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DETERMINING THE BEST USES OF MANGROVE AREAS: AN APPLICATION OF DYNAMIC OPTIMIZATION TO THE CASE OF SHRIMP MARICULTURE IN ECUADOR

BY

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ABSTRACT

This research aims to determine the best uses of mangrove areas, with special emphasis on the shrimp mariculture industry in Ecuador. Traditionally, mangrove areas have been considered useless resources with no economic value except through development. Consequent conversion or exploitation of mangrove areas for urban infrastructural development, agricultural development and, more recently, shrimp mariculture has been taking place in several developing countries. The growing concern for the environment and sustainable development has stressed the multiple-use nature of mangrove areas and the associated trade-offs of their use. Mangrove ecosystems are being increasingly recognized as important renewable resources capable of producing not only goods and services, but also of providing important natural ecological functions. Economic value may then be associated with mangroves in their natural state.

The centerpiece of this work is a formal model integrating biotechnical, ecological, economic, and policy factors to determine the characteristics of the economic activities competing for the use of mangrove areas. The competing economic activities included are shrimp mariculture, mangrove forestry and coastal artisanal fisheries. A simple measure of benefits derived from natural ecological functions performed by mangrove areas is also considered. Standard concepts of natural and environmental resource economics, biological population dynamics and management strategies are combined to determine net social benefits generated by alternative uses of mangrove areas. A multi-sector, dynamic bioeconomic model is developed to determine the optimal intertemporal allocation of mangrove areas among the four alternative activities. The model is used to calculate present values of net benefits under four alternative management strategies. The results support a set of policy recommendations for management coastal resources in Ecuador.

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CHAPTER I

INTRODUCTION

This research aims to determine the optimal rate of conversion of mangrove areas in a dynamic and interdisciplinary context. To achieve this goal a quantitative model is constructed to measure the economic values of different management alternatives, and directed at determining the best alternative uses of mangrove areas. The specific objective is to determine the present value of net benefits generated by alternative uses of mangrove areas under different management strategies. Dynamic optimization techniques are used to construct four bioeconomic models, each representing a different management strategy. These management strategies are compared in order to determine the one which over time maximizes the present value of alternative uses of mangrove areas.

Mangrove areas traditionally have been considered wastelands that are of no value until developed through conversion or other forms of exploitation (Hamilton and Snedaker 1984). Consequently, until the late 1960s mangroves areas were either ignored or abused in most parts of the world, with the exception of a few countries in Asia (Lugo and Snedaker 1974).

The conversion of mangrove areas into shrimp ponds has recently emerged as a profitable venture. Conversion has been triggered by a growing demand for shrimp in developed countries. Shrimp mariculture is present in more than 40 countries around the world (covering approximately one million hectares), and has experienced constant development during the last decade, reaching a record production of 660 thousands metric tons in 1990. The conversion process has been rapid in tropical developing countries like Ecuador, Indonesia and Philippines where pond yields are high, production costs relatively low and foreign exchange needed (Agüero and González 1991, 58p). The eastern hemisphere produces about 85 percent of the worlds production and the western hemisphere the remaining 15 percent. In 1990, Ecuador produced 76 percent of the total shrimp production in the western hemisphere in 1990. Shrimp mariculture in Ecuador is the most important economic activity in the coastal zone of Ecuador, being the most largest source of foreign exchange for the country after oil (Agüero and González 1991).

Reclaiming mangrove areas for infrastructural or agricultural development has also been a driving force for converting mangroves into apparently more profitable uses. In countries like Fiji, New Caledonia, Malaysia and Indonesia, mangroves have been converted into crop lands or plantations; in Singapore, mangroves have been reclaimed into human settlements and industrial estates, and, in

American Samoa, the construction of transportation facilities has displaced mangroves (Maragos et al. 1983).

Policy makers presently face the predicament of supporting mangrove conversion into apparently more profitable alternatives (shrimp mariculture, agriculture, infrastructure development), or of attempting to preserve them because of what appears to be purely hypothetical or almost sentimental arguments (Agüero and González 1991, 58p.). Hamilton and Snedaker (1984), based on simple calculations involving estimated values of foregone benefits from mangrove conversion, show that the benefits of conversion cannot be taken for granted. Thus, decisions with respect to conversion or preservation of mangrove areas are being taken in daily basis without the proper tools.

A world wide growing concern for the environment and sustainable development has stressed the multiple-use nature of mangrove areas and the associated trade-offs. Mangrove areas are being increasingly considered as important renewable resources capable of producing not only goods and services, but also providing important natural ecological functions such as: shoreline stabilization and protection, being the habitat for a variaty of life forms, controlling estuarine water quality (Hamilton and Snedaker 1984, Snedaker and Getter 1985, Bossi and Cintrón 1990, Agüero and González 1991 58p.).

This thesis is organized as follows. Next, in Chapter II, a global review is presented of mangrove areas, the natural functions associated with them and their uses is presented. Also presented in Chapter II is a review of the origin, development and present situation of shrimp mariculture in Ecuador. Chapter III presents the methodological approach adopted in this research, where the four bioeconomic models are constructed under their respective management strategies, and calculation of required model parameters are explained. The results and their implications are presented in Chapter IV. Finally, conclusions derived from this research, its shortcomings and limitations, and suggestions for further research are contained in Chapter V.

CHAPTER II

MANGROVE AREAS AND THEIR ALTERNATIVE USES, THE CASE OF ECUADOR.

This chapter is divided in two sections. The first provides a brief description of mangrove areas, their distribution, their natural role and traditional uses. The second presents the shrimp industry in Ecuador, including its evolution and present situation.

A.- MANGROVE AREAS, A COMPLEX ECOSYSTEM.

The term mangroves refers to the group of woody, salt tolerant plants that grow, while exposed to tidal influence, on the tropical and subtropical coasts of the world. The term mangrove areas in this study refers to the community of plants, animals and their surrounding environment (i.e., the ecosystem). The most common species of mangrove trees are red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*).

The size of mangroves depends on the environment where they develop. In the Caribbean, for example, they range from approximately 1 m to more than 40 m (Bossi and Cintrón 1990). There are approximately 24 million hectares of coastal zone (intertidal zone or immediately above it) dominated by mangroves around the world (Snedaker and Getter

1985). Mangrove areas in Latin America and the Caribbean cover approximately 6 million hectares (Table 2.1). Mangrove areas in South America account for 75 percent of the total area with 4.48 million hectares and the remaining 25 percent is located in the Caribbean.

Table 2.1 Distribution of mangrove areas in Latin America.

Country	Hectares
Caribbean	1,526,400
Belize	73,000
Costa Rica	39,000
Cuba	400,000
Dominican Republic	9,000
El Salvador	45,000
Guadeloupe	8,000
Guatemala	50,000
Haiti	18,000
Honduras	145,000
Jamaica	7,000
Mexico	660,000
Martinique	1,900
Nicaragüa	60,000
Puerto Rico	6,500
Trinidad & Tobago	4,000
South America	4,485,100
Brazil	2,500,000
Colombia	510,300
Ecuador	177,770
French Guiana	55,000
Guyana	80,000
Panama	486,000
Peru	2,500
Surinam	115,000
Venezuela	673,600

Source: Snedaker et al. (1986), Bossi and Cintrón (1990)

1. Natural functions of mangrove areas.

Among the major natural, ecological or environmental functions performed by mangroves are a) being aquatic nurseries, b) being a wildlife habitat, c) providing shoreline stabilization and protection and d) providing water quality control.

Mangrove areas provide abundant food and protection to larvae and juveniles of several types of fish and shellfish (Bossi and Cintrón 1990). Mangroves contribute to the existence of abundant food in two ways. First, their intricate root systems play an important role in the retention of nutrients and sediments carried with the riverine fresh water input, greatly contributing to a high primary production (Odum et al. 1982, Snedaker and Getter 1985). Second, mangrove litter fall is the energy basis for the detritus-based foodwebs in mangrove swamps (Odum et al. 1982). Mangroves' intricate root system also offers good protection to fish and shellfish larvae and juveniles against predators.

Mangrove areas support an abundant and varied wildlife (birds, fish, reptiles, etc) due to the diversity of habitats existing in a mangrove ecosystem (the canopy, the roots, the muddy ground, associated water bodies). Many of the species have a temporal relation to mangrove areas (e.g., birds and shrimp) and others are permanent residents, such as insects, reptiles, crustaceans and mollusks (Odum et al. 1982, Snedaker and Getter 1985, Bossi and Cintrón 1990).

Mangroves have the ability to trap, hold and, to some degree, stabilize intertidal sediments. In summary, they function as stabilizers of sediments that have been deposited by geomorphological processes (Odum et al. 1982). Bossi and Cintrón (1990) state that during times of quiet weather, the network of prop roots slow the flow of water currents inducing suspended particles to settle out and deposit in the outer edge of the mangrove fringe. These authors add that silts that otherwise would be transported to coastal waters are trapped on the landward side of mangroves. Although mangroves are susceptible to damage by tropical storms, they provide substantial protection to areas on their landward side. In areas of yearly occurence of tropical storms mangrove areas are known to be a buffer against the wave damage to low land areas (Snedaker and Getter 1985). The degree of protection provided by mangroves to flooding and wave damage depends on the width of the mangrove zone (Odum et al. 1982). Bossi and Cintrón (1990) mention that fishermen and other coastal people in the Caribbean have known for centuries that mangrove areas offer good protection for boats in time of hurricanes.

Mangroves play an important role in preserving water quality (i.e. reducing eutrophication process) in estuarine ecosystems due to their ability to trap nutrients and sediments from water currents. Mangrove forests are dependent on external sources of minerals to maintain their high level of productivity, and anaerobic mangrove sediments have also the ability to isolate and remove heavy metals and pesticides. Mangroves, therefore, have the capacity to trap inorganic nutrients, heavy metals or pesticides that otherwise would flow to estuarine waters, degrading water quality (Snedaker and Getter 1985, Bossi and Cintrón 1990).

2. Mangrove uses.

Mangrove areas around the world have traditionally been the source of various products of value for subsistence economies and more recently for commercial use. Most common products obtained from mangrove areas are firewood, charcoal, wood, wood chips, and domestic products like honey (Snedaker and Getter 1985).

Bossi and Cintrón (1990) report that European settlers in the wider Caribbean soon discovered that the mangrove forest could yield several products such as tanbark, fuel, building materials, and several aquatic organisms may be gathered from their prop roots. Throughout the Caribbean mangrove wood is also used as construction materials for houses (e.g. poles and beams) and in many places fishermen still use mangrove wood to build fish pots and frames for small boats. In addition, different parts of the red, black and white mangroves trees are used to prepare a variety of folk remedies to treat ailments and maladies ranging from arthritis to ulcers.

Mangrove use in South America

There is poor documentation of the historical uses of mangroves and mangrove products in South America, and much of the information is based on conventional wisdom and anecdote. Pre-Colombian and historical uses of mangroves are presumed to be the same as the traditional uses currently observed. Among the main traditional uses observed are the cutting of trees for firewood, charcoal and poles for construction. These activities are undertaken by single families or several adults from one village operating at a very small scale level. Another use was the extraction of bark for the production of tannin, but this activity has been almost eliminated by the collapse of the world market for tannin (Snedaker et al. 1986).

Utilization of mangrove forests on a large commercial scale is recent in South America. Most of its development is government inspired (Brazil, Panamá and Venezuela), although it still in the planning stage. The only exception is the exploitation of large trees of red mangrove in the Orinoco delta for use as power utility poles elsewhere in Venezuela (Snedaker et al. 1986).

The same authors also report that other forms of utilization of mangrove areas includes the clearing of mangrove forests, with or without utilization of the wood, and conversion of the land to salt-evaporation ponds or to maricultural ponds. Conversion of mangrove areas for shrimp pond construction has mainly taken place in Panamá, Colombia, Ecuador and Perú.

B.- THE SHRIMP INDUSTRY IN ECUADOR.

Ecuadorean shrimp production stems from two distinct sources, the wild fishery and the shrimp mariculture industry. Until the early 1970s, the bulk of production consisted of sea harvested shrimp with a volume ranging between 6,000 and 8,000 mt of whole shrimp per year (McPadden 1989). Since then, commercial shrimp mariculture has steadily increased its contribution to shrimp industry production.

1. Capture Fisheries.

Significant shrimp production in Ecuador began around 1952 with the development of an offshore trawl fleet based on local demand and consumption. Two years later, in 1954, the first shrimp were exported to the United Sates (McPadden 1989).

According to Sutinen et al. (1989), wild caught production increased rapidly and steadily during the 1960s as did the shrimp fishing fleet. From 1955 to 1958, production increased from less than 1,000 mt to more than 3,000 mt. During the decade of the 1960s, production increased about 250 percent reaching approximately 9,000 mt by 1969. Simultaneously, the fleet grew 200 percent during the fifties, from 30 fishing units in 1955 to 100 units in 1959. During the sixties the fleet's rate of growth decreased slightly, increasing only 150 percent and reaching 259 vessels by 1969. However, this change in fleet size was accompanied by the adoption of new fishing technology in the 1960s when the fishing industry began to use the more efficient double-rigged trawlers.

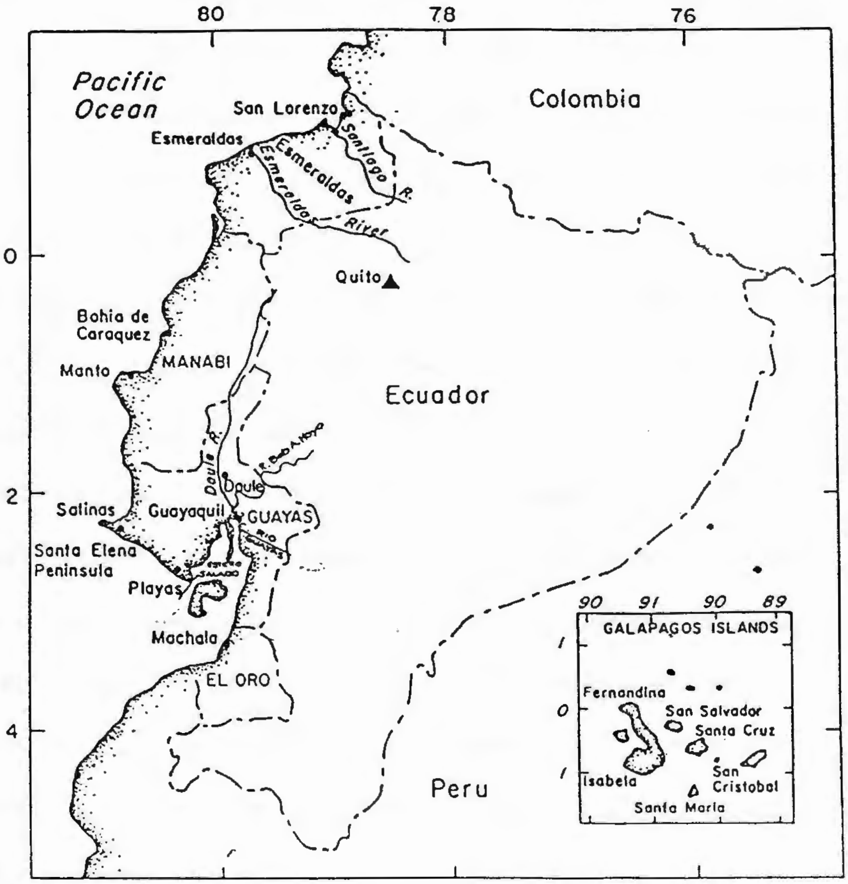
The decade of the 1970s showed cyclical variations both in production and fleet. From 1970 to 1971 production dropped to a level of 6,000 mt, in 1973 production rose to 8,000 mt to drop back again to 6,500 mt in 1974, in 1975 it recovered reaching 7,500 mt. Simultaneously, the number of vessels increased up to 270 by 1972 but decreased in 1975, with less than 250 units in operation.

Variations in shrimp catches are also influenced by the El Niño phenomenon, a physical and atmospheric event inducing increases in air and water temperatures, and in rainfall levels. This phenomenon is associated with increases in shrimp stock productivity. When comparing production obtained during El Niño years (1958, 1965, 1969, 1973, etc) with non El Niño years, one can detect a significant increase in productivity during the former. Sutinen et al. (1989) estimated increases of 27 percent in the average production of the offshore fleet. These increases in ecosystem productivity can affect production for one or two years after the El Niño.

McPadden (1989) described the Ecuadorean shrimp fishing fleet. The typical vessels are 50-70 feet in length with engines ranging from 220 HP to 440 HP. Most of them spend between 15 and 22 days at sea per trip and are equipped with refrigerated sea water tanks. Some smaller vessels spend up to four days at sea and carry ice, principally those targeting Pomada (*Protrachypenaeus precipua*) and Titi shrimp (*Xipopenaeus riveti*). The entire fleet uses double-rigged otter trawls with mesh size of 2 inches in the main body of the net and 1.4 inches in the cod end.

In 1985 the main body of the fleet operated off Guayaquil, the most important port of Ecuador, on fishing grounds located in the Gulf of Guayaquil (Figure 2.1). In the mouth of the Gulf, between Puna and Playas, a day fishery, consisting of a small fleet of 52 fishing vessels, is based at Posorja and operates from there. These vessels target on Pomada (*Protrachypenaeus precipua*) and Titi shrimp (*Xipopenaeus riveti*).

Figure 2.1 Coastal provinces in Ecuador.



Source: Twilley (1989)

Esmeraldas, in northern Ecuador, is another important center for the trawl fishery. The fishing grounds off Esmeraldas are worked by a small fleet of 26 vessels and also by fishing vessels coming from Guayaquil. Another important fishing area in the north is the Manta/Palmare stretch which is also fished by vessels from Guayaquil. An offshore deep water shrimp fishery has developed over the past five years but little is known about its potential for expansion (McPadden 1989).

In 1985 the bulk of Ecuadorean shrimp production consisted of white shrimp (*Penaeus vannamei*, *Penaeus stylirostris* and *Penaeus occidentalis*), which accounted for about 90 percent of the total. Pomada and Titi shrimp (*Protrachypenaeus precipua* and *Xipopenaeus riveti*) represented 4 percent of the 1985 production, and Red and Brown shrimp (*Penaeus brevirostris* and *Penaeus californiensis*) formed only 2 percent of the total production, with red shrimp being the more important of the two (McPadden 1989).

Sutinen et al. (1989) analyzed the development of the shrimp capture fishery in Ecuador and stated that by the mid-1970s the offshore shrimp fishery had reached maturity. At that time the resource was thought to be fully exploited and the fleet size oscillating at its long-run maximum.

McPadden (1989) describes the development of the fishery as follows. Between 1974 and 1977, white shrimp production was relatively stable, at around 3,500 mt per year. After 1977 production dropped to about 1,000 mt, slowly increasing later to reach of 2,500 mt in 1982. In 1983, the El Niño phenomenon induced a dramatic increase in production which peaked at about 9,600 mt. In the following year, 1984, white shrimp (*Penaeus vannamei*, *Penaeus stylirostris* and *Penaeus occidentalis*) production was extremely low compared to the almost 2,000 mt of Red and Brown shrimp (*Penaeus brevirostris* and *Penaeus californiensis*). In terms of the species composition for White Shrimp production, the total production of *Penaeus occidentalis* and *Penaeus stylirostris* remained fairly stable between 1974 and 1977, unlike the production of *Penaeus vannamei* which gradually increased. In 1977 the percentage of *Penaeus vannamei* in the total White Shrimp production, increased by 40 percent over that of 1974 according to factory samples. Between 1978 and 1983 the difference in composition was larger due to a gradual decrease in the amounts of *Penaeus occidentalis* and *Penaeus stylirostris* and a simultaneous increase in *Penaeus vannamei*'s landings. Thus, in 1978, *Penaeus occidentalis* represented about 60 percent of the total catch of white shrimp while *Penaeus vannamei* represented only 15 percent. By 1983, the situation reversed with *Penaeus vannamei* representing 38 percent and *Penaeus occidentalis* 26 percent of the total white shrimp sea captures (See Table 2.2).

2. Shrimp Mariculture.

Shrimp farming is increasingly carried out in coastal tropical areas of developing countries. In most of these countries mangrove areas are converted into shrimp ponds. Shrimp ponds are filled with estuarine water and stocked with shrimp juveniles, both of which are highly dependent on the lagoonal / estuarine conditions of these ecosystems. Usually shrimp are grown to commercial size with the help of man-made feed and then sold in international markets.

a. Physical production and production systems.

Shrimp mariculture on a commercial scale began in Ecuador in 1968 when businessmen involved in the banana industry attempted to reproduce the South East Asian experience (CPC 1989, Sutinen et al. 1989 and Villalón et al. 1989).

Initially, total production was insignificant compared to that of capture fisheries. By 1977, there was a "gold rush" entry into shrimp mariculture, yet production was very low (Hirono 1983).

Table 2.2 Ecuadorean white shrimp production (head off), by especies in metric tons (mt).

Year	P. Vannamei (mt)	P. styilirostris (mt)	P.occidentalis (mt)	Total (mt)
1974	229	828	1,991	3,048
1975	289	1,201	2,176	3,666
1976	313	1,557	1,716	3,586
1977	362	1,424	1,911	3,697
1978	393	633	1,585	2,611
1979	539	588	1,125	2,252
1980	-	-	-	-
1981	743	667	1,152	2,562
1982	691	887	944	2,522
1983	3,662	3,500	2,485	9,647
1984	147	161	267	575
1985	525	473	586	1,584

Source: McPadden (1989) Table 1c.

By 1979, shrimp mariculture production represented 38 percent of total shrimp production with the first significant commercial production of 4,700 mt (Table 2.3). In 1983 farm-raised shrimp production took the lead in total shrimp production with about 80 percent of the country's total of 35,600 mt. This upward trend modified in the next two years, when farm production fell to 30,205 mt. Later, from 1986 to 1988, the industry showed a substantial recovery reaching its peak production in 1988 with approximately 70,000 mt, accounting for 87 percent of the total Ecuadorean shrimp production (Table 2.4).

By 1985 three systems of production were in use in shrimp mariculture in Ecuador, known as extensive, semi-extensive and semi-intensive systems of production (Meltzoff and LiPuma 1986, Sutinen et al. 1989, Villalón et al. 1989). Extensive systems of production began to be used in the late 1960s in El Oro province where mangrove areas were cleared to construct shrimp ponds. As the industry spread to Guayas, Manabí and Esmeraldas provinces semi-intensive systems of production were also adopted. By 1985 about 35 percent of existing ponds were extensive operations, 55 percent were moderately extensive and only 10 percent were semi-intensive (Meltzoff and LiPuma 1986). The change from extensive to semi-intensive systems of production was induced by shortages of post-larvae supplies in 1984 and 1985 (Villalón et al. 1989).

Table 2.3 Wild caught and pond raised shrimp production (mt), period 1976-1985.

Year	Trawler (mt)	Farming (mt)	Total (mt)
1976	n.a.	n.a.	9,000
1977	n.a.	n.a.	8,600
1978	n.a.	n.a.	9,200
1979	7,787	4,698	12,485
1980	7,800	9,180	16,980
1981	8,000	12,100	20,100
1982	8,000	21,500	29,500
1983	8,900	35,600	44,500
1984	6,300	33,600	39,900
1985	6,023	30,205	36,228

Source: Sutinen et al. (1985) Table 5, Dirección General de Pesca.

Table 2.4 Estimated wild caught and pond raised shrimp production (1) in million pounds head off, period 1976-1988.

Year	Trawler	Farming	Total
1976	n.a.	n.a.	12.90
1977	n.a.	n.a.	12.30
1978	n.a.	n.a.	13.20
1979	11.10	6.70	17.80
1980	11.20	13.10	24.30
1981	11.40	17.30	28.70
1982	11.40	30.70	42.10
1983	12.70	51.10	63.80
1984	9.00	48.00	57.00
1985	8.60	43.20	51.80
1986	13.10	62.40	75.50
1987	15.30	98.90	114.20
1988	15.50	100.30	115.80

Source: Dirección General de Pesca, elaborated by CPC 1989.

(1) To convert to head-on or live weight, a conversion factor of 65% is used as efficiency in production, according to CPC (1989).

There are no clear distinctions between extensive and semi-extensive systems of production, and they are referred in this study as extensive systems only. Agüero and González (1991) characterized extensive and semi-intensive system of production for shrimp mariculture in Ecuador as follows. Extensive systems of production have a stocking density ranging from 10 thousand to 40 thousand juveniles per hectare per year. No supplemental feeding is used relying only bimonthly tidal water exchange to provide for the required food input. Average yield (head off) ranges between 100 and 500 kg per hectare per year. Semi-intensive systems of production are characterized by the use of nursery ponds, stocking densities ranging from 40 thousand to 120 thousand juveniles per hectare, the use of supplemental feeding, periodic mechanic water exchange. Average yields (head off) for this system are 500 to 2,200 kg per hectare per year.

b. Land use in shrimp farming.

The industry's expansion in volume produced was accompanied by a parallel expansion in surface under cultivation. A rough proxy of this expansion is the variation of authorized land concessions over time (Table 2.5). In 1976, only 439 hectares were authorized in Ecuador for shrimp mariculture.

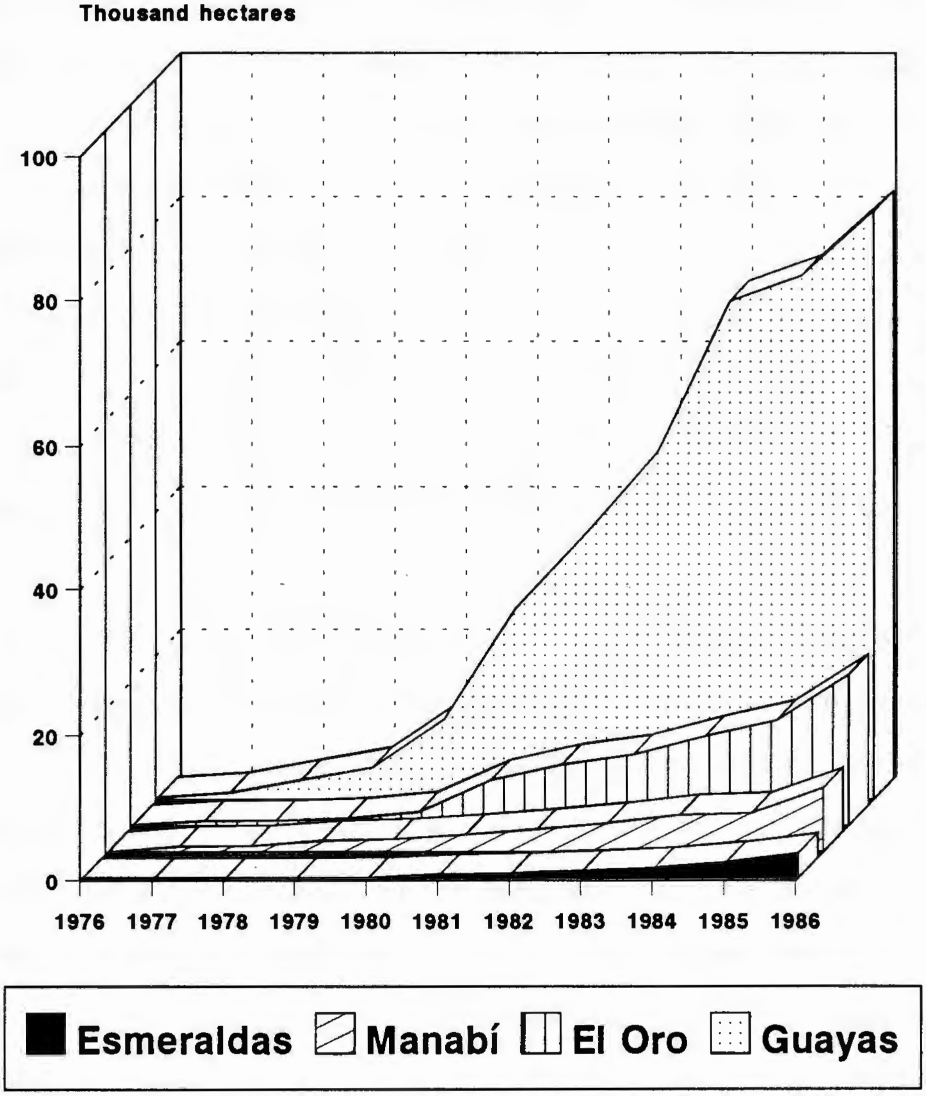
Table 2.5 Authorized land for shrimp mariculture in Ecuador, by zone in hectares, period 1976-1987.

Year	High Lands			Intertidal Zone			Total	Cum.Total
	Ha	Cumulat.	% Change	Ha	Cumulat.	% Change	Ha	Ha
1976		0.00	0.00	439.00	439.00	100.00	439.00	439.00
1977		0.00	0.00	1,906.00	2,345.00	100.00	1,906.00	2,345.00
1978		0.00	0.00	1,833.00	4,178.00	100.00	1,833.00	4,178.00
1979	1,903.00	1,903.00	27.40	864.00	5,042.00	72.60	2,767.00	6,945.00
1980	3,068.00	4,971.00	33.80	4,694.00	9,736.00	66.20	7,762.00	14,707.00
1981	10,005.00	14,976.00	42.68	10,380.00	20,116.00	57.32	20,385.00	35,092.00
1982	8,364.00	23,340.00	48.35	4,822.00	24,938.00	51.65	13,186.00	48,278.00
1983	9,439.00	32,779.00	52.66	4,530.00	29,468.00	47.34	13,969.00	62,247.00
1984	18,115.00	50,894.00	58.87	6,084.00	35,552.00	41.13	24,199.00	86,446.00
1985	10,123.00	61,017.00	59.54	5,918.00	41,470.00	40.46	16,041.00	102,487.00
1986	10,419.00	71,436.00	58.80	8,593.00	50,063.00	41.20	19,012.00	121,499.00
1987	4,921.00	76,357.00	59.20	2,554.00	52,617.00	40.80	7,475.00	128,974.00
Revocations	-6,591.00	69,766.00		-8,178.00	44,439.00		-14,769.00	114,205.00
Total	69,766.00			44,439.00			114,205.00	

Source: Dirección General de Pesca, elaborated from Camará de Productores de Camarón (1989).

By 1980, there were 14,707 hectares of land area devoted to shrimp mariculture, an impressive 3,250 percent increase. In 1981, an additional 20,385 hectares were authorized, more than doubling the total land area for shrimp mariculture. In 1984, the addition of land to the industry again peaked with 24,199 hectares authorized, the highest yearly incorporation in the decade. In the next three years, this upward trend reversed with substantial decreases in the yearly authorization of lands for shrimp mariculture. By 1987, after accounting for the loss of 14,769 hectares due to a number of revocations during the decade, the industry's legal authorized land area was of 114,205 hectares. The spatial expansion of shrimp mariculture began in Guayas, El Oro and Manabí provinces (Figure 2.2). In 1976 Guayas had the leading position with a total of 2,681 Hectares of land allocated (68 percent of the total land for mariculture). El Oro and Manabí provinces followed with 27 and 4 percent respectively of the total allocated land area. By 1980, Guayas province had consolidated its leading position with an impressive 3566 percent increase in land area allocated to mariculture (75 percent of the total land nationally assigned). The percentage of allocated land in the Manabí and El Oro provinces declined to about 12 percent of the total in each area. In 1980, Esmeraldas entered the industry with less than 0.5 percent of the total land.

Figure 2.2 Authorized land for shrimp mariculture in Ecuador, by province. Period 1976 - 1986



Source: Dirección General de Pesca, Ecuador, from Sutinen et al. (1989) and Epler (1989).

This upward trend continued until 1984 when Guayas province reached its peak with a 525 percent increase with respect to 1980. Simultaneously, it reached its highest importance in the industry with 78 percent of the total land area for shrimp mariculture (Table 2.6). At that time, El Oro province followed with 14 percent of the total land area allocated. Manabí province, with a substantially lower rate of growth, had only 6 percent of the total land area with 5,124 hectares. The incipient industry in Esmeraldas province reached almost 2 percent of the total allocation of land. Thereafter, the growth rate for Guayas province diminished relative to those of the other coastal provinces. Manabí and Esmeraldas provinces showed the steeper slope indicating an upward trend in spatial expansion (Figure 2.2).

The land allocated to shrimp mariculture in Ecuador can be classified under two broad categories: High Lands and Beach, Intertidal Zone, Land (Table 2.5). Prior to 1979 all authorized land fell into the intertidal zone. From 1979, when high lands represented 27 percent of the total land area for shrimp mariculture, until 1981, the industry's expansion was based on both intertidal zone and high land. Thereafter, there is a clear trend of allocation of more high land than intertidal zone land to shrimp mariculture. During that period both types of land were allocated at similar rates.

Table 2.6 Authorized land for shrimp mariculture In Ecuador, by province in hectares, period 1976-1986.

Year	Guayas			El Oro			Manabi			Esmeraldas			Total	Cumulat.
	Ha	Cumulat	% Change	Ha	Cumulat	%Change	Ha	Cumulat	% Change	Ha	Cumulat	% Change	Ha	Ha
1976	300	300	68.34	119	119	27.11	20	20	4.56		0	0.00	439	439
1977	615	915	39.02	559	678	28.91	732	752	32.07		0	0.00	1,906	2,345
1978	1,766	2,681	64.17	15	693	16.59	52	804	19.24		0	0.00	1,833	4,178
1979	1,706	4,387	63.17	318	1,011	14.56	743	1,547	22.28		0	0.00	2,767	6,945
1980	6,613	11,000	74.79	874	1,885	12.82	225	1,772	12.05	50	50	0.34	7,762	14,707
1981	15,210	26,210	74.08	4,379	6,264	17.70	630	2,402	6.79	456	506	1.43	20,675	35,382
1982	10,620	36,830	75.06	2,156	8,420	17.16	739	3,141	6.40	172	678	1.38	13,687	49,069
1983	11,312	48,142	76.49	1,326	9,746	15.49	859	4,000	6.36	372	1,050	1.67	13,869	62,938
1984	20,562	68,704	78.45	2,551	12,297	14.04	1,124	5,124	5.85	401	1,451	1.66	24,638	87,576
1985	3,504	72,208	76.53	2,199	14,496	15.36	283	5,407	5.73	790	2,241	2.38	6,776	94,352
1986	9,039	81,247	71.15	6,206	20,702	18.13	3,421	8,828	7.73	1,181	3,422	3.00	19,847	114,199
Total	81,247			20,702			8,828			3,422			114,199	

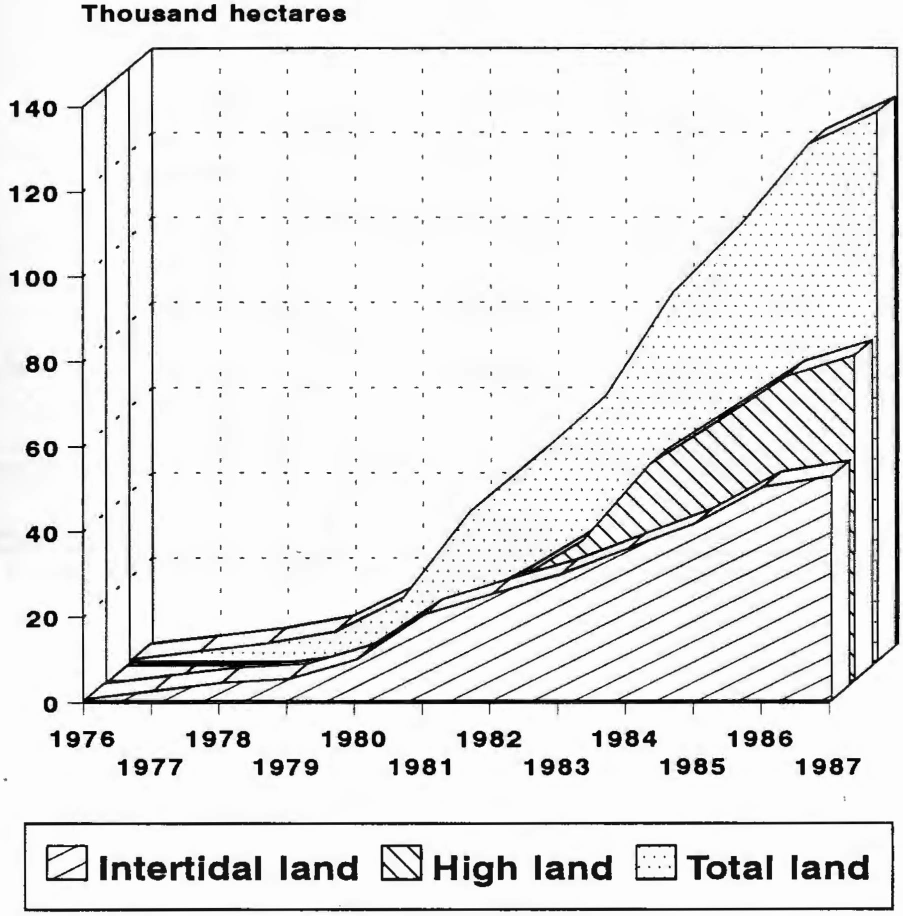
Source: Dirección Gneral de Pesca, elaborated from Sutinen et al. (1989) and Epler (1989).

By 1986, high lands devoted to shrimp mariculture represented 59 percent of the total Ecuadorean land area of 121,499 hectares. In 1987, land allocation rate diminished by about 50 percent for high land, and 70 percent for intertidal zone land (Figure 2.3).

Intertidal zone land is under government control through the Ministry of National Defense, namely the "Dirección General de la Marina Mercante y del Litoral". A lease (Concession) on the land for 10 years must be obtained in order to legally engage in shrimp mariculture. After the 10 year period the lease expires and a renewal must be obtained in order to continue the activity. The government policy on leases has been to renew existing leases but not to issue new ones (CPC 1989). This may explain the trend in expansion on high lands, which are private property and do not require leases or renewal to operate, once the permit for converting this type of land to mariculture have been issued.

Together with the allocation of high land and intertidal zone areas to shrimp mariculture it is also interesting to examine the variations in mangrove areas during the expansion of shrimp mariculture (Table 2.7). Figure 2.4 shows existing mangrove area by province for the years 1969, 1984 and 1987. In 1969 there was a total of 203,695 hectares of mangroves in the provinces of Guayas, El Oro, Manabí and Esmeraldas.

Figure 2.3 Authorized land for shrimp mariculture in Ecuador, by type of land. Period 1976 - 1987



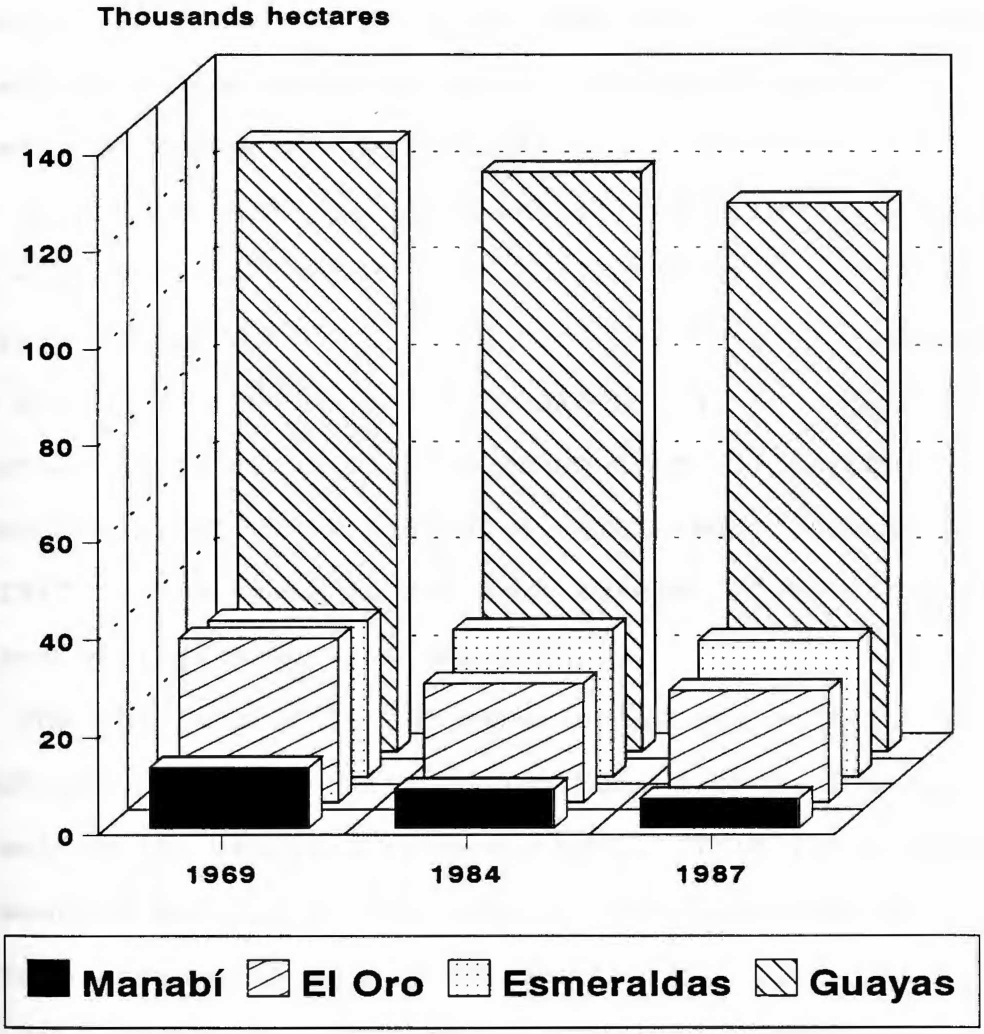
Source: Dirección General de Pesca, Ecuador, from Camará de Productores de Camarón (1989).

Table 2.7 Mangrove area in Ecuador, by province, years 1969, 1984 and 1987.

		1969	1984	1987
Guayas	Area (Ha)	125,613.30	119,526.16	113,090.30
	% Total	61.67	65.64	66.47
	Remain.%	100.00	95.15	90.03
El Oro	Area (Ha)	33,633.50	24,435.80	23,035.50
	% Total	16.51	13.42	13.54
	Remain.%	100.00	72.65	68.49
Manabi	Area (Ha)	12,415.75	7,973.41	6,000.75
	% Total	6.10	4.38	3.53
	Remain.%	100.00	64.22	48.33
Esmeraldas	Area (Ha)	32,032.55	30,152.58	28,000.55
	% Total	15.73	16.56	16.46
	Remain.%	100.00	94.13	87.41
Total Area (Has)		203,695.10	182,087.96	170,127.10
Total Remaining %		100.00	89.39	83.52

Source: Camará de Productores de Camarón, elaborated from Espinoza (1989).

Figure 2.4 Mangrove area (hectares) in Ecuador, by province.



Source: Camara de Productores de Camarón, from Espinoza (1989).

Guayas province had the largest area of mangroves, representing 62 percent of the total. El Oro and Esmeraldas provinces each had about 16 percent of the total, and Manabí had the remaining 6 percent of mangrove area. By 1984 there were 119,526 hectares of mangrove standing in Guayas, a reduction of 5 percent from the 1969 area. El Oro had 72 percent remaining of the original 1969 area, Manabí 64 percent and Esmeraldas 94 percent.

By 1987 Manabí saw the greatest reduction in mangrove area with only 48 percent left of its original area of live mangrove. El Oro had 68 percent of its original mangrove area standing. Guayas and Esmeraldas had the least reduction in mangrove with 90 percent and 87 percent, respectively, of their 1969 area remaining. Between 1969 and 1987 33,568 hectares, or 16.5 percent of the original surface of live mangroves was cut.

The province of Manabí experienced the largest reduction of mangrove area during this period, losing 52 percent of its original mangrove area. This loss, however, represented only 19 percent of the country's cleared mangrove area, with 6,415 hectares cut.

Espinoza (1989), citing sources from Camara de Productores de Camarón (CPC), shows the development of the total area of land authorized versus the actual area under production over the last two decades (Table 2.8).

Table 2.8 Land for shrimp mariculture in Ecuador, period 1975-1988. Total authorized area and actual area under production.

Year	Total area Authorized (Ha)	Total Area Under Production (Ha)
1975	63	150
1976	363	800
1977	1,655	3,000
1978	3,177	5,800
1979	5,416	6,400
1980	12,351	12,600
1981	27,951	16,600
1982	39,966	29,573
1983	52,856	49,000
1984	76,506	46,200
1985	92,303	41,547
1986	105,294	63,000
1987	113,530	55,000
1988	118,000	61,000

Source: CPC 1989, from Espinoza (1989).

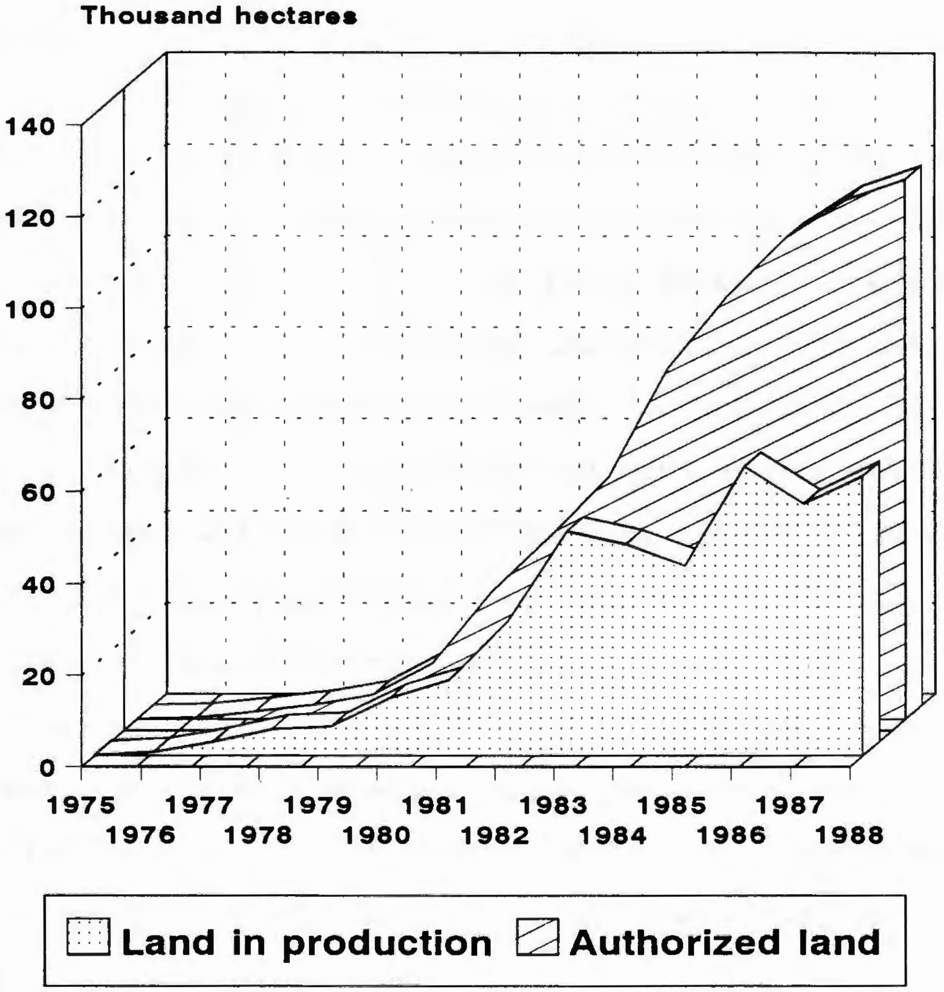
Before 1980 the actual area under production was consistently larger than the authorized surface for mariculture, as shown in figure 2.5. After 1980, the land allocated to shrimp mariculture became under-utilized and, by 1988, 49 percent of the total land allocated to shrimp mariculture was out of production.

c. Postlarvae supply.

Two main species have been adopted for shrimp mariculture in Ecuador, *Penaeus vannamei* and *Penaeus stylirostris*. Of these two only *Penaeus vannamei* has shown economically attractive returns. *Penaeus vannamei* is also the farmers' species of choice because of its ability to survive handling and resist disease, and grow in the rigorous environment existing in the ponds (Snedaker et al. 1986).

According to Villalón et al. (1989), the farming industry has four main sources of Postlarvae: 1) wild caught postlarvae purchased from middle-men or brokers; 2) wild caught Postlarvae collected by farmers from natural estuaries near the farm, such as artificial estuaries built around the farm, water intake canals, and nursery ponds; 3) purchases of hatchery-raised postlarvae; and 4) Postlarvae imports from others countries.

Figure 2.5 Shrimp mariculture in Ecuador, authorized land, and land in production (hectares), period 1975 - 1988.



Source: Camara de Productores de Camarón, from Espinoza (1989).

Historically, the most popular source of postlarvae is wild caught postlarvae purchased from brokers. These larvae come from the existing postlarvae fishery and represent 50 to 60 percent of the total postlarvae supply to the industry (Villalón et al. 1989). During the period 1976-1985 nearly all postlarvae used in shrimp mariculture came from the wild postlarvae fishery (Sutinen et al. 1989). According to Arellano et al. (1989), during the period 1986-1987 60 to 70 percent of total postlarvae supply were wild caught.

The postlarvae fishery employs postlarvae fishermen and seed brokers. Postlarvae fishermen ("Larveros") use various designs of fine meshed nets, with the push-net being the most popular. Fishing efficiency increases during the bimonthly high tides when postlarvae concentrate in creeks and along beaches. The highest catch rate occurs during a 3-4 hour period when the postlarvae must struggle against the outgoing water flow to swim-up into the mangroves. At these times a fisherman can catch 20,000 to 50,000 postlarvae per tide. Since these quantities are small and fishermen are widely dispersed along the coast, their production is collected by postlarvae brokers representing 20 to 30 fishermen and resold to pond owners (Meltzoff and LiPuma 1986, and Epler 1989).

According to Epler (1989), there are variations in the natural abundance of postlarvae along the Ecuadorean coast. There is also a seasonality pattern in the abundance of post-larvae, with catches peaking between December and March and bottoming out between May and October. During the peak season *Penaeus vannamei* represents 50 percent or more of the total catch of postlarvae (Epler 1989 and Villalón et al. 1989).

There are no consistent and reliable records on the number of fishermen engaged in the postlarvae fishery. The U.S. Department of Commerce (1981) reported 2,000 to 3,000 active fishermen in 1980. One of the most quoted estimations is that of McPadden (1986) who counted about 90,000 active fishermen in 1983. However, this is likely to be a high-end estimate (Olsen et al. 1989). Commenting on the same information, Sutinen et al. (1989) claim that many of the 90,000 fishermen may be engaged in post-larvae fishing on a part-time basis. They also add that in most production activities only a small portion of the total number of producers supply the largest share of the product.

Post-larvae price data (Table 2.9) is incomplete and difficult to interpret. When looking at seasonal influence there is consistency with respect to expected behavior. The peak season shows the lowest prices and the season of relative scarcity is marked by high prices. Intertemporal or cross year comparison, on the other hand, is more difficult to interpret. Nominal prices for the years 1984, 1985 and 1986 were relatively stable while the real prices for the same period declined (Sutinen et al. 1989).

Table 2.9 Postlarvae prices in Sucres per 1000 individuals.

Date	Beach Price (Sucres/1000)	Farm price (Sucres/1000)	Estimated Real Farm price (1) (Sucres/1000)
1980		75-100	60-180
Feb-84		450-540	160-190
Feb-85	100	400-600	110-165
May-85		1300	330
Aug-85		1800	440
Oct-85		1500	365
12/85-1/86		1200	285
Feb-86		500	120
Mar-86		700-800	

Source: Elaborated from Sutinen et al. (1989), various original sources.

(1) Index 1979 = 100.

Seasonal instability of postlarvae supply and prices have led the industry to construct hatcheries. Theoretically these facilities should allow the industry to break its dependence upon the environment for postlarvae through the development of technology and the capability of controlling the biological cycle of shrimp and, hence, the required flow of postlarvae to the ponds. Arellano et al. (1989) reports "the shrimp industry with an initial investment of approximately $ 2 billion, cannot continue to depend solely on a natural supply of larvae, which are only seasonally available. If the industry is to stabilize, the development of hatcheries is required to maintain current levels of exportation."

One of the first hatcheries constructed in Ecuador was that of Semacua in 1980 (USDC 1985, CPC 1989, Epler 1989). The hatchery "boom" started around 1984 when economic incentives appeared through an Interamerican Development Bank (IDB) industrial credit line, and funds available from FONAPRE (CPC 1989). Four hatcheries were in production by 1984 and about 14 others were in the process of construction (Epler 1989, Sutinen et al. 1989). According to the United States Department of Commerce (1985) only two of the existing facilities produced at noticeable levels, and their total production was less than 0.3 billion postlarvae. By 1985 there were between 3 an 50 hatcheries in operation (Sutinen et al. 1989). Although there were higher estimates for the 1985 production of postlarvae, the most quoted one is that of Leslie'[1] of 500 million postlarvae for 1985. This level is consistent with USDC (1985) estimates that Ecuadorean production of postlarvae would not exceed 0.7 million in 1985 and 1986. Epler (1989), citing data from CPC 1987, reported 43 hatcheries in operation, presumably in 1986, ranging from 4 to 5 million postlarvae per year, and an additional 14 facilities under construction. By 1987, there were 99 hatcheries authorized with an estimated yearly production of 7,000 million postlarvae. Of the total number of hatcheries, 55 facilities were to be located in Guayas, 25 in Manabí, 12 in Esmeraldas and 7 in El Oro. Only 55 of the total were finished and only 10 were producing (CPC 1989). Epler (1989), citing data from the Subsecretaría de Recursos Pesqueros (SRP) 1988, gave the same projected figures for 1987, but concluded that there were a total of 110 hatcheries constructed with a potential production of 8 billion postlarvae per year. He also stated that actual production might be only about 25 percent of the installed capacity.

According to Sutinen et al. (1989), during periods of supply shortage, postlarvae have been imported from several Latin American countries, the United States and even the Philippines.

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[1] See Epler 1989 page 5 and Sutinen et al. (1989) page 25.

Two principal methods to estimate the use or demand for postlarvae have been used by several authors (Epler 1989, Sutinen et al. 1989, USDC 1985, Villalón et al. 1989), based on adult shrimp production and area under cultivation. Both methods have some problems due to inaccuracy of the existing information on physical production and area under cultivation. Nonetheless, they are useful as rough estimates for the industry.

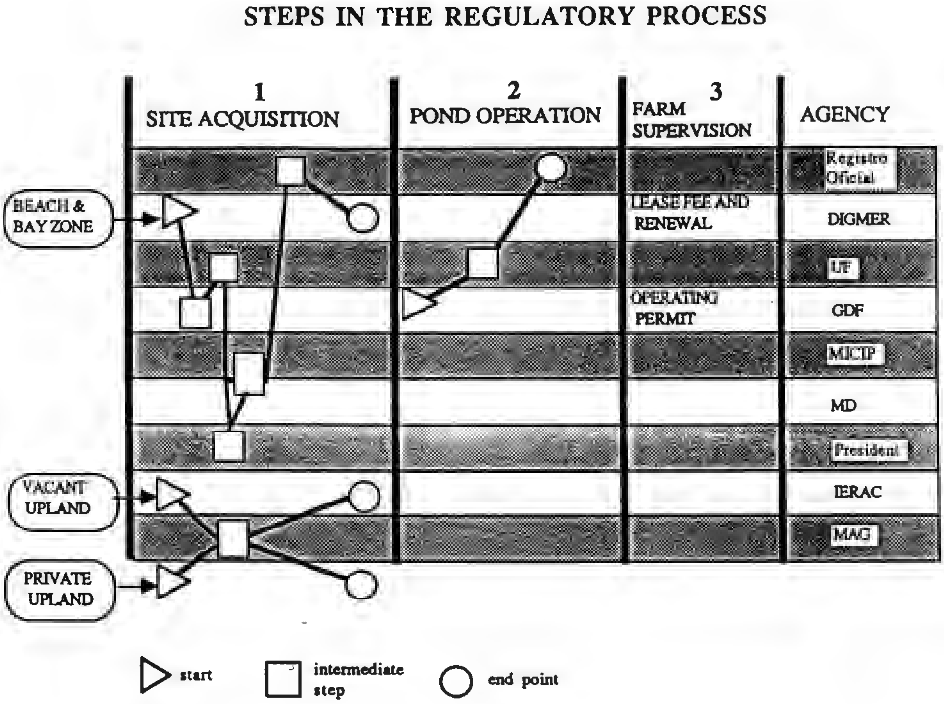
d. Legal and Institutional aspects.

Meltzoff and LiPuma (1986), applying a modified Pontecorvo model, determined that in 1984 all marine related activities of the coastal zone of Ecuador accounted for 25 to 30 percent of the country's Gross Net Product (GNP), and thus accounted for a significant share of the national wealth. Coastal zone marine activities contributing to Ecuador's GNP include offshore oil drilling, shrimp pond production, agriculture, water management, and harvesting of mangrove products. Until 1986, there was no integrated coastal and regulatory program to manage Ecuador's coastal resources (Meltzoff and LiPuma 1986). The same authors also state that concern for coastal zone management arose from the socio-economic problems posed by uncontrolled growth of the shrimp mariculture industry. The Ecuadorean government responded to this concern in 1975, with the creation of a set of regulations for the industry under the title *"Reglamento para la cría y cultivo de especies bioacuáticas"*. Significant regulations include recommendations for the use of salt flats (Article 3), a ban on the use of arable land for mariculture, the separation of shrimp farms from traditional agricultural farming (Article 4), and a ban on the destruction of mangroves for shrimp ponds (Article 24). This ministry regulation became a government decree in 1978 and an official law in 1985.

At the same time, a procedure for the establishment of shrimp farm operations was designed. The procedure established was described by Perez and Robadue (1989) as a three step process for pond owners and operators (Figure 2.6): 1) to obtain a site for the operation, 2) to obtain permission to operate the shrimp farm, and 3) to accept periodic reviews of the lease and operating permits. A large number of institutions are involved in this process, including the Dirección General del Litoral y Marina Mercante (DIGMER), the Subsecretaría de Pesca (SP), the Dirección General de Pesca (DGP), the Ministerio de Industria, Comercio, Integración y Pesquería (MICIP), the Ministerio de Defensa (MD), the Instituto Ecuatoreano para la Reforma Agraria y Colonización (IERAC), and the Ministerio de Agricultura y Ganadería (MAG).

The most cumbersome of the three steps is the acquisition of the site for operation. This step is

Figure 2.6 An outline of the regulation of shrimp farming.



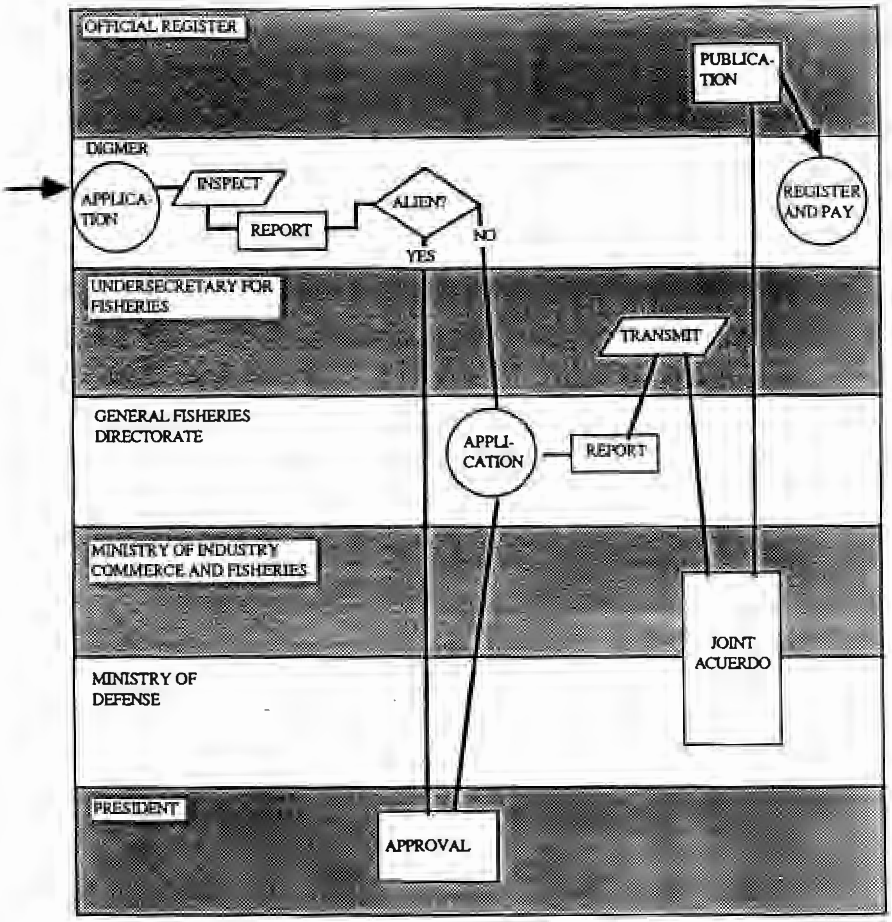
DIGMER: Merchant Marine and Coastal Directorate
UF: Undersecretary for Fisheries
GDF: General Directorate of Fisheries
MICIP: Ministry of Industry,Integration and Fisheries
MD: Ministry of Defense
IERAC: Ecuadorian Institution for Agrarian Reform and Colonization
MAG: Ministry of Agriculture and Livestock

Source: Perez and Robadue (1989).

divided in two different processes according to the type of land. For the government-owned land in the beach and bay zone (intertidal zone), there is a series of steps to be followed and permits to be obtained, described in Figure 2.7. The process for high land, either privately owned or unclaimed, is fairly simple compared to that of beach and bay zone leases.

In reference to obtaining a concession over government owned land, Meltzoff and LiPuma (1986) mention most of the previously listed institutions as being involved in the process, and added that "the separate agendas and interest of the different agencies are the main mechanism for balancing competing social, economic, or environmental factors." Along the same lines they comment that obtaining "free" concessions is "costly and time consuming", adding that the ordinary businessman can secure the concession in one to three years and that "... unofficial payments... of US$ 10,000 are by no means unusual for a 100-hectare concession". By the same token, government officials, particularly high ranking officials in agencies overseeing natural resources, obtain concessions in a much shorter time and with no unofficial monetary payments. Payment, however, is in political leverage rather than in cash.

Figure 2.7 Acquisition of leases in the beach and bay zone.



Source: Perez and Robadue (1989).

Other requirements for the establishment of a shrimp farm operation include a bank loan to finance construction, a partner able to visit the site of operation weekly, and perhaps a pond manager familiar with shrimp mariculture (Meltzoff and LiPuma 1986). Ecuadorean banks secure their loans with up to 125 percent of their value, having, in most cases, strict collateral requirements of houses and land. Government land cannot be used as collateral. According to the same authors, the easiest way of getting financing is through government financing from the *Banco de Fomento* and by making a bank official a partner in exchange for loan approvals. Private banking has much stricter policies regarding loans to bank officials and/or relatives. Meltzoff and LiPuma (1986) state that an ideal combination to establish a shrimp pond operation would be ".. to have a partner who is a government official or military officer to obtain the permits, perhaps a banker to secure the loan, and a businessman familiar with the agricultural export industry. These partnerships confer other advantages such as access to earthmoving equipment, foreign aid programs, and subsidized agricultural loans." Finally, they characterize the Ecuadorean shrimp mariculture as having a "... duality of interest maintained both by government appointees and elected officials. They are producers and exporters, and simultaneously members of the regulatory agencies."

The "*Reglamento para la cría y cultivo de especies bioacuâticas*" is basically concerned with allocation of land and, in particular with the concession of government owned land. According to Perez and Robadue (1989), specific regulations for the mariculture industry have been issued in only the last few years. Examples of these regulations are 1) R. 131-84-CNDP from the "*Consejo Nacional de Desarrollo Pesquero*" which establish policies for enterprise classification and shrimp exports, allows shrimp farmers to form joint ventures with packing plants, and awards benefits through classification; 2) D.E 1142, 1985 which establishes new regulations for the granting of classifications and reclassifications under categories A or B; 3) several reforms and regulations issued to induce industry growth including, D.E. 1312, 1982, D.L. 03, 1985, and D.E. 1062, 1985; 4) Regulation A. 123, 1985 which governs the production of hatchery-raised postlarvae and the capture of adult gravid females in their natural environment; 5) MICIP regulation (A.22, 1986) which lists which Ecuadorean products related to shrimp mariculture cannot be exported; and 6) D.E. 964, 1985 which stipulates tariff-free larvae imports.

Several authors (McPadden 1986 and 1989, Sutinen et al. 1989, Epler 1989, Meltzoff and LiPuma 1986, Perez and Robadue 1989) state that historically there have been a great number of illegally operated pond farms. The authorities have been pressing the unauthorized operators to apply for operating permits. Although there has been a surge in authorizations since 1977, currently there is no certainty about the actual area under production.

e. Processing and Marketing.

The processing and marketing sector of the Ecuadorean shrimp industry traditionally has been export oriented. Exporting began around 1954 with two packing firms, two years after offshore trawling started. According to Banco Central (1982) 2,226 mt of shrimp were exported in 1970 with a value of 1.7 million US$. By 1976, there were about 4,000 mt of shrimp exported at a value of 14.5 million US$. As volume almost doubled, the nominal value of shrimp exports increased more than eight times.

Although the packing sector initially opposed expansion of shrimp mariculture fearing a decrease in catch, shrimp farming ultimately had a positive impact on the processing and packing sectors. Before 1980, there were only about 20 packing firms and by 1985 there were over 70 firms. Sutinen et al. (1989) found no serious problems with the structure and performance of the processing and packing sectors in 1986. Shrimp production has been reasonably distributed among the increasing number of firms; during 1982-1984, 10 percent of the firms exported about 45 percent of the product by weight and value. However, Enaca, one of the largest firms, had its share of product reduced by half from 20 percent in 1980 to 10 percent in 1984. As seen in Table 2.10, in 1985 there were 69 packing firms in the country and the majority of them (48) were located in Guayas province. By 1987 Ecuador had a total of 75 packing firms with the majority of them (57) located in Guayas.

The remaining coastal provinces have a few packing plants, the number of which remained constant over this three year period.

Shrimp constituted the fourth most valuable export commodity in 1980, preceded by petroleum, bananas and cacao, traditionally the most important commodities of Ecuador. In 1983 and 1984 shrimp became the second most valuable export commodity, although in 1985 it returned to fourth position (Sutinen et al. 1989). In 1986 shrimp became the second most valuable export commodity of the country, after petroleum, in 1986 and remained there during 1987 and 1988 (CPC 1989) .

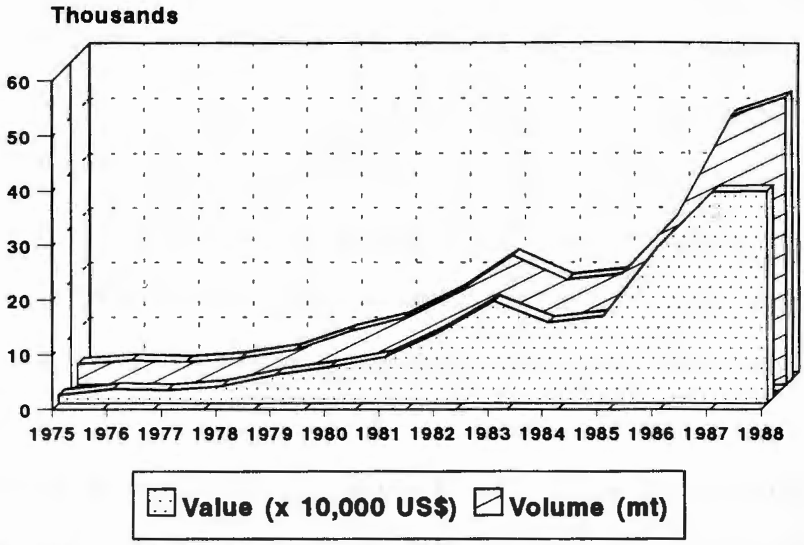
Figure 2.8a shows the variation of Ecuadorean shrimp exports in volume (mt) and value (US$) for the period 1975-1988, and also shows the estimated average price paid for exports in US$ per pound. Shrimp exports, in volume, were fairly stable during 1975-1978 at levels around 5,000 mt per year.

Table 2.10 **Number of existing packing plants in Ecuador, by provinces, years 1985, 1986 and 1985.**

Year	Guayas	Manabí	El Oro	Esmeraldas	Total
1985	48	9	9	3	69
1986	51	8	6	3	68
1987	57	8	8	2	75

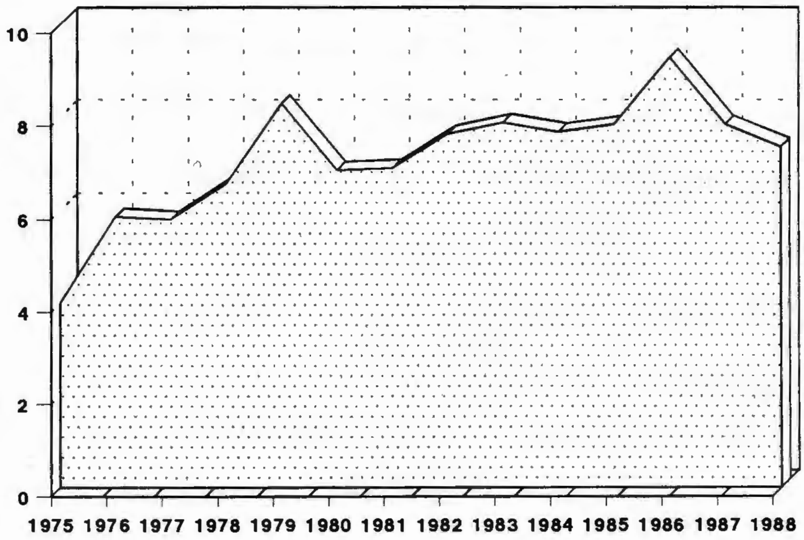
Source: CPC (1989), data from Dirección General de Pesca.

Figure 2.8a Ecuadorean shrimp exports, by volume (mt) and value (x10,000 US$). Period 1975 - 1988



Source: Banco Central de Ecuador, from Espinoza (1989).

Figure 2.8b Price of Ecuadorean shrimp exports. Period 1975 - 1988.



Source: Banco Central de Ecuador, from Espinoza (1989).

Between 1979-1983 exports in volume increased steadily reaching a maximum of 23,500 mt in 1983.

In 1984 the industry experienced a fall in the volume exported, which was recovered in the next two years. By 1986, the volume of exports had surpassed 1983 levels and continued to increase at an increasing rate through 1987, with a total of 49,000 mt. During 1988 volume exported continued to increase but at a slower rate of only 7 percent compared to the 52 percent and 59 percent for 1986 and 1987, respectively.

Behavior of the value of exports is fairly similar to volume, where 1983 show a peak at about 185 million US$ in exports. The next two years exhibited a fall in export value which later recovered and surpassed 1983 levels. By 1987 and 1988 the total value of exported shrimp was about 385 and 387 million US$, respectively.

The history of average estimated price of exports is somewhat different (figure 2.8b). During the period 1975-1979 there was a fairly constant upward trend in prices increasing from 4.01 US$/lb in 1975 to 8.3 US$/lb in 1979. Prices fell in 1980 to 6.87 US$/lb but, in 1981 prices recovered, and by 1986 reached 9.28 US$/lb. Since 1986, prices have fallen, and in 1988 the average export price was 7.37 US$/lb.

Notice that export values do not represent gross sales by exporters since payments in dollars must be converted to sucres through the Central Bank of Ecuador at an exchange rate below the free market rate. Furthermore, sales estimates, calculated by multiplying export value by the official exchange rate, do not take into account the Export Tax Credit provided to the industry by the government. By the mid 1980s this tax credit was about 15 percent of the export values (FOB) in sucres, converted using the official exchange rate. This credit was payable in a 15 month period without interest. Therefore, a common practice for exporters is to sell at 50 percent of current value (Sutinen et al. 1989).

In 1981, about 80 percent of Ecuadorean shrimp production was exported and by 1984 about 99 percent of production was shipped out of the country. The destination of these exports is mainly the U.S., which receives approximately 96 percent of total exports. The remaining 4 percent goes principally to Japan and Europe (Sutinen et al. 1989).

Several authors (LiPuma and Meltzoff 1985 and 1986, USDC 1985-1986, Sutinen et al. 1989, CPC 1989) have reported on unofficial exports, especially through Peru because of its more favorable exchange rate conditions and tax credits incentives.

f. International markets for shrimp.

Traditionally, Ecuadorean shrimp has been marketed primarily in foreign countries, particularly in the U.S. Recently, Ecuador has been expanding its marketing effort in Europe (Aquaculture Digest 1989).

The U.S. shrimp market has experienced dramatic changes in the last decade. One of the major structural changes in this market has been a shift in supply sources and an important increase in consumption of shrimp (O'Connell 1988). In 1985, shrimp accounted for 20.3 percent of the value of all seafood products consumed in the U.S. (USDC 1987). Chauvin and Roberts (1983) postulate that on a per pound basis, the value of shrimp has increased relative to most other seafood products. During 1986 and a great part of 1987, there continued to be a strong demand for shrimp products in the U.S. market. Factors contributing to this strong demand include the rising consumption of seafood in general, the relatively low price of shrimp as compared to other fishery products, consistent availability, increased marketing efforts and the shortage of other fish on the market (INFOFISH and FAPFA 1988).

One of the main components of the supply increase in the U.S. shrimp market is the increasing role played by imports. During 1971-1980 shrimp imports represented approximately 52 percent of the total U.S. supply (Chauvin and Roberts 1983). According to USDC (1987), during

1983-1986, imports represented about 70 percent of the total supply. Traditionally, Latin America has been the main supplier for the U.S. shrimp market, contributing more than 75 percent of the total. However, this situation changed and by 1986 Latin American supplies dropped to about 51 percent due to increased Asian supplies, particularly from China and Taiwan. The rapid expansion of shrimp mariculture has led to a flood of cultured shrimp into the U.S. market. In 1981, only 8 percent of U.S. shrimp imports were cultured; by 1987 30 percent were cultured (Sribhibadh 1988).

The main species of shrimp exported to U.S. by Latin America is *Penaeid* shrimp with similar characteristics to U.S. domestic shrimp. According to INFOFISH and FAPFA (1988), U.S. imports expanded by 16 percent to 148,600 mt during the first nine months of 1987. Medium sized shrimp from Ecuador (particularly size 31/35) kept the U.S. market fully supplied and took the lead among suppliers of the U.S. market, accounting for about 25 percent of the market with 37,325 mt in the first few months of 1987. Mexico followed Ecuador in U.S. shrimp imports with 24,600 mt during January-October 1987.

The most important forms of shrimp coming to the U.S. wholesale shrimp market have been shell-on raw headless, peeled, breaded and canned shrimp (Hu 1983). Raw headless shrimp is the most popular form used in restaurants and retail fish markets, representing about 64 percent of all imported shrimp in 1986. Peeled shrimp is also becoming popular, entering the wholesale market from foreign or domestic processors processing domestic or foreign product. Breaded shrimp is also becoming an important product, representing about 14 percent of total supply in 1986. Canned shrimp has decreased in popularity representing only 5 percent of the market in 1986. Imported cooked shrimp has been increasing, reaching almost 9 percent of total imports in 1986 (USDC 1987). According to O'Conell (1988), the product form demanded by the market is changing as a result of changing tastes of consumers, implying realignments of wholesale market demand.

g. Present Situation of Shrimp Mariculture in Ecuador.

The Ecuadorean shrimp industry produces 76 percent of the western hemisphere's total shrimp production. Shrimp is the most important source of foreign exchange for the country after oil. According to the National Fisheries Institute of Ecuador, in 1990 the industry produced a total of 76,7500 mt of head-on shrimp generating a total of $ 340 million US of exchange earnings in exports (INP 1991). Ecuador ranks as the second world exporter and as the fourth world producer of cultured shrimp (Aquaculture Digest 1991). In 1991 the El Niño returned and Ecuador produced a record 100,000 mt of head-on shrimp, thus resuming its position as the number one supplier to the US market and exporting 30 percent of its production to Europe. Total export earnings reached $ 420 million US in 1991 (Fitzgerald 1992). The INP also estimates that the shrimp industry in Ecuador gives employment to approximately 250,000 people in the different activities related to production and marketing.

Physical Production and Production Systems.

The shrimp industry and farming sector has significantly expanded since its beginning, comprising in 1989 approximately 1,500 farms, 71 packing plants, 80 hatcheries and 120 export companies (Aquaculture Digest 1991).

According to INP (1993), 91 percent of 1990 shrimp production came from shrimp farming, 8 percent from the trawling fleet and 1 percent from the small-scale fishing sector.

Shortages in postlarvae supplies led to changes in management strategies. The semi-intensive system of production is the most important in Ecuador. It yields about 60 percent of total farm production in spite the fact that it represents only 40 percent of the land in production. In 1990, intensive systems of production were still conducted on an experimental basis by less than 1 percent of the shrimp farms (Agüero and González 1991). Intensive system of production in Ecuador are characterized by stocking rates ranging between 80,000 to 500,000 juveniles per hectare per year, yields range between 2,200 and 7,300 kilograms per hectare per year, and supplemental feeding, mechanical water exchange and aeration systems are required (Agüero and González 1991).

Land use in shrimp farming.

CLIRSEN (1992) defines a portion of the coastal zone as the area of influence of mangrove ecosystems, and estimate it to be of approximately 314,000 hectares. This area of influence may be divided in 160,000 hectares of mangrove areas (51 %), 145,000 hectares of shrimp ponds (46 %) and 6,000 hectares of salt flats (CLIRSEN, 1992). By 1987 a total of 118,000 hectares of shrimp ponds had been constructed along the Ecuadorean coast. Of this total, 38,500 hectares were located in salt flats and 28,500 hectares in converted mangrove swamps (Southgate 1992). Between 1987 and 1991 approximately 13,000 hectares of mangroves were converted to other uses. Thus, approximately 40,000 hectares of mangroves have been converted since 1969 for several purposes (CLIRSEN 1992). In 1991 sixty four percent of the land allocated to shrimp mariculture was located in El Guayas province, 22 percent in El Oro province, 9 percent in Manabí province and the remaining and the remaining 5 percent in Esmeraldas province.

Postlarvae supply.

The shrimp mariculture industry has several sources of post-larvae, but the two most popular are the postlarvae fishery and hatcheries. Supplies of post-larvae are highly variable, depending on season and changing climatic conditions (El Niño phenomenon), and geographical location (Epler 1989).

Wild postlarvae availability in 1988 through April 1989 decreased after the recovery exhibited in 1986-87. This is reflected in higher prices, an increasing number of unstocked ponds and lower production compared to previous years. The 1989 production dropped 40 percent compared to that of 1988 (CPC 1989, Aquaculture Digest 1989, and Chua 1990).

The expansion of the shrimp fishery along with the high variability of postlarvae supply caused the expansion of hatcheries. Aquaculture Digest (1989) claims 80 hatcheries existed in 1989, although it did not specify how many were actually producing. Chua (1990) estimates there are about 100 hatcheries of varying capacities (20 to 200 million postlarvae per month), most of which are modern but only a few producing at full capacity. Most hatcheries produce at 25 to 50 percent of their designed capacity.

3. Mangrove areas, shrimp stocks and shrimp farming.

Several authors have shown the existence of a relationship between the amount and quality of mangrove areas and the abundance of certain marine species including penaeid shrimp (Turner 1977, Boesch and Turner 1984, Pauly and Ingles 1988, Turner 1989, Twilley 1989). It is known that shrimp begin their life cycle in open seas where they spawn, during larval stages they drift with currents towards the coast, and during their post-larval stage enter the lower-salinity estuarine waters with the help of tidal currents (Snedaker and Getter 1985, Turner 1989). In the estuaries they seek nutrient-rich sustrates (e.g. mangrove roots) where they eventually become bottom dwelling individuals growing in a environment rich in food and providing shelter against predators (Odum et al. 1982., Snedaker and Getter 1985, Turner 1989). There is sufficient knowledge to demonstrate that destruction and degradation of mangrove ecosystems have an impact in the abundance of shrimp stocks, among others (Turner 1989 and Twilley 1989).

Shrimp mariculture makes use of mangrove areas and other coastal intertidal zones, and is an activity which significantly influences the ecosystem and is reciprocally influenced by it. According to Twilley (1989), the shrimp mariculture industry and the ecosystem that sustains it are linked in two main directions. First, the ecosystem influences shrimp mariculture through changes in water quality and the availability of shrimp postlarvae. Second, shrimp mariculture influences ecosystem through conversion on mangrove areas and the discharge of organic and inorganic effluents into the ecosystem.

In summary, conversion of mangrove areas into shrimp ponds, among other uses, has a significant impact upon the ecosystem. In turn, negative impacts in the ecosystem affect those activities based on the use of natural resources located in it. Efficient use of mangrove areas and their associated natural resources therefore has to account for such relationships. In the next chapter a methodological approach which internalizes these effects is adopted to construct a bioeconomic model to measure net benefits form alternative uses of mangrove areas.

CHAPTER III

BIOECONOMIC MODEL FOR ALTERNATIVE USES OF MANGROVE AREAS IN ECUADOR

A.- METHODOLOGICAL APPROACH.

The centerpiece of this work is a mathematical model integrating biotechnical, ecological and economic factors which determine the characteristics of the economic activities competing for the use of mangrove areas. Standard concepts of natural and environmental resource economics and biological population dynamics are combined to determine social net benefits generated by alternative uses of mangrove areas.

The problem at hand is to determine the best intertemporal allocation of mangrove areas and the natural resources associated with them among alternative uses, in such a way that generated net benefits are maximized. Natural and environmental resource economics has traditionally resorted to capital theory to cope with this kind of problem (Clark 1976, Clark and Munro 1982, Johanson and Lofgren 1985). Expressed in this way the problem is addressed as the determination of the rate of resource exploitation which maximizes the present value of net benefits generated. Specifically, it is to determine the optimal rate of conversion of mangrove areas into shrimp mariculture and the optimal harvest rate of associated natural resources.

Tropical coastal areas, and mangrove ecosystems in particular, are intricate and delicate systems which influence the production processes based upon them. This influence, although always present, is rarely recognized by most producers since they are only concerned with maximizing net benefits for their own unit of production and do not account for the global impact of the industry. The economic concept of incorporation or internalization of externalities was applied to address this issue.

Monetary returns from use of mangrove areas are not the only kind of benefits derived. Other non-market values, such as benefits derived from natural/ecological functions performed by mangrove areas, are also considered in estimating total benefits generated by alternative uses of this ecosystem. These benefits are not perceived as monetary payments although they can be valued in monetary terms, such as the avoided cost of damages produced by sea storms. The basis for the model used to represent alternative uses of mangrove areas was laid out by Agüero and González (1991, 58p.). Their model follows neo-classical economics but it further incorporates benefits derived from sources other than goods and private or public services. Namely, there is an attempt to incorporate those benefits derived from the natural functions being performed by natural and environmental resources. The approach adopted is to view coastal tropical natural and environmental resources, such as mangrove areas, as supporting not only the production of goods (e.g.; wood poles, charcoal, firewood, shellfish and finfish, among others) and the supply of services (e.g.; transport, scenery for tourism, habitat for human settlements, etc), but also the performance of important natural/ecological functions such as wind and storm protection, flood control, nutrient and sediment retention, and groundwater recharge and discharge. Furthermore, mangrove ecosystems are used or exploited in two ways: a) the sustainable use of mangrove areas in their natural state by economic sectors such as forestry and estuarine fisheries, and b) the conversion of mangrove areas into alternative uses of land and water by economic sectors such as shrimp mariculture which convert them into shrimp ponds. Agüero and González (1991, 58p.) present a model which represents total, per hectare, net benefits society derives from the use of mangrove areas as the summation of net benefits generated by a) using mangrove areas in their natural state, b) developing economic activities in converted mangrove areas, c) performing natural/ecological functions by existing mangrove areas. It is also necessary to add to the above the negative or positive net economic impact of bio-technical externalities arising from converting mangrove areas into other uses, in this case shrimp mariculture. Thus, total net benefits may be mathematically expressed as follows.

$$NB(L) = MG(M(L)) + NF(M(L)) + SM(L) \pm E(L) \tag{1}$$

where:

$\overline{M}$: the amount of existing mangrove areas, in hectares.

L : the amount of converted mangrove areas, in hectares.

MG(M): net benefits (US$), generated by using mangrove areas in their natural state. Associated artisanal coastal fisheries and forestry are considered in this model[1].

NF(M): benefits (US$), derived from the natural/ecological functions performed by existing mangrove areas[2].

SM(L): net benefits (US$), generated by economic activities developed in converted mangrove areas.

E(L) : net economic value (US$) of biotechnical externalities arising from the conversion of mangrove areas.

Notice that:

$$M = \overline{M} - L \tag{2}$$

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[1] Examples of this are presented in section 3.2

[2] Examples of this are presented in section 3.1

where:

$\overline{M}$: is the original total mangrove area, in hectares.

Thus, equation (1) may be re-written as:

$$NB(L) = MG(\overline{M}-L) + NF(\overline{M}-L) + SM(L) \pm E(L) \tag{3}$$

The nature of the problem at hand is that of a non-linear dynamic optimization process, which may be addressed using a mathematical programming approach. Mathematical programming techniques are applied to solve problems seeking to determine the best value (maximum or minimum) for a certain function subject to a number of conditions or restrictions (Hillier and Lieberman 1974, Salkin and Saha 1975, Harvey 1979 and Dykstra 1984). Mathematical programming techniques have a wide range of applications for agriculture, industrial management, engineering and government or military purposes (Harvey 1979). Examples of problems to which mathematical programming has been applied are transportation, product mix, inventory control, machine loading, corporate short term planning and optimal feeding schedules for farming (Salkin and Saha 1975). All the above are cases where there is either a need to maximize output or benefits subject to resource or budget constraints, or a need to minimize costs subject to certain levels of output or benefits. Thus, mathematical programming is an appropriate technique to reach the objective of determining the best alternative use of mangrove areas subject to various biotechnical, ecological and economic constraints.

The General Algebraic Modelling System (GAMS) is a general and accessible mathematical programming software package. This readily available commercial software consists of a mathematical modelling system (GAMS 2.05), a modelling language and several linear, non-linear and integer programming solvers. In this case the GAMS/MINOS modules for non-linear optimization programming was used under a dynamic framework[3].

B.- THEORETICAL MODEL.

This section describes the economic principles and assumptions to be considered in constructing the model representing the alternative uses of mangrove areas.

The model presents the use of mangrove areas under different environmental, economic and institutional conditions. This model theoretically represents the development of alternative uses of a tropical coastal mangrove ecosystem and defines a methodological approach to determine the best alternative use of such ecosystems, that is, the combination maximizing net social benefits generated by the use of mangrove areas by different economic sectors (e.g., forestry, shrimp mariculture and coastal artisanal

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[3] MINOS 5.2 (Modular In-core Non-Linear Optimization System) was developed by the Department of Operations Research at Stanford University.

fisheries). Thus, this model estimates net benefits generated by alternative uses of mangrove areas under different bio-technical, economic and institutional conditions. For this purpose three *scenarios* representing increasing degrees of intervention are analyzed: a) open access, in which firms in all three economic sectors operate under free entry to and exit from a given activity (i.e., current management policy), b) limited entry to shrimp mariculture, in which both forestry and coastal artisanal fisheries continue to operate under open access conditions, but entry to shrimp mariculture is regulated by management institutions seeking to maximize social net benefits generated by this activity (i.e., a partial level of management intervention), and c) limited entry to all three economic sectors, in which access to all three economic sectors and harvest of fish and mangrove trees is controlled by a management institution seeking to maximize social net benefits generated by the alternative uses of mangrove areas (i.e., full level of management intervention).

The *biotechnical* conditions under which firms operate refer to the consideration or disregard of one of the most relevant technological externalities arising from the undertaking of some of the economic activities included in the analysis, namely, the negative impact arising from converting mangrove areas into shrimp ponds.

The model is calibrated with information which represents the average *economic conditions* which reflect the prevailing situation for the economic sectors considered in the analysis. Additionally, two more economic conditions, pessimistic and optimistic, are simulated in order to determine the model's responsiveness to different situations and, simultaneously, to identify which information is critically necessary when applying the model to actual specific case conditions. The pessimistic condition is depicted by either low product price and constant production costs, or constant product price and high production costs. The optimistic condition is depicted by high product price and constant production costs, or low production costs and constant product price.

Net benefits generated by the alternative uses of natural renewable and environmental resources (ecosystems as such) are estimated as the sum of consumers' and producers' surplus and resource rent obtained by the economic activities exploiting or using them and tax revenues. Total net benefits generated by the best uses of a mangrove area are measured by the maximum of the sum of net benefits generated by all economic activities taking place in and using that ecosystem, plus the value associated with natural functions of existing mangrove areas.

1. Bio-technical externality.

According to Boesch and Turner (1984), Snedaker and Getter (1985), Pauly and Ingles (1988), Turner (1989) and Twilley (1989), it is possible to show a general level of dependence between the number of existing mangrove areas and the abundance of marine species which are related to the tropical estuarine ecosystem in some stage of their life. These authors have shown a positive relationship between them, indicating that whenever the existing mangrove area declines the stock abundance of such species declines.

In this modeling effort it will be assumed that a reduction in mangrove areas due to conversion into shrimp ponds will affect the stock abundance of species supporting the coastal artisanal fisheries. As an approximation, it is assumed that the carrying capacity parameter of the ecosystem (K) is exponentially related to the amount of existing mangrove areas[4]. In other words, K has a negative non-linear relationship with the level of mangrove areas converted into shrimp ponds. This is mathematically expressed as

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[4] In ecology, carrying capacity is a concept denoting a point of equilibrium in the population size of living organisms induced by the competition among individuals and, conditions and characteristics of the ecosystem supporting that population. At this point, the population can do no better than replace itself each generation (Begon and Mortimer 1981). Thus, here carrying capacity is defined as the capacity of a certain ecosystem to support a certain level of life (population size).

$$K(L) = K_m + \delta(\overline{M} - L)^2 \qquad (4)$$

where

K_m : is the minimum carrying capacity level associated with a situation where almost all mangrove area have been converted to shrimp ponds.

δ : parameter indicating how fast carrying capacity declines with respect to the level of conversion of mangrove areas.

2. Scenarios I and II (without and with tax on revenues).

This first scenario assumes mangrove areas to be public resources exploited under a regime of open access for all three activities: shrimp mariculture, forestry and coastal artisanal fisheries. Though initially there are no property rights over any plot of land in the mangrove area, once they are converted into shrimp farms, farmers claim exclusive use rights and limit access by others to converted land. Under open access conditions in fisheries, fishing units will enter the activity whenever there are profits to be made. Forestry also operates under open access conditions where forest harvesters have no exclusive rights to any given plot of land per se. Forest harvesters are assumed to operate in similar fashion to fishing units, exploiting the biological stock (i.e., mangrove forest) as soon as the individual trees reach commercial age.

The following assumptions about the firm are made in this scenario: i) there are no barriers to entry to or exit from each economic activity; ii) labor and capital inputs for all firms are remunerated according to the opportunity costs of the marginal inputs; iii) there is no price discrimination among firms; iv) there are differences in efficiency among firms; that is, labor and capital may be combined into production units using different amounts of equipment, they may have a different number of team members employed, a different production time, or a different level of operating costs; and v) every individual firm takes the natural resource stock size as given.

a. Forestry and coastal artisanal fishery.

Under open access conditions, individual firms enter the activity as long as there are profits to be made. This leads to a bioeconomic equilibrium in which resource rent is dissipated, and where the marginal firm operates at a level for which total revenues (TR) are equal to total costs (TC). Thus, net benefits generated by each economic activity (fishery and forestry) will be the summation of the consumers' and producers' surplus generated at the open access bioeconomic equilibrium.

Net benefits are determined by the interaction among technological and economic factors, as well as by the renewable characteristic of the stock under exploitation (e.g., mangrove forest and or coastal-estuarine fish). Thus, it is important to clarify some notions about their population dynamics.

Bio-technical model.

The most simple models used to represent both resource stocks, fish or trees, generally view them as a lumped parameter model which describes growth of the biomass of the entire stock, ignoring its age composition. The mathematical model most frequently applied to represent this behavior is a logistic growth curve (Gordon 1954, Schaefer 1954, Ricker 1975, Clark 1976, Anderson 1977, Hyde 1980, Johnson 1980, Newman 1983, Cunninghan et al. 1985, Johansson and Löfgren 1985, among others). The population size of and unexploited stock is given by

$$X(t) = \frac{K}{1-\left(1-\frac{K}{X_0}\right)e^{-rt}} \tag{5}$$

where:

r : the intrinsic growth rate of the biological stock, fish or mangrove trees.

K : the ecosystem's carrying capacity, in weight or volume.

X : the population size, in weight or volume.

t : the t-th time period.

X_0 : population size a time t=0

The net rate of natural growth is represented by

$$\frac{dX}{dt} = rX\left(\frac{K-X}{K}\right) = G(X) \qquad \textbf{(6)}$$

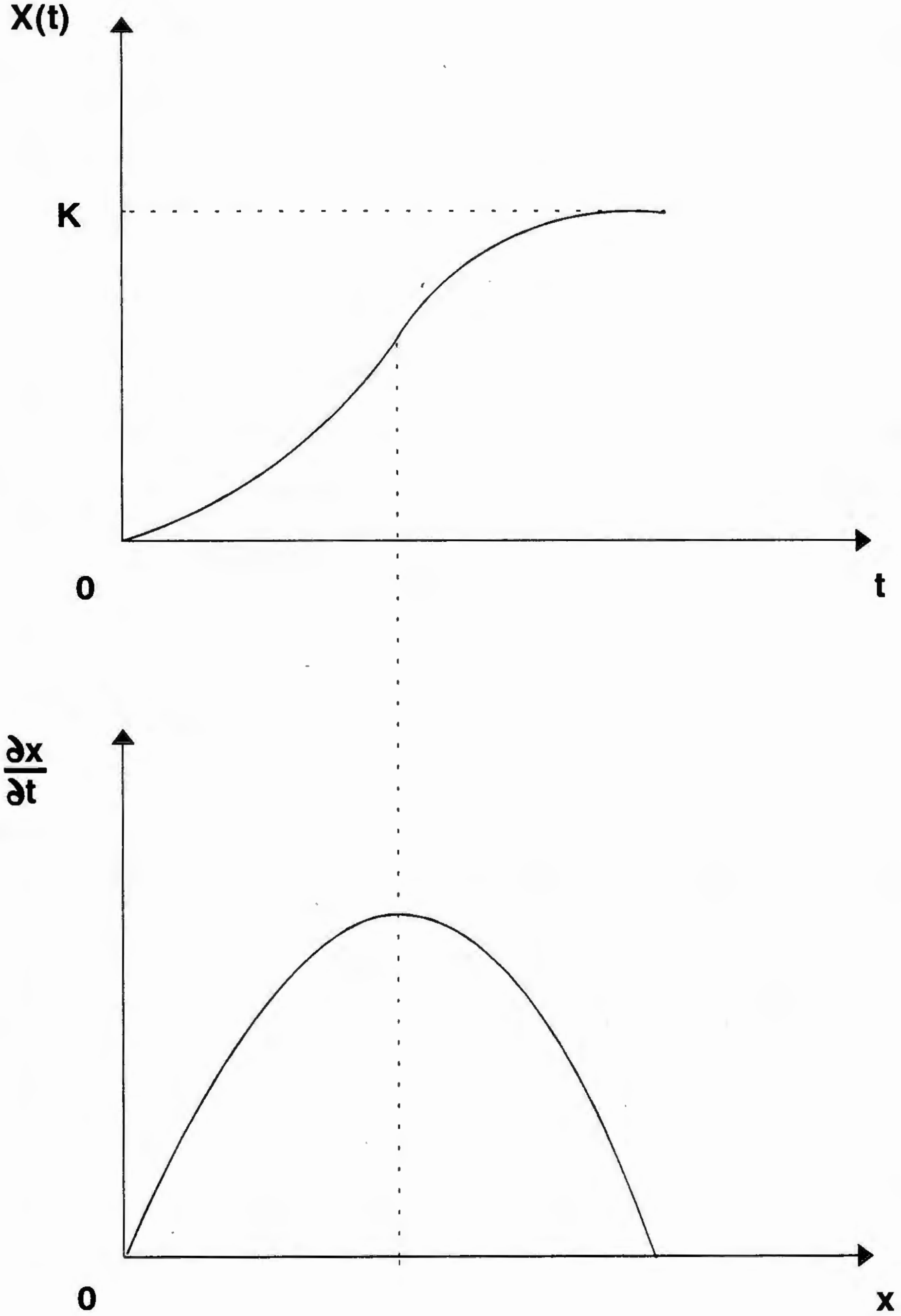
where

dx/dt : total derivative of stock size with respect to time.

Equations (5) and (6) represent the population's dynamics when unexploited, depicted in Figure 3.1 as the population size over time and its corresponding growth rate.

To exploit or use natural resources people combine capital, labor and technical knowledge in order to extract and use the resources as final goods or inputs, with or without transformation. Physical yield (output) is obtained from a combination of technology and the biological characteristics of the resources in use. Production functions are the functional relationships which represent output depending upon inputs and resource dynamics.

Figure 3.1 Population dynamics of Natural Renewable Resources.



Following Sutinen (1985(?) 41), the production function for a fishing unit or firm (also applicable to forestry under open access conditions) may be represented as the combination of labor, capital and stock size. Mathematically it is represented by the following equation:

$$q = q(l,k,X) = f(l,k) * X \tag{7}$$

where:

q : the firm output (catch of fish or harvest of trees) in weight or volume.

l,k : labor and capital as inputs for production.

f(l,k): is the production function for fishing/logging mortality.

A specific functional form for (7) is

$$q = aeX \tag{8}$$

where:

e : is the effort of the firm defined as a combination of l and k such that ae=f(l,k).

a : is the coefficient relating the level of effort to the level of output. It is defined in fisheries as the catchability coefficient.

The production function for the industry may be defined as the aggregate output of the individual firms operating.

$$Q = AEX \tag{9}$$

where:

A : is equal to a, the coefficient relating effort level to output.

E : level of effort applied by the industry, and it is estimated as the summation of the n different firms operating under open access,

$$E = \sum_{i=1}^{n} e_i$$

The change in an exploited population is

$$\frac{\partial X}{\partial t} = G(X) - Q \tag{10}$$

The sustainable yield for the industry (equation 9) is determined under biological equilibrium conditions, which occurs when harvest equals the growth of the resource stock, after a long period of applying a certain level of effort.

$$G(X) = rX\left(1-\frac{X}{K}\right) = Q \qquad \textbf{(11)}$$

Then, solving for X in equation (8) and replacing in the equilibrium condition, yields:

$$SY = KAE\left(1-\frac{AE}{r}\right) \qquad \textbf{(12)}$$

which is the sustainable yield function for the industry.

Bioeconomic model.

Under open access conditions, the natural resources (fish or mangrove trees) are exploited by a varying number of users which do not have the right to exclude others from using the resources. As soon as the individuals of the biological stock (fish or mangrove trees) reach commercial age, each firm attempts to harvest them first. And, new users will enter the activity as long as there are profits to be made. Thus, there is no incentive for long-run profit maximization, as opposed to current profit maximization. Under open access: a) resources are harvested as soon as their market price is greater or equal to their private marginal cost of harvest, b) firms enter the activity as long as there are positive net returns to be captured, and d) no resource regeneration efforts (stocking) are conducted.

Bioeconomic equilibrium under open access conditions is characterized by a situation where the marginal firms operate at a level where total revenue (TR) equals total cost (TC); in other words, where marginal cost equals market price. Again, net benefits are estimated as the sum of consumers' and producers' surplus generated by the industry operating at bioeconomic equilibrium.

Producers' surplus (PS) is defined by Copes (1970, 1971) as a "quasi-rent" received by the intramarginal firms, due to the fact that their opportunity costs are lower than the average market revenue at which the market is cleared (market price). It is attributable to a higher efficiency of these intramarginal firms. In figure 3.2, PS is given by the area ABP_o, which is the area under the market price and above the stock-constant supply curve at open access, $S(\overline{X}_{OA})$.

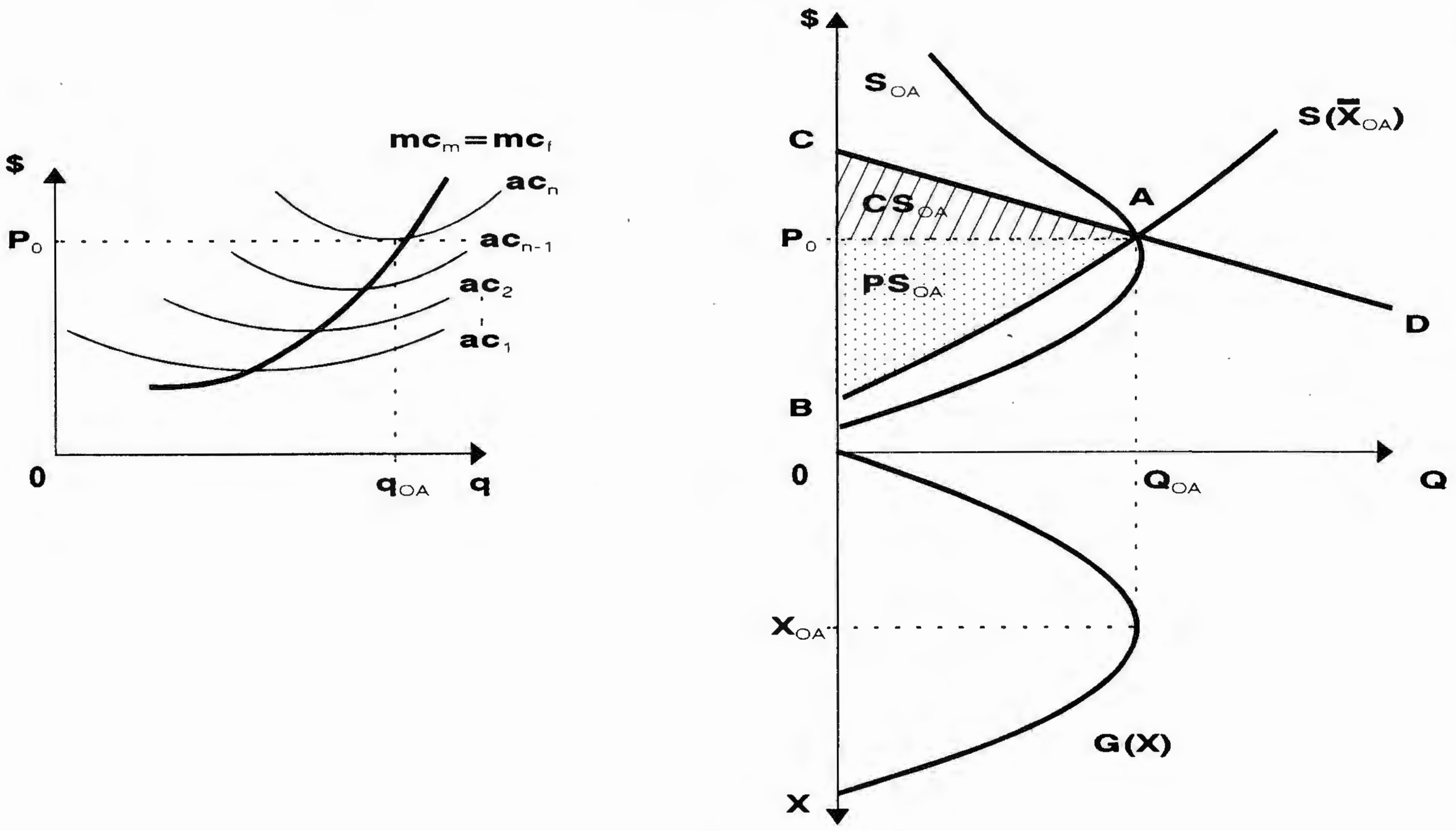
For the industry, producer's surplus is given by

$$PS = TR(Q) - TC(Q,X) \qquad \textbf{(13)}$$

where:

TR(Q):	total revenues as a function of the industry's output level.
TC(Q):	total cost of production as function of the industry's output level and associated biological stock size.

Figure 3.2 Consumer and Producer Surplus under Open Access in Fishery and Forestry.



Let TC(Q,X) represent the total cost function for the industry, a quadratic expression depending upon output level and stock size,

$$TC(Q,X) = C\frac{Q}{AX} + D\left(\frac{Q}{AX}\right)^2 \tag{14}$$

where:

Q : output (ton or m^3) for the industry.

X : biological stock size as defined in equation (5).

A : technical coefficient indicating harvest efficiency, called catchability coefficient in fisheries economics.

The two conditions for bioeconomic equilibrium at open access are

$$P_0 = TC_Q(Q,X) \text{ and } Q = G(X) \tag{15}$$

Where $TC_Q(Q,X)$ is the marginal cost of harvesting, determined by partially differenciating total costs with respect to the harvest rate (Q). The marginal cost of the industry, which represents the stock-constant supply curve, is given by

$$TC_Q(Q,X) = \frac{C}{AX} + 2D\frac{Q}{(AX)^2} \tag{16}$$

Thus, applying the first condition for bioeconomic equilibrium,

$$p_0 = \frac{C}{X} + 2D\frac{Q}{X^2} \tag{17}$$

And solving for Q and re-arranging terms gives

$$Q = \frac{AX}{2D}(AP_0X-C) \tag{18}$$

Applying (18) to the second condition and solving for the stock size at open access equilibrium, yields

$$X^{OA} = K\left(\frac{2Dr + AC}{A^2P_0K + 2Dr}\right) \tag{19}$$

Recall, however, that carrying capacity (K) is a function of the quantity of mangrove areas converted into shrimp ponds. Thus, the stock size at open access equilibrium is also a function of the level of conversion.

$$X^{OA}(L) = \left(K_m + \delta(\overline{M}-L)^2\right) * \left(\frac{2Dr + AC}{A^2P_0\left(K_m + \delta\,(\overline{M}-L)^2\right) + 2Dr}\right) \tag{20}$$

Substituting equation (19) into equation (17) and combining with equation (11), producer's surplus can now be estimated as

$$PS^{OA}(L) = \frac{r}{A}\left(1 - \frac{2rD + AC}{A^2K(L)\,p_0 + 2rD}\right)\left[Ap_0K(L)\,\frac{2rD + AC}{A^2K(L)\,p_0 + 2rD} - C - \frac{rD}{A}\left(1 - \frac{2rD + AC}{A^2K(L)\,p_0 + 2rD}\right)\right] \quad \textbf{(21)}$$

Consumers' surplus, $CS^{OA}(L)$, is estimated as the area ACP_0, the area under the demand curve and above the average market revenue at which the market is cleared (market price) under open access conditions (Figure 3.2). Let the demand for fishery or forestry products be represented by the following equation.

$$Q^D = u - vP_0$$

and price function is: **(22)**

$$P_0 = \frac{U}{V} - \frac{Q^D}{V}$$

Then, consumer's surplus may be expressed by the following equation.

$$CS^{OA}(L) = \left(\frac{U}{V} - p_0(Q)\right)\frac{Q^{OA}(L)}{2} \quad \textbf{(23)}$$

Thus, total net benefits generated by forestry and coastal artisanal fisheries under open access, is equal to the combined consumer and producer's surplus, re-expressed as

$$MG\left(Q_i^{OA}(L), X_i^{OA}(L)\right) = \frac{r}{A}\left(1 - \frac{2r_iD_i + A_iC}{A_i^2K_i(L)\,p_{0i}(Q) + 2r_iD_i}\right)$$

$$\left[A_ip_{0i}(Q)\,K_i(L)\,\frac{2r_iD_i + A_iC_i}{A_i^2K_i(L)\,p_{0i}(Q) + 2r_iD_i} - C_i - \frac{r_iD_i}{A_i}\right. \tag{24}$$

$$\left.\left(1 - \frac{2r_iD_i + A_iC_i}{A_i^2K_i(L)\,p_{0i}(Q) + 2r_iD_i}\right)\right] + \left[\left(\frac{U_i}{V_i} - p_{0i}(Q)\right)\frac{Q_i^{OA}(L)}{2}\right]$$

where:

i : the i-th economic activity using mangrove areas in natural state.

i=1 forestry, i=2 coastal artisanal fishery

b. Shrimp Mariculture.

For shrimp mariculture there are three main natural resources to be considered: mangrove areas in their natural state, shrimp stock, and land converted from mangrove areas. Mangrove areas in their natural state are considered to be under open access, where each firm converts them into shrimp ponds as long as there are net benefits to be captured. Once mangrove areas are converted to shrimp ponds they effectively become private property with exclusive rights of use. Thus, shrimp mariculture firms have incentives to maximize long-run profits on converted land. As the entrance of firms to the activity increases, less accessible and more distant hectares of mangroves are converted into shrimp ponds. Thus, as more firms enter the activity, the cost of production increases for the marginal hectare.

Shrimp exports in Ecuador have been normally subject to an indirect tax on revenues. This indirect tax on revenues is collected through the imposition of an official exchange rate on exports which is lower than the market exchange rate. Thus, two submodels to represent the shrimp industry will be used: one which includes a tax on revenues and one without the tax.

Bio-technical model.

Since net benefits generated by each firm are determined by growing and harvesting shrimp, it is important to look at its population dynamics. Commercial aquaculture is based on the production of a certain number of individuals which are stocked in ponds or cages, and which are grown to a certain marketable age and size. The simplest biological models portray a biological stock in aquaculture as a population of even-aged individuals which are grown for a certain period, throughout which they experience a gain in weight, often with the help of additional feed, and during which the total number of individuals decreases due to natural mortality. Bjorndal

(1990) adapts the Beverton-Holt model to mathematically express this process using a combination of two equations:

i) The number of individuals in-pond at any time.

$$N(t) = Re^{-mt} \tag{25}$$

where:

R : the number of individuals, shrimp post-larvae in this case, stocked into shrimp ponds at t=0.

m : the instantaneous natural mortality rate of shrimp, which is assumed to be constant for the growing period.

t : the t-th period of time.

ii) The change in individual weight of shrimp at any time, which is considered to be a function of: a) individual weight, b) the number of individuals in-pond (density), and c) the quantity of feed available.

$$w_t = g(w(t), N(t), F(t)) \tag{26}$$

where:

w(t): shrimp individual weight at time t.

N(t): number of individuals in-pond at time t, $g_N < 0$.

F(t): quantity of feed available at time t, $g_F > 0$.

Following Bjorndal (1990), growth may be expressed only as a function of time, $w_t = g(t)$, presupposing a certain in-pond density and feeding path. Thus, the individual weight of shrimp at harvest time may be expressed as:

$$w(t) = w(0) + \int_0^t w'(u)\,du \tag{27}$$

where:

w(0) : shrimp individual weight at t=0.

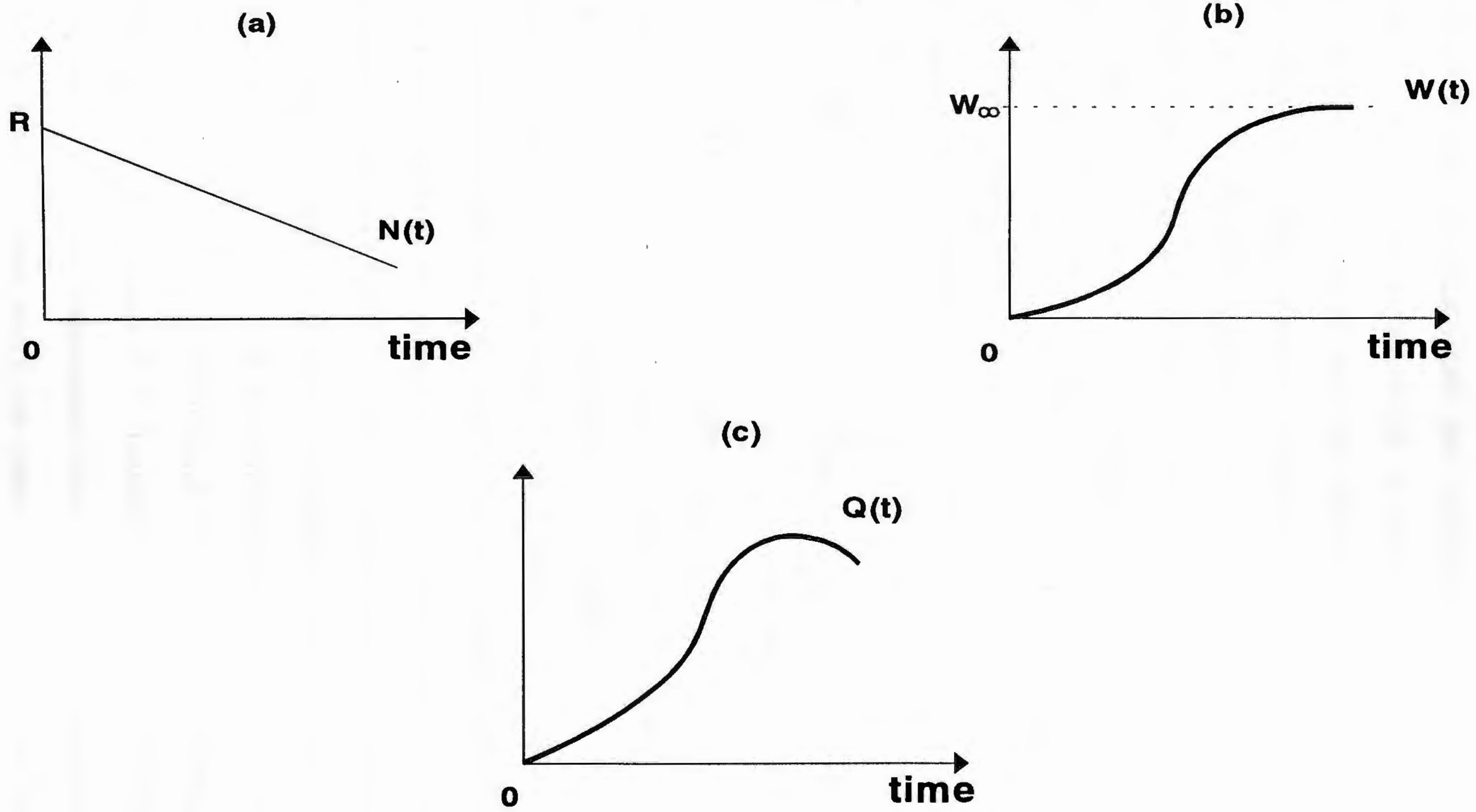
w'(u): is the change in individual weight ($\partial w/\partial t$).

And the biomass of shrimp harvested and marketed may be expressed as:

$$Q(t) = N(t)\,w(t) \tag{28}$$

Figure 3.3 portrays the population dynamics of in-pond shrimp in terms of the variation in number of individuals (figure 33a), their individual weight in time (figure 33b) and the total biomass of in-pond shrimp (figure 33c).

Figure 3.3 Population Dynamic in Shrimp Farming



Bioeconomic model without tax on revenues.

The aquaculture production process is similar to the one for timber production in the presence of private property rights. The central concern in forest economics literature is determining when to cut the forest stand (Johansson and Löfgren 1985). The optimal rate of exploitation in forestry is determined by the rotation time of the forest, that is, the time interval between harvests. An optimal rotation rate is one which, over time, maximizes the net benefits generated by forest exploitation (Hyde 1980, Newman 1983, Johansson and Löfgren 1985). There has been much debate in forest economics theory about what is the optimum rotation rate and how to estimate it. But the Faustman (1849) optimal decision rule for maximizing discounted net revenues has been accepted as superior for society in the economics literature (Newman 1983).

Production cost and benefits generated by shrimp mariculture, therefore, are analyzed by applying the principles of forest economics. The central decision rule used in shrimp production will be the Faustman equation which is used to determine the optimal rotation time.

Let us first focus on the hectare. Assuming that product price (p) and the discount rate (ρ) are constants, one hectare will produce at a level from which the present value of net benefits generated over time is maximized. Also, assume that land will be used repeatedly for this activity. Mathematically, this level of production is determined by maximizing the present value of net benefits over time, considering perpetual use of land for shrimp mariculture. That is

$$\underset{t}{MAX}\ V(t) = \frac{(p-c)\,q(t)\,e^{-\rho t} - (d+cn)}{(1-e^{-\rho t})} \tag{29}$$

where:

t : rotation time.

p : product market price.

c : per unit cost of harvesting and feeding, and it is defined as

$$c = h + c_f f$$

where:

h : per unit cost of harvesting shrimp and is assumed to be constant.

c_f : per unit cost of feed, assumed to be constant.

f : feed conversion ratio, which is the ratio of increase in weight to available quantity of feed, also assumed to be constant.

d : fixed cost per hectare, includes costs of required infrastructure to growout and stock shrimp in ponds.

cn : per hectare conversion cost of mangrove into shrimp ponds.

ρ : the discount rate which measures the opportunity cost of capital at the market rate.

Thus, the first order condition (FOC) for maximizing V(t) with respect to rotation time (t) is

$$V_t = \left\{(p-c)\,q_t e^{-\rho t} - \rho\,(p-c)\,q(t)\,e^{-\rho t}\right\}(1-e^{-\rho t}) - \rho\left\{(p-c)\,q(t)\,e^{-\rho t} - (d+cn)\right\}e^{-\rho t} = 0 \qquad \textbf{(29)}$$

Rearranging terms, the FOC may be expressed as:

$$(p-c)\,q_t(1-e^{-\rho t}) = \rho\,(p-c)\,q(t) - \rho\,d \qquad \textbf{(30)}$$

which is known as the Faustman equation and indicates that shrimp will be harvested and re-stocked when <u>the expected marginal value product is equal to the revenues foregone by delaying harvest one period, minus the gain from delaying re-stocking costs one period</u>. Bearing this in mind, the optimal constant-flow output for one hectare of land is:

$$\frac{q^*}{t*} = \frac{q_t}{t^*}\,\frac{(1-e^{-\rho t})}{\rho} + \frac{d+cn}{(p-c)\,t^*} \qquad \textbf{(31)}$$

Let us now focus on the industry level. Under open access firms will enter the activity as long as there are positive net returns to be captured. In other words, more distant and less accessible hectares of mangroves are brought into shrimp mariculture as long as there are profits from doing so. At the point of bioeconomic equilibrium under open access, the marginal hectare produces at the level where its total revenue (tr) equals total costs (tc). This is mathematically expressed as:

$$p\left(\frac{q^*}{t^*}\right) = c\left(\frac{q^*}{t^*}\right) + (d + cn) \qquad \textbf{(32)}$$

and the intramarginal hectares are producing at:

$$p\left(\frac{q^*}{t^*}\right) > c\left(\frac{q^*}{t^*}\right) + (d + cn) \qquad \textbf{(33)}$$

Under these conditions total net benefits should be determined by the summation of CS and PS, but shrimp mariculture in most cases faces a perfectly competitive international market. Thus, the industry is price taker facing a perfectly elastic demand curve. Consumer's surplus, therefore, is zero for Ecuador in the case of shrimp production.

Net benefits in this case correspond only to producer's surplus, the summation of the difference between market price and the average cost of production for all the firms operating at the open access equilibrium (figure 3.4). The mariculture industry seeks to maximize the present value of the difference between total revenues and total costs over time. That is,

$$\underset{t,\,CR}{MAX}\; PS(L) = \int_0^\infty e^{-\rho t}\left[\left((p-c)\, q_t e^{-\rho t} - dL_t\right)\frac{L_t}{t} - cnCR_t^2\right]dt$$

$$\textit{Subject to:}\qquad \begin{aligned} L_{t+1} &= L_t + CR_t \\ L_t &= \overline{M} - L_t \end{aligned} \qquad \textbf{(34)}$$

$$\textit{Initial conditions:}\qquad L_0 \begin{cases} = 0 & \textit{for starting mariculture industry} \\ > 0 & \textit{for today's mariculture industry} \end{cases}$$

where:

L : cumulative amount of land converted (ha).

t^* : optimal rotation time.

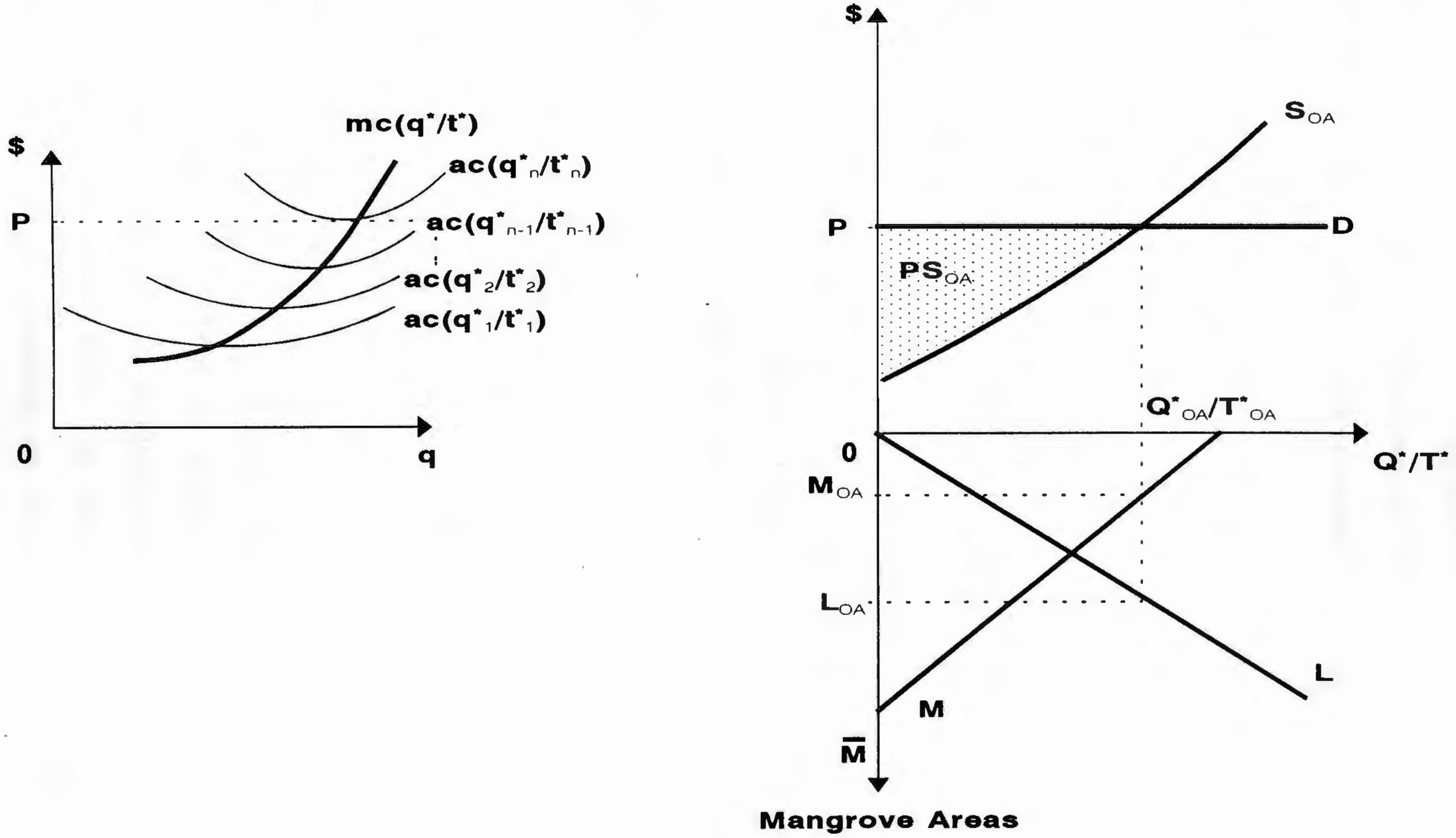
CR : the rate of mangrove conversion (ha) in any given time.

Note that q,p, c, d and cn are as previously defined.

Bioeconomic model with tax on revenues.

The tax on revenues introduces a rather simple difference in the specification of the bioeconomic model in use.

Figure 3.4 Producer Surplus in Shrimp Mariculture.



This modification is introduced by substracting from shrimp price the portion related to the tax. Thus, the bioeconomic model may be re-expressed as follows:

$$\underset{t,\,CR}{MAX}\ PS(L) = \int_{0}^{\infty} e^{-\rho t}\left[\left(\left(\left(p\left(1-tax\right)\right)-c\right) q_t e^{-\rho t} - dL_t\right)\frac{L_t}{t} - cn\,CR_t^2\right]dt$$

Subject to:

$$\begin{aligned} L_{t+1} &= L_t + CR_t \\ L_t &= \overline{M} - L_t \end{aligned}$$

Initial conditions:

$$L_0 \begin{cases} = 0 & \textit{for starting mariculture industry} \\ > 0 & \textit{for today's mariculture industry} \end{cases} \qquad (35)$$

where:

L : cumulative amount of land converted (ha).

t^* : optimal rotation time.

CR : the rate of mangrove conversion (ha) in any given time.

tax : index for tax on revenues.

Finally, total net benefits generated by alternative uses of mangrove areas under open access conditions is expressed as the summation of all net benefits previously determined, plus benefits derived from natural functions performed by existing mangrove areas. Benefits associated with natural functions are assumed to be constant per unit of area (i.e., per hectare). In spite of the minimal specific information existing to date in reference to the value assigned to natural functions of mangrove areas, and for that matter for most natural ecosystems, it is important to consider it in order to theoretically include them in the process of resource allocation. Any possible under- or over-estimation of their order of magnitude may be considered in a sensitivity analysis and, thus, its relative importance established.

Then, in the absence of tax revenue, total net benefits derived from alternative uses of mangrove areas under open access correspond to the summation of benefits generated by fisheries, forestry, shrimp mariculture and associated natural/ecological functions.

$$NB(L) = \int_{0}^{\infty} e^{-\rho t}\left[MG\left(Q_i^{OA}(L)\,,\,X_i^{OA}(L)\right) + VF\left(\overline{M} - L_t\right)\right] dt + SM(L) \qquad \textbf{(36)}$$

Where:

VF : per hectare values associated with natural/ ecological functions of mangrove areas.

SM(L) : is equal to the output of maximizing the present value of net benefits (PS) generated by shrimp mariculture overtime.

And finally, in the presence of tax revenue, total net benefits derived from alternative uses of mangrove areas under open access correspond to the summation of benefits generated by fisheries, forestry, shrimp mariculture, associated natural/ecological functions, and tax revenues perceived by the goverment.

$$\begin{aligned} NB(L) = & \int_0^\infty e^{-\rho t}\left[MG\left(Q_i^{OA}(L), X_i^{OA}(L)\right) + VF\left(\overline{M} - L_t\right)\right] dt + SM(L) \\ & + \int_0^\infty \left(p\,(tax)\, q_t \frac{L_t}{t}\right) dt \end{aligned} \tag{37}$$

3. Scenario III.

In this third scenario, mangrove areas are assumed to also be a public resource, but the right to convert them is controlled by the government through a management agency which oversees government properties. Although there is still open access to the natural renewable resources existing in the area (here mainly represented by mangrove forest and associated fish), the land in it and the adjacent water channels cannot be unilaterally appropriated by any private agent. The mechanism to be considered for land allocation is leasing it from the government.

All basic assumptions about the firm remain identical to the first scenario, except that now there are controls on entry to shrimp mariculture which are set by a central authority. Simultaneously, however, firms in forestry and coastal artisanal fisheries still operate under conditions of free entry to and exit from the economic activity.

Thus, in this scenario, it is assumed that a government agency or individual is in charge of managing resource use in the ecosystem of interest. The agency's objective in this case, is to maximize present value of net benefits derived from alternative uses of mangrove areas over time. That is, it must determine the optimal intertemporal allocation of mangrove areas among forestry, coastal artisanal fishery and shrimp mariculture, an allocation which maximizes the present value of total net benefits generated by them, plus benefits derived from the natural functions performed by the existing mangrove areas. In other words, the agency must determine how much mangrove is to be used in its natural state and how much is to be converted into shrimp ponds. The key issue associated with this allocation process is the determination of the optimal trade-off to be made between current and future outputs (Clark 1976). The maximization process takes place in two steps: first, shrimp farmers will maximize net benefits obtained in a per hectare basis, and second, the management agency maximizes present value of total net benefits with respect to the total amount of land to be used for shrimp mariculture and the amount to be used for forestry and associated estuarine fisheries, over time. Let us now analyze the process occurring in each sector.

a. Forestry and coastal artisanal fishery.

Recall that forestry and estuarine fisheries continue to be operated under open access. Thus, whatever amount of natural resources (i.e., mangrove forest and related fish stock) are left, will be exploited under open access conditions. Net benefits generated by these activities are determined as before. The sole exception is that now the decision making agency has to bear in mind the effect of technological externalities, when maximizing present value of net benefits.

According to the conditions set in this scenario, forestry and coastal artisanal fisheries net benefits per period are determined exactly as before. Therefore, equation (23) continues to be the appropriate equation for this purpose.

b. Shrimp Mariculture.

For one hectare of land, shrimp farmers maximize net benefits according to the FOC established in equation (28), which leads to a per period constant-flow of output as expressed in equation (29).

Since the maximization process over land takes place at the aggregate or industry level it is necessary to determine the net benefits generated by the industry per period of time. This is expressed in equation (35).

Therefore, present value of total net benefits generated by forestry, estuarine fishery and shrimp mariculture, plus natural functions, are maximized over time with respect to and as follows.

$$\underset{t,\,CR}{Max} NB(L) = \int_{0}^{\infty} e^{-\rho t}\Big\{ \Big[\big((p-c)\ q_t\ e^{-\rho t} - dL_t\big)\tfrac{L_t}{t} - cnCR_t^2 \Big] + \Big[MG\big(Q_t^i(L), X_t^i(L)\big) + VF\big(\overline{M} - L_t\big)\Big] \Big\} dt$$

subject to:

$$\begin{aligned} L_{t+1} &= L_t + CR_t \\ L_t &\leq \overline{M} - L_t \\ Q_i(L) &= Q_i^{OA}(L),\ X_i(L) = X_i^{OA}(L) \\ q^* &\geq 0,\ t^* \geq 0 \end{aligned} \qquad \textbf{(38)}$$

initial conditions:

$$L_0 \begin{cases} = 0 & \text{for starting mariculture industry} \\ > 0 & \text{for today's mariculture industry} \end{cases}$$

4. Scenario IV.

This fourth scenario is set under the assumption that a government management agency controls the uses of mangrove areas generate the maximum net benefits to society. Thus, the management agency's role is to allocate mangroves areas and associated resources (mangrove forest and fish stocks) among their alternative uses in such a way that present value of net benefits generated by these uses and benefits derived from natural functions of existing mangrove areas, over time, are maximized.

The new basic assumption about the firms is that there are controls on access to all three economic sectors. Furthermore, the manager has to determine the optimal harvest rate for both coastal artisanal fisheries and forestry. Thus, the management agency, seeking to maximize net benefits from forestry and coastal artisanal fisheries, will also set controls on harvest rates for both activities. All other assumptions about the firms remain identical to those previously stated.

Forestry and coastal artisanal fisheries are no longer operated under open access. This is because, as widely discussed in the literature (Gordon 1954, Copes 1970-71, Clark 1976, Andersen 1977, Cunningham et al. 1982), open access conditions lead to inefficient resource allocation and resource rent dissipation. Controlling access to the activities does not ensure economic efficiency per se; thus, it is also necessary for the management agency to control effort or harvest rates in fisheries and forestry directly or indirectly (possibly through the allocation of individual transferable quotas). Therefore, the agency will seek to jointly maximize the present value of total net benefits generated by all three economic sectors, plus benefits derived from natural functions of existing mangrove areas. Since the key issue is to determine the optimal intertemporal allocation of mangrove areas among alternative uses, the joint maximization process must be done with respect to land use and harvest in forestry and coastal artisanal fisheries. Shrimp farmers naturally maximize net benefits over time due to the existence of private property rights for shrimp and shrimp ponds.

a. Forestry and coastal artisanal fishery.

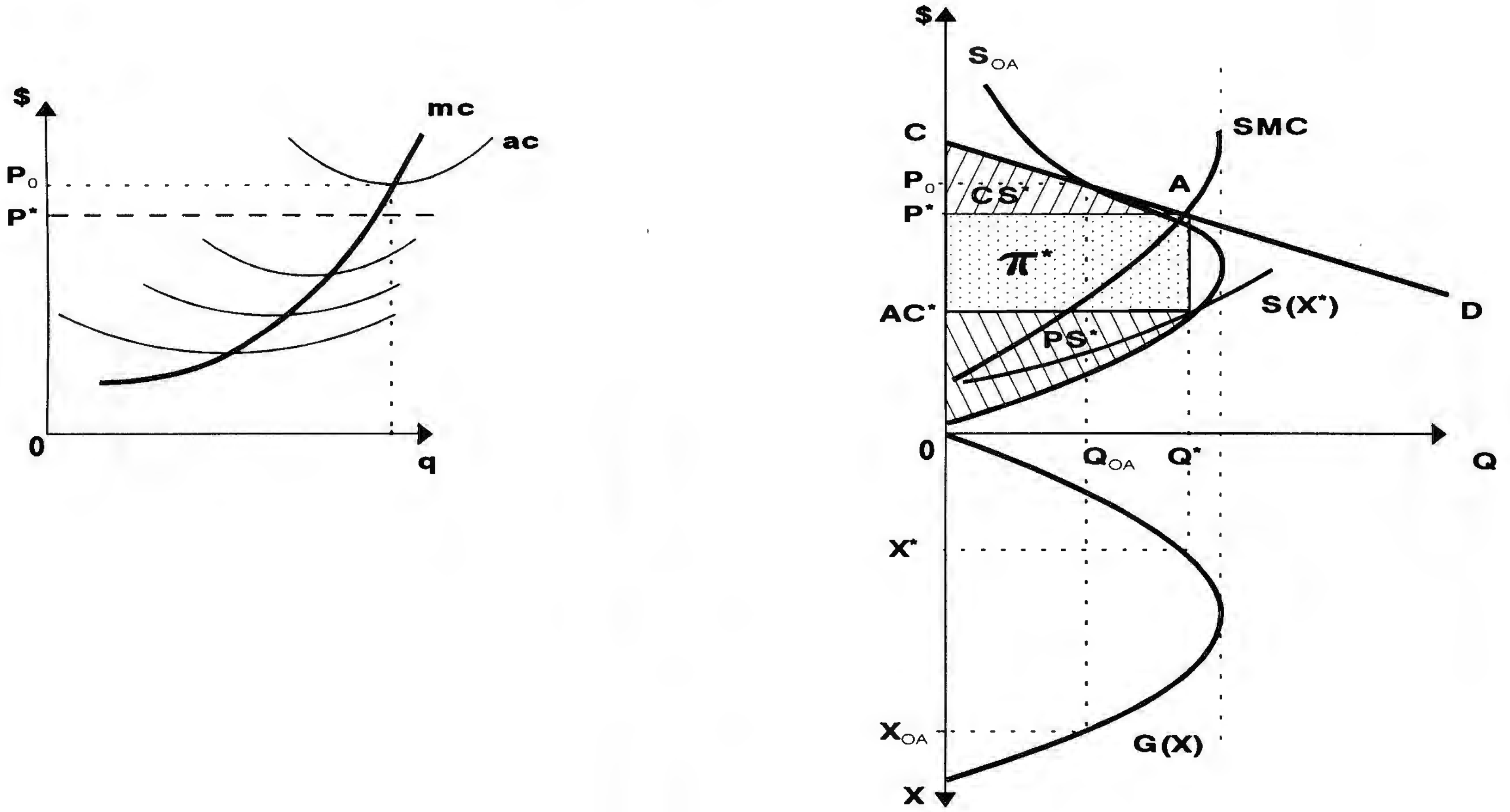
The problem for the government agency can be rephrased as one of determining the harvest schedule for forestry and fisheries which maximizes the present value of net benefits over time (figure 3.5). That is, it has to determine the optimal harvest/use policy. Therefore, the agency will maximize the present value of PS, CS and resource rent with respect to output. The social optimum level of production, according to criterion of marginal cost pricing, is achieved at the level of output for which price (demand) and marginal social cost are equal (Copes 1970).

Bearing this in mind the agency's problem may be defined as

$$\max_{Q_t^i} MG(Q_t^i) = \int_0^\infty e^{-\rho t} \left[PS(Q_t^i) + CS(Q_t^i) \right] dt$$

$$\begin{aligned} &\textit{Subject to:} \\ &\qquad X_{t+1}^i = X_t^i + G(X_t^i) - Q_t^i \\ &\qquad Q_t^i \geq 0 \\ &\qquad Q_t^i \leq X_t^i \\ &\textit{and initial conditions:} \\ &\qquad X_0^i = \begin{cases} X_{OA}^i & \textit{for stock at open access equilibrium} \\ K^i & \textit{for virgin stock} \end{cases} \end{aligned} \tag{39}$$

Figure 3.5 Combined Consumer and Producer Surplus and Resource Rent in Fishery and Forestry



Recall that total producer's surplus (PS) is defined as the difference between total benefits and costs, thus it may expressed as follows.

$$PS\left(Q_t^i\right) = p\left(Q_t^i\right)\, Q_t^i - \left[C^i\left(\frac{Q_t^i}{A^i X_t^i}\right) + D^i\left(\frac{Q_t^i}{A^i X_t^i}\right)^2\right] \tag{40}$$

Consumer's surplus is defined as before and it is mathematically expressed as follows.

$$CS\left(Q_t^i\right) = \left[\frac{U^i}{V^i} - p\left(Q_t^i\right)\right]\frac{Q_t^i}{2} \tag{41}$$

Recall that demand and related price functions are defined as in equation (22). Substituting price function in equations (40) and (39) and rearranging terms, the present value of net benefits over time is expressed as

$$\underset{Q_t^i}{Max}\ MG\left(Q_t^i\right) = \int_0^{\infty} e^{-\rho t}\left[\left(2U^i - Q_t^i\right)\frac{Q_t^i}{2V^i} - C^i\left(\frac{Q_t^i}{A^i X_t^i}\right) - D^i\left(\frac{Q_t^i}{A^i X_t^i}\right)^2\right]dt$$

Subject to:

$$\begin{aligned} X_{t+1}^i &= X_t^i + G\left(X_t^i\right) - Q_t^i \\ Q_t^i &\geq 0 \\ Q_t^i &\leq X_t^i \end{aligned} \tag{42}$$

and initial conditions:

$$X_0^i = \begin{cases} X_{OA}^i & \textit{for stock at open access equilibrium} \\ K^i & \textit{for virgin stock} \end{cases}$$

b.   Shrimp mariculture.

Since shrimp farmers, induced by private property rights, maximize net benefits over time for each hectare of converted mangrove areas, the firm and industry behavior in this scenario is exactly the same as in the second scenario.

Finally then, the agency seeks to jointly maximize present value of total net benefits from allocation of mangrove areas according to the following:

$$\underset{t,\,CR,\,Q_t^i}{Max}\ NB\left(Q_t^i, L_t\right) = \int_0^{\infty} e^{-\rho t}\left\{\left[\left((p-c)\,q_t e^{-\rho t} - dL_t\right)\frac{L_t}{t} - cnCR_t^2\right]\right.$$

$$\left.\left[\left(2U^i - Q_t^i\right)\frac{Q_t^i}{2V^i} - C^i\left(\frac{Q_t^i}{A^i X_t^i}\right) - D^i\left(\frac{Q_t^i}{A^i X_t^i}\right)^2\right]\right\}dt$$

Subject to:

$$\begin{aligned} L_{t+1} &= L_t + CR_t \\ L_t &= \overline{M} - L_t \\ X_{t+1} &= X_t^i + G\left(X_t^i\right) - Q_t^i \\ Q_t^i &\geq 0 \\ Q_t^i &\leq X_t^i \end{aligned} \tag{43}$$

and initial conditions:

$$L_0 \begin{cases} = \text{ for starting mariculture industry} \\ > \text{ for today's mariculture industry} \end{cases}$$

$$X_0^i \begin{cases} X_{OA}^i \text{ for stock at open access equilibrium} \\ K^i \text{ for a virgin stock} \end{cases}$$

C.- GAMS/MINOS MODEL.

This section describes the bioeconomic model in its GAMS/MINOS format. All four scenarios in Section A are presented in a continuous time framework, and the consideration for perpetual alternative uses of mangrove areas implies an infinite time horizon.

To properly work with GAMS/MINOS, models for all scenarios have to be transformed into a discrete time framework. Also, since an infinite time horizon cannot be handled by GAMS/MINOS, an approximation to forty periods, or years, has been used. A time horizon of forty years is considered to be sufficient for all practical purposes due to the strong impact of discounting after 40 or 50 periods.

1. Scenario I.

The discrete time specification for scenario I is given by

$$
\begin{aligned}
NB(L) = &\left\{ \underset{RT,\, L}{Max} \sum_{t=1}^{40} (1+\rho)^{-t} \Big[\big((p-c)\, q_t (1+\rho)^{-RT} - dL_t \big) \frac{L_t}{RT} - cnCR_t^2 \Big] \right\} \\
&+ \sum_{t=1}^{40} (1+\rho)^{-t} \Big[MG\big(Q_{OA}^{i}(L_t),\, X_{OA}^{i}(L_t) \big) + VF\big(\overline{M} - L_t\big) \Big]
\end{aligned}
\tag{44}
$$

subject to:

$$
\begin{aligned}
&L_{t+1} = L_t + CR_t \\
&L_t \leq \overline{M} - L_t \\
&q^{*} \geq 0,\ t^{*} \geq 0
\end{aligned}
$$

initial conditions:

$$
L_0 \begin{cases} = 0 & \textit{for starting mariculture industry} \\ > 0 & \textit{for today's mariculture industry} \end{cases}
$$

2. Scenario II.

The discrete time specification for scenario II is given by

$$
\begin{aligned}
NB(L) = &\left\{ \underset{RT,\, L}{Max} \sum_{t=1}^{40} (1+\rho)^{-t}\Big[\Big(\big(\big(p(1-tax)\big)-c\big)\, q_t(1+\rho)^{-RT} - dL_t\Big)\frac{L_t}{RT} \right. \\
&\left. - cnCR_t^2 \Big]\right\} + \sum_{1}^{40} (1+\rho)^{-t}\Big[p * tax * q_t \frac{L_t}{RT}\Big] \\
&+ \sum_{t=1}^{40} (1+\rho)^{-t}\Big[MG\big(Q_{OA}^{i}(L_t),\, X_{OA}^{i}(L_t)\big) + VF\big(\overline{M} - L_t\big)\Big]
\end{aligned}
\tag{45}
$$

subject to:

$$
\begin{aligned}
L_{t+1} &= L_t + CR_t \\
L_t &\leq \overline{M} - L_t \\
q^* &\geq 0, \quad t^* \geq 0
\end{aligned}
$$

initial conditions:

$$
L_0 \begin{cases} = 0 & \textit{for starting mariculture industry} \\ > 0 & \textit{for today's mariculture industry} \end{cases}
$$

3. Scenario III.

The discrete time specification for scenario III is

$$
\begin{aligned}
\underset{RT,\, CR}{Max} NB(L) = \sum_{t=1}^{40} (1+\rho)^{-t}\Big\{ &\Big[\Big((p-c)\, q_t(1+\rho)^{-RT} - dL_t\Big)\frac{L_t}{t} - cnCR_t^2 \Big] \\
&+ \Big[MG\big(Q_t^{i}(L),\, X_t^{i}(L)\big) + VF\big(\overline{M} - L_t\big)\Big] \Big\}
\end{aligned}
$$

subject to:

$$
\begin{aligned}
L_{t+1} &= L_t + CR_t \\
L_t &\leq \overline{M} - L_t \\
Q_i(L) &= Q_i^{OA}(L), \quad X_i(L) = X_i^{OA}(L) \\
q^* &\geq 0, \quad t^* \geq 0
\end{aligned}
\tag{46}
$$

initial conditions:

$$
L_0 \begin{cases} = 0 & \textit{for starting mariculture industry} \\ > 0 & \textit{for today's mariculture industry} \end{cases}
$$

4. Scenario IV.

The discrete time specification for scenario IV is

$$\max_{RT,\, CR,\, Q_t^i} NB\left(Q_t^i, L_t\right) =$$

$$\sum_{t=1}^{40} (1+\rho)^{-t} \left\{ \left[\left((p-c)\, q_t^{*}(1+\rho)^{-RT} - dL_t \right) \frac{L_t}{RT} - cn\,CR_t^2 \right] + \left[\left(2U^i - Q_t^i\right) \frac{Q_t^i}{2V^i} - C^i\left(\frac{Q_t^i}{A^i X_t^i}\right) - D^i\left(\frac{Q_t^i}{A^i X_t^i}\right)^2 \right] \right\}$$

Subject to:

$$\begin{aligned} L_{t+1} &= L_t + CR_t \\ L_t &= \overline{M} - L_t \\ X_{t+1}^i &= X_t^i + G\left(X_t^i\right) - Q_t^i \\ Q_t^i &\geq 0 \\ Q_t^i &\leq X_t^i \end{aligned} \qquad \textbf{(47)}$$

and initial conditions:

$$L_0 \begin{cases} = 0 & \textit{for starting mariculture industry} \\ > 0 & \textit{for today's mariculture industry} \end{cases}$$

$$X_0^i = \begin{cases} X_{OA}^i & \textit{for stock at open access equilibrium} \\ K^i & \textit{for virgin stock} \end{cases}$$

Note that in the continuous time framework the growth rate of the biological stock, $G(X_t^i)$, is expressed as in equation (6). The state equation for the stock, then, expresses that at any given period the stock size depends on the stock size in the previous period, plus the difference between the growth of the stock and the harvest in that previous period. In continuous time framework, this difference is instantaneously accounted for, but in discrete time framework a one period delay will be in effect. Thus, for the first period, the state equation, as expressed in equation (6), will estimate stock size as the summation of the stock and its growth rate one period earlier, minus the harvest rate one period earlier. This means that the relation between harvest and biological stock will only start to exist from the second period on, thus introducing some irregularities in the model. A discrete time framework version of the state equation is therefore required to ensure a proper specification of the bioeconomic models. This version is given by:

$$X_{t+1}^{i} = \left(X_t^{i} - Q_t^{i}\right) + r^{i}\left(X_t^{i} - Q_t^{i}\right) - \frac{r^{i}}{K^{i}\left(L_t\right)}\left(X_t^{i} - Q_t^{i}\right)^2 \qquad \textbf{(48)}$$

This specification indicates that the stock size at any given period is equal to the summation of the previous period stock size after harvest and the growth rate of that same stock size after harvest.

Full versions of the bioeconomic models in GAMS language syntax for all scenarios are presented in Appendix I.

D.- DATA FOR THE GAMS/MINOS MODELS.

This section presents the data used to run the bioeconomic models for all three scenarios. The bioeconomic model in scenario I was calibrated to reflect current conditions (as of 1990) use of mangrove areas in Ecuador. Secondary and primary data were used to estimate model parameters, applying the theoretical framework presented in Section A of this chapter. Calculations were made using both normal arithmetic procedures and spreadsheet analysis. All secondary information used was extracted from the background information presented in Chapter II.

1. Shrimp mariculture.

The bioeconomic model for shrimp mariculture requires data on land use, volume of production, cost of conversion, cost of production and product price.

Land Use.

As of 1987 about 28,500 (Ha) of mangrove areas in Ecuador have been converted into shrimp ponds (Southgate 1989). Information on mangrove areas published by CLIRSEN (1992) indicates that about 39,000 (Ha) of mangroves had been cleared for shrimp mariculture by 1991. A conservative estimate of 30,000 (Ha) of converted mangrove areas for 1990 was used in calibrating the submodel for shrimp farming in first scenario. Information on land use was expressed in thousands of hectares for modeling purposes.

Two approaches were used to set initial values for the level of mangroves conversion. The initial value for land use in first scenario was set at the present estimate level of conversion, to reflect the present situation. Two different initial values for land use in scenarios II and III, were used. One started with no mangrove areas converted into shrimp ponds and the other starting at the present level of mangrove conversion. This was to compare the difference in net benefits generated by an industry operating under management from the beginning and an industry subject to management after an open access equilibrium had been reached.

Costs and revenue structure.

Primary data for a shrimp farm operating a semi-intensive system of production was collected in Manabí Province, Ecuador, in 1990. The data collected correspond to volume of production, production costs and product price for 19 ponds per crop or rotation (Appendix II). Using this data, a cost and revenue structure for the average hectare was estimated (see Table 3.1).

Table 3.1 Costs and revenues structure for a shrimp farm using semi-intensive system of production in Ecuador 1990.

Cost, Revenue Structure	**Lb**[1]	**Kg**[1]
Harvest[2] (per Ha-Year)	2,834.00	1,288.00
Price (US$ / unit weight)	3.00	6.60
Variable Cost (US$/unit weigth)	1.36	2.99
Fixed cost (US$ / Ha-year)	2,500.00	2,500.00

Source: primary data collected in Manabí, Ecuador in 1990.
1) Shrimp tails.
2) Two crops per year were considered.

Although no specific information on the cost of converting mangroves was found in the literature, estimates were made based on information on cost of pond construction for different land types. Construction costs for shrimp pond have been reported to be about 6,000 US$ per hectare in mangrove areas and 1,000 US$ per hectare in coastal upland (Snedaker et al. 1986). Falconi and Miranda (1989), reported a cost of approximately 4,500 US$ per hectare in coastal upland. A conservative value of 2,500 US$ per hectare was used to estimate the conversion cost of mangrove areas. This conversion cost, which equals the average conversion cost for the industry, was used to estimate the corresponding parameter "cn" considered in the bioeconomic model.

This parameter was estimated as follows:

$$\text{Average Conversion Cost} = cn * CR$$

Recall that CR is the variable corresponding to an annual rate of mangrove conversion, which is expressed in thousand of hectares per year. An annual average conversion rate of 10,400 hectares was estimated for the entire coastal area of Ecuador, based on information reported by CLIRSEN (1992) on land use between 1987 and 1991. Thus, the conversion cost parameter was estimated as follows.:

$$cn = \frac{2{,}500{,}000}{10.4} = 240{,}385$$

where:

2,500,000 *is the average cost of conversion per thousand hectares.*

10.4 *is the annual conversion rate in thousand hectares.*

Similarly, the estimate for the fixed cost of production presented in Table 3.1 was used to calculate the corresponding parameter considered in the bioeconomic model. This parameter was labeled "d" and its value was estimated as follows:

$$d = \frac{\text{Fixed Cost} * RT}{L} = \frac{2{,}500{,}000 * 0.5}{30} = 41{,}667$$

where:

2,500,000 *is fixed cost of production per thousand hectares.*
30 *is total land converted in thousand hectares.*
0.5 *is rotation time in years.*

Price and variable costs were directly related to the submodel for shrimp mariculture as parameters.

Volume of production.

Biotechnical parameters required for the shrimp mariculture production function were estimated from primary data collected in Ecuador and secondary information. Spreadsheet analysis was used to estimate instantaneous growth and mortality rates required to build the production based on stocking rates, initial and final individual weight (Table 3.2)

Table 3.2 Biotechnical parameters for shrimp mariculture.

Parameter	**Symbol**	**Value**
Initial individual weight (Kg)	W0	1e-6
Final individual weight (Kg)	Wf	0.0145
Stocking rate (indiv./Ha-year)	N	120,000
Instantaneous mortality rate	m	0.052
Instantaneous growth rate	r	26

Finally, a private rate of discount of 10 % per year was assumed and a social discount rate of 10 percent per year was used for all scenarios. The tax on revenue used in shrimp industry has been reported by Fitzgerald (1992) to be between 8 and 12 percent. An estimate of 10 percent was used in this study.

2. Coastal artisanal fisheries and forestry.

Bioeconomic model on coastal artisanal fisheries and forestry also requires data on volume of production, stock size, cost of production, and product price.

Coastal artisanal fisheries.

Scott and Torres (1991) report that size estimates for the small-scale fishing fleet in Ecuador vary widely from 1,500 to 11,000 units and that the most reliable estimate (Fallow 1989) was of 9,000 fishing units. A conservative estimate of 5,000 fishing units for the coastal artisanal fishing fleet exploiting species related to mangrove areas in some stage of their life was used in this study. Estimates on harvest, product price and harvesting costs were based upon a study of the Ecuadorean fishing fleet by Scott and Torres (1991). Based on economic and technical information for four types of artisanal fishing boats reported by Scott and Torres (1991), a harvest volume of 4.4 tons of fish per year was estimated for an average representative fishing unit. Similarly, an average product price of 2,264 US$ per ton of fish and an average cost of harvest of 1,380 US$ per ton were estimated (Appendix II). Thus, a total capture volume of 22,000 ton per year was calculated for the estimated fleet size of 5,000 fishing units.

Fish stock size and harvest rate at open access equilibrium for the present conditions were estimated from spreadsheet analysis. Values on parameters of an hypothetical local demand equation for fish, on ecosystems' carrying capacity and on biotechnical externalities parameters were assumed to estimate harvest rates and associated stock sizes with levels in the vicinity of the ones estimated from the literature (See Table 3.3). Next, biotechnical externality parameters were assumed in such a way as to roughly fit the present level of mangrove conversion and fish harvest under open access conditions.

Table 3.3 Bioeconomic parameters for coastal artisanal fisheries.

Parameter	**Symbol**	**Value**
Stock intrinsic growth rate	r	0.32
Catchability coefficient	A	0.00045
Minimal carrying capacity	k1	0.015
Slope for carrying capacity	gamma	0.02
First parameter harvest cost	c	20
Second parameter harvest cost	d	0.75
Intercept on demand equation	u	250
Slope on demand equation	v	0.0001

Estimated carrying capacity at the present level of mangrove conversion was about 338 thousand tons of fish.

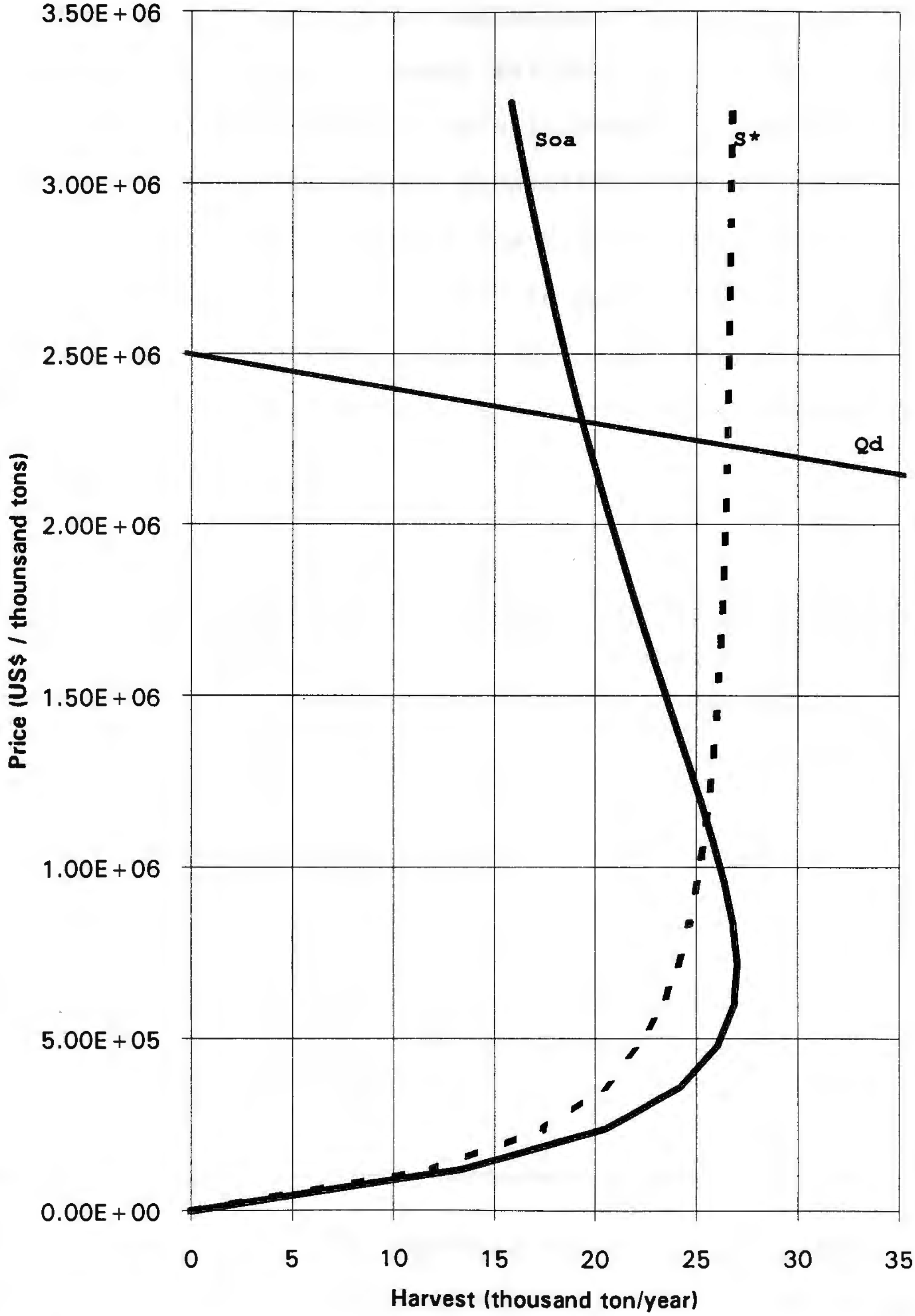
Estimated harvest rate and stock size at open access equilibrium were about 19 thousand and 79 thousand tons per year respectively. Figure 3.6 depicts the estimated harvest volumes under the conditions assumed here (See Appendix II for spreadsheet estimations).

Forestry.

No specific information on levels of production and cost and revenue structures in mangrove forestry in Ecuador was obtained.

Mangrove forestry activity in Ecuador is conducted on a small-scale basis and most common products are firewood, charcoal and construction poles. Similar forestry activities are developed in other tropical areas around the world. Information on mangrove forestry production and product value from Guinea, West Africa reported by Lootvoet & Millimono (1989) was used to estimate parameters required by the bioeconomic model for forestry operations. According to these authors wood production at stumpage varies from 3.75 to 5 cubic meter per hectare per year. Stumpage price of wood is about 0.093 US $ per log with an average log of 1.4 meter length and 12 centimeter diameter (Lootvoet & Millimono 1989). Thus, the stumpage price of mangrove wood was estimated as 5.8 US $ per cubic meter.

Figure 3.6 Supply curves for Coastal Artisanal Fisheries.



Assuming a conservative production level of 3.75 cubic meter per hectare per year for Ecuador and considering a total of 130,000 hectares of existing mangrove areas, a total wood production of about 487,000 cubic meters per year was estimated for Ecuador. This information and estimates of biotechnical and economic parameters were combined in a spreadsheet analysis applying the bioeconomic model presented in Section B, in order to calculate open access levels of mangrove forest stock and mangrove harvest rate (Appendix II). Biotechnical and economic parameters used are presented in Table 3.4.

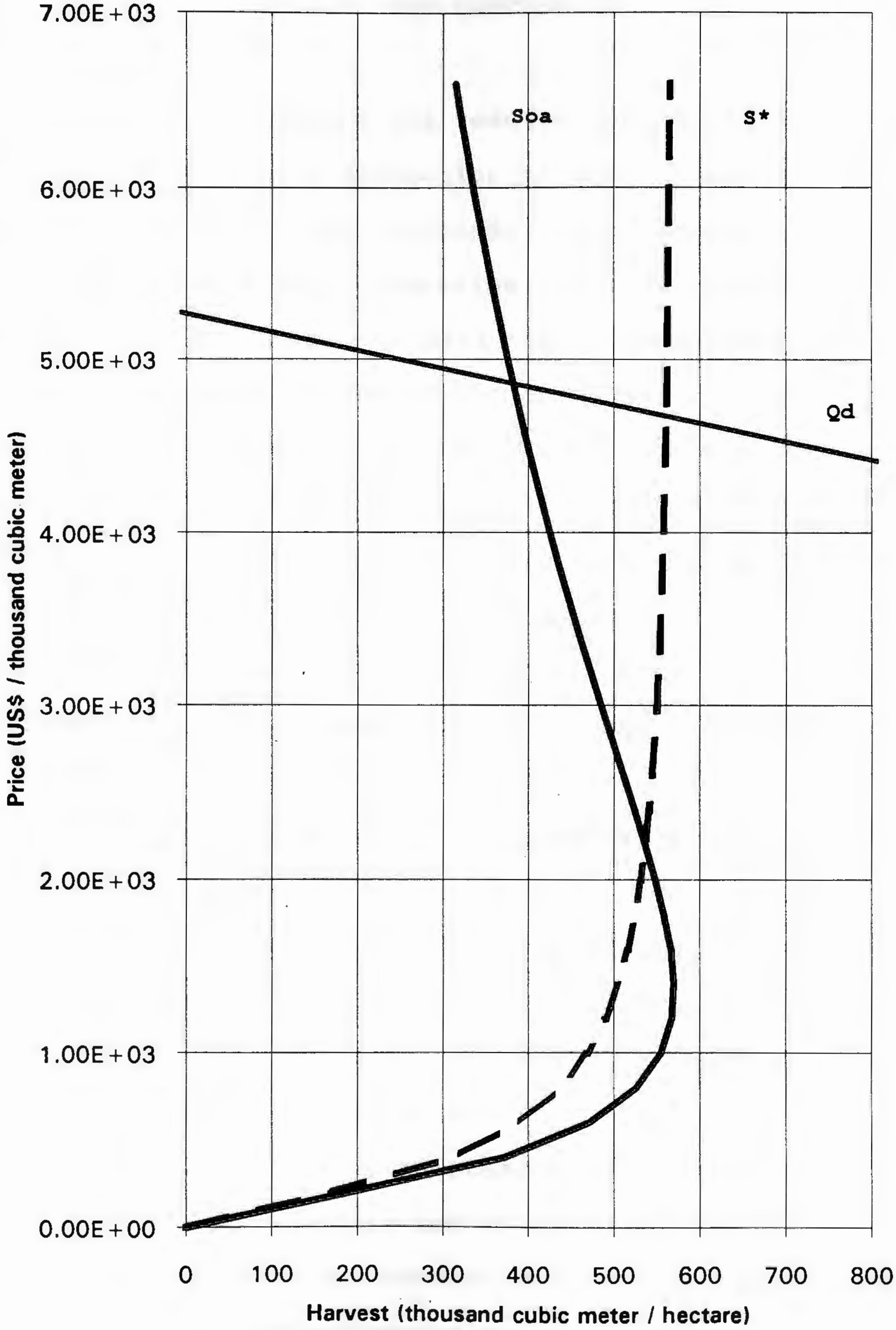
Table 3.4 Bioeconomic parameters for mangrove forestry.

Parameter	**Symbol**	**Value**
Stock intrinsic growth rate	r	0.3
Catchability coefficient	A	0.00004
Minimal carrying capacity	k1	0.0015
Slope for carrying capacity	gamma	0.45
First parameter harvest cost	c	20
Second parameter harvest cost	d	0.025
Intercept on demand equation	u	5000
Slope on demand equation	v	0.95

Estimated carrying capacity at the present level of mangrove conversion was about 7.600 million cubic meters of mangrove wood. Estimated harvest rate and stock size at open access equilibrium were about 380 thousand cubic meters and 1.600 million cubic meters of mangrove wood per year respectively. Figure 3.7 depicts the estimated harvest volumes under the conditions estimated here.

As reported in Chapter II, measurement of non-market values associated to mangrove areas in Ecuador are non-existent. Southgate (1992) reports an estimate of the economic impact of tropical deforestation in Ecuador on global warming effects of about 300 US $ per hectare per year. This value was used in this model as a rough approximation of the benefits derived by natural functions performed by mangrove areas in Ecuador.

Figure 3.7 Supply curves for mangrove forestry.



CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the results generated for all scenarios, as well as a discussion of their implication for development and management purposes. Four models, one for each scenario, were run. Scenarios I and II present current conditions for all three economic activities under, shrimp mariculture, coastal artisanal fisheries and mangrove forestry. A fourth sector is included to account for natural/ecological functions of mangrove areas. Scenarios I and II differ in that I does not include a tax on revenues charged to shrimp exporters and II does. Scenario I is included in order to have a point of reference for conversion of mangrove areas for comparison with those scenarios with management strategies. Scenarios III and IV are included in order to study the impacts of alternative management strategies.

The section labeled *"Base Case"* presents an analysis of results from the bioeconomic models for all scenarios. The model for each scenario is initialized with conditions representing the current situation in Ecuador. The section labeled *"Sensitivity Analysis"* presents a discussion of results from the bioeconomic models for scenarios II, III and IV run under different initial conditions. The purpose of this analysis is to determine how sensitive the models are to changes in relevant biological, biotechnical and economic parameters. Finally, implications the results have for policy are discussed.

A.- THE BASE CASE.

Four bioeconomic models initialized with conditions representing the present situation in Ecuador with respect to mangrove areas converted and the bioeconomic performance of the economic activities considered in this study. All scenarios are analyzed with respect to: a) total and per sector present value of net benefits generated by alternative uses of mangrove areas, b) total quantity of mangrove areas converted into shrimp ponds, c) mangrove conversion rates over time, d) biological stock size for coastal artisanal fisheries and mangrove forestry, and e) harvest rates over time for coastal artisanal fisheries and mangrove forestry.

The four scenarios analyzed are defined as follows.

Scenario I: there is open access to mangrove areas, mangrove forest and coastal fish stocks (i.e., no management intervention),

Scenario II: there is open access to mangrove areas, mangrove forest and coastal fish stocks, but a tax on revenues applied to shrimp exports is included (i.e., to reflect current policy),

Scenario III: there are controls on access to mangrove areas for shrimp mariculture, and open access conditions in coastal artisanal fisheries and mangrove forestry (i.e., partial level of management intervention with the application of optimization techniques), and

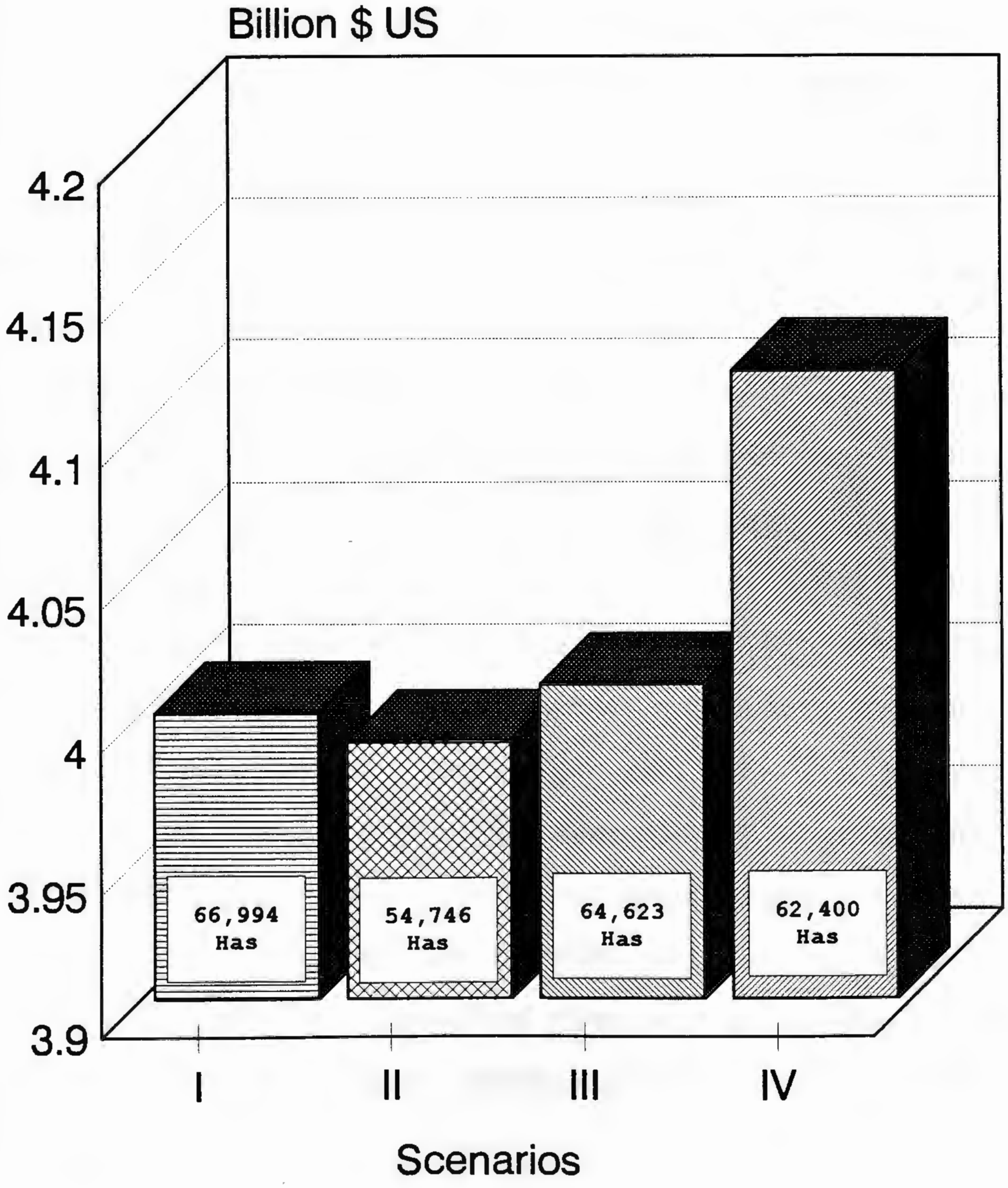
Scenario IV: there are controls on access to mangrove areas, mangrove forest and coastal fish stocks, and controls on harvest rates for both coastal artisanal fisheries and mangrove forestry are considered (i.e., full level of management intervention with the application of optimization techniques).

1. Present value of net benefits generated by alternative uses of mangrove areas.

The present value of total net benefits from alternative uses of mangrove areas in Ecuador is estimated to range from approximately 3.9 to 4.12 billion US$ for a time horizon of 40 years and a social discount rate of 10 percent.

Significantly different levels of benefits and conversion of mangrove areas are generated by all scenarios analyzed. This is depicted in Figure 4.1 where Scenario II induces the lowest level of conversion of mangrove areas with approximately 54,700 ha converted into shrimp ponds.

Figure 41 Present value of total net benefits from alternative uses of mangrove areas

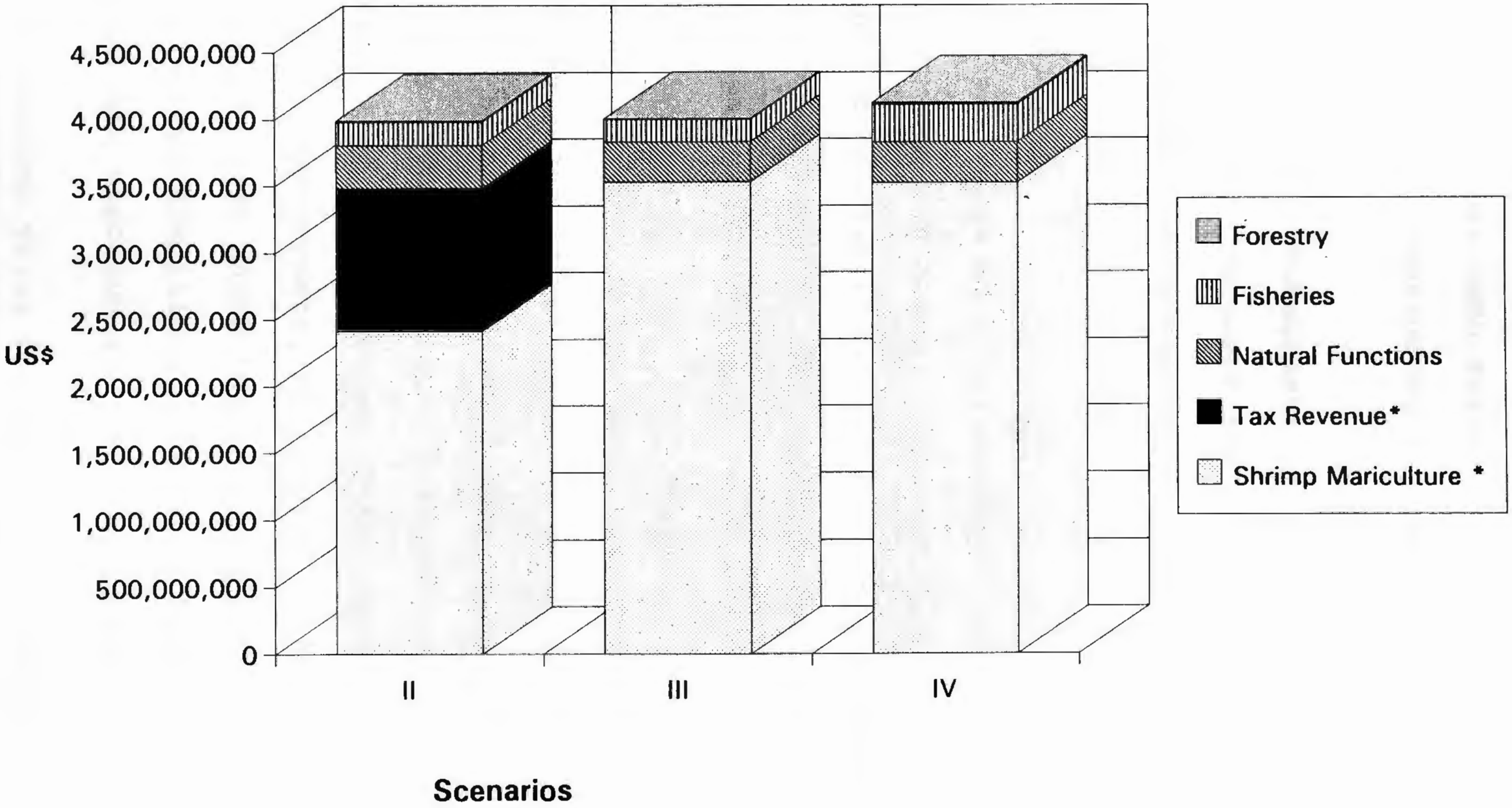


Scenario IV, on the other hand, generates the highest present value of total net benefits, with an intermediate quantity of mangrove areas converted into shrimp ponds (62,400 ha). Thus, although Scenario II induces a lower level of mangrove conversion, Scenario IV generates the highest net benefits to the country. Scenario I shows that the level of mangrove conversion induced by Scenario IV and III is lower than it would be if no tax on revenues of shrimp exports is considered. Although Scenario III also represents an improvement in present value of net benefits with respect to current policy (scenario II), it clearly generates less benefits than Scenario IV.

Though present value of total net benefits generated by alternative uses of mangrove areas is of critical importance to resource allocation, it is also important, for decision making, to understand how these benefits are distributed among competing uses and the environment (i.e., natural functions). Figure 4.2 depicts how net benefits generated by all economic sectors considered and benefits derived from natural functions of mangrove areas change when moving from current policy to higher levels of management intervention.

The application of the current policy (scenario II) yields the lowest net benefits from shrimp mariculture and the highest present value associated with natural functions of mangrove areas.

Figure 4.2 Percent distribution of present value of net benefits among economic sectors under different scenarios.



Notice, however, that depicted present value of shrimp mariculture in figure 4.2 has been scaled down 10 times, thus, its absolute value is considerably larger than it appears to be.

The application of full management intervention (scenario IV) significantly increases the present value of net benefits generated by shrimp mariculture, fisheries and forestry. The higher level of mangrove conversion reached in this scenario, compared to current policy (scenario II), drives down the present value of benefits associated with natural functions of mangrove areas.[1] However, the relative change in value of natural functions, compared to scenario II, is smaller than the change in net benefits generated by mariculture, fisheries and forestry.

Though the application of partial management intervention (scenario III), compared to current policy, increases the present value of net benefits generated by shrimp mariculture, the present value of benefits from fisheries, forestry and natural functions is reduced compared to scenario II. The reduction of net benefits generated in fisheries and forestry is caused largely by the open access conditions under which they are assumed to operate. The open access conditions drive biological stocks down and, with them, the opportunity cost of converting

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[1] Recall that a constant value per hectare was assumed to account for economic value of natural/ecological functions of mangrove ecosystems.

mangrove areas into shrimp ponds. This lower opportunity cost induces a higher level of mangrove conversion, compared with the application of current policy and a full level of management intervention.

2. Conversion path of Mangrove Areas.

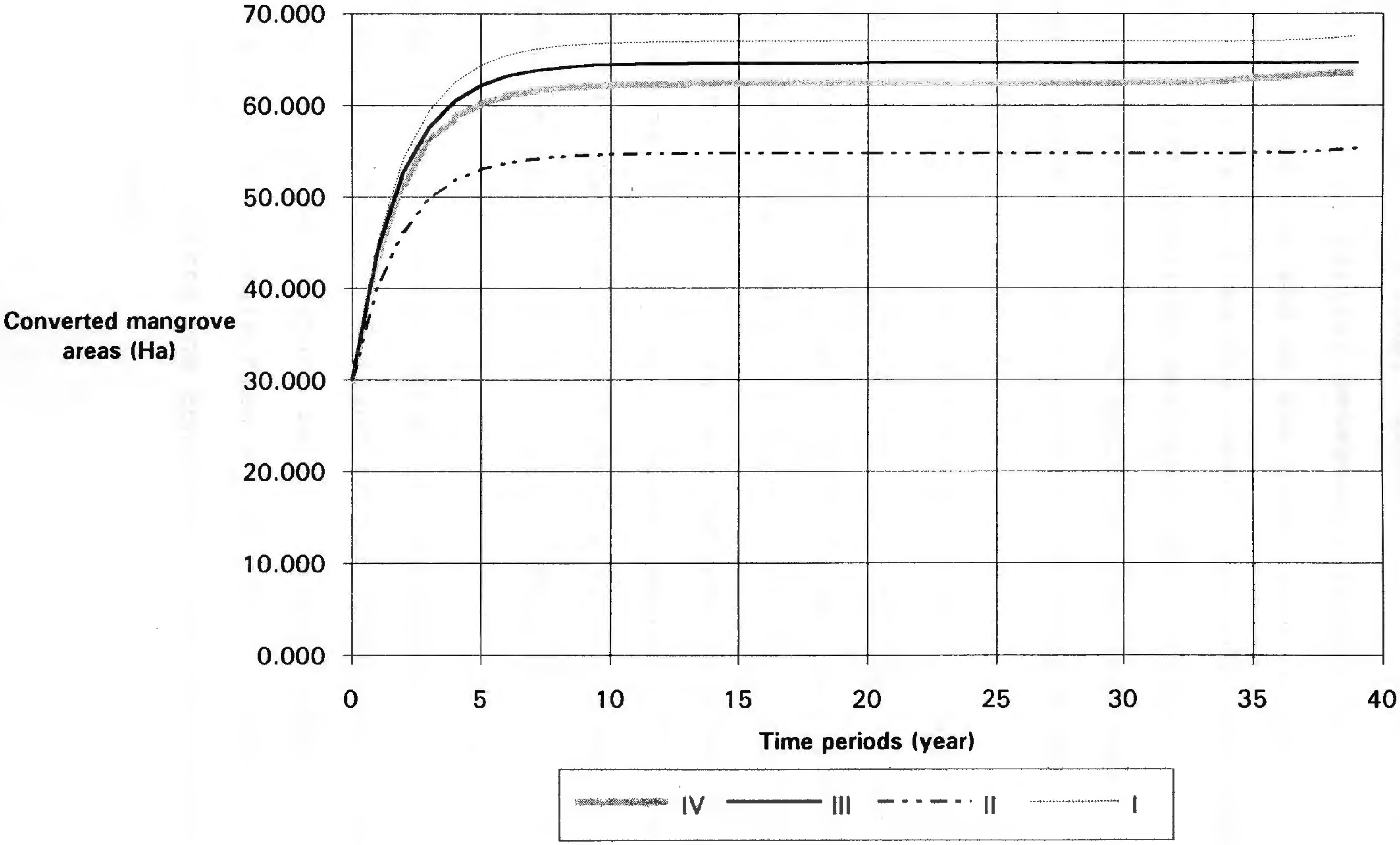
The total quantity of converted mangrove areas ranges from approximately 54,700 ha to 64,700 ha for scenarios II, III and IV. The highest level of conversion (67,000 ha) is observed in scenario I, which is used only for comparison purposes.

Conversion of mangrove areas under all four scenarios shows a smooth, yet relatively fast, convergence path towards a steady-state equilibrium. Figure 4.3 depicts the total mangrove area converted over time, that is, the conversion path of mangrove areas for all scenarios. Conversion occurs significantly rapidly during the first five periods, after which it slows down, reaching the steady-state equilibrium between the 10th and 15th period.

Figure 4.4 portrays the rates of conversion of mangrove areas, over time, for a transformation process starting with initial conditions, which indicate the present level of mangrove conversion for Ecuador (30,000 ha). Conversion rates resulting from the application of the current policy (scenario II) are smallest until the 7th period, after which they equal those produced by scenario IV.

Figure 4.3 Conversion Path of Mangrove Areas.

(Conversion on mangrove areas starting at present level)



Conversion rates for scenario II reach near zero values after approximately 10 periods. Conversion rates resulting from implementation of partial management (scenario III) are highest until almost the end of the conversion process, where they become level with the conversion rates generated by scenarios II and IV before reaching zero values. Conversion rates resulting from applying full management intervention (scenario IV) are intermediate during the entire conversion process.

Figure 4.4 also reflects the speed at which mangrove areas would be converted in each scenario, moving in less than five periods from more than 20,000 ha to about 2,000 ha of mangrove areas converted per period in Scenario I. In scenarios III and IV, during the same period, conversion rates fall from about 14,000 ha to approximately 1,000 ha per period. Note that the total quantity of converted mangrove areas in each scenario is represented by the area under the conversion rate curve.

For comparison purposes, paths of conversion of mangrove areas were estimated using initial conditions which reflect a new shrimp mariculture industry (zero level of conversion) along with virgin fish and mangrove forest stocks. Figure 4.5 depicts the conversion paths estimated under these conditions.

Figure 4.4 Conversion rate of mangrove areas over time for different scenarios.

(Conversion of Mangrove Areas Starting at Present Level)

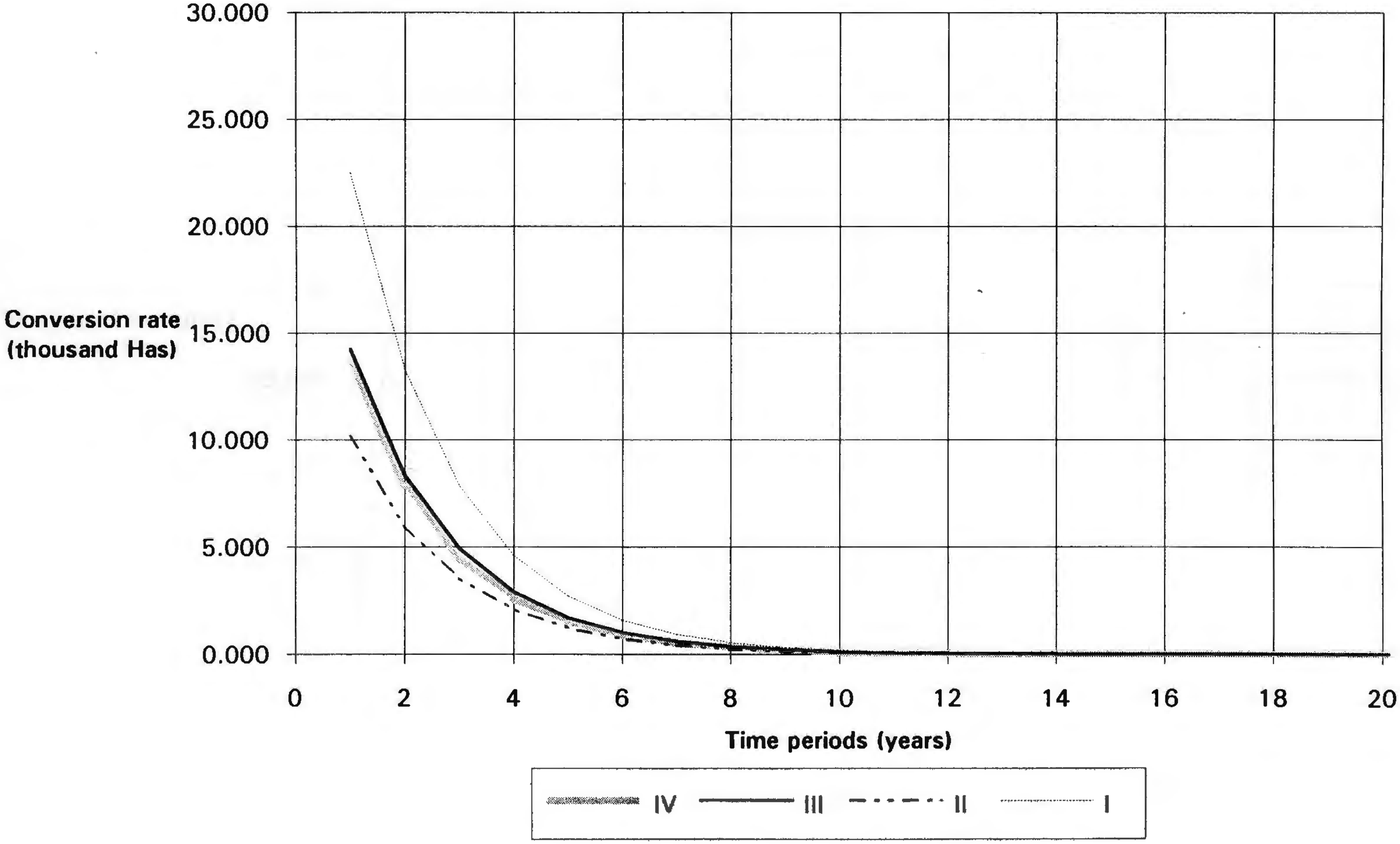
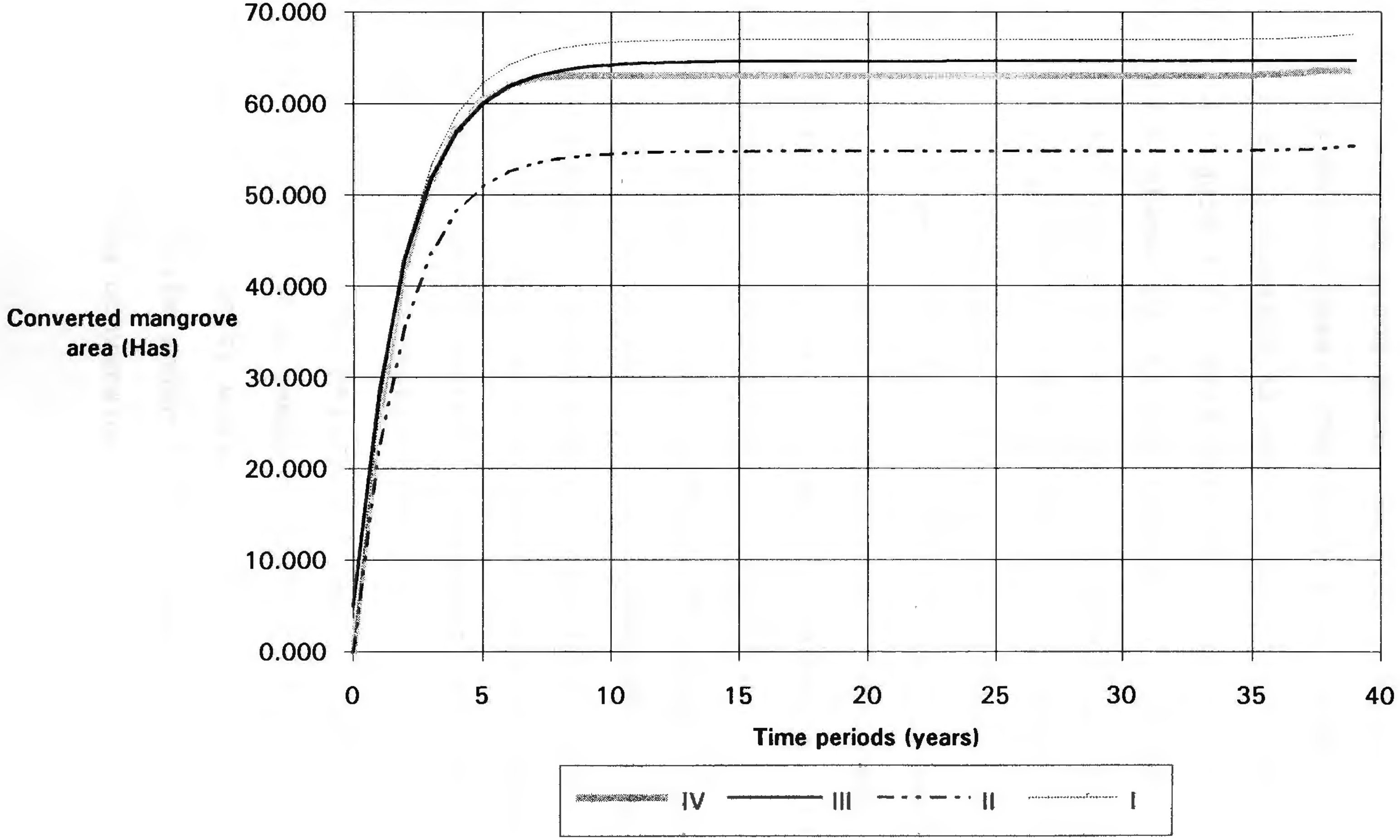


Figure4.5 Conversion path of mangrove areas.

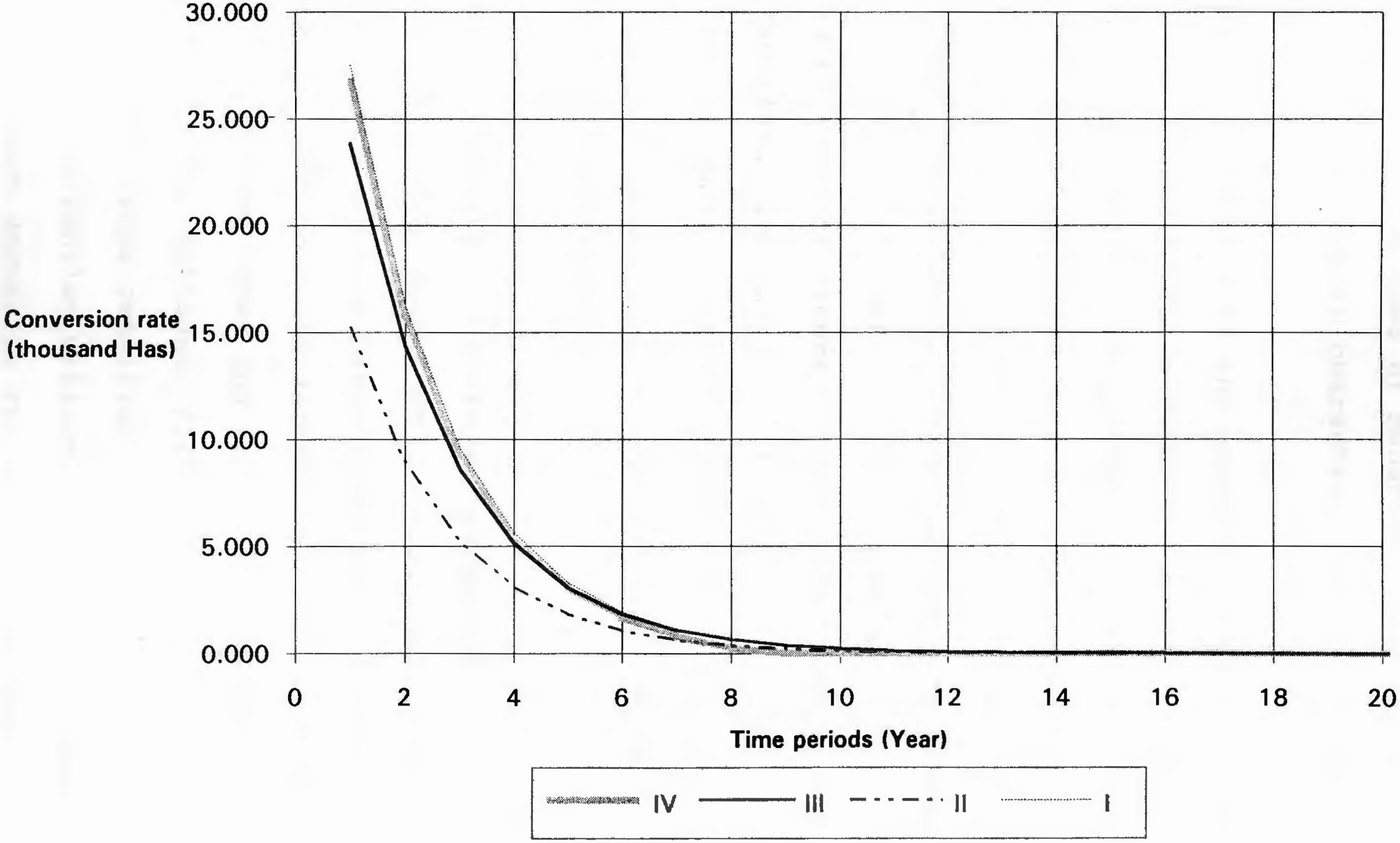
(Conversion of mangrove areas considered from the begining)



All four scenarios smoothly converge towards a total quantity of converted mangrove areas identical to the ones estimated in the previous case. The conversion rates resulting from the application of scenarios II, III and IV are portrayed in figure 4.6. This analysis shows that conversion rates produced by the application of current policy are still the lowest, but land transformation under these conditions stops at a later period than in scenario IV. Conversion rates calculated by applying partial management intervention (scenario III) are initially smaller than the ones calculated under full management intervention (scenario IV). After the 5th period, however, scenario III generates higher conversion rates than scenario IV. Conversion rates calculated under scenario IV are initially larger than those for II and III. These conversion rates decline at a fastest pace, being smaller than those for scenario III after the 5th period and smaller than the ones for scenario II after the 8th period. Conversion of mangrove areas under full management intervention stops at earlier periods than those for current policy and partial level of management intervention. This seems to indicate the existence of higher opportunity costs for use of mangrove areas in their natural state under full management conditions, thus, driving conversion rates down faster.

Figure 4.6 Conversion rate of mangrove areas over time for different scenarios.

(Conversion of Mangrove Areas Considered from the Begining)



In other words, a stronger recognition of benefits generated by alternative uses of mangrove areas and benefits derived from their intrinsic characteristics is present in Scenario IV.

Two important aspects of the scenarios should be kept in mind when interpreting these results. First, these scenarios are set under the assumption of constant economic and technical conditions; thus, there is no place for uncertainty and speculative behavior of the economic agents represented here. This may explain the divergence between the actual conversion path and those calculated here. Second, this analysis considers a finite and fixed time horizon. The fixed time horizon induces a distortion in the steady-state equilibrium near the end of the time horizon. Therefore, the last portion of the time horizon should be ignored for analytical purposes.

3. Biological stocks and associated harvest rates.

Understanding the impacts of different management strategies upon the stock of natural resources and their harvest rates is important for decision making. Figures 4.7 and 4.8 portray harvest rates and stock size, respectively, over time, for coastal artisanal fisheries under all scenarios. Harvest rates resulting from the application of full management intervention ultimately are larger than those estimated under scenarios II and III (figure 4.7).

Figure 4.7 Harvest rates over time in fisheries for different scenarios

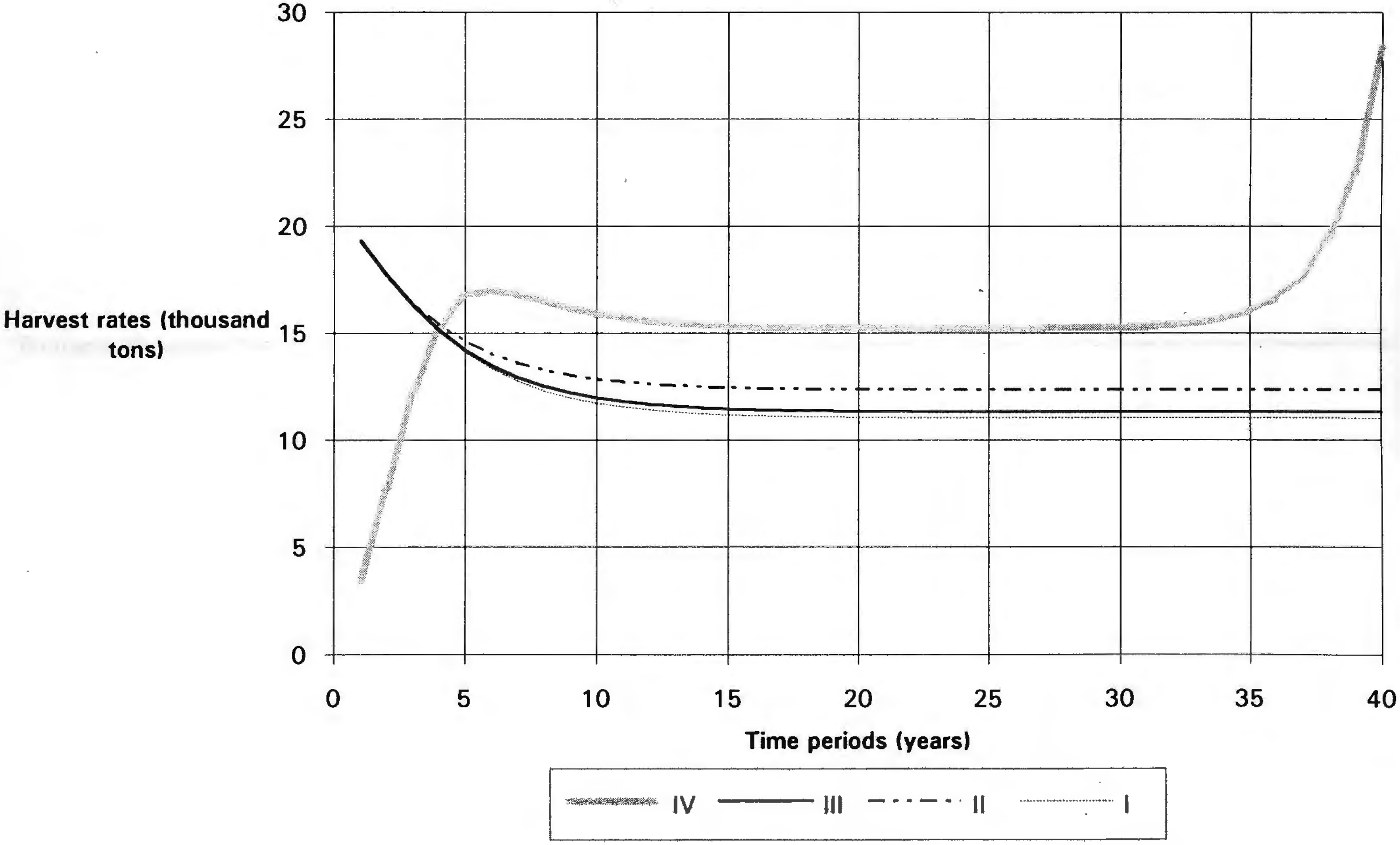
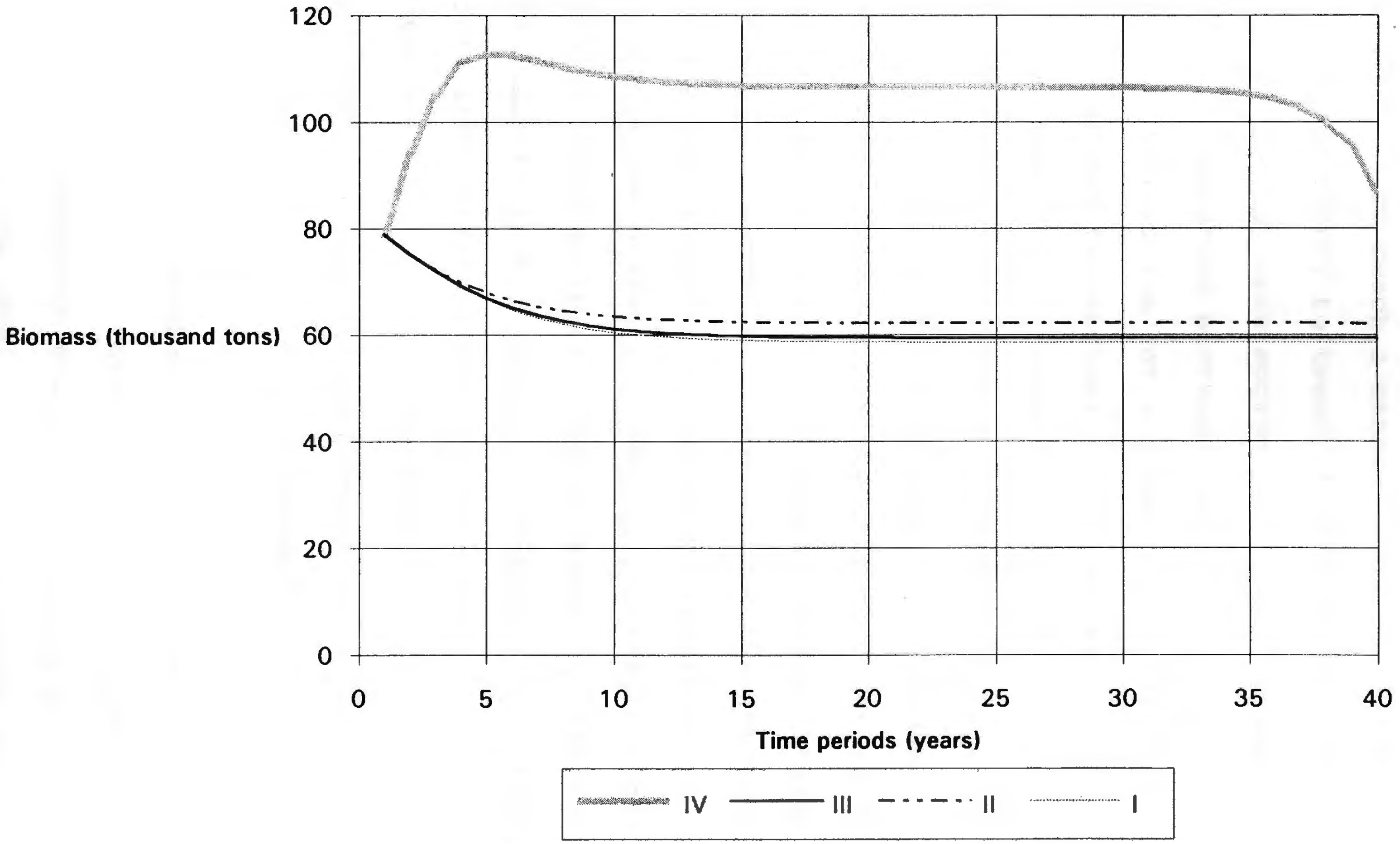


Figure 4.8 Fish stock size over time for different scenarios.



Scenarios I, II and III induce a decrease in stock size and harvest rates which reach a steady-state equilibrium after approximately twenty to twenty five periods. This behavior is explained by open access conditions assumed in three of the four scenarios pictured here.

Open access equilibrium for a heterogenous fishing fleet is characterized by marginal fishing units operating at a point where their total revenues equal total cost (i.e., they operate at zero profits). Whenever changes in the biological stock and/or economic conditions induce higher harvest costs, marginal fishing units are forced out of the activity reducing total fishing effort and allowing for stock recovery. Opposite changes induce the entrance of new fishing units, increasing fishing effort which ultimately reduces the biological stock and drives out the marginal fishing units again, leading to a new equilibrium. This process leads to an economically overexploited fishery and, simultaneously, dissipation of resource rent.

Under scenario IV, on the other hand, direct or indirect controls on access and on harvest rates are introduced. Total fishing effort is reduced as harvest rates are regulated in order to reach the stock size which maximizes net benefits (consumer's surplus, producer's surplus and resource rent). This is reflected in the behavior of harvest rates for Scenario IV (figure 4.7), where they begin at a low level in the first period and start increasing until reaching a peak near the 6th period. Fishing effort and biological stock interact to drive harvest rates and stock size (Figure 4.8) to a steady-state equilibrium between the 15th and 25th period. Steady-state harvest rates for Scenario IV are between 25 and 36 percent higher than in Scenarios I, II and III. Simultaneously, associated stock size (Figure 4.8) rises from its open access equilibrium condition in the first period to reach an equilibrium size approximately 68 percent higher than the one attained in the three other scenarios. Notice that steady-state stock and harvest rate levels are also affected by the biotechnical externalities, which drive down carrying capacity as conversion of mangrove areas takes place.

Increases in harvest rates in the last ten periods are explained by the existence of a finite time horizon which increases current harvest, since there are no future periods for benefit generation. Again, these last periods should not be considered for analytical purposes.

Figures 4.9 and 4.10 show similar results for mangrove forestry. Forestry is seen to operate under similar conditions to fisheries operations, where fishing units are replaced by forest harvest units concerned only with harvesting and not engaging in resource regeneration (i.e., stocking).

Figure 4.9 Harvest rates over time in forestry for different scenarios

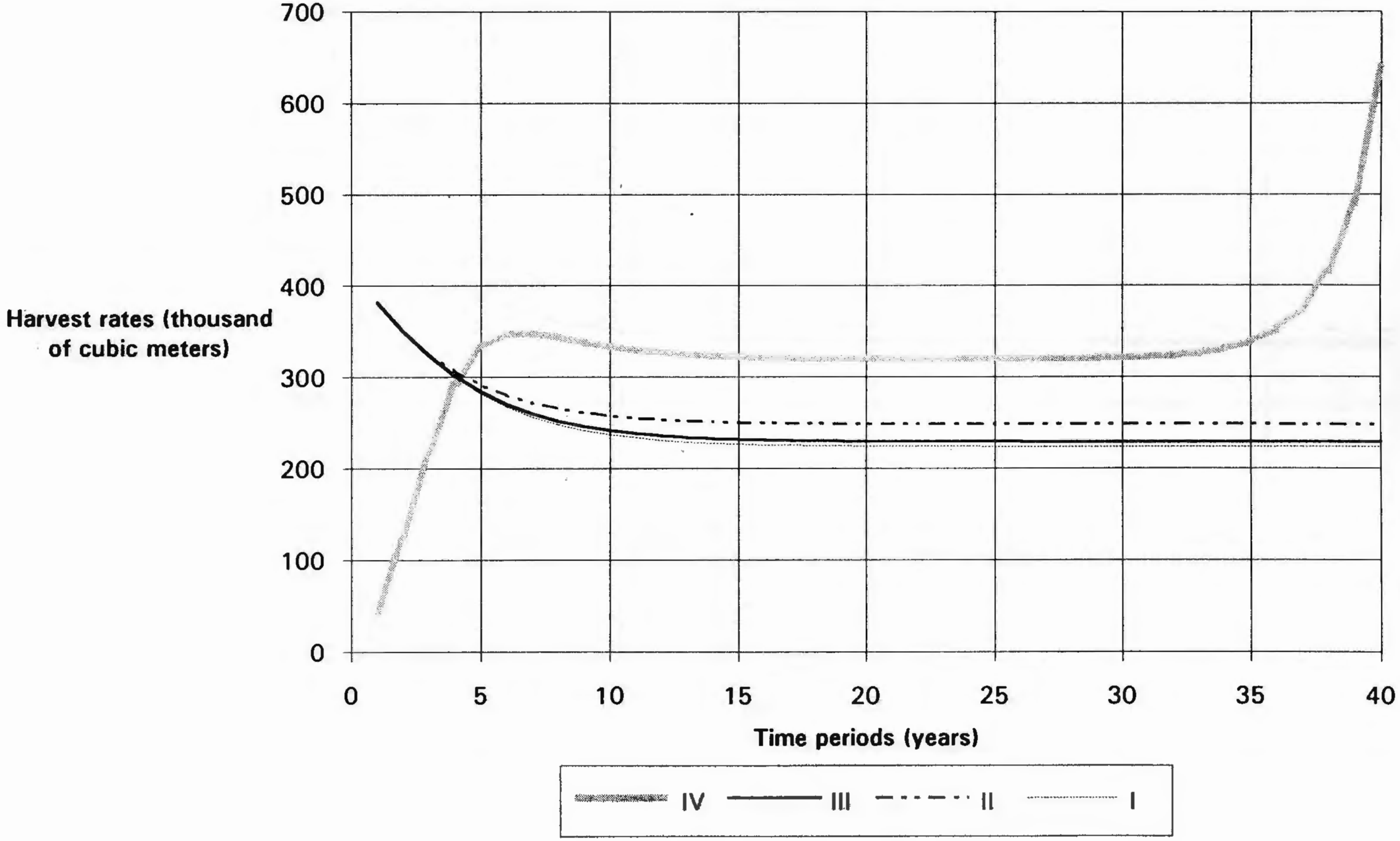
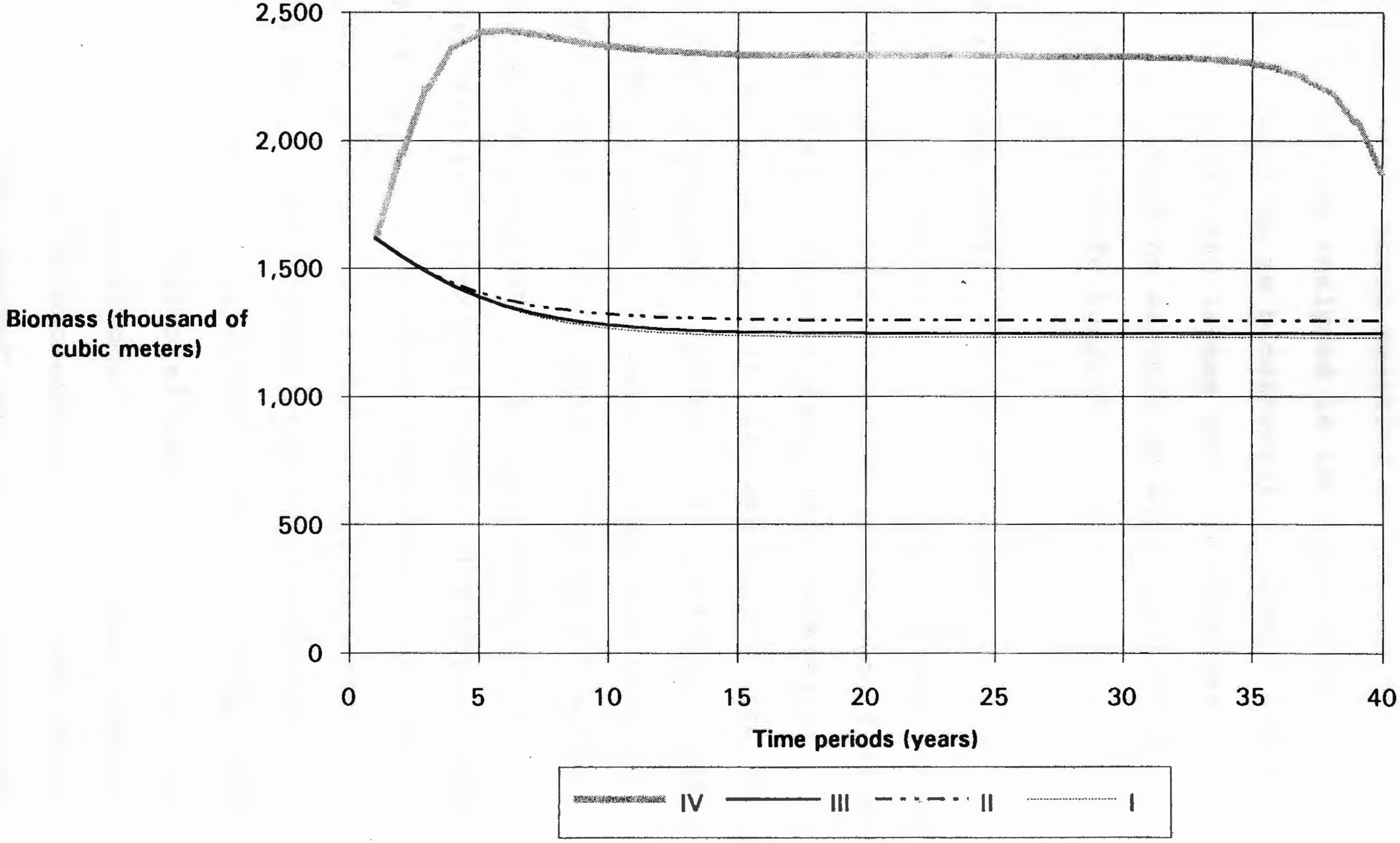


Figure 4.10 Mangrove forest size over time for different scenarios.



The fact that Scenario IV induces the existence of a higher mangrove forest stock relative to the other management alternatives analyzed is important when considering aspects such as biodiversity. Common sense suggests that stronger and larger biological stocks (mangrove forest) would be associated with a larger and stronger capacity for life support.

B.- SENSITIVITY ANALYSIS.

Sensitivity analysis is performed with the purpose of determining how changes in relevant parameters would affect the outcomes of the alternative management strategies investigated. Only Scenarios II, III and IV are considered in this analysis since they represent the current situation and possible improvements. Scenario I was used only for comparison purposes and is not relevant to this analysis.

Indicators analyzed are: a) present value of net benefits generated from alternative uses of mangrove areas, b) quantity of converted mangrove areas, and c) harvest rates of biological stock in fisheries and forestry.

Ten and twenty five percent changes in biological, biotechnical and economic parameters were performed. Only ten percent changes are presented here since twenty five percent changes have proportional effects on the outcomes. No optimal solution to the bioeconomic model under scenario IV was found with a ten percent increase in biotechnical externality parameter, thus, only a five percent increase in this parameter was used in this scenario.

Changes in biological and biotechnical parameters allow for the impact of possible errors in the estimation of the current conditions of the stock and ecosystem. The relevant biological parameter is the intrinsic growth rate of the biological stocks. The intrinsic growth rate (r) directly affects the speed at which fish and mangrove trees grow, influencing the speed at which these stocks reach equilibrium. The biotechnical externality parameter (δ) [see equation (4), Chapter III], affects the extent to which biological stocks are effected by a change in the ecosystem through changes in carrying capacity.

Relevant economic parameters are product price, production cost and conversion costs. Changes in economic parameters reflect the impact of different conditions in product and factor markets. This is important to consider, since the Base Case reflects the estimated situation under current conditions. Traditionally, optimistic and pessimistic approaches are considered for economic conditions in sensitivity analysis. Optimistic conditions are reflected by increases in product price and pessimistic conditions by increases in costs of production and conversion.

Finally, changes in the social discount rate are needed to consider possible changes in the weight society places on the preservation of resources for future use. An increase in the social discount rate implies that society associates less importance to the future use of resources. A reduction, on the other hand, implies that society places higher importance on the future use of resources.

1. Present value of net benefits generated from alternative uses of mangrove areas.

Changes in the present value of total net benefits generated by alternative uses of mangrove areas under scenarios II, III and IV are presented in Table 4.1. Only two of the nine parameters used have a significant impact upon the outcome of the management strategies analyzed. Shrimp price is the most relevant parameter to consider, since a 10 percent increase in its value induces approximately a 30 percent change in total net benefits for all scenarios considered. The impact of changes in the social discount rate (both increase and decrease) is directly proportional. A 10 percent change in discount rate induces about an 11 percent change in total net benefits. Another important parameter is the fixed cost of production in mariculture, which has a noticeable effect although less than proportional.

The effects on mariculture, fisheries and forestry sectors are also investigated.

Table 4.1 Percent change in present value of total net benefits from alternative uses of mangrove areas, due to percent changes in relevant model parameters.

		Shrimp Mariculture			Coastal Fisheries & Mangrove Forestry				Natural	Social
Scenario	Percent Change	Product Price	Fixed Cost	Conversion Cost	Product Price	Harvest Cost	Stock's Intrinsic Growth Rate	Biotechnical Externality*	Functions of Mangroves	Discount Rate
II	-10									11.05%
	0									
	10	32.18%		-0.15%						-9.31%
III	-10							0.08%		11.21%
	0									
	10	32.05%	-6.62%	-0.16%	-0.02%	0.03%	0.60%	-0.09%	0.75%	-9.44%
IV	-10							0.33%		11.28%
	0									
	5							-0.33%		
	10	30.39%	-6.04%	-0.14%	-0.03%	0.14%	1.02%		0.74%	-9.50%

Table 4.2 Percent change in present value of net benefits from shrimp mariculture, due to percent changes in relevant model parameters.

		Shrimp Mariculture			Coastal Fisheries & Mangrove Forestry				Natural	Social
Scenario	Percent Change	Product Price	Fixed Cost	Conversion Cost	Product Price	Harvest Cost	Stock's Intrinsic Growth Rate	Biotechnical Externality*	Functions of Mangroves	Discount Rate
II	-10									11.31%
	0									
	10	41.57%		-0.13%						-9.53%
III	-10							0.01%		11.50%
	0									
	10	37.51%	-8.02%	-0.20%	0.00%	-0.01%	-0.37%	-0.01%	-0.02%	-9.68%
IV	-10							0.05%		11.47%
	0									
	5							-0.06%		
	10	37.66%	-8.04%	-0.20%	0.00%	-0.01%	-0.09%		-0.03%	-9.66%

Shrimp price and social discount rate also have a significant impact on net benefits generated by Shrimp Mariculture (Table 4.2). The shrimp price effect is more than proportional, resulting in about a 40 percent increase in generated net benefits from a 10 percent increase in price. The effects of a 10 percent decrease in the social discount rate are proportional with an approximately 11 percent increase of net benefits from mariculture in all scenarios. A 10 percent increase in the social discount rate has a nearly proportional effect resulting in a 9.6 percent reduction in net benefits from shrimp mariculture for all three scenarios.

The analysis for forestry and fisheries was done combining these two economic sectors (Table 4.3). Three parameters have a significant effect on the level of net benefits generated. These are, in order of importance, shrimp price, the intrinsic growth rate and the social rate of discount. As expected, an increase in price of shrimp has a negative effect on the net benefits generated by fisheries and forestry. A 10 percent increase causes a 15 percent reduction in net benefits. Increasing the intrinsic growth rate of fish and mangrove forest stocks yield larger harvest rates. Larger harvest rates, under constant economic conditions, induce a positive change in net benefits generated in both fisheries and forestry.

Table 43. Percent change in present value of combined net benefits from coastal artisanal fisheries and forestry associated to mangrove areas, due to percent changes in relevant model parameters.

Scenario	Percent Change	Shrimp Mariculture			Coastal Fisheries & Mangrove Forestry				Natural Functions of Mangroves	Social Discount Rate
		Product Price	Fixed Cost	Conversion Cost	Product Price	Harvest Cost	Stock's Intrinsic Growth Rate	Biotechnical Externality*		
II	-10									8.86%
	0									
	10	-4.74%		0.07%						-7.55%
III	-10							1.83%		8.58%
	0									
	10	-6.58%	2.61%	0.15%	-0.35%	0.84%	13.77%	-1.97%	0.11%	-7.28%
IV	-10							4.31%		10.87%
	0									
	5							-4.19%		
	10	-15.06%	7.13%	0.28%	-0.42%	2.02%	14.94%		0.22%	-9.14%

Table 44. Percent change in total quantity of mangrove areas converted into shrimp ponds due to percent changes in relevant model parameters.

Scenario	Percent Change	Shrimp Mariculture			Coastal Fisheries & Mangrove Forestry				Natural Functions of Mangroves	Social Discount Rate
		Product Price	Fixed Cost	Conversion Cost	Product Price	Harvest Cost	Stock's Intrinsic Growth Rate	Biotechnical Externality*		
II	-10									0.44%
	0									
	10	20.14%		0.00%						-0.44%
III	-10							0.19%		0.43%
	0									
	10	18.74%	-9.00%	0.00%	0.01%	-0.14%	-0.22%	-0.15%	-0.27%	-0.42%
IV	-10							0.49%		0.23%
	0									
	5							-0.50%		
	10	20.21%	-9.26%	0.00%	0.02%	-0.06%	-0.76%		-0.29%	-0.25%

The effect of a 10 percent increase in the intrinsic growth rate is more than proportional, resulting in a 14 and 15 percent increase in the combined present value of net benefits for these two sectors in scenarios III and IV, respectively.[2]

An increase in the externality parameter implies placing a higher weight on the relationship between mangrove conversion and the level of ecosystem degradation. Recall that it has been assumed that a higher degree of ecosystem degradation implies a greater reduction in the ecosystem's carrying capacity. Changes in the externality parameter have the expected, although not significant, impact in net benefits generated by fisheries and forestry. A 10 percent increase and reduction in the externality parameter in scenario III yields a 1.83 and -1.87 percent change in combined net benefits. In scenario IV a 10 percent reduction in the externality parameter yields a 4.31 percent increase in combined net benefits, while a 5 percent increase in the externality parameter yields a 4.19 reduction in combined net benefits. The larger effect in scenario IV may be explained by the fact that harvest rates are used in the optimization process to maximize present value of net benefits generated by fisheries and forestry, while in Scenario III stock size and harvest rates are

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[2] Scenario II was not considered since fisheries and forestry are not part of the maximization process.

determined under open access conditions. Thus, changes in carrying capacity have a higher effect in the determination of stock size and associated harvest rates in Scenario IV than in Scenario III.

A 10 percent reduction in the social discount rate has a significant effect in Scenario IV, inducing a proportional increase in generated net benefits. An identical increase in the social discount rate yields an almost proportional reduction in combined net benefits. Similar changes in the social discount rate in scenario III yields relevant, though not significant, changes in combined net benefits (Table 4.3).

2. Conversion of mangrove areas.

The total quantity of converted mangrove areas is significantly affected only by changes in the price of shrimp and fixed cost of mariculture (Table 4.4). A 10 percent increase in price of shrimp induces approximately a 20 percent increase in the quantity of mangrove areas converted into shrimp ponds for scenarios II, III and IV. A 10 percent increase in fixed cost induces approximately a 9 percent decrease in the level of conversion of mangrove areas.

The average conversion rate of mangrove areas is also significantly affected by the price of shrimp (Table 4.5). Scenario II shows the highest impact with a change of approximately 43 percent in the average conversion rate.

The impact of an identical change in Scenario IV is lower, inducing an increase of 37 percent in the average conversion rate of mangrove areas. The lowest effect is observed in scenario III with an increase of only 23 percent in the average conversion rate. As expected, a 10 percent increase in fixed cost of shrimp culture has a more than proportional negative effect on the average conversion rate of mangroves in scenario IV.

Although in scenario III the effect of an increase in fixed cost of shrimp mariculture is still negative, it is insignificant, inducing less than 1 percent decrease in the average conversion rate.

Changes in the biotechnical externality parameter under scenario III also have a significant impact on the average conversion rate of mangrove areas. On one hand, a 10 percent decrease in the externality parameter causes a 55 percent increase in the average conversion rate and, on the other hand, a 5 percent increase in this parameter yields a 9 percent decrease in the average conversion rate. The directions of change due to changes in this parameter are as expected.

Table 45. Percent change in the average conversion rate of mangrove areas. due to percent changes in relevant model parameters.

		Shrimp Mariculture			Coastal Fisheries & Mangrove Forestry				Natural Functions of Mangroves	Social Discount Rate
Scenario	Percent Change	Product Price	Fixed Cost	Conversion Cost	Product Price	Harvest Cost	Stock's Intrinsic Growth Rate	Biotechnical Externality*		
II	-10									0.96%
	0									
	10	42.62%		0.27%						-0.95%
III	-10							55.49%		-2.34%
	0									
	10	23.13%	-0.83%	0.00%	0.10%	-6.24%	-9.12%	-9.12%	-0.50%	2.50%
IV	-10							0.32%		0.73%
	0									
	5							-0.33%		
	10	37.07%	-17.46%	-0.05%	0.04%	-0.01%	-3.44%		-0.53%	-0.73%

Table 46. Percent change in the average harvest rates for fisheries and forestry in scenario IV due to percent changes in relevant model parameters.

		Shrimp Mariculture			Coastal Fisheries & Mangrove Forestry				Natural Functions of Mangroves	Social Discount Rate
Scenario	Percent Change	Product Price	Fixed Cost	Conversion Cost	Product Price	Harvest Cost	Stock's Intrinsic Growth Rate	Biotechnical Externality*		
Fishery	-10							6.00%		-0.17%
	0									
	10	-20.32%	10.08%	0.14%	-0.15%	0.92%	12.12%	-5.98%	0.31%	0.14%
Forestry	-10							6.01%		-0.09%
	0									
	10	-20.29%	10.10%	0.14%	-0.02%	1.03%	12.37%	-2.60%	0.31%	0.05%

* an increase of only 5% is considered.

Other parameters having a degree of effect on the average conversion rate in scenario III are fisheries and forestry harvest costs, and the intrinsic growth rate of the fish and mangrove stocks. It is interesting to note that the direction of effect of social discount rate on average conversion rate depends upon conditions of open access or optimal control for fisheries and forestry.

3. Full management and harvest rates.

The sensitivity analysis for harvest rates was performed only for scenario IV since it is the only one using them as control variable for the optimization process. The effect of changes in relevant model parameters upon harvest rates for fisheries and forestry is summarized in Table 4.6. Again, shrimp price and fixed cost of shrimp mariculture have the largest effect upon these decision variables. A 10 percent increase in shrimp price induces approximately a 20 percent decrease in the average harvest rates for both fisheries and forestry. A 10 percent increase in fixed cost of shrimp mariculture causes a proportional increase of 10 percent in the average harvest rate of both economic sectors. The above changes may be observed in Figures 4.12 and 4.13.

Figure 4.12 Changes in harvest rates of coastal artisanal fisheries due to 10 % changes in parameters for shrimp mariculture.

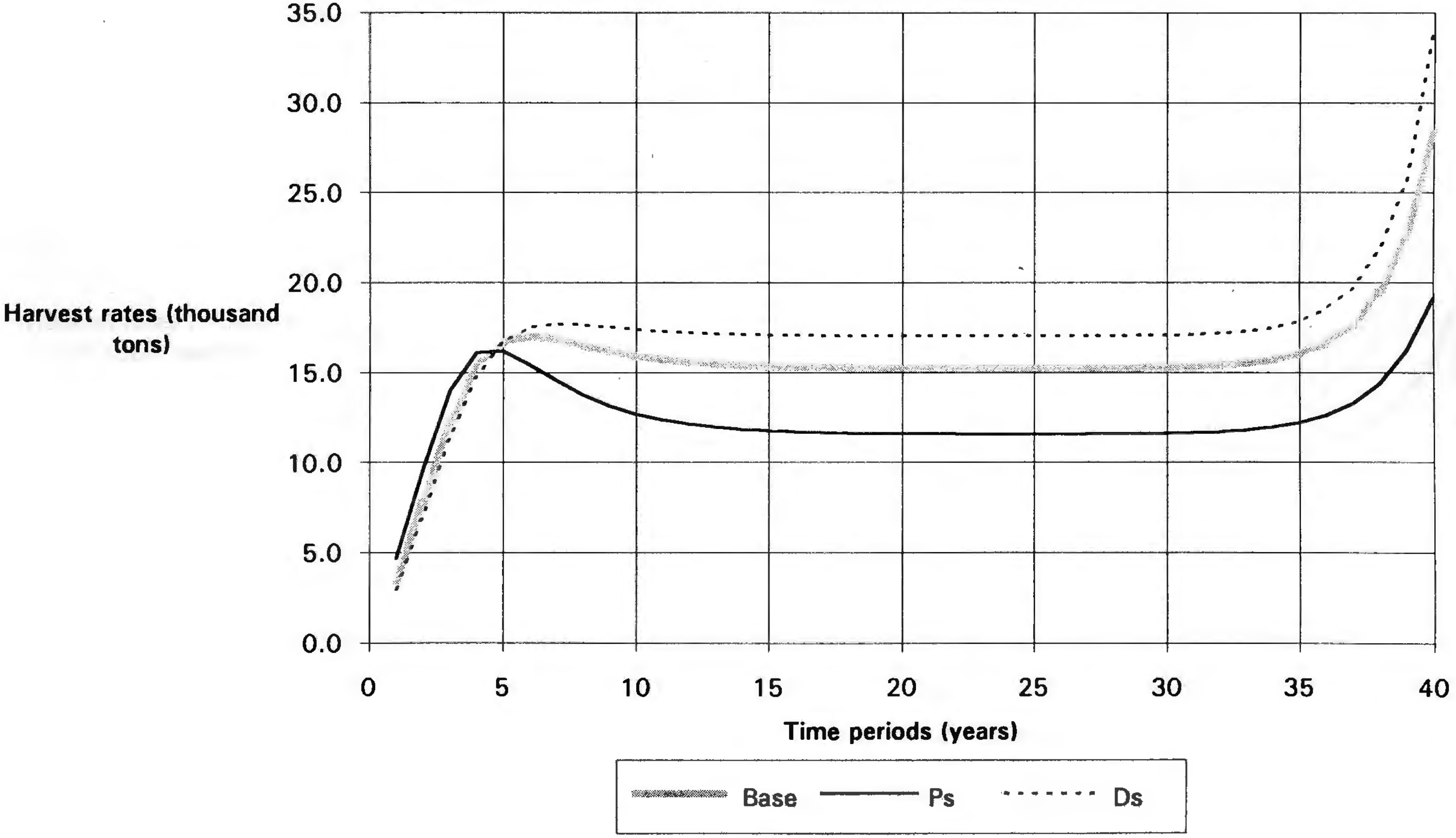
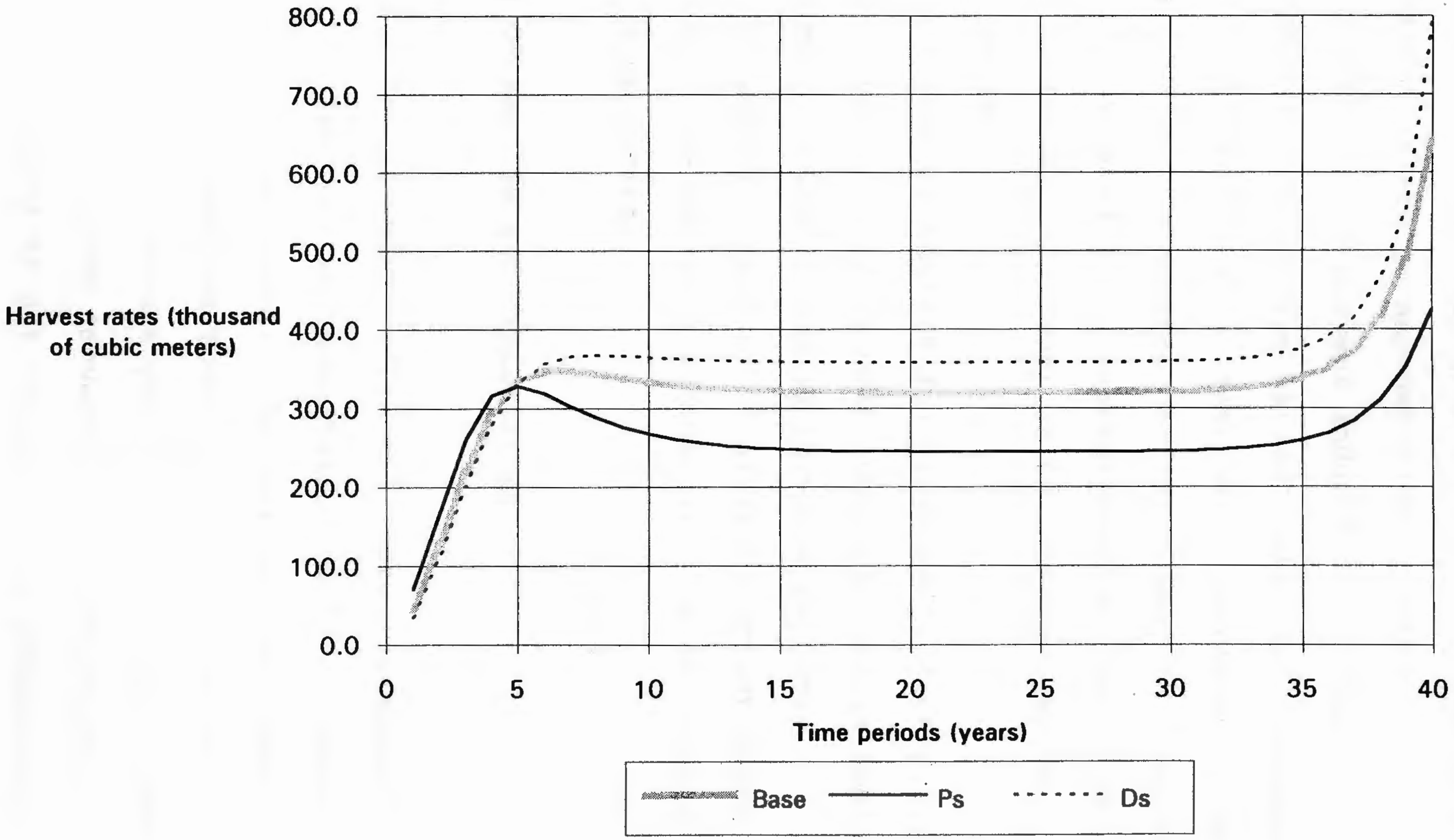


Figure 4.13 Changes in harvest rate of mangrove forestry due to 10% changes in shrimp mariculture parameters.



A change in the intrinsic growth rate of the stock also has a significant effect in harvest rates (Figures 4.14 and 4.15). An increase of 10 percent induces an increase of about 12 percent in the average harvest rates for fisheries and forestry. The biotechnical externality parameter also has a relevant effect in average harvest rates. A 5 percent increase in the externality parameter induces a more than proportional decrease (6 percent) in the average harvest rate for fisheries.

Conversion cost, fisheries and forestry product price, harvest costs, and value of natural functions induce changes in the expected direction although they are not very important. The observed changes in average harvest rates due to changes in the social discount rate are as expected, although not significant.

C.- SUMMARY OF RESULTS AND IMPLICATIONS.

The comparison of results from all three management strategies indicates that the application of a full level of management intervention (scenario IV) yields the highest present value of net benefits from uses of mangrove areas (figure 4.1). Although current policy (scenario II) yields the lowest level of mangrove conversion, it also produces the lowest present value of net benefits from alternative uses of mangrove areas.

Figure 4.14 Changes in harvest rates of coastal artisanal fisheries due to 10 % increase in the intrinsic growth rate of fish stock.

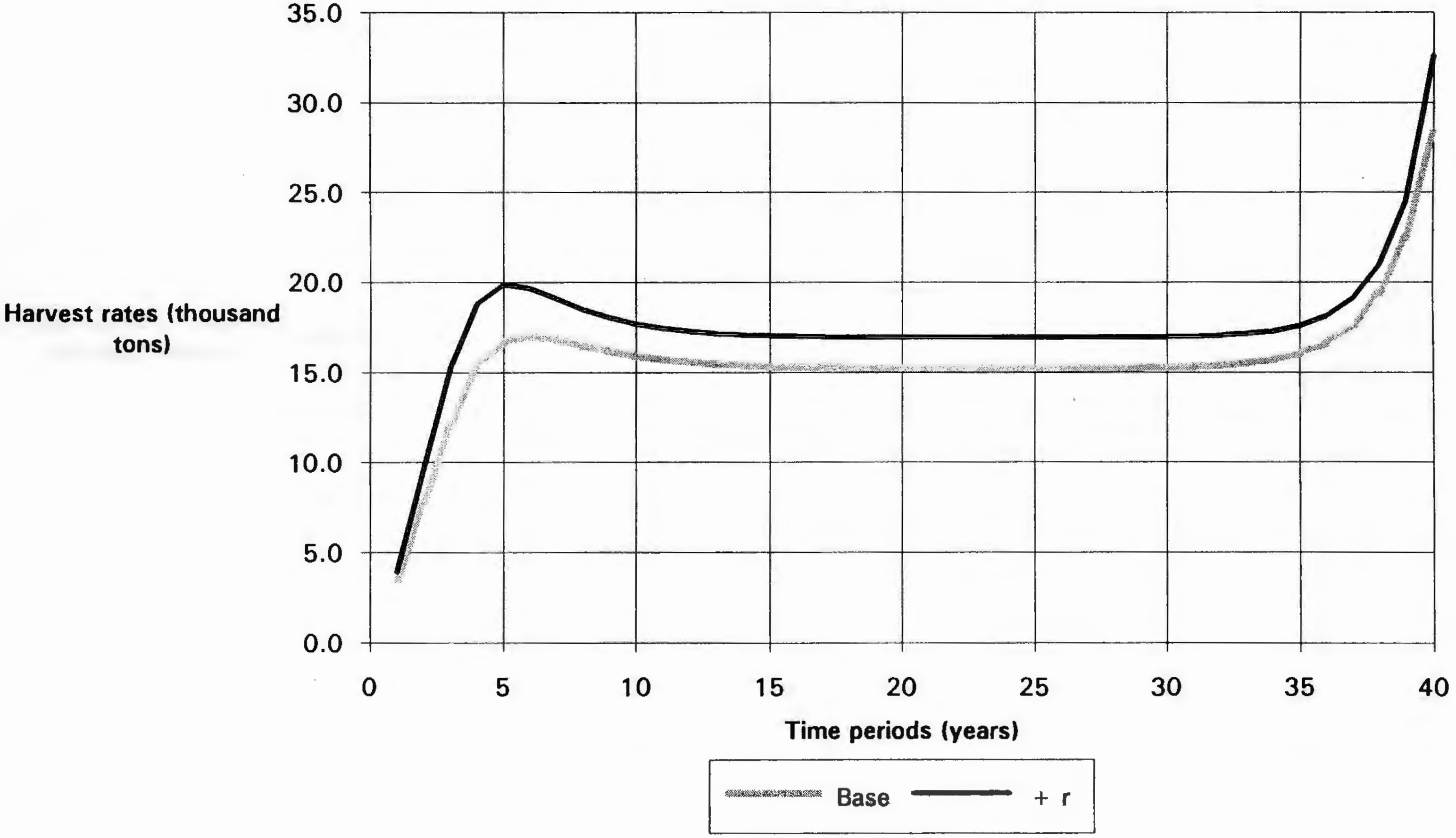
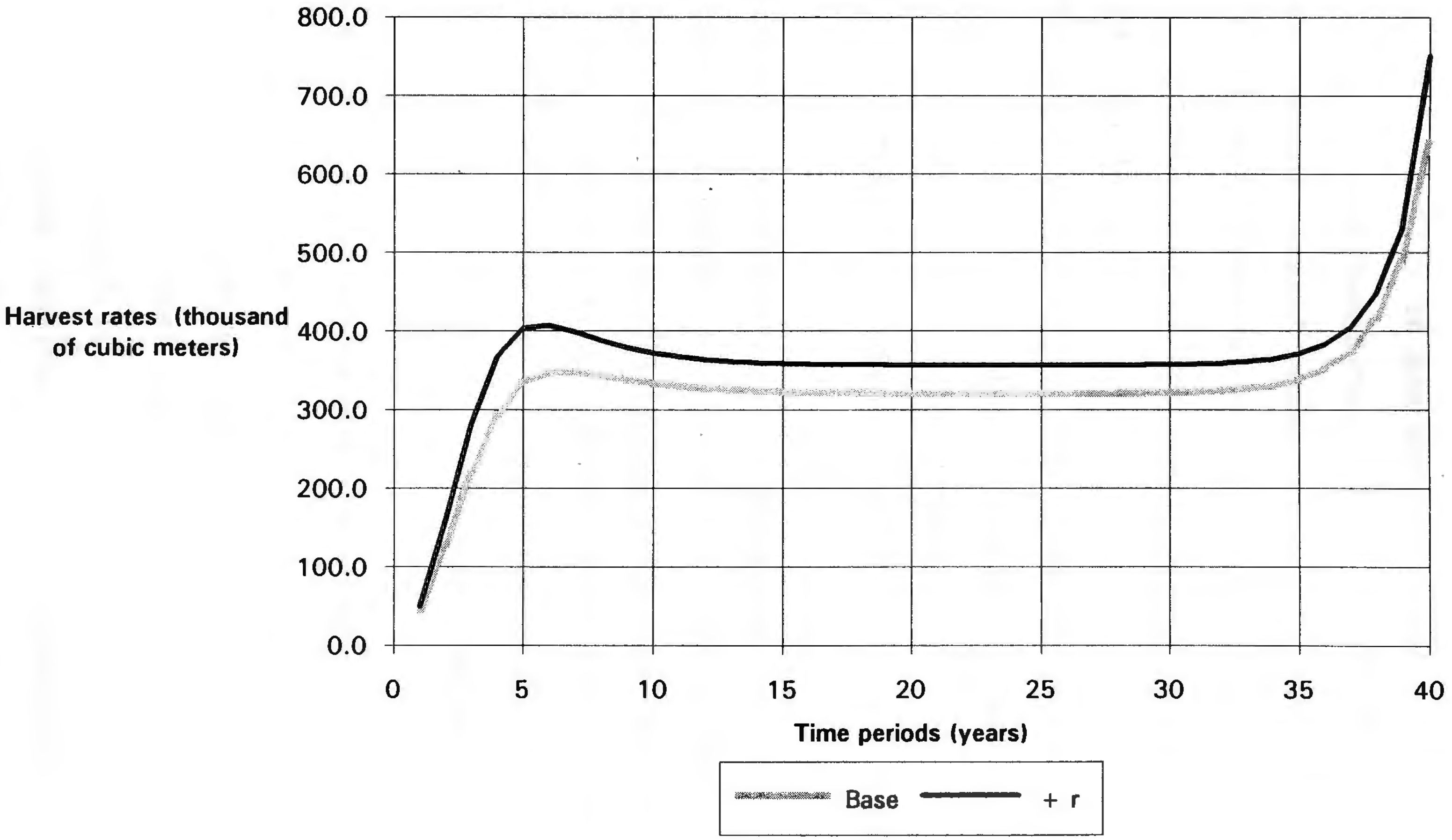


Figure 4.15 Changes in havest rates of mangrove forestry due to 10 % increase in the intrinsic growth rate of mangrove forest.



The application of a partial level of management intervention (scenario III) is non optimal and yields an intermediate level of net benefits.

A change from the current policy to a full level of management yields an improvement in net benefits generated by shrimp mariculture, coastal artisanal fisheries and mangrove forestry (figure 4.2).

Although there is an associated decline in benefits derived from natural functions, improvements in other sectors more than compensate for the negative effect. This causes an overall improvement when moving from scenario II to scenario IV.

A comparison of conversion paths among the three management strategies shows that scenario IV captures the opportunity cost of converting mangrove areas generated by their uses in their natural state. This scenario, starting at initial conditions, leads to intermediate conversion rates and total amount of mangrove converted (figures 4.3 and 4.4).

Consideration of full management intervention dramatically improves the levels of harvest rates and stock sizes in fisheries and forestry. Both harvest rates and stock sizes reach their highest levels under scenario IV (figures 4.7, 4.8, 4.9 and 4.10).

Sensitivity analysis confirms that the bioeconomic models constructed for all three management strategies behave according to economic theory. Though some outcomes may seem counter intuitive, they arise from the conditions of open access assumed in scenario III and those used to reflect the current situation for initial conditions in scenario IV.

Results obtained from the base case, and sensitivity analysis, show a strong influence of economic parameters of shrimp mariculture in the outcomes for all three management strategies. Variations in the parameters produce significant changes in the present value of net benefits, the total quantity of mangrove areas converted into shrimp ponds, and the harvest rates for fisheries and forestry.

The biotechnical externality parameter and the intrinsic growth rate of biological stocks have a significant effect upon the results for fisheries and forestry, along with a marginal impact on the overall outcome of the entire system. Increases in the intrinsic growth rate of fish and mangrove forest stocks induces an increase in their harvest rates.

Finally, variations in the social discount rate induce significant variations in the present value of net benefits, but have a marginal effect on the level of mangrove conversion.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Under the conditions assumed in this study, the adoption of full management intervention (scenario IV) is the best strategy to develop and control the use of mangrove areas. The present value of net benefits generated by a combination of mangroves conversion and use in their natural state is maximized under a full intervention. The optimal management strategy is defined as limiting access to shrimp mariculture (mangrove conversion), fisheries and forestry, and controlling harvest rates for fisheries and forestry.

Current management policy (scenario II) is not optimal, though it maximizes the level of mangrove preservation, since it generates the lowest present value of net benefits generated by alternative uses of mangrove areas. Under the conditions assumed, adoption of the current management policy is costing the country of Ecuador a total of US$ 132 million in present value terms, approximately equivalent to an annuity of US$ 13 million per year or 3 percent of the shrimp exports in 1991. Adoption of partial management intervention is considered to be non-optimal since it yields an intermediate level of net benefits and a higher level of mangrove conversion.

Results from this study suggest that the Government of Ecuador could maximize the net benefits generated from the use of mangrove areas by changing its current management policy to a full management intervention strategy. Management regulations to achieve results from full management intervention can be divided into those required to control conversion of mangrove areas and those required to control mangrove forest and fisheries exploitation.

To control conversion of mangrove areas, a government agency could calculate the optimal quantity to be converted in every period, using the model developed here, which accounts for externalities of conversion. The actual allocation of portions of the total amount of mangrove areas to be converted can be done by either setting an auction, where potential users can bid for mangrove areas up to the total quantity previously determined, or setting a price, equal to the opportunity cost of mangrove areas. At this price potential users can buy as much mangrove areas as they are willing. The relative efficiency of these two approaches depends upon uncertainties in data required to estimate values or quantities of mangroves to be converted (Weitzman 1974 and Yohe 1984).

To control the exploitation of mangrove forests and associated fisheries, full management may be achieved by implementing policies based on incentives or on conventional methods of regulations. Examples of Conventional methods of regulations are total allowable catches or harvest, gear regulation, seasonal closures, or fleet size limits. Under conventional methods of regulations though, resource users still operate under open access, leading to resource overexploitation, industry overcapitalization and resource rent dissipation.

Two examples of policies based on incentives are the imposition of taxes and the implementation of right-based methods. The application of a tax on harvest rates for fisheries and forestry, in US$ per ton of fish or cubic meter of wood, could theoretically induce the levels of harvest and benefits determined in scenario IV. The magnitude of the tax imposed on users has to be equal to the opportunity cost of the mangrove forest or fish stock. The application of taxes is a sound theoretical approach, but it has problems in its practical implementation. Two of these problems include the need for periodical re-assessment of the opportunity costs of the resources involved, and taxes may induce a negative reaction on the part of resource users which may lead to the failure of its implementation due to political resistance. An alternative incentives approach is the implementation of property rights, or use rights-based methods, of which a individual transferable quotas (ITQs) are representative. For fisheries and forestry a total allowable catch or harvest is determined and individual transferable quotas are allocated among the users of the fish stock and the mangrove forest. Examples of problems with these management options are a) the selection of the mechanism for initial allocation of rights, b) the potential high cost of enforcement, and c) need for periodical re-assesment of the opportunity costs of the resources. A positive aspect of ITQs is that there are several examples of successful implementation around the world (Sutinen et al. 1992).

Analysis of the results indicate the shrimp mariculture sector has a strong impact on the entire system analyzed. Sensitivity analysis demonstrates that even though the impact of biological parameters and biotechnical externality parameters upon the fisheries and forestry sectors is significant, the impact of these parameters is marginal with respect to the entire system analyzed (i.e., mariculture, fisheries, forestry and natural functions). This is explained by the small size of the net benefits generated by fisheries and forestry relative to shrimp mariculture.

The effect of a change in social discount rate under optimal management strategy is relevant for management purposes. A lower discount rate produces a significant increase in the present value of total net benefits from alternative uses of mangrove areas. However, the associated impact on total quantity of mangrove conversion is marginal. A lower discount rate reflects society placing a higher value on future resource use than it would with a higher discount rate. Thus, conversion and harvest rates are reduced in early periods and increased in future periods when a lower social discount rate is used. This, however, is not readily observable from the results obtained for scenario IV, where an increase in conversion rates is observed for early periods with a decrease in the social discount rate. A plausible explanation for this result is that a reduction in early periods of harvest rates for fisheries and forestry (due to the decrease in social discount rate) generates lower net benefits. These lower net benefits represent a lower opportunity cost of using mangrove areas for shrimp mariculture and, therefore, higher conversion rates are induced. These higher conversion rates lead to an increase in the total quantity of mangrove areas converted into shrimp ponds. Proportional but inverse effects are obtained for a higher social discount rate.

Model shortcomings

Sensitivity analysis indicates the existence of some parameters having a large impact on the results. Thus, the results are heavily dependent on these data. The greater the uncertainty about the value of these parameters, the less reliable the policy prescriptions produced by the model. These are the relationships which policy makers and researchers have to study carefully if comprehensive, efficient and timely management decisions are desired.

The model does not include the costs of management, and the consideration of such costs may have a significant effect on the results obtained. Enforcement costs in fisheries, under full management intervention, may be so high that their inclusion may result in lower present value of total net benefits compared to an open access situation, making scenario III preferable to a full level of management intervention.

For purposes of simplification, the model developed here considers the existence of only one type of mangrove areas, one system of production, and does not differentiates between geographical location (coastal provinces). The model also does not include in the analysis the use of salt flats and agricultural land for shrimp mariculture. Incorporation of the existing differences in mangrove areas (shore side and inland), in systems of production (extensive, semi-intensive and intensive), in geographical location (El Oro, Guayas, Manabí and Esmeraldas provinces), and of other types of land (salt flats and agricultural land) may significantly affect the results of the model. Fluctuations in market conditions (international and local) are also not considered, though they are important factors which may also affect the results obtained.

Estimates of values associated with natural functions of mangrove areas are rough approximations borrowed from other ecosystems due to the lack of existing measurements and information for these directly related to mangrove areas, specially for the case of Ecuador. Dramatic variations on the magnitud of the values used may affect the results of this study.

Despite the limitations of this research, the results indicate that the dynamic optimization technique is a relatively simple and efficient quantitative tool to examine the impact of alternative management decisions.

Suggestions for future research

There are several ways in which the bioeconomic model developed here can be improved, including:

a) determination of reliable point estimates of the parameters critically affecting the model;

b) incorporation of existing differences in types of mangrove areas, systems of production for shrimp mariculture, alternative types of land and among coastal provinces;

c) inclusion of the time paths of actual and expected prices and costs to further explain the evolution of the shrimp mariculture industry; and

d) consideration of management costs associated with alternative management strategies.

e) incorporation of ecological modeling to improve the representation of interactions between economic activities and the ecosystem (externalities).

The bioeconomic model is deterministic, while real world processes are stochastic. Thus, further refinements of this research should introduce uncertainty by including probability distributions for the future benefits.

APPENDIX I

MODEL LISTING FOR ALL SCENARIOS

```
* ---------------------------------
* -          MODEL  FOR            -
* -         SCENARIO  II           -
* -                                -
* -   Filename: SCEN1 GAMS         -
* ---------------------------------

* ----------------------- indexes -------------------
 SET T  time periods                                  /1 * 40/;
 SET TFIRST(T)  first period;
     TFIRST(T) = YES$(ORD(T) EQ 1);
 SET TLAST(T)  last period;
     TLAST(T) = YES$(ORD(T)  EQ CARD(T));

* ----------- Parameters for shrimp mariculture ------------
 SCALARS
       LI  initial converted mangrove area      /30/
      TAX  tax imposed through exchange rate    /0.100/
       RT  rotation time in shrimp mariculture /0.4858/
       WF  final individual weight              /1.45e-5/
       WO  initial individual weigth ton        /1.00E-9/
        N  number of stocked shrimp pl          /120000/
        R  stock intrinsic growth rate          /26/
        M  instantaneous mortality rate         /0.052/
        C  variable cost us$ per 1000 tons      /2.99E6/
        D  fixed cost per 1000 hectares         /41667.00/
     CONV  conversion cost per 1000 hectares    /240385.00/
        p  market price us$ per 1000 ton        /6.60E6/
      RHO  interest rate                        /0.100/;

 SCALAR
       Q  harvest (ton per hectare) in shrimp mariculture;
       Q = ((WO*WF) / ( WO+ (WF-WO)*EXP(-R*RT) ))
                              *(N*exp(-M*RT));

* --------- Parameter for terminal value equation ----------
 SCALAR
     MAN  initial mangrove area (1000 ha)                /160/
      TM  coefficient for mangrove areas                 /0/
      TL  coefficient for converted area                 /250000/;

* -----------  Financial parameters ----------------------
 PARAMETER
        VAL(T) numerical time;
        VAL(T) = ORD(T);


 PARAMETER
        ALPHA(T) discounting factor;
        ALPHA(T) = (1/((1+RHO)**VAL(T)));

 DISPLAY ALPHA;
```

```
* ----------------------------------
* -      Defining the model        -
* ----------------------------------
 VARIABLES

* --------- control variables ----------------
        L(T) land used for shrimp mariculture
       CR(T) mangrove conversion rate
* --------  auxiliary variables ---------------
      TMV(T) terminal value
* --------- objective function ------------------
          V  present value of net benefits;

 EQUATIONS
        VALUE   objective function
     LAND(T)    land used for shrimp mariculture
     CONST(T)   constraint for conversion
     TERMV(T)   terminal value equation;

  VALUE ..     V =E= SUM(T,ALPHA(T)*(
                  (((p*(1-tax))-C)*Q*(1/((1+RHO)**RT))-(D*L(T)))
                    *(L(T)/RT) - (CONV*(CR(T)**2)) ) + TMV(T));

  LAND(T+1) .. L(T+1) =E= L(T) + CR(T);
  CONST(T) ..  CR(T) =L= (MAN-L(T));
  TERMV(TLAST)..   TMV(TLAST) =E= ALPHA(TLAST)*
                              ((TM*(MAN-CR(TLAST)))
                              + (TL-TM)*(L(TLAST)+CR(TLAST) ));
* --- bound for variables -----;
  L.LO(T) = li;
  L.UP(T) = MAN-li;
 CR.LO(T) = 0;
* --- initial values for variables -----;
  L.FX(TFIRST) = LI;

 MODEL SCEN1T /ALL/;

 SOLVE SCEN1T USING NLP MAXIMIZING V;

 DISPLAY L.L, L.M, CR.L, TMV.L;

* ---------- Total yield for shrimp mariculture ----------
 PARAMETER
       YIELD(T)  total industry roduction;
       LOOP (T, YIELD(T) = (Q*L.L(T))/RT);
 DISPLAY YIELD;

* ----------------------------------------
* -  Accounting for Total Net Benefits   -
* -       and net benefits at the        -
* -             activity level           -
* ----------------------------------------

* --- Parameters for using mangroves in natural state ------

 SET I  Activity using mangrove areas in natural state
        /FISHERY, FORESTRY/;

* ---- Natural functions of mangrove areas -------------
  SCALAR
     VF value of natural functions (US$ per 1000 ha)
                                                            /300000/;
```

```
* ------ Parameters for fishery and forestry -----------
 PARAMETER
 GAMMA(I)    externality coefficient          /FISHERY 0.02
                                                FORESTRY 0.45/
    K1(I)    minimum carrying capacity        /FISHERY 0.015
                                                FORESTRY 0.0015/
    R1(I)    stock intrinsic growth rate      /FISHERY 0.32
                                                FORESTRY 0.30/
     A(I)    catchability coefficient         /FISHERY 0.000045
                                                FORESTRY 0.00004/
    C1(I)    first coefficient for cost       /FISHERY 20
                                                FORESTRY 20/
    D1(I)    second coefficient for cost      /FISHERY 0.75
                                                FORESTRY 0.025/
  XOA1(I)    stock size at open access        /FISHERY 78.8
                                                FORESTRY 1619.4/
    U1(I)    intercept for demand funct.      /FISHERY 250
                                                FORESTRY 5000/
    V1(I)    slope for demand funct.          /FISHERY 0.0001
                                                FORESTRY 0.95/;

* --- fishery price is in US$ per thousand tons and per
       thousand ha
* --- forestry price is in US$ per thousand m3 and per
       thousand ha


* ---- calculating auxiliary parameters ---------------
  PARAMETER
      AO(I)   first coefficient for price equation;
      AO(I) = U1(I)/V1(I);
  PARAMETER
      A1(I)   second coefficient for price equation;
      A1(I) = 1/V1(I);


  PARAMETER
      KI(I)   initial carrying capacity;
      LOOP (I, KI(I) = (K1(I) + (GAMMA(I)*( (MAN-LI)**2 ))
                           ));

 PARAMETER
      X1(I,T)  stock size fishery forestry;
* --- initializing stock size ------
  LOOP (I, X1(I,TFIRST) = XOA1(I) );

 PARAMETERS
      KK(I,T)  carrying capacity fishery and forestry
  LOOP((I,T), KK(I,T) = ((K1(I)+(GAMMA(I)*(MAN-L.L(T))**2))) ;
    X1(I,T+1) = (X1(I,T)
                - ((( AO(I)-(C1(I)/(A(I)*X1(I,T))) )
                /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2))))))
                +  R1(I)*(X1(I,T)
                - ((( AO(I)-(C1(I)/(A(I)*X1(I,T))) )
                /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2))))))
                - (R1(I)/KK(I,T))*((X1(I,T)
                - ((( AO(I)-(C1(I)/(A(I)*X1(I,T))) )
                /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2)))))
                    )**2) );
```

```
* ------------------------------------------------
* -      Accounting for Net Benefits at the       -
* -               Activity level                  -
* ------------------------------------------------

* ------  Benefits from natural functions  -------------
 SCALAR
    NF  Present value of natural functions of mangrove
         areas;
    NF = SUM(T, ALPHA(T)*VF*(MAN - L.L(T)) );

* ------- Net benefits fishery and forestry -------------
 PARAMETER
    NB(I) Pres. value of net benefits from fishery and
            forestry;
    LOOP (I,
    NB(I) = SUM(T, ALPHA(T)*(
              (( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
              /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2)) ))
              * (A0(I) - (C1(I)/(A(I)*X1(I,T)))
              - ( (A1(I)/2) + (D1(I) / ((A(I) *X1(I,T))**2)
      ))*(( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
              /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2)) ))
              ) )) );


 PARAMETER
    Q1(I,T)   fishery and forestry harvest;
    LOOP ((I,T), Q1(I,T) = (( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
                      /(A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2))
                          )) );

* ------------ Tax revenues -----------------
  SCALAR
     TAXREV  tax revenues;
     TAXREV = SUM(T, (P*tax)*ALPHA(T)*YIELD(T) );

* ------------ Total net benefits ---------------------
  SCALAR
     TNB  total net benefits generated from alternative uses
          of mangrove areas;
     TNB = V.L + SUM(I, NB(I)) + NF + TAXREV;

  DISPLAY NF, NB, TAXREV, TNB;
  DISPLAY X1, Q1, KK;
```

```
* ---------------------------------------
* -            MODEL  FOR              -
* -          SCENARIO  III             -
* -                                    -
* -      Filename: SCEN2  GAMS         -
* ---------------------------------------

* -----------------  Indexes  ------------------;

 SET    T   time periods                              /1 * 40/;
 SET    TFIRST(T) first period;
        TFIRST(T) = YES$(ORD(T) EQ 1);
 SET    TLAST(T) last period;
        TLAST(T) = YES$(ORD(T) EQ CARD(T));
 SET  I  Activities using mangroves in natural state
                                            /FISHERY, FORESTRY/;

* --------------- Financial parameters -----------;

  SCALAR RHO   interest rate                /0.100/;

 PARAMETER
        VAL(T) numerical time;
        VAL(T) = ORD(T);
 PARAMETER
        ALPHA(T) discounting factor;
        ALPHA(T) = (1/((1+RHO)**VAL(T)));


* -------- Paremeters for shrimp mariculture ----------;
 SCALARS
       LI   initial amount converted mangrove   /30/
       RT   rotation time in shrimp mariculture /0.4858/
       WF   final individual weigth             /1.45E-5/
       WO   initial individual weigth           /1.0E-9/
        N   number of stocked shrimp pl         /120000/
        R   stock intrinsic growth rate         /26/
        M   instantaneous mortality rate        /0.052/
        C   variable cost 1st coefficient       /2.99E6/
        D   variable cost 2nd coefficient       /41667.00/
     CONV   per hect.cost of conversion         /240385.0/
        p   market price                        /6.60E6/;

 SCALAR
       Q  harvest (ton pe hectare) in shrimp mariculture;
       Q  = (WO*WF*N*EXP(-M*RT))
                          / (WO+(WF-WO)*EXP(-R*RT));


* -------- Parameters for Mangroves Functions -----------;

  SCALAR
       VF   value of natural functions (1000 ha)  /300000/
      MAN   initial mangrove area (1000 Ha)       /160/;


* ---------- Parameters terminal value equation -----------;

 SCALAR
   TM  coefficient for mangrove areas              /600000/
   TL  coefficient for converted mangrove areas          /250000/;
```

```
* -------- Parameters for Fishery and Forestry ----------;

 PARAMETERS

   GAMMA(I)  externality coefficient      /FISHERY 0.020
                                            FORESTRY 0.450/
      K1(I)  minimum carrying capacity    /FISHERY  0.015
                                            FORESTRY  0.0015/
      R1(I)  stock intrinsic growth rate /FISHERY 0.352
                                            FORESTRY 0.330/
       A(I)  catchability coefficient     /FISHERY 0.000045
                                            FORESTRY 0.00004/
      C1(I)  variable cost 1st coeff.     /FISHERY 20
                                           FORESTRY 20/
      D1(I)  variable cost 2nd coeff.     /FISHERY 0.7500
                                            FORESTRY 0.02500/
      U1(I)  intercept for demand         /FISHERY 250.0
                                            FORESTRY 5000/
      V1(I)  slope for demand             /FISHERY 0.0001
                                            FORESTRY 0.9500/
    XOA1(I)  open access stock size       /FISHERY 78.8
                                            FORESTRY 1619.4/;

* --------------------------------------------------
* -  Fishery price is US$ per ton per thousand ha  -
* -  Forestry price is US$ per thousand m3 per     -
* -  per thousand ha.                              -
* --------------------------------------------------

* --- calculating auxiliary parameters for fishery forestry;

 PARAMETER
     A0(I) First coefficient price equation;
     A0(I) = U1(I)/V1(I);

 PARAMETER
     A1(I) Second coefficient for price equation;
     A1(I) = 1/V1(I);

 PARAMETER
       KI(I)  initial carrying capacity;
  LOOP (I, KI(I) = (K1(I)+( GAMMA(I)*((MAN-LI)**2) )));



* ----------------------------------------
* -        Defining the Model            -
* ----------------------------------------


 VARIABLES
* ------------ Control variables --------
        L(T) land used for shrimp mariculture
       CR(T) mangrove conversion rate

* ------------ Auxiliary variables ------
     KK(I,T) carrying capacity for fishery
     X1(I,T) fishery and forestry stock size
      TMV(T) terminal value
```

```
* ------------ Objective function  ------
          V  present value of net benefits;

 EQUATIONS
        VALUE objective function
      LAND(T) land used for shrimp mariculture
     CONST(T) constraint for conversion
   CARRY(I,T) harvest at open access
   STOCK(I,T) fishery and forestry state eq. for stock
     TERMV(T) equation for terminal value;

  VALUE ..    V =E= SUM(T,ALPHA(T)*(
               ((p-C)*Q*(1/((1+RHO)**RT)) - (D*L(T)) )
               *(L(T)/RT) - CONV*(CR(T)**2)
               + VF*(MAN - L(T)) ) + TMV(T) )
               + SUM((I,T), ALPHA(T)*(
                 (( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
                /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2)) ))
                * (A0(I) - (C1(I)/(A(I)*X1(I,T)))
                - ( (A1(I)/2) + (D1(I) / ((A(I) *X1(I,T))
                   **2) )) *(( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
                 /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2)) ))
                 ) ));

  LAND(T+1) .. L(T+1) =E= L(T) + CR(T);
  CONST(T)  ..  CR(T) =L= MAN - L(T);
  CARRY(I,T) ..  KK(I,T) =E= (K1(I)+ (GAMMA(I)*(MAN-L(T))**2) );
  STOCK(I,T+1) .. X1(I,T+1) =E= ( X1(I,T) -
                   (( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
                   /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2))
                     ))) + R1(I) *
              (X1(I,T) - (( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
                /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2)) ) ))
                - (R1(I)/KK(I,T))*
             ((X1(I,T) - (( A0(I)-(C1(I)/(A(I)*X1(I,T))) )
               /( A1(I)+(2*D1(I)/((A(I)*X1(I,T))**2))
                   )))**2);

  TERMV(TLAST) .. TMV(TLAST) =E= ALPHA(TLAST) *
                   (TM* (MAN-CR(TLAST))
         + (TL-TM)*(L(TLAST)+CR(TLAST)));



* --- bound for variables -----;
  L.LO(T) = li;
  L.UP(T) = MAN-li;
 CR.LO(T) = 0;
 X1.LO(I,T) = 1E-6;
 X1.UP(I,T) = Ki(I);
 KK.LO(I,T) = K1(I);
 KK.UP(I,T) = Ki(I);

* --- initial values for variables -----;
   L.FX(TFIRST) = LI;
  X1.FX(I,TFIRST) = XOA1(I);
* X1.FX(I,TFIRST) = KI(I);
  KK.L(I,T) = ki(i);
```

```
 MODEL SCEN2T /ALL/;

 SOLVE SCEN2T USING NLP MAXIMIZING V;
 DISPLAY L.L, L.M, CR.L, KK.L, TMV.L,
         X1.L, X1.M;

* -------------------------------------------------
* -     Accounting for Net Benefits at the        -
* -              Activity level                   -
* -------------------------------------------------

 SCALAR
    NF  Present value of natural functions of mangrove areas;
    NF = SUM(T, ALPHA(T)*VF*(MAN - L.L(T)) );
 PARAMETER
    NB(I) Pres. value of net benefits from fishery and forestry;
    LOOP (I,
    NB(I) = SUM(T, ALPHA(T)*(
             (( A0(I)-(C1(I)/(A(I)*X1.L(I,T))) )
             /( A1(I)+(2*D1(I)/((A(I)*X1.L(I,T))**2)) ))
              * (A0(I) - (C1(I)/(A(I)*X1.L(I,T)))
              - ( (A1(I)/2) + (D1(I)/((A(I)*X1.L(I,T))**2)))
              *(( A0(I)-(C1(I)/(A(I)*X1.L(I,T))) )
              /( A1(I)+(2*D1(I)/((A(I)*X1.L(I,T))**2)) ))
              ) )) );



 PARAMETER
    Q1(I,T)  harvest for fishery and forestry;
  LOOP ((I,T), Q1(I,T) = (( A0(I)-(C1(I)/(A(I)*X1.L(I,T))) )
               /( A1(I)+(2*D1(I)/((A(I)*X1.L(I,T))**2)) )));

 SCALAR
     SM  Pr. value of net benefits for shrimp mariculture;
     SM =  SUM(T,ALPHA(T)*(
                ((p-C)*Q*(1/((1+RHO)**RT)) - (D*L.L(T)) )
                *(L.L(T)/RT) - CONV*(CR.L(T)**2) ));
   DISPLAY  Q1, NF, NB, SM;
```

```
* ----------------------------------------
* -             MODEL   FOR              -
* -           SCENARIO   IV              -
* -                                      -
* -       Filename: SCEN3  GAMS          -
* ----------------------------------------

* ----------------- Indexes -------------------;
 SET     T   time periods                       /1 * 40/;

 SET     TFIRST(T) first period;
         TFIRST(T) = YES$(ORD(T) EQ 1);

 SET     TLAST(T) last  period;
         TLAST(T) = YES$(ORD(T) EQ CARD(T));

 SET     I   activities using mangrove in natural state
                                             /FISHERY, FORESTRY/;

* ------- Parameters for shrimp farming -------------------;
 SCALARS
       LI   initial amount of converted mangrove /30/
       RT   rotation time in shrimp mariculture  /0.4858/
       WF   final individual weigth              /1.45E-5/
       WO   initial individual weigth            /1.00E-9/
        N   number of stocked shrimp pl          /120000/
        R   stock intrinsic growth rate          /26/
        M   instantaneous mortality rate         /0.052/
        C   variable cost US$ per 1000 ton       /2.99E6/
        D   fixed cost US$ per 1000 hectare      /41667.00/
     CONV   convers.cost US$ per 1000 hectare    /240385.00/
        p   market price US$ per 1000 ton        /6.60E6/
      RHO   interest rate                        /0.100/;

SCALAR
    Q  harvest (ton per hectare) in shrimp mariculture;
    Q = (WO*WF*N*EXP(-M*RT)) /
                         (WO+(WF-WO)*EXP(-R*RT));

* ---- Parameter for natural functions of mangroves -------;

 SCALAR
      VF   per-hectare benefits nat.funct.     /300000/
     MAN   initial mangrove area (1000 ha)     /160/;

* ----- Parameters for terminal value equation ---------;

 SCALAR
     TM  coefficient for mangrove areas           /600000/
     TL  coefficient for converted mangrove areas /250000/;

* ------  Parameters for fishery and forestry ----------;

 PARAMETER
       K1(I) minimum carrying capacity     /FISHERY  0.015
                                            FORESTRY 0.0015/
       R1(I) stock intrinsic growth rate   /FISHERY 0.320
                                            FORESTRY 0.300/

       A1(I) catchability coefficient     /FISHERY 0.000045
                                           FORESTRY 0.00004/
```

```
      C1(I) variable cost 1st coeff.     /FISHERY 20
                                           FORESTRY 20/
      D1(I) variable cost 2nd coeff.     /FISHERY 0.7500
                                          FORESTRY 0.02500/
      U1(I) intercept for demand         /FISHERY 250.0
                                          FORESTRY 5000/
      V1(I) slope for demand             /FISHERY 0.0001
                                          FORESTRY 0.9500/
   GAMMA(I) externality parameter        /FISHERY 0.02
                                          FORESTRY 0.45/
    XOA1(I) biomass at open access       /FISHERY 78.8
                                          FORESTRY 1619.4/
    QOA1(I) catch at open access         /FISHERY 19.3
                                          FORESTRY 382.4/;

* ----- Financial parameters ----------------------;

 PARAMETER
        VAL(T) numerical time;
        VAL(T) = ORD(T);

 PARAMETER
        ALPHA(T) discounting factor;
        ALPHA(T) = (1/((1+RHO)**VAL(T)));

* ------ Auxiliary parameters for fishery and forestry ----;

 PARAMETER
    KI(I)  initial carrying capacity;
   LOOP (I, KI(I) = K1(I) + (GAMMA(I)*((MAN-LI)**2)) );

* ---------------------------------
* -     Defining the Model        -
* ---------------------------------

 VARIABLES

* ----- Control variables ----------;

      L(T) land used for shrimp mariculture (1000 hectares)
     CR(T) mangrove conversion rate
   Q1(I,T) i-th's activity harvest (1000 ton or m3) in t-th
             period

* ------ Auxiliary variables --------;

   X1(I,T) i-th's activity stock size (1000 ton or m3) in
             t-th period
   KK(I,T) carrying capacity for fishery and forestry
    TMV(T) terminal value

* ------- Objective function ---------;

         V  present value of net benefits;

 EQUATIONS
          VALUE    objective function
        LAND(T)    land used for shrimp mariculture
       CONST(T)    constraint for conversion
    STATE1(I,T)    state function
    CONST1(I,T)    stock constraint on harvest
     CARRY(I,T)    carrying capacity for fishery and forestry
```

```
      TERMV(T)   terminal value equation;

  VALUE ..    V =E= SUM(T,ALPHA(T)*(
                     ((p-C)*Q*(1/((1+RHO)**RT)) - (D*L(T)) )
                     * (L(T)/RT) - (CONV*(CR(T)**2))
                     + (VF*(MAN-L(T))) ) + TMV(T))
                     + SUM((I,T), ALPHA(T)* (
                     (2*U1(I) + Q1(I,T)) * (Q1(I,T) /V1(I))
                         *0.5 - C1(I)*(Q1(I,T)/(A1(I)*X1(I,T)))
                     -D1(I)*((Q1(I,T)/(A1(I)*X1(I,T)))**2)
                      ));

  LAND(T+1) ..    L(T+1) =E= L(T) + CR(T);
  CONST(T) ..     CR(T) =L= (MAN - L(T));
  CARRY(I,T) ..   KK(I,T) =E= K1(I) + GAMMA(I)
                                *((MAN-L(T))**2);
  TERMV(TLAST) .. TMV(TLAST) =E= ALPHA(TLAST) * (TM
                                 *(MAN - CR(TLAST))
       + (TL-TM) * (L(TLAST) + CR(TLAST)));
  STATE1(I,T+1) .. X1(I,T+1) =E= (X1(I,T)-Q1(I,T))
                       + R1(I)*(X1(I,T)-Q1(I,T))
                       - (R1(I)/KK(I,T))* ( (X1(I,T)
                           -Q1(I,T))**2);
  CONST1(I,T) ..    Q1(I,T) =L= X1(I,T);

* --- bound for variables -----;
    L.LO(T) = li;
    L.UP(T) = MAN-li;
   CR.LO(T) = 0;
   X1.LO(I,T) = 1E-5;
   X1.UP(I,T) = Ki(I);
   Q1.LO(I,T) = 1E-5;
   KK.LO(I,T) = K1(I);
   KK.UP(I,T) = Ki(I);

* --- initial values for variables -----;
   L.FX(TFIRST) = LI;
* X1.FX(I,TFIRST) = XOA1(I);
  X1.FX(I,TFIRST) = KI(I);
  KK.L(I,T) = KI(I);
* Q1.L(I,TFIRST) = QOA1(I);
  Q1.L(I,T) = Q1.LO(I,T);

 MODEL SCEN3T /ALL/;
 SOLVE SCEN3T USING NLP MAXIMIZING V;


 DISPLAY L.L, L.M, CR.L, KK.L, Q1.L,
         X1.L, X1.M;

* -------------------------------------------
* -    Accounting for net benefits at the    -
* -          activity level                  -
* -------------------------------------------

 PARAMETER

    NB  Present value of net benefits generated from using
        mangroves in their natural state;
```

```
  LOOP (I,
      NB(I) = SUM(T, ALPHA(T)* (
                 (2*U1(I) + Q1.L(I,T)) * (Q1.L(I,T)
                      / V1(I))*0.5
                   -C1(I)*(Q1.L(I,T)/(A1(I)*X1.L(I,T)))
                 -D1(I)*((Q1.L(I,T)/(A1(I)*X1.L(I,T)))**2)
                 )));

 DISPLAY NB;

SCALAR
   NF    Present value Natural functions of mangrove areas;

   NF   = SUM(T, ALPHA(T)*VF*(MAN-L.L(T)));

  DISPLAY NF;

SCALAR
   SM    P. value net benefits generated by shrimp
           mariculture;

   SM    = SUM(T, ALPHA(T)*( ((p-C)*Q*(1/((1+RHO)**RT))
           - (D*L.L(T)) )*(L.L(T)/RT)
           - (CONV*(CR.L(T)**2)) ));

  DISPLAY SM;
```

APPENDIX II

DATA USED TO ESTIMATE MODEL PARAMETERS

Appendix II a. Cost and revenue structure for 19 shrimp ponds operating in Manabi, Ecuador. 1990.

Pond	1	2	3	4	5	6	7	8	9	10
Size (Ha)	13.50	9.70	13.50	14.70	7.70	10.20	7.30	5.00	5.00	7.50
Harvest (lb/ha-cicle)										
Whole	1,832.15	2,001.86	2,139.41	1,982.93	2,373.51	1,971.27	2,407.40	2,290.80	2,478.80	1,519.47
Tail	1,249.70	1,350.31	1,443.56	1,344.69	1,612.08	1,348.63	1,629.18	1,547.00	1,670.60	1,035.07
Price (S./ lb-tails)	2,621	2,683	2,534	2,234	2,043	2,330	2,242	2,204	2,134	2,521
Total revenues (S)	3,275,511	3,623,514	3,657,335	3,003,441	3,293,862	3,142,235	3,651,966	3,409,681	3,565,111	2,609,258
Variable costs (S/.Ha)	1,088,418	1,283,563	1,115,509	857,782	1,466,026	1,025,736	1,285,795	1,272,323	1,224,045	965,604
Juveniles	669,529	663,666	641,954	674,483	710,831	496,717	709,083	590,323	647,345	573,604
Feed	368,889	570,103	423,704	132,653	705,195	478,922	569,863	672,000	527,000	385,333
Fertilizer	50,000	49,794	49,852	50,646	50,000	50,098	6,849	10,000	49,700	6,667
Fixed Costs (S/.Ha)	750,360	1,026,480	955,800	715,260	1,692,900	1,488,580	805,600	891,195	1,084,800	820,705
Price (US$/lb-tails)	3.49	3.58	3.38	2.98	2.72	3.11	2.99	2.94	2.85	3.36
Var. Costs (US$/lb-tails)	1.16	1.27	1.03	0.85	1.21	1.01	1.05	1.10	0.98	1.24
Juveniles	0.71	0.66	0.59	0.67	0.59	0.49	0.58	0.51	0.52	0.74
Feed	0.39	0.56	0.39	0.13	0.58	0.47	0.47	0.58	0.42	0.50
Fertilizer	0.05	0.05	0.05	0.05	0.04	0.05	0.01	0.01	0.04	0.01
Fixed costs (US$/ha)	1,000.48	1,368.64	1,274.40	953.68	2,257.20	1,984.77	1,074.13	1,188.26	1,446.40	1,094.27
Net Rev. (US$/lb-tails)	1.53	1.30	1.46	1.42	0.11	0.62	1.28	1.07	1.00	1.06

Exchange rate 750

Continuation Appendix II a.

Pond	11	12	13	14	15	16	17	18	19	AVERAGE	TOTAL
Size (Ha)	7.50	3.90	8.60	8.40	8.60	8.60	2.80	3.40	1.50	7.76	147.40
Harvest (lb/ha-cicle)											
Whole	1,976.00	2,290.51	1,741.05	472.50	1,517.79	951.98	3,429.29	2,774.12	3,686.67	2,096.71	39,837.48
Tail	1,331.20	1,535.13	1,206.40	320.83	1,024.53	647.79	2,274.64	1,879.41	2,472.67	1,417.02	26,923.42
Price (S./ lb-tails)	2,065	2,529	2,066	2,200	2,402	2,055	2,231	1,835	1,869	2,253	2,228
Total revenues (S)	2,749,407	3,882,585	2,492,087	705,984	2,460,759	1,331,443	5,074,046	3,448,852	4,620,400	3,191,851	59,997,476
Variable costs (S/.Ha)	1,094,481	1,545,766	1,287,165	958,656	1,169,061	415,698	2,660,193	2,233,850	2,743,333	1,352,263	25,693,004
Juveniles	578,814	852,176	747,863	653,894	699,177	293,023	1,213,765	1,272,085	1,423,333	742,719	14,111,665
Feed	466,000	680,769	489,535	254,762	419,767	72,093	1,428,571	947,059	1,286,667	572,573	10,878,885
Fertilizer	49,667	12,821	49,767	50,000	50,116	50,581	17,857	14,706	33,333	36,971	702,455
Fixed Costs (S/.Ha)	1,000,050	830,775	857,220	730,080	923,400	678,300	876,090	850,915	845,880	938,126	17,824,390
Price (US$/lb-tails)	2.75	3.37	2.75	2.93	3.20	2.74	2.97	2.45	2.49	3.00	2.97
Var. Costs (US$/lb-tails)	1.10	1.34	1.42	3.98	1.52	0.86	1.56	1.58	1.48	1.36	1.27
Juveniles	0.58	0.74	0.83	2.72	0.91	0.60	0.71	0.90	0.77	0.78	0.70
Feed	0.47	0.59	0.54	1.06	0.55	0.15	0.84	0.67	0.69	0.53	0.54
Fertilizer	0.05	0.01	0.06	0.21	0.07	0.10	0.01	0.01	0.02	0.05	0.03
Fixed costs (US$/ha)	1,333.40	1,107.70	1,142.96	973.44	1,231.20	904.40	1,168.12	1,134.55	1,127.84	1,250.83	23,765.85
Net Rev. (US$/lb-tails)	0.66	1.31	0.38	-4.08	0.48	0.49	0.90	0.26	0.56	0.77	0.82

Appendix II b. Cost and revenues structure of the Ecuadorean artisanal fleet.

	Canoes	Bongo1	Bongo2	Wooden Plank	Fleet Average	Total
Fleet size (units) 1)	1,800	1,200	1,500	1,500		6,000
Harvest 2)	2,064	2,907	4,414	8,381	4.4	26,395
Crustaceans	109			285		
White fish	318					
Menudo	1,636			4,068		
Langostino		318	318			
Pomada		2,589	4,095			
Sea bass				4,027		
Other pelagic						
Other demersal						
Price 3)	1.1	4.7	3.0	1.0	2,264.3	
Crustaceans	14.7			10.2		
White fish	1.2					
Menudo	0.2			0.7		
Langostino		14.7	17.1			
Pomada		3.4	2.0			
Sea bass				0.6		
Other pelagic						
Other demersal						
Costs (US$/year)	429.8	8,907.3	9,024.4	6,481.8	5,787.0	
Fuel		1,674.0	1,900.4	1,885.6		
Gear repair & maint	320.0	520.0	520.0	888.9		
Vessel repair & maint	55.6	666.7	666.7	533.3		
Depreciation	54.2	1,428.4	1,508.4	1,646.7		
Subtotal	429.8	4,289.1	4,595.6	4,954.4		
Labor		4,618.2	4,428.9	1,527.3		
Costs 3)	0.2	3.1	2.0	0.8	1,379.9	
Net Revenues 3)	0.9	1.6	1.0	0.2	884.4	2.33E+07

Source: Elaborated from Scott and Torrez (1991).

1) assumed values for the moment

2) expressed in kg/year for the average boat and in ton/year for the fleet

3) expressed in US$/kg for the average boat and in US$/ton for the fleet.

rate = 450
metric = 2.2
artisanal fleet size = 6000
conversion = 1000

Appendix II c. Estimation of supply and demand curves for coastal artisanal fisheries.

Biotechnical Parameters		Economic Parameters		Spreadsheet Parameters	
K =	0.015	c =	20	inc0 =	40
r =	0.32	u =	250	inc1 =	120000
A =	0.000045	d =	0.75	perc1 =	1
gamma =	0.02	v =	0.0001	perc =	1
kk =	338.015			scale =	1000
L =	30				
M =	160				

p	Soa	Xoa	S*	X*	Qd
1.00E-04	0	339	0	338	250
1.20E+05	13	289	12	295	238
2.40E+05	20	252	17	270	226
3.60E+05	24	224	20	253	214
4.80E+05	26	201	22	241	202
6.00E+05	27	183	23	232	190
7.20E+05	27	167	24	225	178
8.40E+05	27	154	25	219	166
9.60E+05	26	143	25	214	154
1.08E+06	26	133	25	211	142
1.20E+06	25	125	26	207	130
1.32E+06	25	117	26	205	118
1.44E+06	24	111	26	202	106
1.56E+06	23	105	26	200	94
1.68E+06	22	100	26	198	82
1.80E+06	22	95	26	197	70
1.92E+06	21	91	26	195	58
2.04E+06	21	87	26	194	46
2.16E+06	20	83	27	193	34
2.28E+06	19	80	27	192	22
2.40E+06	19	77	27	191	10
2.52E+06	18	74	27	190	-2
2.64E+06	18	71	27	189	-14
2.76E+06	17	69	27	188	-26
2.88E+06	17	66	27	187	-38
3.00E+06	17	64	27	187	-50
3.12E+06	16	62	27	186	-62
3.24E+06	16	60	27	186	-74

Appendix II d. Estimation of supply and demand curves for forestry in mangrove areas.

Biotechnical Parameters		Economic Parameters		Spreadsheet Parameters	
k1 =	0.002	c =	20	inc0 =	60
r =	0.3	RHO =	0.1	inc1 =	200
A =	0.00004	d =	0.025	inc2 =	0.5
X0 =	1	u =	5000	scale1 =	1000
L =	30	v =	0.95	SCALE =	1000
KK =	7,605.0			perc1 =	1
kk1 =	58.5			perc =	1
gamma =	0.45				
MG =	160				

p	Soa	Xoa	S*	X*	Qd
0.00E+00	0	8,011	#DIV/0!	#DIV/0!	5,000
2.00E+02	194	6,892	172	6,980	4,810
4.00E+02	371	6,048	313	6,354	4,620
6.00E+02	471	5,388	391	5,935	4,430
8.00E+02	526	4,858	438	5,634	4,240
1.00E+03	555	4,423	469	5,407	4,050
1.20E+03	568	4,059	490	5,230	3,860
1.40E+03	570	3,751	505	5,089	3,670
1.60E+03	566	3,486	516	4,973	3,480
1.80E+03	559	3,256	525	4,876	3,290
2.00E+03	548	3,055	532	4,794	3,100
2.20E+03	537	2,877	537	4,723	2,910
2.40E+03	524	2,718	541	4,662	2,720
2.60E+03	511	2,576	545	4,609	2,530
2.80E+03	498	2,449	548	4,562	2,340
3.00E+03	485	2,333	550	4,520	2,150
3.20E+03	473	2,228	552	4,482	1,960
3.40E+03	460	2,132	554	4,448	1,770
3.60E+03	448	2,043	555	4,418	1,580
3.80E+03	437	1,962	557	4,390	1,390
4.00E+03	426	1,887	558	4,364	1,200
4.20E+03	415	1,818	559	4,341	1,010
4.40E+03	405	1,753	560	4,320	820
4.60E+03	395	1,693	561	4,300	630
4.80E+03	385	1,637	561	4,281	440
5.00E+03	376	1,584	562	4,264	250
5.20E+03	368	1,535	563	4,248	60
5.40E+03	359	1,489	563	4,234	-130
5.60E+03	351	1,445	564	4,220	-320
5.80E+03	343	1,404	564	4,207	-510
6.00E+03	336	1,365	564	4,195	-700
6.20E+03	329	1,329	565	4,183	-890
6.40E+03	322	1,294	565	4,172	-1,080
6.60E+03	316	1,261	565	4,162	-1,270

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