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## **The Impact of Shrimp Farming on Mangrove Ecosystems and Local Livelihoods Along the Pacific Coast of Ecuador**

Stuart Edward Hamilton  
*University of Southern Mississippi*

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The University of Southern Mississippi

THE IMPACT OF SHRIMP FARMING ON MANGROVE ECOSYSTEMS AND  
LOCAL LIVELIHOODS ALONG THE PACIFIC COAST OF ECUADOR

by

Stuart Edward Hamilton

Abstract of a Dissertation  
Submitted to the Graduate School  
of The University of Southern Mississippi  
in Partial Fulfillment of the Requirements  
for the Degree of Doctor of Philosophy

August 2011

## ABSTRACT

### THE IMPACT OF SHRIMP FARMING ON MANGROVE ECOSYSTEMS AND LOCAL LIVELIHOODS ALONG THE PACIFIC COAST OF ECUADOR

by Stuart Edward Hamilton

August 2011

This manuscript examines the expansion of Ecuador's shrimp aquaculture industry since 1970 and the implications of this expansion on coastal residents' food security and livelihood options. Shrimp aquaculture expanded from essentially nothing in 1970; to account for 26% of all Ecuadorian private exports by 1998. The rapid expansion of shrimp aquaculture in Ecuador's estuaries has caused a fundamental shift in livelihoods among those who live and work in the immediate vicinity of the newly created shrimp farms. This research not only details the important land use change that has occurred within Ecuador's estuaries during the transition from mangrove estuary to shrimp-farmed estuary but also examines the change in the human condition through a series of interviews with residents who are dependent on the estuary. Research findings indicate that, despite massive investment in the shrimp industry of Ecuador and the relative success of the industry in terms of export dollars generated, local livelihood options and economic wellbeing have actually decreased in the aquaculture regions during the aquaculture boom. The pathway from the growth of a giant new export industry to a decrease in local economic opportunity are based on environmental, ecological, and economic alterations that have occurred in the coastal communities of Ecuador during the period of aquaculture expansion.

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## TABLE OF CONTENTS

ABSTRACT .....	ii
ACKNOWLEDGMENTS .....	iii
LIST OF TABLES .....	vi
LIST OF ILLUSTRATIONS .....	vii
LIST OF ABBREVIATIONS.....	xi
CHAPTER	
I.    INTRODUCTION .....	1
Research Objectives and Significance	
Study Areas	
II.   MANGROVE FORESTS.....	18
Biology of Mangroves	
Mangrove as a Keystone Species	
Mangrove Forest Goods and Services	
Mangroves and Fisheries	
Mangrove Summary	
III.  SHRIMP FARMING .....	32
The Growth of Commercial Aquaculture	
Shrimp Farm Financing	
Shrimp Farm Construction, Technical Operation, and Lifespan	
The Importance of Ecuador’s Coastal Estuaries to <i>P. vannamei</i>	
Aquaculture & Shrimp Summary	
IV.  MATERIALS AND METHODS .....	54
Image Selection and Sensor Information	
Data Pre-Processing	
Land Use Change Detection	
Interview and Survey Details	

V.	RESULTS.....	65
	Chone Estuary Land Use Change	
	Chone Estuary Food Security and Livelihood Implications	
	Cojimíes Estuary Land Use Change	
	Cojimíes Estuary Food Security and Livelihood Implications	
	Muisné Estuary Land Use Change	
	Muisné Estuary Food Security and Livelihood Implications	
	Cayapas-Mataje Estuary Land Use Change	
	Cayapas-Mataje Estuary Food Security and Livelihood Implications	
	Rio Hondo Estuary Land Use Change	
	Rio Hondo Estuary Food Security and Livelihood Implications	
	Grande Estuary Land Use Change	
	Ecuador Level Results	
VI.	CONCLUSIONS .....	149
VII.	POLICY RECOMMENDATIONS .....	159
	APPENDIXES .....	164
	REFERENCES .....	167

## LIST OF TABLES

### Table

1.	Site Selection Details and Area Calculations.....	12
2.	Ecuadorian Mangrove Taxa.....	20
3.	Traditional Mangrove Forest Goods and Services.....	25
4.	International Aid and the Funding of Aquaculture from 1977 to 1983 .....	38
5.	<i>P. vannamei</i> in a Farmed Environment.....	45
6.	Estuary Change Detection Possible Output Values and Descriptors.....	60
7.	Base Level Mangrove, Shrimp Farms, and Other Land Use .....	136
8.	Current Mangrove, Shrimp Farms, and Other Land Use.....	137

## LIST OF ILLUSTRATIONS

### Figure

1.	World Seafood Origin by Source as a Percentage of Total Seafood Supply .....	2
2.	Shrimp Origin by Source as a Percentage of Total Supply. ....	2
3.	Ecuador Overview and Study Sites.....	10
4.	Commercial Aquaculture as a Percentage of Total Seafood Production from 1970 to 2006 .....	34
5.	Ecuadorian Aquaculture Output from 1970 to 2006.....	35
6.	Ecuadorian Aquaculture Output in USD 2000 from 1970 to 2006 .....	35
7.	Shrimp Ponds in an Ecuadorian Estuary.....	41
8.	A Typical Ecuadorian Shrimp Pond Water Intake System.....	42
9.	A Typical Ecuadorian Shrimp Pond Discharge System .....	42
10.	Abandoned Shrimp Ponds on the Fringe of the Chone Estuary .....	44
11.	Nauplii Stage of Shrimp Development in an Ecuadorian Hatchery .....	47
12.	Algae Rich Tanks Housing Zoea and Mysis at an Ecuadorian Hatchery .....	48
13.	Ecuadorian Shrimp Nursery on a Shrimp Farm.....	48
14.	Transferring Postlarvae from the Nursery to a Growout Pond .....	49
15.	Ocean Fishmeal Destined for an Ecuadorian Shrimp Farm.....	50
16.	Ecuador Aquaculture Output and Disease Outbreaks.....	51
17.	Establishing a Pixel Size for Aerial Photography.....	56
18.	Chone Estuary Base Level Mangrove Cover, 1968.....	65
19.	The First Arrival of Shrimp Farms in the Chone Estuary, 1977.....	66

20.	Chone Estuary Land Use, 1984 .....	68
21.	Chone Estuary Land Use Change from 1977 to 1984 .....	69
22.	Chone Estuary Land Use, 1991 .....	71
23.	Chone Estuary Land Use Change from 1984 to 1991 .....	72
24.	Chone Estuary Land Use, 2001 .....	73
25.	Chone Estuary Land Use, 2006 .....	74
26.	Chone Estuary Land Cover Change from 1968 to 2006.....	76
27.	Chone Estuary Annual Rates of Mangrove Deforestation from 1968 to 2006.....	76
28.	Chone Estuary Land Use Change from 1968 to 2006 .....	77
29.	Cojimías Estuary Base Level Mangrove Cover, 1971 .....	85
30.	Cojimías Estuary Land Use, 1986 .....	86
31.	Cojimías Estuary Land Use, 1998 .....	87
32.	Cojimías Estuary Land Use Change from 1986 to 1998 .....	88
33.	Cojimías Estuary Land Use, 2006 .....	89
34.	Cojimías Estuary Land Cover Change from 1971 to 2006.....	91
35.	Cojimías Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006..	91
36.	Cojimías Estuary Land Use Change from 1971 to 2006 .....	92
37.	Muisné Estuary Base Level Mangrove Cover, 1971 .....	95
38.	Muisné Estuary Land Use, 1986.....	96
39.	Muisné Estuary Land Use, 1998.....	97
40.	Muisné Estuary Land Use Change from 1986 to 1998.....	98
41.	Muisné Estuary Land Use, 2005.....	99



42.	Muisné Estuary Land Cover Change from 1971 to 2005 .....	100
43.	Muisné Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006 ..	100
44.	Muisné Estuary Land Use Change from 1971 to 2005.....	101
45.	Cayapas-Mataje Estuary Land Use, 1986 to 2006.....	107
46.	Cayapas-Mataje Estuary Land Cover Change from 1986 to 2008 .....	107
47.	Mangrove Cultural Symbols In and Around Cayapas-Mataje.....	111
48.	Rio Hondo Estuary Base Level Mangrove Cover, 1973.....	116
49.	Rio Hondo Estuary Land Use, 1985 .....	117
50.	Rio Hondo Estuary Land Use, 1990 .....	118
51.	Rio Hondo Estuary Land Use, 1997 .....	119
52.	Rio Hondo Estuary Land Use, 2000 .....	120
53.	Rio Hondo Estuary Land Use, 2006 .....	121
54.	Rio Hondo Estuary Land Cover Change from 1974 to 2006.....	122
55.	Rio Hondo Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006 .....	123
56.	Rio Hondo Estuary Land Use Change from 1971 to 2005 .....	123
57.	Grande Estuary Base Level Mangrove Cover, 1963 to 1977 Composite.....	126
58.	Grande Estuary Land Use, 1985 .....	128
59.	Grande Estuary Land Use Change from 1963 Composite to 1985.....	129
60.	Grande Estuary Land Use, 1997 .....	130
61.	Grande Estuary Land Use Change from 1985 to 1997 .....	131
62.	Grande Estuary Land Use, 2006 .....	132
63.	Grande Estuary Land Cover Change from 1963/1977 Composite to 2006 .....	133

64.	Grande Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006 ..	134
65.	Grande Estuary Land Use Change from 1971 to 2006 .....	135
66.	Ecuador Estuary Land Use Change .....	139
67.	Mangrove Loss Equation .....	140

## LIST OF ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CLIRSEN	Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos
DAC	Development Assistance Committee
FAO	Food and Agriculture Organization
FARC	Revolutionary Armed Forces of Colombia
FDI	Foreign Direct Investment
FEDARPOM	Federación de Artesanos Recolectores de Productos Bioacuaticos del Manglar
FUNDECOL	Fundación de Defensa Ecológica de Muisné
GIS	Geographic Information Systems
GLCF	Global Land Cover Facility
GLOVIS	USGS Global Visualization Viewer
IGM	Instituto Geográfico Militar
NGO	Non Governmental Organization
NIMA	National Imagery and Mapping Agency / US National Geospatial-Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
PRP-E	Provisional South American Datum – Ecuador, Datum Code
PSAD	Provisional South American Datum
RS	Remote Sensing
UN	United Nations

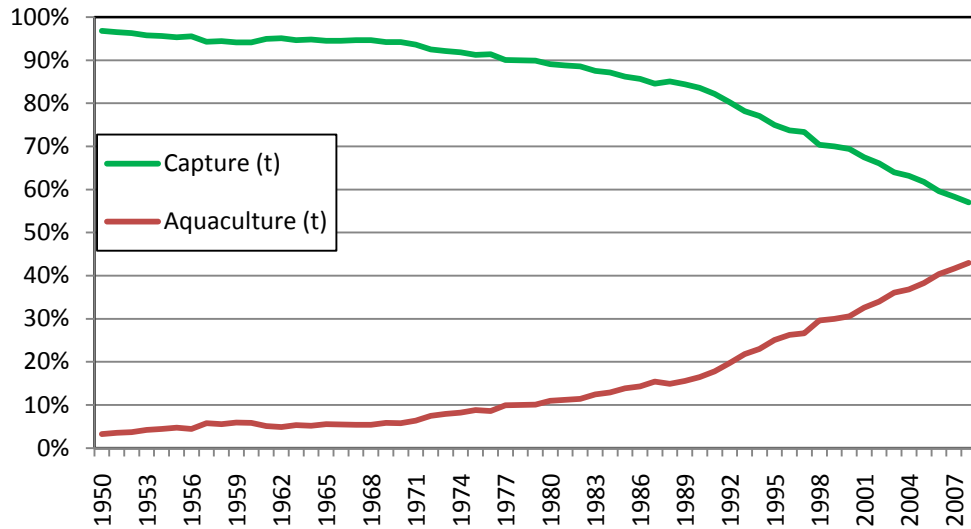
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
WGS 1984	World Geodetic System of 1984

## CHAPTER I

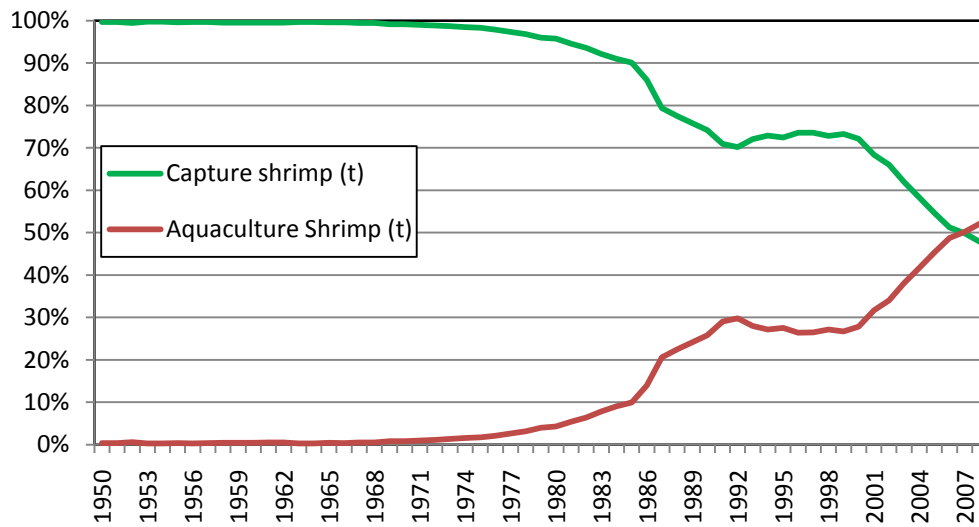
### INTRODUCTION

Rising international demand for seafood and the stagnation of wild catch has driven commercial aquaculture output to unprecedented levels. This rapid growth in commercial aquaculture shows no signs of abating (Figure 1). If current trends continue, commercially farmed seafood will surpass wild catch as the predominant global source of seafood supply in 2013 (FAO Fisheries and Aquaculture Department 2009; FAO Fisheries and Aquaculture Department 2010). Certain species such as shrimp have already passed this critical threshold, with aquaculture now the predominant global supplier of shrimp (Figure 2). The expansion of commercial aquaculture, driven by the developed worlds' increasing appetite for seafood, is visible on the ground throughout the tropical coastline of the Americas and beyond.

Within Ecuador, commercial aquaculture output has actually outpaced the international numbers presented in Figure 1 and Figure 2 (FAO Fisheries and Aquaculture Department 2009; FAO Fisheries and Aquaculture Department 2010). Within Ecuador, commercial shrimp aquaculture is valued at \$720 million annually as of 2008, and shrimp aquaculture accounts for 94 percent of all Ecuadorian aquaculture production (FAO Fisheries and Aquaculture Department 2009; FAO Fisheries and Aquaculture Department 2010). During the peak shrimp production year of 1998, farmed shrimp exports were valued at \$875 million and constituted 26 percent of total private exports out of Ecuador. Ecuador is the fifth largest global producer of shrimp and the largest producer outside of Southeast Asia. Almost all of this production occurs in Ecuador's coastal estuary environments.



*Figure 1.* World Seafood Origin by Source as a Percentage of Total Seafood Supply. (FAO Fisheries and Aquaculture Department 2009; FAO Fisheries and Aquaculture Department 2010).



*Figure 2.* Shrimp Origin by Source as a Percentage of Total Supply. (FAO Fisheries and Aquaculture Department 2009; FAO Fisheries and Aquaculture Department 2010).

The developed world is the driving force powering the growth of shrimp aquaculture. The developed world consumes the products of shrimp aquaculture and provides the capital and expertise to operate the shrimp farms. Developed world governments and UN policies generally support the expansion of aquaculture in the

developing world as a sustainable practice that is beneficial to both livelihoods and food security. The majority of the academic literature supports the notion of shrimp aquaculture as a positive societal advancement. Much of the academic research into shrimp aquaculture focuses on the establishment and management of shrimp farms and their potential to alleviate food insecurity (Fridley 1995; Hopkins et al. 1995a; Levings et al. 1995; Tibbetts 2001; McLeod, Pantus and Preston 2002; United Nations Committee on World Food Security 2003; Rajitha, Mukherjee and Chandran 2007). Indeed, many academic journals focus solely on the expansion and technical operation of aquaculture ventures. In the majority of aquaculture studies, mangrove forests are discussed as potential buffers or nutrient mitigation systems to permit more efficient and intensive shrimp aquaculture (Fridley 1995; Gautier, Amador and Newmark 2001; Shimoda et al. 2005; Rajitha et al. 2007).

Despite the ever-increasing demand for shrimp products, the capital investment available for new ventures, and the vast amount of literature supporting shrimp aquaculture, an increasing body of evidence has led to questions about the role of commercial shrimp farming in improving food security and livelihoods, particularly at the artisanal scale in and around estuary environments (Dalsgaard 1993; deFur and Rader 1995; Ellison and Farnsworth 1996; Barraclough and Finger-Stich 1996; Ong 2002; Batagoda 2003a; Batagoda 2003b; Call 2003; Shimoda et al. 2005; Deutsch et al. 2007; Swedish Society for Nature Conservation 2007). Much of the current environmental literature as it pertains to shrimp aquaculture raises doubts about shrimp farm productivity by focusing on the highly productive mangrove forests that shrimp farms often displace. Local residents are already aware of the productivity of mangrove

forests, particularly artisanal fisherfolk, and often oppose the expansion of shrimp farming in their community (Call 2003).

Ecuador has one of the longest histories of commercial shrimp farming worldwide, and many of Ecuador's first shrimp farms appeared before the launch of the now ubiquitous land use change monitoring systems such as the landsat program. For this reason, much of the research on ecological and environmental impacts of shrimp farming in Ecuador is conducted without reliable measures of mangrove forest displacement or knowledge of historic mangrove cover. This is particularly true in the estuarine areas of Cayapas-Mataje, Muisné, and Cojimíes where reliable measures of mangrove forests and shrimp aquaculture areas are difficult to obtain and are the source of political and social discord. However, the loss of these highly productive mangrove ecosystems is the primary reason for questioning the beneficial role of shrimp aquaculture in the developing world (Pons and Fiselier 1991; Odum and Heald 1972; Ewel, Twilley and Ong 1998; Batagoda 2003b). Within coastal Ecuador, no studies have measured the influence of commercial aquaculture expansion on mangrove ecosystems, local livelihoods, or food security. A number of studies have been conducted on the role of mangrove ecosystems in traditional communities (Veach 1996; Armitage 2002; Cuoco 2005; Ocampo-Thomason 2006; Collins 2010), but little research exists on the impact of shrimp farming on communities living around aquaculture-impacted estuaries.

### Research Objectives and Significance

This research has two primary objectives. The first is to quantify the displacement of mangrove forest by commercial shrimp farms within Ecuador's estuaries. The second is to examine the changes to local livelihood options and food



security resulting from this transition. By addressing these two primary objectives, the questions below are addressed.

1. How much mangrove forest has been lost since the advent of commercial aquaculture in Ecuador's estuaries?
2. What was the mangrove forest base level before aquaculture arrived in Ecuador?
3. What is the current mangrove forest level in Ecuador?
4. What are the temporal patterns and regional variations of mangrove deforestation in Ecuador's estuaries?
5. How much shrimp aquaculture is now occurring in Ecuador's estuary environments?
6. What are the temporal patterns and regional variations of shrimp farm expansion in Ecuador's estuaries?
7. How much mangrove has been directly displaced by shrimp aquaculture in Ecuador's estuaries?
8. What are the implications of questions one through seven on the food security of local residents of these estuary environments?
9. What are the implications of questions one through seven on the livelihood options to local residents of these estuary environments?
10. What are the macro and micro forces resulting in, and restricting, shrimp farm expansion and mangrove deforestation in Ecuador's estuaries.

Additionally, this manuscript documents the historic and current utilization of the mangrove forest in Ecuador's estuaries and documents the process of estuary-based commercial shrimp aquaculture now present in the region. No current comprehensive

documentation exists of these processes in Ecuador and this manuscript can serve as a historic record of such activities.

This research provides information about the mangrove holdings of coastal Ecuador and the rate at which commercial shrimp farming is depleting this resource. Within its own right, the land use change analysis will fill a critical hole in the literature for this region providing quantifiable measures of mangrove holdings and mangrove forest change over time (Twilley 1989). These calculations fill research gaps in publications such as the International Mangrove Atlas, the International Mangrove Database, the Global Mangrove Information System, the Conservation Atlas of Tropical Forests and relevant international fisheries publications concerned with aquaculture levels. As early as 1989, the international scientific community voiced a need for this type of research in Ecuador. An analysis such as this is required to, “. . . document the loss of mangroves from the coastal zone of Ecuador, since mangroves are the center of controversy on impacts in the coastal zone, then all premises related to this impact will require information of the extent of loss. . .” and to “. . . document the present distribution of mangrove forests to identify present and future impacts on this natural resource. . .” (Twilley 1989, 103). Additionally, this information will provide researchers another measure of deforestation as a basis for examining wider global environmental change, as well as acting as a mangrove base level for future mangrove research in Ecuador.

This research provides insights beyond quantifying the land use change within the estuaries. The goal is to provide a unique contribution to the scientific body of knowledge by accounting for changes in the human condition, with particular emphasis

on coastal residents' livelihoods and their access to nutrition during the process of coastal mangrove deforestation driven by the growth in commercial aquaculture. Livelihood changes throughout the period of shrimp farming are examined with direct knowledge of the land use changes occurring on the same spatio-temporal scales.

At the macro scale, this research will provide further insights into the boom-bust cycle that has historically plagued Ecuador (Thoumi 1990) and much of the tropical developing world. Commercial aquaculture is an extractive industry following the economic model of developed world investment in under-developed nations' resources to extract a product destined for developed world consumption. On a broader scale, this manuscript also provides valuable insight into the loss of an important tropical habitat -- mangrove forests -- that remain less understood relative to the more studied tropical environments such as rainforests or coral reefs. Of current interest to climate scientists, are the role of mangrove forests as carbon sinks and their role in reducing the impacts of global climate change. Although not a focus of this research, climate change researchers should take note of another potentially significant carbon sink being destroyed and the release of sequestered carbon.

This research fits well into current themes prominent in geographic theory and discourse. The first is the integration of the disparate disciplines within geography. Geographic Information Systems and Political Ecology being are both established sub-disciplines within the broader field of geography, yet syntheses of these two sub-disciplines remains in its infancy. It is the goal of this research to avoid being two parallel studies, one from the remotely sensed land use change perspective, and one from the field researched ethnographic perspective. The goal is to take an integrated research

approach, producing an interrelated body of research with GIS / RS providing the engine to drive a more complete understanding of a region's ecology. Additionally, this research helps establish a new lexicon for geographers to exchange ideas and findings when discussing land use change in non-land environments. The aquatic repurposing that accompanies shrimp farms, salmon fisheries, and other forms of aquaculture fit poorly in the current language of land use change.

Outside academia, this research has numerous implications to public policy and international financing at all scales. For this reason, policy recommendations are presented in the final chapter of the manuscript. The UN and other international funding agencies persist with the view of commercial aquaculture and shrimp farming as a boon to local livelihoods and nutrition. The results of this research call into question the capacity of aquaculture to meet global food challenges. At the local level, this research will give insights into how communities adapt to aquaculture expansion while trying to ensure that livelihoods and food security do not diminish during the process of aquaculture expansion.

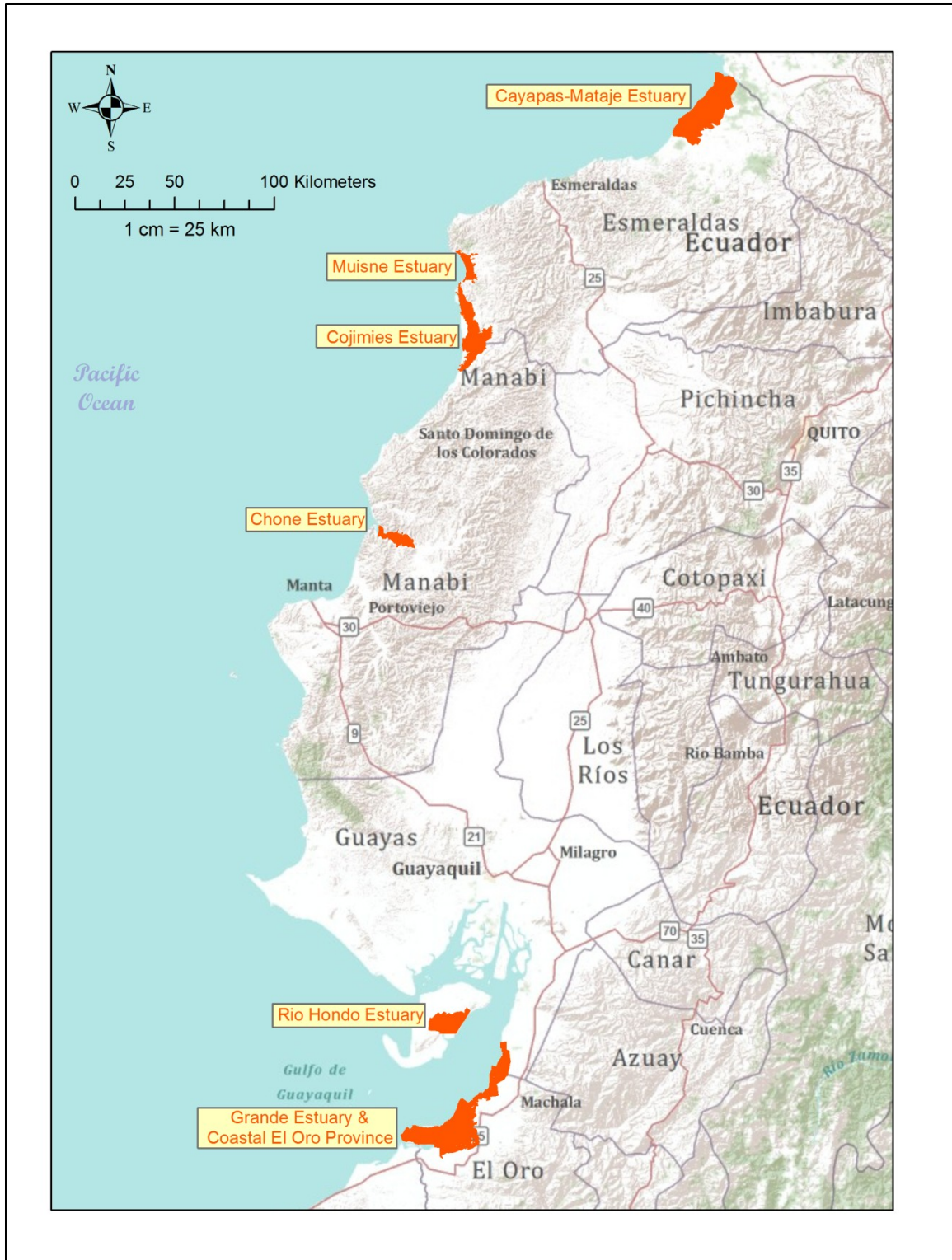
### Study Areas

As depicted in Figure 3, only the four provinces of Esmeraldas, Manabí, Guayas, and El Oro border the Pacific Ocean, forming the *Costa* region of Ecuador.<sup>1</sup> Due to the abrupt rise in elevation and rugged terrain moving eastward from the Pacific coast, only these four coastal provinces have the potential for mangrove growth and estuarine shrimp farming. Although Los Rios belongs to the *Costa* region due to its lowland location, it has no saltwater inputs to sustain mangrove forests. The province of Galápagos does

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<sup>1</sup> This manuscript uses the 2006 Ecuadorian provincial boundaries and names.

have a Pacific coastline but due to its protected status and distance from mainland Ecuador, it is not included in this analysis. The research area for this study comprises the major estuaries within these four coastal provinces capable of sustaining mangrove forests and suitable for commercial shrimp farming. The combined coastline of these provinces varies within the literature from 4,957 km (World Resources Institute 2007) to 2,237 km (Central Intelligence Agency 2008). This variation is likely due to the complex fractal analysis required to measure a meandering coastline.



*Figure 3.* Ecuador Overview and Study Sites. Study boundaries are depicted in orange. Table 1 lists the attributes of each study site. Study areas delineated by author overlaid on ESRI world topographic map.

Within the four coastal provinces, the largest estuarine environments are analyzed (Figure 3), with the exception of Guayas Province. In Esmeraldas province, the study areas are the Cayapas-Mataje Estuary in and around the Cayapas-Mataje Mangrove Reserve located on the Colombian border, and the Muisné estuary located around the city of Muisné on the Manabí provincial border. In Manabí Province, the study areas are the Chone Estuary in and around the city of Bahía de Caráquez, and the Cojimíes Estuary on the northern provincial border with Esmeraldas. In El Oro Province, the study area is the entire El Oro province coastline including Grande Estuary. The study areas for Guayas province are Rio Hondo Estuary on Puná Island and a portion of eastern mainland Guayas province. This accounts for all the major mangrove estuarine environments in mainland Ecuador with the exception of the Guayas estuary in Guayas Province (Bodero 1993; Spalding, Kainuma and Collins 2010). These regions account for approximately 50 percent of the 1969 base level mangrove present in Ecuador (Centro De Levantamientos Integrados De Recursos Naturales Por Sensores Remotos 2007).

In further delineating study areas below the provincial level, it is assumed that nowhere with an elevation six meters receives tidal saltwater input and therefore these areas will not support coastal mangroves. This is based on a maximum tidal range in our study areas of 4 m at Cayapas-Mataje (Blanchard and Prado 1995). This allows for localized regional topography that may magnify the estuarine tidal ranges beyond the maximum reported value. To obtain topography below 6 m, a 30 m resolution digital elevation model was derived using elevation data from the Instituto Geográfico Militar (IGM) topographic database of 30 million elevation points within Ecuador (Souris 2008). By extracting all areas with elevations below six meters, we are able to narrow the

potential mangrove area down to 3,547 km<sup>2</sup> of coastal Ecuador. Final delineation of the study sites was conducted by utilizing topographic maps to identify the major estuaries within these parameters. This resulted in the delineation of the six estuaries. The final study combined study area size is 196,748 ha (Table 1). The 2008 combined population estimate within 5 km of all estuaries is 379,389, and the combined population estimate with 10 km of all estuaries is 558,040 (Oak Ridge National Laboratory and UT-Battelle LLC 2008).

Table 1

*Site Selection Details and Area Calculations*

Study Area	Province	Estuary / Location	Major City	Size (ha)
1	Manabí	Chone Estuary	Bahía de Caráquez	8,744
2	Manabí	Cojimíes Estuary	Cojimíes	27,410
3	Esmeraldas	Muisné estuary	Muisné	6,662
4	Esmeraldas	Cayapas-Mataje Estuary	San Lorenzo	50,714
5	Guayas	Rio Hondo Estuary / Gulf of Guayaquil	Guayaquil	31,308
6	El Oro	Grande Estuary / Entire coast of El Oro / Portion of Guayas coast	Machala	71,923
Total				196,761



### *Chone Estuary*

Figure 3 depicts Study Area 1. This estuary is known locally and globally as Chone Estuary. Chone Estuary is located in Manabí Province where the Chone River becomes an estuary. The city of Bahía de Caráquez at the mouth of the estuary is a tourist center popular with the political and elite members of Quito society. Away from the tourist center, numerous small fishing communities reside on the terrestrial edge of the estuary and residents in these communities have traditionally made their living from the good and services offered by the estuary. Chone Estuary also has a relatively strong near-shore fishing industry. Unlike the other five estuaries analyzed, Chone is the only one that has a clear delineation with mountains and hills bordering the estuary in many locations.

The region around Chone Estuary has suffered recent catastrophic *El Niño* (Evans 2003) and earthquake (Fernandez and Yepes 1998) events and is yet to recover basic services such as potable water. In response to these catastrophes, Bahía de Caráquez at the mouth of Chone Estuary has branded itself the ecological city of Ecuador with the goal of becoming the sustainability capital of Ecuador. The Chone Estuary area is subject to a special area management plan. The goal of the plan is to manage land use and activity around the estuary and provide local stakeholders incentives to participate in the recovery of the estuary (Coello, Proafio-Lerowr and Robadue 1993). The Corazón and Fraguas Islands Wildlife Reserve is located in the center of the estuary and the Swedish Nature Conservancy and the US environmental group Planet Drum are both active in and around the estuary. The 2008 population estimate within 5 km of the

estuary is 37,783 and the population estimate with 10 km of the estuary is 68,737 (Oak Ridge National Laboratory and UT-Battelle LLC 2008).

### *Cojimies Estuary*

Figure 3 depicts Study Area 2, the estuary of Cojimies, which is located in northern Manabí Province and southern Esmeraldas Province. Numerous small traditional villages dot the estuary, including Zapotal, Daule, Mocoral, Cojimies, San José de Chamanga, Beche, and Cheve with traditional fisherfolk and traditional agriculture the dominant occupation. A few kilometers to the south of the estuary is the regionally important city of Pedernales. The towns surrounding the estuary, particularly those towards its interior, have traditionally made their income from goods and services offered by local mangroves. The estuary borders the Mache Chindul Ecological Reserve and recovery efforts supported by USAID aim to restore the estuary so that local inhabitants can once again achieve sustainable livelihoods (Herrera and Elao 2007; Crawford 2010). The 2008 population estimate within 5 km of the estuary is 12,812, and the population estimate with 10 km of the estuary is 18,232 (Oak Ridge National Laboratory and UT-Battelle LLC 2008).

### *Muisné Estuary*

Figure 3 depicts Study Area 3, the Muisné Estuary, which is located in southern Esmeraldas Province. Muisné has a mixed economy based on tourism, agriculture, and traditional fishing. Muisné itself is located at the northern end of the estuary on an offshore island with no vehicular access. The majority of its population is Afro-Ecuadorian. The Mangroves of the Muisné River Estuary Wildlife Reserve is located within the estuary. Field observation suggests a high proportion of the residents still rely

on the mangrove forest for traditional goods and services. To the south of Muisné is the tourist town of Mompiche, north of Muisné are dotted numerous small ecotourism centers around the town of San Francisco. The estuary contains numerous small islands that are mostly uninhabited. The region is well connected to the rest of Ecuador, as it is located on the *Via del Pacífico* and is in close proximity to the provincial capital and oil port of Esmeraldas. The 2008 population estimate within 5 km of the estuary is 13,977, and the population estimate with 10 km of the estuary is 23,168 (Oak Ridge National Laboratory and UT-Battelle LLC 2008).

#### *Cayapas-Mataje Estuary*

Figure 3 depicts Study Area 4, referred to in this manuscript as Cayapas-Mataje. Cayapas-Mataje is located on the Colombian border in northern Esmeraldas Province in and around the Cayapas-Mataje Mangrove Reserve. The region is considered to be Ecuador's most pristine mangrove environment (Ocampo-Thomason 2006) and potentially the most pristine along the entire Pacific coast of the Americas (Wetlands International 2004). The entire region is an original Ramsar site (Ramsar 2006). Cayapas-Mataje contains the tallest known mangroves in the world, with heights up to 64 m (Spalding et al. 2010). The almost total Afro-Ecuadorian population in and around the 44,000 km<sup>2</sup> reserve area and the surrounding towns rely on the mangrove forest for their income with over 85 percent of households supplementing their income from the traditional uses of the forest (Ocampo-Thomason 2006). This region consists of pristine estuary environments, freshwater and inter-tidal flooded wooded wetlands, and wooded peat lands (Wetlands International 2004).

The closest town to Cayapas-Mataje is San Lorenzo. This region has been historically isolated from Ecuador due to factors relating to political instability in the troublesome Colombian borderlands, thus leading to a lack of foreign investment. The region suffers from relative isolation with roads only arriving within the last decade and an unreliable rail connection to the *Sierra* region, which has now ceased operation. A single road connects the region to the *Sierra* via the town of Ibarra but this road is subject to frequent closure due to rockslides. The *Via del Pacífico*, which connects Cayapas-Mataje to the provincial capital of Esmeraldas, was only connected to this region in recent years. This road now gives Cayapas-Mataje accessibility to the rest of coastal Ecuador including the major Pacific ports. The U.S. State Department has regular advisories against travel into this area due to drug and activity of Revolutionary Armed Forces of Colombia (FARC), a Colombian Marxist guerilla movement. The 2008 population estimate within 5 km of the estuary is 17,104, and the population estimate with 10 km of the estuary is 21677 (Oak Ridge National Laboratory and UT-Battelle LLC 2008), including residents on the Columbian side of the estuary.

#### *Rio Hondo Estuary*

Study Area 5, the Rio Hondo Estuary, is located on the southeastern corner of Puná Island and is located in the province of Guayas. The Rio Hondo Estuary is approximately one-third of Puná Island. The island is dotted with small traditional communities that lack regular power supply or running water. Along the coast, fishing appears to be the predominant activity, with some cattle grazing in the interior. Regular boat charters run to the island from Posorja, Machala and other areas of southern Guayas. No paved roads exist on the island and boats are the primary mode of transportation.

Dolphin watching around the island is a popular tourist activity although few tourists actually visit the island. Puná island has had protected status since 2009 although the legal standing of the designation is unclear. The population estimate for Puná island is 15,473 (Oak Ridge National Laboratory and UT-Battelle LLC 2008).

### *Grande Estuary*

Study Area 6 consists of the entire coastal portion of El Oro Province and 15 km of Guayas province directly to the north of El Oro (Figure 3). The southern limit of the study area corresponds to the Peruvian border. The largest named estuary in this area is Grande Estuary, which is bordered by Peru to the south and the urban center of Machala to the north. Grande is the largest estuary in El Oro province. The estuary forms numerous small islands, which are mostly uninhabited. Numerous fishing communities dot the estuary, the largest of which Puerto Bolívar has become mostly consumed as a Machala suburb and is now a large commercial banana port. The tourist town of Jambelí is located on the western most portion of the estuary and mostly caters to residents of Machala. Of the six Ecuadorian estuaries analyzed, Grande Estuary is the only one where population pressure likely led to mangrove loss. Three of the four sides of the city of Machala are bordered by mangroves or shrimp farms and the city may have expanded into the mangrove habitat over the last forty years. The estuary and mangroves do not appear to have any protected status beyond the national environmental laws that apply to all Ecuadorian mangrove forests and estuaries. The 2008 population estimate within 5 km of the estuary is 282,240, and the population estimate with 10 km of the estuary is 410,756 (Oak Ridge National Laboratory and UT-Battelle LLC 2008). Almost all of this population is the greater Machala area and includes people in extreme northern Peru.

## CHAPTER II

### MANGROVE FORESTS

Mangrove, mangrove forest, mangrove trees, and mangal are used interchangeably in the geographic literature to describe the tree, plant, and shrub vegetation that exists within the inter-tidal zone of tropical estuaries and rivers. The term mangal represents the entire flora present in a mangrove swamp and the term mangrove refers to those species within mangal that are taxonomically classified as mangrove (Macnae 1968). Although somewhat redundant, this appears to be the most consistent usage of this terminology in the botanical literature. This manuscript follows the usage convention outlined by Macnae (1968).

#### Biology of Mangroves

While there is general agreement on the species that are considered mangroves, the rationale behind the grouping differs from the typical practice of basing biological taxa on common ancestry. This is likely because mangroves have not evolved from a single parent species, but have converged due to environmental adaptations from inhabiting similar environments. Hence, mangrove taxonomy utilizes the environmental conditions of the flora habitat to delineate what species constitute mangroves. As such, species labeled as mangrove do not necessarily belong to the same taxa; for example, the seven species of mangrove within Ecuador belong to five different families and only two species of Ecuadorian mangrove belong to the same genus. Classification of mangrove species is thus a circular process, since the term mangrove is generally applied to plant species with certain adaptations that inhabit tropical tidal swamps, yet tidal swamps close

to the tropics are typically defined by the fact they have mangrove present within them (Tomlinson 1986; Hogarth 1999; Hogarth 2007).

Several common characteristics generally exist in the majority of species referred to as mangrove: (i) A physical adaptation to an anaerobic environment, (ii) an adaptive mechanism for existing in highly saline water and soils, (iii) taxonomic isolation from terrestrial relatives (Tomlinson 1986) and (iv) geographic fidelity (Tomlinson 1986), and (v) the unexplained presence of a vivipary / cryptovivipary embryonic structure (Tomlinson 1986; Kelvin et al. 2001).<sup>2</sup> Geographic fidelity refers mangroves' tendency to exist in dense stands composed of a single species with a geographically clear transition from one mangrove species to the next (Hogarth 2007). This sorting of species is usually attributed to salinity tolerance levels, although this is an over-simplification of the complex processes that result in the homogeneity of species within regions of a single swamp (Tomlinson 1986).

Mangroves are also only classified as mangrove when they exist within or in close proximity to a tropical climate, such as those in southern Florida. Outside of tropical climates, species that inhabit salt marshes are generally classified into traditional biological genre based on common ancestry and genetic similarity. An example of this would be inter-tidal seagrass species of North America. No seagrasses are classified as mangrove, although according to the environmental classification system employed above, they easily could belong to this grouping aside from the fact they exist mostly outside of a tropical climate. Additionally, numerous landside flora species exist on the

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<sup>2</sup> Vivipary is the condition whereby the embryo grows first to break through the seed coat then out of the fruit wall while still attached to the parent plant. Cryptovivipary refers to the condition whereby the embryo grows to break through the seed coat but not the fruit wall before it splits open (Smithsonian Tropical Research Institute 2009).

fringe of intertidal swamps but are omitted from the general classification of mangrove due to their appearance in terrestrial taxonomies and regions.

Due to their non-traditional taxonomic definition, the number of identified mangroves species varies in the literature. Tomlinson's (1986) mangrove classification system allows for fifty-four mangrove species in twenty genera and sixteen families, whereas other classifications allow for as many seventy (Spalding, Blasco and Field 1997) and eighty (Blaber 2007) distinct mangrove species. Table 2 identifies the seven species of mangrove in Ecuador (Harcourt and Sayer 1996; Spalding et al. 1997; Smithsonian Tropical Research Institute 2009). Ecuador has four fewer species than western coastal Colombia and five fewer than Panama's Pacific coast. Peru has five mangrove species, all of which exist only in close proximity to the Ecuadorian border.

Table 2  
*Ecuadorian Mangrove Taxa*

Species Name	Common Name	Family	Genus
<i>Acrostichum aureum</i>	Golden Leather Fern, Mangrove fern Chuya macho, Esnargan, Gugara de puerco, Helecho de manglar, Negra jorra	Pteridaceae	Acrostichum
<i>Avicennia germinans</i>	Black Mangrove, Aili, Calumate, Mangle negro, Mangle salado, Palo de sal	Verbenaceae	Avicennia
<i>Conocarpus erectus</i>	Buttonwood, Button Mangrove ,Sea Mulberry Botoncillo, Button mangrove, Button wood, Mangle botoncillo, Mangle mariquita, Mangle torcido, Zaragoza, Zarragosa	Combretaceae	Conocarpus



Table 2 (continued).

Species Name	Common Name	Family	Genus
<i>Pelliciera rhizophorae</i>	Mangle piuelo, Palo de sal Pie de santo	Theaceae	Pelliciera
<i>Rhizophora harrisonii</i>	Mangle caballero	Rhizophoraceae	Rhizophora
<i>Rhizophora mangle</i>	American Mangrove, Red Mangrove, Mangrove, Aili ginnid, Ailikinnut, Mangle, Mangle colorado, Mangle gateador, Mangle rojo, Mangle salado,	Rhizophoraceae	Rhizophora

*Note.* *Acrostichum danaefolium* is a distinct species but similar in appearance, size and spectral signature to *Acrostichum aureum*.

They are usually counted as a single species for the purpose of land cover classification as they generally inhabit the same location.

Not field verified in Ecuadorian estuarine study areas, likely only in fresh water environments. *Conocarpus erectus* is often described as not a true mangrove (IFAS 2009). *Rhizophora harrisonii* is also known as *Rhizophora brevistyla*.

The lack of mangrove species diversity in Ecuador is a result of two interacting conditions. First, although on the equator, southern Ecuador is close to the maximum southern extent of mangal on the Pacific coast of the Americas. This is because mangroves rarely exist where the sea surface temperature is colder than 20 °C (Blaber 2007); this isotherm is located at approximately S3.75° (Spalding et al. 1997) off the western coast of South America due to the frigid Humboldt Current in this area of the Pacific Ocean. By contrast, the southern extent of mangroves on the Atlantic side of South America is S33° and the maximum known southern extent of mangroves is S38.8° in New Zealand (Hogarth 2007), both again due to favorable ocean currents. Secondly, the diversity of mangrove species in Ecuador is also limited by geographic isolation from the species-rich area of Australasia and Southeast Asia (Spalding et al. 1997). These

areas have forty-seven and fifty-one mangrove species respectively as opposed to only seven in Ecuador. All Ecuadorian mangrove species exist in other parts of the Americas and six of the seven exist in West Africa.

### Mangroves as a Keystone Species

The scientific community first recognized the importance of mangrove forests in the late 1960s and early 1970s. Around the same time, the scientific community began to explore the possibility of raising shrimp and other marine life using methods similar to those utilized in commercial agriculture. Odum and Heald (1972) first elucidated the role of mangrove forests as a driver of biodiversity during their pioneering research into mangroves of the Florida Everglades. Their research demonstrated that mangroves are a keystone species that underpins the entire ecology of an estuarine environment; they concluded that the Florida mangrove forests are essential to almost all regionally important species, from crustaceans to deepwater fish of the Gulf of Mexico (Odum and Heald 1972).

Prior to the research of Odum and Heald (1972), mangrove forests had a reputation as having little ecological, environmental, or economic value. As late as 1974, mangrove forests were seen as having little societal benefit (Lugo and Snedaker 1974). In 1969, the USDA Soil Conservation Service did not classify mangrove forests as an area suitable for crops, pastures, woodland, wildlife, or indeed any other use (Lugo and Snedaker 1974). Much of the focus on mangroves during this period, in fact, was on reclamation, which illustrates that society and the scientific community valued them only for what they could be converted into (Ellison and Farnsworth 1996). Even today, concern over mangrove destruction and displacement by commercial aquaculture is

confined largely to specialist literature (Valiela, Bowen and York 2001). Unlike coral reefs, rain forests, and other threatened habitats, mangroves are not widely recognized by policymakers or the public.

This view of mangrove as a nuisance or a useless land-cover has been slow to retreat, but the importance of this ecosystem is becoming apparent within the estuarine research community. Indeed, the inter-tidal marshes of the tropics may owe their existence to mangrove forests. Mangroves forests are not merely a part of one of the most productive ecosystems on the planet; in many ways, they create these ecosystems by stabilizing the soil and creating habitat in which other organisms flourish (Hogarth 2007). Thus, mangrove forests support one of the most biologically diverse and productive ecosystems in the world (Costanza et al. 1997; Kathiresan and Qasim 2005; Blaber 2007). For example, in Colombia and the Caribbean, mangrove forests have been shown to support over 140 bird species, 200 fish species, and many hundreds of terrestrial and marine invertebrates, which is the basis for high floral and faunal biodiversity in otherwise low biodiversity mud and salt flats (Alvarez-León and Garcia-Hansen 2003). This is particularly relevant to coastal Ecuador as this region is described as undergoing a massive extinction of flora and fauna, driven by deforestation (Dodson and Gentry 1991). Despite this significant decline in biodiversity, the estuarine environments of Ecuador appear to have maintained the same relatively high biodiversity associated with estuarine mangrove environments in other areas of the world. In this regard, the remaining mangrove in Ecuador can be viewed as an oasis of biodiversity, thereby magnifying the ecological importance of the mangrove species.

#### Mangrove Forest Goods and Services

Table 3 describes the major functions of mangrove forests with regard to coastal populations. All mangal provide plant products, protect shorelines, provide food and habitat for animals, improve water quality, process nutrients, and trap sediments (Ewel et al. 1998). Mangal also plays an important global role as a sink for carbon. Each hectare of mangal contains 700 tonnes of carbon per meter of sediment (Ong 2002), and sediment in mangal is often many tens of meters thick. Additional important global habitat and food security mangal functions include providing habitat to numerous endangered species and to pollinating bees and bats.

Table 3

*Traditional Mangrove Forest Goods and Services*

<b>Direct Food</b>	<b>Timber</b>	<b>Mitigation</b>	<b>Habitat</b>	<b>Other</b>
Wild shrimp	Charcoal	River flood control and protection	Maintenance of biodiversity	Tourism
Wild fish	Firewood	Shoreline stabilization	Fish hatchery	Recreation
Bait fish	Boats	Wind protection	Juvenile habitat	Medicinal plants
Mollusk	Poles	Water purification	Migratory Bird habitat	
Crab	Home construction	Wastewater treatment	Coral habitat support	
Clam	Thatched roofing	Carbon sequestration	Pollinating bats and bees	
Eel	Tannins / dyes	Ground water management		

Table 3 (continued).

<b>Direct Food</b>	<b>Timber</b>	<b>Mitigation</b>	<b>Habitat</b>	<b>Other</b>
Traditional aquaculture products		Pollutant treatment (agriculture runoff)		
Cockles		Ocean / surge protection		
Edible bark				
Edible plants				
Pollinating species				
Sugar				
Honey				
Alcohol				

Note: Table adapted from various sources (Macnae and Kalk 1962; Macnae 1968; Tomlinson 1986; Blanchard and Prado 1995; Naylor et al. 1998; Armitage 2002; Batagoda 2003a; Batagoda 2003b; Warne 2007).

Traditional livelihood-related uses of mangrove include utilizing them for a variety of renewable timber resources, including firewood and charcoal production, for construction of the boats and houses of local people, the manufacture of natural dyes (Macnae 1968; Blanchard and Prado 1995; Armitage 2002; Warne 2007;), roof thatching (Macnae 1968), and sewage treatment (Tomlinson 1986). Mangrove forests also provide key habitat to important traditional coastal seafood in the form of fish (numerous species), crab, shrimp, clam, sea snail, eel, (Armitage 2002). Other food provided by mangrove forests include wild honey and edible plants (Warne 2007), and mangrove

forests are a prime habitat for nypa palm that provide sugar (Armitage 2002) and alcohol to traditional communities. Other traditional uses include the utilization of mangrove litter for animal feed, medical plants, (Warne 2007), tourism, and recreation (Batagoda 2003b). Furthermore, mangrove forests have been used to raise species such as shrimp for hundreds of years (Macnae and Kalk 1962; Naylor et al. 1998) in traditional, subsistence aquaculture. Traditional utilization of mangrove forests is typically conducted in a sustainable manner allowing for harvesting of differing products throughout the year (Armitage 2002). For all of these reasons, mangrove forests have been called an entrepreneur's dream (Tomlinson 1986), as they produce raw materials from sea-water and other renewable energy sources and pass on these goods to traditional communities.

The economic value of a mangrove forest is difficult to calculate because it involves placing a numeric value on a long-term communal resource. Despite this problem, there have been attempts to calculate the direct economic benefit of mangrove to traditional communities. It has been argued that estuarine mangrove ecosystems has one of the highest natural economic values per hectare of any ecosystem (Costanza et al. 1997), and that the rapid pace of mangrove deforestation and estuarine disturbance is due to the slow realization of this fact by economists (Blaber 2007). The direct economic benefit of a preserved mangrove forest has been estimated to be \$12,229 per-year per-hectare in Sri Lanka (Batagoda 2003a) and as high as \$751,368 per-hectare in Costa Rica (Tomlinson 1986). It is estimated 1994 value of a mangrove swamp was \$9,990 per-hectare per-year with estuaries at \$22,832 per-hectare per-year, exclusive of each other (Costanza et al. 1997). This is a global average. By comparison, the same amount of

corn in a highly productive cornfield in the United States during the same time period generated revenue of \$15 per-hectare per-year (Pollock 2001). Even adjusted for inflation, mangroves offer substantial economic benefits when compared to traditional cash crops.

Literature on livelihoods in Ecuador, though limited, supports the view of mangrove forests providing numerous goods and services when utilized in a traditional manner. Within Ecuador, mangroves have traditionally been used for timber, charcoal, and tannins (Spalding et al. 1997). Mangroves are also used to shelter homes from the strong coastal wind and flood events, in addition to providing materials such as timber and poles for the construction of homes (Ocampo-Thomason 2006). In parts of coastal northern Ecuador the mangal and the mangrove forest still powers the entire community by providing jobs, income and a stable supply of food (Veitch 1996; Ocampo-Thomason 2006). It was calculated that 85 percent of rural residential households around San Lorenzo, Esmeraldas depend on traditional use of the mangrove for fishing or the collection of cockles and crabs (Ocampo-Thomason 2006).

#### Mangroves and Fisheries

One of the most contested and important facets of mangroves forests are their role in enhancing fisheries. Approximately 75 percent of the world's commercial fish are over-exploited and in short supply (Deutsch et al. 2007). It is argued that mangrove forests play an important role in fisheries sustainability and global food security by sustaining commercial wild fish populations (Odum and Heald 1972; Chong 2007; Shervette et al. 2007). Therefore, it can be deduced that mangrove deforestation likely contributes to fisheries decline. Mangroves support offshore fisheries by providing

habitat for juveniles and adult fish species and allow for productive trophic exchange. Mangroves in Florida are shown to provide habitat, shelter, and food sources for animals at the base of the food chain that power the entire South Florida ecosystem (Odum and Heald 1972; Gore 1977). An estimated 90 percent of commercial fish species in Florida are reliant on mangrove habitat for their existence at some point in their life cycles (Gore 1977). The same pattern exists worldwide. Mangrove forests in Sulawesi, Indonesia provide important spawning ground and habitat to the most important regional aquatic life including commercially and locally important fish, shrimp, crab, and mollusks (Armitage 2002).

This idea that mangroves support fisheries is not without its critics (Blaber 2007). The thesis of the opposing argument is that most studies that equate mangrove losses to fisheries decline show correlation but not causation and are plagued by problems of auto-correlation because commercial over-fishing and mangrove depletion occurred on a similar temporal scale. Numerous other counter-perspectives that advocate the importance of mangrove to off-shore fisheries began to appear at the same time as Blaber's work (Chong 2007; Frias-Torres et al. 2007; Granek and Frasier 2007; Koenig et al. 2007; Lugendo et al. 2007; Nagelkerken 2007; Shervette et al. 2007). For example, it is estimated that the 567,000 ha of mangrove forests in Malaysia sustain more than half of Malaysia's annual fish catch totaling 1.28 million tonnes, through larval retention, trophic supply, and habitat support (Chong 2007). That equates to annual offshore fishery catch in excess of 2.25 tonnes annually that is dependent on each hectare of mangrove. Even the limited research in coastal Ecuador points to the importance of



mangroves in sustaining regionally important commercial fish species (Shervette et al. 2007).

Although Blaber (2007) contests the relationship between the decline of fisheries and mangrove deforestation on a global scale, his stance is unequivocal when dealing with traditional fishing communities and their relationship to mangrove. He states, “. . . it is important to distinguish between ‘fisheries within mangrove systems’, usually of an artisanal or subsistence nature in developing countries, and ‘offshore (of mangroves) fisheries’ that are usually commercial or industrial concerns. In the former case, the activities by traditional or artisanal fishermen may be long-established and are totally dependent on the existence of the mangrove system” (Blaber 2007, 465).

Within Ecuador, only one peer-reviewed study examines the relationship between mangrove and fish species. This analysis compares fish populations in a mangrove swamp at the mouth of the Rio Palmer to the mangrove-free river mouth of Rio Javita, approximately 1.5 miles from the mouth of the Rio Palmar. This study inventoried thirty-six fish species in sixteen families within the Rio Palmar and Rio Javita. Twenty-one of these species occurred only in the Rio Palmar. Not only was species variety greater in the mangrove area, but more importantly, nine of the twelve economically important fish species occurred only in the mangrove habitat, despite the altered state of this habitat (Shervette et al. 2007). This research is heavily compromised by the fact it was conducted in an inter-tidal environment that had already been stripped of almost all of its historic mangrove. According to landsat imagery of the area, the inter-tidal mouth of the Rio Palmar had twenty-fold more area under aquaculture than what remained as mangrove. Despite the fact that only a small portion of Rio Palmar's mangrove remains

intact, it appears to sustain more fish biodiversity than the nearby river that has been denuded of its mangroves. These results indicate that mangrove in Ecuador plays an important role in sustaining local and regionally important fish species. Other research in Ecuador points to artisanal fisherfolk utilizing shrimp and other biological resources of the mangroves for hundreds of years, noting that the entire lifecycle of shrimp in Ecuador's coastal waters is reliant on mangrove (Cuoco 2005).

### Mangrove Summary

Mangroves are the foundation of one of the most biologically diverse and economically rewarding ecosystems on the planet. Using the metric of biological species richness or the metric of economic return, mangrove forests are under-valued.

Mangroves sustain fisheries, provide economic opportunities, provide a secure supply of food and protein to local residents, purify water, trap sediment and nutrients, protect coastlines from natural disasters, provide habitat, and mitigate atmospheric carbon levels. These functions of mangrove benefit not only local communities but also the wider world.

Although mangroves play a global role, it is at the micro level in traditional fishing communities that mangroves are most beneficial. During times of food stress, mangrove habitat provides a ready source of freely available protein. During times of fuel shortages, mangroves provide the wood and charcoal necessary for hot, sanitary water and act as cooking fuel. Mangroves provide the homes and boats for coastal populations to earn a living. In many regions, insects, birds, and bats of the mangrove help to pollinate local agricultural crops. Perhaps most importantly, mangroves stabilize the shoreline by providing solid ground for local plant and tree species to inhabit swamp

environments. Local communities traditionally benefit most from mangroves and thus local populations are most adversely affected by their removal. The process of mangrove deforestation in much of the underdeveloped world and particular in Ecuador is now driven by the growth in commercial aquaculture.

## CHAPTER III

### SHRIMP FARMING

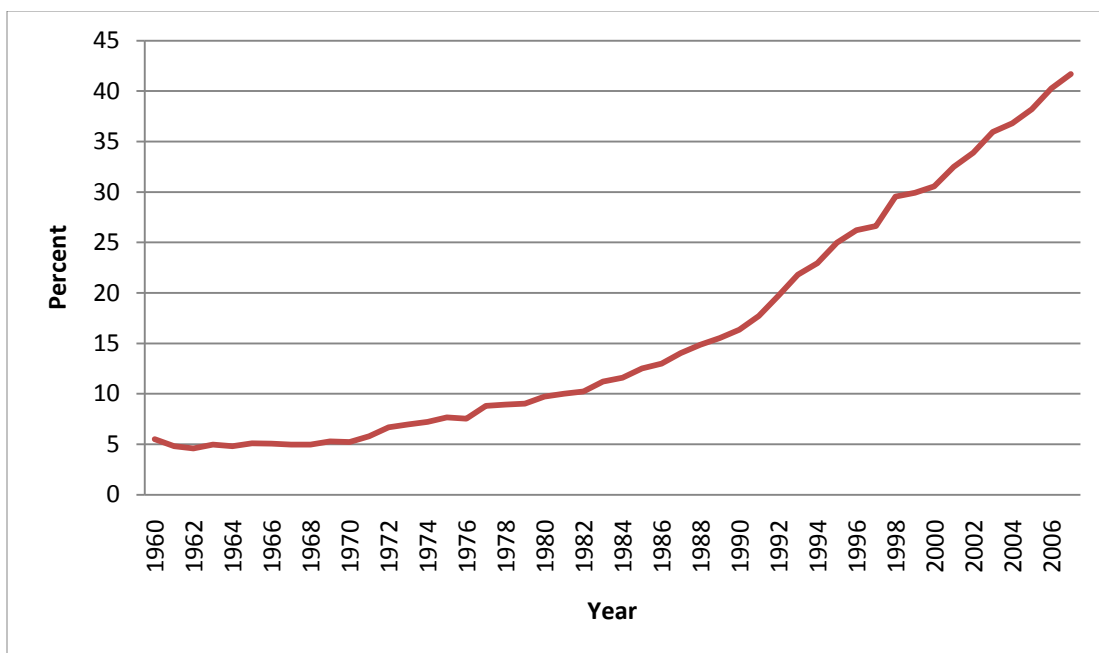
Traditional coastal communities have reared shrimp in artificial enclosures for centuries (Naylor et al. 1998). This traditional shrimp aquaculture focused on local cultivation of native shrimp species within the mangrove forest. The general method is to trap wild shrimp inside small earthen mounds within the forest and harvest them as required. Pre-existing nutrients provide the conditions for shrimp growth. This form of small-scale shrimp farming is for local consumption utilizing the local environmental conditions. These aquaculture practices continue currently in isolated coastal communities in parts of Bangladesh, Malaysia, and Indonesia. Such methods of aquaculture are more akin to traditional fishing practices and do not relate to the modern concept of commercial aquaculture.

#### The Growth of Commercial Aquaculture

Shrimp farming as a viable commercial aquaculture process began in Crystal River, Florida and Panama City, Florida (Cheshire 2005; Rosenberry 2008) in the mid-1960s. It was first documented in western scientific literature by National Geographic in 1965 (Idyll 1965). Both the Crystal River and Panama City enterprises utilized US capital and Japanese scientific expertise. A group of former DuPont employees began the Panama City facility and Purina directly funded the Crystal River facility. It was soon realized that the lack of suitable Postlarvae in local areas and the environmental conditions of the Gulf Coast of Florida made Florida inappropriate for successful commercial shrimp production (Cheshire 2005; Rosenberry 2008). The Crystal River operation relocated to Panama City, Panama in the early 1970s (Rosenberry 2008), but

ceased operations by the mid-1970s with many of the staff relocating to Ecuador (Cheshire 2005). In 1974, staff from the Panama City hatchery, operated by Marifarms, visited Esmeraldas, Ecuador to obtain *P. vannamei*, and noted that environmental conditions in Ecuador were suitable for year-round shrimp farming due to the climate and natural richness of feed in tidal waters. After the failure of the Panama City farm, Marifarm employees returned to Ecuador and collaborated with Ecuadorian producers to establish a hatchery in Manta (Cheshire 2005). By 1980, mass production of shrimp was underway in Ecuador.

By any unit of measure, and when viewed from either side of the scientific debate, the growth of commercial aquaculture and shrimp farming since 1970 has been remarkable and rapid. In 1970, less than 4 percent of seafood consumed worldwide was reared in a farmed environment (Figure 4). By 2009, aquaculture accounted for over 40 percent of all seafood consumption. Aquaculture will likely continue to be an expanding production system with growth rates continuing to exceed 10 percent annually (Diana 2009). In many developing nations, growth of aquaculture since 1970 has exceeded 10 percent annually (FAO Fisheries and Aquaculture Department 2006). As a comparison, farmed meat production grew by an average of 2.8 percent for the same period (FAO Fisheries and Aquaculture Department 2006; United Nations Committee on World Food Security 2003). Within fifty years of its inception, commercial aquaculture production will soon surpass wild catch as the primary source of seafood protein in human diets (Figure 4). Although difficult to compare, it is worth noting that the conversion from wild terrestrial animal stock to farmed terrestrial stock took approximately 200,000 years.



*Figure 4.* Commercial Aquaculture as a Percentage of Total Seafood Production from 1970 to 2006 (FAO Fisheries and Aquaculture Department 2006). Percent total includes worldwide consumption of all fisheries and wild catch seafood, including aquatic plants.

By 2004, seafood exports contributed \$71.5 billion to developing countries' economies, more than coffee, tea, bananas, rice, and meat combined, forty-three percent of these exports were derived from aquaculture (Diana 2009). Aquaculture production in Ecuador mirrors the global trend. In 1970, aquaculture production in Ecuador was at fifty tonnes per year. By 2007, it had grown to 171,020 tonnes, (Figure 5) with a value of \$763 million (Figure 6), of which 94 percent is farmed shrimp (FAO Fisheries and Aquaculture Department 2009; FAO Fisheries and Aquaculture Department 2010). If Ecuadorian aquaculture and wild catch continue on their current trends, aquaculture will soon surpass wild catch in tonnage and due to the high dollar value of shrimp compared to other fish species.

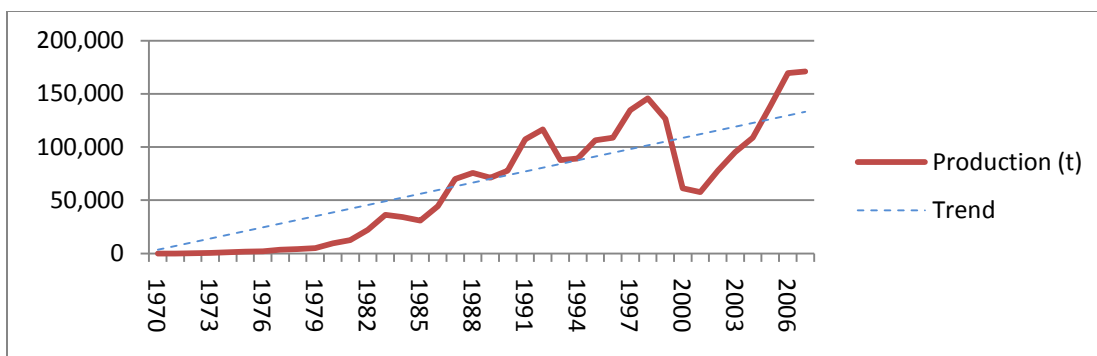


Figure 5. Ecuadorian Aquaculture Output from 1970 to 2006. (FAO Fisheries and Aquaculture Department 2006).

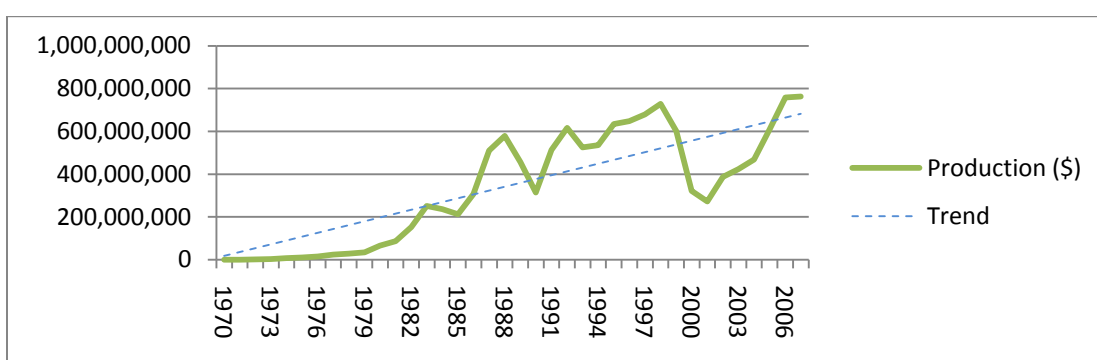


Figure 6. Ecuadorian Aquaculture Output in USD 2000 from 1970 to 2006. (FAO Fisheries and Aquaculture Department 2006).

### Shrimp Farm Financing

Shrimp farms, hatcheries, and nurseries are capital-intensive operations that require high levels of initial investment (Asian Development Bank-INFOFISH 1991; Rajitha et al. 2007) with capital inputs diminishing once the ponds are operational. Some of the initial funding undoubtedly comes from within the host nation and local communities investing in pond construction but most of the investment in shrimp farms likely originates from within international aid agencies, international financial institutions, and private foreign direct investment. The United Nations Committee on World Food Security reported as late as 2003, that commercial aquaculture has a role to play in eliminating hunger and malnutrition, and this role will be particularly beneficial to

artisanal fishing populations (United Nations Committee on World Food Security 2003). Such statements and related policy goals likely explain the headline rationale for development bank investment and bilateral aid directed towards commercial aquaculture.

Capital flows into shrimp aquaculture are one of the most opaque components of the farm-to-table shrimp story. Donors sensitive to environmental degradation caused by shrimp farms do not necessarily want their aid tagged as going to this agro-industrial sector, yet it is with these outside monies that shrimp farms in the developing world historically have relied upon. Public Citizen<sup>3</sup> cites international financing institutions—direct investment, bilateral aid, multilateral support and technical assistance—as the driving forces behind aquaculture development in developing countries (Public Citizen’s Food Program 2005a). They list the primary developmental bank assistance as originating from the World Bank, International Monetary Fund, International Bank for Reconstruction and Development, Asian Development Bank, African Development Bank, and Japanese Development Bank. The same source lists primary bilateral aid as originating from the Overseas Economic Cooperation Fund, Japan International Cooperation Agency, USAID, Canadian International Development Agency, European Investment Bank, and the Norwegian Agency for Development Cooperation. Public Citizen lists multilateral support as coming from the UN FAO and the United Nations Development Program (Public Citizen’s Food Program 2005). Most of this aid and investment is loaned or given as direct assistance with stated the goal of improving food security.

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<sup>3</sup> Public Citizen is a national, nonprofit consumer advocacy organization founded in 1971 to represent consumer interests in Congress, the executive branch and the courts.



Public Citizen's claim that development banks and bilateral assistance are key supporters of aquaculture globally is confirmed in the scientific literature (Nash 1987; Shehadeh and Orzeszk 1997; Rivera-Ferre 2009). Table 4 summarizes the principle findings of the shrimp financing literature review. Nash (1987) calculates that \$376 million flowed into aquaculture from development agencies between 1977 and 1983. Shehadeh and Orzeszk (1997) calculate that almost \$1 billion flowed from these same agencies between 1988 and 1995. These figures do not include donors from outside of Development Assistance Committee (DAC)<sup>4</sup> donors, private donors, foreign direct investment, or internal funding.

To fill in the data gaps as they pertain to aquaculture and to permit analysis of international aid according to donor/donor type and sector, figures on international aid to Ecuador were extracted from the AidData database. This international aid database allows for a narrowing-down of aid flows into Ecuador by sector, year, and donor and potentially by location (Nielson, Powers and Tierney 2010). AidData reveals that 7,123 aid commitments were made to Ecuador from 1970 – 2006, totaling \$23.4 billion (USD 2000) Using a combination of AidData and – Organization for Economic Cooperation and Development project codes, the amount of aid moving into fisheries and agro-industry can be determined. The fisheries and agricultural sectors are the typical classifications into which direct aid to aquaculture falls. Development of homes, roads, and other infrastructure associated with aquaculture would likely fall into other economic and social classifications. The fisheries and agricultural sectors of aid into Ecuador show 942 commitments comprising \$2.4 billion (USD 2000).

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<sup>4</sup> A list of DAC and non-DAC donors can be found at [http://usoda.eads.usaidallnet.gov/about/donor\\_list.html](http://usoda.eads.usaidallnet.gov/about/donor_list.html).

Table 4

Author	Donor	1977-1983	Percent of Total Funding
Nash	Development Banks	\$189,894,000	51.5
Nash	UN and UN Trust Funds	\$37,141,000	10.1
Nash	Multilateral Donors	\$227,035,000	61.6
Nash	Bilateral Donors	\$95,173,000	25.9
Nash	Other Donors	\$45,859,000	12.5
Total External Assistance		\$368,067,000	100

Author	Donor	1988-1995	Percent of Total Funding
Shehadeh	Development Banks	\$686,550,000	69
Shehadeh	Bilateral Donors	\$169,150,000	17
Shehadeh	Multilateral Donors	\$69,650,000	7
Shehadeh	Other	\$69,650,000	7
Total External Assistance		\$995,000,000	100

Note. Dollar amounts are USD 2000. International Aid and the Funding of Aquaculture from 1977 to 1983 and (Nash 1987; Shehadeh and Orzeszk 1997)

Clearly, AidData will only contain a small fraction of all flows, and this search focused only on keywords related to shrimp aquaculture. In a more extensive accounting

of the foreign aid going to support shrimp aquaculture, Public Citizen reports \$1.8 billion flowing into Ecuadorian, Honduran, Nicaraguan, Mexican, and Brazilian aquaculture in a twenty-year period starting in 1980 from various aid agencies and investment banks (Public Citizen's Food Program 2005a). The UN estimates it gave \$89 million to support aquaculture between 1987 and 1997, and that this was only 10 percent of public sector lending to aquaculture during this period (Public Citizen's Food Program 2005a). This would assume total investment of almost \$1 billion annually into aquaculture for this ten-year period. Additionally, private financing from companies such as Purina (Rosenberry 2008), Marifarms (Cheshire 2005) and others contributed many millions of dollars during the initial period of investment in Ecuadorian aquaculture.

International support of aquaculture through development assistance and aid has not ceased, even as questions about the detrimental environmental effects of certain aquaculture practices have surfaced. In 2002, USAID directed \$26 million to projects that include aquaculture in the relatively pristine aquaculture free zone of the Ecuador / Colombian border under the stated intent of improving quality of living along Ecuador's northern border (United States Agency for International Development 2003). As late as 2006, a USAID-sponsored report promoted aquaculture in Iraq as an opportunity for private sector employment and economic growth. Ironically, this report notes that \$26,000 is the typical investment required to start a pond, but this can drop to only \$11,000 if conducted in a semi-intensive manner in the marshes at the intersection of the Tigris and Euphrates Rivers (The Louis Berger Group 2006).

Aquaculture in developing countries is thus built on a foundation of investment and aid from developed countries, particularly through international financial aid

institutions (Nash 1987; Shehadeh and Orzeszk 1997; Hamilton and Stankwitz 2011a; Hamilton and Stankwitz 2011b) and foreign direct investment. Regardless of the nature of aid and investment, exact dollar amounts of support, and the opaqueness of the aid component of aquaculture in the aid databases, it is clear that aquaculture in developed countries is heavily subsidized by the international community.

#### Shrimp Farm Construction, Technical Operation, and Lifespan

Shrimp farms in Ecuador are generally located within the inter-tidal environment of sheltered estuaries, or on higher terrestrial ground in close proximity to the estuary to allow for affordable water exchange. Locating shrimp farms more than 9 m above the high-tide line of an estuary would involve the use of expensive submersible pumping systems or multiple pumping stations and reservoirs. These sheltered estuarine environments that are the preferred home of shrimp farms in coastal areas of Ecuador are identical to those of mangrove forests described previously in Chapter II. Establishing the amount of mangrove directly displaced by shrimp ponds is one of the major goals of this manuscript, but it should be noted that direct mangrove displacement by shrimp farms is still disputed. Some researchers state that the majority of aquaculture actually occurs above the high tide level due to its advantageous location (Boyd and Clay 1998) and hence away from mangroves, and that global losses of mangroves due to aquaculture amount to less than 10 percent of the total (Menasveta 1997; Correia et al. 2002; Diana 2009).

Figures 7 through 9 depict the most common estuarine shrimp pond systems utilized in Ecuador. Figure 7 depicts a shrimp farm with many growout ponds. Juvenile shrimp are reared in growout ponds until they reach maturity and market size. The

growout ponds are divided from each other by earthen dikes up to 5 m in height, one dyke usually serves two ponds or one pond and the estuary edge. Each pond can vary in size from a few hectares to fifty hectares. The ponds depicted in the Figure 7 are on the large end of this scale. Figure 8 illustrates the water intake of a growout pond in an estuary. Ponds replace approximately 10 percent of their water daily, typically pumping this water from the estuary in which they are located on a continuous basis (Stram, Kincaid and Campbell 2005). In a study of pond water exchange in a Columbian pond system, it was estimated that a typical size pond replaces 345 m<sup>3</sup> to 600 m<sup>3</sup> of water per day (Gautier et al. 2001). Figure 9 demonstrates the draining of the water from a shrimp pond back into the estuary. Water intakes and outflows are usually located in different parts of the pond. This aquaculture system is generally referred to as semi-intensive shrimp farming although the term intensive is occasionally applied when stocking densities are extremely high.



*Figure 7.* Shrimp Ponds in an Ecuadorian Estuary. Looking east from Leónidas Plaza away from the ocean on the southern side of Chone estuary, January 2008.



*Figure 8.* A Typical Ecuadorian Shrimp Pond Water Intake System. The pipes and pump located in the pump-house move water from the estuary to the shrimp pond. The shrimp pond is located behind the wooden pump house pictured. Picture taken near the village of Salinas on the northern side of Chone Estuary, January 2008.



*Figure 9.* A Typical Ecuadorian Shrimp Pond Discharge System. The concrete and wooden damn returns water from the shrimp pond to the estuary. The shrimp pond is located behind the outflow pictured. Picture taken near the village of Salinas on the northern side of Chone Estuary, January 2008.

Estuarine shrimp farming has a detrimental effect on estuary water quality.

Shrimp ponds contain higher levels of nutrients, biological oxygen demand, and salinity

than estuary waters outside the ponds. The effluent load discharged from farms in Chone Estuary alone is estimated to equal the domestic waste load of 1.5 million to 2.5 million human inhabitants (Arriaga, Montaña and Vásconez 1999). The critical threshold as it pertains to estuarine health appears to be between 40 percent and 60 percent conversion of mangroves to shrimp farm within the estuary. Stram et al. (2005), state that when 40 percent of the mangroves in the upper estuary, or 60 percent in the lower estuary, are lost to shrimp farming than dissolved inorganic nitrogen levels approach the same level as though one-hundred percent of mangroves had been converted to shrimp ponds. Such high levels of nutrients emanating from shrimp ponds have resulted in numerous toxic algae blooms along the coast of Ecuador that are deadly to all fish species, including wild shrimp (Jimenez 1989; Twilley 1989; Stram et al. 2005)

Estuarine shrimp pond lifespan is short. The length of shrimp pond productivity is dependent on the practices and location of the shrimp pond. In the literature, shrimp farm lifespan is given as five to ten years (Naylor et al. 1998) in an intensive system or seven to fifteen years in a less intensive system, with initial high yields usually followed by a dramatic collapse (Paez-Osuna 2001). Bacterial contamination of the sediment at the base of the pond and viral disease are the primary reasons for shrimp pond abandonment and production collapses. There is general agreement that abandoned farms rarely regain their productivity after a collapse. Most authors also contend that abandoned farms are not rehabilitated back into mangrove ecosystems, nor are they converted to other agricultural uses (Naylor et al. 1998; Paez-Osuna 2001), although again this fact is disputed (Diana 2009). Ecuadorian shrimp farms follow the general trends noted in the literature. Many abandoned farms along the coast are still visible on

the landscape many years after abandonment despite the recent resurgence in Ecuadorian shrimp farm output. Few if any ponds appear to return to aquaculture. Figure 10 depicts numerous abandoned ponds on the fringes of the Chone Estuary.



*Figure 10.* Abandoned Shrimp Ponds on the Fringe of the Chone Estuary. The ponds are in the foreground with grass growing on the former dykes. Note the former base of the ponds have little or no vegetation. The estuary is visible in the background. Picture taken approximately 5 km east of Puerto Larrea on the southern side of Chone Estuary, January 2008.

#### The Importance of Ecuador's Coastal Estuaries to *P. vannamei*

Ecuador's Pacific coast provides an ideal environment for shrimp farming due to its tropical climate, consistent year-round sea temperatures above 20 °C, and waters laden with natural feed. In addition to the suitable environment, the native *P. vannamei* shrimp species of this region is highly suited to pond rearing (Wyban and Sweeney 1991). Over time, these shrimp have become the primary pond-reared shrimp species in the Americas. *P. vannamei* shrimp are native to the tropical Pacific coast of the Americas and are common between Mexico and Northern Peru. Their primary habitats are areas where sea temperatures are above 20 °C year-round (Wyban and Sweeney 1991). Interestingly, this



is the same temperature within which mangrove thrives (Blaber 2007). Thus, wild shrimp and mangrove forests compete for space with commercial shrimp farms in Ecuador's coastal estuaries.

*P. vannamei* has numerous properties that make it desirable when compared to other shrimp species in farmed environments (Table 5). It grows rapidly, is amenable to high stocking densities as it is not as aggressive as other species, has a relatively low protein requirement, is tolerant of lower water quality and a wide range of salinity, resists melanosis,<sup>5</sup> and has a taste and color that is agreeable to US shrimp consumers (Briggs et al. 2004). In addition, captive *P. vannamei* females have been known to produce as many as 2.2 million Nauplii<sup>6</sup> during their lifespan (Wyban and Sweeney 1991), thus providing high yields if suitable females are bred. For these reasons, and the fact it is native to Ecuador, *P. vannamei* is the preferred shrimp species in all Ecuadorian shrimp farms.

Table 5

*P. vannamei* in a Farmed Environment

Characteristic	<i>P. vannamei</i>
Growth Rate	1-1.5 g/wk up to 20 g
Stocking Density	Typical stocking densities 60 m <sup>3</sup> - 150 m <sup>3</sup> , up to 400 m <sup>3</sup> . Not as aggressive as other species
Salinity Tolerance	Tolerant of a wide range of salinities (0.5 ppt - 45 ppt)

<sup>5</sup> Melanosis (Black Spot) is a harmless discoloration of shrimp. Consumers avoid shrimp with melanosis.

<sup>6</sup> The first larval stage of a crustacean lifecycle.

Table 5 (continued).

Characteristic	<i>P. vannamei</i>
Larval Rearing	High survival rates in hatchery of 50-60 percent
Post-Harvest	If treated with ice will not discolor

Note. Growth units are grams per week. Adapted from Briggs et al. (2004).

Examining the *P. vannamei* lifecycle is important to understanding both their preferential use in aquaculture and their reliance on the mangrove forest. In the Postlarvae stage, *P. vannamei* molt every four to six days (Wyban and Sweeney 1991). During this vulnerable stage, *P. vannamei* generally burrow in the soft detritus of the mangrove environment to evade predators. The mangrove environment also provides juvenile habitat. *P. vannamei* are catadromous, which means they spawn and mature to Postlarvae in offshore environments before returning to progress through their remaining lifecycles in mangrove estuaries. During the estuarine / mangrove period of the shrimp life cycle, shrimp are actually carnivorous, feeding on microorganisms in the estuary. In the natural environment, estuarine mangrove habitats provide the feeding grounds and habitat that transform the Postlarvae into full-grown adult shrimp.

Semi-intensive shrimp farming as commonly practiced in Ecuador operates on an approximately ninety-day cycle from the laying of eggs to the harvesting of adult shrimp. During this time, shrimp move from a hatchery, to a nursery, and finally into a growout pond. Shrimp pass through four distinct life stages during the first ten to fourteen days of their existence. The first stage of the shrimp lifecycle occurs in a hatchery in the aquaculture environment. Hatcheries are typically located away from the shrimp farms,

with each major shrimp farming region having one or two hatcheries. After mating in the hatchery, the female disperses her eggs and they hatch into Nauplii (the first larval stage of the shrimp) within one day (Figure 11). It is not uncommon for a single female to produce hundreds of thousands of eggs in one hatching event, and many millions of eggs over a lifetime. No feed is required at the Nauplii stage in the aquaculture or wild environments, as all necessary nutrients are contained within the Nauplii shell. Figure 11 depicts the Nauplii stage of the shrimp lifecycle in an Ecuadorian hatchery.



*Figure 11.* Nauplii Stage of Shrimp Development in an Ecuadorian Hatchery. This equates to approximately 1,000 shrimp. Town of Canoa, August 2009.

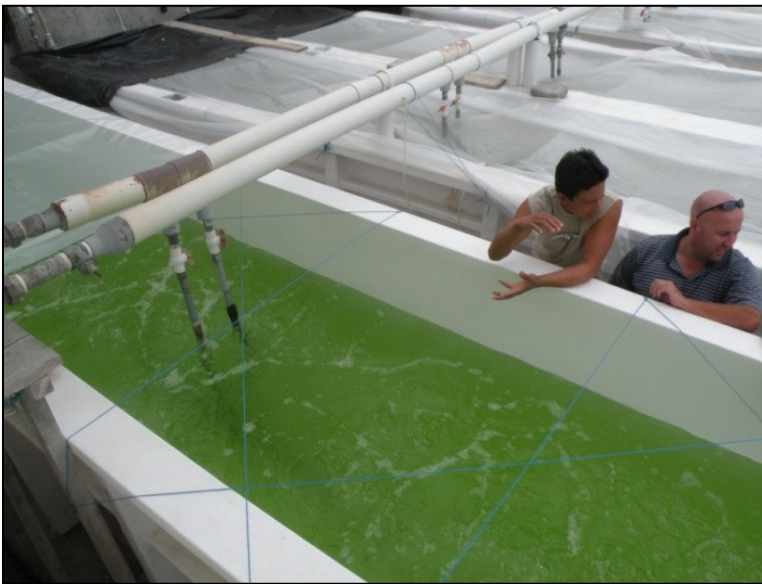
After the Nauplii stage of development shrimp progress to Zoea<sup>7</sup> and then into Mysis.<sup>8</sup> At these two stages, shrimp are omnivores with algae providing all the necessary nutrients for growth. In aquaculture, the algae are provided in small feed tanks in the nursery (Figure 12). After about 10-14 days, the Mysis metamorphose into Postlarvae.

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<sup>7</sup> The stage of the shrimp lifestyle when it starts to swim using the thorax.

<sup>8</sup> The stage of the shrimp lifestyle after Zoea but before post larvae. Commonly referred to as M3 in the shrimp rearing literature. Thoracopods are now used for swimming and an eye has developed.

Postlarvae are essentially juvenile shrimp. At this time, the Postlarvae are transported to a shrimp nursery typically located within, or in close proximity close to, the final estuary destination (Figure 13). The carnivorous Postlarvae are provided with high protein artificial feed while in the nursery. After about 21 days in the nursery, the Postlarvae are then released into a growout pond in the estuary (Figure 14). Juvenile shrimp spend the next two to three months maturing into full sized adult shrimp in these growout ponds, which are located in the intertidal bays and estuaries along the entire range of the tropical Pacific and Atlantic coastlines of Latin America.



*Figure 12.* Algae Rich Tanks Housing Zoea and Mysis at an Ecuadorian Hatchery. Canoa, August 2009.



Figure 13. Ecuadorian Shrimp Nursery on a Shrimp Farm. Chone, August 2009.



Figure 14. Transferring Postlarvae from the Nursery to a Growout Pond. This equates to approximately 50,000 – 100,000 shrimp. Chone, August 2009.

While in the growout ponds, *P. vannamei* shrimp are fed a diet primarily of fishmeal, krill, soybean, and shrimp byproducts such as shrimp heads. The average protein content of feed utilized in Ecuador is between 25 percent and 35 percent. Figure 15 depicts a full truck of fishmeal destined for the shrimp industry of Manabí. As with hatcheries, feed-stores are often located away from the actual farms in a nearby urban center. Differing feed protein grades cost more money and higher protein levels are generally applied earlier in the pond / nursery cycle with protein levels dropping as the

shrimp mature. One of the benefits of Pacific *P. vannamei* is that protein levels can be 12 to 20 percent lower than other shrimp species resulting in reduced expenditure for feed.

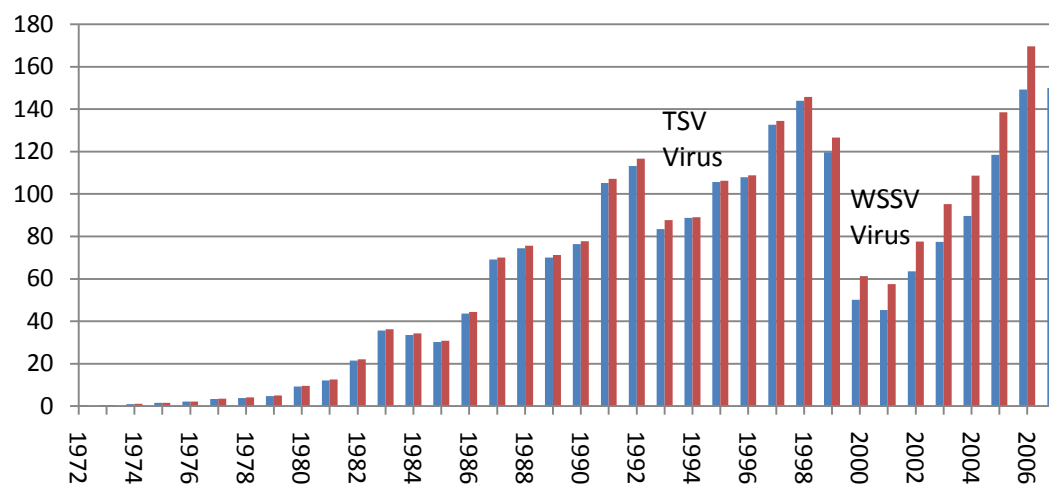


*Figure 15.* Ocean Fishmeal Destined for an Ecuadorian Shrimp Farm.

Other inputs applied to growout ponds include herbicides to remove vegetation from the bottom of the ponds, pesticides to remove non-shrimp fauna, and lime to treat the sediment (Paez-Osuna 2001). Other chemical agents are added during the growout cycle to improve water quality (Naylor et al. 1998). Although, the EU and the USA have banned the import of shrimp treated with antibiotics, and Ecuador supplies shrimp to both regions, shrimp antibiotic use appears widespread in Ecuadorian commercial shrimp aquaculture. Officially, no shrimp arrives in the EU or the US that is treated with antibiotics, yet on the majority of farms observed, antibiotic use is a widespread and accepted practice. The economic hardship caused by a failed harvest due to disease makes antibiotic use a safeguard against negative economic returns. Each major shrimp-producing town has a store from which farmers purchase antibiotics for treatment in their feed and farms. This mitigates potential losses from diseases such as Taura Syndrome



Virus and White Spot Syndrome that have periodically devastated the Ecuadorian farmed shrimp industry since the early 1990s (Pena 2004) (Figure 16). Indeed, these disease outbreaks contribute to questions the long-term benefit of shrimp aquaculture in general (Hopkins et al. 1995b; Venizelos and Benetti 1996; Rodríguez et al. 2003; Pena 2004).



*Figure 16.* Ecuador Aquaculture Output and Disease Outbreaks. Red indicates total aquaculture production and blue shrimp aquaculture. Units are thousands of tonnes.

#### Aquaculture and Shrimp Summary

It is incontestable that aquaculture and shrimp farming has grown in developing countries over the last forty years. Ecuador is no exception (Figure 16). Shrimp aquaculture output has undergone exponential growth during the past forty years. Use of water resources to raise seafood, as opposed to merely catching seafood, mirrors processes that have been and are occurring with the terrestrial food supply. Unlike land-based grazing practices, or even offshore aquaculture, preferred shrimp farming environments are in geographically limited settings within tropical estuaries. Shrimp farms and aquaculture now provide vast returns to local and national economies in Ecuador and elsewhere in the tropical developing world. Despite the economic returns, protein supply, and livelihood options offered by shrimp farming; questions remains

about the long-term economic viability, livelihood benefits, and food security offered by the industry. The majority of the questions raised about long-term benefits of shrimp farms are based on the fact the shrimp farms may displace highly productive mangrove ecosystems. Additional questions are raised as to the role of shrimp farming plays in the estuary environment on which local residents rely and the fact that shrimp aquaculture itself tends to be a boom and bust industry with ponds abandoned after short periods due to disease.

International aid, international financing institutions, and multi-national corporations directly finance shrimp farming and aquaculture. Such institutions are generally viewed as providing aid, development assistance, or investment that benefits the receiving nation or region. Doubts raised about the potential benefits of aquaculture call into question the motives and practices behind such financing. More specifically, who benefits from shrimp farm financing?

The methods employed by shrimp aquaculture during the shrimp lifecycle, the shrimp utilized in the farming system, the feed and other inputs utilized by shrimp farms, and most importantly, the location of growout ponds may all have wider ecological consequences that are not fully accounted for within the existing economic and environmental analyses of commercial aquaculture. Nature provides numerous subsidies to shrimp farming, including clean water to maintain the growout ponds, processing of waste and other chemicals exported from the farms, fishmeal and feed for the shrimp, and perhaps most importantly, a nutrient rich estuarine environment for the growout ponds. Without accounting for such natural subsidies, alterations in local livelihoods and the loss



in mangrove forest and estuarine environment caused by shrimp farming, the true cost / benefit analysis of shrimp farming remains incomplete.

## CHAPTER IV

### MATERIALS AND METHODS

#### Image Selection and Sensor Information

For each study-area estuary, the landsat archives at the Global Land Cover Facility (GLCF) and at the Global Visualization Viewer (GLOVIS) were visually examined to determine the first appearance of commercial shrimp farming in each estuary. If this date could be determined from the landsat archives, then the earliest landsat image with no commercial shrimp farming and with suitable atmospheric conditions was selected as the base level dataset for that estuary. In the Rio Hondo and Cayapas-Mataje estuaries, the earliest Landsat images are from 1973 and 1986 respectively and are utilized as the base level datasets. In Chone Estuary, Grande Estuary, Muisné Estuary, and Cojimíes Estuary shrimp farms are clearly visible in the earliest landsat images available. For these areas, supplemental pre-landsat land cover was required. For this purpose, topographic maps were obtained from the IGM in Quito and the IGM in Guayaquil and used as a base level to delineate mangrove land cover. The topographic maps for Chone represent 1968 land use, topographic maps for Cojimíes and Muisné estuaries represent 1971 land use, and topographic maps for Grande Estuary represent 1963 and 1968 land use with small areas supplemented with maps from 1971 and 1977.

Decadal longitudinal surveys were conducted to document land use change from pre-aquaculture to the present day in each estuary. Due to data omissions and issues of cloud cover, each estuary was not sampled at exactly decadal intervals. Chone was over-sampled to give insight into trends between the decadal periods. All Landsat images for

the decadal surveys were obtained from GLOVIS or the GLCF. The three differing landsat sensors utilized are Landsat 4, Landsat 5, and Landsat 7. For the most recent longitudinal data points, the Nature Conservancy donated Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery for the entire coastline of Ecuador. ASTER was utilized due to Landsat 7 being mostly unsuitable after May 2003 due to instrument failure. The estuary of Muisné does fall inside the Landsat 7 small envelope of correct data and hence is utilized in this estuary for the most recent longitudinal point for this region.

#### Data Pre-Processing

The primary local data sources utilized for mangrove base level delineation pre-landsat are 1:25,000 topographic maps. The analog topographic maps are referenced using the Provisional South American Datum (PSAD) of 1956 within Universal Transverse Mercator (UTM) zone 17, which is the reference system utilized throughout this analysis. To convert the analog topographic maps to a digital product, a 1,000 m point mesh in UTM 17S PSAD 1956 was developed to span the entire coastal region of Ecuador, as well as adjacent areas of the Pacific Ocean. The topographic maps were then scanned at 300 DPI and georeferenced by matching the graticule intersections of the topographic map to the 1,000 m mesh intervals. This grid structure allows for fourteen exact reference points on the x-axis and eight exact reference points on the y-axis for a potential maximum of 112 control points on a typical 1:25,000 topographic map.

In the Chone Estuary, the topographic maps are supplemented with 1968 and 1977 1:60,000 black and white aerial photography. The 1968 photography is utilized to fill data gaps in Chone as not all of the required topographic maps are available. The

1977 photography is utilized to add an additional longitudinal data point for the Chone Estuary. The photography is available on traditional black and white silver halide crystal plates with each plate measuring 23 cm on the x and y axis. Complete metadata for these photographs is not available, although the scale is stamped on each photo. The scale was verified by comparing observable point-pairs in the imagery to observable point-pairs on the 1:25,000 topographic maps. Each aerial photograph was scanned at 1400  $\mu\text{m}$  and its scale calculated to represent a ground pixel resolution of 0.84 m (Figure 17).

$$Pm = \frac{(S \times \mu m)}{1,000,000}$$

$$Pm = \frac{(60,000 \times 14)}{1,000,000}$$

$$Pm = .84$$

*Figure 17.* Establishing a Pixel Size for Aerial Photography. Pm = pixel size in meters, S = Scale (1:60,000 would be represented as 60,000), = Scanning precision in micrometers (Jensen 2005).

The Chone Estuary photography was resampled to one-meter resolution and referenced using a second order polynomial with identifiable features from the photography and the 1968 topographic maps used as ground control points. The imagery-to-map control was supplemented with GPS data control collected at the intersection of roads and concrete commercial piers that have remained stable since 1968. It is likely that these images are also the source for the topographic maps used in this analysis, as it is unlikely two aerial flights were undertaken in 1968.

For all decadal longitudinal data points, landsat and ASTER imagery were reprojected from UTM 17 World Geodetic System 1984 (WGS 1984) system to UTM 17 PSAD 1956 using cubic convolution for visual analysis and nearest neighbor when

performing automated classifications. The transformation utilized to convert was PRP-E  $\Delta X$  (278 m),  $\Delta Y$  (171 m) with established errors of  $\pm 3$  m, and  $\pm 5$  m respectively (NIMA 2000). It should be noted that Ecuador does not have a single consistent transformation from PSAD 1956 to WGS 1984. This generates small over-estimation or underestimations in each estuary. This error is managed by two approaches. Firstly, the reporting units of this analysis are 10,000 m<sup>2</sup> derived from data with a mapping unit of 900 m<sup>2</sup> or less.<sup>9</sup> Therefore, any error caused by slivers wholly contained within the reporting units. Secondly, by reporting inverse changes (shrimp to mangrove as well as mangrove to shrimp) any slivers will offset and sum to zero in the final analysis. That is, any sliver incorrectly classified as converting from mangrove to shrimp will have an equally sized corresponding sliver classified in the opposite direction. Such errors likely introduce spatial uncertainty in the location of the land use change; although the estuary level estimates of change remain valid.

Mangrove forests were delineated for the pre-aquaculture period by heads-up digitizing from the georeferenced topographic maps and aerial photographs. On the topographic maps, areas with mangrove land cover were denoted by a distinct symbol and boundary and were labeled. On the aerial photography, mangrove forests have a distinct spectral signature different from surrounding water, vegetation, or development. Mangrove delineation from ASTER and landsat was done with manual digitizing techniques overlaid on a normalized difference vegetation index calculated from each satellite image and distinct mangrove emphasizing bands combinations. Manual

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<sup>9</sup> One temporal data-point for Puná Island has a mapping unit of 3,600 m<sup>2</sup> this is still below the reporting unit and constitutes <0.01 percent of the entire analysis area over the combined study period.

digitizing was based on the distinct spectral signature of mangrove forests against the backdrop of estuarine water, mud, and saltpans. In-situ ground data was utilized to confirm areas of 2006 to 2008 mangrove in all estuaries aside from Grande Estuary. With landsat and ASTER, several different color composite images were created with different band combinations in order to distinguish mangrove forests from non-mangrove land cover. Landsat primary band combinations were 5-4-3 and 4-5-3. In the 5-4-3 color composite image, mangrove displays as dark green, and in 4-5-3, mangrove displays as dark orange. ASTER bands utilized were 3-2-1 for a color IR appearance and band combination 5-4-3 depict mangrove forests as a deep blue. Unsupervised and supervised classifications with ground control points obtained in the field were utilized in the Chone Estuary to verify the results of the manual digitization.

On the Ecuadorian topographic maps, areas of shrimp farms are depicted using dyke markings on earlier maps and on later maps shrimp farm terminology is used to identify ponds. On satellite imagery shrimp farms display as distinctive polygons with straight edges, occurring generally in clusters within the estuary. The clusters of ponds are many hectares in size and large enough to be viewed with the spatial resolution of 30 m for the landsat products. Some of these ponds may occasionally be used for tilapia but this is generally conducted on an ad-hoc basis when a pond is recovering from a period of shrimp activity, and tilapia production still falls under the wider aquaculture umbrella. Shrimp ponds cannot be automatically extracted from satellite data as immediately after a pond-refill, which is typically conducted multiple times per week, the shrimp pond and the surrounding estuary waters have the same spectral signature. Areas within the estuary not covered by mangrove or shrimp aquaculture were coded as other. The other

classification consists almost entirely of estuary surface water. In addition to water, the other classification encompasses small areas of mud flats, salt pans, and areas of non-mangrove vegetation within an estuary.

#### Land Use Change Detection

After checking for topological errors the digitized vector files created in steps were merged to create one land cover vector file for each study area, which consisted of a multi-part polygon for each mangrove stand, a multi-part polygon for each set of shrimp ponds, and a single part polygon for other land uses. Each cell was attributed with a land use category during digitization with a numerical value representing the type of land cover dominant in that cell. Mangrove is depicted by the value 1, shrimp farms are depicted by the value 3, and other land use by the value 7. These values were selected due to the unique outputs when map algebra subtraction is conducted on them. Resultant vector layers were then utilized to establish the area of each land-cover type in each estuary for each longitudinal data point.

The vector layers were then rasterized into one square meter cells with the entire estuary consisting of the cell values 1, 3, or 7. Simple change detection was then conducted by subtracting each longitudinal data point from its predecessor and by subtracting the final longitudinal survey from the base level longitudinal survey. The benefit of this method is that it produces not only raw change numbers but identifies the actual land use change that occurred. This method also allows for land use change analysis at the cell level between all three land use classifications. The possible output values of the land use change analysis are listed in the table below (Table 6). Although the unit of analysis is the one-meter cell, the smallest identifiable ground unit is 900 m<sup>2</sup>

for all estuaries aside from one temporal point in Rio Hondo Estuary that is 3,600 m<sup>2</sup>.

The reporting units of the analysis are reported 10,000 m<sup>2</sup> or hectares.

Table 6

*Estuary Change Detection Possible Output Values and Descriptors*

<b>Land Use Change Output Value</b>	<b>Land Use Change</b>
6	Mangrove > Other
4	Shrimp > Other
2	Mangrove > Shrimp
0	No Change
-2	Shrimp > Mangrove
-4	Other > Shrimp
-6	Other > Mangrove

### Interview and Survey Details

During three visits to the study areas, the researcher lived in local communities for a total of four months, which allowed time for ethnographic research (Jorgensen 1989; Hume and Mulcock 2005). Ethnographic research consisted primarily of thirty-five semi-structured interviews conducted with approximately sixty-one local residents and estuarine stakeholders.<sup>10</sup> An attempt was made to interview those who make their living in the estuary from traditional goods and services provided by the estuary, those who work on the shrimp farms or in support of shrimp farms that are now the dominant service offered by the estuary, and community leaders with insights about past and present use of estuaries. Artisanal fishermen were also targeted for semi-structured interviews as they rely on the natural goods and services of an estuary to make their living. The goal of the semi-structured interviews is to understand how the period of

<sup>10</sup> In the group semi-structured interviews, some members would leave and others arrive during the interview. Some semi-structured interviews were conducted with groups of 3 - 10 people.



commercial shrimp farming in the estuary combined with the observed mangrove deforestation in the estuaries has altered the livelihood and food security options available to those dependent on the wider goods and services of the estuary. In other words, to gain insight into the implications of land use conversion from mangrove forest to aquaculture.

The researcher spent most of his time in the field in Cayapas-Mataje (four weeks) and Chone (eight weeks) estuaries. These estuaries provide two extremes in shrimp aquaculture, with Chone being a heavily modified, shrimp farmed, and deforested estuary, whereas Cayapas-Mataje is a pristine, largely unaltered estuary with vast undisturbed mangrove forests and relatively few shrimp farms. Spending the majority of time in two of the estuaries allowed for a deeper understanding of the implications of the land use change that may not have been obtained with shorter visits more estuaries. For these reasons, the majority of my field-based findings derive from Chone and Cayapas-Mataje estuaries. Semi structured interviews were conducted in Muisné, Cojimies and Rio Hondo but participatory observation time was limited to about ten days total in these areas. Grande Estuary area was only visited for two days and has the most limited amount of ethnographic research. For this reason, food security and livelihood results from ethnographic research are not produced for the Guayas estuary. In addition to visiting all of the major estuary sites in Ecuador, an additional two weeks was spent on an earlier visit touring the smaller riverine former mangrove forests that dot the coastline where smaller rivers meet the Pacific Ocean. Examples of these towns are Las Penas, Esmeraldas, Palmar, Alto Manglar, and La Boca.

Activities conducted during the ethnographic research phase of this research include: working in and observing activities on a shrimp farm in Chone Estuary, taking numerous fishing trips with artisanal fisherman, touring the mangroves with artisanal fisherman, touring a shrimp hatchery, touring a feed store, living with a fishing syndicate president, and visiting each estuary via boat. I also attended a meeting of a fishing syndicate in Chone Estuary and spent numerous nights in isolated mangrove communities in Chone and Cayapas-Mataje. I employed a shrimp farm worker who used to be an artisanal fisherman and the wife of a shrimp farm employee as translators as well as receiving translation assistance from Dr. Klaus Meyer-Arendt of the University of West Florida. I spent approximately two days in Quito working alongside personnel at Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos (CLIRSEN) and the IGM. While in Quito, I also spent time at the offices of UN FAO, discussing macro trends in aquaculture with staff. In addition to these activities, I visited the only *Sierra*-based aquaculture project in Ecuador.

The occupational summary for the semi-structured interviewees are listed in Appendix A. IRB approval was obtained from The University of Southern Mississippi and is attached in Appendix B. Oral consent was approved and utilized due to the lack of literacy among many of the artisanal fisherman and itinerant workers. Each interview was recorded after oral consent was given with additional field notes made during or after the interview. All semi-structured interviews were conducted during late 2009 and involved contacts made during earlier trips in 2007 and 2008. Again, Chone was oversampled with regard to semi-structured interviews in an attempt to give additional insight at one of the study locations. Transcripts of the semi-structured interviews are

available in Swem Library, Williamsburg, VA and contact information is provided in Appendix C. One semi-structured interviewee was uncomfortable with the prospect of being recorded and as a result, the interview was terminated and no information from it was included in this analysis. Out of respect for the privacy of each interview participant, all personally identifiable information has been removed from all semi-structured interview responses.

Within Chone, ethnographic research took the additional form of collaborative mapping. This portion of the ethnographic research was based on the recent advancement of participatory research mapping techniques that have shown to be an effective technique to assess resource use and histories among tradition communities (Stocks 2003; Wood 2005; Cochran 2008). Arrangements were made with the local fishing syndicate to have a group meeting and free flowing discussion driven by poster-sized maps generated from semi-decadal land use within the estuaries. Participants were encouraged to discuss the forces behind the land use change and the implications to their livelihoods of the land use change (Stocks 2003). The participants annotated the maps with symbols representing the various areas of seafood catch throughout time. Due to limited time in the regions, the collaborative mapping exercise cannot be considered a fully-fledged participatory research mapping activity as this requires more time among the local actors. Despite this, the collaborative mapping project proved a highly effective method of stimulating meaningful conversation and breaking down barriers.

In addition to the semi-structured interviews, two socioeconomic surveys were conducted in collaboration with another researcher who was conducting a similar study at the time and place regarding local dependency on mangroves. The raw data of these

surveys was made available to me in return for my data on historic mangrove holdings. The collaboration resulted in joint authorship on a livelihoods article submitted to the Royal Society of Geographers. These socioeconomic surveys supplement findings from my ethnographic research in the northern estuaries. These socioeconomic surveys focused on household data and community data within the aforementioned study areas of Cayapas-Mataje, Muisné, Cojimíes, and Chone. The household survey focused on mangrove dependency at the household level whereas the community survey focused on the relationship between place and mangrove deforestation (Collins 2010). In total 215 household socioeconomic surveys were conducted and forty-one community surveys across all coastal provinces.

Finally, a literature review relating to livelihood options in Ecuador activity resulted in two socioeconomic studies that are useful for this research. Ocampo-Thompson (2006) conducted 170 socioeconomic surveys and one-hundred interviews in 2003 with a focus on mangrove dependent livelihoods in Cayapas-Mataje Estuary. Veach (1996) conducted sixty-one household interviews in and around Cayapas-Mataje, although focused on gender roles this research does contain substantial information on the rates of utilization of mangroves goods and services (Veach 1996). These secondary data sources are used to supplement information gained from the ethnographic research.

## CHAPTER V

## RESULTS

## Chone Estuary Land Use Change

The Chone Estuary study area is 8,744 ha in size. In 1968, the estuary was comprised of 4,238 ha of mangrove forest and 4,506 ha of other land cover including surface water, saltpans, and mud flats (Figure 18). This base level land cover was derived from topographic maps and aerial photography flown in 1968. Nothing was learned from interviews or field trips that suggest the 1968 mangrove level cannot be considered representative of historic mangrove cover for this estuary. At the mouth of the estuary mangrove forests dominate the terrestrial edge of the estuary and in the upper estuary mangrove forests dominate the central portion of the estuary. The majority of the mangrove forest exists in six or seven large stands.

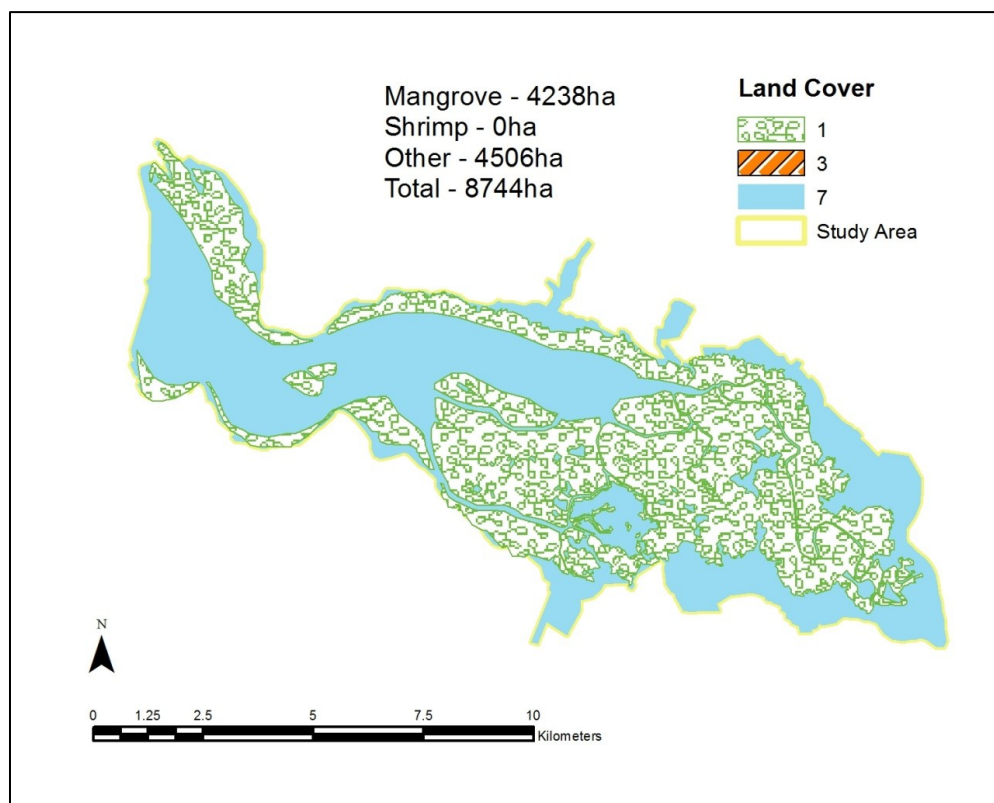


Figure 18. Chone Estuary Base Level Mangrove Cover, 1968.

In Chone Estuary, the period between 1968 and 1977 is characterized by the arrival of shrimp aquaculture and maintenance of mangrove cover (Figure 19). The first shrimp farms appear during this period and are located on the terrestrial edge of the estuary. Although mangrove forests decline by 388 ha during this nine-year period, only 21 ha of this decrease corresponded to direct displacement of mangrove by shrimp farms. Aside from the addition of these relatively few shrimp farms and the loss of small amounts of mangroves, the estuary land cover remains consistent between 1968 and 1977. The location of the early shrimp farms in the Chone Estuary supports the view that shrimp aquaculture, at least in its early stages, occurs on the terrestrial edge of the estuary, and is not responsible for mangrove deforestation (Menasveta 1997; Boyd and Clay 1998; Diana 2009).

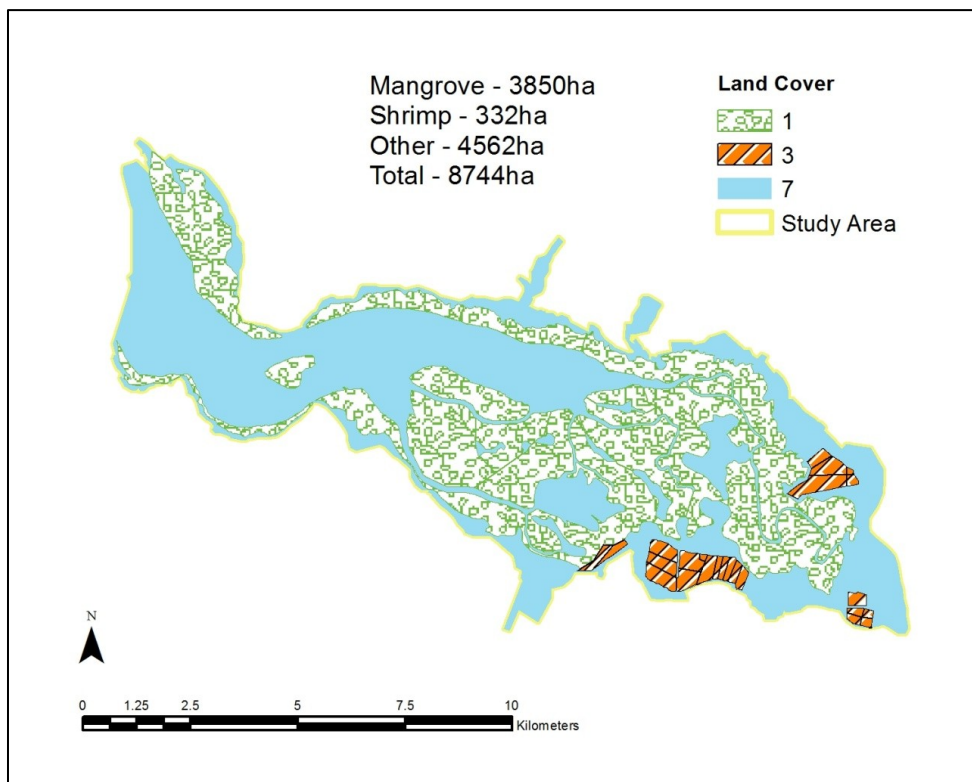


Figure 19. The First Arrival of Shrimp Farms in the Chone Estuary, 1977.

In the Chone Estuary, the period between 1977 and 1984 is characterized by rapid shrimp farm expansion, high rates of mangrove deforestation, and high rates of direct displacement of mangrove by shrimp farms. During this seven-year period, mangrove cover decreases by 1,679 ha, from a 1977 level of 3,850 ha to a 1984 level of 2,171 ha (Figure 20). Hence, by 1984 only 50 percent of the base level mangrove forest remains in the Chone Estuary. In the seven years from 1977 to 1984, 44 percent of the mangrove forest has been cleared. During this identical period, shrimp aquaculture increases eleven fold from the nominal 1977 level of 332 ha to the 1984 level of 3,739 ha. Indeed, by 1984 shrimp aquaculture is the majority estuary land cover overtaking mangrove and the other land-cover classification that includes surface water. Unlike the initial period of shrimp expansion when farms only appear along the terrestrial edge of the estuary, the new farms during this period often locate in the center of the estuary and in areas only accessible by boat. During this period, almost all of the mangrove forest loss is caused by direct displacement of mangrove forest by shrimp aquaculture (Figure 21). Mangrove forests appear to be the preferred location of the newly arriving shrimp farms.

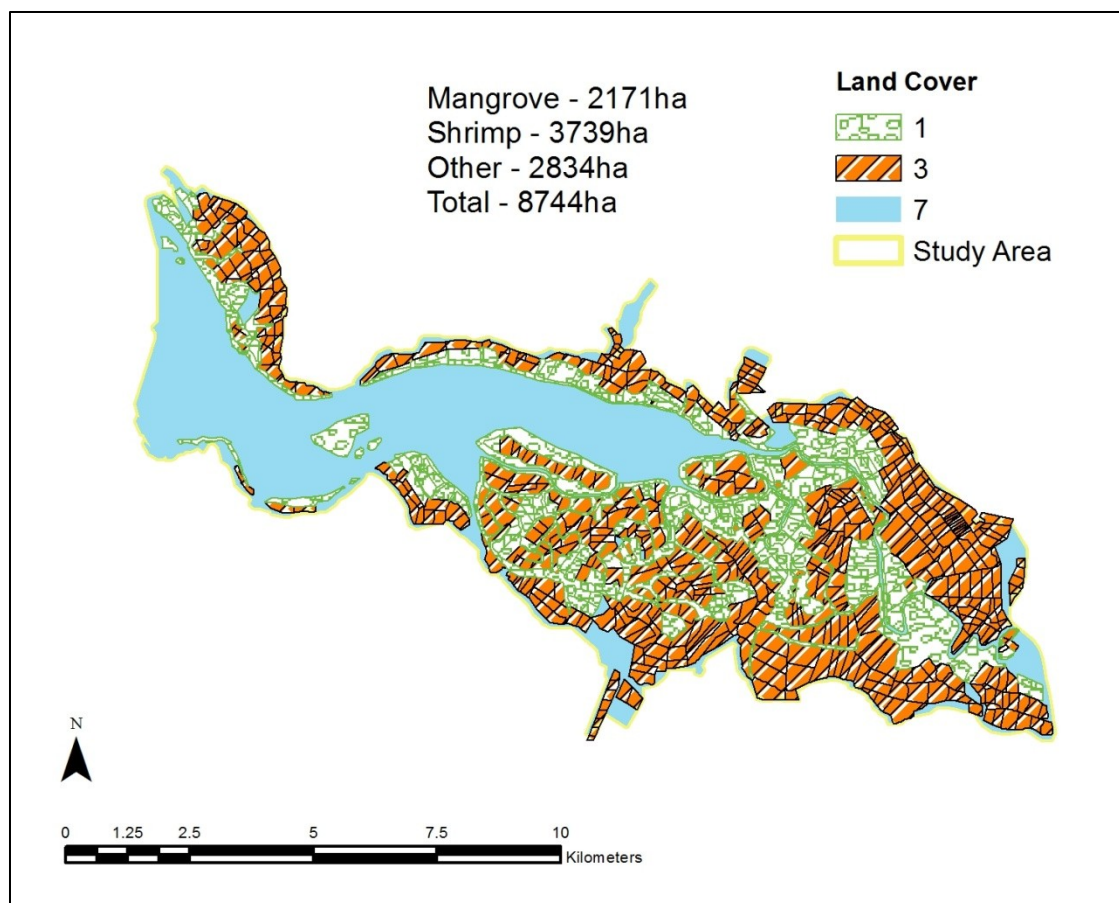
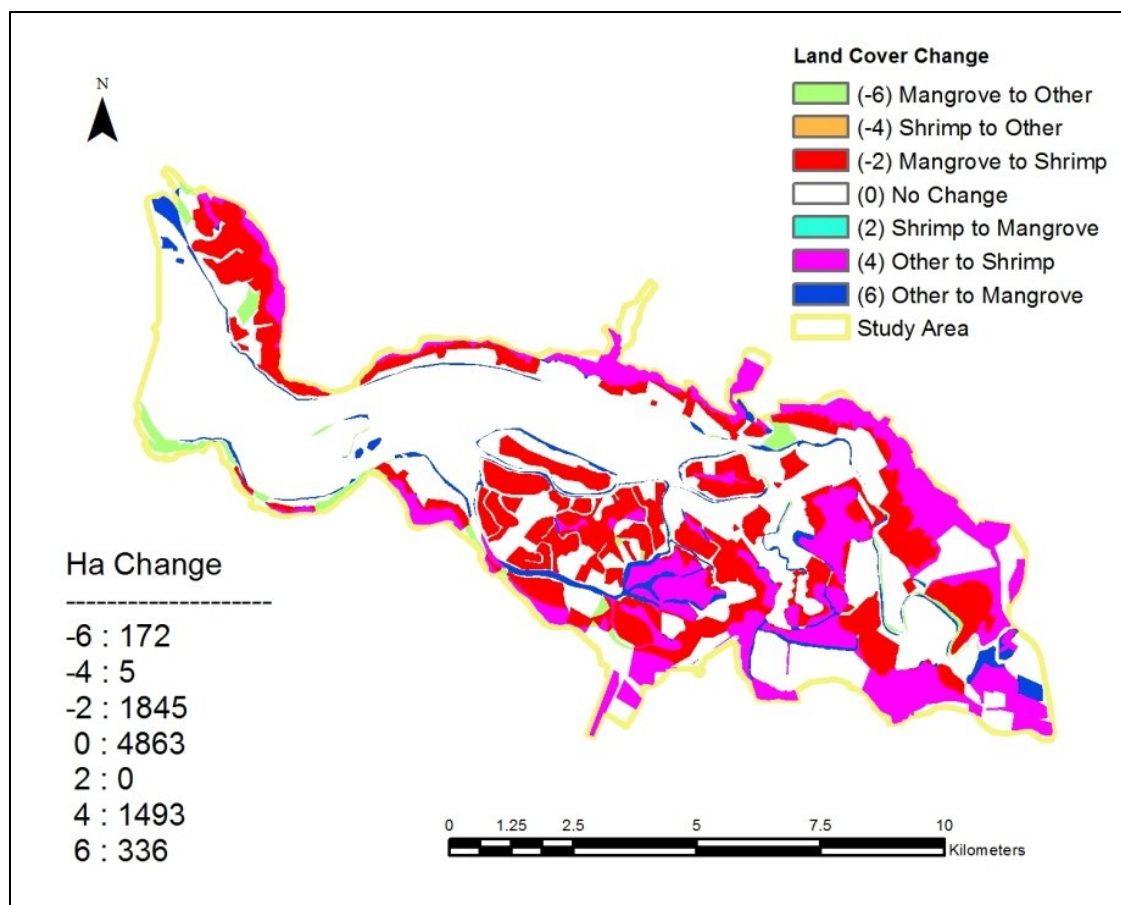


Figure 20. Chone Estuary Land Use, 1984.





*Figure 21.* Chone Estuary Land Use Change from 1977 to 1984. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the lower left indicate the magnitude of the land use change in hectares.

Between 1984 and 1991, shrimp farm expansion and mangrove denudation both continue in the Chone Estuary. Although the rate of shrimp farm expansion and the rate of mangrove deforestation decline from the previous period, they both remain relatively high (Figure 22). The decline in shrimp farm expansion is likely due to a lack of estuarine space available for expansion due to the near saturation of shrimp farms. An additional 1,008 ha of mangroves are lost between 1984 and 1991. This loss equates to 46 percent of the remaining mangrove forest. By 1991, only 27 percent of the 1968 base level mangrove forests remain (Figure 23).

Shrimp farm expansion during this period follows a pattern that includes the displacement of mangrove that remain in the center of the estuary and the expansion outwards of ponds from the terrestrial edge of the estuary towards the center of the estuary. This is particularly true in the upper estuary. Rows of singular ponds expand to form multiple stacks of two or three ponds that reach further out into the estuary. This expansion is particularly evident on the north side of the estuary with ponds stacked two, three, or even four deep. The northern interior portion of the estuary is home to the majority of the traditional fishing communities in this region. Once again, almost all of the shrimp farm increase of 1,174 ha was at the direct expense of mangrove forests (Figure 23). The shrimp farm expansion during this period raised increased farm coverage to 4,913 ha. By 1991, shrimp farms occupy more of the Chone Estuary than mangrove, surface water, saltpans, mud flats, and all other land cover combined. The 1991 longitudinal data point marks the final period of rapid shrimp farm expansion and rapid mangrove loss in the Chone Estuary.

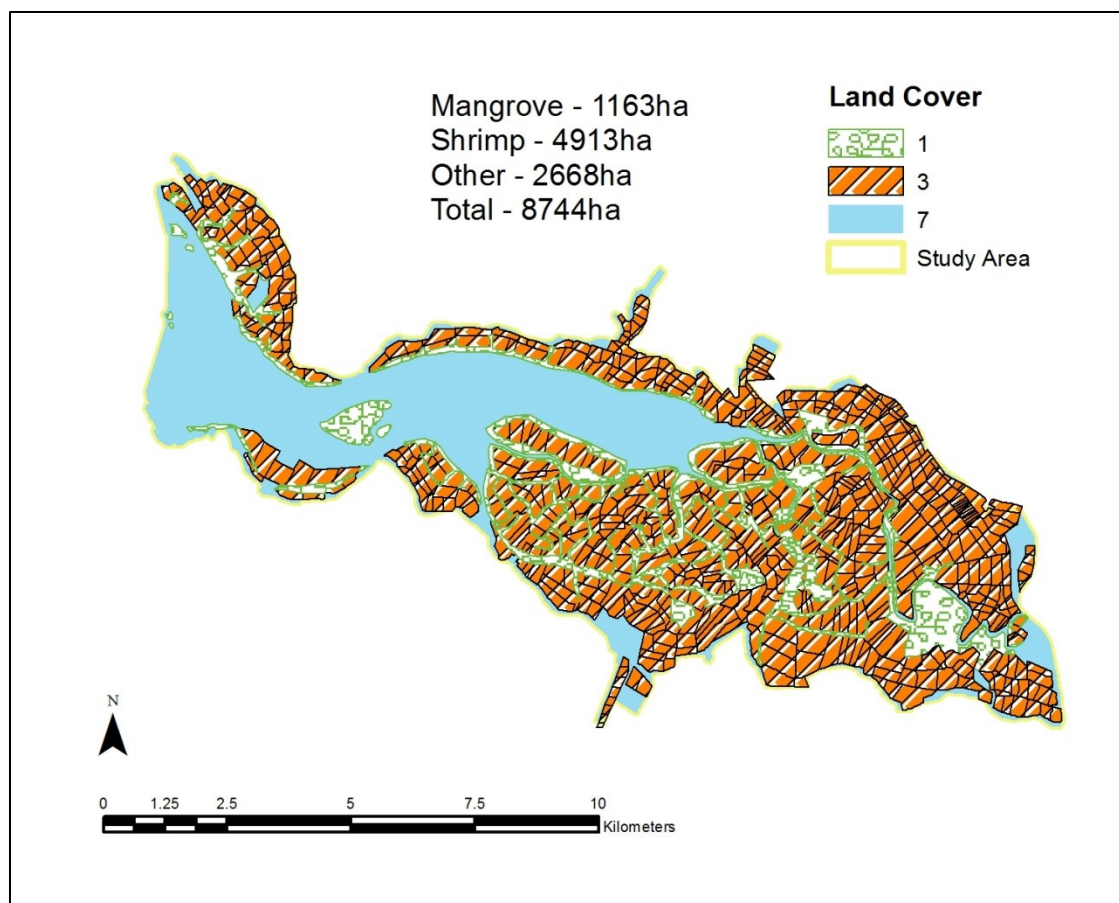
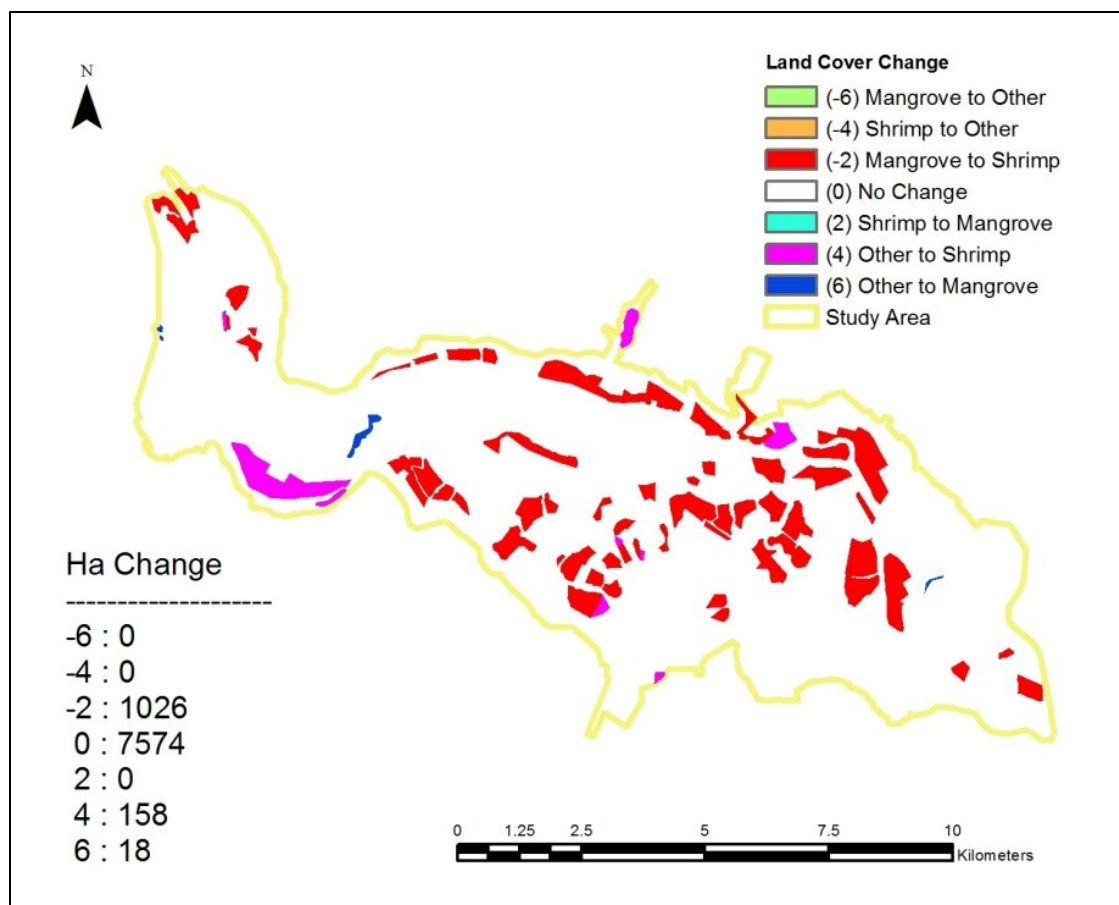


Figure 22. Chone Estuary Land Use, 1991.



*Figure 23.* Chone Estuary Land Use Change from 1984 to 1991. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the lower left indicate the magnitude of the land use change in hectares.

Between 1991 and 2001, shrimp farm expansion and mangrove depletion continue in the Chone Estuary but at much slower rates than during the two previous periods. This decrease may be due in part to a lack of mangrove forest to convert to new shrimp farms. Between 1991 and 2001, shrimp farms increase by another 205 ha to 5,117 ha. Conversely, mangrove forest cover decreases by 128 ha from 1,163 ha to a longitudinal low amount of 1,035 ha (Figure 24). At this low point, only 24 percent of the 1968 base level mangrove remains with the estuary having lost a remarkable 3,202 ha of mangrove over a period of approximately fourteen years. Direct displacement of

mangrove forest by shrimp farms during this period is slightly above 50 percent, with 112 ha out of the 205 ha of new shrimp farms directly displacing mangrove forest. During this period, shrimp farms also displace surface water at an equal rate to their displacement of mangrove forest. Shrimp farms still occupy more of the estuary than mangrove and all other land uses combined including surface water (Figure 24).

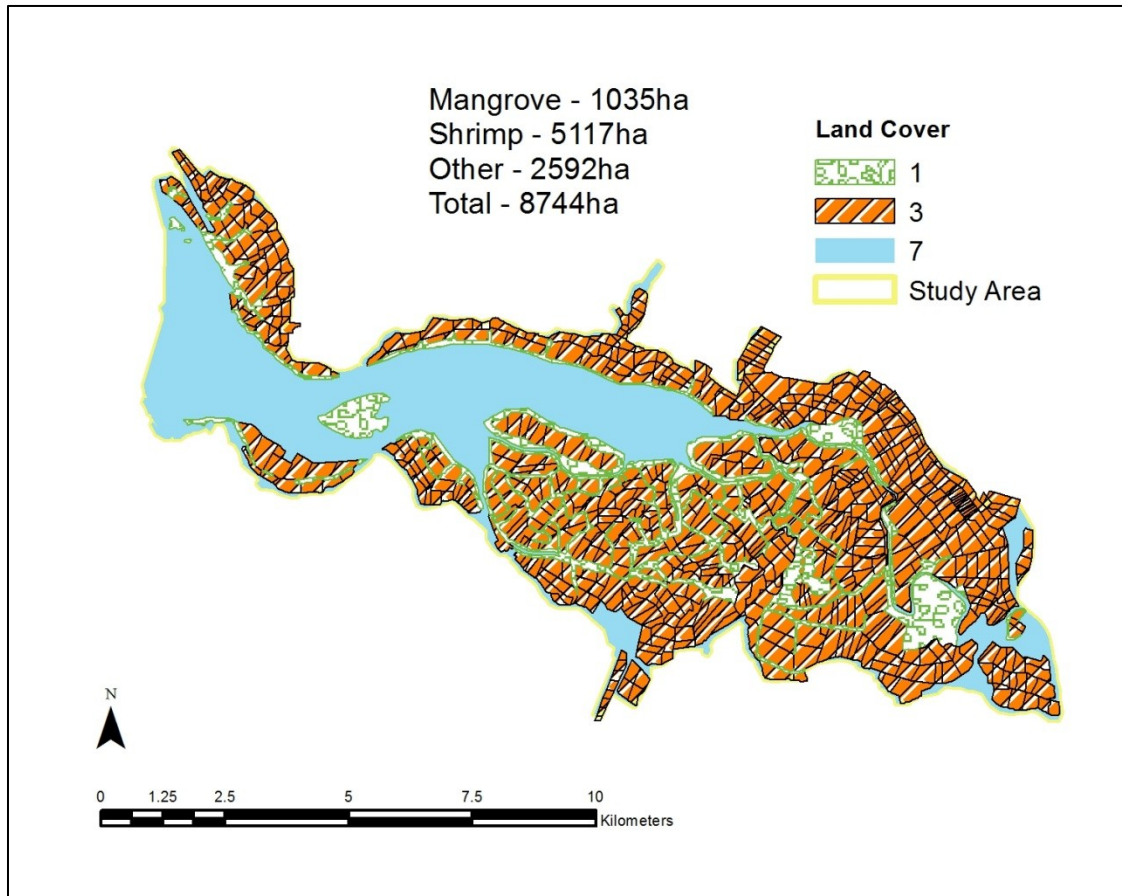


Figure 24. Chone Estuary Land Use, 2001.

The period from 2001 to 2006 is one of mangrove recovery and shrimp farm inertia within the Chone Estuary. Shrimp farm acreage increases only a nominal amount from 5,117 ha to 5,191 ha (Figure 25). Unlike the earlier periods, mangroves also increase by 430 ha, from a low of 1,035 ha to 1,465 ha. Almost all of this mangrove expansion during this period is associated with Isla Corazón in the center of the estuary

(Figure 25). By 2006, mangrove cover increases to 36 percent of base level forest cover from a low of 24 percent in 2001. Despite the reforestation of mangrove within the estuary, shrimp farms continue to cover more of the estuary than all other land uses combined; including mangrove and surface water. The area of mangrove regeneration is in a region that appears to have historically lacked mangrove cover (Figure 18) and does not actually displace shrimp farms. The mangrove expansion replaces mud flats and water as opposed to shrimp farms. The reason for this expansion is a response by fisherfolk to the diminishing shrimp and fish catches in the estuary and is discussed in more detail later in this chapter.

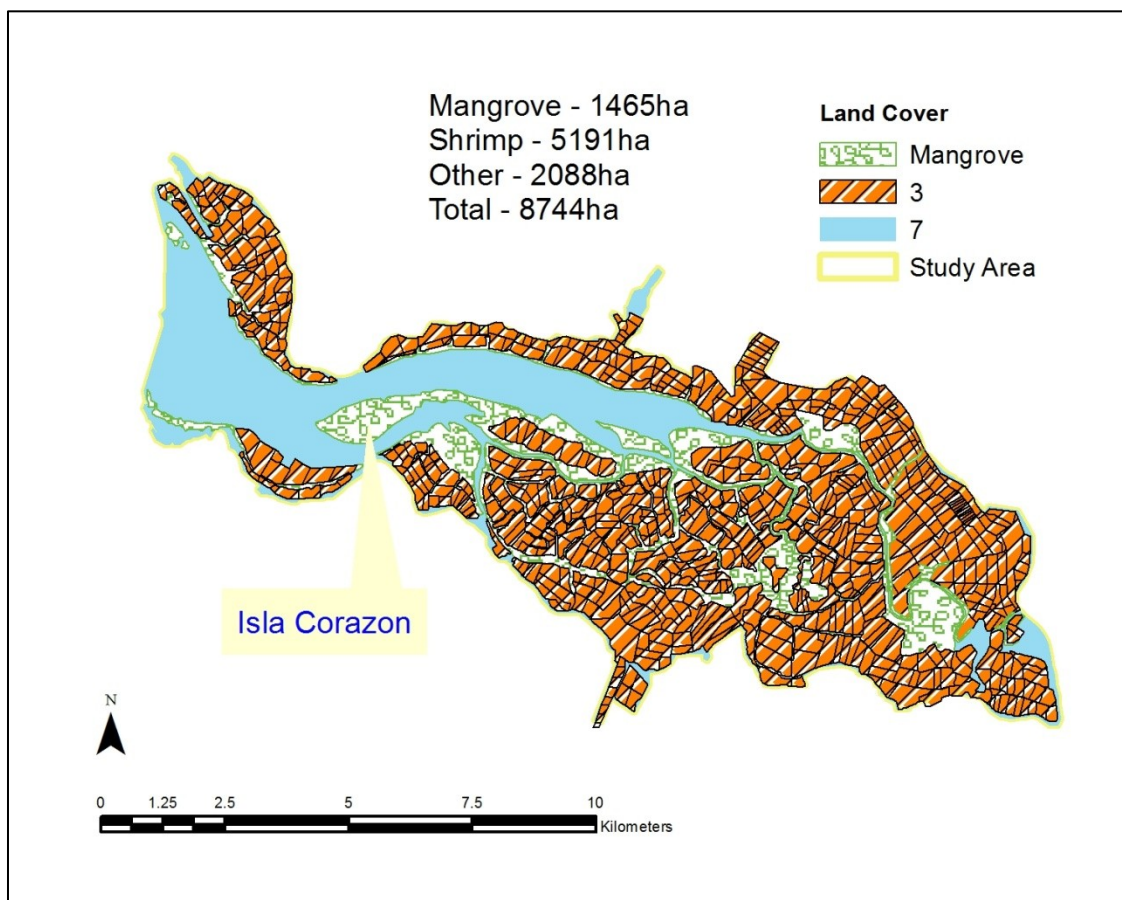


Figure 25. Chone Estuary Land Use, 2006.

In summary, within the Chone Estuary shrimp farms expand from nothing in 1968 to 5,191 ha by 2006 (Figure 26). Despite some limited mangrove recovery towards the end of the analysis period, shrimp farms still cover more of the estuary than mangrove, surface water, and all other land cover combined. The period from 1977 to 1991 was a time of rapid shrimp farm expansion, whereas post-1991 shrimp farms continue to expand but at a more modest rate. Shrimp farm expansion continues through all longitudinal surveys until the final survey in 2006. Early shrimp farms appear to be located on the terrestrial edge of the estuary whereas the newer farms fill in the central portions of the estuary

Mangrove forest cover has a direct inverse relationship to shrimp farms in the Chone Estuary during the analysis period (Figure 26). Mangrove decreases from 4,238 ha in 1968 to 1,465 ha by 2006. The 2006 mangrove level is actually a recovery from the 2001 mangrove low level of 1,035 ha. This represents a 76 percent base level mangrove loss by the 2001 survey point, and a 66 percent mangrove loss at the 2006 survey point. The period from 1977 to 1984 has the most rapid mangrove deforestation, with annual deforestation rates as high as 6.42 percent (Figure 27). The decade from 1991 to 2001 reveals only slight a loss of mangrove forest within the estuary. The final period from 2001 to 2006, shows mangroves recovering in the estuary and reforestation rates as high as 2.87 percent annually. This reforestation rate is slightly deceiving as mangrove is starting from such a low level following the period of deforestation. A future survey will be required between 2015 and 2020 to establish if the mangrove forests of Chone are truly recovering and the noted regrowth is not merely a decadal anomaly.



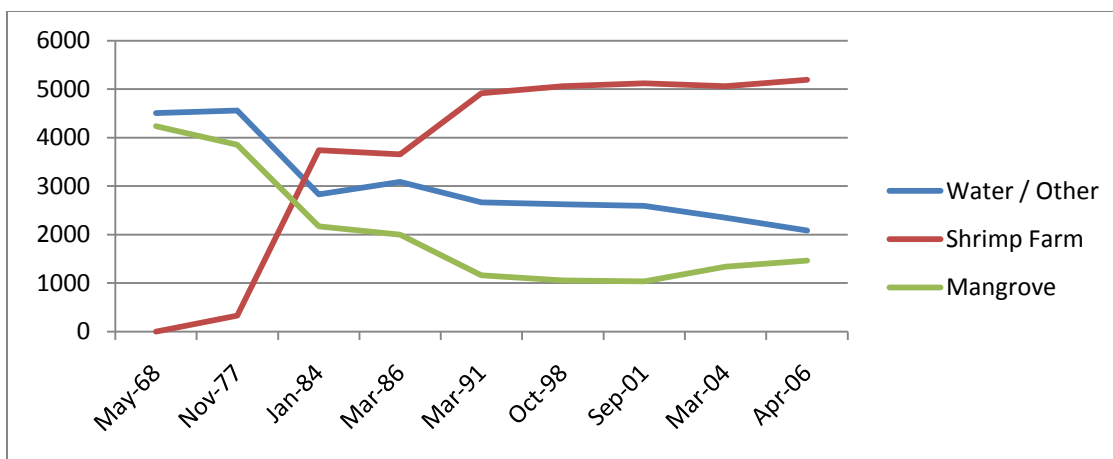


Figure 26. Chone Estuary Land Cover Change from 1968 to 2006. Land cover changes between longitudinal data points assume a linear interpolation. The y-axis is hectares.

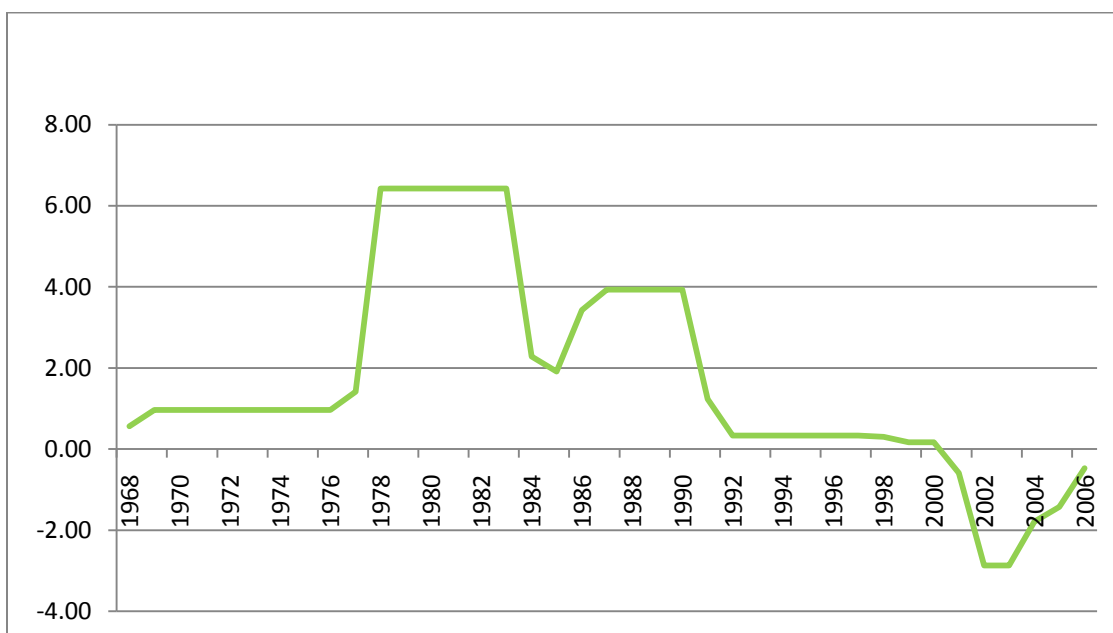
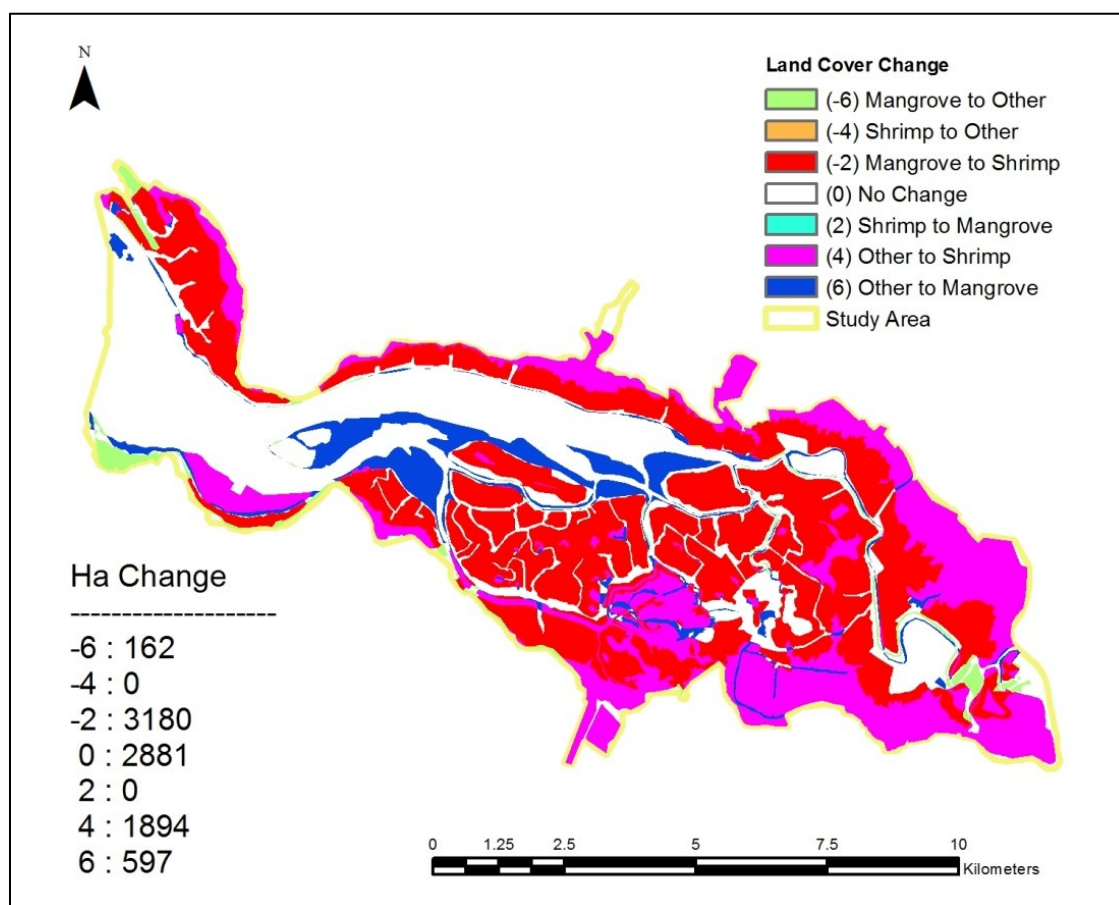


Figure 27. Chone Estuary Annual Rates of Mangrove Deforestation from 1968 to 2006. Mangrove losses between longitudinal data points assume a linear interpolation. The y-axis is percentage deforestation year-over-year.

Of the 5,191 ha of new shrimp farms created during the study period, 3,180 ha of these new shrimp farms exist in areas that were once mangrove forests (Figure 28). This equates to 61 percent of shrimp farms being located in former mangrove forests and 39 percent in other land cover categories. Direct displacement of mangroves by shrimp



farms accounts for 95 percent of the mangrove loss during the entire study period. Aside from the earliest shrimp farms, Chone Estuary does not appear to follow patterns cited by skeptics of the shrimp – mangrove relationship who argue that as little as 10 percent of mangrove losses are the result of shrimp farming (Menasveta 1997; Boyd and Clay 1998; Diana 2009). Indeed, almost all of the mangrove loss in the Chone Estuary between 1968 and 2006 is due to direct displacement by shrimp farms. In addition to the displacement of mangrove forests, substantial portions of the non-mangrove estuary are impacted with 2,881 ha of other land cover converted into shrimp farms.



*Figure 28.* Chone Estuary Land Use Change from 1968 to 2006. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the lower left indicate the magnitude of the land use change in hectares.

### Chone Estuary Food Security and Livelihood Implications

The land use transition from mangrove forest to shrimp farming in the Chone Estuary appears to have decreased local livelihood options and food security among traditional fishing populations. This has occurred due to two aquaculture driven processes. The first is the decline of preexisting livelihood options once aquaculture arrived and the second is the lack of livelihood options provided by aquaculture to local communities once it became established. In the latter, shrimp farms in Chone have not created many jobs and the jobs created have gone to people outside traditional fishing communities. Almost all interview participants indicated that few, if any, employment opportunities were created by the arrival of shrimp aquaculture. Even today, Chone Estuary aquaculture appears to import migrant labor from other regions to operate the shrimp farms and houses these workers on-site. Such practices have been described as typical of commercial shrimp farming worldwide (Environmental Justice Foundation 2003; Solidarity Center AFL-CIO 2008). Local employment on shrimp farms appears limited to seasonal work at harvest, with negligible community involvement in day-to-day farm management. What employment does occur on the farms is generally low paying and requires supplemental income to make a living. In the Chone area, the shrimp processing industry that arrived with aquaculture now appears to have closed, removing this secondary form of employment that women in the community traditionally filled. The few professional positions that are available with aquaculture appear to be involved in the hatchery, about an hour north of the Chone Estuary, and in specialized technical positions such as a pump mechanic or chemist, although even these workers report their income as intermittent and not enough to support a family.

Shrimp farming not only provides few employment opportunities in the Chone Estuary area, it also damages other occupations that fisherfolk practiced before the arrival of aquaculture. The depletion of wild fish stocks in the estuary was the biggest factor cited in the decline of traditional livelihoods and an increase in levels of food insecurity. For example, one interview respondent stated that the depletion of wild fish stocks in the estuary and near-shore areas was due to mangrove deforestation and the advent of shrimp farming, and this was the primary cause of their economic hardship. Fish or bust, is the term another respondent used to describe local dependence on estuary catch in Chone. Semi-structured interview respondents on the north side of the Chone Estuary stated that fishing employs approximately 60 percent to 80 percent fewer families today than in the 1970s, and that it is no longer possible to support a family by fishing the estuary. Indeed, local residents reported that in non-adjusted USD, fisherfolk now make approximately 50 percent of what they typically made in the 1970s. The lack of seafood catch opportunities not only affects livelihoods but also has an adverse affect on food security to people of this region.

The pathways mentioned that have caused wild catch decrease include the use of herbicide in the farms, the loss of habitat in the mangrove forest, and water quality issues connected to shrimp farm practices such as effluent drainage. Within the Chone Estuary, interview respondents claimed that water quality has declined due to mangrove depletion and shrimp farm practices. This statement is supported in the only peer-reviewed study of water quality in the Chone Estuary (Stram et al. 2005). During my three tours of the estuary, weedy growth appeared to be a major problem that was not present in the non-farmed estuaries such as Cayapas-Mataje to the north or those to south of Chone such as

the mangroves around San Clemente. It is likely the estuary is suffering from oxygen depletion and high levels of nutrient loading due to the sheer magnitude of shrimp farms (Stram et al. 2005). This may be in part due to the loss of the mangrove filter that otherwise mitigated terrestrial agricultural runoff. One interview respondent commented that some aquatic species such as crab, conch, and crayfish have disappeared from the estuary altogether or are now only available in very limited amounts. Another respondent noted that offshore fishermen appear to have not fared as badly as those in the estuary have and that although catches have declined they seem to be on the rise again. Pressure on offshore fisheries may actually increase beyond the habitat damage and extraction of feed and Postlarvae from the ocean. The lack of fishing in the estuary appears to have forced fisherfolk to move from the estuary into off shore waters further increasing demand on an already stressed resource.

Interviews with members of the fishing syndicate provided the most insight into temporal information about the Chone Estuary and deforestation. All of the fishermen within the Chone Estuary appear to understand the relationship between mangrove forest and wild catch. This was most clearly expressed by syndicate members when they stated that they have replanted mangroves on the Isla Corazón so they can return to fishing the estuary as well as to promote tourism. Various interview respondents stated that it was a lack of local knowledge in the early days of aquaculture that prevented them organizing and resisting the shrimp farms. This lack of knowledge about the impacts of aquaculture ties in with the land use analysis and information gleaned from Cayapas-Mataje fishing syndicates. Those in communities to the north stated that they resisted shrimp farms due to the fact they had learned of the negative impacts of shrimp farms from such places as

Chone. Fisherfolk in Chone also state that businessman who purchased their terrestrial lands deceived them after the transaction. The shrimp farm companies would purchase terrestrial land only for the purchaser to take ownership of aquatic land on the boundary of the terrestrial purchase and build shrimp farms out into the estuary. This practice was verified by respondents in Cayapas-Mataje that stated this method was employed to get around the fisherfolk blockade of aquaculture. This pattern of shrimp farm expansion is visible in the land use change analysis. Fishing communities in the Chone Estuary stated that they willingly gave land concessions to early shrimp farmers with the return promise of employment for all that never materialized.

Syndicate fishermen from the Chone Estuary state that by 1990 fishing within the bay had essentially ceased. Again, this ties in well with land use change findings with 1991 being the apex of shrimp farm expansion and mangrove depletion in the estuary (Figure 22). The Chone syndicate fishermen, along with other interview respondents, believe poison used in ponds to kill vegetation and other non-shrimp species is a major reason for the decline of local fisheries. Chone fisherfolk also indicate they traditionally relied on the estuary mangroves for wood, tannins, charcoal, medicine, and even for use in making shoes before the advent of shrimp farming, and all of these activities are now extinct. Social changes have also been driven by the arrival of shrimp farms in Chone Estuary. Some individuals in the fishing syndicate blame the decline in fishing on forcing women into work in the community often in the early processing plants that have now left the area.

Other negative impacts related to shrimp farming in Chone Estuary are the impediment of physical access to the estuary and conflicts between different stakeholders

in the area. Traditional Chone fisherfolk now have their access to the estuary blocked by the shrimp farms and migrant shrimp farm workers who patrol the private terrestrial land. This phenomenon is visible in the land use change analysis (Figure 25), with the entire interior portions of the Chone Estuary inaccessible due to multiple stacking of shrimp farms along the terrestrial edge of the estuary. Numerous respondents mention that Chone Estuary shrimp farms are guarded due to the value of the product in the ponds and incidents of shrimp theft. Just before harvest, people have been known to steal shrimp by casting a net into the ponds at night and then selling the vast catch to vendors. Such actions results in shrimp farm owners being less likely to allow artisanal access to the estuary, as now security and fences, not merely ponds, impede fisherfolk and their attempt to access the estuary (Ocampo-Thomason 2006). Conflict has arisen between artisanal fisherfolk and shrimp farm employees with assault and murder reported (Environmental Justice Foundation 2003). Again, such conflict appears consistent between aquaculture and fisheries stakeholders in estuaries worldwide (deFur and Rader 1995; Adams 2001; Brugere 2006; Cormier-Salem 2006; Gowing, Tuong and Hoanh 2006; Hoanh et al. 2006; Le Tissier and Hills 2006).

Chone's residents appear to be reacting to the land use change occurring in the estuary and are active participants in the regeneration that is occurring. At the macro-level, activities such as the creation of the eco-city label enthusiastically adopted by the citizens of Chone, the preservation and management status now attached to the estuary, and the recently implemented catch season and size rules all demonstrate a commitment to improve and restore the estuary to its former health. A concrete example of this regeneration mindset is found in the land use analysis with Chone Estuary exhibiting

robust levels of reforestation of mangroves over the last decade (Figure 26). The Corazón fishing syndicate is directly responsible for 90 percent of this replanting with other groups including the Peace Corps, NGOs, and elementary school children responsible for the rest. This replanting appears to be returning the estuary, or at least portions of the ocean-side of the estuary, back into productive fishing grounds. This regrowth area is also a tourist attraction and has become a major frigate bird nesting site. In addition to the reforestation of mangroves, the period of shrimp farm expansion in the estuary appears to have ended (Figure 26). I did witness farms under construction on terrestrial land close to the Chone Estuary that will obtain their water from, and likely drain into, the estuary environment but this appears to be the exception and not the current norm.

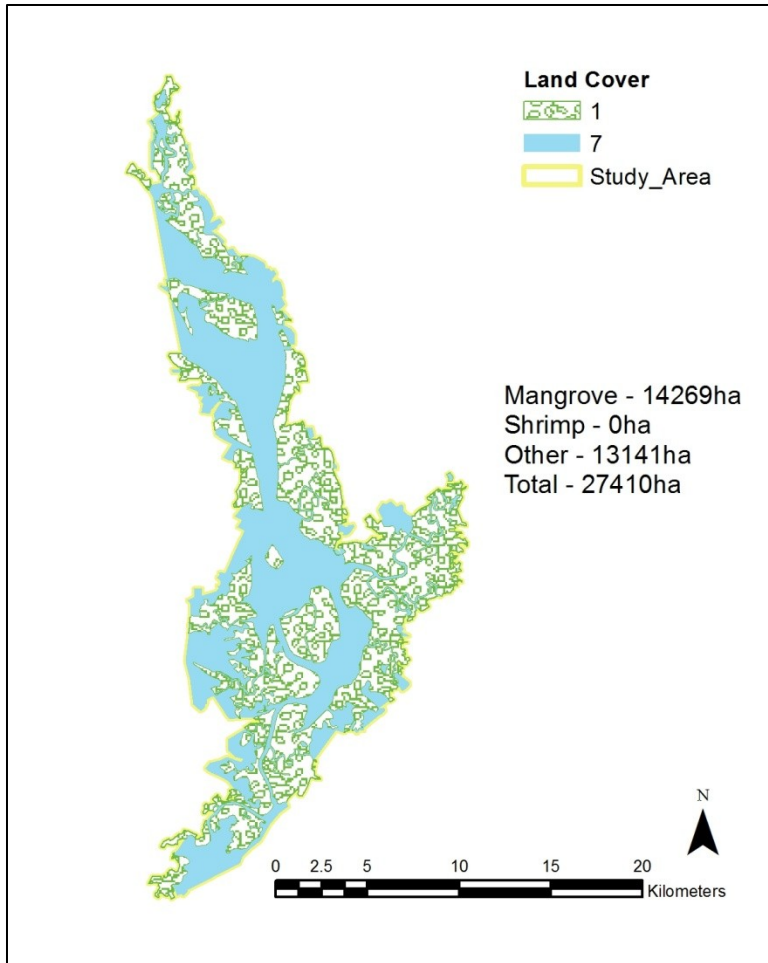
Other signs of estuary improvement in the Chone Estuary are the adoption of better shrimp farm operating practices and the advancement of other livelihood options now fishing is no longer possible. For example, respondents note that almost all shrimp farm Postlarvae are obtained from hatcheries as opposed to being extracted from the wild. A shrimp farm within the estuary has also experimented with non-fishmeal feed and has received an organic certification (Cuoco 2005; Saulnier 2007) although the meaning of this certification is at best questionable. In addition to these activities, the central government plays a role assisting the fishing communities so they benefit from tourism-based livelihoods. During two of my three trips to Chone, I encountered a tourist development officer from Quito who is working among the fisherfolk to develop and assist them with a plan to bring tourists from other areas of South America to the estuary. This official visits every few months to guide the fisherfolk and provides limited amounts

of financial support. I observed a number of Chilean tourists at Isla Corazón touring the mangroves with traditional fisherfolk in dugout canoes during my time in this community. Fisherfolk did express that tourism was contributing to the economic health of their community now that mangroves are recovering in the estuary.

#### Cojimíes Estuary Land Use Change

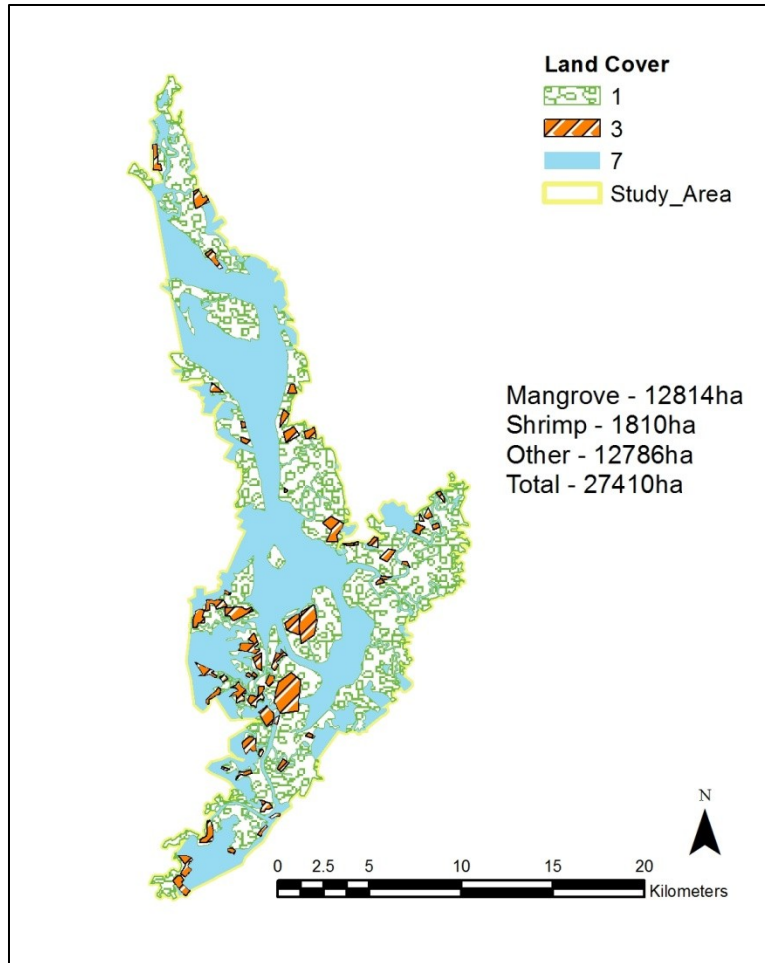
The Cojimíes Estuary study area is 27,410 ha in size. In 1971, the estuary was comprised of 14,269 ha of mangrove forest and 13,141 ha of other land cover including surface water, saltpans, and mud flats (Figure 29). The base level land cover is derived from topographic maps, which are based on aerial photography flown in April 1971. No interview respondents or field observations lead me to suspect that the 1971 mangrove level is not representative of historic mangrove cover for this estuary.





*Figure 29. Cojimies Estuary Base Level Mangrove Cover, 1971.*

In the Cojimies Estuary, the period between 1971 and 1986 is characterized by the arrival of shrimp aquaculture and slow rates of mangrove deforestation (Figure 30). The first shrimp farms appeared between 1971 and 1986 and are equally dispersed throughout the estuary. Of the 1,455 ha of mangrove deforestation that occurred during this fifteen-year period, 1,447 ha is direct displacement of mangrove by newly constructed shrimp farms. Aside from the addition of these relatively few shrimp farms and the loss of small amounts of mangroves, the rest of the land cover of the estuary remained essentially unchanged between 1971 and 1986. Deforestation rates are below 0.7 percent annually.



*Figure 30. Cojimies Estuary Land Use, 1986.*

In Cojimies Estuary, the period between 1986 and 1998 is characterized by rapid shrimp farm expansion, high rates of mangrove deforestation, and high rates of direct displacement of mangrove by shrimp farms. During this twelve-year period, mangrove cover decreases by 10,135 ha, from a 1986 level of 11,814 ha to a 1998 level of 1,679 ha (Figure 31). Hence, by 1998 only 19 percent of the base level mangrove forest remains in the Cojimies Estuary. During this identical period, shrimp aquaculture increases eleven fold from the 1986 level of 1,810 ha, to a 1998 level of 13,815 ha. Indeed, by 1998 shrimp aquaculture actually became the majority estuary land cover surpassing mangrove and all the other land cover classifications combined. During this period,

almost 10,121 ha of the mangrove forest loss is direct displacement of mangrove by shrimp aquaculture. This results in a remarkable 80 percent of estuarine mangrove forest being directly displaced by shrimp farms in a twelve-year period (Figure 32). The 1998 longitudinal data point marks the final period of rapid shrimp farm expansion and rapid mangrove deforestation in the Cojimías Estuary. This may be due to a lack of remaining forest to clear as opposed to reflecting a change in practices.

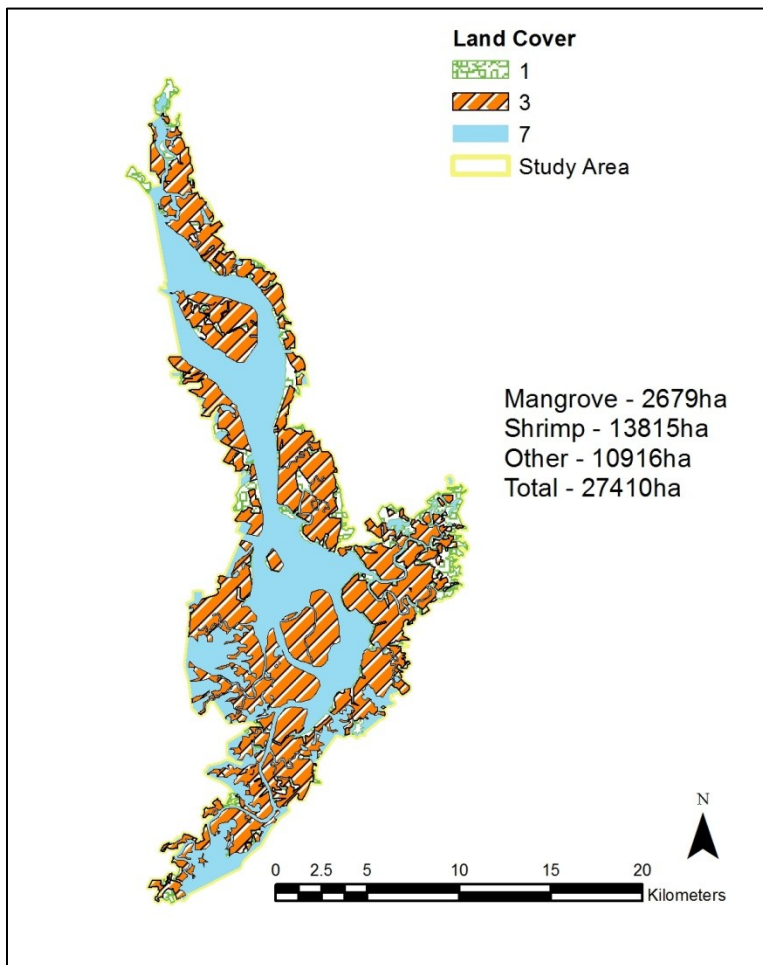
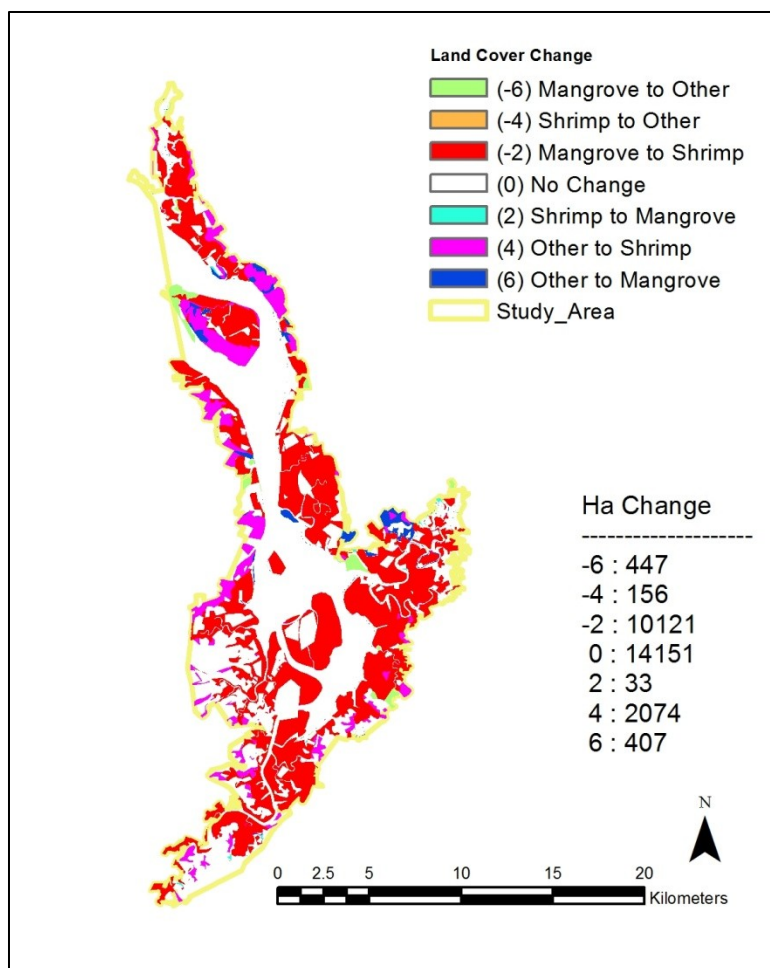


Figure 31. Cojimías Estuary Land Use, 1998.



*Figure 32.* Cojimies Estuary Land Use Change from 1986 to 1998. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the lower right indicate the magnitude of the land use change in hectares.

The period between 1998 and 2006 in Cojimies Estuary is characterized by limited mangrove reforestation and limited declines in shrimp farming. Mangrove increases from 2,679 ha in 1998, to 4,579 ha in 2006 (Figure 33). This represents a 70 percent increase from the low mangrove level in 1998. Despite this recovery mangrove remains at only 32 percent of its base level. Much of the mangrove regrowth appears on the eastern interior edge of the estuary. Shrimp farms declined by 1,597 ha during this period, their only period of decline. This indicates that shrimp farms are being classified

as mangrove which in-turn indicates anthropogenic activities are responsible for the regrowth. Despite the small decrease in shrimp farming, it should be noted that shrimp farms still cover more of the estuary than any other land cover but no longer constitute more than 50 percent of the estuary.

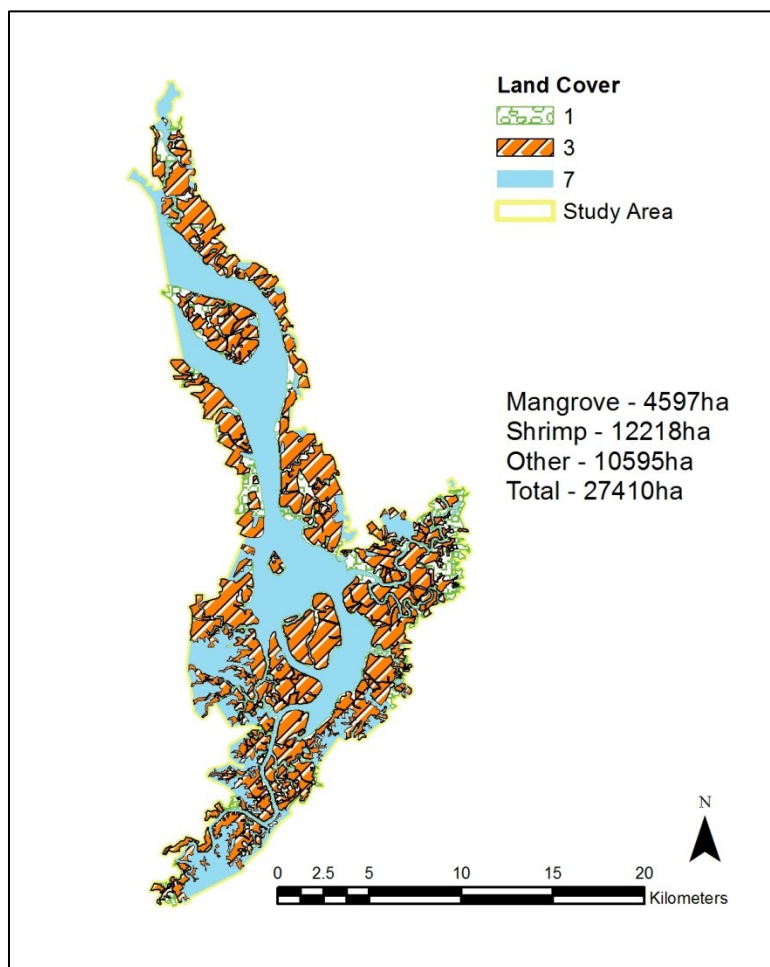
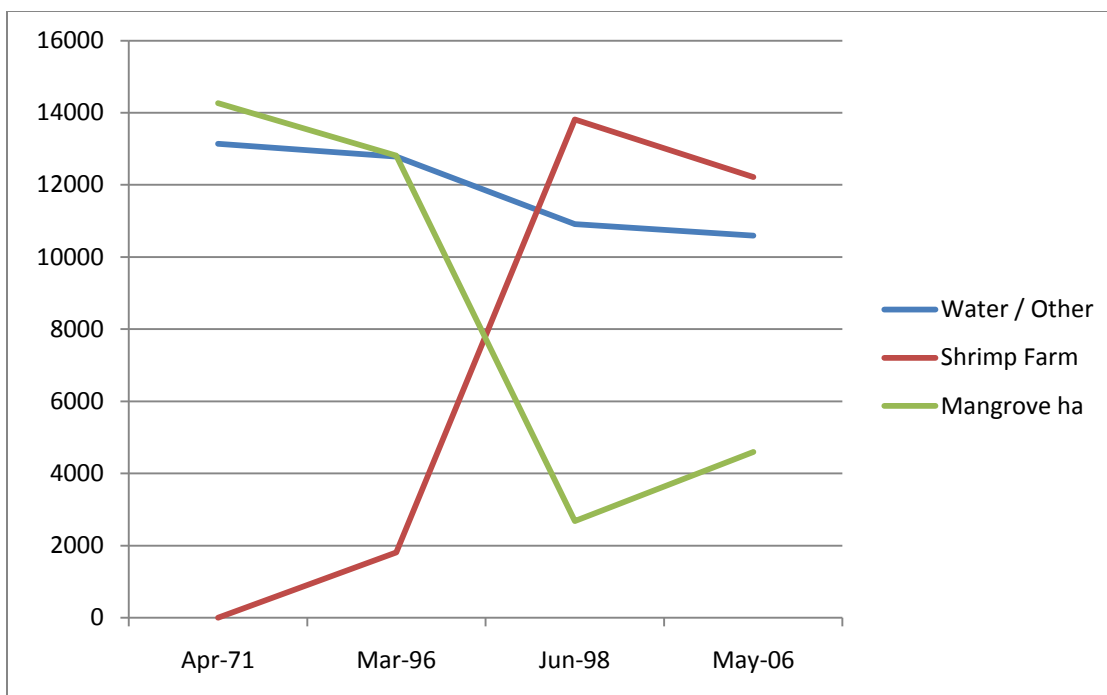


Figure 33. Cojimies Estuary Land Use, 2006.

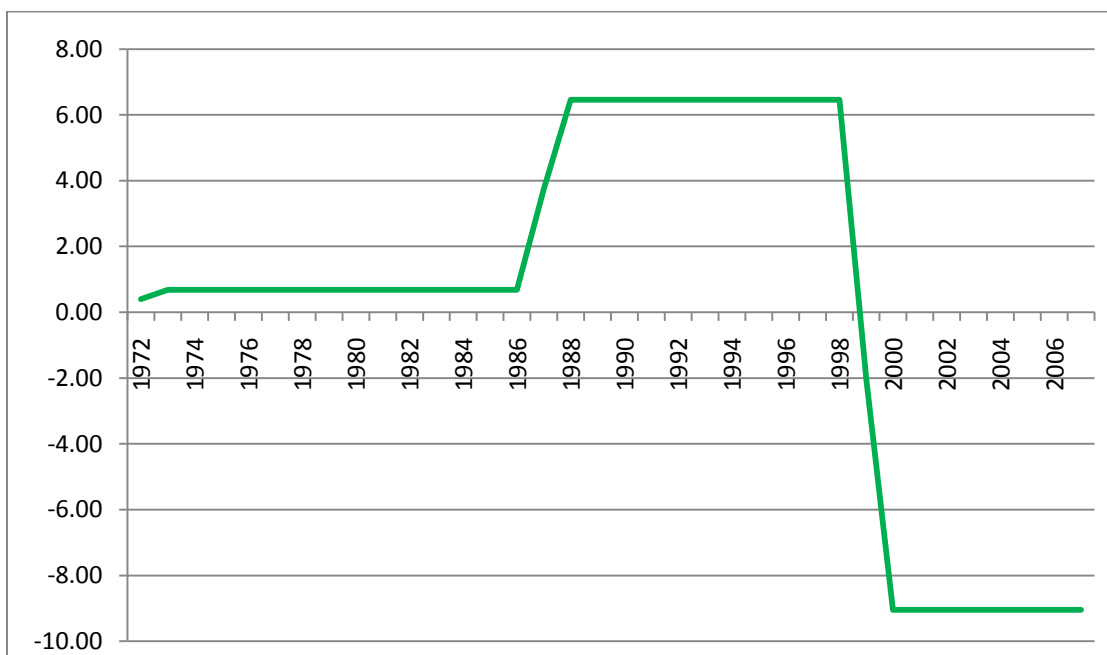
In summary, within the Cojimies Estuary shrimp farms expand from nothing in 1971 to 13,815 ha by 1998. Between 1998 and 2006, shrimp farms decrease slightly from 13,815 ha to 11,218 ha. As of 1998, shrimp farms cover more of the estuary than mangrove, surface water, and all other land cover combined. By 2006, the shrimp farm percentage land cover decreases to slightly below 50 percent due to the conversion of

some shrimp farms to other uses. The period from 1986 to 1998 is characterized by rapid shrimp farm expansion with almost all shrimp farm expansion occurring at the expense of mangrove forests. After 1998, shrimp farm acreage begins to decrease. The early period of shrimp farm expansion in Cojimíes does not appear to have originated from the terrestrial edge of the estuary, as was the pattern in Chone. This may be in part due to almost all shrimp farms appearing in a single twelve-year window and replacing almost all of the entire mangrove forest within the estuary.

Mangrove deforestation has a direct inverse relationship to shrimp farm expansion in the estuary (Figure 34). Mangrove forests in the Cojimíes Estuary decrease from 14,269 ha in 1971 to 4,597 ha in 2006. The 2006 mangrove level actually represents a slight recovery from the 1998 low level of 1,679 ha of mangrove. Cojimíes deforestation levels represent an 81 percent base level mangrove loss at the 1998 survey point, and a 68 percent base level mangrove loss at the 2006 survey point. The period from 1986 to 1998 was the period of rapid mangrove deforestation with annual deforestation as high as 6.46 percent (Figure 35). The period after 1998 is characterized by a substantial recovery of mangrove forests within the estuary with reforestation rates of 9 percent annually, although again this reforestation is starting from a very low level. Considering the time required for a mangrove forest to reach maturity, another land cover survey will need to be conducted between 2015 and 2020 to establish if mangroves in these estuaries are truly recovering.

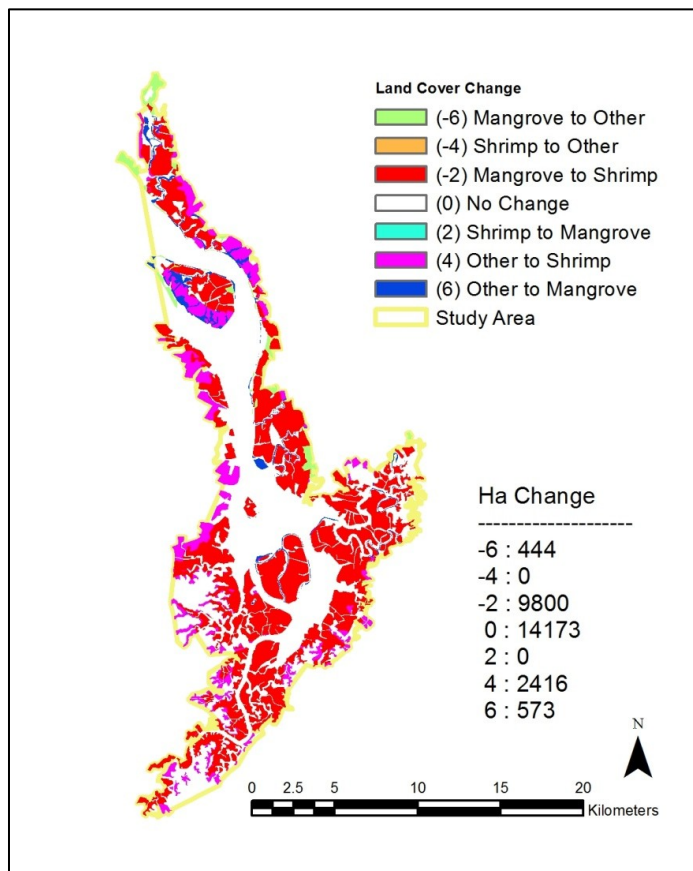


*Figure 34.* Cojimies Estuary Land Cover Change from 1971 to 2006. Land cover change between longitudinal data points assumes a linear interpolation. The y-axis is hectares.



*Figure 35.* Cojimies Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006. Mangrove loss between longitudinal data points assumes a linear interpolation. The y-axis is percentage deforestation year-over-year.

Of the 11,218 ha of shrimp farms in Cojimíes Estuary by 2006, 9,800 ha of them are located on land delineated as base level mangrove forest (Figure 36). This equates to 80 percent direct displacement of mangrove forest by shrimp farms over the analysis period. As with Chone Estuary, Cojimíes Estuary does not follow the worldwide-ascribed pattern of only 10 percent of mangrove deforestation resulting from shrimp aquaculture activity (Menasveta 1997; Boyd and Clay 1998; Diana 2009). Indeed, almost all of the earliest farms within the estuary appear to have located on former mangrove forests and shrimp farms appear to have favored locating in mangrove forests throughout the study period.



*Figure 36.* Cojimíes Estuary Land Use Change from 1971 to 2006. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the lower right indicate the magnitude of the land use change in hectares.



## Cojimíes Estuary Food Security and Livelihood Implications

The traditional mangrove economy is extinct in Cojimíes Estuary. This observation appears most true in the southern interior portion of the bay where shrimp farms are most dominant. One respondent noted that at the mouth of the estuary near the village of Cojimíes, traditional fishermen still exploit the offshore waters but not estuary waters. During my limited time in this area, the small fishing communities around Cojimíes Estuary appear to be the most impoverished of all study sites and the quality of the estuary livelihoods available is likely the driving force behind the poverty. Cojimíes Estuary once had a thriving fishing and *Concha*<sup>11</sup> industry that supported the local population. The extreme poverty today is due to the shrimp farm driven decline of the livelihood and food security options provided by the mangrove forest (Herrera and Elao 2007; Crawford 2010). As of 1998, Cojimíes only had 19 percent of its former mangrove remaining and shrimp farms covered in excess of five times more area than mangrove. This is the most extreme of shrimp to mangrove relationship in all study sites over all time-periods. Fisherfolk in the southern portion of the estuary that are not employed on the this farms appear to make a living by combining what limited resources the estuary has to offer combined with animal husbandry and farming of small agricultural plots.

The degradation Cojimíes Estuary is blamed almost entirely on shrimp farming by local residents (Collins 2010) although other factors appear to have played a role in Cojimíes. Cojimíes Estuary is surrounded by agricultural land and many of the rivers entering the estuary are now dry most of the year according with the water diverted for agricultural use. Additionally, unlike the eco-city approach of Chone, or the tourism

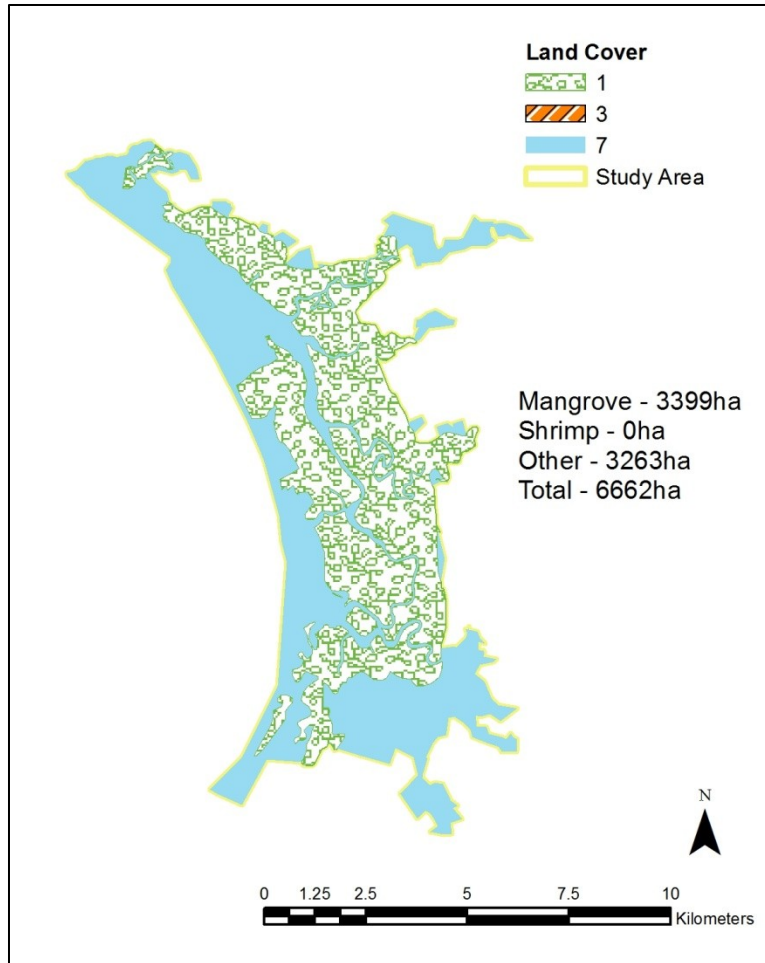
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<sup>11</sup> Concha does not refer to conch. They are a black clam. *Anadara tuberculosa*.

present in Muisné, the residents of Cojimíes appear to have no other livelihood options to replace the traditional estuary livelihoods that have been lost. Finally, it appears that agricultural run-off may be an important factor limiting the productivity of the estuary, although this may be partially due to the loss of the filtration and sediment capture function formally provided by the mangrove forest. The pathways to livelihood loss mentioned by senior fisherman in the region are similar to those mentioned in the Chone Estuary. They point to a lack of early resistance being due to a lack of knowledge, the particular destruction of shellfish in the estuary, and the use of poison to clear the farms.

#### Muisné Estuary Land Use Change

The Muisné Estuary study area is 6,662 ha in size. In 1971, the estuary was comprised of 3,399 ha of mangrove forest and 3,263 ha of other land cover including surface water, saltpans, and mud flats (Figure 37). This base level land cover was derived from topographic maps themselves derived from aerial photography flown in April 1971. No interview respondents or field observations led me to believe that the 1971 mangrove level is not representative of historic mangrove cover for this estuary.



*Figure 37.* Muisné Estuary Base Level Mangrove Cover, 1971.

In the Muisné Estuary, the period between 1971 and 1986 is characterized by the arrival of shrimp aquaculture and limited amounts mangrove deforestation (Figure 38). The first shrimp farms in Muisné Estuary arrived between 1971 and 1986 and appear to favor the terrestrial edge of the estuary. Of the 180 ha of mangrove deforestation that occurred during this fifteen-year period, only 74 ha was direct displacement of mangrove by the newly arrived shrimp farms. Aside from the addition of these relatively few shrimp farms, and the loss of small amounts of mangroves in the estuary, land cover for the Muisné Estuary remains essentially constant between 1971 and 1986. Establishing an actual deforestation rate for the first period of shrimp farm expansion is difficult as the

window between the first and second land use survey is approximately fifteen years and few farms appear.

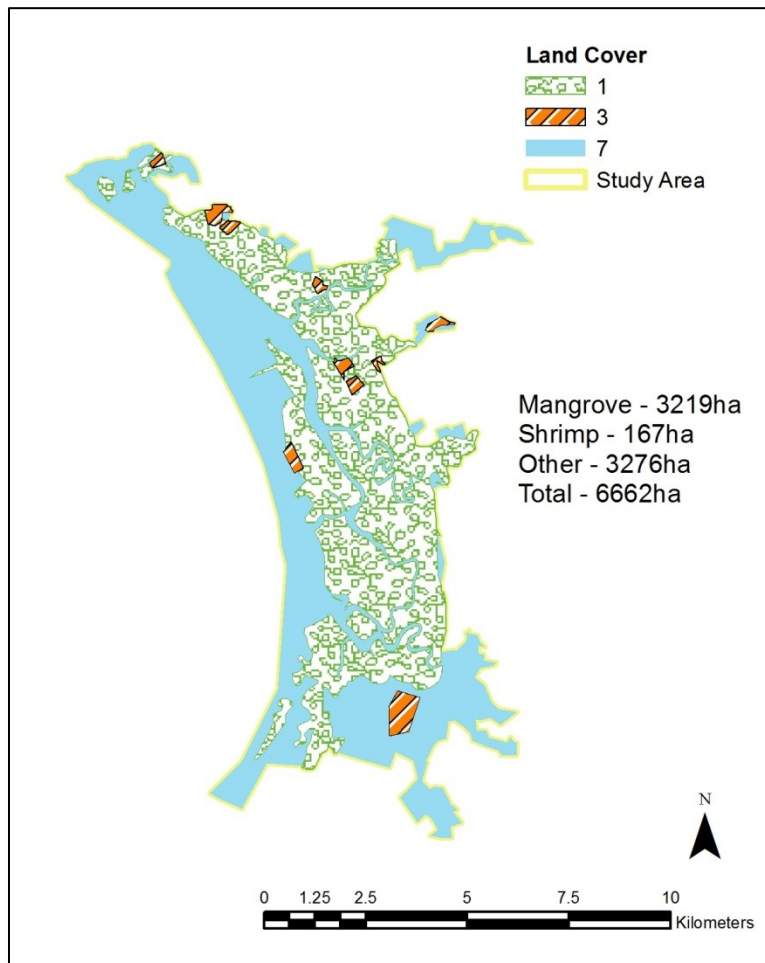


Figure 38. Muisné Estuary Land Use, 1986.

In the Muisné Estuary, the period between 1986 and 1998 is characterized by rapid shrimp farm expansion, high rates of mangrove deforestation, and high rates of direct displacement of mangrove by shrimp farms. During this twelve-year period, mangrove cover decreases by 1,219 ha, from a 1986 level of 3,219 ha to a 1998 level of 1,000 ha (Figure 39). Hence, by 1998 only 29 percent of the base level mangrove forest remains in the Muisné Estuary. In the twelve years from 1986 to 1998, a remarkable 69 percent of the remaining mangrove in Muisné is cleared. During this same period,

shrimp aquaculture increases nineteen fold from a nominal 1986 level of 167 ha, to a 1998 level of 3,277 ha. Indeed, by 1998 shrimp aquaculture is the majority estuary land cover in the estuary surpassing mangrove and all other land use classifications combined. During this period, 2,127 ha of mangrove forest loss is direct displacement by shrimp aquaculture. This equates to 69 percent of total mangrove being displaced by shrimp farms in a twelve-year period (Figure 40). The 1998 longitudinal data point marks the final period of rapid shrimp farm expansion and rapid mangrove deforestation in Muisné Estuary. By 1998, shrimp farms occupy more surface area of the estuary than all other uses of the estuary.

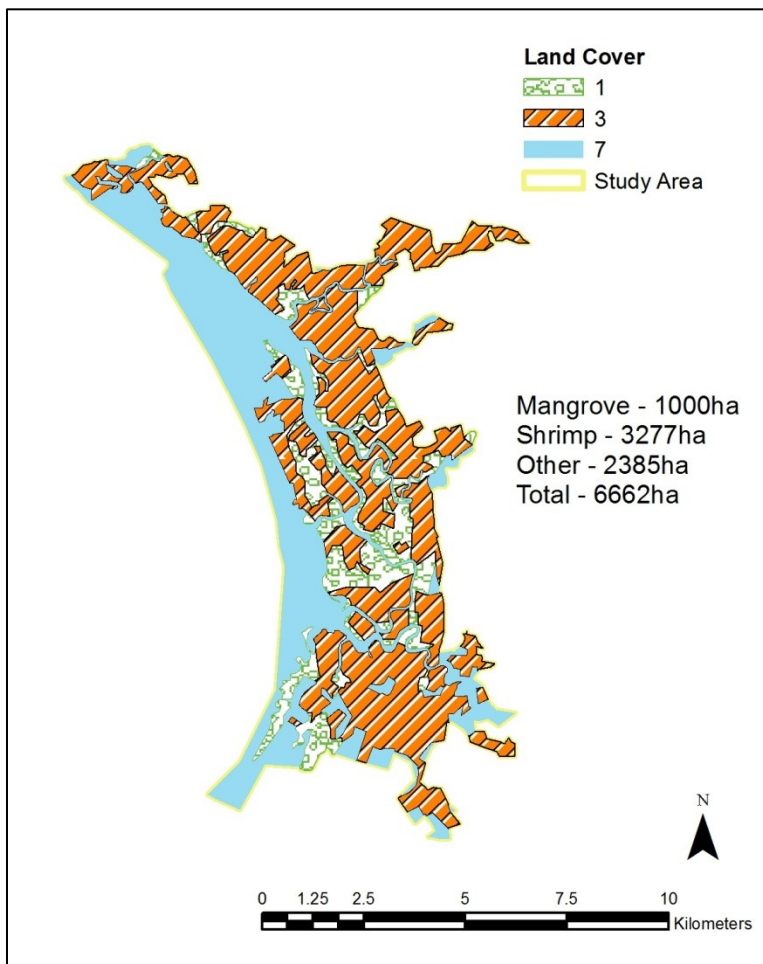
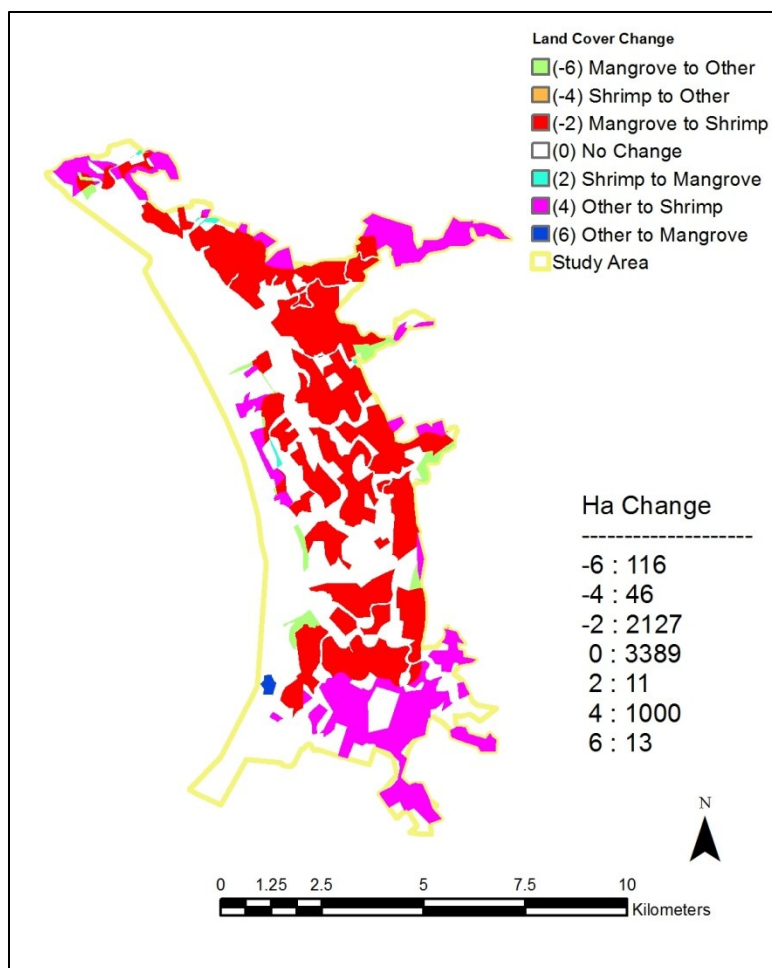
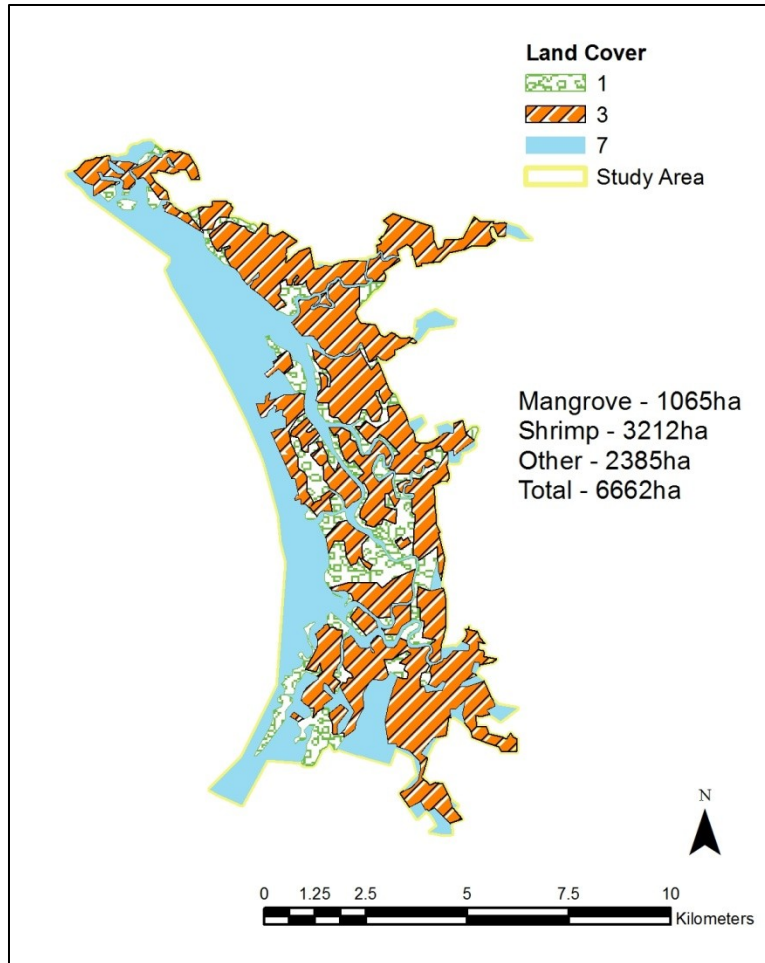


Figure 39. Muisné Estuary Land Use, 1998.



*Figure 40.* Muisné Estuary Land Use Change from 1986 to 1998. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the lower right indicate the magnitude of the land use change in hectares.

The period between 1998 and 2005 in Muisné Estuary is typified by land use equilibrium. Mangrove increases nominally from 1,000 ha in 1998 to 1,065 ha in 2006 (Figure 41). This represents a 7 percent increase from the longitudinal low mangrove level of 1998. Despite this slight recovery mangrove remains at only 31 percent of its base level. Shrimp farms declined slightly during this period by 55 ha, but remain the dominant land use in the estuary.



*Figure 41.* Muisné Estuary Land Use, 2005.

Mangrove forest cover has an almost inverse relationship to shrimp farms in the Muisné Estuary (Figure 42). Mangrove forests decrease from 3,399 ha in 1971 to 1,065 ha by 2005, whereas shrimp farms increase from nothing to 3,212 ha during the same period. The current mangrove level actually represents a recovery from the 1998 low level of 1,000 ha of mangrove cover. The 1998 mangrove level represents a 71 percent base level mangrove loss from the initial pre-aquaculture longitudinal data point. Within the Muisné Estuary the period from 1986 to 1998 was the period of most rapid mangrove deforestation with annual deforestation rates as high as 5.6 percent (Figure 43). The period after 1998 is characterized by stabilization of both mangrove forests and shrimp

farms. Once again, another land use change survey is required between 2015 and 2020 to establish that mangrove forest is recovering.

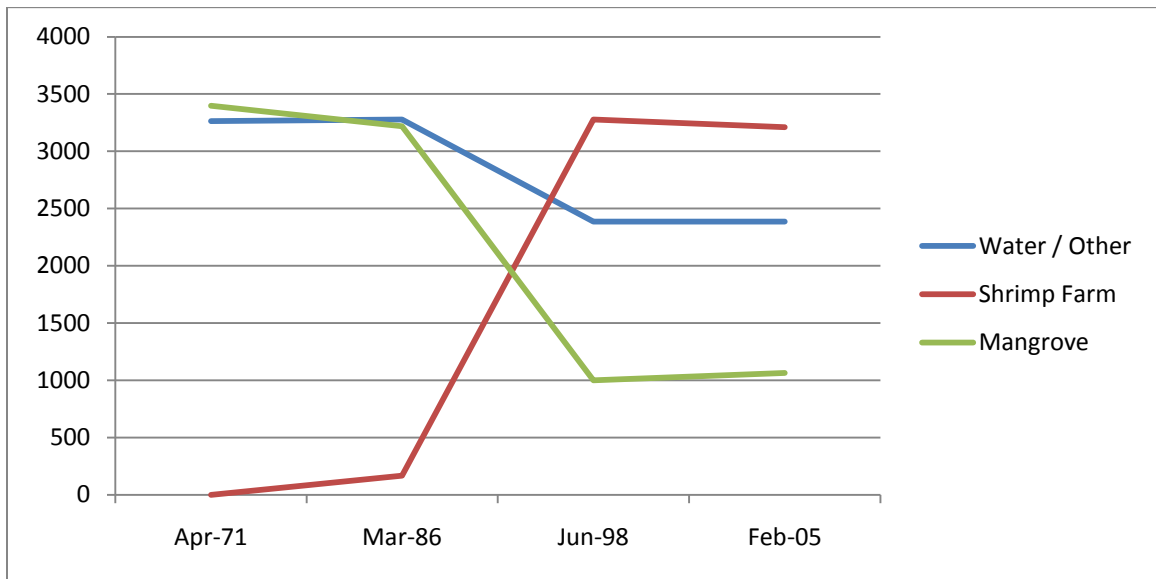


Figure 42. Muisné Estuary Land Cover Change from 1971 to 2005. Land cover change between longitudinal data points assumes a linear interpolation. The y-axis is hectares.

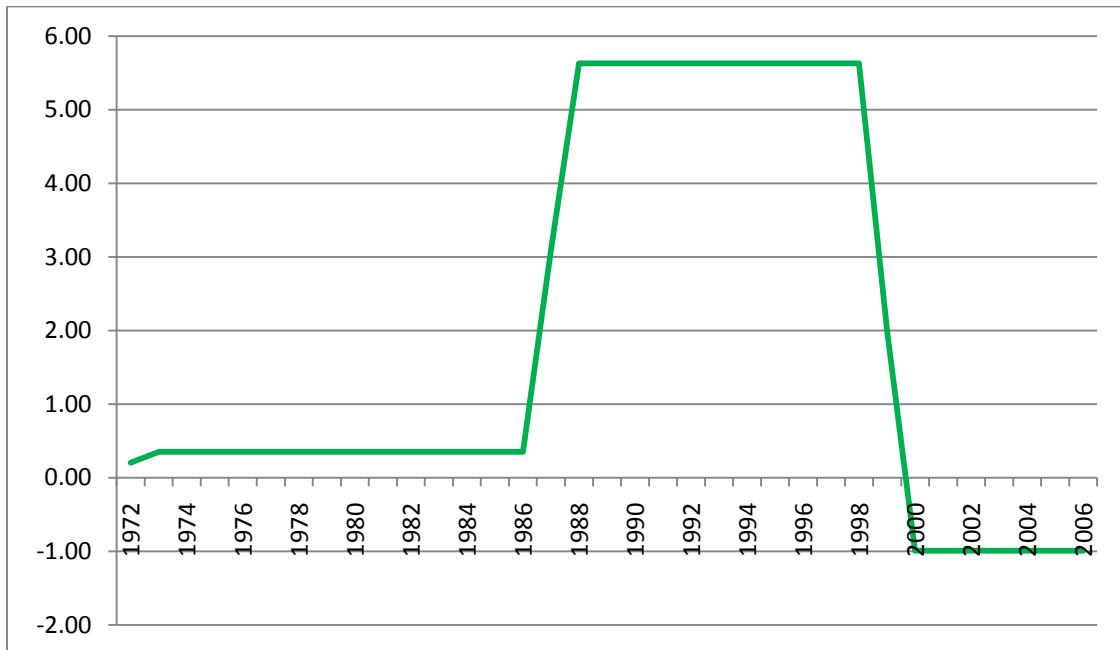
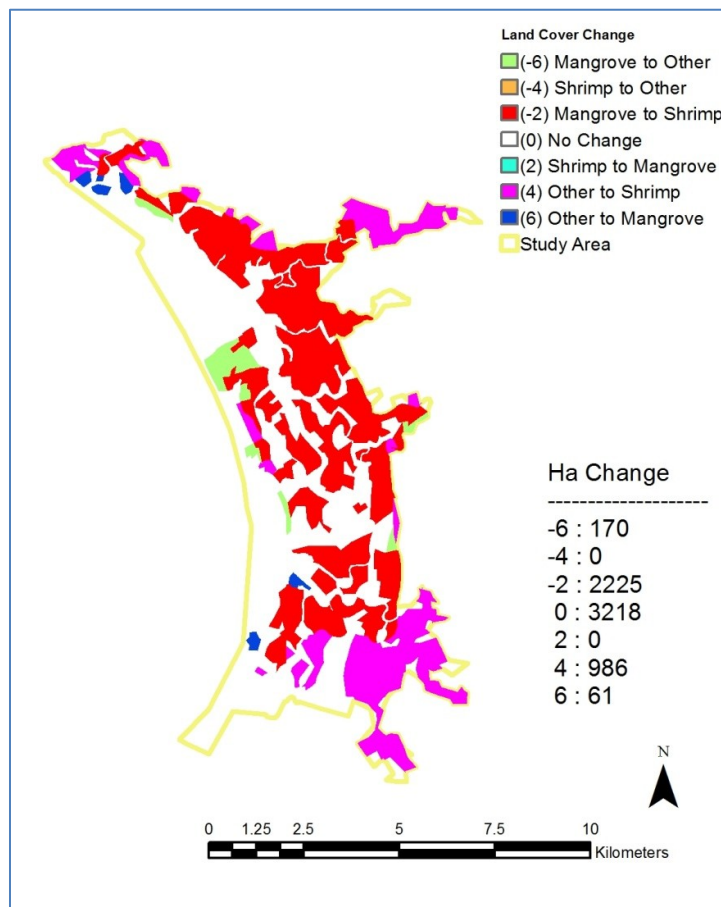


Figure 43. Muisné Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006. Mangrove loss between longitudinal data points assumes a linear interpolation. The y-axis is percentage deforestation year-over-year.



Of the 3,212 ha of shrimp farms in the Muisné Estuary by 2005, 1,225 ha of them exist on land delineated as base level mangrove forest (Figure 44). This equates to 95 percent direct displacement of mangrove forest with shrimp farms over the analysis period. As with the Chone and Cojimías estuaries, Muisné Estuary does not follow the worldwide-ascribed pattern of only 10 percent of mangrove deforestation resulting from shrimp aquaculture activity (Menasveta 1997; Boyd and Clay 1998; Diana 2009). Indeed the majority of farms within the estuary appear to have selected former mangrove forest as their preferred environment.



*Figure 44.* Muisné Estuary Land Use Change from 1971 to 2005. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the lower right indicate the magnitude of the land use change in hectares.

### Muisné Estuary Food Security and Livelihood Implications

In Muisné Estuary, the shrimp farms economy appears to have reduced local livelihoods and food security but the impacts were not as severe as in other shrimp regions. Of 215 households surveyed, 28 percent still reported having a household member engaged in the mangrove economy (Collins 2010). This is remarkable considering mangrove forests are only one-third of their original land cover level. It is still far below the 86 percent level of Cayapas-Mataje with a preserved mangrove forest and similar socio-economic characteristics. In comparison, the shrimp farm economy in Muisné Estuary, which now covers the majority of the estuary, only employs 6 percent of those surveyed<sup>12</sup>. This reflects the fact that shrimp aquaculture is not an employee intensive industry but instead requires a large input of initial capital and ongoing technical costs but actually requires very little labor once operational (Asian Development Bank-INFOFISH 1991; Rajitha et al. 2007). As opposed to Cayapas-Mataje, Chone, and Puná Island, traditional fisherfolk do appear to work in the shrimp farms and even own some of the farms. Although limited, in Muisné Estuary the promise of employment appears somewhat realized. Despite this, one respondent farm worker described employment as intermittent and low paying.

Muisné appears to have adapted to the degradation of the mangrove economy. The town has reinvented itself as a regional tourist center and appears successful in this regard. In addition to local residents obtaining limited livelihoods from the mangrove economy that persists, the area has a small but robust commercial center based on seasonal tourism. Despite this, traditional fishing families that still engage in traditional

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<sup>12</sup> Twenty-five out of 416 household members define themselves as having some employment in the shrimp farm industry.

livelihood activities report problems with access to the estuary and the depletion of mangrove-related resources and cite mangrove deforestation as the major cause of hardship in the region. Indeed, the lack of access to the estuary appears to affect local women and the poorest members of the community in a disproportion manner (Collins 2010). Traditional *Concha Negra* collectors and artisanal fisherman require land access to the estuary to obtain their catch. On the other hand, wealthier fishermen with boats are less severely impacted as direct access to the estuary is not required. As in Cojimíes and Chone, it appears that communities located along the interior portions of the estuaries are most adversely affected by the conversion of mangrove into shrimp farms. This may be due in part to their entire livelihood depending on the mangrove economy as opposed to the coastal residents who also exploit coastal waters. These non-Coastal populations have also benefited less from activities such as tourism that have replaced the mangrove economy nearer the coast. As in Chone, some respondents blamed shrimp farming for initiating the out-migration of the young due to a lack of employment or mangrove livelihood opportunities.

Muisné exhibited other environmental ramifications of the mangrove to shrimp farm conversion not witnessed elsewhere. The ocean-side portion of the Muisné Estuary is exposed to direct wave impacts as opposed to other study sites that are almost protected from direct wave action in sheltered estuaries. In Muisné, numerous coastal shrimp farms have been breached by storm events. The enclosing dykes are eroded away exposing the farms to wave action and ending shrimp-production in the affected farms. The coastline behind these breached farms also shows signs of rapid erosion. This is confirmed by one respondent in the interviews and is attributed to the loss of mangroves

and their displacement by shrimp farms. Rapid and massive erosion during El-Niño driven storm events is reported on the outer-banks of Muisné as the mitigation affect of a fringe mangrove forest that dissipates wave action and collects sediment has been lost (Federici and Rodolfi 2001). In many areas, this erosion is threatening traditional communities.

Within Muisné, antibiotic use in shrimp farms appeared widespread, validating the assertion of some reports that certain developing world growers are circumnavigating the U.S. and EU ban on imported shrimp treated with antibiotics (Public Citizen's Food Program 2004; Public Citizen's Food Program 2005b; Food and Water Watch 2006). Several shrimp farm workers verified the use of antibiotics during the interview process. *Dispensas* (commercial aquaculture chemists) are located alongside feed stores in Muisné and the treatment process is supported by central government with tax relief given to those who purchase antibiotics for their farms. It is possible that none of the shrimp treated in this manner is exported; this may occur in Muisné as many of the growers appear to be local residents running locally owned and operated shrimp farms as opposed to the larger commercial ventures in the study sites to the south.

Muisné fisherfolk also reported deceitful practices by intermediaries who purchase their shrimp for conglomerates. Intermediaries from the *Sierra* or Guayaquil begin by negotiating a price with the grower. After the grower drains his pond and collects the shrimp, the buyer drops the price and the grower has no power in the transaction as shrimp has a very short life unless rapidly transported onto a processing factory or frozen. It was reported that occasionally the intermediary would cancel the

transaction at the last minute and the shrimp farmer would attempt to sell the shrimp locally at reduced price and under pressure to sell the rapidly spoiling product.

Reforestation efforts are occurring in Muisné under an Ecuadorian NGO named FUNDECOL (Fundación de Defensa Ecológica de Muisné). This is the most high profile of all mangrove reforestation groups encountered in Ecuador with international recognition, a fundraising website, and international volunteers. Although advertising itself as a community organization, FUNDECOL appears more along the line of a U.S. advocate NGO. FUNDECOL work alongside groups such as the Environmental Justice Foundation based in the United States and can often be found referenced in advocacy magazines and journals in the developed world (Environmental Justice Foundation 2003). Interestingly, despite having the most vociferous and well-known reforestation group in Ecuador, Muisné appears to have experienced relatively little reforestation compared to the study sites further south (Figure 43).

The successes of Muisné appear to be the development of an alternate economy based on tourism, limited local ownership and employment on the shrimp farms, and a relatively high proportion of local residents still able to derive a living from the limited remaining mangrove forest. Major challenges are related to erosion, shrimp farm practices, and reforestation exists in the community. Much like Cojimíes and Chone, Muisné also had a clear delineation of those most adversely affected by the mangrove to shrimp farm conversion and those that have managed to avoid the most damaging aspects of the transition. Women, those that inhabit on the interior of the estuary, those without boats, and the poor are the most adversely affected by the transition from mangroves to shrimp farms in Muisné.

### Cayapas-Mataje Estuary Land Use Change

Cayapas-Mataje Estuary is unique among the estuary environments studied. It is as a Ramsar site, national preserve, and is home to the world's tallest mangrove trees. The area of the Cayapas-Mataje Estuary is calculated to be 50,714 ha. During the entire study period, mangrove decreases only slightly from 35,114 ha pre-aquaculture to a low of 31,344 ha in 2008 (Figure 44). Shrimp farms increase from nothing in 1986 to a maximum area of 1,800 ha in 2008, and occupy only 5 percent of the estuary by the end of the study period. One-hundred percent of these few shrimp farms did locate in former mangrove forests. This may be due in part to the lack of a terrestrial environment in this region. Cayapas-Mataje has the lowest rates and lowest percentage of mangrove loss and had the lowest rates and lowest percentage growth in shrimp farms among all estuaries (Figure 45). The relatively shrimp farms that did appear displaced mangrove forest but it was noted during a 2009 field trip to the region that all the shrimp farms in Cayapas-Mataje, aside from the cluster in the south-west portion of the estuary, are abandoned. A community leader and tour guide confirms this fact. Interview respondents indicated that the mangroves in this area are entirely the product of recent regrowth since complete deforestation around 1955. Cayapas-Mataje is unique among Ecuadorian estuaries in that it has maintained almost of its mangrove forest during the analysis period and although shrimp farms did appear, they remained low as a percentage of total area and in number.

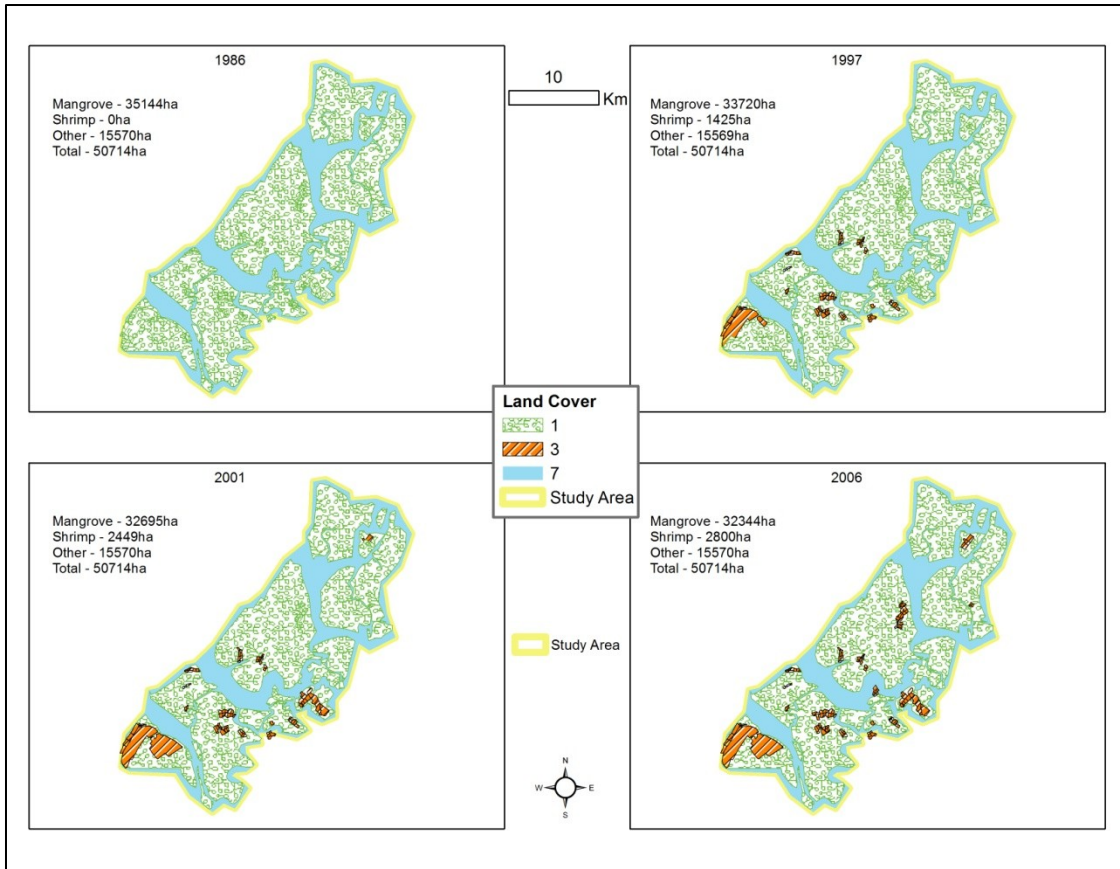


Figure 45. Cayapas-Mataje Estuary Land Use, 1986 to 2006.

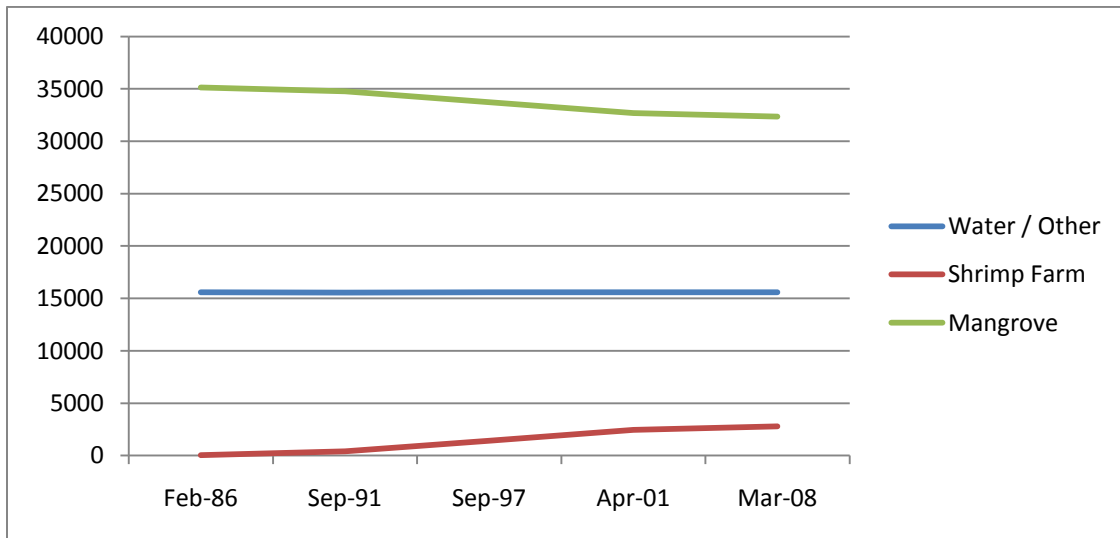


Figure 46. Cayapas-Mataje Estuary Land Cover Change from 1986 to 2008. Land cover change between longitudinal data points assumes a linear interpolation. The y-axis is hectares.

### Cayapas-Mataje Estuary Food Security and Livelihood Implications

Traditional livelihood opportunities and food security in Cayapas-Mataje appear to remain unaltered during the period of shrimp aquaculture expansion in Ecuador. This is a result of, and potentially a cause of, the relative lack of shrimp farms that have located in the estuary (Figure 46). Within Cayapas-Mataje, the traditional mangrove economy still dominates, according to all respondents, and mangrove is still the predominant land cover (Figure 46). Unlike the fisherfolk of other estuaries, fisherfolk in the Cayapas-Mataje region are reported to be able to provide for their families entirely on wild catch from the mangroves (Veatch 1996; Ocampo-Thomason 2006). As of 2004, it is estimated that only 0.6 percent of households have a resident who works on a shrimp farm, whereas 87 percent of households are reliant on the mangrove ecosystem for their primary employment and income (Ocampo-Thomason 2006). Fishing and collection of *Concha Negra* are the most important mangrove based livelihoods and food security options with 67.7 percent of households reliant either one or both of these activities (Ocampo-Thomason 2006). Interview respondents stated that other important uses of the mangrove include utilizing wood for construction and charcoal, and utilizing the tree products for use in traditional medicinal remedies as a coagulant.

The land use change analysis indicates that mangrove deforestation is more limited in Cayapas-Mataje Estuary than any other location in Ecuador. Despite this, several respondents blame mangrove deforestation and the arrival of shrimp farms for a decrease in estuarine biodiversity and commercially important seafood species and the majority of residents of the region oppose shrimp farms (Veatch 1996). Numerous respondents stated that residents of this region have successfully unified against shrimp



farms and have preserved 53,000 ha of estuary with meaningful and enforced national legislation. Respondents also reported that 14,000 ha (18,000 is the number from the legal decree) of mangrove forest is preserved as part of this legislation by the central government as a direct response to the threat of shrimp farming. Ecuadorian law validates these statements. This Cayapas-Mataje mangrove and estuary environment preservation has legal standing as the Cayapas ñ Mataje Ecological Reserve, a region created in 1996 making the state the legal owner of the estuary with the Ministry of the Environment managing the resource (Ocampo-Thomason 2006).<sup>13</sup>

As early as 1995, one-hundred percent of *concehros* and 82 percent of fisherfolk in this region described shrimp farming as bad for the community (Veatch 1996). All respondents in Cayapas-Mataje mentioned local resistance against shrimp farming and several noted that local syndicates and community groups have managed to close down the illegal shrimp farms operating in the area. These views compliment my field observations and the land use analysis that indicate all remaining shrimp ponds in Cayapas-Mataje reserve are abandoned.

Not only does Cayapas-Mataje have meaningful, enforced, and delineated protection areas, respondents in the area indicated that catch amounts are restricted seasonally and daily. Fisherman mentioned that licenses are required to fish in the estuary and a local fisheries center provides training and education to fisherfolk as well as monitoring. As of 2009, San Lorenzo, the major town in the region, had three active fishing inspectors and an enforcement office. Such strict catch regulations were not seen in other locations.

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<sup>13</sup> Resolution 001 DE 052-A-DE

Cayapas-Mataje has an informal and adhered to gender code regarding exploitation of traditional estuarine goods and services. The men of this region predominantly fish or shrimp, whereas the *Concha Negra* catch is reserved for female residents. The *Concha* harvesters have formed collectives that protect the *Concha Negra* beyond the imposed legal limits imposed by the government. The *Concha* harvesters and other traditional estuary users have organized and formed a regional group called Federación de Artesanos Recolectores de Productos Bioacuaticos del Manglar (FEDARPOM). FEDARPOM includes fisherfolk and agriculturalists in an attempt to conserve livelihood resources inside in and around Cayapas-Mataje (Ocampo-Thomason 2006). Conflict between FEDARPOM and shrimp farmers occurs but unlike other estuaries the conservationists appear to have mostly prevailed. For example, it is reported that the *concehros* have confronted shrimp farmers who try to block their access to *Concha* in the estuary. *Concehros* maintain that even if the shrimp farmers legally purchased land for a shrimp farm it is terrestrial land they purchased and does not give the landowner the rights to the mangrove or *Concha* alongside their land, nor does it give the landowner the right to block the *Concha* harvesters' access to this resource (Veach 1996). According to respondents and observation, the *Concha Negra* captured by the women is mostly exported out of the region to the interior of Ecuador and Guayaquil.

During the participatory observation phase of research, several respondents noted that two separate community activities existed for residents to express their support of the mangroves (Figure 47-1). Indeed, in this area the mangrove economy appears close to a form of worship. An example of this is the town square monument. In most local towns, the monument depicts a religious figure or prominent historic local resident. In the town

square of the regional center of San Lorenzo the town square monument depicts a fisherfolk family with the husband catching fish, the wife collecting *Concha Negra*, with the children helping in the activities (Figure 47-4). Indeed, many of the homes have ornate murals that depict the mangrove economy in a reverential manner (Figure 47-2, Figure 47-3). One respondent also mentioned that mangroves provide a unique form of recreation not found elsewhere, with local residents travelling into the mangrove forest by boat to partake in dance parties and other recreational activities.



Figure 47. Mangrove Cultural Symbols In and Around Cayapas-Mataje. Picture one, Day of the Living Mangrove: Community Struggle and Progress. Picture two a household mural depicting a fishing catch with mangrove in the background. Pictures three and four, a family harvesting seafood from the mangrove forest. Picture 4. A family partaking in mangrove fishing and *Concha Negra* collection.

Numerous reasons likely exist for the relative lack of shrimp aquaculture and the preservation of mangroves in Cayapas-Mataje. Respondents generally referred to

community organizations and their active resistance as the primary force behind the preservation of the mangrove forest. This community response appears to be motivated by two forces related to an earlier period of deforestation and the date of first arrival of aquaculture in the region. Firstly, almost all respondents mentioned learning about the economic importance of mangroves from an earlier period of mangrove deforestation that damaged local livelihoods and depleted wild estuarine fisheries. This is recorded in the literature as a government-sponsored industrial program to exploit the mangroves of Cayapas-Mataje for tannin production from the mid-1950s until about 1968 (Labastida 1995). The deforestation continued until a collapse in worldwide tannin prices (Snedaker 1986) and a switch by timber companies to other environments such as cloud forests and rainforests for tannin (Ocampo-Thomason 2006). Secondly, respondents also pointed to knowledge of the destruction shrimp farms had caused further south as a reason for their collective response opposing the shrimp farms. The land use analysis supports these statements. Aquaculture arrived later in Cayapas-Mataje than any other estuary (Figure 45). Local residents indicate they knew of the environmental degradation shrimp farms had already caused in estuaries such as Chone, Cojimíes, and particularly in Muisné and responded accordingly.

The environmental conditions of Cayapas-Mataje are highly suited to commercial shrimp farming and should likely dictate an early arrival of shrimp aquaculture. Indeed, the first reliable captures of pregnant female *P. vannamei* occurred around Cayapas-Mataje, Esmeraldas and were then transported to the first Ecuadorian hatchery near Manta (Cheshire 2005). The reasons for the late arrival of shrimp farms into Cayapas-Mataje is therefore likely related to non-environmental factors such as the physical

infrastructure of Cayapas-Mataje, the geopolitical situation of Cayapas-Mataje, and the cultural traditions of Cayapas-Mataje.

The primary factor hindering shrimp farm expansion in Cayapas-Mataje is likely the historic isolation of the region and lack of reliable paved roads connecting Cayapas-Mataje to the rest of Esmeraldas. Indeed, until the 1990s, only an unreliable train or unimproved road connected Cayapas-Mataje to the highlands and no paved roads ran south into Esmeraldas until the mid-2000s. This resulted in difficulty moving heavy equipment into the area to build farms and even more difficulty exporting bulk quantities of iced or fresh shrimp out of the region. As late as 2009, no roads connected the majority of the mangrove forest to the existing regional road network and the primary form of transportation of goods and people in Cayapas-Mataje are dugout canoes. Unlike Cayapas-Mataje, all the estuaries further south that are all generally well connected to the Ecuadorian commercial centers and ports of Esmeraldas, Manta, Guayaquil, or Machala via a paved road network.

An additional geographic issue that may have hindered development of shrimp farms was the investment climate of the region between 1970 and 2000. For much of the analysis period, Cayapas-Mataje was located in a geopolitical hotspot on the Colombian / Ecuadorian border. Columbian drug-traffickers and FARC rebels had free access to and from Cayapas-Mataje with Ecuador effectively maintaining its border on the highland side of the town. Kidnappings and skirmishes were commonplace. This likely restricted equipment and shrimp movement, and more importantly limited inputs of aid and FDI that financed aquaculture during the analysis period. Finally, as mentioned, the cultural traditions of the Afro-Ecuadorian population of Cayapas-Mataje appear to be more

interwoven with the mangrove forest than the non-Afro populations further south.

Indeed, the closest parallel to the lifestyle found in Cayapas-Mataje in Muisné, which has the next highest percentage of Afro-Ecuadorians.

The future of the traditional mangrove economy appears relatively secure in Cayapas-Mataje Estuary. The combination of community organizations resisting the shrimp farms, government support, enforced estuary land use regulations with a focus on preservation, and restrictions on fishing catches combined with the relatively few shrimp farms are likely to continue to restrict shrimp farm advancement. Ocampo-Thomason (2006), reports the potentially damaging practice of fisherman catching pregnant females and Postlarvae to sell to hatcheries and nurseries outside of Cayapas-Mataje Estuary is occurring. This potentially destructive practice has been opposed by fisherfolk (Veach 1996), this indicates that local fisherfolk fully understand the shrimp lifecycle and their reliance on the mangrove forest beyond the physical location of shrimp farms. In 2009, interviews did not indicate that the Postlarvae extraction practice is not currently occurring; this is likely due to the abandonment of shrimp farms in Cayapas-Mataje in the last three years and the reliance on hatcheries in regions outside Cayapas-Mataje.

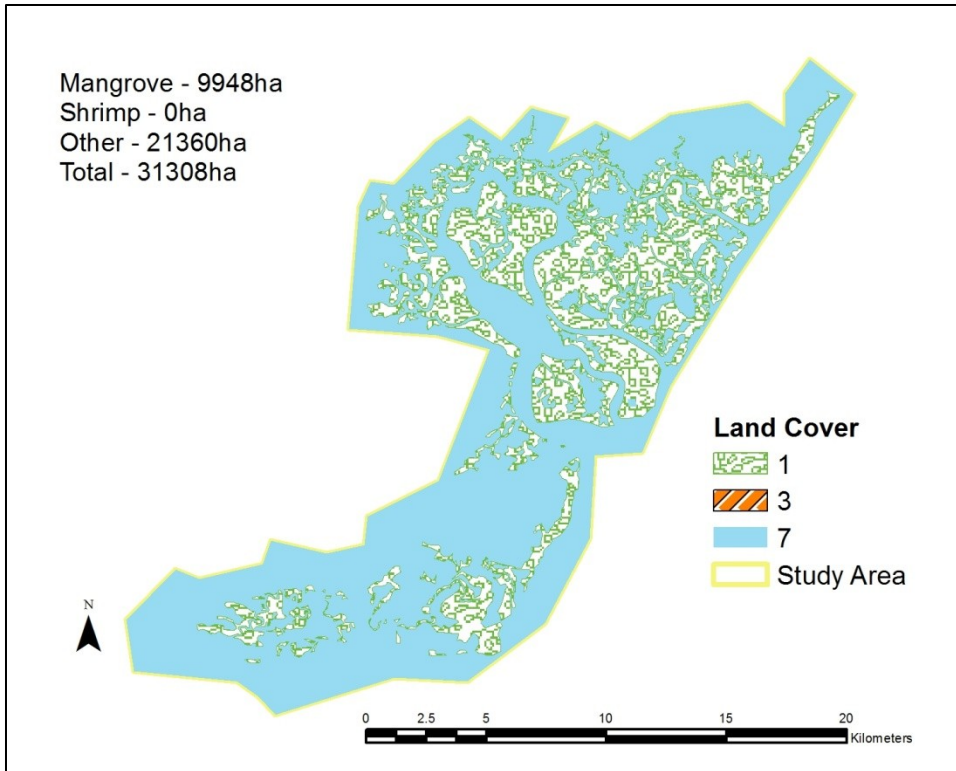
Challenges to the mangrove economy are likely to arise. The transportation hindrance and the geopolitical hindrance to aquaculture in Cayapas-Mataje are both essentially resolved. The region is now well connected to the road-network and the FARC are in substantial retreat and no longer control border areas of the Colombian border. These positive developments will likely present a challenge to the preservation of the mangrove driven lifestyle of Cayapas-Mataje. Northern Esmeraldas is now open to foreign aid and FDI, and a target for aid groups due to the region's period of isolation.

Cayapas-Mataje is viewed as somewhere that will benefit from outside investment with USAID citing aquaculture as a possible way forward in this region (United States Agency for International Development 2003).

Another challenge in Cayapas-Mataje is the influx of itinerant unregulated fisherfolk into the area. This in-migration is likely occurring as Cayapas-Mataje remains one of the few, and maybe only large estuary in Ecuador that traditional fisherfolk can exploit in an artisanal manner. Local fisherfolk blame outsiders for placing stress on the resources of the estuary and not following the regulated or community established catch rules. Several local respondents, along with Ocampo-Thomason (2006) mention the problem of itinerant fisherman working the estuary and not respecting the rules and regulations established by the community. Locals view this as a major threat to the *Concha* industry and wild fish stocks. Many of these itinerant fisherfolk arrive from Columbia and others from the shrimp farmed estuaries of southern Ecuador that no longer can provide a catch driven artisanal lifestyle due to the destruction caused by aquaculture.

#### Rio Hondo Estuary Land Use Change

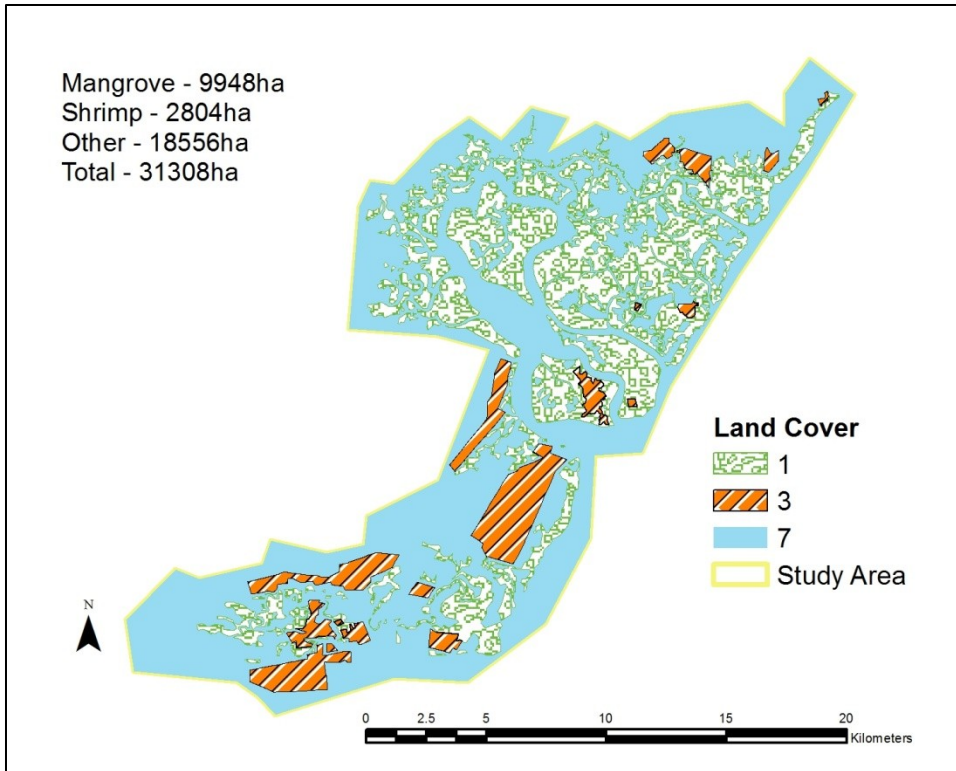
The Rio Hondo Estuary study area is 31,308 ha in size. In 1973, the estuary was comprised of 9,948 ha of mangrove forest and 21,360 ha of other land cover including surface water, saltpans, and mud flats (Figure 48). This base level land cover was landsat 1 collected in April 1973. This is the only estuary that utilizes landsat 1 as the base level and hence the base level mangrove delineation may not be as accurate as other areas due to the limited spatial and spectral resolution of landsat 1.



*Figure 48.* Rio Hondo Estuary Base Level Mangrove Cover, 1973.

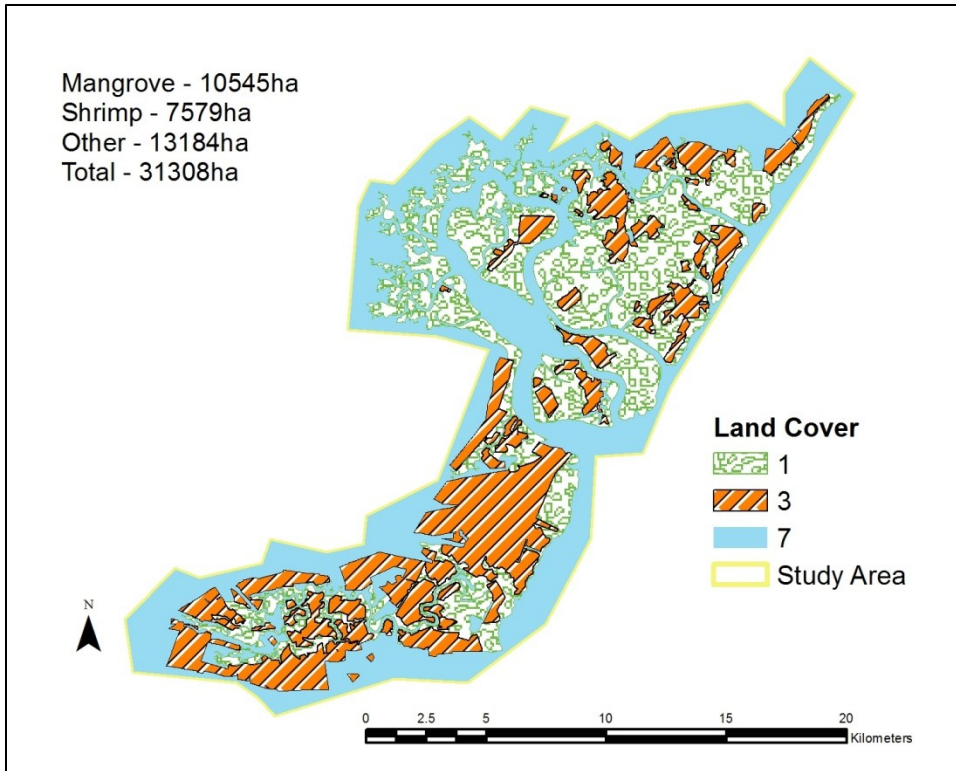
In the Rio Hondo Estuary, the period between 1973 and 1985 is characterized by the first arrival of shrimp farms and stable mangrove forest cover (Figure 49). The first shrimp farms appeared between 1973 and 1985 and favor areas with no pre-existing mangroves. Assessing the mangrove forest spatial pattern present in 1973 it is likely that the mangrove forest was cleared just before the 1973 data point but no earlier source exists to verify this observation. Aside from the arrival of these early shrimp farms, the remainder of the estuary is relatively stable during this period.





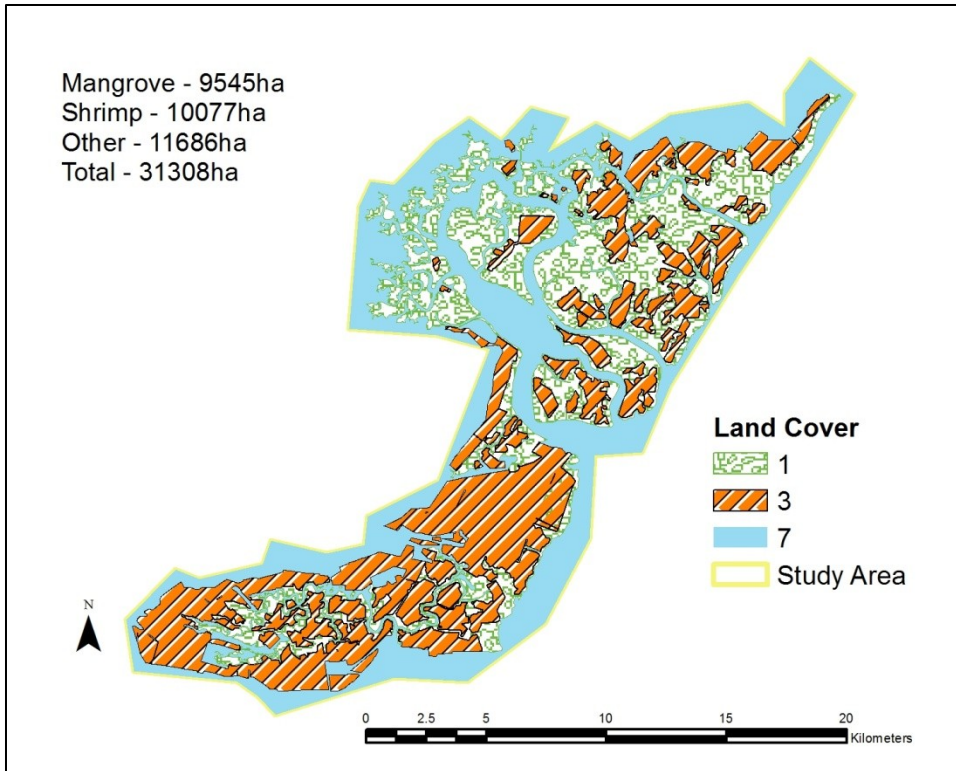
*Figure 49.* Rio Hondo Estuary Land Use, 1985.

In the Rio Hondo Estuary, the period between 1985 and 1990 is characterized by rapid shrimp farm expansion, but as with the earlier period, shrimp farms do not displace mangrove forests. During this five-year period, mangrove cover actually slightly increased by 597 ha (Figure 50). Despite the rapid increase in shrimp farms during this period mangrove does not decline. By 1990, shrimp farms have increased from 2,804 ha to 7,579 ha and now cover 25 percent of the entire estuary.



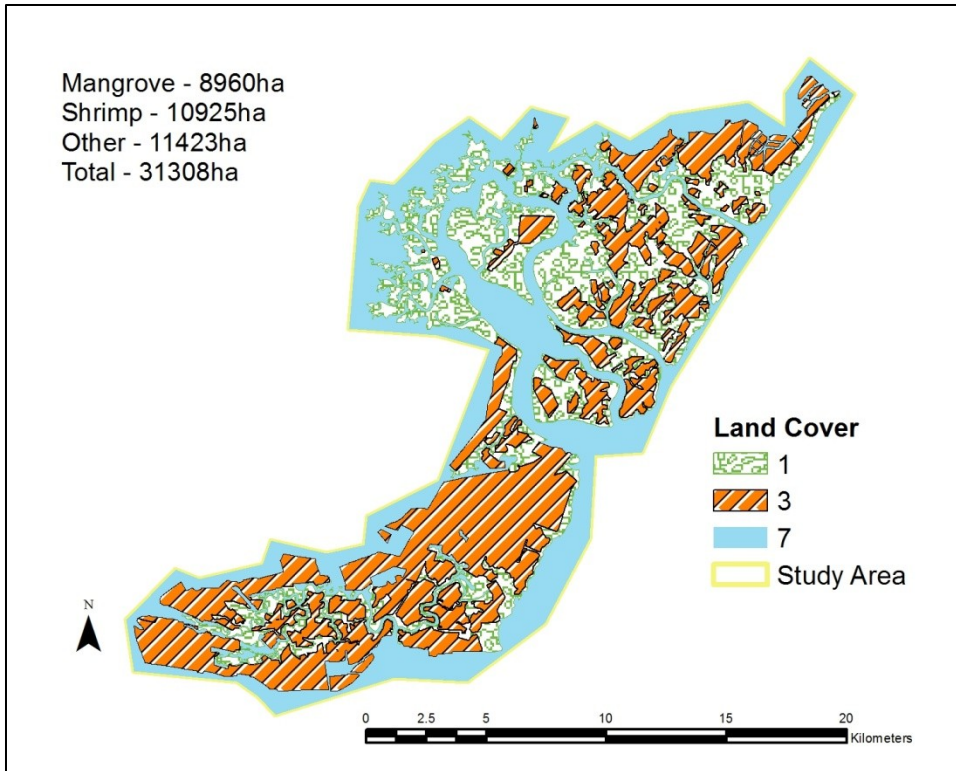
*Figure 50.* Rio Hondo Estuary Land Use, 1990.

In the Rio Hondo Estuary, the period between 1990 and 1997 is characterized by rapid shrimp farm expansion and of mangrove deforestation. During this seven-year period, mangrove cover decreased by 1,000 ha (Figure 51) and ended the period 403 ha below base level. Shrimp farms increased from 7,579 ha to 10,077 ha, and now cover 32 percent of the estuary. During this period, shrimp farms start to displace mangrove forests but at more limited rates than other estuaries in this research.



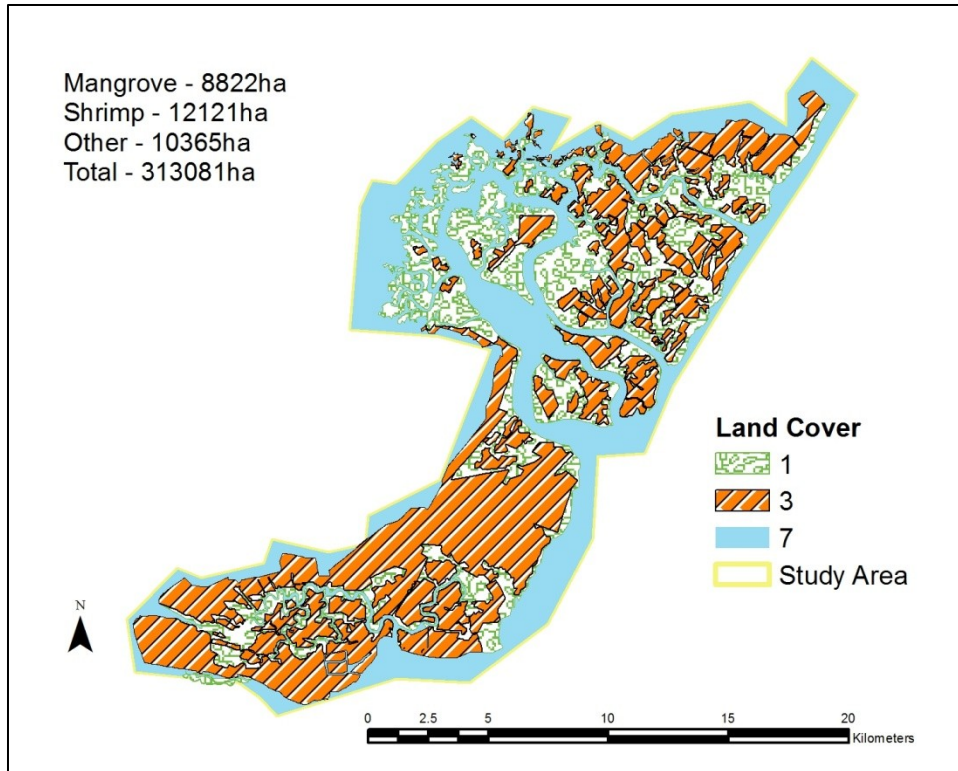
*Figure 51.* Rio Hondo Estuary Land Use, 1997.

In the Rio Hondo Estuary, the period between 1997 and 2000 continues the trend of the previous period. During this three-year period, mangrove cover decreases by 585 ha (Figure 52) and ends the period 988 ha below base level. Shrimp farms increase from 7,579 ha to 10,925 ha and now cover 35 percent of the estuary. During this period, shrimp farms are displacing mangrove forests but again at rates lower than all other estuaries.



*Figure 52.* Rio Hondo Estuary Land Use, 2000.

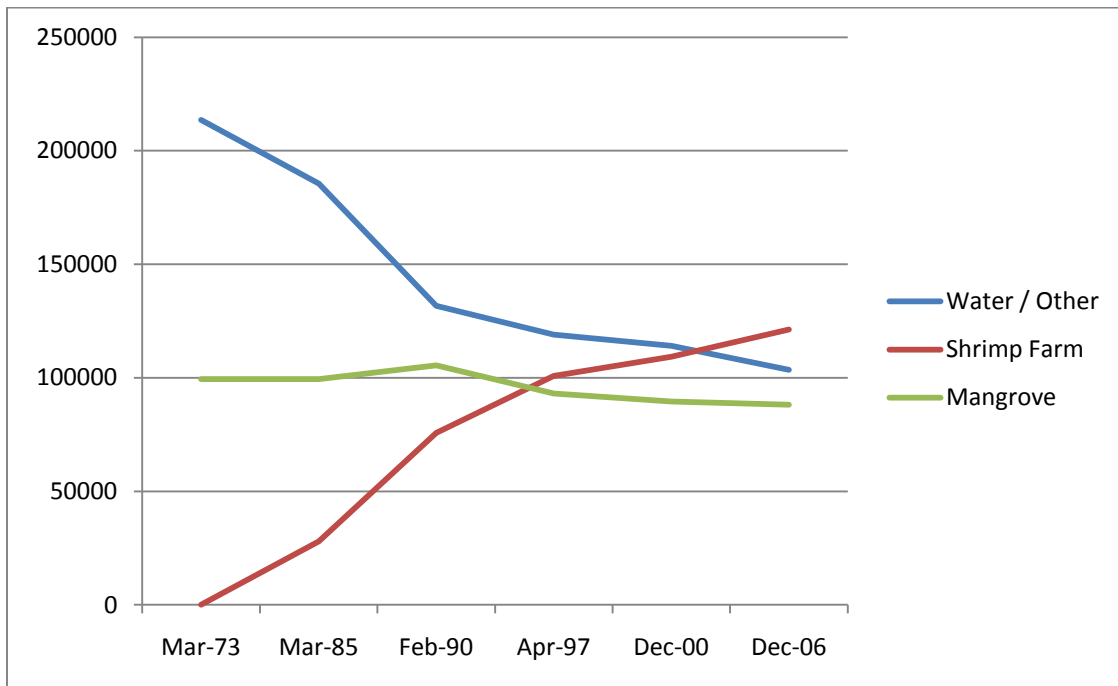
In the Rio Hondo Estuary, the period between 2000 and 2006 continues the trend of the previous two periods. During this eight-year period, mangrove cover decreases slightly by 138 ha (Figure 53) and ends the period 1,126 ha below base level. Shrimp farms increase from 10,925 ha to 12,121 ha and now cover 39 percent of the estuary. Most of this expansion again occurred outside of mangrove forests.



*Figure 53.* Rio Hondo Estuary Land Use, 2006.

In Rio Hondo Estuary, unlike all other estuaries, shrimp farm expansion appears to displace the water and the other classification as opposed to mangrove forest (Figure 54). Compared to the other estuaries, mangrove deforestation rates are low and the period of reforestation almost equaled the period of deforestation (Figure 55). Mangrove forest only declines slightly during the study period and mostly post-1997, which is a period of regrowth in the other estuaries. It is possible that an earlier period of mangrove deforestation has been omitted from this analysis. Even if an earlier period of deforestation occurred, Rio Hondo would be the only estuary south of Cayapas-Mataje that maintained its mangrove cover during the 1970s and 1980s. Shrimp farms have expanded as rapidly as in other estuaries, from none to 12,121 ha during the analysis period, but almost all of this expansion was into areas of the estuary without mangrove

cover (Figure 56). As in all estuaries aside from the preserve of Cayapas-Mataje, shrimp farms occupied more area of the estuary than all other land-cover categories (Figure 54). Within the Rio Hondo Estuary, shrimp farm expansion continued almost consistently throughout the analysis period with expansion throughout the 2000s. This is unique among the estuaries and is documented in the literature with commercial shrimp farms being created as late as 1998 (Madsen, Mix and Balslev 2001).



*Figure 54.* Rio Hondo Estuary Land Cover Change from 1974 to 2006. Land cover change between longitudinal data points assumes a linear interpolation. The y-axis is hectares.



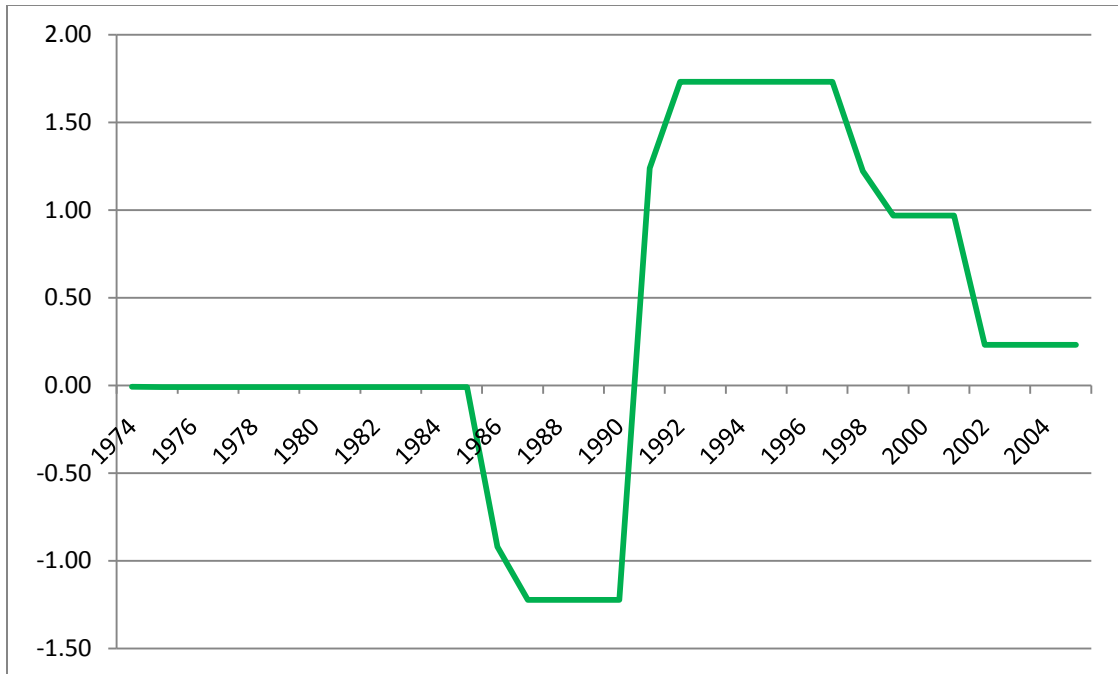


Figure 55. Rio Hondo Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006. Mangrove loss between longitudinal data points assumes a linear interpolation. The y-axis is percentage deforestation year-over-year.

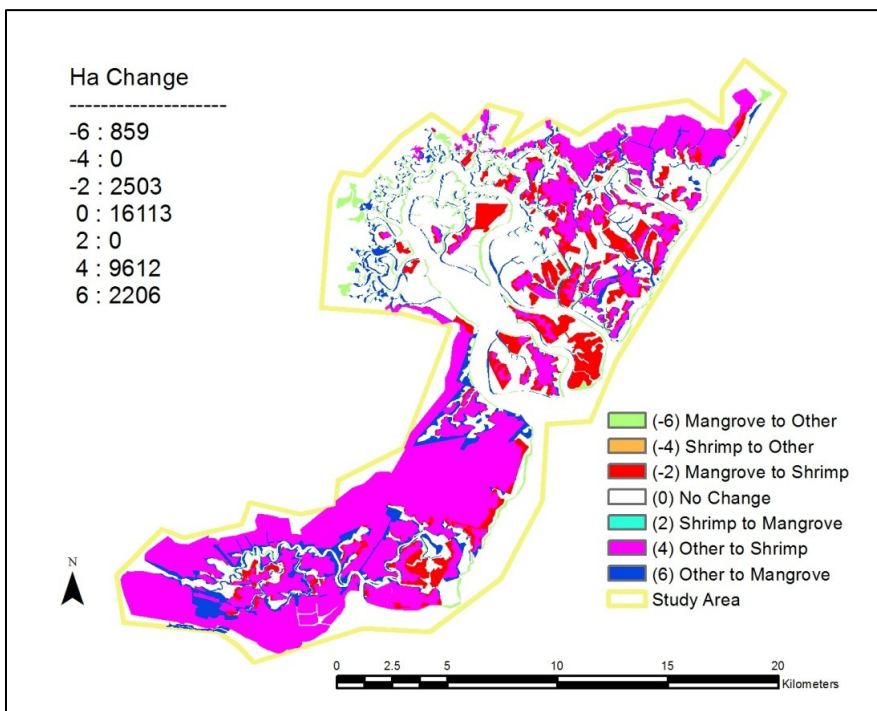


Figure 56. Rio Hondo Estuary Land Use Change from 1971 to 2005. The lower right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion

from mangrove forest to other. The numbers in the upper left indicate the magnitude of the land use change in hectares.

### Rio Hondo Estuary Food Security and Livelihood Implications

During the ethnographic research phase of this research, the shrimp farm industry in Puná Island and other estuaries in southern Guayas were shut down due to disease. On Puná Island, the reason given by one respondent was an outbreak of white spot disease, on the mainland, another respondent mentioned disease at the hatcheries. Outbreaks of Taura Syndrome Virus and White Spot Syndrome are common on shrimp farms in Ecuador (Hopkins et al. 1995b; Rodríguez et al. 2003; Pena 2004) and highlight the boom and bust nature of the industry. This emphasizes one of the primary arguments of advocates opposed to the commercial shrimp industry in Ecuador. Shrimp disease in stock ponds leads to extended periods of no production; this in turn leads to a lack of employment on the shrimp farms and a lack of mangrove economy employment due to shrimp farm displacement. Indeed, White Spot Syndrome and Taura Syndrome Virus may even result in severe human health implications in the densely farmed Guayas region. It is such diseases that have led to a reliance on antibiotics in shrimp ponds and there is evidence one of the major deadly human outbreaks of antibiotic resistant Cholera originated due to over-exposure of workers to antibiotics in Guayas (Weber et al. 1994).

Although participatory observation participatory observation and other field-based research was limited in this area, two of the three fishing syndicates presidents interviewed stated that catches have reduced in modern times by as much as 50 percent. This reduction is blamed on over-fishing and commercial fishing, and it is commonly stated that shrimp farms do not affect offshore fisheries. One respondent did voluntarily



mention that this was not entirely true and the extraction of fishmeal from the offshore waters had a negative impact on offshore wild catch. One estuary-based respondent noted declines in large fish in the estuary such as *corvina* and the destruction of the shellfish catch noted by respondents in all other estuaries since the advent of commercial shrimp farming. Conversely, one syndicate president indicated a stable catch during the analysis period although again this related to offshore catch.

As in all study areas south of Esmeraldas, local respondents stated that employment for the shrimp farm industry generally benefits outsiders. Several respondents blamed shrimp farming for estuary contamination and mangrove destruction. Interestingly, respondents did not blame shrimp farming for decreases in offshore catches, despite the almost universal agreement of wild-catch decline during the period of shrimp aquaculture. This may be due to the complex pathways such as loss of juvenile habitat, fishmeal extraction, disease transmission, and Postlarvae extraction that underpin the mangrove – fisheries relationship. Indeed, the connection between wild fisheries decline and mangrove deforestation is only currently being accepted within the academic literature. Fishing syndicates of Guayas point to over fishing and the suppression of seafood prices as the major challenges facing the artisanal offshore fishing industry as opposed to estuarine aquaculture.

#### Grande Estuary Land Use Change

The Grande Estuary / El Oro study area is 71,923 ha in size. As of the 1963 – 1977 composite map data, the estuary was comprised of 32,925 ha of mangrove forest, 35,439 ha of other land cover including surface water, saltpans, and mud flats; and 3,559 ha of early shrimp aquaculture (Figure 57). This base level land cover is derived from

topographic maps themselves derived from aerial photography flown between 1963 and 1977. The base level mangrove habitat may be as much as 10 percent under-represented due to the early arrival of shrimp aquaculture in this area and the lack of pre-1977 data in parts of the estuary. Again though, it appears these earliest farms may have located outside of the preferred mangrove habitats on the terrestrial side of the estuary and do not affect mangroves (Figure 57).

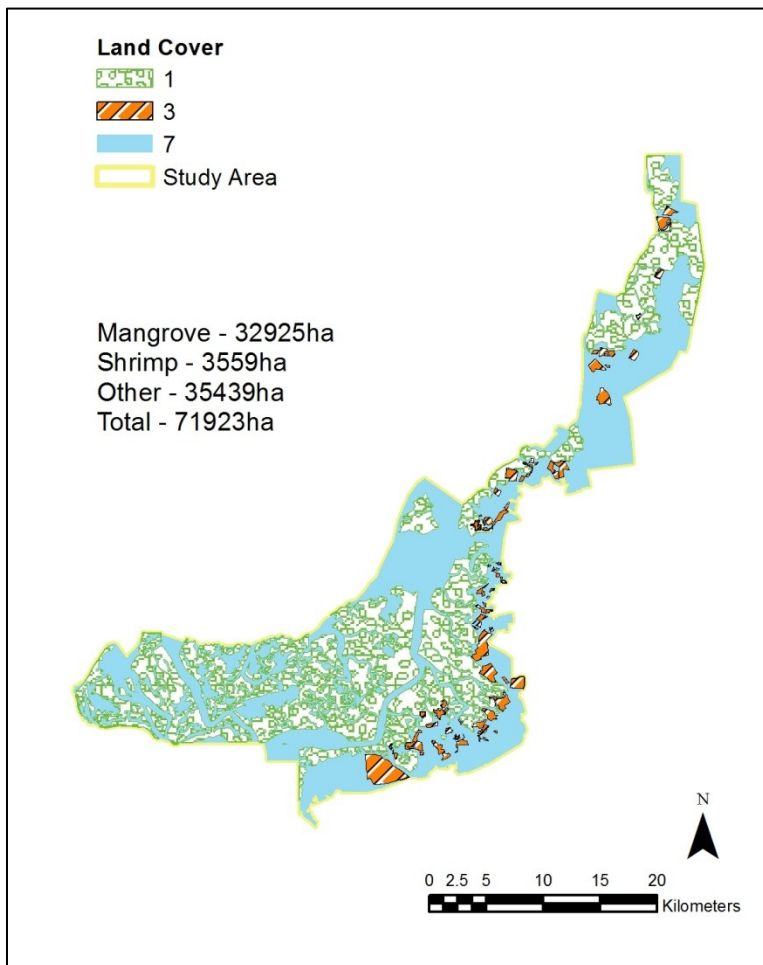


Figure 57. Grande Estuary Base Level Mangrove Cover, 1963 to 1977 Composite.

In Grande Estuary, the years between the 1963/1977 composite and 1985 are characterized by a substantial and rapid conversion of estuarine land to shrimp farms and rapid rates of mangrove deforestation (Figure 58). Between 1977 and 1986, a remarkable

22,984 ha of shrimp farms appear in the estuary. This represents a 745 percent increase from the base shrimp farm level established during this research. This corresponds to an annual shrimp farm expansion rate of between 1031 ha (1963) and 2,554 ha (1977). The map evidence suggests the higher of these numbers is most likely as shrimp farms do not start to appear of any major consequence until the latest series of maps. For this reason, and the dates of shrimp farming arrival in the other estuaries, this manuscript utilizes 1977 as the temporal base level for Grande Estuary. Of the 22,984 ha of shrimp farms that arrive between 1977 and 1985, 9,891 ha of these farms appear in areas previously delineated as mangrove forest (Figure 59). This results in mangrove loss rates as high as 3 percent annually within the estuary, and a mangrove loss of 8,311 ha or 25 percent in totality during the 1977 to 1985 analysis period. It should be noted that some mangrove regrowth also occurs during this period. By 1985, shrimp farms consume more of the estuary than mangrove forest or the other classification that includes surface water.

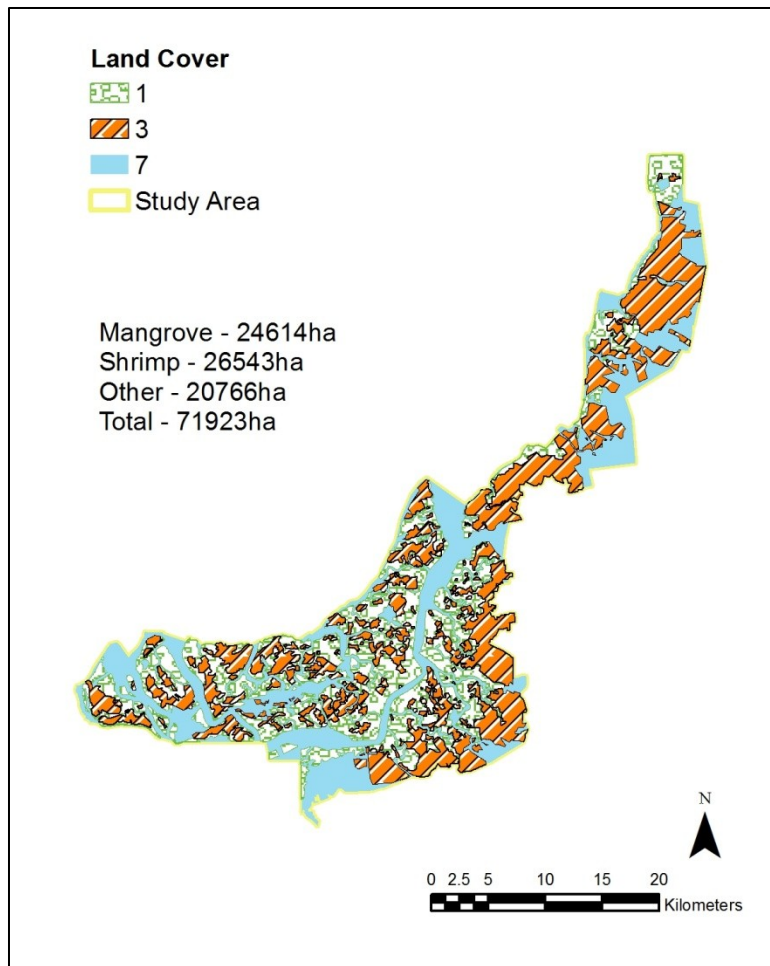
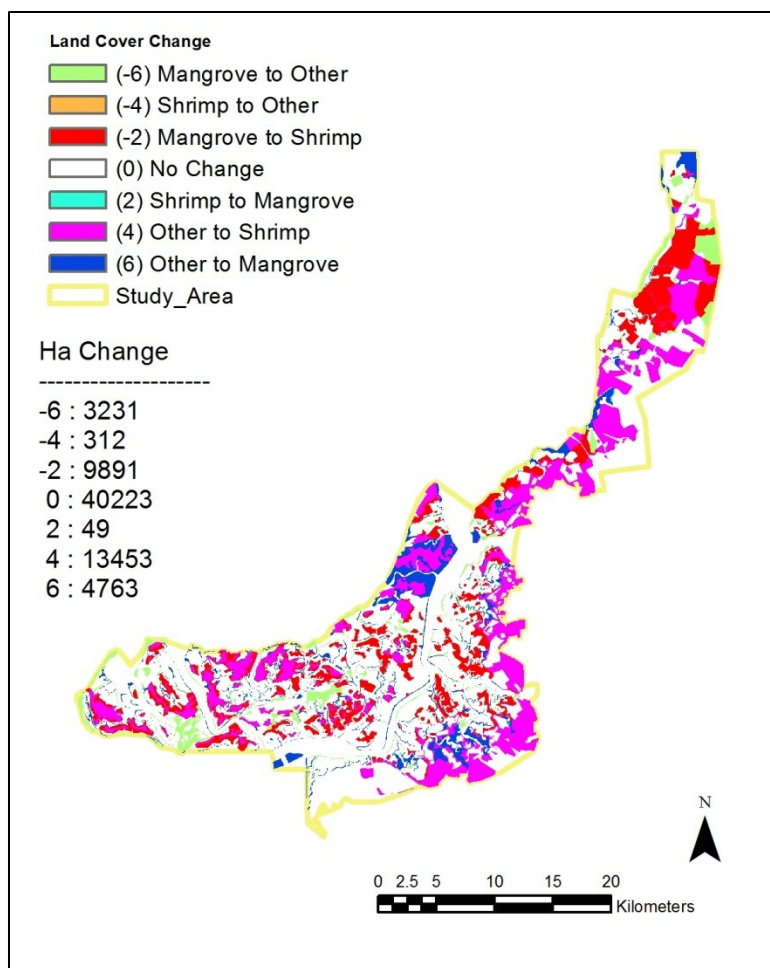


Figure 58. Grande Estuary Land Use, 1985.



*Figure 59.* Grande Estuary Land Use Change from 1963 Composite to 1985. The upper left legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farms whereas green indicates a conversion from mangrove forest to other. The numbers in the middle left indicate the magnitude of the land use change in hectares.

In the Grande Estuary, the years between 1985 and 1997 are characterized by continued rapid shrimp farm expansion, relatively high rates of mangrove deforestation, and high rates of direct displacement of mangrove by shrimp farms. During this twelve-year period, mangrove cover decreases by 6,361 ha, from a 1985 level of 24,614 ha to a 1997 level of 18,253 ha (Figure 61). Hence, by 1997, 45 percent of the base level mangrove forest had been displaced in the Grande Estuary. In the twelve years from 1985 to 1997, an additional 26 percent of the remaining mangrove is deforested. During

this identical period, shrimp aquaculture increases from the 1985 level of 26,543 ha to a 1997 level of 36,364 ha (Figure 60). Indeed, by 1997, shrimp aquaculture actually becomes the majority estuary land cover overtaking mangrove and the other land cover classification. During this period, almost all of the mangrove forest loss is due to direct displacement by shrimp aquaculture (Figure 61). The 1997 longitudinal data point marks the final period of rapid shrimp farm expansion and rapid mangrove deforestation in the Grande Estuary. Once again, this may be due to a lack of remaining forest to clear as opposed to any reflection of a change in practices.

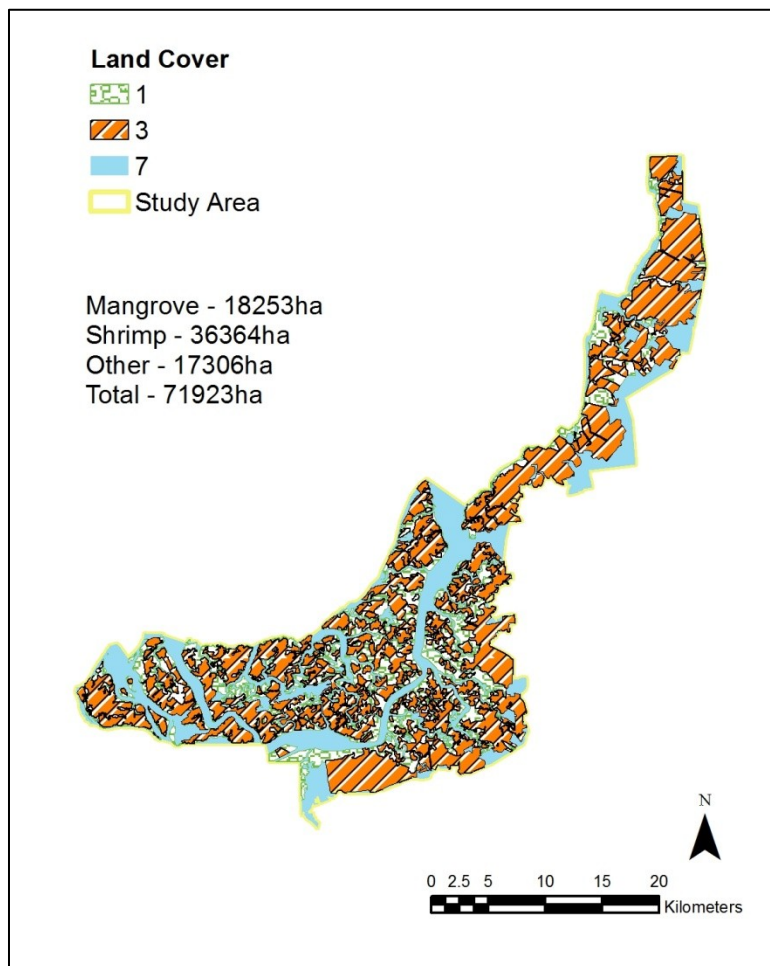
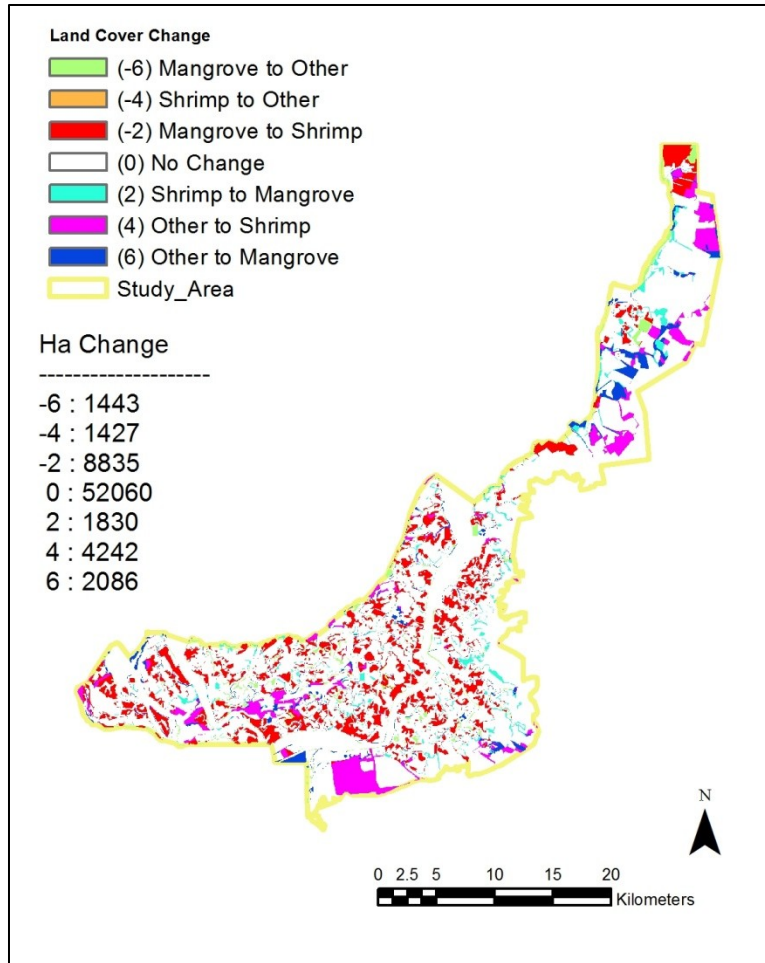


Figure 60. Grande Estuary Land Use, 1997.



*Figure 61.* Grande Estuary Land Use Change from 1985 to 1997. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farming and green indicates a conversion from mangrove forest to other. The numbers in the lower left indicate the magnitude of change in hectares.

The period between 1997 and 2006 in Grande Estuary marks the end of rapid mangrove deforestation and rapid rates of shrimp farm expansion. As in the other northern estuaries, mangrove actually increases 554 ha, from 18,253 ha in 1998 to 18,807 ha in 2006 (Figure 62). Despite this limited recovery mangrove remains at only 57 percent of its base level. Much of the regrowth of mangrove appears on the eastern terrestrial edge of the estuary and is likely due to active replanting. Shrimp farms increase by 1,202 ha during this period but not at the expense of mangrove. Despite the

relative increase mangrove forest, it is noted that shrimp farms still cover more of the estuary than all other land cover, including surface water and mangrove.

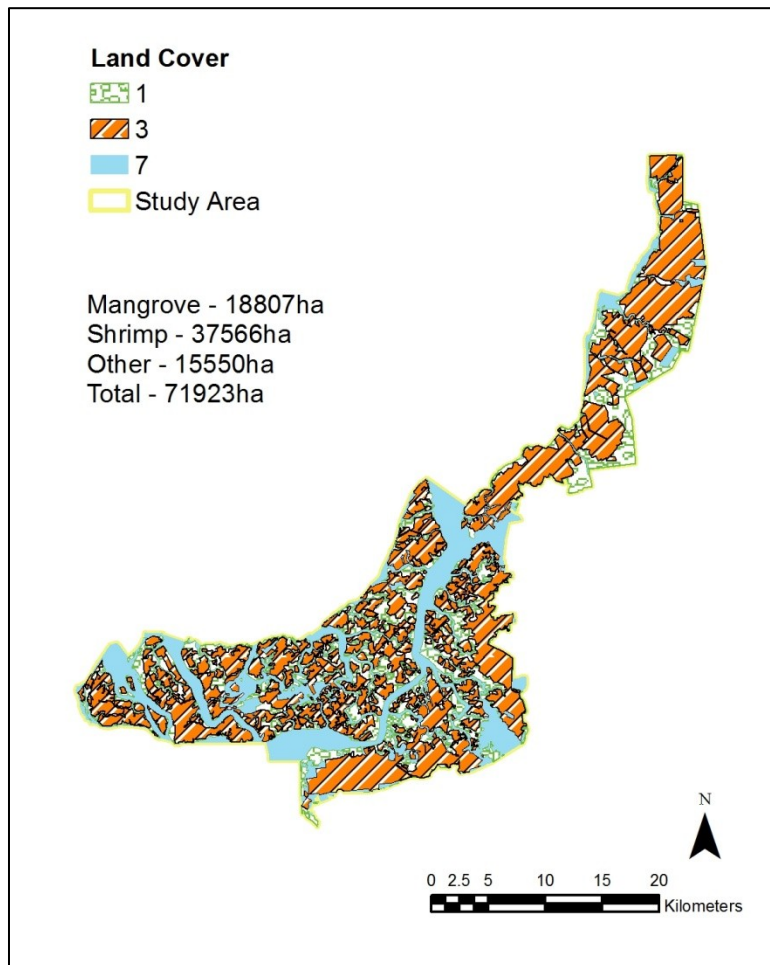


Figure 62. Grande Estuary Land Use, 2006.

In summary, within the Grande Estuary shrimp farms expand from 3,559 ha in 1977 to 37,566 ha in 2006. As of 1997 shrimp farms cover more of the estuary than mangrove, surface water, and all other land cover combined and this pattern continues through to the present. The period from 1977 to 1997 is characterized by rapid shrimp farm expansion with much of the expansion occurring at the expense of mangrove forests. After 1997, shrimp farm increases continue but at a far slower pace, and do not appear to follow a terrestrial to center tendency as noted in Chone Estuary.



Mangrove forest cover has almost a direct inverse relationship to shrimp farms in the estuary (Figure 63). Mangrove forests in the Grande Estuary decrease from 32,925 ha in 1977 to 18,807 ha in 2006. The 2006 level actually represents a slight recovery from the 1997 low level of 18,253 ha of mangrove cover. This represents a 43 percent base level mangrove loss during the analysis period. The period from 1977 to 1985 is also when the most rapid mangrove deforestation occurred with annual rates as high as 3 percent (Figure 64). The period after 1997 is characterized by a slight recovery of mangrove forests within the estuary with reforestation rates <0.5 percent annually. Of the total mangrove lost during the analysis, almost one-hundred percent is the result of shrimp farm displacement (Figure 65). A future survey will be required to determine if the mangrove regrowth is a long-term pattern or merely a one-off event.

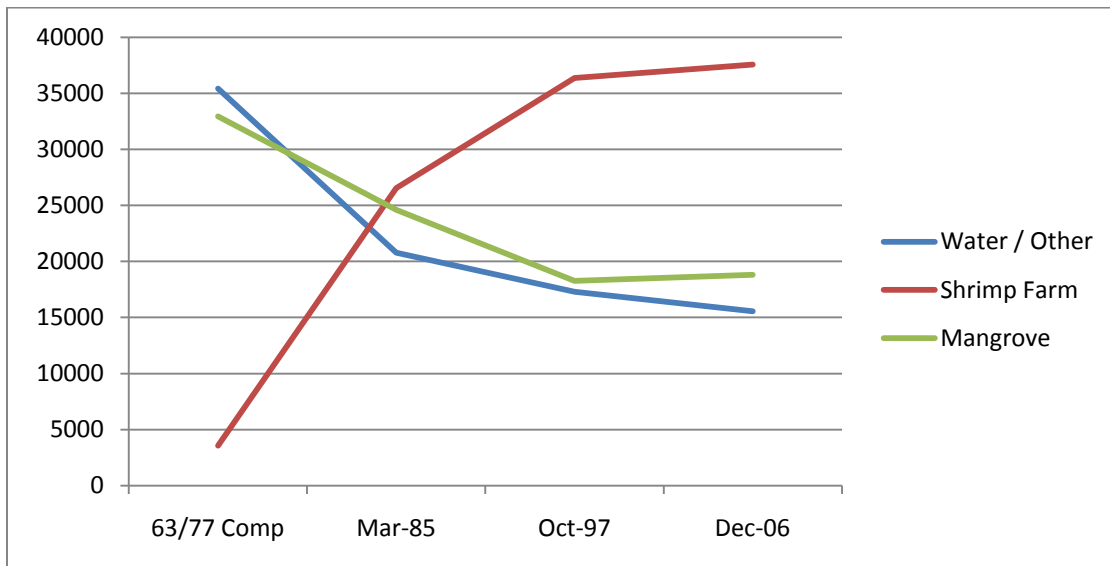
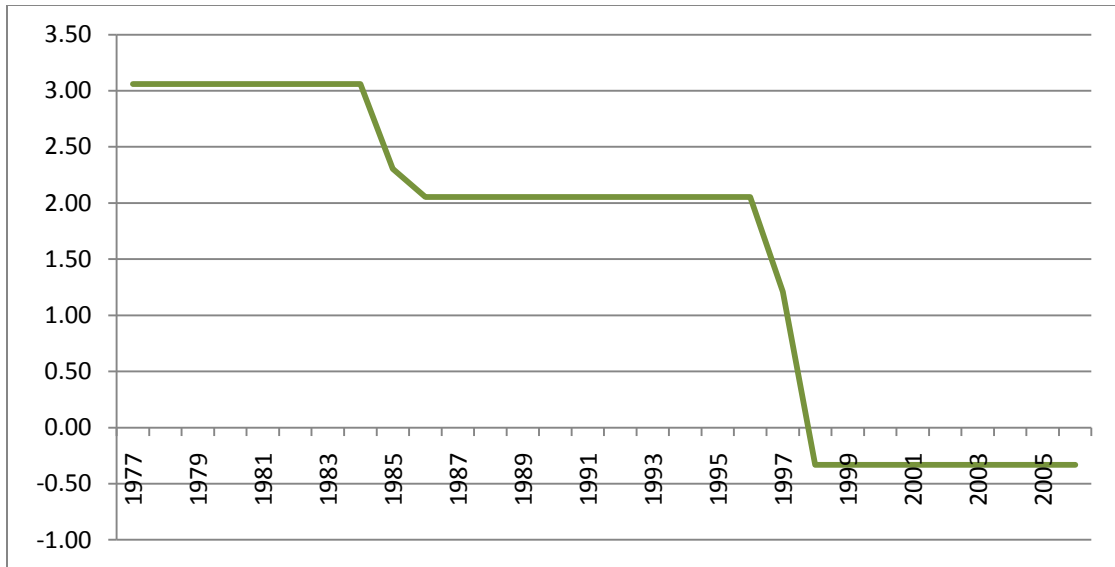
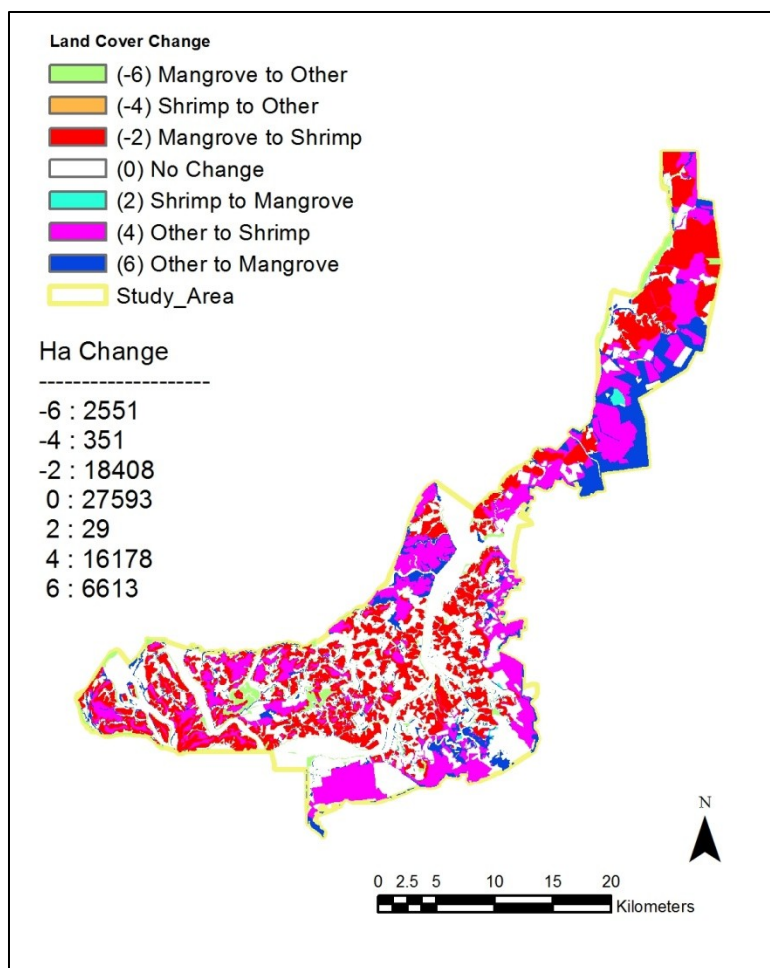


Figure 63. Grande Estuary Land Cover Change from 1963/1977 Composite to 2006. Land cover change between longitudinal data points assumes a linear interpolation. The y-axis is hectares.



*Figure 64.* Grande Estuary Annual Rates of Mangrove Deforestation from 1971 to 2006. Mangrove loss between longitudinal data points assumes a linear interpolation. The y-axis is percentage deforestation year-over-year.



*Figure 65.* Grande Estuary Land Use Change from 1971 to 2006. The upper right legend indicates the direction of land use change. For example, red indicates a conversion from mangrove forest to shrimp farming and green indicates a conversion from mangrove forest to other. The numbers in the lower left indicate the magnitude of change in hectares.

### Ecuador Level Results

The combined estuarine study area size across all four provinces of coastal Ecuador is 19,6748 ha. Of the 19,6748 ha of estuary, the base level of mangrove forest is 99,223 ha, or 51 percent of the entire estuary environment (Table 7). The 99,223 ha of mangrove analyzed is approximately 50 percent of the entire mangrove present in Ecuador before the advent of commercial aquaculture (Centro De Levantamientos Integrados De Recursos Naturales Por Sensores Remotos 2007). Most of the mangrove

missing from the analysis is at the mouth of the Guayas River. The base level shrimp farm level of the estuaries analyzed is a nominal 3,559 ha, or 2 percent of the estuaries analyzed (Table 7). The base level other category accounts for the remaining 47 percent, or 93,629 ha, of the estuaries land cover (Table 7). The base level dates are consistent in that they predate aquaculture aside from a small portion of Grande Estuary.

Table 7

*Base Level Mangrove, Shrimp Farms, and Other Land Use*

Study Area	Base level Mangrove	Base level Shrimp	Base level Other	Base level Total
Chone Estuary	4238	0	4506	8744
Cojimíes Estuary	14269	0	13141	27410
Muisné Estuary	3399	0	3263	6662
Rio Hondo Estuary	9948	0	21360	31308
Grande Estuary	32925	3559	35439	71923
Cayapas-Mataje Estuary	35144	0	15570	50714
<b>TOTAL</b>	<b>99923</b>	<b>3559</b>	<b>93269</b>	<b>196761</b>

Note. All units are ha.

During the entire analysis period, total mangrove forest decreases by 33 percent from 99,923 ha at base level, to 67,100 ha at the final combined longitudinal survey points (Table 8). This equates to 33,823 ha of mangrove deforestation. As of the latest survey, mangrove forest only occupies 34 percent of the estuary space as opposed to 51 percent pre-aquaculture. This decrease in mangrove cover is despite forest recovery

across almost all study areas in the last decade. During the entire analysis period across all study areas, shrimp farms increased from 3,559 ha to 73,108 ha (Table 8), and changed from occupying 1.8 percent of Ecuador's estuary environments pre-aquaculture, to occupying 37 percent of the available estuary space at the current time. Indeed, if the patterns in the un-surveyed areas of Ecuador follow the pattern of the analyzed estuaries, it is likely that shrimp farms now cover almost as much of Ecuador's estuaries as do mangrove forests, surface water, saltpans, other vegetation, and mudflats combined. The other category that includes mostly surface water, saltpans, mudflats and other vegetation decreased from 93,269 ha to 56,533 ha during the analysis, and now only occupies 29 percent of the total estuary space as opposed to the base level of 47 percent (Table 8).

Table 8

*Current Mangrove, Shrimp Farms, and Other Land Use*

Study Area	End Mangrove	End Shrimp	End Other	End Total
Chone Estuary	1,465	5,191	2,088	8,744
Cojimíes Estuary	4,597	12,218	10,595	27,410
Muisné Estuary	1,065	3,212	2,385	6662
Rio Hondo Estuary	8,822	12,121	10,365	31,308
Grande Estuary	18,807	37,566	15,550	71,923
Cayapas-Mataje Estuary	32,344	2,800	15,570	50,714
TOTAL	67,100	73,108	5,6553	196,761

All units are in hectares.

As dramatic as the increase in shrimp farming and the decrease in mangrove forests are in coastal Ecuador during the analysis period, the numbers above may actually underestimate the proportion of land use change. Cayapas-Mataje Estuary is a mangrove ecological preserve with enforced protected status. In many ways, Cayapas-Mataje Estuary is a control site in this analysis and exemplifies a traditional mangrove based economy that existed before aquaculture. Cayapas-Mataje Estuary is the only mangrove location in Ecuador with this level of protected status. When Cayapas-Mataje Estuary is excluded from the analysis, the mangrove deforestation and shrimp farm expansion rates across Ecuador both increase and are likely more representative of the entire unprotected coast.

With Cayapas-Mataje Estuary excluded, total mangrove across all study areas actually decreases by 46 percent from 64,779 ha to 34,756 ha. Despite a decade of regrowth, mangrove forests currently occupy only 24 percent of the estuary space, as opposed to 51 percent pre-aquaculture (Figure 66). Conversely, with Cayapas-Mataje excluded, shrimp farms expanded by 66,749 ha during the analysis period. Shrimp farms now account for 48 percent of the entire land use within Ecuador's estuaries by the end of the analysis period (Figure 66). Indeed, if the patterns in the un-surveyed areas of Ecuador follow the pattern of analyzed estuaries, it is likely that shrimp farms now cover almost as much of Ecuador's estuaries as every other land use, including surface water, combined. The other category that includes mostly surface water, saltpans, and other vegetation now only occupies 28 percent of the total estuary space as opposed to the base level of 53 percent (Figure 66).

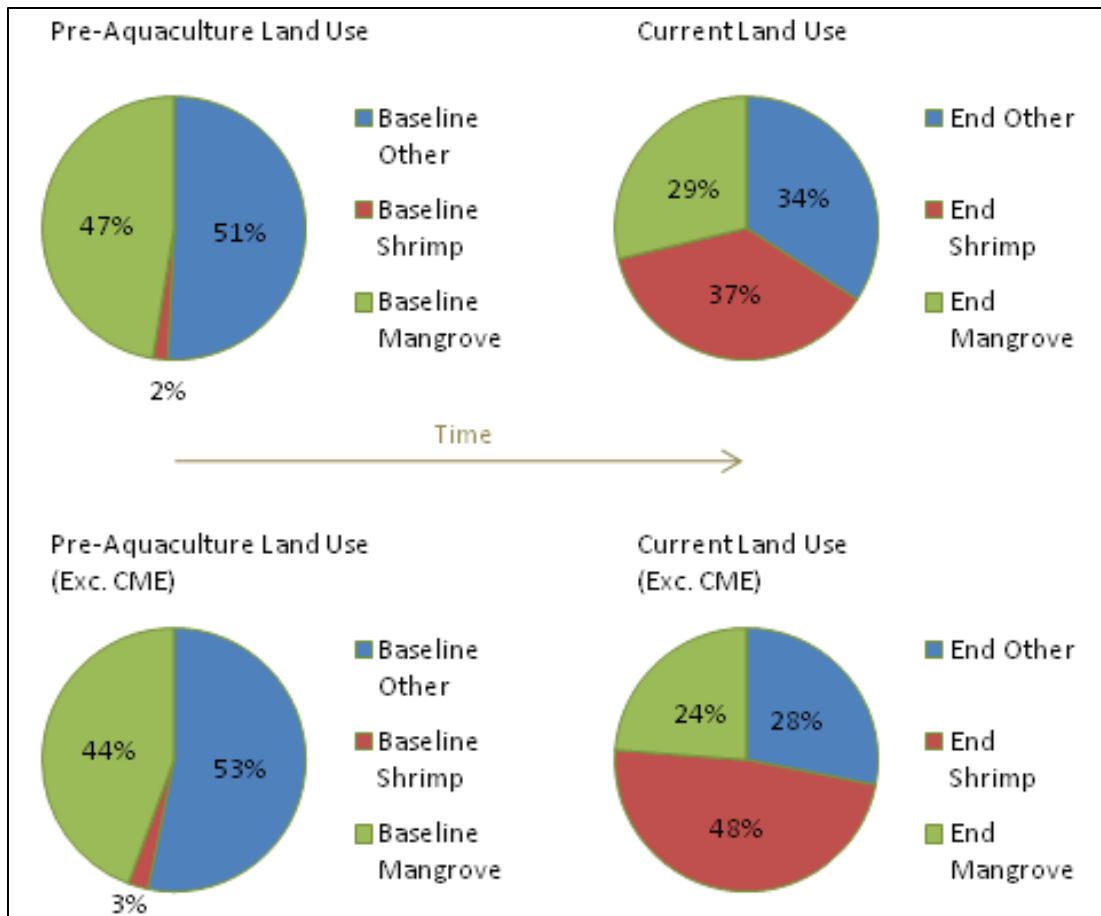


Figure 66. Ecuador Estuary Land Use Change. Red indicates shrimp farming, green mangroves, and blue other land use. The lower pair of Pie Charts Excludes Cayapas-Mataje.

Almost all of the mangrove loss in Ecuador is direct displacement by shrimp ponds. Only Rio Hondo Estuary is exempt from this statement. Using the land use change equation in Figure 67, it is calculated that 89 percent of the mangrove forest loss in Ecuador is attributable to direct displacement by shrimp farms. Either Ecuador does not follow the international trend with shrimp farming only responsible for 10 percent of the global loss of mangrove forest (Boyd and Clay 1998; Diana 2009) or the often-cited international numbers are erroneous. Indeed, it appears that direct displacement by

aquaculture is the only major driver of mangrove destruction in Ecuador with only 11 percent of deforestation occurring for other purposes.

$$100 \left( \frac{(\sum 2LUC) - (\sum -2LUC)}{\text{tot mangorve loss}} \right)$$

*Figure 67.* Mangrove Loss Equation. LUC indicates the land use change value Table 6.

In addition to the ramifications of such extensive mangrove loss, this analysis raises questions about the preferred habitat of shrimp farms in coastal environments. In all study sites combined, 38,916 ha of the 68,549 ha of the newly arrived shrimp farms reside in areas of traditional mangrove forest coverage. This equates to 57 percent of shrimp farms residing on land classified in the previous period as mangrove. Ecuador does not adhere to the theory that ponds built prior to 1997 are built on terrestrial land for drainage purposes and that aquaculture is responsible for minimal amounts of mangrove deforestation (Menasveta 1997; Boyd and Clay 1998; Diana 2009). Indeed, this claim lacks an understanding of the tidal nature of estuaries and the ease of drainage at low tide and the fact that locating in the estuary has a distinct set of advantages including feed supply, pond washing, and not having to purchase only limited terrestrial real estate.

Rates of deforestation presented in this section are significant by any measure or when compared to any other contemporary land use change. For example, a study using almost identical methods and time frame estimates deforestation in the Brazilian Amazon as 6 percent in total between 1978 and 1988 (Skole and Compton 1993). Although difficult to estimate due to various analysis dates differing study lengths the estimate of mangrove deforestation using a linear deforestation rate between years would result in a mangrove deforestation rate of approximately 40 percent for the same period, including



the relatively untouched mangroves of Cayapas-Mataje. In comparing the two deforestation rates, the decadal level of Brazilian Amazon rainforest loss is equivalent to the annual loss of mangrove forest in certain Ecuadorian estuaries.

The land use change noted above appears to have had the most adverse effects of food security and livelihood options in areas that have the most severe amounts of mangrove loss and shrimp farm growth. For example, respondents from both Chone and Cojimíes estuaries reported devastation of the artisanal fishing lifestyle. Conversely, despite reporting problems due to over-fishing from outsiders, the artisanal livelihood options and food security options available in Cayapas-Mataje Estuary appear relatively unaltered during the analysis period.

The pathways from mangrove deforestation and shrimp farm expansion within the estuary environment to a decrease in local livelihoods and food security fit into the general categories of environmental degradation, lack of economic opportunity, and issues related to property rights enforcement. Problems exist disentangling environmental damage caused by the location of shrimp farms, the operation of shrimp farms, and the decreases in mangrove forest cover within the estuary. Many of the environmental and economic disruptions encountered by local residents are likely an interaction of all three processes.

The most common environmental pathway to reduced livelihoods reported by interview respondents is a decline in estuary fisheries due primarily to shrimp farm construction and operation practices. Firstly, many respondents mention the use of poison in the shrimp farms to kill existing flora and fauna in the ponds. This poison is applied at the beginning of the shrimp farm life and throughout the lifecycle of the ponds.

Locals report that the release of poison when the pond is flushed causes a decrease in species diversity and species number in the estuary. This results in declines of wild catch available within the estuary. The residents are referring to a combination of pesticides and herbicides used in the shrimp industry when establishing a farm when using the phrase poison. Other residents discussed the release of waste into the estuary from the farm as an issue. Concentrated shrimp waste is discharged into the estuary daily from all operational farms. Additional forms of contamination come from the release of feed and disease from the estuaries. Local fisherfolk almost all point to the most pervasive declines in shellfish and *concha*. It is unclear if these declines are a result of shrimp farm practices or mangrove deforestation; it is likely a combination of both. Other shrimp farm practices such as the extraction of fishmeal for feed and the extraction of Postlarvae for the farms are also mentioned as practices that restrict wild catch, although the latter appears almost resolved with the use of hatcheries.

The decline in estuary water quality is once again likely a combination of mangrove deforestation and shrimp aquaculture expansion in the estuaries. Aside from Cayapas-Mataje Estuary and Rio Hondo Estuary, all other study sites have surpassed the 40 percent to 60 percent mangrove to shrimp farm conversion rate that appears to be the critical threshold based on dissolved inorganic nitrogen levels, to maintain estuary water quality and sustain wild fish populations within the estuary (Stram et al. 2005). During field visits, it was noted that Chone Estuary and Cojimies Estuary both exhibited signs of substantial weedy growth and algae blooms within the interior portions of the estuary. Such blooms are indicative of excessive levels of dissolved inorganic nitrogen, lead to red-tide events, are toxic to wild fish populations (Jimenez 1989; Twilley 1989) and in

turn will likely contribute to the decline of local livelihoods within the estuary dependent on estuary wild catch. Cojimíes and Chone estuaries areas have suffered far in excess of 40 percent mangrove to shrimp conversion in the interior of the estuary and this appears to be the key parameter in sustaining healthy estuary nutrient levels (Stram et al. 2005).

Using land use change results presented, the organic laden water discharge into the estuaries by the shrimp farms is between 36.3 million and 60.5 million cubic meters of water daily. The biological oxygen demand load estimate from shrimp farm induced the effluent discharge is equivalent to that of 16.5 million to 27.5 million inhabitants assuming the effluent loading equation developed by Arriaga et al. (1999) for Chone Estuary is applicable across all estuaries. Indeed, the true figure is likely closer to 73 - 121 million cubic meters of wastewater and 33 million to 55 million inhabitants once Guayas estuary is included. The entire population Ecuador as of 2009 is approximately 14 million, of which approximately 6 million live in the coastal provinces.

The mangrove to shrimp transition not only causes direct declines in water quality within the estuary through the pathways mentioned above but also exacerbates terrestrial activities that contribute to declines in estuarine water quality even when aquaculture is not present. For example, the conversion of forestlands to agriculture is a general trend in Latin America over the last thirty years (Dodson and Gentry 1991; Southgate and Whitaker 1992; Southgate et al. 2000; Jokisch and Lair 2002). Coastal Ecuador is no exception to this deforestation pattern (Dodson and Gentry 1991). Within coastal Ecuador, terrestrial deforestation and the transition to agriculture likely leads to increases in sediment and nutrient loading within Ecuador's coastal estuaries. Yet in a mangrove estuary both terrestrial sediment and terrestrial nutrients are captured and sequestered by

mangrove forests whose very survival and expansion depends on their ability to capture terrestrial sediment and nutrients. This appears particularly evident in the Chone Estuary where the fishing syndicate and the dock master both reported increased levels of sedimentation in the estuary. This is likely due to terrestrial deforestation within the estuary watershed combined with mangrove deforestation in the estuary itself. The displaced mangrove can no longer sequester terrestrial sediment and nutrients and the aquatic mangrove deforestation releases all of the historically captured sediment and nutrients that is tens of meters thick across thousands of hectares.

Many additional sediment and nutrient burdens are placed on the estuary when shrimp farmers displace mangroves. Firstly, the estuary suffers from a release of sequestered sediment and nutrients from within the mangrove forest when the deforestation occurs. Assuming a conservative average mangrove sediment depth of 5 meters, the land use analysis results indicate that within the studied estuaries during the analysis period, 1.6 billion m<sup>3</sup> of sediment has been released directly into the estuaries from mangrove deforestation alone. Secondly, the estuary is affected by the loss of the sequestration system for terrestrial runoff provided by the mangrove. Additionally, once deforested, mangroves can no longer mitigate the outputs from shrimp farms located on terrestrial land outside the estuary. Finally, the estuary now has additional nutrient and sediment loads created by the shrimp farms that displace mangrove forest within the estuary.

Mangrove deforestation and the loss of this important habitat is in and of itself a major reason for the decline of wild fisheries within the estuaries, particularly the decline of shellfish as reported by almost all respondents. Crab, shrimp, clam, sea snail, *concha*,

and crayfish are wholly dependent on the mangrove forest for primary habitat for at least part of their life cycles. Shrimp utilize the mangrove for juvenile habitat to avoid predators; *Concha Negra* appear to reside only in amongst the roots of the mangrove forest and in no other locations; crabs rely on the mangrove to burrow and escape predators; sea snails make their home in the sediment. This is in addition to the mangrove forest providing the primary habitat for numerous fish species. As with any other forest habitat, if the forests are removed the species that rely on the forest will struggle to survive. The mere location of shrimp ponds in areas of former mangrove forests is likely enough to result in dramatic declines in available protein and livelihood options within an estuary without the magnifying factors directly related to the management and operation of the shrimp farms. Additional environmental issues such as increased levels of erosion, salt leaching into ground water when farms are located outside of the estuary edge but water is still pumped from the estuary and the chemical and bacterial laden soils that remain when a shrimp farm is abandoned have all been observed in coastal Ecuador.

The economic pathways to a loss of local livelihoods and decrease in food security are not only due to the environmental degradation of the estuary caused by the loss of mangroves and creation of shrimp farms, but also by employment practices and conditions that exist on the newly created farms. All respondents that discussed shrimp farm hiring practices agree that the industry provides relatively few jobs, particularly when compared to the mangrove economy that still thrives in Cayapas-Mataje. The jobs that created are intermittent and disappear entirely during times of disease. The shrimp jobs are now reliant on the commodity price of worldwide shrimp over which shrimp

farm workers have no control. Aside from some farms in Muisné and Rio Hondo, it appeared that almost all jobs go to migrant workers housed on site at the shrimp farm and few, if any, locals benefit from the process. Indeed, reports of workplace abuses and mistreatment of employees are commonplace inside Ecuador and beyond in the shrimp industry (Call 2003; Environmental Justice Foundation 2003; Solidarity Center AFL-CIO 2008). Furthermore, all interview respondents with knowledge of shrimp farm employment agreed that shrimp farm wages were not enough to support a family. In the locations where traditional fisherfolk have embraced commercial shrimp farming and participate in the means of production, they appear vulnerable to manipulation by merchants. For example, in Muisné where locals appear more involved in the ownership and management of the aquaculture process the fisherfolk owners are often exploited by merchants who act as intermediaries between producers and exporters. This is not reported on the large private commercial farms in areas such as Chone where shrimp farm owners likely sell directly to large shrimp vendors without intermediaries.

The issue of property rights and enforcement of these rights is one of the unexpected results of the analysis. Land use change has left many fisherfolk unable to access the estuary to catch fish or harvest *concha*. Aside from Cayapas-Mataje, all the study sites have regions in which access to the estuary would require either a boat or vehicle, or trespassing on what is claimed as private land. The former is beyond the economic means of all artisanal fisherfolk in the area and the latter is difficult due to security employed on the farms and conflict between the shrimp farm owners and artisanal fisherfolk. As with the shrimp farm employment practices the access burden has been pushed disproportionately onto the poorest in society. Those who cannot afford a

boat, those that traditionally fished from the edge of the estuary, and female *concehros* who traditionally collected *Concha Negra* from the edge of the estuary are the most severely impacted. Fishermen who own boats and fish the mouth of the estuary or near shore waters are less impacted.

Additional property rights issues are related to the ownership of aquatic resources. In both Cayapas-Mataje and Chone interview respondents reported that they were tricked into giving up their access to the mangrove forest. Investors purchased terrestrial land, which in Ecuador comes with no aquatic ownership rights. After purchasing terrestrial land on the edge of the estuary they then took ownership of the mangrove adjacent to their land, deforested the mangrove, constructed shrimp farms in the former mangrove forests, and the block local fisherfolk access to the estuary. Such activity would technically be illegal under numerous Ecuadorian laws but no environmental enforcement appears to have taken place during the analysis period. The land use analysis shows that once farms are constructed they are rarely if ever removed and reforested. Indeed, the land use change analysis not only supports this claim of terrestrial purchases leading to aquatic expansion but also goes one-step further. In Chone, Grande, and Cojimíes farms began as single stacked ponds on terrestrial land and then expanded into double or even triple stacked ponds. An additional temporal phase of expansion then occurs, the farms appear to expand beyond the actual mangrove forest into land that was previously aquatic estuary resulting in almost as surface water being lost to shrimp farms as mangroves have been lost.

The relationship between mangrove deforestation and artisanal fisheries in the estuary is elucidated in the academic literature and supported by this analysis. The role

of mangrove deforestation in supporting offshore fisheries is open to more debate. As late as 2007, the relationship between mangrove deforestation and declines in fisheries is described as a persistent dogma (Blaber 2007). Although it is beyond the scope of this analysis to establish a relationship between offshore wild catch and mangrove deforestation, the evidence of a threshold at which point mangrove deforestation begins to affect wild catch appears to exist. This is currently an active research topic in the fisheries community evidenced by Marine Science Resource Bulletin recently dedicating an entire issue to the mangrove fisheries relationship (Serafy and Araojo 2007). Twenty-one of the twenty-five articles in the special edition support some form of strong relationship between mangrove and wild catch outside of the estuary. In this scenario, increases in aquaculture do not necessarily increase available protein if mangroves are depleted at the expense of aquaculture. If this pattern is correct shrimp, farm activity in Ecuador's coastal estuaries likely causes livelihood losses to a far-wider community than stated in this manuscript. For example, if Ecuadorian mangroves support the same wild catch per acre as noted in Malaysia (Chong 2007), then the land use change analysis predicts that 73,852 tonnes of wild catch are lost annually and in perpetuity due to the mangrove deforestation within Ecuador's estuaries. This equates to approximately 19 percent of Ecuador's 2007 wild catch total (FAO Fisheries and Aquaculture Department 2009). This calculation only accounts for approximately 50 percent of Ecuador's base level mangrove forests. With Guayas included, the wild catch depletion is likely closer 40 percent of Ecuador's total catch. This does not include potential disruption of wild catch resulting from extraction of fishmeal for the ponds or loss of catch inside the estuaries.



## CHAPTER VI

### CONCLUSIONS

From 1970 to present, with the exception of Cayapas-Mataje, Ecuador's coastal estuaries' have undergone a process of commoditization. Ecuador is now the major US market supplier of headless shell-on frozen shrimp and is among the top four suppliers of peeled shrimp (FAO Fisheries and Aquaculture Department 2010). It took approximately twenty years for the transition from communal utilization of estuarine environments to the private ownership of the goods and services offered by estuarine environments to be completed. Ecuador's estuaries now cater to international demand for shrimp as opposed to producing goods and services that cater to the needs of the local populations. This transition can be viewed as part of the macro-scale transition of environmental resources encouraged by neoliberal policies in Latin America since 1970 (Liverman and Vilas 2006). Within Ecuador, this commoditization has resulted in rapid and substantial depletion of mangrove forest and degradation of estuary water quality. This has in turn resulted in decreases of local livelihood options and food security for local inhabitants who rely on mangrove forests and healthy estuary environments.

Although only in one county, and for one resource, the neoliberal claim of private ownership of natural resources providing improved resource management appears fallacious in this example. Definable, defendable, and divestible rights that neoliberal reasoning portrays as the defender of such resources were lacking from Ecuadorian estuaries and mangrove forests before the advent of commercial aquaculture, yet Ecuador's estuaries were communally utilized without over-exploitation. During the period of shrimp aquaculture within the estuaries, private interests begin to dominate the

estuary with individuals and corporations claiming rights to the aquatic resources. Yet when this occurred the estuarine and mangrove resources were exhausted within just two decades. This depletion applies not only to traditional livelihoods but also to the wider fisheries. This is evidenced by the numerous disease outbreaks on the shrimp farms, abandonment of shrimp ponds, and overall fisheries depletion during the analysis period. The conversion process from mangrove to shrimp aquaculture appears to fit into broader perspectives of neocolonial control of an environmental or communal resource, which then turned a local resource into an international commodity that is now exploited for capital accumulation mostly benefiting those residing outside the region of commodity extraction (Harvey 2005).

A simple economic analysis of the estuary environment reveals the extent of this commodity driven extraction. Without accounting for the disputed decline in offshore fisheries, the economic loss sustained due to Ecuador's mangrove deforestation and estuary transition is substantial. The economic valuation of the deforested mangroves and transition of estuary in Ecuador during the analysis period in the study areas is calculated at \$2.257 billion dollars annually<sup>14</sup> using the global valuation of estuaries and mangroves as derived by Costanza et al. (1997). With Guayas included, this number is likely closer to \$4.5 billion dollars annually, or approximately 11 percent of Ecuador's 2006 GDP. This figure does not include the potential loss of offshore fisheries. These figures are direct losses than do not account for many of the uses of mangrove revealed in this analysis, such as medicinal and construction uses. This loss is borne in perpetuity annually by the residents of coastal Ecuador. As of 2008, shrimp farming offsets only

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<sup>14</sup> Adjusted to USD 2000 using CPI-U annual average US.

\$720 million of this total annually. As opposed to the \$4.5 billion that the estuarine mangrove forests provided to the local community in the form of goods and services, the majority of the \$720 million generated by commercial shrimp farming leaves the estuary communities.

Numerous claims pertaining to the shrimp farm industry seem to run counter to the results of this research. For example, claims that shrimp farming worldwide is responsible only for 10 percent of mangrove deforestation (Menasveta 1997; Correia et al. 2002; Diana 2009) do not appear to apply to Ecuador. Indeed, almost all mangrove loss in all regions of the country is directly attributable to displacement by shrimp farming. The claim that shrimp farming prefers terrestrial locations as opposed to aquatic locations (Boyd and Clay 1998; Diana 2009), and hence does not conflict with mangrove forests is also refuted by the results of this study. Indeed, shrimp aquaculture appears to prefer mangrove forests as a location even when other locations are available. The claim that aquaculture provides a pathway towards food security and employment income for artisanal coastal residents (United Nations Committee on World Food Security 2003) has not borne fruit. Shrimp farming in Ecuador is likely depleting available protein resources available to local populations and providing few employment opportunities to local residents.

The primary pathway from shrimp farm expansion to a decrease in livelihood options and food security among local populations is the destruction of mangrove forests to accommodate the shrimp farms. Within the majority of Ecuador's estuaries mangroves have been depleted to a small fraction of their former area. Indeed, excluding the mangrove preserve of Cayapas-Mataje, shrimp farms now occupy twice as much

estuarine land as mangrove forests. Technically speaking, small amounts of mangrove forests now exist in Ecuador's shrimp farmed estuaries, as opposed to shrimp farming existing in mangrove estuaries. The loss of mangroves has led to a loss of forest-based livelihoods and shrimp farm advocates economically appear to undervalue these livelihoods when evaluating the cost benefit of shrimp farms. Shrimp farms likely contribute to wider livelihood and food security issues if the recently advocated relationship between mangrove deforestation and declines in offshore wild catch are applicable to coastal Ecuador. Additionally, shrimp farm practices, such as the use of pesticides and herbicides, magnify the environmental degradation of the estuary beyond the mere loss of mangrove forest resulting in further livelihood disruption. Indeed, the heavily shrimp farmed estuaries of Ecuador are no longer functioning as estuarine environments when the full biogeochemical suite of functions of healthy estuaries are considered. Additionally, employment created by shrimp aquaculture and employment conditions on farms do not compensate for loss of traditional livelihoods resulting from shrimp farm expansion into estuaries.

The varying levels of mangrove depletion across the study areas and survival of traditional mangrove economies appears to be dictated by a combination of community knowledge, community organization, and geographic chance. Estuaries that are geographically isolated and not well connected to Ecuador's road network, such as Cayapas-Mataje Estuary and Rio Hondo Estuary, appear to have maintained their traditional livelihoods more so than those that are well connected. Estuaries that had late arrival of aquaculture generally maintained their traditional livelihoods more so than those that had early arrival of shrimp aquaculture. This is likely due to community

knowledge of the relationship between mangrove deforestation and local livelihoods gleaned from estuaries that had early arrival of aquaculture. Estuaries where community fisherman organized and resisted shrimp farms appear to have maintained their mangrove based economies whereas those that did not resist, or welcomed the shrimp farm economy, have not.

The socioeconomic implications of shrimp farms displacing mangroves are numerous. The transition from mangrove to shrimp farm appears to have adversely affected the poorest members of society more than wealthier members. For example, *concehros* require direct foot access to a mangrove estuary. Social custom is to preserve these positions for women in the community. Shrimp farms not only impede this group's access to the estuary but have also depleted the resource on which they rely. Again, poorer fishermen without boats are more adversely affected than wealthier fishermen who have access to boats with motors. These poorer fishermen require direct access to the estuary that is now impeded by the shrimp farms. Shrimp farming has forced women within traditional fishing communities into the cash labor economy as estuary resources are depleted. These unskilled women generally inhabit the bottom rung of the employment ladder. Regions such as Muisné, Cojimíes, and Chone have experienced out-migration due to the lack of livelihoods available from the estuary. This in turn has likely led to increased fishing pressure on preserved estuaries that have resisted the advance of aquaculture as many of these displaced fishermen have likely relocated to estuaries that still support their traditional livelihood employment. Those that inhabit the inland interior of an estuary are generally poorer than those that reside or more expensive

coastal land. Again, these communities rely entirely on the mangrove estuary and suffer the most adverse livelihood and food security impacts of the land use conversion.

One of the major differences between other forms of deforestation and mangrove deforestation is the relative depletion of livelihood options and food security associated with mangrove deforestation. For example, rainforest deforestation and mangrove deforestation both result in macroclimate changes, both result in losses of biodiversity, and both have socioeconomic implications for residents that reside in the area. Yet, estuary mangrove forests are a major food production system with each hectare lost resulting in the loss of many local livelihoods. Other types of forest such as rainforest do not have the same impact on highly productive food production systems per hectare of loss. Indeed, tropical forest have only 6 percent of the food productivity of a tropical estuary, 7 percent of the food productivity of a mangrove forest, and only 3 percent the rate of a mangrove forest and estuary combined (Costanza et al. 1997). Although shrimp farms that displace the mangrove forests are a food production system in their own right, they appear not to be as productive at food production, particularly at the artisanal level, as the resource they displace.

Restoring traditional livelihood options, improving food security, and decreasing poverty among traditional communities in coastal Ecuador are likely dependent on reforestation within the analyzed estuaries. The estuaries and mangrove forests of Cayapas-Mataje are an example of how historically depleted resources can return to its former condition through a combination of community organization, government support, and shrimp farm resistance. As depicted in the land cover change analysis, Chone fisherman, Muisné activists, and Cojimíes outsiders are currently attempting limited

amounts of reforestation in all estuaries. Fortunately, compared to other threatened forest environments, regrowth of mangrove can occur in relatively short periods. Newly planted mangrove seedlings begin to reach maturity in twenty years or less, and reforestation can be achieved by direct replanting of mangrove as opposed to having to transition through other intermediary land cover stages. The realization of mangrove importance to a traditional fishing lifestyle appears to be understood within all estuaries. This is demonstrated by the active reforestation of mangrove forests in almost all estuaries studied. For this expansion of mangrove forest to be successful, however, shrimp farms will likely have to be removed from the estuaries to restore aquatic health. For this to occur a full livelihood and food security analysis of the shrimp aquaculture vs. mangrove forest conflict will likely need to be realized.

Currently the shrimp farm / mangrove cost benefit model is skewed artificially in favor of the extractive aquaculture practice. Removal of shrimp ponds and reforestation of mangroves in the former ponds is unlikely unless the true value of mangroves and the full costs of shrimp farming are determined. This will take a fundamental shift in economic valuation of natural resources. For example:

1. Shrimp farmers rely on huge economic subsidies and even larger subsidies from nature to operate. They are not required to produce or secure all the capital required to establish the shrimp farms. This cost is born by residents of the developed world.
2. Shrimp farmers do not have to purchase aquatic resources in Ecuador, historically they have just built out from the terrestrial edge of the estuary into the unclaimed

mangrove forest. Yet it has been shown the mangrove s located within estuaries are the potentially the most economically productive land cover on earth. Shrimp farmers are not required to purchase the largest input to their process, economically productive estuarine real estate.

3. Shrimp farmers are not required to account for the effluent outputs produced by the commercial pond rearing of shrimp. These costs are borne by the local community.
4. Shrimp farmers are not required to purchase the input estuary water provided to sustain their farms. This cost is borne by the local community.
5. Shrimp farmers are not required to compensate artisanal fisherman for the depletion of fisheries resulting from red-tide events and anoxic conditions induced by their farms. Such costs as these are borne by the local community.
6. Shrimp farmers are not required to address the issue of terrestrial induced sedimentation and terrestrial nutrient loading of the estuary that was once mitigated by the mangrove forest. Such costs as these are borne by the local community.
7. Shrimp farmers are not required to compensate adjacent landowners or residents for salinization of ground water. Such costs as these are borne by the adjacent landowner and community residents.
8. Shrimp farmers are not required to return the soil or sediment to its prior condition once a shrimp farm is abandoned. Such costs as these are borne by the local community.
9. Shrimp farmers are not required to reimburse terrestrial landowners for



increased rates of coastal erosion due to mangrove removal. Such costs as these are borne by the adjacent landowner and community residents.

10. Shrimp farmers are not required to reimburse communities for increased impacts from *El Niño* driven storm events and increased flooding due to mangrove removal and shrimp farm construction. Such costs as these are borne by the local community, national government, and often the international community.
11. Shrimp farmers are not required to compensate for human health conditions that workers, and even wider communities, suffer due to shrimp farm practices. Such costs as these are borne by the local community, government, and the international community.
12. Shrimp farmers pay only market price for Postlarvae and fishmeal regardless of the true economic value of these products to fisheries. Such costs as these are borne by the local community and those reliant on fisheries at all scales.
13. Shrimp farmers are not required to partake in carbon purchasing programs that would require offsets for the forest removed. Such costs as these are borne by the local community, government, and the international community.
14. Shrimp farmers bear none of the cost of restoring estuaries to their former condition. Again, in Ecuador this cost is borne mostly by the local community.

Once the true value of mangrove livelihoods are understood and advocated, and the true costs of shrimp farm creation and operation are charged to the industry as opposed to being borne by traditional fisherfolk who reside in region, then the

rehabilitation of Ecuador's estuaries becomes not only practicably possible but also economically feasible. If such a socioeconomic rebalancing occurs, the full potential of traditional livelihoods based on the estuaries and the potential for ensuring long-term food security among local populations dependent on the estuary, are likely to be realized.

## CHAPTER VII

### POLICY RECOMMENDATIONS

The results of this manuscript indicate that ceasing investment in shrimp aquaculture in Ecuador's coastal zone and reassessing development and investment priorities to reflect the importance of pristine mangrove estuarine environments will have several key benefits. Such a reprioritization will promote long-term sustainable economic development within the region, increase food security for local residents, increase the amount of available protein available to local residents, improve local health outcomes, and help support micro and macro level fisheries. This manuscript presents several concrete macro-level policy recommendations to mitigate and improve the current loss of livelihood opportunities and food security caused by the long-standing support of shrimp aquaculture development in mangrove ecosystems.

1. *Redirection of development agency objectives away from aquaculture support towards forestry support and conversion of aquaculture lands back into their original land use.*

Although outliers still exist, the preponderance of the scientific evidence views aquaculture, particularly shrimp aquaculture in tropical estuarine environments, as detrimental to local livelihoods, food security, and the wider goal of development. These findings are supported by this research in coastal Ecuador. The optimistic viewpoint stated in the early years of shrimp aquaculture in Latin American estuaries that aquaculture can be a positive force for sustainable development, create jobs, and promote a healthy environment (Dewalt, Vergne and Hardin

1996) has not materialized. Indeed, within Ecuador shrimp aquaculture has proven to be entirely unsustainable, causes a loss of jobs, and results in massive environmental degradation. Despite this evidence, agencies tasked with encouraging development within Ecuador are still supporting aquaculture as a means of alleviating poverty. Within even the last few years, aquaculture projects have been proposed in the pristine Ecuadorian forests on the Colombian border.

2. *Shift from support of fisheries and aquaculture to support of fisheries exclusively at all levels, but particularly within the United Nations.*

Currently, the FAO supports aquaculture through the Division of Fisheries and Aquaculture. At the artisanal level, the evidence is insurmountable that these two activities are diametrically opposed (Blaber 2007). This manuscript supports this finding. Aquaculture depletes local fisheries and this depletion adversely affects local livelihoods. Evidence is mounting that this relationship also exists at the macro level when pertaining to wild catch. Currently, donors and agencies tasked with sustaining and supporting wild fisheries are having their resources utilized for an activity that undermines the desired developmental goal, as aquaculture promotion is also the mandate of these agencies yet aquaculture may deplete fisheries.

3. *A holistic approach to determining the economic value of a mangrove forest in estuaries that includes all the sustainable goods and services provided by a mangrove forest.*

It is contended that to fully evaluate the economic costs and benefits of shrimp aquaculture, the costs and impacts associated with other food production systems - for example, ranching -- must be analyzed and compared (Diana 2009). This statement on the surface appears entirely reasonable, and indeed such analyses should be undertaken. Yet conversely, a more holistic approach to valuing shrimp aquaculture in estuarine environments must also be undertaken. Such analyses should account for the fact that shrimp aquaculture actually displaces a highly productive food production system, has numerous environmental costs associated with its operation, and generally exports the majority of its output and profit overseas. If such holistic economic approaches were undertaken, the basic economic cost / benefit analysis would likely prohibit shrimp farms being built in a mangrove estuarine system. The mangrove food production system is one that supports fisheries at all scales, provides numerous other goods and services to local communities, and continues its economic output across many generations, as opposed to the five to fifteen-year life span of a shrimp pond. Within Ecuador, it is unlikely that even the most productive shrimp farming system provides more economic returns than a pristine mangrove environment even when the environmental costs associated with shrimp farming are excluded from the analysis. International aid flowing into aquaculture projects may actually force disequilibrium into this cost benefit equation and make shrimp aquaculture appear to be more economically beneficial than would have been the case if all the costs of the aquaculture project had to have been met by free market investment capital.

4. *Support of the conversion of ownership of estuaries to local stakeholders, who benefit from well-stocked fisheries and a healthy mangrove forest.*

Within Manabí and Esmeraldas Province, the restoration of mangrove forest and the halt of the advance of shrimp farming in mangrove forests has arisen from artisanal fishing communities and formal or informal syndicates within these communities. The situation appears to be the inverse of a Tragedy of the Commons (Hardin 1968). The privatization of the communal estuary has resulted in the depreciation of the communal resource as opposed to the preservation of the resource. For example, the Chone shrimp syndicate only controls a small portion within the Chone Delta and it is in this area, mangrove forest is thriving. Yet, the remaining estuary is almost depleted of its entire forest cover, with 90 percent of the mangrove forest lost. In Cayapas-Mataje, traditional estuarine users halted and then reversed the creation of shrimp farms. The approach advocated here is similar to the conclusion reached in Southern Thailand (Vandergeest 2007) and stated that that local communities and local governments are currently the most effective regulators of shrimp farming. Passing estuary decisions onto estuarine stakeholders will likely assist in the restoration of the estuary, as it will be in the economic interest of the stakeholders to maintain aquatic health.

5. *Increased assistance by enforcement agencies, policies, and policing of laws that protect estuarine environments.*

One of the persistent themes associated with aquaculture is the issue of enforcement. Robust earlier studies of this nature all point to the role of enforcement of regulation such as environmental impact statements and delineating protected areas in sustainable shrimp farming. The development community would see increased results if it invested in these activities, as opposed to those that replace such ecosystems. Although this manuscript rejects the notion of sustainable commercial shrimp farming in tropical estuarine mangrove forests, it does recognize the importance of enforcement of existing law as it pertains to mangrove deforestation and land ownership. Indeed, Ecuador has laws in place that prohibit mangrove deforestation but they are rarely if ever enforced.

## APPENDIX A

## OCCUPATIONAL SUMMARY

The occupational summary for the principles interviewees in the semi-structured are: thirteen fishermen, six heads of regional fishing syndicates or fishing inspectors, seven guides who are typically part-time fisherfolk and part-time guide but list their occupation as guide, six shrimp farm workers or workers who rely on the shrimp farms for employment, and three other.



## APPENDIX B

## IRB APPROVAL



## THE UNIVERSITY OF SOUTHERN MISSISSIPPI

Institutional Review Board

118 College Drive #5147  
 Hattiesburg, MS 39406-0001  
 Tel: 601.266.6820  
 Fax: 601.266.5509  
 www.usm.edu/irb

**HUMAN SUBJECTS PROTECTION REVIEW COMMITTEE  
 NOTICE OF COMMITTEE ACTION**

The project has been reviewed by The University of Southern Mississippi Human Subject Protection Review Committee in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services (45 CFR Part 46), and university guidelines to ensure adherence to the following criteria:

- The risks to subjects are minimized.
- The risks to subjects are reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered regarding risks to subjects must be reported immediately, but not later than 10 days following the event. This should be reported to the IRB Office via the "Adverse Effect Report Form".
- If approved, the maximum period of approval is limited to twelve months. Projects that exceed this period must submit an application for renewal or continuation.

PROTOCOL NUMBER: **29092201**

PROJECT TITLE: **The Impact of Commercial Aquaculture on Mangrove Ecosystems, Local Livelihoods, and Food Security Along the Pacific Coast of Ecuador**

PROPOSED PROJECT DATES: **10/01/09 to 05/31/10**

PROJECT TYPE: **Dissertation or Thesis**

PRINCIPAL INVESTIGATORS: **Stuart Hamilton**

COLLEGE/DIVISION: **College of Science & Technology**

DEPARTMENT: **Geography & Geology**

FUNDING AGENCY: **N/A**

HSPRC COMMITTEE ACTION: **Expedited Review Approval**

PERIOD OF APPROVAL: **10/05/09 to 10/04/10**

## APPENDIX C

## INTERVIEW HOUSING

Interviews are available in transcript and audio format from CGA, Swem Library, Williamsburg, VA 23185. Email [sehamilton@wm.edu](mailto:sehamilton@wm.edu) or contact the Swem reference desk for more information.

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