Mangrove and Forest Loss near Three Coastal Protected Areas in Ecuador: Integrating Global Tree Cover and National Census Data

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May 2014

Abstract

Mangrove forests not only sustain high biodiversity and productivity, but capture sediments and nutrients, stabilize soils, prevent erosion, and provide food and livelihoods for the human populations that surround them. These ecosystems are threatened by numerous anthropogenic activities that lead to deforestation or forest degradation. This research aims to examine the proximate causes and underlying driving forces of mangrove and surrounding deforestation in three coastal protected areas in Ecuador: Cayapas Mataje in the Cayapas Mataje Estuary, Churute in the Guayas River Estuary, and Mache Chindul in the Cojimies Estuary. Using the University of Maryland's global forest change dataset, calculations for tree cover loss within protected areas and within surrounding 25 km buffer areas were derived in ArcMap 10.2. An analysis of census data from Ecuador's National Institute on Data and Statistics was completed to determine provincial population sizes and projections. The analysis indicated that higher levels of tree cover loss occur in the buffer zones outside of protected areas rather than within protected areas. Analysis of census data revealed that the largest provincial populations are located on the western coast near the protected areas, but that the majority of projected percent population changes for 2020 will actually occur in the eastern, interior region of the country. Additional research is needed before realistic management recommendations can be made, particularly on proposed management plans, other driving forces leading to deforestation, and different as well as additional buffer zone specifications.

Introduction

Mangroves live in the intertidal zones where salt water, fresh water, and land all meet. There are nearly 73 different species of mangrove trees that live in these intertidal areas, in over 123 countries worldwide. Thriving in tropical environments, mangroves can be either the trees that characterize these areas or the entire communities that groups of these trees form (Spalding et al. 2010). The ecosystems themselves are typically composed of a myriad of different vegetation types, with each species being affected by changes in others (INEFAN/GEF 1998). Mangrove species have the unique ability to adapt to a physical environment with normally anaerobic soils continually flooded by the tides (Spalding et al. 2010). Mangroves are not only crucially important to the ecosystems they are a part of, but help create these ecosystems via soil stabilization, which prevents erosion and minimizes damage from hurricanes or typhoon (Hamilton and Collins 2013). Mangroves sequester and capture both sediment and nutrients, preventing runoff and nutrient overloading (Hamilton 2012). Levels of productivity higher than even temperate or tropical forests enhance these ecosystem services (Spalding et al. 2010).

Mangroves are also often called foundation species because of their significant influence on biodiversity and species dynamics (Polidoro et al. 2010). They sustain high biodiversity and provide habitats for numerous species, including over 140 bird species, 200 fish species, and hundreds of other terrestrial species in Colombia and the Caribbean (Alvarez-León and Garcia-Hansen 2003). Different organisms also utilize mangrove forests during different parts of their life cycles (Hamilton 2012) Many of these species, such as fish, crabs, and conch, represent important sources of traditional seafood to local communities and people, while other plants provide uses such as wild honey, sugar, and alcohol (Hamilton and Collins 2013).

Local residents also rely on mangrove forests for housing materials, firewood, fuel wood, building boats, and sewage treatment (Hamilton and Collins 2013). Other activities, such as recreation, tourism, and aquaculture have led to numerous studies quantifying the economic value of mangrove ecosystems, with the global average in 1994 being $9,990 per hectare annually for mangrove swamp and $22,832 per hectare annually for estuaries (Costanza et al. 1997). However, more recently in northern Haiti, mangroves have been reported to be worth as much as $35,000 per hectare per year (Inter-American Biodiversity Information Network 2009) and at least $1.6 billion per year in total (Polidoro et al. 2010). These estimates do not include other functions that mangrove ecosystems provide, such as carbon sequestration, pollination, and medicinal purposes (Hamilton and Collins 2013).

Mangrove Ecosystem Degradation

The extent of mangrove and ecosystem loss has been uneven across the planet. It has been estimated that somewhere between 20-35% of mangrove areas has been lost globally since 1980, although these figures differ by country and region (Polidoro et al. 2010). For example, in Ca Mau, mangrove cover fell from 200,000 to 60,000 hectares due to shrimp farming from 1975-2004. In the Philippines, nearly half of the mangroves had been developed into shrimp aquaculture ponds as of 1988 and in Thailand around 253,000 hectares of 380,000 had been destroyed by shrimp farming as of the 1990s (EJF 2004). Additionally, in at least 12 countries, important RAMSAR wetland sites are under threat from shrimp farming (EJF 2004). The RAMSAR convention is an international treaty for the conservation and sustainable utilization of wetlands, including mangroves, which designates areas important for conservation.

Mangrove ecosystems suffer from degradation and deforestation due to many different immediate causes and underlying drivers. For example, around 26% of mangrove cover loss has been attributed to types of wood extraction, while 38% is due to aquaculture (Polidoro et al. 2010). Geist and Lambin’s (2002) framework for analysis of the proximate causes and underlying driving forces of tropical deforestation can be applied to mangrove deforestation and degradation. Proximate causes leading to deforestation include agricultural expansion such as cultivation or cattle ranching, wood extraction, infrastructure, as well as other factors such as shrimp aquaculture. Underlying driving forces can be categorized as either demographic, economic, technological, policy and institutional, or cultural (Geist and Lambin 2002). These factors may also interact in complex ways, often synergistically, to lead to mangrove deforestation or degradation.

One specific cause of mangrove degradation seen recently is land use change due to shrimp aquaculture development. The commercial cultivation of shrimp for human consumption was introduced into mangrove ecosystems in the early 1970s because mangrove habitats can act as a nursery for fish and invertebrates. More prevalent in the tropics of developing countries, the rapid expansion of shrimp aquaculture was unplanned and unregulated (EJF 2004). Governments, international organizations, and aid agencies all supported and encouraged the development of the industry because shrimp farming represented a new source of income for typically poorer nations (EJF 2004). To create the shrimp pools and ponds necessary for cultivation, mangrove forests were deforested and surrounding habitats were adversely affected, increasing coastal exposure to storms and erosion, reducing biodiversity, emitting pollution from organic wastes or chemicals, depleting wild fish and shrimp stocks, and prompting numerous indirect results. Many traditional fishermen have also been directly affected as their livelihood options are reduced (Hamilton 2012).

The role of protected areas in stemming mangrove degradation

South America contains 15.7% of the world's mangroves (Spalding et al. 2010), depicted in Figure 1 (Polidoro et al. 2010). Ecuador in particular is a prime location for tropical mangrove habitat, lying on the equator. Ecuador is also representative of different levels of mangrove degradation and different levels of protected status for protected areas. Although a significant portion of the mangrove deforestation that has occurred in Ecuador can be directly attributed to shrimp aquaculture development, further analysis could reveal other, additional proximate causes and underlying driving factors. In this study, through an investigation of tree cover data and demographic census data in ArcMap 10.2, population-related factors will be examined for their potential to lead to mangrove deforestation in relation to the influence of protected areas.

The study region and coastal protected areas in Ecuador

According to Article 70 of Ecuador's 1979 National Forest, Protected Area and Wildlife law (*Ley Forestal y de Conservación de Areas Naturales y Vida Silvestre*), there are seven possible categories of protected areas in Ecuador: National Park, Biological Reserve, Ecological Reserve, Geobotanical Reserve, Fauna Production Reserve, National Recreation Area, and Awá Reserve (INEFAN 1996, INEFAN/GEF 1998, MAE 2005). The protected areas examined in this study all fall under the classification of Ecological Reserve. In 1981, additional legal frameworks established more types of protected area types and created additional reserves, parks, and protected areas (INEFAN/GEF 1998).

Management plan foci can be explained in part by the historical relationship between economics and natural resource use in Ecuador. The country's economic development has always been closely tied to the exploitation of natural resources. Therefore, the conservation and protection of important ecosystems is significantly based on the goods and services that they are able to provide. Although the ecological, aesthetic, and cultural value of ecosystems are significant, it is often their economic benefits that provide the strongest justification for their conservation (INEFAN/GEF 1998). When Ecuador decided to invest in conservation and the maintenance of the economic potential of these ecosystems, focus was given to ecotourism, environmental services, sustainable extraction of non-timber products, regulating bioprospecting and sustainable agroforestry activities (INEFAN/GEF 1998). It is hoped that advocating for these activities will increase the desire to also conserve the cultural, ecological, or aesthetic facets of these protected areas and natural ecosystems (INEFAN/GEF 1998).

Degradation in selected study regions

Three Ecuadorean coastal protected areas and the nearby, large estuaries are the focus of this study: the Cayapas Mataje Ecological Reserve (Cayapas Mataje) near the Cayapas Mataje Estuary, the Churute Mangrove Reserve (Churute) near the Guayas River Estuary, and the Mache Chindul Ecological Reserve near the Cojimies Estuary. Degradation has been reported in each estuary and near each protected area, but over various time scales and at different levels. Minor loss of mangrove forest occurred in Cayapas Mataje from 1970-2008 with approximately 3,000 hectares (ha) of forest cover lost (Hamilton 2012). From 1969 to 1991, the Guayas Estuary experienced an 18% loss in mangrove cover, while the Churute reserve within it experienced a 4.3% loss (Bodero and Robadue 1995). Most of this loss was due to shrimp aquaculture development, but the reserve is still considered a success in comparison to the mangrove loss that has occurred outside of it. In the Cojimies Estuary, near Mache Chindul, approximately 10,000 ha of mangrove forests were lost from 1971 to 2006, including 66% of the mangroves in the estuary. These losses were primarily due to shrimp aquaculture development (Hamilton and Collins 2013). One can see the range of degradation represented by these three protected areas and estuaries, with Cayapas Mataje being the least degraded and Mache Chindul with the nearby Cojimies Estuary experiencing the most degradation.

Reserva Ecológica Manglares Cayapas Mataje

The 51,300 ha Cayapas Mataje Ecological Mangrove Reserve (Cayapas Mataje) is in the northern province of Esmeraldas, located in northwestern Ecuador (Figure 2). It was created in 1996 under an executive resolution (No. 001-DE 052-A-DE) of the Instituto Ecuatoriano Forestal de Areas Naturales y Vida Silvestre (INEFAN) after the president realized the importance of protecting the mangroves there from the ecological, social, and economic impacts of human pressures (INEFAN/GEF 1998). A management plan for the reserve was first introduced in 1998, two years after the reserve was created (INEFAN/GEF 1998). Approximately 18,000 ha of mangroves in the reserve are protected under Ecuadorean law (Hamilton and Collins 2013). The reserve also has special recognition as a RAMSAR site (INEFAN/GEF 1998; Hamilton and Collins 2013).

Manglares Churute

The Churute Mangrove reserve extends over 49,984 ha and straddles both the Guayas and El Oro provinces (Figure 2). The park was created in 1979 by Interministerial Agreement No. 322 in 1979, updated in 1987 by Ministerial Agreement No. 513, and refined in 1992. A management plan was introduced in 1996 (INEFAN 1996). The reserve encompasses part of the Guayas Estuary, which is home to 130,000 ha of mangroves as of 1995 and is the largest estuary on the Pacific coast of South America (Bodero and Robadue 1995). Guayaquil, the largest city in Ecuador with over 2 million residents, is located nearby. Additionally, Churute is protected as a RAMSAR site (INEFAN 1996).

Reserva Ecológica Mache Chindul

The Mache Chindul Ecological Reserve (Mache Chindul) encompasses 121,376 ha distributed between the Esmeraldas and Manabí provinces, and is located just inland of the Cojimies Estuary (MAE 2005) (Figure 2). The management plan was introduced in 2005, over ten years after the reserve was created in 1996. The estuary itself has no protected status but mangroves are listed as one of four public conservation areas and an ecosystem that should receive some conservation benefits due to the proximity of the Mache Chindul protected area. Approximately 362,802 ha of mangrove ecosystem are listed under the zone of influence of the protected area (MAE 2005). The reserve also falls in the Choco-Darien biodiversity hotspot, which extends into northwest Ecuador from Colombia, and is part of the Choco-Manabi corridor designed by Conservation International (MAE 2005). While Mache Chindul is not entirely coastal like Cayapas Mataje and Churute, it represents an important comparison between the effects of including mangrove ecosystems in a designated protected area versus solely under a zone of protective influence.

Methods

The data utilized in this study include the University of Maryland global forest change dataset, which is derived from time-series analysis of remote sensing data, specifically 654,178 Landsat 7 ETM+ images over 2000-2012 (Hansen/UMD/Google/USGS/NASA 2013). The tiles downloaded for Ecuador include 0N 80W, 10N 80 W, 0N 90W, and 10N 90W. Downloadable files used were tree canopy cover in 2000, global forest cover loss from 2000-2012, and a data mask. Other data used for this analysis include the protected area shape files for the three sites of interest, downloaded from the World Data Base on Protected Areas (WDPA); provincial boundaries from the Food and Agriculture Organization (FAO) geonetwork; mangrove distribution from the United Nations Environmental Protection Center (Giri et al. 2011), and census data from Ecuador's National Institute of Statistics and Census (INEC).

Tree Cover Loss Analysis

The four 10x10 tiles for loss, the mask, and canopy cover were all joined using the "Mosaic to new raster" tool in ArcMap 10.2. Twenty five kilometer buffers were generated around each protected area. The mask and loss rasters were clipped to the size of the protected area buffers to increase processing speed. The mask and loss clipped rasters, protected area shapefiles, and protected area buffers were reprojected from a geographic coordinate system to Albers Equal Area to achieve more accurate area calculations. Areas were tabulated for land area and tree cover loss within buffers and within the protected areas. Percent tree cover loss was calculated by (tree over loss from 2000-2012 divided by total land area)*100. The data mask was utilized to account for areas with no data, mapped land surfaces, and permanent water bodies (Hansen/UMD/Google/USGS/NASA 2013).

Census Population Analysis

Population data by province for 2010 and population projections by province for 2020 were accessed from INEC. In Microsoft Excel, the projected population percent increase over this ten year period was calculated for each province. The spreadsheet was then joined to spatial provincial data in ArcMap 10.2 to create choropleths with user-defined data intervals for the 2010 population, 2020 projected population, and projected population percent increases over this time period. Data at the province, canton, and parish level are published by INEC, but only provincial level data were used in this study. Cantons are the second level sub divisions of Ecuador, below the provinces, while parishes are the third level subdivisions, below the cantons.

Results

The percent tree cover loss results revealed that the Cayapas Mataje buffer area experienced the highest levels of tree loss with 12.82% lost from 2000-2012 (Table 1). In general, higher levels of tree cover loss were experienced within buffer zones than within protected areas (Table 1). Mache Chindul was the protected area with the highest percent tree cover loss. Cayapas Mataje experienced slightly more loss than Churute, especially in regards to their respective buffer areas (Table 1).

The population analysis determined that 2010 population levels are highest and are projected to be the highest for 2020 along the coast of Ecuador, near the projected areas (Figure 3). However, the rates of increase from 2010 to 2020 will actually be higher in other parts of the country, mainly the west. Projected population sizes for Guayas and El Oro, surrounding Churute, total more than 5 million people. Esmeraldas, where the majority of Mache Chindul and all of Cayapas Mataje are located, is expected to have almost 1 million residents as of 2020. Guayas and El Oro provinces are not projected to rapidly increase in population by more than 16-21% at the most (Figure 3).

Discussion

Cayapas Mataje: a traditional mangrove community

The northwestern coastal region of Ecuador, where Cayapas Mataje is located, is characterized by traditional forest extraction activities and complex social and economic relations (INEFAN/GEF 1998), possibly an explanation for the historically low levels of tree cover loss there. Complicated relationships have been formed between traditional communities and larger corporate aquaculture companies, as well as due to Cayapas Mataje's proximity to Colombia. Cayapas Mataje experienced very low levels (less than 1%) of tree loss over the 12 year analysis period (Table 1). Many previous studies have cited the Cayapas Mataje Estuary as still representing a traditional pre-aquaculture mangrove community (Bodero and Robadue 1995; Hamilton 2012; Hamilton and Collins 2013). Cayapas Mataje is also sometimes considered to be a sort of control site when compared with other estuaries that have been more rapidly developed (Hamilton and Collins 2013).

Since the introduction of shrimp aquaculture around 1970, very little land use change has occurred in Cayapas Mataje. Even after aquaculture development, shrimp farming only came to occupy 2800 ha, or around 10% of the Cayapas Mataje region (Bodero and Robadue 1995). Other studies have indicated that shrimp farms only occupy 2.2% of the reserve area (INEFAN/GEF 1998). In 2009, all shrimp farms in this estuary were classified as abandoned (Hamilton 2012). Local residents have been credited with discouraging shrimp farming after witnessing its damaging effects in other Ecuadorean estuaries (Hamilton and Collins 2013).

Population growth has not been directly cited as a possible threat to the mangrove ecosystems in Cayapas Mataje. However, local communities do utilize certain forest species for timber and non-timber products. Mangroves typically fall under the category of timber products, used for fuelwood, housing, or other purposes (INEFAN/GEF 1998). Despite relative preservation in Cayapas Mataje, mangroves also facilitate habitat for collectible food items such as conch and other edible marine products (INEFAN/GEF 1998). Nearly 15,000 local inhabitants are dependent on fishing and the collection of organisms such as mollusks and crustaceans for their livelihoods (INEFAN/GEF 1998). Reserve land is also used for agriculture, such as the cultivation of coco, cacao, yucca, guayaba, sugar cane, guanábana, lime, orange, plantain, pineapple, and mango (INEFAN/GEF 1998).

It is possible that these traditional uses have led to the 12.82% tree cover loss within the Cayapas Mataje buffer (Table 1), but the true causes are unknown. The province of Esmeraldas was predicted to increase in population size by 16.67% from 2010 to 2020. This population increase has the potential to also increase the traditional extractive activities near Cayapas Mataje, posing a demographic driver of deforestation. In future studies, more disaggregate canton or parish level data will be used so demographic drivers can be identified more precisely and the more immediate area surrounding Cayapas Mataje can be analyzed.

Churute: a relative success

The tree cover loss analysis completed revealed that Churute experienced the lowest levels of loss over the 12 year period, with only a 0.29% loss. The buffer area also experienced relatively low loss levels (1.52%) (Table 1). These figures are fairly consistent with the low level of mangrove loss reported within the reserve as of 1995 (Bodero and Robadue 1995). The low buffer tree cover loss from 2000-2012 may not be sufficiently representative of mangrove loss or may suggest a decrease in deforestation rates, as Guayas and El Oro provinces together as a representation of the Guayas Estuary were reported to have lost 18% of their mangroves by 1995. Nearby estuaries in the same provinces saw even more severe declines in their mangrove ecosystems, such as a 52% decline in the Jambeli Estuary and a 25% decrease in the Naranjal Estuary (Bodero and Robadue 1995). These discrepancies could also be due to the time frame for analyses, with deforestation possibly decreasing after 1995 with lower levels after 2000. Because of these relatively low loss levels, Churute is considered a success as a reserve by relevant literature, partially due to strict and constant governmental control, and the additional commitment of agencies such as INEFAN and NGOs like the Fundación Natura (Bodero and Robadue 1995).

Population increases could be viewed as a demographic driving force for deforestation in the area, as they are relatively higher in the surrounding Guayas province than all other provinces of Ecuador. The Guayas province is also expected to see a 16.89% increase in population by 2020 (Figure 3), and although projected percent increases are higher in other areas of Ecuador, this could still be problematic when considering further urbanization, urban sprawl out of Guayaquil, pollution, or land use change prompted by a growing population. In mangrove areas, the principal activities of human settlements are shrimp farming and artisanal fishing, and increases in these activities from a growing population also have the potential to be threatening to mangrove ecosystems (INEFAN 1996).

Mache Chindul: historic loss

While levels of tree loss calculated for Mache Chindul were still relatively low (4.37%) (Table 1), it was not surprising that they were the highest of all protected areas examined. Loss within the buffer zone (7.63%, Table 1) was actually expected to be higher, given reports regarding the nearby Cojimies estuary (e.g., Hamilton 2012), which has undergone drastic land use change and degradation. Shrimp farming has been reported in around 50% of the estuary, occupying more area than all other land uses combined, including surface water and remaining mangrove forests (Hamilton 2012). A land cover map generated by the Ministerio Ambiente de Ecuador (MAE) in 2004 shows that the majority of vegetation cover has been modified from its original classification, with only 46.86% or 56, 874 ha of the reserve remaining as natural forest cover (MAE 2005). Mangrove ecosystems were also identified as being present in the Cojimies estuary despite the majority having been eliminated from shrimp farming related activities (MAE 2005).

The Manabí province, like most coastal Ecuadorean provinces, is expected to continue to increase in population. Only a 9.98% increase in population is projected to take place by 2020. Using census data from the 1990-2001 period, the population size within the Mache Chindul reserve has actually been estimated by two previous studies to be 8,484 (Espín 1998 in MAE 2005) and 6,466 (MAE 2005). These estimates are based on the number of families, using an average family size of 6 (MAE 2005). They suggest that even though an overall population increase is projected for the province in 2020 according to the census, the reserve actually witnessed a slight decrease in population before 2000. This discrepancy could be due to the current inclusion of the entire Manabí province or the utilization of more up to date data representing a growing population.

Management planning and recommendations

Much more research needs to be conducted before realistic management recommendations can be made, but the results of this study indicate important trends in forest cover change and demographic contexts. As well, the respective management plans for each protected area serve as useful indicators of proximate sources and drivers of deforestation, and as points of departure for future updates.

The Cayapas Mataje management plan, introduced in 1998, extensively reviews management objectives as well as how they would be introduced and executed. Its main objectives are to solve three major problems occurring in Cayapas Mataje: insufficient administration, inadequate and disorganized natural resource use, and increased shrimp farming area. Operations for various subprograms to solve these problems are included. For example, the program for environmental management includes 6 operations for protection and 4 for investigation and monitoring (INEFAN/GEF 1998).

Another important management goal is to develop sustainable use patterns and educational programs for the traditional communities living near or in the Cayapas Mataje reserve. The analysis conducted in this study indicates that the area immediately surrounding the Cayapas reserve experienced the greatest loss of forest cover. This suggests that reserve management may need to address forest degradation and loss outside of the limits of the reserve as well. Research should be done with aims of establishing a better 'ripple effect', where the conservation influence of the reserve spreads outward. The frameworks set forth in the management plan to address insufficient administration, natural resource use, and shrimp farming should be reviewed and applied to be adapted to the current situation (INEFAN/GEF 1998).

The Churute management plan (1996) includes the objectives of conserving natural ecosystems, protecting unique resources, conserving resources for future use, controlling erosion and invasions, administering recreation and tourism services, and assuring and promoting livelihoods towards a communal benefit (INEFAN 1996). It also sets up a zoning system, creating areas of strict environmental protection and areas where extractive activities by community participants are allowed if certain regulations are followed. The main goals of the plan are to prevent the expansion of shrimp aquaculture, limit other degrading activities such as forestry or fishing, conserve biodiversity, and address the needs of local communities (INEFAN 1996).

While the management of Churute has been relatively successful thus far, its continued effectiveness depends on key factors. For instance, more of the Guayas Estuary should be given some form of protected status so that greater portions of mangrove forests and ecosystems could be preserved there. Since population increases have the potential to drive deforestation in or near Churute (Figure 3), focus should be given to alleviating the detrimental environmental effects of large populations and urban centers on nearby ecosystems.

The Mache Chindul management plan (2005) divides the area into bioclimatic zones to facilitate management of the flora and fauna found in each zone or ecosystem type (MAE 2005). It attempts to accommodate and involve local actors, various political influences, conservation organizations and institutions, as well as community residents. Its general provisions are for a strengthening of the national environmental authority, creation of a participatory management model, natural resource conservation, and improvement of the quality of life for reserve inhabitants through sustainable development. Zones are established with uses ranging from scientific tourism to sustainable use of biodiversity to agriculture and agroforestry (MAE 2005). Environmental education is emphasized as well, as poor education in the area is cited as a potential detriment to sustainability in the future and biodiversity conservation (MAE 2005).

For Mache Chindul, it would be beneficial to address potential threats to mangroves in the larger Cojimies Estuary, limiting further shrimp farm expansion there and promoting reforestation. Better monitoring within the reserve itself should also occur to limit forest loss. Similar to Cayapas Mataje, a ripple effect of conservation management from the reserve is important because it would not only protect more of the Choco-Darien biodiversity hot spot and corridor, but also extend into the coastal mangrove ecosystems.

In the future, it is important to update management plans and make them available to the public. Up to date information on these areas is not readily available to those without the proper resources or in-country contacts. If management of these protected areas could be more transparent, with progress more widely and consistently reported, management recommendations could be more specific and current.

The provisions and strategies set forth in all three management plans all consider multiple influences affecting conservation. However, to be successful and to reach the standards set forth in the plans, monitoring must occur, funds must be obtained, and there must be sufficient manpower, coordination, and organization amongst managers. Coordination should also occur, not only between these three coastal protected areas, but between all Ecuadorean protected areas as a system, to promote the sharing of knowledge and utilization of experts on hand. An update on whether or not the provisions set forth in the management plans, particularly Cayapas Mataje (1998) and Churute (1996) is therefore essential to further recommend management options.

Limitations and future research

While the results achieved in this study give a good idea about the positive effects protected areas may have in terms of preventing tree cover loss, several limitations still exist. Data availability was a major limiting factor in the analyses that could be performed. For example, the University of Maryland global land cover data set defines tree cover loss as stand-replacement disturbance or the complete removal of tree cover at the Landsat pixel scale (Hansen/UMD/Google/USGS/NASA 2013). While this cannot directly represent mangrove loss, it still gives a good idea or representation of the biomass lost in a certain area. However, in the future land cover as well as tree cover data will be incorporated to analyze land cover change over time and investigate agricultural changes and shrimp aquaculture in relation to mangrove deforestation. Additionally, choropleth mapping for the census population analysis should be done with alternative class widths to explore the implications of alternative classification schemes for visual and analytical assessment of population trends.

For the purpose of this analysis, the tree cover rasters were clipped to the reserve buffer boundaries in order to complete processing. In the tree cover analysis, also in ArcMap, 25 km buffers were used for all three protected areas, which does not take into account the area of each individual protected area. Because these reserves have different individual areas, a 25 km buffer width produced buffer areas of very different sizes. In the future, proportional buffers will be used for each protected area. Nested buffers in concentric rings around protected areas buffers will also be used to determine if the protected areas influences the conservation of the surrounding land in a ripple effect, with more tree loss occurring even further away from the protected area. Buffers could also be used to determine the effectiveness of preset zoning by protected area management plans or follow administrative boundaries to determine the effect of the presence of cities or infrastructure. The data for preset zoning were not available for this analysis.

A statistical analysis should be included in the future to determine whether tree cover outcomes between protected areas are significantly different. Modeling could also be incorporated to determine the potential causes and underlying driving forces for each area by incorporating multiple variables and assessing the strength of each one.

More Ecuadorean protected coastal areas or more of Latin America could be included in a very comprehensive analysis or just one protected area could be focused on so detailed, on-the-ground research could be completed. Surveys of mangrove use and threats could be distributed and discussions could be held with local stakeholders to determine public opinion and relationships with managers at the higher level. For example, the role of nongovernmental organizations (NGOs) in protected area creation and enforcement is very important to consider as many are present and involved in Ecuador, such as the Fundanción Natura (INEFAN/GEF 1998). In this way, all factors contributing to deforestation in the area could be analyzed for a greater and more complete understanding of proximate causes and driving forces. Finally, mangrove areas with no nearby protected zones or designated conservation status should be included for comparisons in future studies. This will further help evaluate the efficacy of conservation status for stemming forest loss in an area.

Climate change should also be closely considered in future research on mangroves and other coastal wetland systems. Rising sea levels, erosion, warming temperatures, storm events, and modification of species habitat are all likely to affect mangrove ecosystems and the interactions they have with human populations. If climate change prediction scenarios can be included in modeling, management to protect and conserve coastal ecosystems against climate change can be conducted.

Conclusion

There are many potential causes and driving forces that may lead to deforestation. Analyzing even one of these factors was a challenging task given available data and geographic location. However, results still show that tree cover loss appears to be lower within protected areas than their surrounding buffers, with Mache Chindul exhibiting the most tree loss over a 12 year period. These findings support the creation of more protected areas if a goal is to minimize tree cover loss. Additionally, the large provincial populations on Ecuador's coast may be a potent demographic driving force for deforestation, although the percent increase is projected to be higher in other regions.

Continued research in this area is important in determining the causes and driving forces of deforestation, because achieving an understanding of these factors may allow for more effective management and conservation. Continued deforestation or degradation of mangroves could not only lead to possible extinctions, but also severely affect livelihoods in provinces such as Esmeraldas, where populations directly depend on mangrove products.

Appendix

Tables

Table 1. Percent tree cover loss from 2000-2012 calculated for each protected area and protected area 25km buffer zones. Calculations were done in Microsoft Excel as (tree cover loss divided by original land area) * 100. Land area and loss were calculated using tabulate area in ArcMap 10.2.

	Land Area (ha)	**Loss (ha)**	**Percent tree cover loss**
Cayapas Mataje	39177.54	298.35	0.76
Cayapas Mataje Buffer	310774.95	39846.33	12.82
Mache Chindul	121360.32	5299.11	4.37
Mache Chindul Buffer	526354.47	40177.98	7.63
Churute	44183.97	128.34	0.29
Churute Buffer	381713.4	5792.49	1.52

Figures

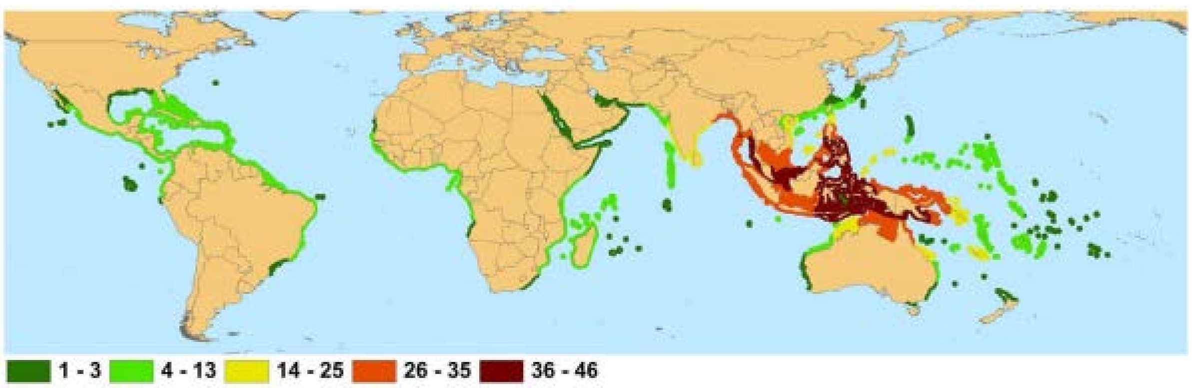

Figure 1. Global mangrove distribution map showing species richness (Polidoro et al. 2010). Only native and not introduced species are shown.

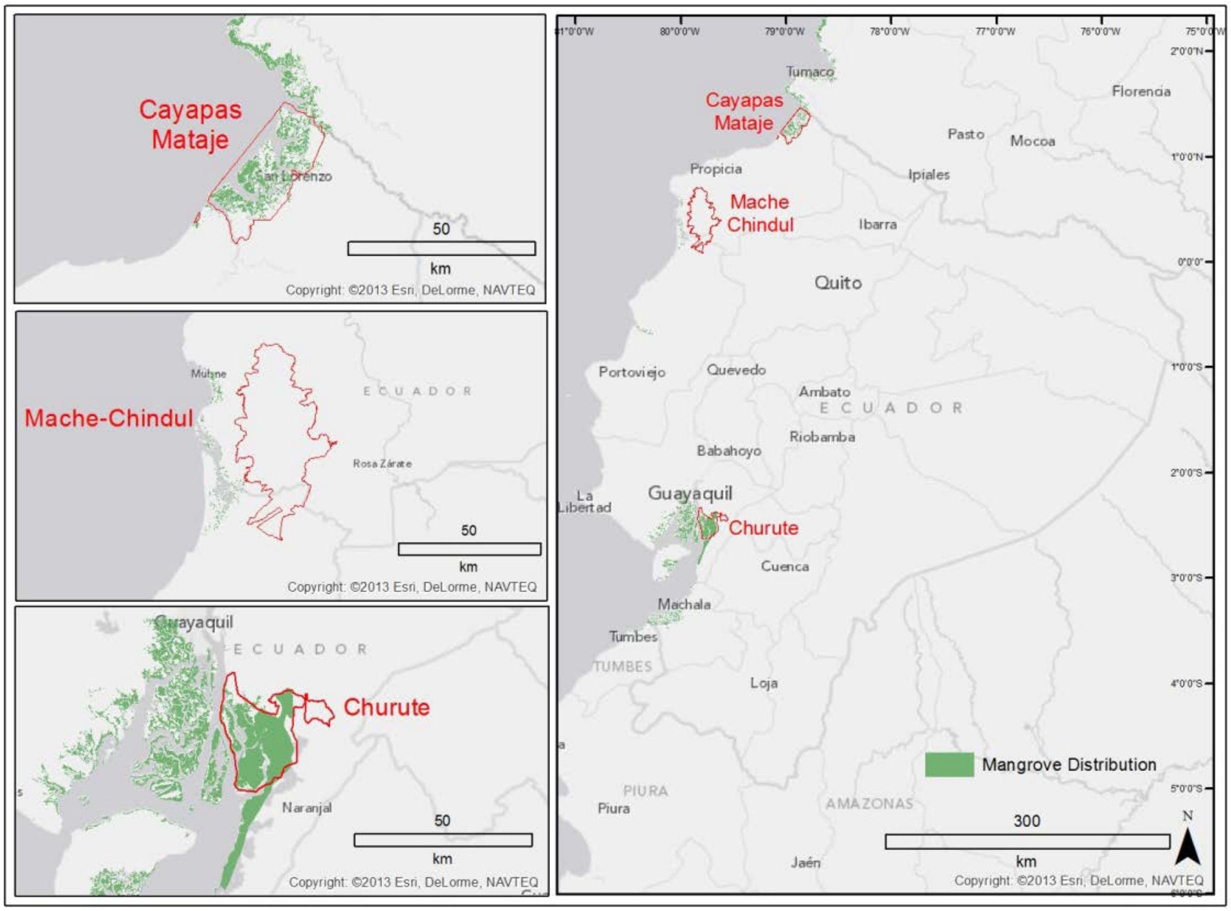

Figure 2. The three coastal protected area study sites in Ecuador. Mangrove distribution is shown (Giri et al. 2011a). Protected area boundary data are from WDPA.

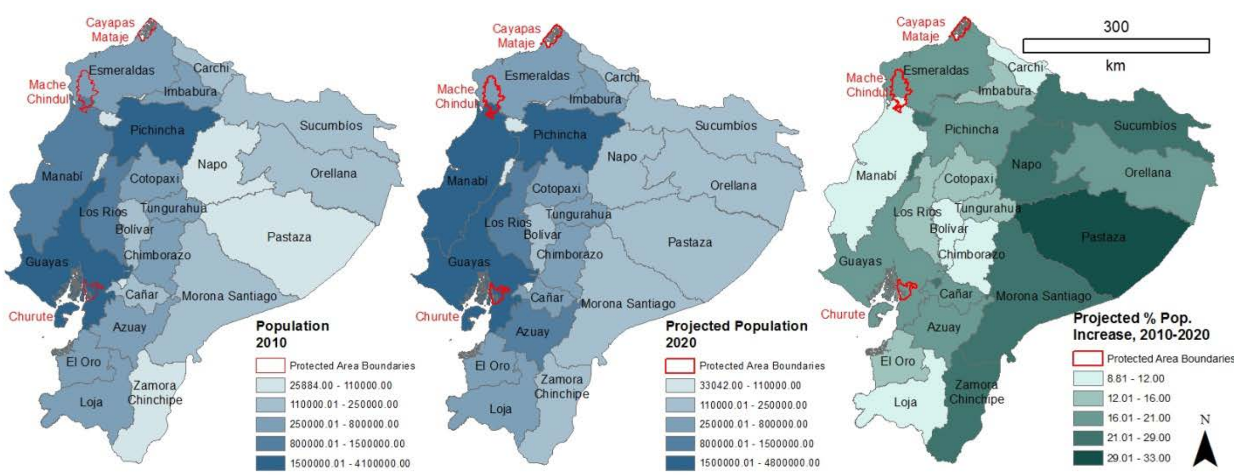

Figure 3. Population choropleths by Ecuadorean province with user-defined data intervals. Data were accessed from INEC and calculations were done in Microsoft Excel.

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