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Volume 33

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Stuart E. Hamilton

# Mangroves and Aquaculture

A Five Decade Remote Sensing Analysis  
of Ecuador's Estuarine Environments

 Springer

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ISSN 2211-0577                      ISSN 2211-0585 (electronic)  
Coastal Research Library  
ISBN 978-3-030-22239-0              ISBN 978-3-030-22240-6 (eBook)  
<https://doi.org/10.1007/978-3-030-22240-6>

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The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*While I was in Ecuador conducting research for this book in April 2016, northern Ecuador was struck by a 7.8 magnitude earthquake centered near Cojimies Estuary. I want to dedicate this text to the families of the 676 people who died in the earthquake, the 17,000 that were injured, and the tens of thousands who lost their homes.*

# Preface

This book has two primary aims:

1. To tell the land use and land cover change story of Ecuador's estuaries from the advent of commercial shrimp aquaculture to the present day
2. To provide a consistent and repeatable remote sensing synthesis methodology that allows for others to conduct such analysis in different regions using different sensors that can be used in both research and instructional settings

This idea for this research began during my first trip to coastal Ecuador in late 2006 and early 2007. During this trip, I traveled up and down the Pacific Ocean coastline between Guayaquil in Guayas Province and San Lorenzo in Esmeraldas. During the long road trips, I saw the magnitude of the landscape changes that had occurred since the advent of commercial aquaculture in this region. I was surprised I did not know about such a massive and recent tropical land cover change. Massive shrimp pond systems dominated the coastal estuaries, while mangrove forests had retreated to a few locations in some isolated locations. Local fisherfolk told me a consistent story of mangrove forest loss and shrimp farm expansion occurring over the prior two or three decades and how now this land cover transition had altered their way of life.

On my return to the USA, I reviewed the academic and broader literature and could only find a limited accounting of what had occurred in this region as it pertained to mangrove loss and shrimp farm expansion. What I did find was a call to arms to tell the story from others interested in this topic. During this time, I had been considering applying to a doctoral program but had yet to find a topic that genuinely motivated me, but upon visiting Ecuador one more time and completing my literature review, I was sure this would be that topic, so I applied to Ph.D. programs with an outline of my dissertation already written. I wanted to tell the land use and land cover change story of Ecuador's coastal estuaries since the arrival of shrimp aquaculture.

I graduated with a Ph.D. about 5 years later with a dissertation entitled, "The Impact of Shrimp Farming on Mangrove Ecosystems and Local Livelihoods Along the Pacific Coast of Ecuador." Although proud of the dissertation, I immediately felt

it only told a small portion of the complete story I had been researching. I began to flesh out more of the story in other venues. I was fortunate that others found the research worthwhile and a raft of publications followed including pieces in *Nature Climate Change*, *Annals of the Association of American Geographers*, *PLOS One*, *Global Ecology and Biogeography*, *Bosque*, and *Proceedings of the National Academy of Sciences of the United States of America* and a chapter in the Coastal Research Library, to which this book belongs. All these manuscripts told interesting, but isolated, portions of the bigger story. This initial mangrove and shrimp farm research agenda additionally provided me both fellowship and further research opportunities in Ecuador to continue researching the topic. As my mangrove research expanded over time, the desire to revisit the entire coastline of Ecuador and attempt to write the definitive text grew stronger. Despite the journal articles, presentations, and book chapter publications, the feeling that the full story was not being told persisted within me, and I began to realize that a comprehensive monograph was likely the only means to get the full story out to other academics and hopefully both the public and policy-makers.

From 2006 to present, I continued expanding on my research into mangrove loss and shrimp farm expansion and visited Ecuador every year for almost a decade, including living on the coast in both 2005 and 2016. Among other activities, I participated on a working shrimp farm, hiked through remote mangrove forests, and visited a shrimp hatchery. While in Ecuador, I visited the remaining mangrove forests that I had been unable to reach prior. From 2006 to 2016, I conducted interviews with fishing syndicates, held meetings with local researchers, conducted ethnographic research, and held PPGIS workshops all along the coast. Sarah Collins took the lead on the livelihood research while I kept expanded the land cover and land use theme of the research. Ramon Cedeno Loor took me under his wing and arranged for visits to ever more remote mangrove forests and meetings with more stakeholders. With the help of many students, I processed more land cover data from ever more resolute Earth observing systems and incorporated these data into my ever-growing spatial databases. By early 2016, the book was ready to be written as I finished my fellowship in Bahia de Caráquez, Ecuador.

From 2016 to 2018, the text was written and revised, and Springer accepted the book as part of their Coastal Research Library series. The book attempts to give as complete as possible account of the land cover and land use change that occurred in Ecuador's estuaries from the advent of commercial aquaculture to present. The book covers each estuary in Ecuador to allow for local, regional, provincial, and national results to be derived. In addition to telling the Ecuador story, the book presents a methodology of remotely sensed data synthesis that can be applied to other regions and other land cover types globally.

The first chapter of the book is dedicated to mangrove forests. It introduces mangrove forests and examines mangrove biology including mangrove adaptive mechanisms that allow them to exist in saline and anaerobic environments, their evolution, their current distribution, their paleodistribution including the mangrove anomaly, their historic and current coverage area estimates, their traditional uses, their species composition, their support of fisheries, their management regime, and their role in

climate change. The chapter examines each of these topics at the global scale, at the Ecuadorian national scale, and when possible at the local scale. The chapter is written for coastal researchers who not are either biologists or botanists but desire to gain a foothold in mangrove research and understand the role of mangrove forests.

The second chapter of the book provides a review of shrimp aquaculture. It provides a background on shrimp farming and wider aquacultural practices. The chapter is again written for none aquaculture experts to gain the required knowledge of shrimp aquaculture to conduct such analysis as this in other regions. This chapter covers the biology of shrimp including the complex lifecycle of *Penaeus vannamei* in both the wild environment and farmed systems. Additionally, it covers the operation and management of shrimp farms, the legal framework of aquaculture in Ecuador, and the importance of Ecuador's estuaries and mangrove forests to both farmed and wild shrimps. Again, the chapter transitions from global to Ecuador to local in scale.

The third chapter of the book delineates the study sites and subdivides the coastline of Ecuador into logical estuarine units for analysis. It is dedicated to the local situation. The chapter provides information on each of the study sites including the climatic conditions of each of the estuaries, the environmental regime present in each estuary, the protected status of each estuary, the biodiversity associated with each estuary, and the socioeconomic condition of the residents who reside near the estuary. It not only attempts to provide the reader with the statistics, facts, and boundaries for each estuary but also attempts to additionally provide information on the milieu of the residents of the estuaries including information on the lifestyle, livelihoods, and culture of each estuarine community.

The fourth chapter is dedicated to the methodology with a significant portion of the chapter describing remote sensing of the Ecuadorian estuaries from pre-1970 to present. It presents a consistent and widely applicable remote sensing methodology that allow for repeating this study in Ecuador and more importantly to duplicate this study in other regions. It reviews the Earth observing instruments used, the feature delineation approaches taken, the GIS tools applied in the method of change detection, and how the differing Earth observing systems and other data were combined into a singular spatiotemporal analysis. The data required to repeat this approach is provided in the accompanying Dataverse.

The fifth chapter presents the results of the study. The results are presented at the estuarine level and then summarized to the national level. The first set of results presented document the changes in areal extent of mangrove forests and shrimp farms across all study sites. The second set of results examines the displacement of one land cover type by another. The results also present the spatiotemporal land cover changes and the sub-estuary and estuary scale. Finally, the estuary results examine the patterns revealed in the remote sensing analysis that validate the oral histories provided by local stakeholders. The data required to repeat this approach is provided in the accompanying Dataverse.

Finally, the sixth chapter of the book is a brief discussion that identifies future research needs and identifies data gaps, presents some potential policy ideas for consideration, and discusses the broader implications of this study at multiple



scales. The discussion also describes the pros and cons of the methodological framework presented and suggests additional regions that may benefit from a similar approach.

The accompanying Dataverse provides all data in GIS and tabular formats. This includes all input data, all output data, and other data required for data processing. The URL is <https://dataverse.harvard.edu/dataverse/MFACRL>.

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# Acknowledgments

I want to thank Dr. Klaus Meyer-Arendt for initially introducing me the coastal region of Ecuador and providing funding for our initial trip up and down the coast. I also wish to thank Donald Hagan and Tia Hagan for introducing me to the mangrove sites in the Rio Chone Estuary that first garnered my interest in this topic.

I want to acknowledge the Nature Conservancy; Secretary of Higher Education, Science, Technology, and Innovation (Senescyt); the University of Southern Mississippi; the University of West Florida; and Salisbury University for funding portions of this research.

Thank you to Clay Harris, Justin Fitt, Christopher Kaempf, Sarah Collins, Marco Millones, Victor Collins, Shauna Kiernan, Mike Mitchell, Ramon Cedeno Loo, Jose Eduardo Ganchozo, Sean Conner, Nathan McKinney, Don Hagan, Erica Moldenhauer, Jose, Leonardo Caeua, Ronald Zembrano, the field staff of Global Student Embassy, the staff of the local MAE office in San Vicente, and countless others for providing their labor free of charge while in the field.

Thank you to Clare Stankwitz, John Lovette, Sarah Byrd, and all the Salisbury University geography students for their help with digitizing and extracting land use and land cover data for the estuaries.

I would like to thank the fisherman of the Isla Corazon community for allowing me to interview the cooperative members and for providing numerous trips into the mangrove forest.

I would like to thank Clare Stankwitz for her help on compiling the shrimp farm financing data used in Chap. 2.

I would like to thank John Talbot for automating of tasks within this process.

I would like to thank Liam Hamilton for summarizing global mangrove numbers and cross-checking math operators.

I would like to thank Paige Roberts for her editorial assistance and reviewing Chap. 2 as well assisting with the remote sensing systems timeline graph.

I would like to thank Noah Krach, Gustavo Castellanos, and Paige Roberts for reviewing each of the chapters of this book and providing throughout insights to improve the text.

Without funding and data availability decisions made by the NASA, the USGS, the Government of Japan, and other agencies, then, research of this type would become unaffordable.

Thank you to Sarita Collins for the translation services, assistance in the field from her and her extended family, helping develop the ideas for this book, and always being available at short notice with a team of workers to assist in the field. She not only assisted but applied her local knowledge to help me gain access to many local communities as well as fulfill my other important roles while in the field. She is the only other individual aside from Ramon Cedeno Loor and I involved from start to end in this research process, and without her, this research would not have been possible.

I would like to thank Noah Krach for cleaning the data and helping process the estuarine data. Noah is a coauthor on the published data on the Dataverse. Without his effort, Chap. 4 would have extended on indefinitely.

Finally, I would like to thank my good friend Ramon Cedeno Loor for the 13 years of support in Ecuador and beyond. He introduced me to the local fisherman, took me to the major shrimp farms, and was always happy to set up meetings with public officials. He provided many of the insights that are fleshed out in this text. He traveled with me every trip and worked every day to achieve the environmental goals of the research. He ensured my safety in dangerous areas and worked tirelessly everyday to help me achieve the goals of this manuscript. His dedication to the ecological health of the region is second to none, and without him, this manuscript would be no more than an unfulfilled idea.

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# Acronyms

AC	Agulhas Current
ACEP	Atlantic, Caribbean, and Eastern Pacific
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BC	Brazilian Current
BeC	Benguela Current
BMN	Baculoviral Midgut Gland Necrosis
BOD	Biological Oxygen Demand
CE	Chone Estuary
CI	Confidence Interval
CJ	Cojimies
CLIRSEN	Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos
CM	Cayapas-Mataje
DAC	Development Assistance Committee
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
EAC	East Australian Current
EOS	Earth Observing System
ESA	European Space Agency
ETM+	Landsat Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization of the United Nations
FARC	Revolutionary Armed Forces of Colombia
FCR	Feed Conversion Ratio
FDI	Foreign Direct Investment
FUNDECOL	Fundación para la Defensa Ecológica
GDP	Gross Domestic Product
GFC	Global Forest Cover
GG	Gulf of Guayaquil
GIS	Geographic Information System
GLCF	Global Land Cover Facility



GS	Gulf Stream
HAB	Harmful Algal Bloom
HC	Peruvian/Humboldt Current
IFC	International Finance Corporation
IGM	Instituto Geografico Militar
IHHNV	Infectious Hypodermal and Hematopoietic Necrosis
IMF	International Monetary Fund
ISME	International Society for Mangrove Ecosystems
ITTO	International Tropical Timber Organization
IUCN	International Union for Conservation of Nature
IWP	Indo-West-Pacific
KC	Kuroshio Current
LULC	Land Use and Land Cover
MAE	Ministerio del Ambiente del Ecuador
MFW	Mangrove Forests of the World
MHHW	Mean Higher High Water
MLC	Maximum Likelihood Classification
MS	Muisne
MSS	Multispectral Scanner 1
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NGO	Nongovernmental Organization
NOAA	National Oceanographic and Atmospheric Administration
OECD	Organisation for Economic Co-operation and Development
OLI	Operational Line Imager
PBDE	Polybrominated Diphenyl Ethers
PCB	Polychlorinated Biphenyls
PCDD	Polychlorinated Dibenzodioxins
PCDF	Polychlorinated Dibenzofurans
PMRC	Coastal Resources Management Program
PPGIS	Public Participation Geographic Information Systems
PSAD	Provisional South American Datum
RBV	Return Beam Vidicon
REMCAN	Reserva Ecológica Manglares Cayapas Mataje
REye	RapidEye
RMSE	Root-Mean-Square Error
SLC	Scan Line Corrector
SNAP	Sistema Nacional de Áreas Protegidas del Ecuador
SPOT	Satellite Pour l'Observation de la Terre
SWIR	Short-Wave Infrared
TIR	Thermal Infrared
TM	Landsat Thematic Mapper
TOA	Top of Atmosphere
TSV	Taura Syndrome Virus
UAV	Unmanned Aerial Vehicle

UN	United Nations
USAID	United States Agency for International Development
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VHR	Very High-Resolution Satellite-Based Optical Imagery
VNIR	Visible and Near-Infrared
WDPA	World Database on Protected Areas
WGS	World Geodetic System
WRS	World Reference System
WSSV	White Spot Syndrome Virus
ZEM	Special Area Management Plan