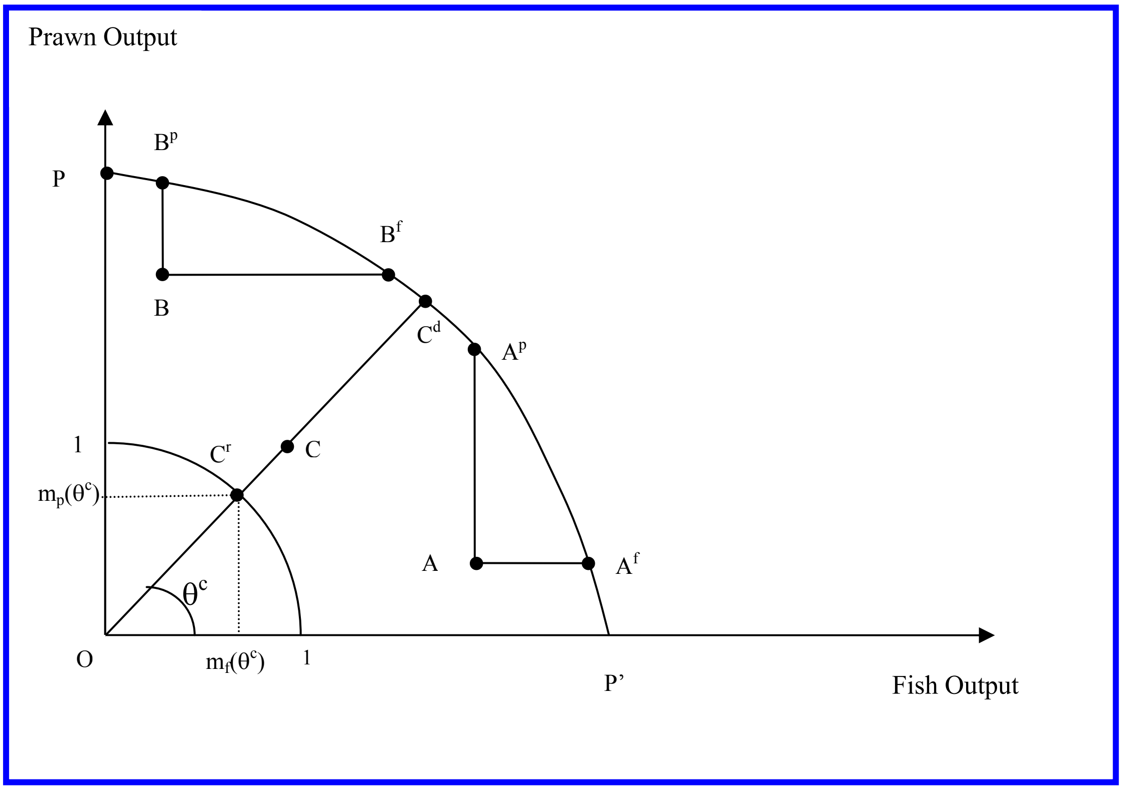

Figure 2: Distribution of Number of Species Grown on the Farm

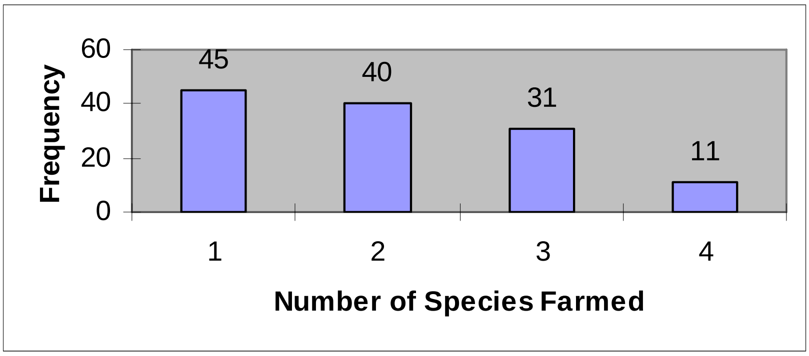

Figure 3: Frequency distribution of efficiency scores

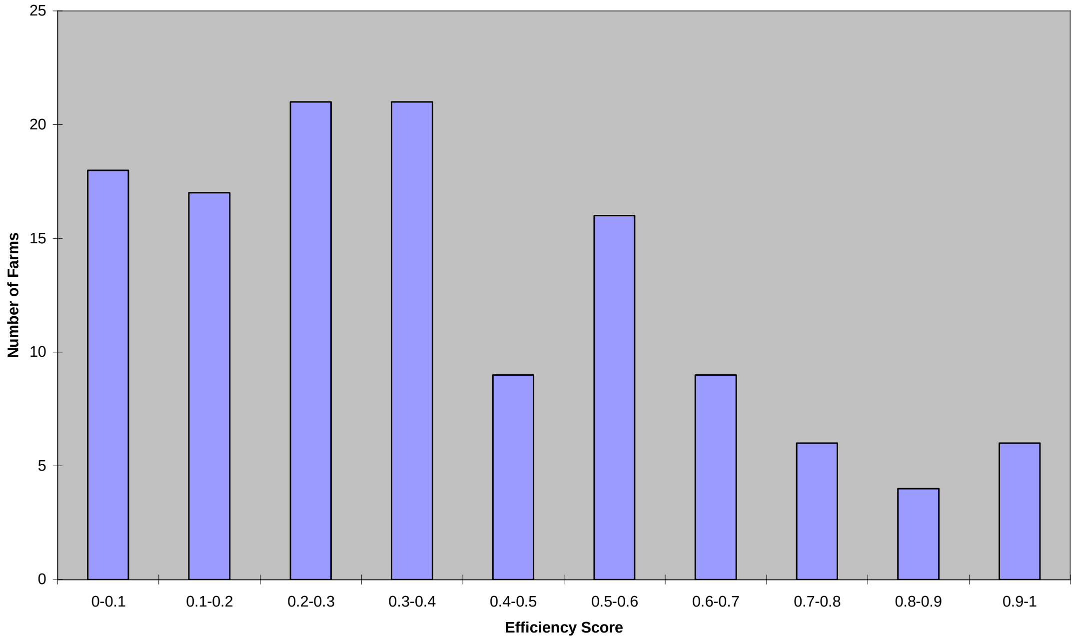

Table 1: Summary statistics*

Variable	Mean	Mean producers**	Std Dev.	Std Dev. Producers**	Minimum	Maximum
OUTPUTS						
Milkfish (Kg)	4,356	5,075	1,098	13,339	0	80,000
Tilapia (Kg)	674	2,950	230	4,886	0	25,600
Prawns (Kg)	691	1,111	202	2,832	0	22,240
Crabs (Kg)	311	878	79	1,330	0	8,000
INPUTS						
Land (ha)	11.5	-	1.9	-	0.1	130.0
Labour (man days)	1,160	-	220	-	187	26,312
Feeds (Pesos)	95,259	-	39,617	-	0	4,420,893
Fert (Pesos)	33,578	-	5,867	-	0	403,260
Fry/fingerlings (Pesos)	183,770	-	46,518	-	0	4,140,000

* All variables are expressed on a per year basis.
** Mean and standard deviation computed over the sub-sample of farms producing a positive quantity of the product.

Table 2: Inverse relationship based on partial productivity measures

	Dependent Variable		
	Log(harvest weight per hectare)	Log(harvest value per hectare)	Gross Margin per hectare
Regressors:			
Constant	6.52	11.60	90,940
	(37.32)	(71.78)	(6.78)
Log(Farm size)	0.87	-0.22	-8,953
	(11.91)	(-3.30)	(-1.60)
Regional Dummy	-0.85	-1.69	-63,528
	(-4.04)	(-8.69)	(-3.93)
R2	0.55	0.42	0.13

Table 3: Specification tests

Null Hypothesis	Log-likelihood	LR statistic	Critical Value 5%	Critical Value 1%	Outcome
1 No inefficiencies	-113.0	39.2	8.8	12.5	Reject
2 No inefficiency effects	-104.3	21.9	6.0	9.2	Reject
3 No regional effects	-94.1	1.6	6.0	9.2	Accept
4 No farm size effect	-100.0	13.4	3.8	6.6	Reject
5 Input-output separability	-195.2	203.8	16.9	21.7	Reject
6 No cross-terms	-136.2	85.7	12.6	16.8	Reject

Table 4: estimation results of ray production frontier

Parameter	Estimate	t-ratio
Ray frontier		
α_0	0.569	0.68
α_a	0.018	0.01
α_l	0.965	0.83
α_i	-0.890	-1.40
$\alpha_{\theta t}$	-0.685	-0.64
$\alpha_{\theta c}$	0.417	0.36
$\alpha_{\theta p}$	-0.858	-1.87
β_{aa}	0.047	1.27
β_{ll}	0.001	0.08
β_{ii}	-0.092	-13.76
$\beta_{\theta t\theta t}$	0.140	0.20
$\beta_{\theta c\theta c}$	-0.320	-0.48
$\beta_{\theta p\theta p}$	0.448	2.00
β_{al}	0.034	0.98
β_{ai}	0.403	11.72
$\beta_{a\theta t}$	-0.689	-0.69
$\beta_{a\theta c}$	0.588	0.34
$\beta_{a\theta p}$	0.998	1.88
β_{li}	-0.218	-5.16
$\beta_{l\theta t}$	0.103	0.11
$\beta_{l\theta c}$	-0.920	-0.86
$\beta_{l\theta p}$	-0.031	-0.09
$\beta_{i\theta t}$	0.843	1.53
$\beta_{i\theta c}$	0.580	0.69
$\beta_{i\theta p}$	0.368	1.14
$\beta_{\theta t\theta c}$	0.120	0.22
$\beta_{\theta t\theta p}$	0.084	0.27
$\beta_{\theta c\theta p}$	0.066	0.24
Inefficiency Model		
δ_0	-2.356	-2.26
δ_a	2.292	4.43
Variance Parameters		
$\sigma^2=\sigma_u^2+\sigma_v^2$	1.052	3.02
$\gamma=\sigma_u^{2/}\sigma^2$	0.944	32.46
Log-likelihood	-94.147	

Subscript notations: a=land input, l=labour inputs, i=intermediate inputs, (θt, θc, θp)=three polar coordinate angles corresponding to tilapia, crabs and prawns respectively; α0 and δo are the constant parameters.

Table 5: Elasticities of estimated ray production function (at sample mean)

Elasticity w.r.t.	Estimate	t-ratio
Land	0.58	4.51
Labour	-0.03	-0.43
Intermediate Inputs	0.36	7.90
θ_t	0.03	0.12
θ_c	0.08	0.34
θ_p	0.61	7.37

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Appendix to paper 5: Dual properties of the ray production function

The revenue maximisation problem can be written in terms of the ray function as:

$$R(p,x) = \underset{y}{Max}(py) : f(x,\theta(y)) \geq \|y\| \quad \text{(A.1)}$$

This constrained optimisation problem is solved by introducing the following Lagrangian:

$$L(y,\lambda) = py + \lambda[f(x,\theta(y)) - \|y\|] \quad \text{(A.2)}$$

The first order conditions are:

$$\frac{\partial L}{\partial y_j} = p_j + \lambda[(\sum_{m=1}^{M-1}\frac{\partial f}{\partial \theta_m}\frac{\partial \theta_m}{\partial y_j}) - \frac{y_j}{f}0] = 0 \quad \text{(A.3)}$$

$$\frac{\partial L}{\partial \lambda} = f(x,\theta(y)) - \|y\| = 0 \quad \text{(A.4)}$$

which are more conveniently written as:

$$p_j = -\lambda[(\sum_{m=1}^{M-1}\frac{\partial f}{\partial \theta_m}\frac{\partial \theta_m}{\partial y_j}) - \frac{y_j}{f}] \quad \text{(A.5)}$$

$$f(x,\theta(y)) = \|y\| \quad \text{(A.6)}$$

Multiplying (A.5) by y_j and summing over all outputs, one obtains:

$$\sum_{j=1}^{M} p_j y_j = -\lambda\sum_{j=1}^{M}[(\sum_{m=1}^{M-1}\frac{\partial f}{\partial \theta_m}\frac{\partial \theta_m}{\partial y_j}) - \frac{y_j^2}{f}] \quad \text{(A.7)}$$

$$\sum_{j=1}^{M} p_j y_j = -\lambda[\sum_{j=1}^{M}\sum_{m=1}^{M-1}\frac{\partial f}{\partial \theta_m}\frac{\partial \theta_m}{\partial y_j}y_j - \frac{\sum_{j=1}^{M} y_j^2}{f}] \quad \text{(A.8)}$$

The first term of this sum can be re-written as $\sum_{m=1}^{M-1}\frac{\partial f}{\partial \theta_m}\sum_{j=1}^{M}\frac{\partial \theta_m}{\partial y_j}y_j$, but since the function θ_m is homogenous of degree zero in y, $\sum_{j=1}^{M}\frac{\partial \theta_m}{\partial y_j}y_j = 0$. Further, using (A.4), equation (A.8) reduces to:

$$R(p,x) = \sum_{j=1}^{M} p_j y_j = \lambda.f \Rightarrow \lambda = R(p,x)/f \quad \text{(A.9)}$$

This expression means that the Lagrange multiplier is simply the unit value of the norm. Applying the envelop theorem to the original problem (A.2) therefore gives us:

$$\frac{\partial R}{\partial x_k} = \lambda\frac{\partial f}{\partial x_x} = \frac{R}{f}\frac{\partial f}{\partial x_x} \Rightarrow \frac{\partial \ln R}{\partial \ln x_k} = \frac{\partial \ln f}{\partial \ln x_k} \quad \text{(A.10)}$$

Hence, the elastictities of the revenue function and output ray function with respect to any input *k* are equal and are expected to be positive. We also use (A.9) to rewrite (A.3):

$$p_j = -\frac{R}{f}[(\sum_{m=1}^{M-1}\frac{\partial f}{\partial \theta_m}\frac{\partial \theta_m}{\partial y_j}) - \frac{y_j}{f}] \quad \text{(A.11)}$$

It follows that the marginal rate of transformation between two outputs is:

$$\frac{p_j}{p_i} = \frac{(\sum_{m=1}^{M-1} \frac{\partial f}{\partial \theta_m} \frac{\partial \theta_m}{\partial y_j}) - \frac{y_j}{f}}{(\sum_{m=1}^{M-1} \frac{\partial f}{\partial \theta_m} \frac{\partial \theta_m}{\partial y_i}) - \frac{y_i}{f}} \qquad (A.12)$$

It can also be written in terms of log derivatives as:

$$\frac{p_j}{p_i} = \frac{y_j(\sum_{m=1}^{M-1} \frac{\partial \ln f}{\partial \ln \theta_m} \frac{\partial \ln \theta_m}{\partial \ln y_j} - 1)}{y_i(\sum_{m=1}^{M-1} \frac{\partial \ln f}{\partial \ln \theta_m} \frac{\partial \ln \theta_m}{\partial \ln y_i} - 1)} \qquad (A.13)$$

Suppose all the derivatives of the ray function with respect to the angles are equal to 0. This implies that the marginal of transformation becomes:

$$\frac{p_j}{p_i} = \frac{y_j}{y_i} \qquad (A.14)$$

The previous expression can only be valid if the PPF is perfectly approximated in the plane ($y_i;y_j$) by a circle. Hence, the restriction that all derivatives of the ray production function with respect to the *(M-1)* angles are equal to zero means that the PPF is a perfect sphere of dimension *M*.

The ray function also shares some dual properties with the minimum cost function. We proceed as before to rewrite the Lagrangian of the cost minimisation problem:

$$L(x,\lambda) = -wx + \lambda[f(x,\theta(y)) - \|y\|] \qquad (A.15)$$

The FOCs are:

$$\frac{\partial L}{\partial x_k} = -w_k + \lambda \frac{\partial f}{\partial x_k} = 0 \qquad (A.16)$$

$$\frac{\partial L}{\partial \lambda} = f(x,\theta(y)) - \|y\| = 0 \qquad (A.17)$$

Multiplying (A.15) by x_k and summing over all inputs gives:

$$\lambda = \frac{C}{f.\varepsilon_{scale}} \qquad (A.18)$$

It follows from (A.16) that:

$$\frac{w_k x_k}{C} = S_k = \frac{\partial \ln f}{\partial \ln x_k} \frac{1}{\varepsilon_{scale}} \qquad (A.18)$$

The elasticity of the ray function with respect to any input x_k is therefore interpreted as the scale-adjusted (optimal) cost share of that input.