An Economic Analysis of Tilapia Production by Small-Scale Farmers in Rural Honduras

By

Gord Kurbis

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Department of Agricultural Economics and Farm Management
University of Manitoba
Winnipeg, Manitoba

March 2000

0-612-51735-7

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION PAGE

An Economic Analysis of Tilapia Production by Small-Scale Farmers in Rural Honduras

BY

Gord Kurbis

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree of Master of Science

Abstract

In Honduras, Central America, aquaculture as practiced by small-scale farmers can be characterized as having experienced mixed success at best. Yields are poor and well below potential yields indicated by field trials. In order to improve yields through public policy regarding extension practices and input availability where applicable, knowledge of aquacultural production must be improved. This analysis uses primary data collected by the author to obtain econometric estimates of a production function for the aquaculture technology used by small-scale farmers. Factor elasticities and returns to scale were estimated, as were coefficients for various qualitative factors captured by dummy variables. The results of this analysis recommend changes to public policy to improve yields for existing ponds and identify circumstances where yields can be improved for future ponds. Recommendations include the following changes in extension practices. First, lower-cost, mixed-sex aquaculture technology should be promoted in favour of other production methods. Second, fishponds using non-mixed sex production methods should be located in proximity to existing sources of seed fish. Third, efforts should be redoubled to improve pond management skill, which was found to be strongly correlated with yields. Finally, return on investment in small-scale aquaculture was estimated and found to be positive under some circumstances; however, poor success rates and other anecdotal evidence presented in the analysis suggest a need for further research to assess whether aquaculture extension is an appropriate use of scarce development and public sector resources.

Acknowledgements

I wish to express my gratitude to my major advisors, Jim MacMillan and Merle Faminow, for their guidance and encouragement throughout the research process. Special thanks also go to Daryl Kraft, Bonnie Warkentine, Barry Coyle, fellow grad students and members of my thesis committee for their support. Financial assistance from the Canadian International Development Agency and the Canadian Bureau for International Education are gratefully acknowledged.

I am also indebted to the people and organizations in Honduras who eased the task of primary data collection as well as other difficulties associated with my stay and travels. I wish to thank Dan Meyer, Carlos Cruz, the U.S. Peace Corps and Zamorano Escuela Agricola Panamericana. Very special thanks also go to Steve Cox, Miguel McGuire and Steve Sherwood.

Finally, I would like to dedicate this thesis to my wife, Chris Thompson, without whom none of this would have been possible.

Table of Contents

List of Tables and Figures

CHAPTER ONE: INTRODUCTION

1.1 Research Objectives

Fish farming, or aquaculture, has been and continues to be perceived as a promising technology in terms of achieving rural development goals of improved nutrition and food and income security. In Honduras, Central America, aquaculture as practiced by small-scale farmers can be characterized as having experienced mixed success at best. On one hand, there are pockets of fishponds in rural Honduras that appear to provide food and income security benefits to the families involved. On the other, successes are far from widespread and the literature appears to suggest an emerging consensus that there are intractable problems with small-scale aquaculture in Honduras. A review of the literature and numerous interviews with extensionists, aquaculture biologists and other development professionals in Honduras suggest that a major constraint to successful fishponds is the wide gap between actual yields achieved by small-scale farmers versus the potential yields indicated by field trials. In order to develop successful public policy regarding extension practices and input availability where applicable, knowledge of aquacultural production must be improved. The research objective of this thesis is to respond to this requirement by obtaining econometric estimates of a production function for the aquaculture technology used by small-scale farmers.

1.2 Method of Analysis

The Translog and Cobb-Douglas functional forms were specified for the production function in order to provide a flexible functional form and to support statistical discrimination between functional forms.

The parameters of empirical interest that are estimated in this analysis are:

i. inputs significant to the production process
ii. the factor elasticity of each significant input
iii. significance of qualitative variables captured by dummy variables (e.g., elevation above sea level)
iv. the elasticity of scale

The two models are assumed to be single equation models where output is an endogenous variable and inputs are all exogenous variables. The Ordinary Least Squares method was used for the Cobb-Douglas and Translog models and included appropriate tests for multicollinearity and heteroskedasticity. Shazam software was used for econometric estimation. Confidence intervals were constructed for factor elasticities and the elasticity of scale. The t and F distributions were employed to test individual and joint hypotheses of the significance of estimated coefficients.

1.3 Data Source

Primary data were collected from small-scale farmers in rural Honduras by the author, who lived there during 1995 and 1996 for 14 months. Semi-structured interviews were carried out using a combination of informal and questionnaire-style interviews to define the parameters for the analysis. To develop the initial criteria with regard to selecting the sample of farmers, interviews were conducted with 23 extensionists, aquaculture biologists and other development professionals. Based on these discussions, the sample was collected from a total of 16 clusters at three different elevation-based agricultural regions (sea level to 500 meters; 501-1000 meters; and greater than 1000 meters).

Small-scale aquaculture in Honduras tends not to be evenly distributed throughout the country; instead, ponds are generally located in clusters where extensionists were active. The sixteen clusters visited resulted in a total of 73 interviews with small farmers who had tried fish farming. Of these interviews, quantitative data was collected from 25 farmers. The remainder were judged to be unsuitable for inclusion on the basis of not meeting three criteria. First, ponds had to be active. Second, the pond had to have yielded at least two harvests, since discussions with extensionists suggested that the first yield was often a poor indicator of subsequent yields. Finally, fishponds had to be judged as being non-commercial in nature, i.e., owned and operated by farmers who had limited land holdings where various crops and livestock provided the immediate family with little, if any, surplus available for sale.

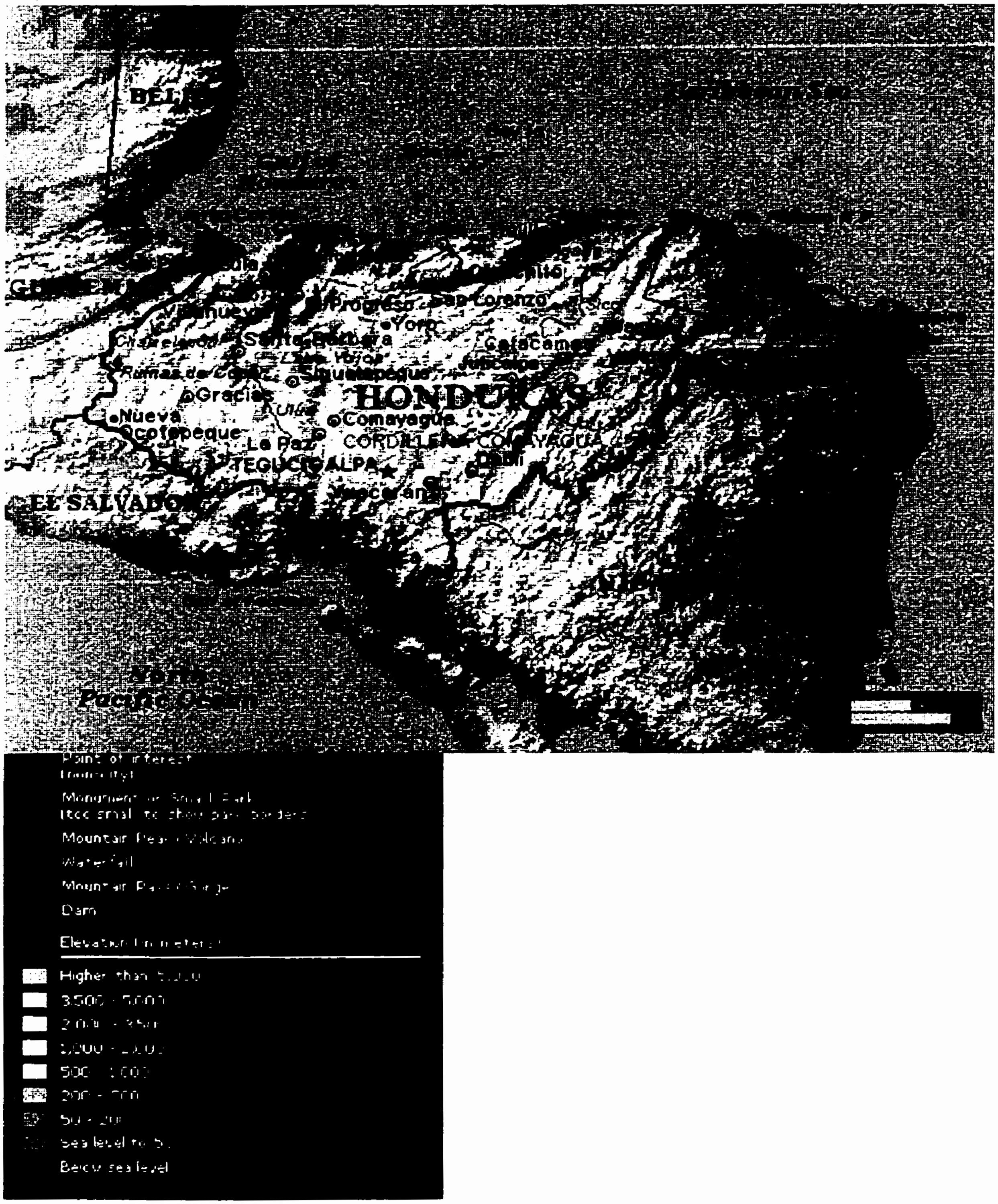
The 25 farmers who met these three criteria were observed to have land holdings of 0.1 Ha to 2.0 Ha. Of the original 16 clusters visited, the final sample of 25 farmers represented nine clusters or three from each elevation-based agricultural region. From the three clusters located in the coastal plains region (sea level to 500 meters elevation), seven farmers were selected for the final sample. At the mid-range elevation (501 to 1000 meters above sea level), three farmers were selected from each of two clusters at that elevation. A third cluster consisted of two farmers for a total of eight at the mid-range elevation. From the highlands region (greater than 1000 meters above sea level), three farmers were selected from each of two clusters and four were selected from a third cluster for a total of ten. Common elements of farming systems observed at all elevations were a corn-beans rotation and several chickens, typically less than 15, which subsisted mainly on insect life and small quantities of corn. Other crops that were present on some but not all farms where interviews were conducted were plantain, bananas, yucca (cassava), vegetables, sugar cane and fruit trees.

Fishponds were not a normal part of farming systems and tended to be uncommon outside areas where extensionists specifically trained in aquaculture had worked.

The final sample of 25 farmers is considered a judgement sample. It is uncertain what proportion of the total number of fishponds the sample represents, since that total figure is unknown. A crude upper limit on the total number of small fishponds in Honduras based on fingerling distribution is estimated in section 1.4 at approximately 1900 (page 12). Based on this estimate, the sample represents approximately 1.5 per cent of the total. Given this small proportion, the sample's objective is to capture the variability and characteristics featured by small-scale aquaculture in Honduras. It is the contention of this thesis that the final sample of 25 farmers satisfies that objective. The qualitative data collected from development professionals and farmers outside the sample did not suggest further variability and characteristics beyond the final sample of 25 farmers.

From that sample, quantitative and qualitative data were collected with regard to the following items: pond construction inputs, input quantities, yields, timing of operations, alternative uses for various farm resources, labour requirements, available feedstuffs, yield losses and other specific production characteristics featured by each farmer's pond or ponds. Price data were also collected but were not included in the analysis beyond the derivation of a feed use index due to the discovery of significant measurement error in certain inputs (see section 4.5).

Figure 1.1: Map of Honduras with Elevation Regions[1]



[1] Source: The University of Texas at Austin,
http://www.lib.utexas.edu/Libs/PCL/Map_collection/americas.html#H

1.4 Selective Review of Relevant Literature

The literature specifically tied to small-scale aquaculture in Honduras is sparse, although enough has been written to present a reasonable picture of the development and status of the enterprise. The following review presents a scenario of optimism that appears to have existed until the early 1990s, followed by a synopsis of studies detailing the aquaculture's serious if not intractable problems. In addition, a summary is provided of studies related to the subject matter but focusing either on neighboring countries in Central America or on larger scale or commercial production.

An example of the type of optimism that appears to have driven funding and projects involving Honduran aquaculture is the following statement by Hatch and Hanson (1991):

> Aquaculture is a production enterprise with great potential in tropical LDCs (less developed countries). In many areas, aquaculture is a new, alternative source of income and nutrition that is both sustainable and environmentally sound. Subsistence or low-resource, integrated agro-aquaculture allows greater use of on-farm resources, resulting in increased resource conservation and efficiency, and diminished purchased inputs.

Aquaculture began to attract interest and development funding in Honduras beginning in the early to mid 1970s (Blenker and Thompson, 1991). It was during this period that aquaculture increasingly came to be accepted internationally by donors as having significant potential for providing food security for the rural poor. Even prior to this rally of interest, projects in Honduras involving aquaculture had already been under way. As early as 1954, a Chinese development organization, Missión China, initiated research to investigate the feasibility of introducing fishponds to traditional small-scale farming systems (Blenker and Thompson, 1991). In general terms, the overall objective of that and smaller, subsequent initiatives in aquaculture was to supplement protein in the diets of the rural poor and generate occasional cash income. However, Honduran aquaculture would not receive significant funding from major donors such as USAID for approximately two more decades. The mid seventies saw a rally of renewed interest in Honduran small-scale aquaculture from national and international organizations (Nuñez, 1991a). Like the initial Chinese effort to introduce aquaculture as a production technology for small-scale farmers, the projects initiated as a result of renewed interest had a general objective of using aquaculture as a tool to help combat the endemic malnutrition problems among small farmers, and to provide income and food security.

In terms of rural poverty, Honduras needed and still warrants attention. The World Bank (2000) notes that "...with an estimated Gross National Product of US$730 per capita, Honduras is one of the poorest countries in the Americas, and approximately 50 percent of the population live in poverty. Almost half of the population lacks access to safe water. Approximately one-third of the population remains illiterate." Table 1.1 summarizes poverty and social indicators for Honduras relative to Latin America as a whole.

Table 1.1: Poverty and Social Indicators

Indicator (1998 data unless noted)	Latin America & the Caribbean	Honduras
Population (millions)	502	6.2
GNP per capita (Atlas method, $US)	3,940	730
GNP (Atlas method, $US billions)	1,978	4.5
Population growth (per cent; 1992-98 average)	1.6	2.9
Growth in labour force (per cent; 1992-98 average)	2.3	3.8
Per cent of population below national poverty line*	-	50
Rural population as per cent of total population*	25	54
Life expectancy at birth (years)*	75	69
Infant mortality (per 1,000 live births)*	70	36
Child malnutrition (per cent of children under 5)*	32	18
Access to safe water (per cent of population)*	8	77
Illiteracy (per cent of population 15+)*	75	29

* Most recent estimate (latest year available, 1992-98)

Source: World Bank (2000)

A study carried out in the early 1990s by the United States Agency for International Development (USAID, 1992) provides a specific context in terms of where Honduras ranks against other countries in Latin America. Honduras had the fourth lowest real GDP per capita, ranking only behind Haiti, Guyana and Nicaragua. Life expectancy and adult literacy ranked sixth worst and third worst at 65 years and 76 per cent. The under-five child mortality rate ranked fifth worst. Finally, the Honduran daily calorie supply per capita was 2,164, ranking higher than only Haiti and Bolivia. Figures distinguishing between rural and urban areas were not available.

Aquaculture appeared to have strong potential to help alleviate rural poverty and malnutrition. Aquaculture was intended to be able to provide much-needed protein in the traditional rural Honduran diet of corn tortillas, beans, plantains and, occasionally, eggs and chicken. It was meant to do so with little or no displacement of scarce on-farm resources available for other crops, since it was to take advantage of on-farm resources considered under-utilized in the context of traditional agricultural systems. Ponds were to be dug on the parts of small-scale landholdings that were unproductive for agriculture. Labour requirements for construction, harvest and daily feeding activities were to be timed around peak periods of demand for labour as determined by the requirements of other crops and off-farm enterprises such as picking coffee beans for a local landowner. Nutrition for the fish was to be provided by adding to the pond on-farm resources considered underutilized such as termites, manure and leaves from trees (a detailed description of aquacultural production systems follows later in this chapter). Moreover, the low-input, non-intensive techniques intended for small scale farmers, which require only fifteen minutes a day for feeding, are productive enough for an average-yielding 100 square meter pond to provide a rural family with about five pounds of fish per month[1]. These and other production characteristics are described in detail in Chapter two.

The U.S. Peace Corps' 1991 seven-year aquaculture project plan summarizes major development initiatives in small-scale aquaculture in Honduras. In 1972, the Honduran National Agrarian Institute and Ministry of Natural Resources, began promoting aquaculture with agricultural cooperatives in order to diversify cooperatives' income-generating enterprises and improve rural nutrition levels. In 1974, the Honduran government created an agency responsible for establishing a national aquaculture program. Direct and indirect funding for these and later Honduran government initiatives included U.S., Swiss, Belgian, and Japanese

[1] Based on average yields observed by Teichert-Coddington (1992).

development agencies. The Canadian International Development Agency and the FAO would also later participate (Molnar et al, 1994). In 1975, the U.S. Peace Corps became involved with aquaculture, focusing primarily on incorporating the enterprise into other agricultural activities. In 1976, the Pan-American Agriculture School constructed an experimental aquaculture station supporting research and serving as a source of seed fish, or fingerlings, for the eastern region of the country. In 1977, aquacultural funding in Honduras saw rapid expansion with the mainly USAID-funded construction of Honduran public sector hatcheries and implementation of extension programs to improve the nutrition of rural families. In 1979, the National University of Honduras incorporated aquaculture into its biology and agronomy curriculums. In 1982, feasibility studies in aquaculture funded by the Belgian government and the Tilapia Food Aid Organization (TFAO) led to the construction of another major aquaculture station/hatchery designed to produce 500,000 fingerlings annually for the 600 adjacent farming communities. In 1983, USAID financed a program to conduct and compare aquaculture production trials in Honduras, Panama, Indonesia and Rwanda. Two years later, the first National Fishculture Congress took place with the participation of approximately 150 participants representing the Peace Corps, USAID, various non-governmental organizations (NGOs), private concerns, the Central Bank of Honduras and other government agencies. In 1986, the Peace Corps began working with the Pan-American Agriculture School (EAP) and this led to what was arguably the most dynamic and concentrated aquaculture extension program in the country (Molnar and Loveshin, 1995).

Records detailing harvest statistics or the number of ponds constructed during this period were unavailable. In lieu of these, the number of fingerlings distributed is an acceptable indicator of the extent to which aquaculture was incorporated into farming systems. In 1980, the number of fingerlings distributed to farmers was 39,000, rising to an estimated one million by 1988 (Blenker and Thompson, 1991). Although the actual number of ponds this figure represents is unknown, the upper limit is estimated at 1900 small-scale ponds. This estimate assumes a mean stocking rate of two fingerlings per square meter, an average pond size of 178 square meters—which was the mean size observed in this analysis—and an average cycle length of one year. It is also assumed that one-third of the one million fingerlings distributed stocked commercial as opposed to small-scale ponds.

The number of donor agencies to have shown interest in small-scale aquaculture in Honduras and the rapid growth in the number of fingerlings distributed could be interpreted as a crude indicator of the attractiveness of the enterprise. In terms of practical results, however, there appears to have been little success. Molnar and Loveshin (1995) note that many subsistence and larger commercial Honduran fish ponds are abandoned or operating at sub optimal levels. Lanza (1991) identifies this same lack of success. Apart from a few small NGO-sponsored projects (Land Use Enhancement Project (LUPE) and Save the Children), international donors are no longer involved with Honduran aquaculture. The U.S. Peace Corps, which Molnar and Loveshin (1995) characterize as having the leading aquaculture extension program in Honduras, removed its last aquaculture volunteer from the country in 1995.

Researchers appear to have begun serious efforts to address these problems in the early 1990s through studies of the enterprise's feasibility undertaken by the U.S. Peace Corps, USAID/Auburn University, and the Honduran ministry of natural resources. These works yield interesting and useful observations, although each is qualitative in nature. The purpose of these works was to identify constraints to full realization of the enterprise. The authors generally acknowledge poor yields, abandonment and poor adoption rates, and their observations are summarized below into the four main constraints they identify: (1) technical unfeasibility; (2) poor yields; (3) overlooked intangible costs; and (4) institutional barriers.

(i) Technical Constraints

A significant number of ponds have been constructed under circumstances where the enterprise is technically unable to produce sufficient yields. With areas of expertise mainly in the field of agriculture, extensionists normally receive only a one-week training course in aquaculture and perceive aquaculture as a secondary activity (Blenker and Thompson, 1992). Consequently, farmers suffer from poor overall technical assistance (Nuñez, 1991). For example, farmers have been ill-advised to construct ponds where adequate water and clay soils are not available. Clay soils are required to prevent excessive water and nutrient filtration from the pond. In addition, water resources are sometimes insufficient due to greater urban pressure (Blenker and Thompson, 1992) and upland deforestation (Loveshin and Molnar, 1995). Finally, technology reliant on external sources of fingerlings has been recommended to remote-area farmers who have difficulties obtaining fingerlings due to unreliability of supply and transportation difficulties (Molnar and Loveshin, 1995). As a result, fingerling costs have become prohibitive in some areas where extensionists are no longer present to subsidize the costs of transporting seed fish from hatcheries to distant fishponds.

(ii) Production Yields

Poor yields can lead to abandonment if marginal revenue is not higher than average variable costs. Predation by birds and thieves with cast nets can substantially reduce harvests and is a serious problem for many producers whose ponds are not beside the family dwelling (Molnar and Loveshin 1995, Blenker and Thompson 1992). In addition, inadequate technical assistance has led to inadequate feed and fertilization, either in terms of too much, too little, or poor timing. The timing and quantity of feeding are critical to maintaining adequate water quality and nutrition for the fish. Inadequate technical assistance may also have led to farmers' inflated yield expectations (Molnar and Loveshin 1995).

(iii) Intangible Costs

Intangible costs associated with investing in aquaculture may have a significant impact in terms of adoption rates. Many Hondurans incorrectly perceive fishponds as stagnant-water mosquito breeding grounds which aggravate malaria and dengue fever problems. This has created pressure to abandon existing ponds and has inhibited entry of new producers (Blenker and Thompson 1992). It is true that stagnant ponds would otherwise increase mosquito reproduction, but this perception is incorrect in the case of fishponds since mosquito offspring do not have the chance to mature because larvae are quickly consumed by the fish. Blenker and Thompson also note that fish are perceived as wild animals, and a passive approach to cultivation is therefore assumed which is incompatible with proper feeding and maintenance of tilapia crops. In addition, the algae-clouded water necessary to good yields creates a lack of observable results which decreases farmer motivation and prevents theft detection. The risk of draining a pond and discovering a poor yield is discouraging enough, but it also represents a highly visible personal failure that may be perceived as damaging to one's personal reputation (Molnar and Loveshin 1995).

(iv) Institutional Barriers

Institutional constraints also may reduce the attractiveness of the investment. Because aquaculture represents a significant initial investment in pond construction, tenant farmers will tend not to invest in the enterprise (Blenker and Thompson, 1992). An average 100 square meter pond requires the equivalent of 19 person-days of labour for excavation, in addition to the equivalent of three to four days' off-farm wages in order to purchase a drainage pipe. Also, lack of political stability, a poor economy, and poor financial assistance are cited as factors inhibiting the development of a strong aquaculture sector (Lanza, 1991). In terms of financing, lending institutions generally have little experience with aquaculture. Consequently, loans are often unavailable because aquaculture is viewed a high-risk investment (Blenker and Thompson, 1992). In addition, the Honduran government has not actively promoted mixed sex tilapia production involving on-farm propagation of fingerlings, which Molnar and Loveshin (1995) view as a superior technology for small-scale farmers. Blenker and Thompson (1992) suggest that this can be explained by the Honduran government's wish to justify the existence of and avoid competition toward their own government-run hatcheries. In addition, until 1988, government hatcheries sold hybrid tilapia fingerlings (Oreochromis hornorum x Oreochromis niloticus) which cannot be used for on-farm propagation (Blenker and Thompson, 1992).

The studies cited above provide useful information. As qualitative works, however, they do not go further than to identify constraints. A study undertaken by USAID Collaborative Research Program (1992) addresses Honduran aquaculture from an economic and quantitative standpoint. Enterprise budgets were prepared to test returns to land, labor and pond management for different feeding regimes. Sensitivity analysis was also used to show the likely impact of changing market prices and interest rates. However, the study focuses on medium to large scale commercial aquaculture, which limits its relevance to small-scale aquaculture.

A study conducted in Panama addresses aquaculture from an economic and quantitative standpoint. There is an interesting parallel with the Honduran situation, as the authors (Loveshin et al, 1986) note that "...freshwater fish culture has grown rapidly...and disillusionment replaced early enthusiasm when initial research and pilot study successes were not duplicated on a larger scale." It, too, however, has limited relevance since it focused specifically on (i) integrated aquaculture which

Molnar (1994) identifies as uncommon in Honduras; and (ii) large scale production practices in a cooperative setting.

A study conducted in Guatemala addresses aquaculture from an economic and quantitative standpoint for small scale farmers, although geographical, cultural and institutional differences in that nation may differ enough to seriously limit their usefulness. A study of small-scale fish farming in Guatemala funded by CARE, Peace Corps, and the Guatemalan Ministry of Agriculture has financial and economic enterprise budgets, cash flows and breakeven times to assess the efficiency of the enterprise (Castillo et al 1992). However, the study has limited relevance to the Honduran situation, since the average yields it presents from small-scale ponds in Guatemala are approximately double the actual yields achieved in Honduras as observed by Teichert-Coddington (1992) and by primary data collected for this analysis.

USAID conducted a study comparing small-scale aquaculture between Rwanda, the Philippines, Honduras, Indonesia and Panama. This study was qualitative with the intent of comparing countries to assess and set research priorities.

1.5 Potential Significance of Results

The observations cited above suggest that small-scale aquaculture in Honduras has had limited success at best, and that serious problems exist with respect to yield and profitability. In addition to the unfeasibility suggested by the literature, most international donors who were active in promoting aquaculture for Honduran small-scale farmers have shifted their focus and resources elsewhere.

The evidence, however, is not conclusive. As Molnar and Loveshin (1995) note, pockets of fishponds which appear to be successful do exist.

The potential significance of the results are twofold. First, the econometric estimates of the production function will be available to help guide policy decisions on yield improvements for existing ponds. Second, the dummy variables included in the model, which capture qualitative features such as susceptibility to theft will provide improved information regarding the circumstances under which yields can be improved for future ponds and for existing ones where applicable. The inclusion of dummy variables is expected to add clarity to or challenge existing hypotheses of which circumstances or characteristics determine a farmer's ultimate success or failure with the enterprise. Finally, the considerable primary data collection undertaking of this study and the subsequent quantitative analysis provide a foundation for recommending areas for further research.

CHAPTER TWO: BACKGROUND

2.1 Introduction

To provide context for analysis, it is necessary to clarify what has been described up until this point as "small-scale aquaculture" in Honduras. Readers already familiar with the wide range of aquacultural technologies that exist will have already identified this need, since using the term aquaculture to describe a production technique is vague and no more descriptive than using the term agriculture, which includes production practices ranging from hand-sown maize to modern hog production. This chapter describes, in lay terms, the technologies relevant to this analysis. An unique illustrated guide prepared in Honduras, as part of a local extension module, is attached in appendix four.

2.2 Aquaculture Technologies: Definition/Description

Dictionaries commonly define aquaculture as the cultivation or rearing of aquatic plants or animals. Hatch and Hanson (1991) describe aquaculture as a food production technology whereby fish or other aquatic organisms are grown in managed systems that produce greater harvests than would naturally occur. The intensity of aquacultural production is related to the degree of modification of the natural environment, to the amount of managerial control over the aquatic environment, and to the quantity and quality of nutrient inputs added to enhance, supplement, or replace natural foods. Aquaculture's diversity and appropriateness are characterized by the choice of fish species, geographic locations, and intensity levels. Aquacultural operations vary by species (plants, finfish, molluscs, crustaceans and other organisms), water environment (fresh, brackish or saltwater), feeding habits (herbivorous, carnivorous, or omnivorous), and the intensity of cultivation (extensive, semi-intensive and intensive production).

Aquaculture has been practiced for thousands of years in Asia and since the beginning of the industrial revolution in Europe. Like livestock production before the late 20th century, aquaculture has traditionally been practiced in environments that rely on the animal's natural ability to forage for itself (Kurbis, 1996).

Although more than 150 different species around the world are grown, the bulk of activity is focused around a few major species-groups (Kurbis, 1996). The most widely cultivated aquacultural species-groups are tilapia and carp (tilapia is the fish of choice in Honduras), followed by molluscs (clams, oysters, etc), seaweed, crustaceans (shrimp) and salmonids (salmon and trout). And, of these, a considerable proportion of production is represented by traditional, low-yielding methods. Table 2.1 provides an indication of the relative proportion of aquaculture using traditional techniques.

Table 2.1: 1995 World Aquacultural Production

Species-Group	Production (thousand tonnes)	Per cent produced intensively	Per cent produced using traditional methods (2)
Carp	7,600	2.5	97.5
Shrimp	950	77	23
Catfish	400	100	0
Tilapia	650	15	85
Salmonids	800	100	0
Other (1)	9,100	4	96
Total	19,500	14	86

Source: Agriculture and Agri-Food Canada (1996)

/1 Excludes aquatic plants

/2 Traditional methods refers to raising fish solely on natural food sources such as algal blooms and phyto- and zoo-plankton growth as opposed to commercially prepared rations.

2.3 Production Environments

Similar to the diversity of livestock production in agricultural systems, production techniques in aquaculture vary significantly. Methods generally fall into one of three main categories: extensive, semi-intensive or intensive production. Extensive aquaculture refers to low-density stocking of natural bodies of water and is generally used to augment existing fish stocks. In this technique, young fish, or fingerlings, are produced in hatcheries or collected from the wild and then released into natural bodies of water. Fish forage on naturally available food sources such as algal blooms, zooplankton, phytoplankton and other fish, and are then harvested in the same manner as capture fisheries.

Semi-intensive aquaculture refers to stocking man-made ponds with fingerlings raised in hatcheries or captured from natural bodies of water. Like pasture-fed cattle, commercial feeds are sometimes used but nutrition is mainly provided by natural sources of feed. Organic or chemical fertilizers are generally added to ponds in order to encourage algal growth, which allows a natural food chain to develop within the system, and which replenishes the levels of dissolved oxygen in the water (oxygen is a by-product of photosynthesis). Water is generally not exchanged, except at infrequent intervals when toxicity or dissolved oxygen levels are undesirable. Fish stocking rates are limited by oxygen levels, the species of fish, and that species' tolerance to toxins from waste.

Intensive aquaculture also refers to stocking man-made ponds, tanks or cages with hatchery-raised seed fish. Like feedlot cattle, fish are fed commercial feed in close quarters. Water is generally exchanged through a series of pumps and filters in order to remove toxins and replenish oxygen. Stocking rates are highest in intensive production systems with an upper limit associated with the system's ability to maintain water quality.

2.4 Production Techniques: Common Elements

Although small-scale aquaculture in Honduras naturally varies from farm to farm, there is a basic set of core practices common to each production technique used by small-scale farmers. The sections below detail these common elements and are followed by a description of the specific techniques that are borne from these practices.

Figure 2.1 Typical small-scale aquaculture ponds in Rural Honduras[1]

[1] Photographs by author.

2.4.1 Water Environment

Ponds constructed by small-scale farmers vary in size from approximately 50 to 250 square meters and are excavated to an average depth of about one meter. Ponds must generally be constructed on soil with water-holding capability or must be lined with clay transported from another region if they are located in an inappropriate soil zone. Ponds must be free from significant shade, since the bulk of natural feed sources are direct functions of the pond's photosynthetic activity. Ponds are generally located beside or close to the family dwelling since, like any livestock, precautions must be taken against theft. During the production cycle, which typically ranges from 6 months to one year, water remains stagnant in the pond. Oxygen is replenished by algal blooms, which naturally recharge the pond's water with oxygen as a by-product of photosynthesis. Fish waste remains in the pond until it is drained for harvest at the end of the cycle. Pond toxicity from fish waste is avoided in this and other semi-intensive technologies by limiting the stocking rate.

2.4.2 Fish Species

The main species of fish used by small-scale farmers in Honduras is gray tilapia (Oreochromis Niloticus). This is a fish with robust production characteristics. Grey tilapia has a favourable feed conversion ratio relative to other species, adapts well to confined and often unfavorable conditions, reproduces with ease in captivity, and is omnivorous and able to thrive on supplemental feeds and/or natural organisms (phyto and zooplankton) that grow in fertilized ponds. These characteristics make it appropriate for the type of water quality conditions and feedstuffs available in rural areas.

The tilapia stocking rate used by small-scale farmers is generally 2 fish per square meter (Peace Corps, 1993). A predator fish called guapote (Cichlasoma Managuense) is commonly stocked with tilapia at a ratio of 20 to 1 in order to control tilapia reproduction (Teichert-Coddington, 1992). The presence of guapote is desirable in keeping harvested tilapia to a marketable size. Although excessive reproduction tends not to affect the total biomass of fish harvested, it does play a role in whether that biomass consists of a large number of small fish or vice-versa. For example, Teichert-Coddington (1992) indicates an average yield from a 100 square meter pond of 56 pounds per year. If excessive reproduction occurs, that yield could be comprised of 1,000 fish, each averaging less than one-tenth of a pound. A properly managed tilapia/guapote polyculture aims to reduce this number to approximately 100 to 200 fish (this technique's effectiveness varies considerably), which would bring the average harvested weight of each fish to 140 to 270 grams (0.3 to 0.6 lbs.), which is a more marketable level. Teichert-Coddington (1992) observes that "the minimum size fish Honduran consumers appeared to accept ranged from 100 to 125 grams (0.2 to 0.3 lbs.). Fish smaller than this can be difficult to market in urban areas, although reports from rural areas indicated that it was possible to sell fish as small as 50 grams (0.1 lbs)".

2.4.3 Feed

The fishes' nutrition is provided through a combination of feed added to the pond and natural feed sources that include, and develop from, algal growth. In terms of feed added to the pond, the type and consistency vary, since on-farm feedstuffs vary from farm to farm. Because tilapia are omnivorous and are able to digest a wide range of feedstuffs, farmers typically feed their fish whatever nutrients they have. In practice, these range from corn, cereal grain milling by-products, compost, termites, unmarketable vegetables, leaves from trees, animal slaughter waste, kitchen scraps, and occasionally commercial chicken or pig feeds.

It is important for a farmer to make sure that excessive feed is not added to the pond and that feed given is in small enough pieces for the fish to eat within approximately fifteen minutes. Feed not consumed during this timeframe tends to be subject to bacterial decomposition, which decreases levels of dissolved oxygen and may create toxicity problems.

Another important element of fish nutrition is simply being aware of what is and what is not toxic to the fish. Molnar and Loveshin (1995) note toxicity problems arising from coffee husks and accidental drainage of household detergents into fishponds from clothes laundering. In practice, toxicity from the fishes' own wastes is rarely a problem amongst small-scale farmers because of low stocking rates and slow growth.

2.4.4 Fertilization

Pond fertilization, which is necessary so the algal blooms have nutrients for photosynthesis, is done mainly with organic fertilizer in small-scale aquaculture. Manure from chickens, pigs, cattle and occasionally horses is used in addition to compost in order to provide nutrients for algal growth. Once the algal blooms begin, phyto- and zooplankton compose the beginnings of a natural food chain, which the omnivorous tilapia depend upon as a food source. In field trials, this technique has yielded the equivalent of 40 pounds per 100 square meter pond per year on fertilizer alone without supplementary feeds added (Teichert-Coddington, 1992). Manure must be broken into smaller pieces and mixed with water to a smooth consistency before being added to the water in order to discourage decomposition and encourage diffusion.

2.4.5 Harvest

Many small-scale farmers choose to harvest by draining the pond while some begin partial harvesting with a cast net a few months before the final harvest. Partial harvesting provides a family the option of being able to consume their harvest gradually without the obvious food storage problems implied by a full harvest. In addition, partial harvesting increases the potential market in terms of the number of days per year the family is able to sell fish to neighbors or passers-by. Regardless of whether the pond is drained or undergoes a series of partial harvests, fish not consumed by the family are generally sold directly from the pond itself using an inexpensive portable scale. Most small-scale producers utilize word-of-mouth to communicate a forthcoming harvest, selling most of the fish to neighbors (Molnar and Loveshin, 1995).

2.4.6 Water Quality

Proper pond management in aquaculture means managing nutrition and water quality. This is done by ensuring that the pond is adequately fertilized, and that the right quality and quantity of feed is available at the right time for fish growth. Another important pond management consideration is avoiding water toxicity through inappropriate feeds or inadvertent introduction of household detergents into the fishpond. Proper feeding and fertilization are crucial, since they: (1) provide adequate nutrition for the fish; (2) ensure adequate levels of dissolved oxygen from good algal growth; (3) minimize the dissolved oxygen-decreasing bacterial decomposition that can result from uneaten feedstuffs in the water; and (4) avoid excessive nutrient loading, which can lead to toxicity problems from excess concentration of fishes' own waste in the water.

2.5 Specific Techniques in Rural Honduras

The range of small-scale production techniques in Honduras can be categorized into four groups which differ mainly by method of reproductive controls. Such control is an important component of production given that Tilapia breed well in captivity and excessive reproduction in an otherwise well-managed pond prevents fish from growing to a marketable size. Female tilapia typically begin reproduction at the three to four month stage under realistic rural conditions, at which point fish populations begin to increase geometrically if no reproductive controls exist. The four technologies are briefly described below, followed by more detailed descriptions in sections 2.5.1 to 2.5.4. Each technique shares the common characteristics of small-scale aquaculture as detailed in the previous section except where noted.

(i) Sex-reversed male tilapia culture: avoids reproduction altogether by relying on the purchase of fingerlings that are uniformly male through a hormonal sex reversal process.

(ii) Hand sexed male tilapia culture: controls reproduction by hand-sexing and isolating male fish for grow-out.

(iii) Mixed sex tilapia culture: uses predators only for control of reproduction.

(iv) Intensive sex-reversed male tilapia culture: uses sex reversed male fingerlings but, unlike other small-scale technologies, replaces the dependence on fertilizer for feed and oxygen with supplemental feeds and constant water exchange.

2.5.1 Sex-Reversed Male Tilapia Culture

The dominant technology in rural Honduras is sex-reversed male tilapia culture of tilapia (Molnar et al, 1994). Androgen sex reversal makes all-male tilapia populations possible and involves adding hormones to the feed given to tilapia within the first month of growth in order to reverse the sex of female fingerlings. The culture of sex-reversed male tilapia fingerlings appears to have been the technology most widely promoted by extension agencies (the appropriateness of this technique is discussed in chapter six).

After sex-reversal, one hundred per cent of fingerlings should theoretically be male, although reproduction observed in ostensibly all-male populations suggests that this is not always the case in practice. The variability associated with this figure is discussed below.

Sex reversal is accomplished in hatcheries by placing new offspring from breeding fish in a separate pond for the first thirty days and adding hormone supplements to the feed. During this time period, the fingerlings grow to about 2 centimeters and are then ready to be sold.

Farmers arrive at hatcheries and typically carry away 100 to 500 fingerlings in a large plastic bag half full of water and half full of air. Fingerlings can survive in these bags without mortality losses for about one hour. At two and four hours, respective losses of about 10 and 25 per cent were common (source: field observations). Losses of fifty per cent occur at about six hours. Actual losses vary from these figures since they are mainly a function of insufficient oxygen and can be reduced by blowing bubbles into the water with a straw. Fingerlings are typically transported by the farmer on a bus, and complete the last leg of their journey to the farmers' ponds by foot or mule. If the total length of time in transit exceeds eight hours, complete mortality can result, so farmers who face these logistics may hire a local pick-up truck, or, more commonly, choose a technology that does not rely on off-farm fingerlings.

The effectiveness of the sex-reversal process is reported to vary. Some farmers experience significant reproduction in a pond which was stocked with what should have been male-only fingerlings. Data is regarding the effectiveness of the sex-reversal process under commercial conditions is unavailable, but the reliability of the process, especially from government hatcheries, is reported to be variable enough to warrant stocking a predator fish. Guapote, which feeds on tilapia offspring, is commonly stocked at a rate of twenty tilapia to one guapote (Peace Corps, 1991, Teichert-Coddington, 1992). Guapote should not exceed the tilapia in size when introduced to the pond, or they may consume the stocked tilapia themselves as opposed to their offspring. After the cycle, the guapote are harvested and eaten along with the adult tilapia.

2.5.2 Mixed Sex Tilapia Culture

Mixed sex tilapia culture involves on-farm propagation and the culture of both male and female offspring. Users of this technology are often located in distant regions relative to hatcheries where sex-reversed male fingerlings can be purchased. At harvest, farmers simply save the offspring present in the pond for their fingerling needs for the next cycle, which begins as soon after harvest as the pond can be filled with water. A higher proportion of predator fish (Guapote) is desirable for this technology, since the reproduction rates can otherwise be excessive. Reproduction can also be controlled with frequent partial harvesting with a cast net. Using this system, farmers can harvest fish weighing up to 1/3 pound each (source: field observations), but typically harvest a larger number of smaller fish.

2.5.3 Hand Sexed Male Tilapia Culture

Hand-sexed technology combines the positive characteristics of on-farm propagation and culture of solely male tilapia. Three ponds are required for this technique. The first and smallest pond contains the breeding fish, whose offspring are captured and placed in the second pond until they reach a large enough size so their sex can be determined (with some difficulty) by sight. The typical length of time these fingerlings spend in the second pond is about two months, after which they are captured again and sexed by hand as a precaution against earlier errors in hand sexing. Males are isolated and stocked in the larger grow-out pond, and females are consumed. Fish too small to be cleaned are generally added to soup or deep fried and eaten like potato chips. The main benefit of this technology is that it enables farmers to harvest good-sized fish from a system that utilizes on-farm propagation. However, labour intensity is greater than in the other three systems, since hand sexing is time-consuming and requires a great deal of skilled technical assistance to learn.

2.5.4 Intensive Sex-Reversed Male Tilapia Culture

Under this system, the pond must be situated so that it has a continual flow of water. This is generally done by introducing new water at one end of the pond through a spigot or natural flowing water source while draining water at the other end by creating a depression that allows overflow without providing enough room for fish to escape the pond. This system is a variation of the sex-reversed male technology described above except that the constant flow of fresh water prevents the development of a natural food chain through pond fertilization. Therefore, fish must rely solely on supplemental feeds for nutrition. This system is not in widespread use among small-scale farmers. Under this method, stocking rates are typically higher than in the other three.

2.6 Summary and Conclusions

Like agricultural production systems, methods used to produce fish can vary significantly between species. This chapter has clarified the use of the term "small-scale aquaculture in Honduras" and provides context for the remainder of the analysis. Small-scale aquaculture typically implies growing fish in stagnant ponds with a reliance on natural food chains developed through pond fertilization. Algal growth provides adequate levels of dissolved oxygen through photosynthesis, and phyto- and zooplankton growth provide nutrition for the fish. The four small-scale production techniques are heterogeneous and differ mainly by method of reproductive control.

CHAPTER THREE: THEORETICAL FRAMEWORK

3.1 Introduction

This chapter summarizes the production theory used in this analysis. This analysis uses a primal approach and estimates the production function directly as opposed to indirectly through a dual approach (cost function). This choice avoids introducing bias from measurement error in the pricing data of certain inputs (the nature and consequences of this constraint are elaborated upon under section 4.5). The first section of this chapter describes the relevant production theory and the second briefly discusses the functional forms that were selected.

3.2 Production Theory

The production function is a purely technical relationship which describes how firms transform inputs into outputs. It is assumed that a relationship exists between inputs and outputs that can be written in a mathematically convenient form:

$$Y(z) = 0 \qquad (3.1)$$

where z is a real-valued, m-dimensional vector containing both inputs used and outputs produced in a given time period. Equation (3.1) can be re-written to separate inputs and outputs into separate categories to improve its intuitive appeal as follows:

$$Y(y,x) = 0 \tag{3.2}$$

where the vectors x and y consist of nonnegative inputs and outputs. In the context of this analysis, (3.2) can be re-written for the case of a single output as:

$$y = f(x) \tag{3.3}$$

where $f(x)$ is single valued; in other words, the production function assumes that the output realized from a set of inputs is the maximum as prescribed by the technological relationship between inputs and outputs.

Further to these assumptions, Chambers (1988) notes that the production function generally incorporates the following properties:

(i) Monotonicity. If $x' \geq x$, then $f(x') \geq f(x)$. An assumption is made that the all marginal products are positive, i.e., that additional units of input must increase output.

(ii) Concavity/quasi-concavity. Diminishing rate of technical substitution/law of diminishing marginal productivity.

(iii) Weak essentiality/strict essentiality. Inputs must be used to produce output/all inputs must be used to produce output.

(iv) Non-emptiness. It is possible to produce any positive output.

(v) $f(x)$ is finite and non-negative.

(vi) $f(x)$ is a continuous function.

Elasticity of Scale (ϵ) measures the percentage change in output with a simultaneous percentage change of equal magnitude in all inputs. The elasticity of scale is the sum of the factor elasticities in the production function:

$$(3.5) \qquad \epsilon = \Sigma E_i \qquad i=1,\ldots,n$$

ϵ is constant if E_i is constant, i.e., if the factor elasticity for X_1 is independent of the quantities utilized of all $X_{i\ (i\ =\ 1\ldots n)}$ and the production function is a homogeneous function. If the production function is homogeneous and $\epsilon = 1$, then the function is said to homogeneous of degree one. If ϵ depends on the level of inputs, then returns to scale differs from point to point on the production surface and the function is said to be homothetic.

The production function is said to exhibit increasing returns to scale if $\epsilon > 1$. In other words, increasing returns to scale describes a technological relationship where a simultaneous increase in all inputs of 10%, for example, results in an increase in output by greater than 10%.

If $\epsilon = 1$, the production function exhibits constant returns to scale. In this case, the technological relationship between inputs and output is such that a simultaneous increase in all inputs by a certain percentage results in an increase in production by the same percentage.

If $\epsilon < 1$, the production function exhibits decreasing returns to scale in which the proportional increase in output is less than the proportional increase in all inputs.

Factor Elasticity (Ei) measures the marginal change in output from a change in a single input while other inputs are held constant.

$$(3.4) \qquad Ei = \frac{\delta y/\delta x_i}{y/x_i}$$

$$= \frac{MPP_i}{APP_i}$$

$$= \beta_i$$

Where APP is the average physical product, MPP is the marginal physical product, and β_i is the estimated coefficient in the production function.

3.3 Functional Forms for Production Functions

As Chambers (1988) notes, classical statistical theory is silent about the choice of functional form and presumes that the researcher knows the most general model against which hypotheses can be tested. In specifying functional forms for applied production analysis, it is therefore advantageous to have estimable relationships that place relatively few prior restrictions on the technology. The primary goal of applied production analysis is empirical measurement of the economically relevant information that characterizes the behaviour of economic agents (Chambers, 1988).

There are several other attributes of a good model for researchers to consider when choosing a functional form. These include parsimony, identifiability, goodness of fit and theoretical consistency (Gujarati, 1988; Kennedy, 1989)

(i) Parsimony. If the complexity of a model which describes reality is extreme such that it is of little practical use, then some amount of simplification or abstraction may be inevitable.

(ii) Identifiability. The model provides a single estimate for a given parameter.

(iii) Goodness of fit. A good model explains as much of the variation in Y as possible by the independent variables.

(iv) Theoretical consistency.

The translog functional form was specified for this study given its consistency with the above criteria and flexibility with regard to prior assumptions. The Cobb-Douglas was also chosen for its simplicity and its convenience in interpreting factor elasticities and elasticity of scale. In addition, the number of parameters of the translog model increases exponentially with the number of inputs included, while the Cobb-Douglas has minimal requirements of degrees of freedom. The choice of these two functional forms was also influenced by the ease of statistical discrimination between the two, because the Cobb-Douglas is nested within the translog model.

3.3.1 Cobb-Douglas Production Function.

The Cobb-Douglas production function has evolved since its development early in the 1900s and is named after the researchers mainly responsible for their popularization in the literature. The Cobb-Douglas function has been widely used in both theoretical and empirical production analyses and can be written as follows:

(3.7) $$y = \alpha X_i^{\beta^i} \ldots\ldots\ldots\ldots X_n^{\beta^n} e$$

where X_i = quantity of input i, β_i is the factor elasticity of input X_i, and $\Sigma\beta_i$ is the elasticity of scale. The technology exhibits decreasing or increasing returns to scale if $\Sigma\beta_i$ is less than or greater than one, respectively. Where $\Sigma\beta_i$ is equal to one, returns to scale are constant. Table 3.1 summarizes additional properties of the Cobb-Douglas production function.

3.3.2 Translog Production Function

The translog functional form places fewer *a priori* restrictions on the production function and is widely used in applied research. Several features of the translog functional form are contrasted with attributes of the Cobb-Douglas model in table 3.1.

The general form of the translog production function can be written as:

$$\ln y = \alpha + \Sigma_i \beta_i \ln X_i + {}^1/_2 \Sigma_i \Sigma_j \delta_{ij} (\ln X_i)(\ln X_j)$$

Table 3.1: Selected attributes of Translog and Cobb-Douglas functional forms

Attribute	Cobb-Douglas	Translog
Homogeneity	homogeneous of degree $\sum\beta_i$	not homogeneous unless $\delta_{ij\ (i=j)} = 0$ and $\delta_{ij\ (i\neq j)} = 0$
Factor elasticity	$E_i = \beta_i$	$E_{i\ (i=1,\ j=1\ldots n)} = B_1 + \delta_{11}\ln X_1 + \delta_{1j}\ln X_j$
Elasticity of scale	$\epsilon = \sum E_i$	$\epsilon = \sum E_{.i.}$
Elasticity of substitution	$\sigma = 1$	σ is not a constant
Slope of isoquant	negative	areas of positive and negative slope
Stages of production	stage I only or stage II only assuming quasi-concavity	stages I, II and III assuming quasi-concavity

Sources: Beattie (1985); Varian (1992)

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

As noted in the introductory chapter, a desirable approach to address the research problem of inadequate baseline information on small-scale aquaculture is econometric estimation of a production function. First, there is a requirement for such information since it contributes to the development of effective policy. Second, the pricing data constraints outlined in chapters one and three preclude approaches which use prices as explanatory variables. As such, the quantitative contribution of this analysis is related to the parameters of empirical interest regarding production technology. To repeat the point made in chapter one, a number of other areas exist for further quantitative research, since the literature and other information sources suggest that much of the existing research has been qualitative in nature and based upon anecdotal evidence. Beyond quantitative analysis, this study goes into considerable detail recommending areas for further research in chapter six.

This chapter describes the method of analysis used in this study, including the models, data collected, variables used, dummy variables added, and econometric methods and hypothesis tests. The first part of this chapter describes the models and variables used in the analysis. The second summarizes the econometric techniques. The final section discusses the significance of pricing data constraints encountered in this study and the impact those problems have had on the design and implementation of this thesis.

The parameters of empirical interest that are estimated in this analysis are:

(i) the inputs that are significant to the production process

(ii) the factor elasticities of each significant input

(iii) which factors captured by dummy variables (e.g., elevation above sea level) are significant

(iv) the elasticity of scale

The relevance of these parameters to the research problem is clear. It is of interest to extensionists which inputs are significant to the production process, and which of those inputs have greater per-unit effects on total production relative to other inputs. In addition, estimation of the coefficients for dummy variables included in the model provides information on which factors such as elevation and production technique affect production. Finally, the elasticity of scale of the technology is of intrinsic interest given its implications for potential changes to the targeted size of future production units.

4.2 Relevant Variables

The production function is specified as Yd = *f*(FD,FT,FG,LB), where:

Yd	=	Quantity of fish produced per square meter of pond area (pounds per m^2)
Fd	=	Aggregate feed input quantity index (quantities weighted by feed prices) (Lempiras per m^2)

Ft	=	Quantity of fertilizer applied (pounds per m^2)
Fg	=	Stocking rate of fingerlings (seed fish per m^2)
Lb	=	Labour in person-days per m^2

These variables are discussed at length in sections 4.2.1 and 4.2.2. Data were normalized for pond size (see sec. 4.2.2.) and are measured in units per cycle (approximately one year).

4.2.1 Data Collection

As was discussed in section 1.3, primary data was collected from small-scale farmers in rural Honduras by the author, who lived there during 1995 and 1996 for 14 months. Semi-structured interviews were carried out using a combination of informal and questionnaire-style interviews to define the parameters for farm investment analysis. To develop the initial criteria with regard to selecting the sample of farmers, interviews were conducted with 23 extensionists and other development professionals.

A total of 73 small farms with fishponds were visited; from these, quantitative data were collected from a sample of 25 farmers. To be included in the final sample, each pond had to meet the following criteria: (i) the pond had to be active; (ii) the pond had to have yielded at least two harvests, since discussions with extensionists suggested that the first yield was often a poor indicator of subsequent yields; (iii) fishponds had to be judged as non-commercial, i.e., owned and operated by farmers who had limited land holdings. The categorization implied by the last criterion was straightforward since income distribution in rural Honduras is such that there was little ambiguity between poor farmers and wealthy farmers. Specifics of the data collected are as follows:

(i) Output (Yd).

Output in this study is defined as the total weight of live fish harvested per square meter of pond per cycle. As discussed in chapter two, predator fish are added to ponds to control reproduction. The two species grown were gray tilapia (Oreochromis Niloticus), the omnivorous fish of principal interest, and the predator species guapote tigre (Cichlasoma Managuense). Interviews with extensionists and observation suggested a stocking rate of one guapote fingerling to 20 tilapia fingerlings. Data collected did not disaggregate output by these two species, and so this study determines a fish production function which includes both species. Both species as raised by small farmers have the same production technique, and the two species are aggregated into a single output Yd.

(ii) Feed (Fd).

The type and consistency of feeds added to ponds vary, since on-farm feedstuffs vary from farm to farm. Since tilapia are omnivorous and are able to digest a wide range of feedstuffs, farmers typically feed their fish whatever nutrients they have. In practice, these consisted mainly of corn, cereal grain milling by-product, yucca (cassava), livestock feeds and miscellaneous items such as unmarketable vegetables, leaves from trees, animal slaughter waste and kitchen scraps. All feeds were put into an aggregate feed input quantity index, which comprises the variable Fd measured in Lempiras per square meter of pond size. The index is defined in terms of prices by summing up the quantities of each feed used weighted by each item's price measured in 1995 Lempiras (equation 4.1). When a price was unavailable (such as for termites), the price of a feed source with similar nutritive value was used as a proxy in order to assign a similar marginal utility. Prices and quantities used are presented in appendix two.

$$(4.1) \qquad \text{Feed input quantity index} = \Sigma_i Q_{ij} P_{ij \, (i = 1,\ldots 6,\, j = 1\ldots 25)}$$

where: Q_{ij} = quantity of feed type i used in pond j

P_{ij} = price of feed type i at pond j (1995 Lempiras)

(iii) Fertilizer (Ft).

Pond fertilization, which is necessary so the algal blooms have nutrients for photosynthesis, is done mainly with organic fertilizer in small-scale aquaculture. Manure from chickens, pigs, cattle and occasionally horses is used in addition to compost in order to provide nutrients for algal growth. Once the algal blooms begin, phyto- and zooplankton compose the beginnings of a natural food chain which the omnivorous tilapia depend on as a food source. The variable Ft is defined as the total quantity (pounds) of manure per square meter of pond added during the production cycle.

(iv) Fingerlings (Fg).

Fg is defined as the total number of seed fish (either sex-reversed male or mixed-sex) added per square meter of pond.

(v) Labour (Lb).

Lb is defined as the total number of person-days per square meter spent tending to the pond.

(vi) Pond Size.

Data were normalized for pond size based on preliminary regression results which resulted in negative estimated coefficients for pond size. Inputs were normalized and defined as quantities per square meter. Initial regressions then included pond size as a separate variable along with normalized data as a further test for the significance of pond size on yield. Regression results supported the choice of data normalization, since the coefficient for pond size was both negative-signed and insignificant. Sricharoen (1991) notes that this practice is followed, without explanation, in other empirical studies of fish production.

4.2.2 Dummy Variables.

On advice from local biology and extension professionals consulted during the data collection process, a dummy variable was added for different elevation regions in the country. Biologists predicted that since the fish species cultivated are cold-blooded, regions with warmer ambient pond water temperatures should yield more fish per square meter (assuming all else is held constant). Small-scale aquaculture in Honduras tends to be located in clusters where extensionists had either lived or worked. Each observation collected from these clusters was classified into one of three elevation regions: sea level to 500 meters above sea level, 501 to 1000 meters above sea level, and greater than 1000 meters above sea level. These three elevation-regions are represented by the creation of two dummy variables E1 and E2:

E1	=	1 if elevation is 501-1000 meters; 0 otherwise
E2	=	1 if elevation is >1000 meters; 0 otherwise

As discussed in chapter two, production methods used by small farmers are heterogeneous. Of the four tilapia production techniques described in section 2.5 (sex-reversed male, mixed sex, hand-sexed reversed male and intensive sex reversed male), the hand-sexed and intensive techniques were observed only on commercial farms and were not included in this analysis. Among small-scale farmers, the two production methods observed were the sex-reversed male and mixed-sex techniques. The two methods were defined in section 2.5 and differ solely in terms of whether ponds are stocked with sex-reversed male fingerlings purchased from a hatchery or with fingerlings of mixed sex obtained from natural reproduction during the previous production cycle. The dummy variable M1 was created to represent production methods:

M1	=	1 if ponds stocked with mixed-sex fingerlings; 0 otherwise

Interviews conducted with biologists, extensionists and other development professionals suggested that pond management skill varied greatly between small-scale farmers, and that production appeared to be quite sensitive to the farmer adequately understanding the basics of the biological processes taking place in the pond. A set of dummy variables was added to test this hypothesis. A proxy was used for a measure of pond management skill. Interviews conducted with biologists and extensionists suggested that water colour was a reasonable indicator, since a deep green colour generally indicated a general understanding of the underlying biological processes of closed system aquaculture. Water colour was placed into three categories, light green, medium green and dark green, to represent low, medium and highly skilled managers, respectively. The dummy variables W1 and W2 were created to represent pond management skill.

W1	=	1 if water colour medium green; 0 otherwise
W2	=	1 if water colour dark green; 0 otherwise

The final dummy variable added to the model represents susceptibility to theft. Anecdotal evidence suggests that theft problems can have a significant effect on yield. Fish are easy to steal with a cast net if the pond is not in close proximity to the family dwelling where the threat of being caught prevents theft problems from developing. Unlike with chickens or other livestock, fish theft is difficult, if not impossible, to detect until harvest because of the lack of water clarity. As a result, remedial measures to prevent further theft cannot be immediately taken and theft can become a serious problem. The susceptibility to theft was measured by whether the pond was out of sight of the family dwelling. The following dummy variables for susceptibility to theft were created:

T1 = 1 if pond located within sight of family dwelling; 0 otherwise

The general model, (4.1) can be rewritten as follows to include the six dummy variables:

(4.2) $$Yd = f(FD, FT, FG, LB, E1, E2, M1, W1, W2, T1)$$

4.3 Econometric Method

The development of the models in this chapter assumes that output is an endogenous variable and inputs are all exogenous variables. Section 4.5 discusses the implications of this assumption and its alternative which endogenizes inputs and assumes yield is exogenous.

The Ordinary Least Squares method was used for the Cobb-Douglas and Translog models and included appropriate tests for multicollinearity and heteroskedasticity. Autocorrelation does not exist because cross-sectional data was used. The Shazam software program was used to run the two models. Confidence intervals were constructed for factor elasticities and the elasticity of scale. The t distribution was employed to test hypotheses of the significance of individual estimated coefficients. The F distribution was employed to test joint hypotheses.

4.4 Translog and Cobb-Douglas Models

Equations (4.1) and (4.2) can be written in logarithmic form in the case of the Translog model as follows:

$$(4.3) \quad \ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + \delta_{LbLb}\ln Lb\ln Lb + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FdLb}\ln Fd\ln Lb + \delta_{FtFg}\ln Ft\ln Fg + \delta_{FtLb}\ln Ft\ln Lb + \delta_{FgLb}\ln Fg\ln Lb + e$$

$$(4.4) \quad \ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + \delta_{LbLb}\ln Lb\ln Lb + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FdLb}\ln Fd\ln Lb + \delta_{FtFg}\ln Ft\ln Fg + \delta_{FtLb}\ln Ft\ln Lb + \delta_{FgLb}\ln Fg\ln Lb + d_1E1 + d_2E2 + d_3M1 + d_4W1 + d_5W2 + d_6T1 + e$$

where:

α is the constant

β_i is the parameter for input X_i; i = Fd, Ft, Fg, and Lb

δ_{ij} is the parameter for input X_i and input X_j; i and j = Fd, Ft, Fg, and Lb

d_i is the parameter for each dummy variable

e is the error term

Equations (4.1) and (4.2) for the Cobb-Douglas functional form can be written in logarithmic form as follows:

(4.5) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + e$$

(4.6) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + d_1E1 + d_2E2 + d_3M1 + d_4W1 + d_5W2 + d_6T1 + e$$

where: α is the constant

β_i is the parameter for input X_i; i = Fd, Ft, Fg, and Lb

d_i is the parameter for each dummy variable

e is the error term

4.5 Data Constraints

Poor pricing data imposed several constraints on this study. Although pricing data were assembled as part of the primary data collection process, further information and analysis strongly suggest significant measurement error. Unfortunately, lack of time and other resources prevented the collection of new data. This section describes: (i) the nature of the measurement error; (ii) how the data constrain the estimation of some parameters that would otherwise be of empirical interest; and (iii) how the data constrain the econometric approach to assuming exogenous input quantities.

Measurement error is significant enough in fingerling and manure prices to warrant exclusion of this data from the study. Data were collected regarding how much each farmer paid for these inputs, but appropriate inquiries regarding the transportation and opportunity costs incurred to bring these inputs to each pond were not made during the data collection process. Subsequent discussion with extensionists indicated that in several cases, the actual purchase price of manure or fingerlings was a small percentage of the actual cash and non-cash cost of adding one more unit of either input. The spatial prices of these inputs vary significantly and are a function of distance and, in the case of fingerlings, the quantity purchased (transportation can be treated as a fixed cost regardless of whether fingerlings are purchased to stock a $10m^2$ pond or a $100m^2$ pond). Little correlation exists between the purchase price of each fingerling and the cost that each farmer must incur per unit of input applied to the pond.

(i) Fingerlings.

The mean fingerling price observed was 30 centavos (100 centavos = 1 Lempira; 1995 average exchange rate of 9.59 Lempiras = US $1.00; source: Central Bank of Honduras). Interviews with extensionists, however, revealed that in at least one extreme case, the price per fingerling to stock a $100m^2$ pond was approximately 2.00 Lempiras or six times greater than the price charged at the hatchery. That farmer's pond was located approximately eight hours by bus and foot from the nearest hatchery. Table 4.1 estimates average spatial fingerling costs based on interviews with extensionists and is presented to feature the components and magnitude of spatial fingerling prices.

Fingerlings are extremely perishable and are shipped in plastic bags filled with water with enough dissolved oxygen that complete mortality is a serious threat after eight hours by conventional transport. Pickup trucks are often hired at a significant increase in cost (320 Lempiras for the previous example). The fixed cost of the transportation plus the cash cost of the fingerlings (0.30 centavos x 200 fingerlings = 60 Lempiras) divided by the number of fingerlings purchased (200) resulted in a total cost of 1.98 Lempiras per fingerling as opposed to the 30 centavo purchase price at the hatchery. Discussions with extensionists suggested that normal variability in actual fingerling costs versus the purchase price at the hatchery ranged from 1.5 to 3 times greater than the hatchery price. In consideration of this magnitude, along with the microeconomic theory which identifies that it is the spatial price of fingerlings at each pond that affects the farmer's production decisions as an economic agent, the collected data were not included in the analysis.

Table 4.1: Estimated spatial vs. nominal fingerling prices

Variable affecting spatial prices (1995 Lempiras)	Distance in hours from pond to hatchery				
	zero	Two	Four	six	eight*
Nominal price per fingerling	0.30	0.30	0.30	0.30	0.30
Number of live fingerlings required in pond	200	200	200	200	200
Mortality in transit (%)	0	10	25	55	20
Number of fingerlings required at hatchery	200	222	267	444	250
Total cash costs at hatchery	60.00	66.67	80.00	133.33	75.00
Cash transportation cost	0.00	9.00	21.00	30.00	320.00
Opportunity cost of time in transit	0.00	10.00	25.00	50.00	0.00
Total transportation costs	0.00	19.00	46.00	80.00	320.00
Spatial Price per live fingerling in pond	0.30	0.43	0.63	1.07	1.98

* After eight hours in transport, oxygen levels are very poor and complete mortality is likely. Farmers whose ponds are located eight hours from the nearest hatchery by normal means of transportation (i.e. a combination of bus, mule and foot) hire pick-up trucks. The figures shown for the eight hour location represent the costs of this option.

(ii) Manure.

The costs associated with getting manure to the pond for fertilization can vary from farm to farm. During the data collection process, the mean price per 100 pound quantity of manure was 2.00 Lempiras. Because of problems similar to the fingerling price problem described above, no data was collected on the spatial cost of manure faced by each farmer. Wide variability is suggested by the range of distances from each pond to the closest source of manure, which ranged from on-farm to 5 kilometers. Input quantities of manure for a 100m^2 pond ranged from 160 and 320 pounds per cycle, so the labour involved is substantial. Little correlation is expected between each farmer's purchase and spatial prices for manure because the costs of transporting the manure relative to the cost of the manure itself, which is virtually free even to a small farmer, can be several times the manure purchase price. Again, the recorded data are inaccurate and were judged to warrant exclusion from the study.

Table 4.2: Estimated spatial vs. nominal manure prices

Variable affecting spatial price (1995 Lempiras)	Distance from pond to manure source			
	0 km	0.5 km	2 km	5 km
Price/opportunity cost of manure (Lempiras/100lbs)	2.0	2.0	2.0	2.0
Number of hours required to pick up and deliver one hundred pounds of manure	0.0	1.6	2.6	4.6
Opportunity cost of labour (Lempiras/hour)	2.5	2.5	2.5	2.5
Total labour costs (Lempiras/100lbs)	0.0	4.0	6.5	11.5
Spatial price of manure (Lempiras/100lbs)	2.0	6.0	8.5	13.5

The consequences of these measurement errors are twofold. First, the data set is such that fewer parameters of empirical interest can be estimated. The cost function yields a set of parameters of interest to the research problem, providing answers to such questions as "What happens to the quantities of other inputs used in the production process if the cost of fingerlings rises?" and "What happens to input utilization if output increases?" The cost function approach is also desirable because it estimates the parameters of empirical interest related to the production function. As Doll (1984) notes, cost functions and production functions are by nature inversely related to each other, and knowledge of one implies knowledge of the other—providing input prices are known. The specific benefits of a cost function approach are discussed in chapter six, which recommends areas for further research.

The second set of consequences is the limitation of econometric techniques. A restrictive assumption of OLS is that observations on the explanatory variables are considered fixed in repeated samples (Kennedy, 1989; Kmenta, 1986). In the context of a production function, this requires the assumption that input quantities are exogenous, output is endogenous, and a unidirectional effect exists between inputs and output. However, a strong case can be made that input quantities are endogenous of input prices and expected yield. The ambiguity between exactly which variables are exogenous and which are endogenous implies a role for a simultaneous equations model which does not require restrictive *a priori* assumptions on exogenous versus endogenous variables. In the context of this analysis, two-stage least squares (2SLS) would be preferable to OLS because it provides this flexibility.

If the relationship between inputs and output for a given production technology is not unidirectional, OLS is not appropriate because one or more of X_i may be correlated with μ. Suppose that the quantity of a certain input (X_1) chosen by a farmer is a function of expected yield and input prices. If the disturbance term causes yield to temporarily decrease, that farmer may choose to decrease X_1. In such a case, μ and X_i are correlated. Here, 2SLS provides a proxy for X_1 which is uncorrelated with μ. In the first stage, X_1 is regressed on expected yield (actual yield may be used as a proxy) and prices of all inputs. The regression equation is then used to derive a vector of expected X_1 which is uncorrelated with μ. The second stage of 2SLS is estimation of the original equation with the use of the modified and uncorrelated X_i.

CHAPTER FIVE: RESULTS

5.1 Introduction

This chapter describes the econometric results of the models specified in chapter four. Results of statistical discrimination between the translog and Cobb-Douglas functional forms is also presented. The practical implications of the econometric results presented in this chapter are discussed at length in Chapter six.

5.2 Cobb-Douglas Model

The Cobb-Douglas production function written in logarithmic form is:

(5.1) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + e$$

Including the dummy variables discussed in chapter four, the function expands to:

(5.2) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + d_1E1 + d_2E2 + d_3M1 + d_4W1 + d_5W2 + d_6T1 + e$$

where:

α is the constant

β_i is the parameter for input X_i; i = Fd, Ft, Fg, and Lb

d_i is the parameter for each dummy variable

e is the error term

and where:	Fd	=	Feed
	Ft	=	Fertilizer
	Fg	=	Fingerlings
	Lb	=	Labour
	E1	=	Dummy for medium elevation region
	E2	=	Dummy for high elevation region
	M1	=	Dummy for production technique
	W1	=	Dummy for medium pond management skill
	W2	=	Dummy for high pond management skill
	T1	=	Dummy for susceptibility to theft

Estimation of equation 5.1 suggested that output was significantly influenced by feed, fertilizer and fingerlings. Labour was not statistically significant at the 95% level. The adjusted R^2 was 0.48. Output from (5.1) and subsequent Cobb-Douglas equations are presented in table 5.1.

The six dummy variables representing elevation, production technique, pond management skill and susceptibility to theft were then added to the model (equation 5.2). The inputs feed and fertilizer were statistically significant as were the dummy variables for pond management skill and susceptibility to theft. Labour, fingerlings and the dummy variables for elevation and production technique were not statistically significant. The adjusted R^2 increased to 0.76.

The variable for labour and the dummy variables for elevation and production technique were then dropped. The coefficient for labour had a negative sign in (5.1) and (5.2), and E1, E2, and M1 were not significant. A joint hypothesis test was conducted for the null hypothesis that $\beta_{Lb} = d_1 = d_2 = d_3 = 0$. This hypothesis was accepted at the 95% level (calculated F-value 1.09 < $F_{95\%, 4,14\ d.f.}$ = 3.11). The model was respecified as:

$$(5.3) \qquad \ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + d_1W1 + d_2W2 + d_3T1 + e$$

The R^2 of equation (5.3) was 0.76. All variables were statistically significant at the 95% level except the dummy variable representing susceptibility to theft. T1 was then dropped and the model was respecified as:

$$(5.4) \qquad \ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + d_1W1 + d_2W2 + e$$

Estimation of equation (5.4) resulted in statistical significance for each input and both dummy variables with an adjusted R^2 of 0.74 The final Cobb-Douglas production function is estimated as:

$$(5.5) \qquad \ln Yd = -1.460 + 0.162\ln Fd + 0.275\ln Ft + 0.367\ln Fg + 0.719W1 + 0.539W2 + e$$

Table 5.1: Cobb-Douglas production function

Variables	Equation (5.1)	Equation (5.2)	Equation (5.3)	Equation (5.4)
Constant	*-0.989	**-1.834	**-1.386	**-1.460
β_{Fd}lnFd	*0.165	**0.190	**0.138	**0.162
β_{Ft}lnFt	**0.264	**0.314	**0.254	**0.275
β_{Fg}lnFg	*0.488	0.269	**0.354	*0.367
β_{Lb}lnLb	0.035	*-0.179	-	-
D_1E1	-	-0.048	-	-
d_2E2	-	-0.223	-	-
d_3M1	-	0.095	-	-
d_4W1	-	*0.817	**0.699	**0.719
d_5W2	-	**0.704	*0.632	**0.539
d_6T1	-	*-0.387	-0.256	-
R^2 (adj.)	0.481	0.762	0.757	0.740
SSE	3.646	1.178	1.538	1.731
d.f.	20	14	18	19

* indicates significance at the 95% level

** indicates significance at the 99% level

5.3 Translog Model

The translog production function specified in chapter four is as follows:

(5.6)

$$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + \delta_{LbLb}\ln Lb\ln Lb + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FdLb}\ln Fd\ln Lb + \delta_{FtFg}\ln Ft\ln Fg + \delta_{FtLb}\ln Ft\ln Lb + \delta_{FgLb}\ln Fg\ln Lb + e$$

Including the dummy variables discussed in section 4.3, the function expands to:

(5.7) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + \delta_{LbLb}\ln Lb\ln Lb + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FdLb}\ln Fd\ln Lb + \delta_{FtFg}\ln Ft\ln Fg + \delta_{FtLb}\ln Ft\ln Lb + \delta_{FgLb}\ln Fg\ln Lb + d_1E1 + d_2E2 + d_3M1 + d_4W1 + d_5W2 + d_6T1 + e$$

where: α is the constant

β_i is the parameter for input X_i; i = Fd, Ft, Fg, and Lb

δ_{ij} is the parameter for input X_i and input X_j; i and j = Fd, Ft, Fg, and Lb

d_i is the parameter for each dummy variable

e is the error term

The translog model was estimated including four input variables as specified in equation (5.7). All coefficients, including the intercept, were statistically insignificant and the adjusted R^2 was 0.64. The model was respecified by including all dummy variables as shown in equation (5.8). Results from these and other translog equations are summarized in tables 5.2 and 5.3.

Equation (5.8) was estimated and all coefficients remained insignificant. The adjusted R^2 was 0.65. A joint hypothesis test was then conducted for the null hypothesis $d_1 = d_2 = d_3 = 0$. These three coefficients were tested because they were found to be insignificant in the first specifications of the Cobb-Douglas production function. The null hypothesis was not rejected (calculated F-value $0.329 < F_{95\%,\ 3,4\ d.f.} = 6.59$). The model was respecified as:

$$(5.8) \qquad \ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + \delta_{LbLb}\ln Lb\ln Lb + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FdLb}\ln Fd\ln Lb + \delta_{FtFg}\ln Ft\ln Fg + \delta_{FtLb}\ln Ft\ln Lb + \delta_{FgLb}\ln Fg\ln Lb + d_1W1 + d_2W2 + d_3T1 + e$$

Estimation of equation (5.9) improved the adjusted R^2 to 0.745. Only the dummy variable W1 was statistically significant. The joint hypothesis test applied to equation (5.8) was expanded to include the variables for labour and susceptibility to theft. This was done because the t-ratios for these two variables in (5.9) were insignificant and because the labour and theft were also dropped from the Cobb-Douglas model. The hypothesis that ($\beta_{Lb} = d_1 = d_2 = d_3 = d_4 = 0$) was not rejected (calculated F-value $0.347 < F_{95\%,\ 5,\ 4\ d.f.} = 6.26$). The model was respecified as:

$$(5.9) \qquad \ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FtFg}\ln Ft\ln Fg + d_1W1 + d_2W2 + e$$

Estimation of equation (5.10) suggested that only feed and the dummy variables for pond management skill were statistically significant at the 95% level. Three hypotheses were then tested: first, that all second order own coefficients were equal to zero ($\delta_{FdFg} = \delta_{FdFt} = \delta_{FtFg} = 0$); second, that all second order cross-coefficients were zero ($\delta_{FdFd} = \delta_{FtFt} = \delta_{FgFg} = 0$); third, that the translog model can be reduced to a Cobb-Douglas production function with the corresponding hypothesis that all second order cross-coefficients and own coefficients were equal to zero ($\delta_{FdFg} = \delta_{FdFt} = \delta_{FtFg} = \delta_{FdFd} = \delta_{FtFt} = \delta_{FgFg} = 0$). These hypotheses imply the following three restricted models:

(5.10) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + d_1W1 + d_2W2 + e$$

(5.11) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FtFg}\ln Ft\ln Fg + d_1W1 + d_2W2 + e$$

(5.12) $$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + d_1W1 + d_2W2 + e$$

F-tests were used to decide whether to reject or accept any of these joint hypotheses. The first hypothesis (equation 5.10) was not rejected (rejected (calculated F-value 0.322 < $F_{95\%,\ 3,\ 13\ d.f.}$ = 3.41). Similarly, the second hypothesis that the second order cross-coefficients were equal to zero (equation 5.11) was not rejected (calculated F-value 1.57 < $F_{95\%, 3, 13 \text{ d.f.}}$ = 3.41). Finally, the hypothesis that the cross-coefficients and the own coefficients equal zero (equation 5.13) was also not rejected (calculated F-value 1.72 < $F_{95\%, 6, 13 \text{ d.f.}}$ = 2.92). Equations (5.10) to (5.12) were estimated in order to examine t-statistics for the second order coefficients. Results of these estimations are presented in table 5.3.

These results find that the second order cross-coefficients and own coefficients are not significantly different from zero. The translog production function (5.9) therefore reduces to a Cobb-Douglas form (5.12). Note that equation (5.12) is identical to the final estimated Cobb-Douglas equation (5.5). The final estimation of the production function is:

(5.12; 5.5) $$\ln Yd = -1.460 + 0.162\ln Fd + 0.275\ln Ft + 0.367\ln Fg + 0.719W1 + 0.539W2 + e$$

Table 5.2: Translog production function (equations 5.6 to 5.9)

Variables	Equation (5.6)	Equation (5.7)	Equation (5.8)	Equation (5.9)
Constant	-1.315	-2.510	-2.208	**-1.540
$\beta_{Fd}lnFd$	0.551	-0.097	-0.197	0.467
$\beta_{Ft}lnFt$	0.576	0.686	1.153	*0.278
$\beta_{Fg}lnFg$	-0.595	-1.044	-1.932	0.306
$\beta_{Lb}lnLb$	0.197	-0.549	-0.455	-
$\delta_{FdFd}lnFdlnFd$	0.011	0.048	0.015	0.015
$\delta_{FtFt}lnFtlnFt$	0.185	0.180	0.179	0.082
$\delta_{FgFg}lnFglnFg$	0.439	0.653	0.640	0.155
$\delta_{LbLb}lnLblnLb$	0.040	-0.705	-0.088	-
$\delta_{FdFg}lnFdlnFg$	-0.237	-0.033	-0.144	-0.001
$\delta_{FdFt}lnFdlnFt$	0.310	0.793	1.047	-0.161
$\delta_{FtFg}lnFtlnFg$	-0.216	-0.430	-0.514	-0.146
$\delta_{FtLb}lnFtlnLb$	0.134	0.116	0.259	-
$\delta_{FgLb}lnFglnLb$	-0.295	-0.377	-0.722	-
$\delta_{FdLb}lnFdlnLb$	0.085	0.084	0.107	-
d_1E2	-	-0.157	-	-
d_2E2	-	-0.324	-	-
d_3M1	-	0.133	-	-
d_4W1	-	0.604	*0.708	*0.367
d_5W2	-	0.608	0.389	**0.458
d_6T1	-	-0.422	-0.308	-
R^2 (adj.)	0.649	0.647	0.748	0.788
SSE	1.234	0.496	0.618	0.966
d.f.	10	4	7	13

* indicates significance at the 95% level

** indicates significance at the 99% level

Table 5.3: Translog production function (equations 5.9 to 5.12)

Variables	Equation (5.9)	Equation (5.10)	Equation (5.11)	Equation (5.12)
Constant	**-1.540	**-1.507	**-1.434	**-1.460
$\beta_{Fd}\ln Fd$	0.467	**0.243	**0.720	**0.162
$\beta_{Ft}\ln Ft$	*0.278	0.162	*0.259	**0.275
$\beta_{Fg}\ln Fg$	0.306	*0.610	0.249	*0.367
$\beta_{Lb}\ln Lb$	-	-	-	-
$\delta_{FdFd}\ln Fd\ln Fd$	0.015	0.037	-	-
$\delta_{FtFt}\ln Ft\ln Ft$	0.082	0.043	-	-
$\delta_{FgFg}\ln Fg\ln Fg$	0.155	-0.169	-	-
$\delta_{LbLb}\ln Lb\ln Lb$	-	-	-	-
$\delta_{FdFg}\ln Fd\ln Fg$	-0.001	-	-0.255	-
$\delta_{FdFt}\ln Fd\ln Ft$	-0.161	-	**-0.188	-
$\delta_{FtFg}\ln Ft\ln Fg$	-0.146	-	0.092	-
$\delta_{FtLb}\ln Ft\ln Lb$	-	-	-	-
$\delta_{FgLb}\ln Fg\ln Lb$	-	-	-	-
$\delta_{FdLb}\ln Fd\ln Lb$	-	-	-	-
d_1E2	-	-	-	-
d_2E2	-	-	-	-
d_3M1	-	-	-	-
d_4W1	*0.367	*0.449	*0.417	**0.719
d_5W2	**0.458	**0.480	**0.489	**0.539
d_6T1	-	-	-	-
R^2 (adj.)	0.788	0.766	0.816	0.740
SSE	0.966	1.318	1.038	1.731
d.f.	13	16	16	19

* indicates significance at the 95% level

** indicates significance at the 99% level

From equation (5.12), the factor elasticities were derived from the formula $E_i = \beta_i$. The factor elasticities are:

(5.13) $$E_{Fd} = \beta_{Fd} = 0.162$$

$$E_{Ft} = \beta_{Ft} = 0.275$$

$$E_{Fg} = \beta_{Fg} = 0.367$$

From the formula $\epsilon = \sum E_i$, the elasticity of scale (ϵ) equals 0.805. Since data were normalized for pond size (section 4.2.2), this figure must be interpreted as a point estimate for returns to scale while holding pond size constant. Confidence intervals for the factor elasticities and the elasticity of scale were constructed and are listed below.

Table 5.4: Confidence Intervals for βi and ϵ

Coefficient	Estimated value	95% Confidence Interval	
		Lower limit	Upper limit
β_{Fd}	0.1621	0.0773	0.2469
β_{Ft}	0.2752	0.1508	0.3996
β_{Fg}	0.3674	0.0572	0.6777
ϵ	0.8048	0.4508	1.1588

An equation was then specified to test the sensitivity of regression results to the Cobb-Douglas assumption of constant returns to scale. Interaction terms were added for the dummy variables for management skill as specified in equation (5.14).

$$(5.14) \quad \ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + d_1W1 + d_2W2 + Z_1\ln Fd{*}W1 + Z_2\ln Ft{*}W1 + Z_3\ln Fg{*}W1 + Z_4\ln Fd{*}W2 + Z_5\ln Ft{*}W2 + Z_6\ln Fg{*}W2 + e$$

$Z_{1..6}$ are the interaction terms which remove the restriction otherwise present in equations (5.1) to (5.13) that dummy variables are free to affect the intercept but not the slope of the regression equation. The null hypothesis that returns to scale are constant and do vary across levels of pond management skill was accepted (calculated F-value for $Z_{1..6} = 0$ hypothesis test = 2.79 < $F_{95\%, 6, 13 \text{ d.f.}}$ = 2.92). The final regression equation (5.5) remains unchanged.

An elasticity of scale of less than one implies that the Cobb-Douglas production function exhibits decreasing returns to scale. The confidence interval of ϵ, however, is such that the hypotheses that $\epsilon = 1$ or $\epsilon > 1$ also cannot be rejected. In this analysis, no theory or anecdotal evidence was found that would favour one *a priori* hypothesis over another. Since there is no evidence to reject any of three individual hypotheses (increasing, constant or decreasing returns to scale), no conclusions in this regard can be drawn from the empirical evidence.

CHAPTER SIX: Conclusions and Recommendations for Further Research

6.1 Introduction

The previous chapter presented the detailed econometric results of the estimated production function. The first part of this chapter elaborates on the significance of those results and draws conclusions with respect to policy implications. The second part of this chapter identifies areas for further research based on: (i) the quantitative results of this study; (ii) the literature review of this thesis, which found other areas of quantitative research lacking; and (iii) other relevant research needs identified through interviews with extensionists, aquaculture biologists and other development professionals. Finally, food security among small-scale farmers in the context of this analysis is discussed.

6.2 Significance and Interpretation of Results

As noted in chapter four, the parameters of empirical interest to this analysis were:

i. the factor elasticities of the inputs determined to be significant to the production process.
ii. the coefficients of the dummy variables added to the model.
iii. whether fish production is characterized by increasing, decreasing or constant returns to scale

The significance and policy implications of each of these items is discussed at length in the next three sections.

6.2.1 Factor Elasticities

It is of interest to extensionists which inputs are significant to the production process, and, of those inputs, which have a greater per-unit effect on total production relative to the other inputs. The inputs specified in the production function in initial regressions were feed, fertilizer, fingerlings, labour and pond size. Econometric estimation indicated that the effects of pond size and labour on fish production were not statistically significant at the 95% confidence level. This implies that extensionists should focus on inputs other than pond size and labour when suggesting strategies for production increases.

Final regression results indicated that feed, fertilizer and the fingerling stocking rate were significant inputs to fish production. The factor elasticities of these inputs were 0.16, 0.28 and 0.37. These are unit-free measurements which do not vary as input levels change and which indicate that a 10% increase in feed, fertilizer or fingerlings increases fish production by 1.6%, 2.8% and 3.7%, respectively. Extensionists may wish to use this information to assist in improving yields where inefficient production is suspected.

Of the three inputs determined to affect fish production, the significance and factor elasticity of the fingerling stocking rate has considerable policy implications given the public sector ownership of hatcheries in Honduras and the high spatial cost component of fingerlings discussed in chapter four. Section 4.5 described the perishability of fingerlings and noted the logistical difficulties and costs associated with moving fingerlings from hatchery to farm. To summarize, it was observed that the actual purchase price of fingerlings comprises only one-sixth or less of the on-farm spatial price where a hatchery is located eight hours or more by conventional transport from the pond.

Subject to certain assumptions regarding the matrix of input demands for fish production (a cost function is recommended for further research in section 6.3), fishponds are presumed to have a higher cost per unit of output as their proximity to a source of fingerlings decreases[1]. This implies higher returns to expenditures on extension in regions within close proximity of hatcheries. Therefore, this analysis recommends that policy be shaped to either concentrate extension efforts within close proximity of hatcheries or that hatcheries themselves should be geographically dispersed. The latter recommendation implies a research need for determination of the elasticity of scale for fingerling production in Honduras. This is discussed further in section 6.3.

6.2.2 Dummy Variables

Dummy variables were added to the production function in order to determine the sensitivity, if any, of fish production to qualitative factors. Dummy variables consisted of pond management skill, elevation, method of production, and susceptibility to theft. Pond management skill was found to have a statistically significant effect on fish production. Production technique, elevation and

[1] Assuming the input demand elasticity for fingerlings is not perfectly inelastic, input utilization and yields increase with proximity to hatcheries.

susceptibility to theft were found not to affect fish production. These results have significant policy implications.

The significance of the effect of pond management skill on fish production confirms initial suspicions that the manner in which feed and fertilizer used is of similar importance to the quantities of these inputs used. The coefficients for medium and high levels of pond management skill were 0.72 and 0.54, respectively. Expected average yield implied by the estimated production function (equation 5.13) was derived using sample means of input quantities and assuming a low level of management skill. Expected average yield with this restriction was 0.44 pounds per square meter. Under restrictions of medium and high levels of pond management skill, expected average yield increased to 0.90 and 0.75 pounds per square meter, respectively.

The sensitivity of fish production to these techniques is presumed to be attributable to two main factors which are captured in the dummy variable for pond management skill. First, some farmers appear to doubt the closed system's ability to provide the fish with oxygen, and so they continue to exchange water. Water exchange is usually done by constantly adding water to the pond on one side and digging a channel for overflow on the other. This causes fertilizer loss which impedes the development of adequate algal blooms which supplement feed. Water exchange in what should be a closed system also drains the pond of feedstuffs that float (termites, floating pellets, leaves). Second, many farmers lack the knowledge that feeds must be added to the pond in small quantities at frequent intervals (twice to three times per day). If the feeds added to the pond are not quickly consumed by the fish (within approximately 15 minutes) a process of microbial decomposition begins. Given that bacterial decomposition depletes the pond of dissolved oxygen and can create other toxicity problems, fish growth becomes constrained by poor water quality as well as lower utilization of supplemental feeds added to the pond.

The results of this study suggest that these yields increase significantly for farmers who understand these concepts. Since approximately one-third of the farmers interviewed in this analysis were observed to have a low level of pond management skill (see section 4.3 for definition), these results imply that extensionists must redouble efforts to improve pond management skill among farmers. While education regarding these techniques has obviously been a goal of previous extension efforts, the contribution of this analysis of quantifying the sensitivity of pond management skill on fish production warrants re-evaluation of the effectiveness of extension efforts in this regard. This is discussed further as a recommendation for further research in section 6.3.

Significant policy implications also arise from the regression results for the production method dummy variable. As discussed in section 4.2.2, two production techniques were used by small-scale farmers and a dummy variable was included to capture the effect on fish yield of sex-reversed versus mixed-sex production methods. No statistically significant effect on yield was found between the two techniques. This is an important result, since no difference exists between the two production methods other than the type and cost of fingerling used. Mixed-sex fingerlings from natural pond reproduction are virtually free relative to sex-reversed male fingerlings. Mixed sex fingerlings appear to have an extremely low opportunity cost because they are edible but not desirable for human consumption given their small size (3-5 cm.). In contrast, sex-reversed male fingerlings must be purchased from a hatchery and transported to the pond. Mixed sex technology, therefore, should prove to be a higher return investment for farmers[1]. This implies that extension efforts should focus on disseminating mixed-sex production methods (see section 6.3 on recommendations for further research).

6.2.3 Returns to Scale

The elasticity of scale of the technology is of intrinsic interest given its implications for potential changes to the targeted size of future production units. This analysis indicates that the fish production function representing small-scale aquaculture in Honduras is homogeneous of degree 0.805, indicating decreasing returns to scale. However, a confidence interval constructed at the 95% level of significance suggested that constant or increasing returns to scale could also be present. In strict terms, therefore, the empirical evidence in this analysis is inconclusive with respect to elasticity of scale.

6.3 Recommendations for Further Research

(i) Cost function

As noted in chapter four, poor pricing data constrained the number of parameters of empirical interest that this analysis was able to estimate. A cost function would provide a number of interesting parameters including a matrix of

---

[1] Assuming certain properties of the matrix of derived demand elasticities for inputs, and assuming that the marginal utility per pound of fish is equal across a realistic range of large versus small fish sizes.

derived input demand elasticities. However, the empirical evidence presented in this analysis implies that the central question to be asked of a cost function is "what would be the expected change in yield from changes in public policy which reduces effective fingerling prices to small-scale farmers?". The estimated factor elasticity of fingerlings showed that production is quite sensitive to changes in the stocking rate, and dummy variable coefficients suggested no yield difference between production methods using low cost versus high cost fingerlings. It is argued that effective fingerling prices for small-scale farmers can be reduced through public policy, since the public sector helps determine (i) the proportion of extension efforts which focus on lower-cost, mixed-sex technology versus sex-reversed male technology; and (ii) the proportion of sex-reversed male technology extension that is concentrated in regions of the country where spatial fingerling prices are low versus regions where spatial prices are high. To summarize, the empirical evidence of this analysis indicates the direction of yield changes in response to lower fingerling prices, but cannot quantify the magnitude of this change. Estimation of a cost function would fill this gap.

(ii) Production function for hatcheries

The issue of spatial fingerling prices implies a second area for further research. While a central conclusion of this analysis is that mixed sex reproduction should be recommended to farmers, it is recognized that the dissemination of sex-reversed technology may be unlikely to change quickly given the slow pace of institutional change and the Honduran public ownership of hatcheries. Blenker and

Thompson (1992) appear to concur, noting that non-promotion of mixed-sex technology may lie in the Honduran government's wish to justify the existence of and avoid competition toward public sector hatcheries.

This analysis indicates that if sex-reversed male technology continues to be promoted by the Honduran public sector, extension efforts should at least be targeted toward regions in reasonable proximity of hatcheries. Assuming future budgetary outlays for public investment in hatcheries, it may be desirable to build a larger number of small, geographically dispersed hatcheries as opposed to a smaller number of larger-sized facilities. Whether this would be an appropriate strategy depends in part on whether fingerling production exhibits increasing, decreasing or constant returns to scale. This implies a role for estimation of a production function for seed fish production in Honduran hatcheries.

(iii) Analysis of extension practices

This analysis has concluded that fish production is highly sensitive to pond management skill. Given that pond management skill was observed to be poor for approximately one-third of small-scale farmers, a role for improved extension practices is recommended. While poor pond management skill is obviously a function of a number of factors other than extension, there is anecdotal evidence that fish production is even more sensitive to poor extension than implied by the empirical evidence in this analysis. As noted in chapters one and four, primary data collected excluded the substantial number of inactive ponds encountered. If pond abandonment is a function of inadequate management skill, then this analysis understates the effect of management skill—and perhaps extension practices—on fish production.

There is anecdotal evidence that abandoned ponds can be attributed to poor extension. A central problem appears to have been that farmers were ill-advised on where to excavate ponds. As a labour-saving technique, many abandoned ponds were dug from existing depressions in land which were natural seasonal drainage routes. Most land plots held by small-scale farmers were located on inclines which resulted in rapid seasonal flows of water. Interviews suggested that many ponds were abandoned after consecutive populations of fish were swept away with annual seasonal rains. In addition, some ponds were dug in sandy soil with poor water-holding ability. Finally, in some cases, ponds were dug downhill from the family *pila*, an outdoor sink where detergents are used for laundry and kitchen duties. Pond contamination by detergents can easily result in complete mortality of fish populations in the closed-system ponds used by small farmers. Qualitative study of these and other site selection problems would be useful in order to establish whether extension practices are at fault, and, if so, what changes need to be made.

(iv) Measurement of return on investment

A much-needed area for further research with respect to small-scale aquaculture is the enterprise's return on investment from the perspective of small farmers. Existing studies which quantify returns either do so on the basis of commercial tilapia production or using yields based on research trials which are unrealistic relative to yields observed during the course of this analysis. A preliminary assessment of return on investment based on the production function estimated in this analysis is provided in appendix three, where internal rates of return were estimated to range from zero to 46%. In addition, it would be useful to assess returns to aquaculture not in isolation but when the enterprise is added to typical small-scale farming systems in Honduras. Failing to do so risks improperly valued opportunity costs of land, labour and other resources. This study recommends farm investment analysis or a similar methodology which captures aquaculture's return on investment when all opportunity costs are properly valued, i.e., the analysis fully incorporates the costs associated with fewer inputs being available for other enterprises present in small-scale farming systems.

(v) Comparison of returns to extension of aquaculture vs. other technologies

Finally, qualitative studies on small-scale aquaculture in Honduras have taken for granted that aquaculture should be a component of broader extension efforts targeted toward rural development. Aquaculture may well be a positive investment, but is it better than other alternatives? If it is, then how do the returns to extension in aquaculture compare to extension of more conventional technology? What if the technology transfer for aquaculture is so complex that it requires a 1:10 extensionist/farmer ratio as opposed to 1:100 for a slightly less profitable technology? Anecdotal evidence suggests that these are relevant questions. Researchers need to examine the full range of opportunity costs associated with promoting the enterprise.

6.4 Food Security

The data and quantitative results of this analysis facilitate a crude estimate of the food security impacts of small-scale tilapia ponds in rural Honduras. In chapter two, it was estimated that 1900 small-scale ponds were operating by the early 1990s. Assuming that each pond-owning household held only one pond and that 50% were abandoned, 950 rural households are estimated to operate fishponds. The mean pond size and yield observed in this analysis were 178 square meters and 0.78 (s.d. = 0.36) pounds per square meter per cycle (approximately one year). Based on these figures, 950 households (less than one per cent of rural Hondurans) netted food security benefits of 11.5 pounds of fish per month per household.

6.5 Summary of Policy Implications and Recommendations

This analysis collected primary data to estimate a production function for tilapia fish production by small-scale farmers in Honduras. Factor elasticities and returns to scale were estimated, as were coefficients for various qualitative factors captured by dummy variables. The results of this analysis have implications for policy regarding private and public extension efforts and research. These are summarized as follows:

i. A key role for further research is assessing return on investment for fish production from the perspective of small farmers. Existing studies have not met this need, and the literature suggests serious problems with respect to the enterprise's profitability. Although the internal rates of return estimated in appendix three suggest that returns can be positive, these figures require further investigation in light of the data constraints highlighted in this report concerning spatial manure and fingerling prices. Research is also required to assess whether returns to extension of aquaculture is the best use of scarce development and public sector resources.

ii. Extension efforts to improve yield should focus on inputs of feed, fertilizer and seed fish, which were found to be statistically significant inputs to fish production. Labour and pond size were not statistically significant inputs.

iii. Quantitative analysis in this study found fish production to be extremely sensitive to pond management skill. It is recommended that extension practices be adjusted accordingly. Anecdotal evidence also exists that abandoned ponds are attributable in part to poor technical advice. Pond abandonment is a significant problem in Honduras and requires research to determine what changes, if any, are warranted for the type and quality of extension.

iv. Empirical evidence provided a point estimate indicating decreasing returns to scale (ϵ = 0.805). However, upper and lower bounds of this estimate at the 95% level of significance suggested that constant or increasing returns to scale could also be present. In strict terms, therefore, econometric estimation of returns to scale for fish production must be considered inconclusive.

v. No statistical evidence was found that lower-cost, mixed-sex fish production yielded less than sex-reversed male production. Since the two technologies' production processes are identical aside from the sex of seed fish used, mixed-sex production is capable of producing the same output at a lower cost[1]. Extension practices should be adjusted accordingly. A limitation of this result is this study's inability to quantify predicted cost savings and increases in yield and input utilization. Estimation of a cost function is recommended in order to quantify these effects.

vi. Where sex-reversed male production continues to be promoted due to institutional interests, high spatial prices of fingerlings suggests that extension efforts should be concentrated on farms in close proximity to hatcheries. This study concludes that such a strategy would, assuming all other variables remain unchanged, result in lower costs and higher yields. Again, this study is able to identify the direction but not the magnitude of these changes. Further research of spatial prices and estimation of a cost function are required to quantify these outcomes. There is a further role for research in determining returns to scale for fingerling production in order to help identify whether it would be desirable to target potential increases in public sector fingerling production toward smaller, more geographically dispersed facilities.

---

[1] Assuming that input demand for fingerlings is not perfectly inelastic.

REFERENCES

Beattie, B.R., and C.R. Taylor. 1985. The Economics of Production. New York: John Wiley & Sons Inc.

Blenker, R.L., and G.L. Thompson. 1991 (unpublished). Fishculture Project Plan 1991-1998. Peace Corps, Honduras.

Castillo, S., T.J. Popma, R.P. Phelps, L.U. Hatch and T.R. Hanson. 1992. Family-Scale Fish Farming in Guatemala. Research and Development Series No. 37. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama.

Central Bank of Honduras. 2000. Precio promedio de venta del dolar en al sistema financiero serie mensual, 1992-1999. www.bch.hn/paginas/frameset.htm

Chambers, R.G. 1988. Applied Production Analysis: A dual approach. Cambridge: Cambridge University Press.

Doll, J.P., F. Orazem. 1984. Production Economics: Theory with Applications, 2nd ed. New York: John Wiley & Sons Inc.

Green, B.W., D.R. Teichert-Coddington and T.R. Hanson. 1993. Development of Semi-Intensive Technologies in Honduras: Summary of Freshwater Aquacultural Research Conducted from 1983 to 1992. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama.

Gujarati, D.N. 1988. Basic Econometrics, 2nd ed. New York: McGraw-Hill, Inc.

Hatch, U. and T. Hanson. 1991. Economic Viability of Farm Diversification through Tropical Freshwater Aquaculture in Less Developed Countries. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama.

Johnson, R.A., D.W. Wichern. 1988. Applied Multivariate Statistical Analysis, 2nd ed.. New Jersey: Prentice-Hall, Inc.

Kennedy, P. 1989. A Guide to Econometrics, 2nd ed.. Cambridge: The MIT Press.

Kmenta, Jan. 1986. Elements of Econometrics, 2nd ed. New York: Macmillan Publishing Co.

Kurbis, G. 1996. Global Aquaculture: Situation and Outlook. Bi-weekly Bulletin, Vol. 9, No. 16. Winnipeg: Agriculture and Agri-Food Canada.

Lanza, W. 1991. Analisis De Los Factores Que Afectan El Desarrollo De La Piscicultura En Olancho. Honduran Ministry of Natural Resources.

Loveshin, L., N. Schwartz, V. de Castillo, C. Engle, and U. Hatch. 1986. Cooperatively Managed Panamanian Fish Ponds: The Integrated Approach. Research and Development Series No. 33. Alabama Agricultural Experiment Station, Auburn University, Alabama.

Meyer, D.E. 1995 (unpublished). Cultivo De Tilapia Con Diferentes Fuentes De Nutrientes. Pan-American Agricultural School (EAP), Honduras.

Molnar, J.J., T.R. Hanson and L.L. Loveshin. 1994. Socioeconomic Dimensions of Aquaculture Development: A Comparative Assessment of Financial Incentives, Adoption Barriers, and Impacts of Tilapia Production Regimes. Alabama Agricultural Experiment Station, Auburn University, Alabama.

Molnar, J.J., and L.L. Loveshin. 1995. Prospects for the Sustained Practice of Tilapia Culture in Honduras: Factors Inhibiting Full Realization of the Enterprise. International Center for Aquaculture and Aquatic Environments, Auburn University, Alabama.

Nuñez, W.L. 1991. Proyecto De Piscicultura En Olancho. Honduran Ministry of Natural Resources.

Peace Corps/Honduras. 1993. Guia Ilustrada De Piscicultura. Tegucigalpa: Peace Corps, Honduras.

Sricharoen, D. 1991. An Econometric Analysis of Fish Seed Production by Government Fishery Stations in Northeast Thailand. Winnipeg: Unpublished M.Sc. thesis, Dept. of Agricultural Economics and Farm Management, University of Manitoba.

Teichert-Coddington, D.R., B.W. Green, M.I. Rodriguez, R. Gomez, and L.A. Lopez. 1992. On-Farm Testing of PD/A CRSP Fish Production Systems In Honduras—Final Report. Corvallis: Pond Dynamics/Aquaculture Collaborative Research Support Program, Oregon State University.

USAID. 1992. Latin America and the Caribbean Selected Economic and Social Data. Washington, D.C.: U.S. Agency for International Development.

Varian, H.R. 1984. Microeconomic Analysis. 2nd ed., New Yok; London: W.W. Norton & Co.

White, K.J. et al. 1993. Shazam Econometrics Computer Program: User's Reference Manual Version

World Bank. 2000. Poverty and Social Indicators: Honduras at a Glance. http://www.worldbank.org/data/countrydata/aag/hnd_aag.pdf.

APPENDIX ONE: Primary Data

Table A.1.1: Inputs and Output

High Elevation Region (>1000 meters)						
Observation	Pond Size	Yield	Feed	Fertilizer	Fingerlings	Labour
1	25	1.00	7.64	4.00	2.40	0.23
2	50	0.76	8.52	6.06	2.00	0.17
3	150	0.57	3.34	0.80	2.00	0.05
4	1,000	1.08	1.98	1.23	2.20	0.01
5	40	1.25	10.88	10.75	0.75	0.23
6	40	1.20	8.70	10.75	1.13	0.19
7	108	0.28	0.78	0.93	0.71	0.03
8	108	0.66	0.78	2.78	1.26	0.03
9	360	0.19	0.73	0.28	0.83	0.05
10	120	1.33	2.13	7.92	2.92	0.10
Medium Elevation Region (501 - 1000 meters)						
	Pond Size	Yield	Feed	Fertilizer	Fingerlings	Labour
11	90	0.78	0.01	8.11	2.78	0.04
12	320	0.54	0.16	1.25	2.50	0.02
13	320	0.38	0.25	2.31	2.50	0.04
14	72	0.69	0.49	7.29	2.08	0.06
15	24	0.73	3.44	8.33	1.04	0.12
16	30	0.83	3.60	1.80	3.33	0.31
17	15	1.20	1.99	8.67	2.20	0.33
18	24	1.25	3.81	7.58	1.25	0.35
Low Elevation Region (0 - 500 meters)						
	Pond Size	Yield	Feed	Fertilizer	Fingerlings	Labour
19	25	0.20	0.66	3.04	2.00	0.12
20	28	1.32	3.29	3.57	2.32	0.30
21	150	1.07	3.89	0.00	2.00	0.06
22	450	0.60	0.47	3.56	1.78	0.03
23	100	0.65	1.15	2.50	3.00	0.06
24	550	0.55	1.60	0.33	1.82	0.02
25	250	0.38	0.80	1.80	2.40	0.02
Mean	178	0.78	2.84	4.23	1.97	0.12
Standard Deviation	226	0.36	3.02	3.45	0.73	0.11

Yield = Quantity of fish produced per square meter of pond area (pounds per m^2)
Pond Size = Measured in square meters.
Feed = Aggregate feed input quantity index (quantities weighted by feed prices) (Lempiras per m^2)
Fertilizer = Quantity of fertilizer applied (pounds per m^2)
Fingerlings = Stocking rate of fingerlings (seed fish per m^2)
Labour = Labour in person-days per m^2

Table A.1.2: Dummy Variables

Observation	E1	E2	M1	W1	W2	T1
High Elevation Region (>1000 meters)						
1	0	1	1	1	0	0
2	0	1	0	0	0	0
3	0	1	0	0	1	0
4	0	1	0	0	1	0
5	0	1	0	1	0	0
6	0	1	0	1	0	0
7	0	1	0	0	0	0
8	0	1	0	0	0	0
9	0	1	0	0	1	1
10	0	1	0	0	1	0
Medium Elevation Region (501 - 1000 meters)						
	E1	E2	M1	W1	W2	T1
11	1	0	0	1	0	0
12	1	0	0	0	1	1
13	1	0	0	0	1	1
14	1	0	0	0	1	1
15	1	0	1	0	0	0
16	1	0	0	1	0	0
17	1	0	1	0	1	0
18	1	0	1	0	1	0
Low Elevation Region (0 - 500 meters)						
	E1	E2	M1	W1	W2	T1
19	0	0	0	0	0	0
20	0	0	1	1	0	0
21	0	0	1	1	0	0
22	0	0	0	0	1	1
23	0	0	0	0	0	0
24	0	0	0	0	1	1
25	0	0	0	0	0	1
Per cent of sample =1	32%	40%	24%	28%	44%	28%

E1 = Dummy for medium elevation region
E2 = Dummy for high elevation region
M1 = Dummy for production technique
W1 = Dummy for medium pond management skill
W2 = Dummy for high pond management skill
T1 = Dummy for susceptibility to theft

Table A.1.3: Matrix for estimation of Cobb-Douglas functional form

$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + d_1E1 + d_2E2 + d_3M1 + d_4W1 + d_5W2 + d_6T1 + e$

Obs.	lnYd	lnFd	lnFt	lnFg	lnLb	E1	E2	M1	W1	W2	T1
1	0	2.033398	1.386294	0.875469	-1.491655	0	1	1	1	0	0
2	-0.274437	2.142416	1.80171	0.693147	-1.794563	0	1	0	0	0	0
3	-0.556288	1.205971	-0.223144	0.693147	-3.083471	0	1	0	0	1	0
4	-0.213193	0.68067	0.371564	0.788457	-4.809737	0	1	0	0	1	0
5	0.223144	2.386467	2.374906	-0.287682	-1.450833	0	1	0	1	0	0
6	0.182322	2.163323	2.374906	0.117783	-1.673976	0	1	0	1	0	0
7	-1.791759	-0.251314	-0.076961	-0.338326	-3.652512	0	1	0	0	0	0
8	-0.920931	-0.251314	1.021651	0.230524	-3.652512	0	1	0	0	0	0
9	-1.637609	-0.316615	-1.280934	-0.182322	-3.023903	0	1	0	0	1	1
10	0.287682	0.758076	2.06897	1.070441	-2.292222	0	1	0	0	1	0
11	-0.251314	-5.192957	2.093235	1.021651	-3.178054	1	0	0	1	0	0
12	-0.609266	-1.856298	1.832581	0.916291	-3.932385	1	0	0	0	1	1
13	-0.9643	-1.386294	0.838329	0.916291	-3.34529	1	0	0	0	1	1
14	-0.364643	-0.721318	1.986732	0.733969	-2.818051	1	0	0	0	1	1
15	-0.470004	1.234744	2.120264	0.040822	-2.148434	1	0	1	0	0	0
16	-0.182322	1.280934	0.587787	1.203973	-1.163151	1	0	0	1	0	0
17	0.182322	0.689808	2.159484	0.788457	-1.098612	1	0	1	0	1	0
18	0.223144	1.338285	2.025953	0.223144	-1.037988	1	0	1	0	1	0
19	-1.609438	-0.415515	1.111858	0.693147	-2.120264	0	0	0	0	0	0
20	-0.074108	1.189584	1.272966	0.842183	-1.199815	0	0	1	1	0	0
21	0.064539	1.359266	-0.405465	0.693147	-2.786012	0	0	1	1	0	0
22	-0.503446	-0.752661	1.268511	0.575364	-3.624341	0	0	0	0	1	1
23	-0.430783	0.139762	0.916291	1.098612	-2.813411	0	0	0	0	0	0
24	-0.606136	0.470004	-1.116961	0.597837	-3.744969	0	0	0	0	1	1
25	-0.967584	-0.223144	0.955511	0.875469	-3.798694	0	0	0	0	0	1

Fd = Feed
Ft = Fertilizer
Fg = Fingerlings
Lb = Labour
E1 = Dummy for medium elevation region
E2 = Dummy for high elevation region
M1 = Dummy for production technique
W1 = Dummy for medium pond management skill
W2 = Dummy for high pond management skill
T1 = Dummy for susceptibility to theft

Table A.1.4: Matrix for estimation of Translog functional form

$$\ln Yd = \alpha + \beta_{Fd}\ln Fd + \beta_{Ft}\ln Ft + \beta_{Fg}\ln Fg + \beta_{Lb}\ln Lb + \delta_{FdFd}\ln Fd\ln Fd + \delta_{FtFt}\ln Ft\ln Ft + \delta_{FgFg}\ln Fg\ln Fg + \delta_{LbLb}\ln Lb\ln Lb + \delta_{FdFg}\ln Fd\ln Fg + \delta_{FdFt}\ln Fd\ln Ft + \delta_{FdLb}\ln Fd\ln Lb + \delta_{FtFg}\ln Ft\ln Fg + \delta_{FtLb}\ln Ft\ln Lb + \delta_{FgLb}\ln Fg\ln Lb + d_1E1 + d_2E2 + d_3M1 + d_4W1 + d_5W2 + d_6T1 + e$$

Obs.	yd	fd	ft	fg	lb	fdfd	ftft	fgfg	lblb	fdft
1	0	2.033398	1.386294	0.875469	-1.491655	4.1347058	1.9218121	0.7664455	2.2250343	2.8188876
2	-0.274437	2.142416	1.80171	0.693147	-1.794563	4.5899478	3.2461582	0.480453	3.2204578	3.8600125
3	-0.556288	1.205971	-0.223144	0.693147	-3.083471	1.4543656	0.049793	0.480453	9.5077946	-0.269105
4	-0.213193	0.68067	0.371564	0.788457	-4.809737	0.4633112	0.1380595	0.621665	23.133573	0.252912
5	0.223144	2.386467	2.374906	-0.287682	-1.450833	5.6952227	5.6401773	0.082761	2.1049161	5.6676332
6	0.182322	2.163323	2.374906	0.117783	-1.673976	4.6799665	5.6401773	0.0138728	2.8021971	5.1376883
7	-1.791759	-0.251314	-0.076961	-0.338326	-3.652512	0.0631589	0.005923	0.1144644	13.340843	0.0193414
8	-0.920931	-0.251314	1.021651	0.230524	-3.652512	0.0631589	1.0437713	0.0531412	13.340843	-0.256756
9	-1.637609	-0.316615	-1.280934	-0.182322	-3.023903	0.1002452	1.6407915	0.0332412	9.1439903	0.4055631
10	0.287682	0.758076	2.06897	1.070441	-2.292222	0.5746796	4.2806379	1.1458448	5.2542831	1.5684372
11	-0.251314	-5.192957	2.093235	1.021651	-3.178054	26.966801	4.3816322	1.0437713	10.100026	-10.87008
12	-0.609266	-1.856298	1.832581	0.916291	-3.932385	3.4458422	3.3583548	0.8395887	15.463653	-3.401817
13	-0.9643	-1.386294	0.838329	0.916291	-3.34529	1.9218121	0.7027958	0.8395887	11.190964	-1.162171
14	-0.364643	-0.721318	1.986732	0.733969	-2.818051	0.5202997	3.9471046	0.5387108	7.941412	-1.433066
15	-0.470004	1.234744	2.120264	0.040822	-2.148434	1.5245939	4.4955175	0.0016664	4.6157704	2.6179837
16	-0.182322	1.280934	0.587787	1.203973	-1.163151	1.6407915	0.3454932	1.4495505	1.3529198	0.7529158
17	0.182322	0.689808	2.159484	0.788457	-1.098612	0.4758355	4.6633722	0.621665	1.206949	1.4896301
18	0.223144	1.338285	2.025953	0.223144	-1.037988	1.7910071	4.104485	0.049793	1.0774184	2.7113026
19	-1.609438	-0.415515	1.111858	0.693147	-2.120264	0.1726531	1.2362271	0.480453	4.4955175	-0.461994
20	-0.074108	1.189584	1.272966	0.842183	-1.199815	1.4151103	1.6204416	0.7092718	1.4395555	1.5142997
21	0.064539	1.359266	-0.405465	0.693147	-2.786012	1.8476032	0.164402	0.480453	7.7618614	-0.551135
22	-0.503446	-0.752661	1.268511	0.575364	-3.624341	0.566499	1.609121	0.3310439	13.135847	-0.954759
23	-0.430783	0.139762	0.916291	1.098612	-2.813411	0.0195334	0.8395887	1.206949	7.9152799	0.1280626
24	-0.606136	0.470004	-1.116961	0.597837	-3.744969	0.2209034	1.2476028	0.3574091	14.024792	-0.524976
25	-0.967584	-0.223144	0.955511	0.875469	-3.798694	0.049793	0.9130021	0.7664455	14.430079	-0.213216

Obs.	fdfg	fdlb	ftfg	ftlb	fglb	E1	E2	M1	W1	W2	T1
1	1.780176	-3.033127	1.213657	-2.067873	-1.305897	0	1	1	1	0	0
2	1.48501	-3.844702	1.24885	-3.233282	-1.243897	0	1	0	0	0	0
3	0.835915	-3.718576	-0.154671	0.688057	-2.137299	0	1	0	0	1	0
4	0.536679	-3.273842	0.292962	-1.787123	-3.792273	0	1	0	0	1	0
5	-0.686544	-3.462364	-0.683218	-3.445591	0.417379	0	1	0	1	0	0
6	0.254803	-3.621352	0.279724	-3.975536	-0.197166	0	1	0	1	0	0
7	0.085026	0.917929	0.026038	0.281101	1.235739	0	1	0	0	0	0
8	-0.057934	0.917929	0.235515	-3.731593	-0.84199	0	1	0	0	0	0
9	0.057726	0.957414	0.233542	3.87342	0.551323	0	1	0	0	1	1
10	0.811476	-1.737679	2.214711	-4.74254	-2.45369	0	1	0	0	1	0
11	-5.305391	16.5035	2.138556	-6.652413	-3.246863	1	0	0	1	0	0
12	-1.700909	7.299679	1.679177	-7.206416	-3.603208	1	0	0	0	1	1
13	-1.270249	4.637556	0.768153	-2.804454	-3.065258	1	0	0	0	1	1
14	-0.529425	2.032711	1.4582	-5.598713	-2.068363	1	0	0	0	1	1
15	0.050405	-2.652767	0.086553	-4.555247	-0.087703	1	0	1	0	0	0
16	1.54221	-1.489919	0.707679	-0.683685	-1.400402	1	0	0	1	0	0
17	0.543884	-0.757832	1.702661	-2.372436	-0.866209	1	0	1	0	1	0
18	0.29863	-1.389123	0.452078	-2.102914	-0.23162	1	0	1	0	1	0
19	-0.288013	0.881002	0.770681	-2.357431	-1.469655	0	0	0	0	0	0
20	1.001847	-1.427281	1.07207	-1.527323	-1.010463	0	0	1	1	0	0
21	0.942171	-3.78693	-0.281047	1.129631	-1.931116	0	0	1	1	0	0
22	-0.433054	2.727901	0.729856	-4.597518	-2.085316	0	0	0	0	1	1
23	0.153544	-0.393208	1.006648	-2.577902	-3.090848	0	0	0	0	0	0
24	0.280986	-1.760149	-0.667761	4.182986	-2.238881	0	0	0	0	1	1
25	-0.195355	0.847654	0.83652	-3.629696	-3.325638	0	0	0	0	0	1

APPENDIX TWO: Aggregate Feed Index

Different feeds used in the production process were aggregated into a feed input quantity index measured in Lempiras per square meter of pond size. The formula used was $Fd = \sum_i Q_{ij} P_{ij\ (i=1,\ldots 5)}$.

Observation	Afrecho (milling by-product) Quantity	Price	Concentrado (prepared livestock feeds) Quantity	Price	Termites Quantity	Price	Corn Quantity	Price
1	200.00	50.00	0.00	80.00	0.00	77.00	0.00	100.00
2	0.00	40.00	0.00	75.00	0.00	77.00	414.00	103.00
3	0.00	50.00	0.00	80.00	0.00	77.00	334.00	100.00
4	0.00	40.00	900.00	75.00	169.00	77.00	1,115.00	105.00
5	0.00	40.00	0.00	60.00	417.00	77.00	0.00	102.00
6	0.00	50.00	0.00	80.00	335.00	77.00	0.00	100.00
7	0.00	60.00	0.00	83.00	32.00	77.00	62.00	95.00
8	0.00	50.00	0.00	80.00	0.00	77.00	0.00	100.00
9	0.00	60.00	180.00	77.00	91.00	77.00	0.00	95.00
10	100.00	50.00	100.00	80.00	97.00	77.00	0.00	100.00
11	0.00	60.00	0.00	83.00	0.00	80.00	0.00	95.00
12	0.00	50.00	0.00	77.00	0.00	80.00	0.00	100.00
13	0.00	60.00	0.00	85.00	0.00	80.00	0.00	98.00
14	0.00	50.00	0.00	80.00	0.00	80.00	0.00	100.00
15	65.00	50.00	0.00	80.00	0.00	80.00	0.00	108.00
16	54.00	40.00	0.00	73.00	0.00	80.00	54.00	110.00
17	25.80	50.00	0.00	80.00	0.00	80.00	17.00	100.00
18	100.00	50.00	0.00	80.00	0.00	80.00	0.00	100.00
19	0.00	60.00	0.00	87.00	0.00	81.00	13.00	98.00
20	0.00	50.00	115.00	80.00	0.00	81.00	0.00	100.00
21	0.00	55.00	687.00	85.00	0.00	81.00	0.00	97.00
22	0.00	45.00	275.00	77.00	0.00	81.00	0.00	104.00
23	0.00	50.00	0.00	80.00	0.00	81.00	0.00	100.00
24	0.00	45.00	250.00	77.00	100.00	81.00	0.00	102.00
25	0.00	50.00	250.00	80.00	0.00	81.00	0.00	100.00

A proxy was used for prices of termites. The marginal utility of termites was assumed to be equal to the mean concentrado price for each elevation region. The marginal utility of miscellaneous items (leaves, peels, vegetables, etc.) was taken as the sum of half the mean corn price and half the mean yucca price for each elevation region.

Observation	Yucca		Miscellaneous (leaves, vegetables, peels)		Feed Use Index	Feed Use Index per square meter
	Quantity	Price	Quantity	Price	Lempiras	Lempiras/m2
1	0.00	50.00	121.00	75.00	190.75	7.64
2	0.00	50.00	0.00	76.50	426.42	8.52
3	334.00	50.00	0.00	75.00	501.00	3.34
4	0.00	50.00	0.00	77.50	1,975.88	1.98
5	0.00	50.00	150.00	76.00	435.09	10.88
6	0.00	50.00	120.00	75.00	347.95	8.70
7	0.00	50.00	0.00	72.50	83.54	0.78
8	0.00	50.00	112.00	75.00	84.00	0.78
9	0.00	50.00	74.00	72.50	262.32	0.73
10	0.00	50.00	68.00	75.00	255.69	2.13
11	0.00	50.00	0.70	72.50	0.51	0.01
12	0.00	50.00	66.00	75.00	49.50	0.16
13	0.00	50.00	108.00	74.00	79.92	0.25
14	0.00	50.00	47.00	75.00	35.25	0.49
15	0.00	50.00	63.00	79.00	82.27	3.44
16	0.00	50.00	34.00	80.00	108.20	3.60
17	0.00	50.00	0.00	75.00	29.90	1.99
18	0.00	50.00	55.00	75.00	91.25	3.81
19	0.00	50.00	5.00	74.00	16.44	0.66
20	0.00	50.00	0.00	75.00	92.00	3.29
21	0.00	50.00	0.00	73.50	583.95	3.89
22	0.00	50.00	0.00	77.00	211.75	0.47
23	0.00	50.00	153.00	75.00	114.75	1.15
24	0.00	50.00	798.00	76.00	879.98	1.60
25	0.00	50.00	0.00	75.00	200.00	0.80

APPENDIX THREE: Estimated Return on Investment

The production function estimated in this analysis enables estimation of the attractiveness of investment in aquaculture. Input and output prices were applied to the technological relationship specified in equation (5.5) in order to estimate annual gross margins. These were converted into annual net capital inflows or revenue streams and then assessed against initial investment costs in order to derive the internal rate of return.

Present value of year n = Net inflow or outflow in year n / $(1 + r)^n$

where net present value is the sum of present values across n = 0....15
where r is the discount rate
where the internal rate of return is the value for r that satisfies the condition that net present value equals zero.

Tables A.3.3 to A.3.6 present the stream of costs and benefits. Year zero consists of investment costs and input costs, with the first harvest appearing in year one. The lifespan of the investment is assumed to be 15 years with zero salvage value at the end of year 15. Year 15 consists of yield revenues only with no input costs incurred.

Table A.3.1 uses nominal fingerling and manure prices discussed in section 4.5. and therefore overestimates the profitability of the enterprise where transportation costs for fingerlings must be incurred (nominal fingerling price = 30 centavos). Tables A.3.2 and A.3.3 examine the sensitivity of IRR to the assumption of proximity to a source of fingerlings. Table A.3.2 assumes a traveling distance of four hours to the nearest hatchery (spatial fingerling price = 63 centavos; see section 4.5 for details). Table A.3.3. assumes a traveling distance by conventional means of eight hours (spatial fingerling price = 198 centavos). The purpose of these calculations is to provide preliminary estimates of profitability for further research. All figures in 1995 Lempiras unless otherwise indicated (1995 exchange rate: 9.59 Lempiras = US $1.00)

Table A.3.1: Estimated return on investment \1

Input Use	Pond Management Skill	Average Cost \2	Gross Margin \3	Internal Rate of Return \4
Minimum	Low	3.4	51	-
	Medium	1.7	143	4%
	High	2.0	114	1%
Mean	Low	4.5	255	11%
	Medium	2.2	868	46%
	High	2.6	671	35%
Maximum	Low	11.1	-569	-
	Medium	5.4	956	26%
	High	6.5	466	12%

\1 Assumes zero hours to hatchery
\2 Average cost per pound of fish produced
\3 Total revenues from fish less total input costs per mean pond size (178 m^2)
\4 Based on 15 year lifespan of investment with zero salvage value.

Table A.3.2: Estimated return on investment \1

Input Use	Pond Management Skill	Average Cost \2	Gross Margin \3	Internal Rate of Return \4
Minimum	Low	6.9	13	-
	Medium	3.3	105	4%
	High	4.0	76	0%
Mean	Low	5.8	158	10%
	Medium	2.8	771	42%
	High	3.4	574	32%
Maximum	Low	12.1	-748	-
	Medium	5.9	778	24%
	High	7.1	288	10%

\1 Assumes four hours to hatchery
\2 Average cost per unit of fish produced
\3 Total revenues from fish less total input costs per mean pond size (178 m^2)
\4 Based on 15 year lifespan of investment with zero salvage value.

Table A.3.3: Estimated return on investment \1

Input Use	Pond Management Skill	Average Cost \2	Gross Margin \3	Internal Rate of Return \4
Minimum	Low	21.5	-149	-
	Medium	10.5	-57	1%
	High	12.6	-86	-
Mean	Low	11.5	-254	5%
	Medium	5.6	359	31%
	High	6.7	162	23%
Maximum	Low	16.3	-1505	-
	Medium	7.9	21	17%
	High	9.5	-469	6%

\1 Assumes eight hours to hatchery
\2 Average cost per unit of fish produced
\3 Total revenues from fish less total input costs per mean pond size (178 m^2)
\4 Based on 15 year lifespan of investment with zero salvage value.

Table A.3.4: Investment and revenue streams for estimation of IRR /1

Input Use	Pond Management Skill	year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Minimum	Low	-1598	51	51	51	51	51	51	51	51	51	51	51	51	51	51	88
	Medium	-1598	143	143	143	143	143	143	143	143	143	143	143	143	143	143	181
	High	-1598	114	114	114	114	114	114	114	114	114	114	114	114	114	114	151
Mean	Low	-1888	255	255	255	255	255	255	255	255	255	255	255	255	255	255	583
	Medium	-1888	868	868	868	868	868	868	868	868	868	868	868	868	868	868	1,196
	High	-1888	671	671	671	671	671	671	671	671	671	671	671	671	671	671	999
Maximum	Low	-3579	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	1,450
	Medium	-3579	956	956	956	956	956	956	956	956	956	956	956	956	956	956	2,975
	High	-3579	466	466	466	466	466	466	466	466	466	466	466	466	466	466	2,485

\1 Assumes zero hours to hatchery

Table A.3.5: Investment and revenue streams for estimation of IRR /1

Input Use	Pond Management Skill	year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Minimum	Low	-1598	51	51	51	51	51	51	51	51	51	51	51	51	51	51	88
	Medium	-1598	143	143	143	143	143	143	143	143	143	143	143	143	143	143	181
	High	-1598	114	114	114	114	114	114	114	114	114	114	114	114	114	114	151
Mean	Low	-1888	255	255	255	255	255	255	255	255	255	255	255	255	255	255	583
	Medium	-1888	868	868	868	868	868	868	868	868	868	868	868	868	868	868	1,196
	High	-1888	671	671	671	671	671	671	671	671	671	671	671	671	671	671	999
Maximum	Low	-3579	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	1,450
	Medium	-3579	956	956	956	956	956	956	956	956	956	956	956	956	956	956	2,975
	High	-3579	466	466	466	466	466	466	466	466	466	466	466	466	466	466	2,485

\1 Assumes four hours to hatchery

Table A.3.6: Investment and revenue streams for estimation of IRR /1

Input Use	Pond Management Skill	year 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Minimum	Low	-1598	51	51	51	51	51	51	51	51	51	51	51	51	51	51	88
	Medium	-1598	143	143	143	143	143	143	143	143	143	143	143	143	143	143	181
	High	-1598	114	114	114	114	114	114	114	114	114	114	114	114	114	114	151
Mean	Low	-1888	255	255	255	255	255	255	255	255	255	255	255	255	255	255	583
	Medium	-1888	868	868	868	868	868	868	868	868	868	868	868	868	868	868	1,196
	High	-1888	671	671	671	671	671	671	671	671	671	671	671	671	671	671	999
Maximum	Low	-3579	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	(569)	1,450
	Medium	-3579	956	956	956	956	956	956	956	956	956	956	956	956	956	956	2,975
	High	-3579	466	466	466	466	466	466	466	466	466	466	466	466	466	466	2,485

\1 Assumes eight hours to hatchery