The Effect of Land Use/Land Cover on Mangrove Forest in the Northeastern Panama Canal Region

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Abstract This study examines how nine anthropocentric Land Use/Land Cover (LULC) types in the Northeastern Panama Canal Region are impacting mangrove forests. Mangroves are ecologic and economic resources that provide protection and livelihood to biological organisms and human populations living in areas where they are present. Despite this importance, mangrove forests in Panama are threatened by land development along the canal. Using satellite imagery, area changes of LULCs from 1996 to 2008 were determined using Definiens Professional object based segmentation and classification software. The rate of mangrove forest area decline was shown to increase threefold from the years before the U.S. Military withdrawal (1996-2000), to the years of Panamanian government control (2000-2008). This rate increased year on year from 1996-2006, but not from 2006-2008. A Pearson correlation coefficient analysis determined that port development and storage yard area increases had the strongest correlation to mangrove forest area decline. These results suggest that the ecological impacts of development, especially port development and storage yard types should be closely monitored to ensure that development decisions do not compromise the ecological integrity of the area.

Introduction

Mangrove trees and shrubs are an important ecological and economic resource in the world's tropics and subtropics that provide protection and livelihoods for biological organisms and humans populations in the areas where they are present (Alongi 2002). They consist of species rich areas with significant biodiversity at the juncture of land and sea and provide ecological services to trap sediments and filter pollutants that come from inland developments (Hogarth 2007). In this way, mangrove forests also impact the seagrass beds and coral reefs adjacent to them, which rely on their sediment and pollutant filtering services (Farnsworth and Ellison 1997). Additionally, mangrove trees and shrubs provide habitat for a mixture of marine and terrestrial species and serve as a nursery for fish, birds, reptiles, and mammals. Human communities that reside near mangrove forests often use them as a source of wood, tannin, charcoal, medicine, furniture, and alcohol (Alongi 2002). They offer a significant economic resource by providing the environment for small scale, sustainable fish and shrimp aquaculture. In areas of high weather variability, mangrove forests serve as buffers to storms and protect communities from storm damage and flooding (Alongi 2002). During the tsunami that struck Asia in 2004, coastal communities with healthy mangrove forests suffered fewer casualties and less severe property damage than those with degraded or deforested mangroves (Danielsen *et al.* 2005).

Despite their critical ecological and economic significance, mangrove forests are one of the world's most endangered ecosystems (Coen and Pollard 2003). This rapid loss has occurred despite mangroves' adaptations that allow their survival in variable conditions, including periodic water-logging, high salinity, variability in ground level temperature, and periodically intense weather conditions (Hogarth 2007). Many ecosystems worldwide suffer from destructive impacts of various types of economic, residential, and agricultural development. Since 1980, mangrove populations have decreased by approximately 20% worldwide due to development and the indirect impacts of pollution and sediment run-off. The mangrove forests located in Panama are no exception, with recent land development along the Panama Canal putting hundreds of hectares (ha) of mangrove forest in danger of destruction (McCall 2005).

Mangroves are a sensitive species that typically disappear as per capita GNP increases (Valiela *et al.* 2001). Valiela *et al.* (2001) shows the percentage loss of mangrove area increases as per capita GNP increases; however, scatter in the data makes it difficult to establish a reliable

prediction of loss. The study attributes this decrease of mangrove forest area to increases in GNP due to overfishing with aquaculture, removal for agricultural, industrial, and urban development, and increased pollution or drying of rivers that feed into mangrove areas. It takes decades after being disturbed for mangrove forests to grow back, and ecosystems are rarely fully restored to their previous species richness and health (Alongi 2002). Therefore, it is important that development decisions take into account the value of this non-monetized natural resource and that the costs and benefits from development are well understood before these irreversible decisions are made.

As one of the most important shipping centers in the world, traffic conducted through the Panama Canal is a measure of world trade activity and a crucial part of Panama's economy (McCall 2005). It was completed in 1914 by the United States and now carries 5% of the world's cargo, with 12,000 ships currently crossing it every year (Alfu 2007). Today Panama is the largest transshipment center in the region, serving Central and South America, the Caribbean, and the East and West coasts of North America (Castillo and Croston 2007). When the U.S. military withdrew from the canal region in 2000, the Panamanian government was able to develop abandoned military land in an effort to increase economic backing and economic activity in the canal area (Coen and Pollard 2003). In addition, land preservation laws were ignored by the government, further contributing to the development of forested land outside previously developed areas (McCall 2005). Since then, port operations have increased, including by 21% from 2003 to 2004, and plans to further increase growth are underway (Castillo and Croston 2007, McCall 2005). With 1.4 billion dollars invested in canal infrastructure, such as dock equipment and container storage areas, today's challenge for Panama has shifted from increasing port investment to meeting the growing demand for air and land merchandise transportation and distribution services (Castillo and Croston 2007).

The Zona Libre de Colón, an important merchandise distribution center in Panama, is located at the northeast opening of the canal in the Province of Colón (Coen and Pollard 2003). This area was established shortly after WWII and is under the administration of a semi-autonomous department of the Government of Panama (Colón Free Zone 2007). It is the world's largest duty free zone after Hong Kong and serves as the region's primary commercial distribution center, with about 2,000 companies present and 10 billion dollars in exports and re-exports handled each year (Colón Free Zone 2007). The comprehensive development plan for the Province of Colón

is to make the Zona Libre de Colón a merchandise distribution center for the region by improving connections between rail, ship, and air services by creating a fluid, multimodal transportation system (Castillo and Croston 2007). Improving this system would decrease transportation time in the delivery of goods and increase the competitiveness of the Zona Libre de Colón as an effective distribution center. Currently, some rail expansions of existing Panama Railway Company infrastructure have already taken place, and talk of plans for France Field Airport expansion are underway in the Province of Colón. The hope is that these expansions will meet the need for the air and land distribution of goods from the canal that do not need to continue via ship to their destinations (Sousa 2007, pers. comm, McKinley and Piette 2007).

As part of the development plan, two companies are also expected to expand their container cargo areas in the Province of Colón adjacent to the Zona Libre de Colón in an area called Coco Solo. Manzanillo International Terminal (MIT) and Colón Container Terminal (CCT) are two international shipping companies that are responsible for 75.6% of transshipment containers handled in Panama before being shipped to other destinations, making them major contributors to the Panamanian economy (Castillo and Croston 2007). Both companies are privately owned and provide customers with container maintenance and repair, container terminal operators, and cargo handling and storage services (McKinley and Piette 2007). Their proposed container area expansions are expected to convert 69 ha of unpolluted and somewhat polluted mangrove forest into shipment container areas (Castillo and Croston 2007). The sites would also indirectly impact 29.9 ha of mangrove forest, some of which are protected by the neighboring Punta Galeta Marine Laboratory (PGML), because the sites are located upstream and adjacent to the river that provides freshwater to PGML (McKinley and Piette 2007). Once built, these developments are predicted to employ 500 persons permanently, as well as hundreds of temporary workers during their construction (Castillo and Croston 2007). In addition to these short term projects, there are also talks to expand the canal to meet the growing demand for ships that are too large to travel through the canal and must therefore go around South America (Alfu 2007). This project would not only add to the destruction of mangrove forest along the banks of the canal, but would also likely fuel economic development that would further encroach into mangrove forest (Sousa 2007, pers. comm.). There are potential economic gains to be had from these two projects and the canal expansion, but the environmental impacts of economic growth through development in the canal area must also be considered.

Panama once had 300,000 ha of mangrove forest but lost 41% of this area from 1960-1988 (Ellison and Farnsworth 1996). The rate of mangrove forest destruction has been highest on the Caribbean coast, with mangrove forest area dropping from 20,400 ha in 1980 to 5,900 ha by the mid 1990s, a loss of approximately 71%, and a significantly higher rate than the worldwide loss of 20% (Ellison and Farnsworth 1996). There are laws and preserved areas in Panama to protect mangrove forests. However, these are typically ignored in favor of potential fiscal gains and are often contradictory to zoning laws which zone some mangrove areas for commercial development (McCall 2005).

As development continues to increase in the canal region, the environmental impacts of the proposed MIT and CCT development on Punta Galeta and surrounding mangrove populations have been called into serious question by scientists at PGML and local community members who are unconvinced that fiscal gains outweigh ecosystem losses. PGML is a research laboratory owned by the Smithsonian Tropical Research Institute that is located on the border of the CCT proposed development site and near the Zona Libre de Colón. The Institute is an important center for international scientists to study coastal ecosystems, with its primary goal being to preserve and understand this unique ecosystem (Coen and Pollard 2003). It also functions as an educational institution for local and international students and as a small source of jobs for local citizens (Coen and Pollard 2003). While the development does not directly affect PGML through mangrove removal, increased soil acidification, sedimentation changes, and increased pollutants are typical negative impacts from development that are likely to occur in PGML from these upstream sites (Ellison and Farnsworth 1996). Polluted or absent mangroves that will result from these developments can impact the species that rely on them as a nursery for their young, the species richness of seagrass beds and coral reefs, and ocean water quality that is unfiltered with sediments and pollutants (Farnsworth and Ellison 1997). These changes can also put pressure on communities that use mangrove forests as a source of livelihood and protection (Alongi 2002).

With the recent rise in industry development, it is unknown how much mangrove forest area has been impacted or destroyed due to canal land development types (McKinley and Piette 2007). As a sensitive, threatened ecosystem that provides economic, educational, scientific, and protective service values to local and international communities, it is important that impacts are documented and quantified to make better environmental assessments for future projects and to

properly understand losses in the name of fiscal gain. To determine how mangrove forest areas are changing through time, as well as which development type is having the greatest impact on mangrove forests, nine Land Use/Land Cover (LULC) anthropocentric types were examined. When analyzed spectrally in satellite imagery, LULCs demark land use patterns to show changes in particular LULC areas over time.

The development situation in the Province of Colón raises the questions: How are mangrove forest areas changing in the Northeastern Panama Canal Region? How are mangrove forest areas being affected by the change in area of LULCs in the Northeastern Panama Canal region? I hypothesize that the rate of mangrove forest depletion from 1996-2000 increased after the U.S. Military withdrawal in 2000. For the null, I hypothesize that there is no difference in rate of mangrove forest depletion between 1996-2000 and 2000-2008. I also hypothesize that the rate of decline continues to increase year on year from 2000 until 2008. For the null, I hypothesize that the rate of depletion remains constant during this time period. Finally, I hypothesize that all of the LULCs have an equal effect on mangrove forests. For the null, I hypothesize that one or more LULC has a disproportionately greater impact on mangrove forests, namely Port Development.

Methods

Data Collection The study site is located on the Northeastern opening of the Panama Canal in the Province of Colón, Panama and is approximately 2050 ha (Fig. 1). Industrial development, railroad infrastructure, an airport, roads, streams, mangrove forest, rain forest, and grassland are all land covers present in the site. The study site is bordered by a major highway, the Atlantic Ocean, and the Zona Libre de Colón. The study examines land use area changes through analysis of satellite images of this area from 1996 until 2008 to determine the rate of mangrove depletion.
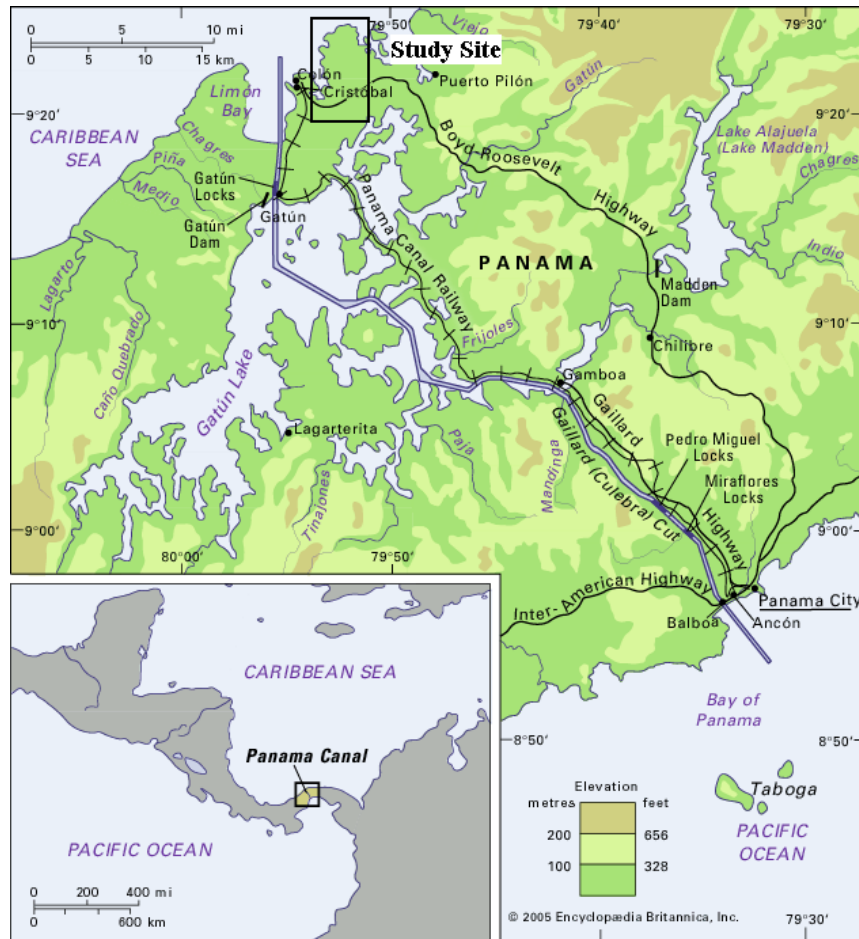
Figure 1. Map of Panama Canal (adapted from Panama Canal 2007).

　　　Several methods can be used to successfully quantify loss of mangrove forest. One method is to travel to the study site and conduct a land use and land area survey. While this can be a very accurate method, it is also a time consuming process and is not feasible within the restraints of this project. An alternative to conducting a physical survey is to use satellite images to determine LULCs and their land areas. This method is very time efficient, widely accepted, and highly accurate depending on the Geographic Information System (GIS) analysis program and specific techniques chosen. One process is to create polygons in ArcGIS with reference points taken in the field and to then hand edit each polygon's attribute table to describe its land cover (Coen and Pollard 2003). This is not the most accurate or quick GIS method because it relies on humans to make classification decisions for every single polygon created by ArcGIS.

　　　Another more efficient and precise option is to use software to perform this task through imagery analysis. Two major analysis techniques include pixel based and object based analysis,

with object based being more accurate for use with high resolution data (Scheiewe *et al.* 2001). There are many software programs with this capability, including: ERDAS IMAGINE, ENVI, and Definiens Professional, formerly known as eCognition. While they are all useful programs, Definiens Professional is arguably the best choice for spectral shape analysis of high resolution satellite images (Tuxen-Bettman 2007, pers. comm.). Studies have been conducted that have positively assessed the accuracy of Definiens Professional (Möller *et al.* 2007), as well as found it to be superior to other similar programs in comparison tests (Manakos *et al.* 2000). Many studies have also successfully used Definiens Professional as part of their land use classification (Benz *et al.* 2004, Bunting and Lucas 2005, Suárez *et al.* 2005). Conducting land use surveys with GIS technologies is an accepted, accurate, and efficient scientific method. Given these reasons and this study's use of high resolution satellite images, the use of GIS and specifically Definiens Professional is the best method to address this study's research question and objectives.

Satellite images used in this analysis were ordered from GeoEye, a company that specializes in geospatial information and imagery. Images from 2000, 2004, 2006, and 2008 were taken with the IKONOS satellite, which has a one meter resolution and creates images that are tonally balanced and map accurate. Information imbedded in the images includes a wavelength spectrum comprised of four bands: red, green, blue, near infrared (NIR). All images were chosen based on complete coverage of the study site, minimal cloud cover, and tilt angles as close to 90 degrees as possible to improve accuracy. A 1996 aerial photograph was also obtained from Coen and Pollard's study (2003), originally obtained from the Instituto Geaografico Nacional. The 1996 image served as the reference year of pre-U.S. military withdrawal and the other four images represented four subsequent years under Panamanian control and development. The four years after 2000 were spaced to ensure that a noticeable change could be detected from image to image.

The satellite images were then examined in ArcGIS to determine LULC classifications similar to those of Coen and Pollard (2003) based on distinct spectral differences. The "Mangrove Forest" LULC describes areas of mangrove that are completely forested, seem undamaged by humans, and appear to be a dull green in the images. "Rainforest" is the other dominant vegetation type present within the study site and is characterized in the images by heavy canopy texture and bright green coloring. "Grassland" is less dominant within the study

site and appears in the images as a smooth texture with light brown coloring. "River" refers to the rivers and streams present within the site, and "Lagoon" is comprised of two areas connected to the site's rivers.

Along with natural land cover, development infrastructure is a dominate land use within the study site. "Residential" refers to areas with occupied residential development. "Storage Yard" includes areas used by companies to store goods and equipment, and "Cleared" describes areas that have been cleared of vegetation but not yet developed. "Port Development" involves areas that are directly involved in port industry. Polygons classified as "Airport" refer to areas including runways and associated cleared areas, "Railway" describes the railroad built after 1996, and "Road" describes any roads or highways that run throughout the site. "Active Military" refers to areas in 1996 that were still used by U.S. Military personnel and "Decommissioned Military" refers to areas that once belonged to the U.S. military but now are owned by the Panamanian government. These nine anthropocentric LULC classifications provide the necessary demarcations needed to ascertain how mangrove forests are being impacted by different development types.

With LULC categories assigned, 500 accuracy assessment points that included a roughly even number of all of the LULC types were randomly chosen from the study area in the 2000 image. While the goal was to reach approximately 150 points, 50 for each vegetation class, 350 more were chosen to account for unreachable points. Their latitude and longitude coordinates were entered into a Garmin GPS unit and as many points as possible were located at the study site during the dates of January 4 to January 16, 2008. 76 points were reached during this time and LULC classification metadata was noted for each of the accuracy points. These 76 points were later used to assess the accuracy of the image classification. The remaining 424 points were unreachable due to difficult terrain and time constraints. Waypoints were also taken with the Garmin GPS unit to be used by the software as training points for classification.

Techniques and Analysis With the necessary data collected and converted, the five images were then spectrally analyzed using the software program Definiens Professional version 5.0, in which similar wavelength groups were segmented into like polygons through object based segmentation. These segments were then assigned the LULC classifications described above using a combination of nearest neighbor and rule based classification (Fig. 2).
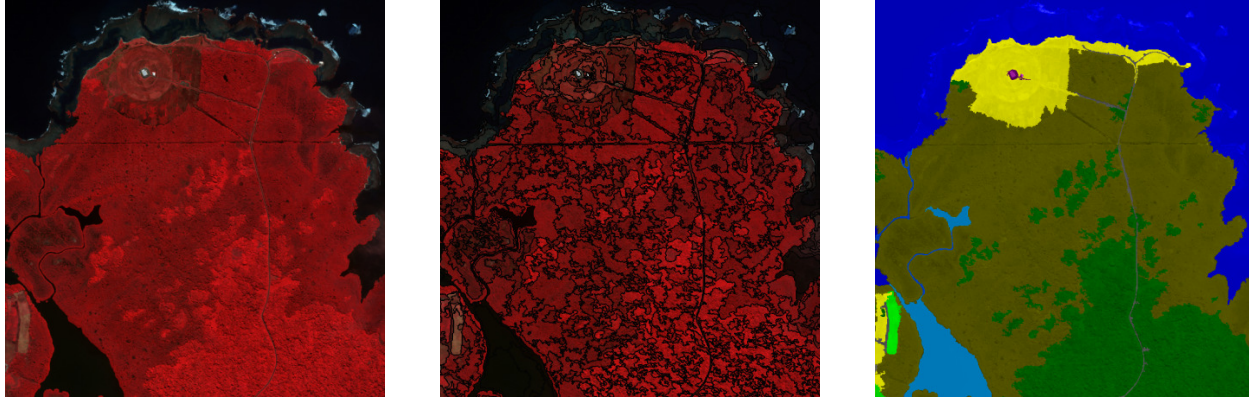
Figure 2. Subset of Northeastern Panama Canal study area from 2000 satellite image in false color, segmented with black lines representing separated LULCs, and classified segmentations. Segmentation and classification performed by Definiens Professional software.

Once the spatial files of the 14 LULC polygons were created, the randomly chosen accuracy points were checked to determine how precisely Definiens Professional assigned the LULCs. The number of accuracy points correctly classified over the total amount of accuracy points determined the percent reliability of the program. Polygon shape files were then imported into ENVI + IDL to determine the area of the LULC polygons through the program's statistical analysis tool.

In order to determine how mangrove forest had changed in relation to development LULCs, a Pearson correlation coefficient analysis was performed. R and p-values were determined in Microsoft Excel based on change in percent land area of Mangrove Forest in relation to all other anthropocentric LULCs. The LULCs with an R value less than -0.80 and a p-value less than 0.05 were considered to strongly correlate to mangrove forest area decline.

Results

The area of Mangrove Forest in the study site was shown to decease year on year from 1996-2008 (Appendix A). The rate of Mangrove Forest depletion increased year on year from 1996-2006, but not from 2006-2008. This rate of depletion increased three fold from 2000-2008 during Panamanian control of the site, from pre U.S. Military withdrawal during 1996-2000 (annualized rate of Mangrove Forest area change from -0.52% to -1.56%). Of the anthropocentric LULCs, Port Development and Storage Yard had the strongest correlation to Mangrove Forest decline.

Performing a classification analysis with Definiens Professional software produced five maps from which area was derived (Appendix B). The classifications of the maps were on average 95.68% accurate. In 1996, some Active Military infrastructure, as well as a large amount of Decommissioned Military infrastructure, were present. Forest in the southwest corner of the study site and east of the major road that runs north/south adjacent to the Port Development were still fairly intact during this time. The change from Military to Port Development is evident by the year 2000, as well as some changes in the aforementioned forested areas to expanded anthropocentric LULCs. As time progressed, the slow conversion of these forested areas into Cleared plots, Storage Yard, and Port Development took place. The 2008 classified image shows the most recently cut plot that took place in November 2007 (Sousa 2007, pers. comm.), as well as new storage development that has replaced Mangrove Forest in the southwest corner of the study site.

The changes that occur in the classified maps can be quantified and shown in the LULC's trends from 1996-2008 (Fig. 3). Mangrove Forest and Rainforest areas declined, while Port Development, Storage Yard, Cleared, and Railroad experienced increases in area from 1996-2008. Airport declined slightly, and Active Military disappeared after the 2000 withdrawal.
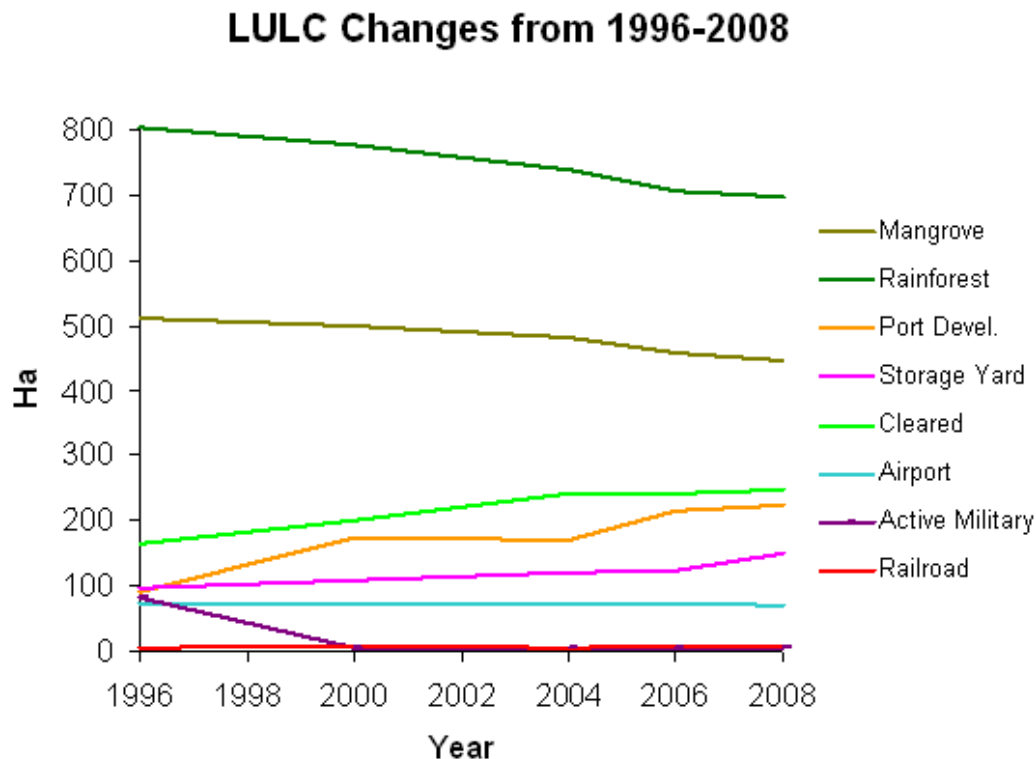

Figure 3. Trend lines of LULC changes from 1996-2008 in the Northeastern Panama Canal Region.

Mangrove Forest, as well as Rainforest, experienced approximately a 13% decline from 1996 through 2008 (Table 1). The rate of decline of mangrove forest increased from 1996-2006, but experienced a slight decrease from 2006-2008. The most significant increases of anthropocentric LULCs occurred with Port Development, Storage Yard, Cleared, and Residential LULCs. All other LULCs experienced low or negative growth.

Table 1. Annualized rate of change of LULCs in the Northeastern Panama Canal Region year to year from 1996 to 2008.

LULC	'96 – '00	'00 - '04	'04 - '06	'06 - '08	Net Change
Mangrove	-0.52%	-0.89%	-2.60%	-1.37%	-12.95%
Rainforest	-0.84%	-1.23%	-2.27%	-0.50%	-13.18%
Grassland	-0.04%	0.21%	2.36%	0.83%	7.16%
River	1.22%	-3.83%	35.51%	35.27%	0.11%
Lagoon	0.00%	-0.40%	-0.80%	0.44%	0.06%
Port Development	22.40%	-0.18%	12.01%	2.30%	144.19%
Storage Yard	3.19%	2.26%	1.89%	10.69%	54.89%
Cleared	5.65%	4.87%	0.08%	1.03%	49.77%
Roads	0.90%	0.17%	9.95%	-0.49%	23.82%
Railway	--	27.29%	13.17%	9.93%	--
Airport	0.00%	-0.21%	0.89%	-2.72%	-4.56%
Residential	17.93%	-9.48%	29.77%	17.23%	128.68%
Active Military	-25.00%	0.00%	0.00%	0.00%	-100.00%
Decommissioned Military	-23.16%	-2.11%	0.00%	-1.39%	-93.46%

As shown in Appendix B, increases in area of Port Development, Storage Yard, Cleared, Railway, and Roads all showed a strong correlation to Mangrove Forest area decline (R = -0.8924, -0.9540, -0.8390, -0.9602, -0.9322). Port Development, Storage Yard, Railway, and Roads all showed high confidence levels for this relationship (p = 0.0417, 0.0118, 0.0095, 0.0210). However, although Railway and Roads confidently demonstrate strong correlations to Mangrove Forest decline, these LULCs comprise a much smaller percent area of the study site (mean area 1996-2008: 0.3%, 3.2%) and therefore did not impact Mangrove Forests as much as the larger areas of Port Development (Fig. 4) and Storage Yard (Fig. 5) (mean area 1996-2008: 8.5%, 5.9%).
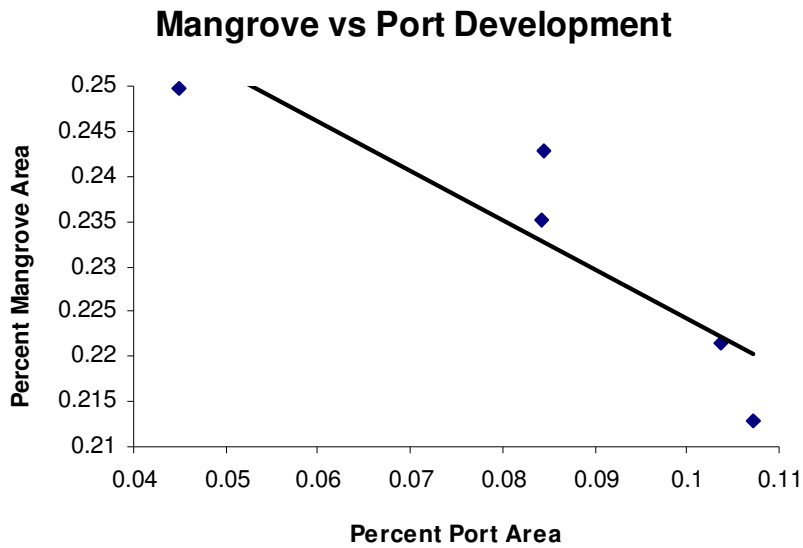
Mangrove vs Port Development

Figure 4. Correlation coefficient analysis showing the negative relationship between percent total Mangrove Forest area and percent total Port Development area.
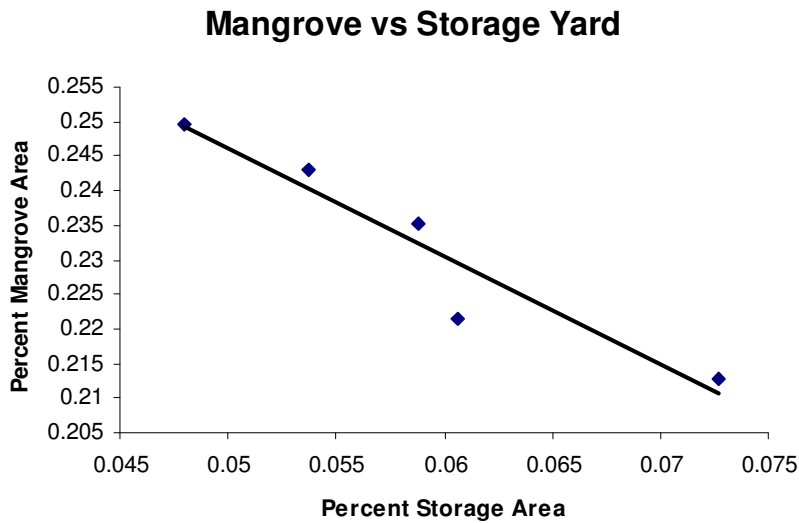
Mangrove vs Storage Yard

Figure 5. Correlation coefficient analysis showing the negative relationship between percent total Mangrove Forest area and percent total Storage Yard area.

Discussion

This project investigated how mangrove forests are being affected by nine different anthropocentric LULCs. Mangrove Forest area was shown to decrease every year that was examined. This rate of depletion increased approximately threefold after U.S. Military

withdrawal in 2000, proving my first hypothesis that rate of decline would increase after the withdrawal of the U.S. Military. This change suggests that the Panamanian government's control of this land could be an indirect factor related to Mangrove Forest area decline. However, rates of Mangrove Forest decline did not increase year on year from 1996-2008, disproving my second hypothesis that rates would continue to increase after U.S. Military withdrawal. The rate of depletion rose from 1996 to 2006, but fell slightly from 2006-2008. This slight decline could be attributed to normal fluctuations in development, as well as the increasingly smaller area of mangrove forest that developers can deforest. Decline of mangrove forest may also be attributed to indirect impacts of development, such as increased sedimentation and pollution runoff, as well as environmental factors, such as El Niño. These types of changes represent one of the limitations of this study, in that they are more difficult to detect and properly attribute using this study's methodology.

Of the nine anthropocentric LULCs, Port Development and Storage Yard area increases had the most significant effect on the reduction in Mangrove Forest area based on the correlation coefficient analysis and their relative area. A possible reason that these LULCs have a higher impact is because they require a large amount of land and must be located close to the shoreline where mangroves are found to transfer goods to and from ships traveling through the canal. Railway and Road area increases also had a high correlation to Mangrove Forest area depletion; however, the small percent of total study area that these LULCs comprise means that this correlation did not contribute as much to Mangrove Forest destruction.   Residential, Airport, Decommissioned Military, and Active Military LULCs had comparatively little to no significant correlation to Mangrove Forest area decline. These findings support my third null hypothesis that one or more LULC will have a strong correlation to Mangrove Forest area decline.

This study contributes to the increasingly common use of remote sensing to assess impacts of land use changes on natural systems. It can be used as a comparison with other remote sensing techniques to detect ecological change. Definiens Professional is relatively new software that has not been used in many studies. Its use in this study provides alternatives to programs and techniques such as IRDAS Imagine, ENVI + IDL, and manual digitization that have been used in many studies (Proisy *et al.* 2007, Coen and Pollard 2003, Jupiter *et al.* 2007). The use of IKONOS images is also not common because aerial photographs and other types of satellite imagery provide adequate detail for many studies for less cost than IKONOS images. Studies

such as Li *et al.* (2007), and Jupiter *et al.* (2007) use aerial photographs and less expensive satellite images to perform similar analysis of mangrove forest quality and depletion. This study provides an example of another type of satellite imagery that can be used to assess changes in LULC areas.

In addition to showing alternatives with GIS programs and imagery type in the growing field of remote sensing, this study builds upon Coen and Pollard's (2003) study of the Northeastern Panama Canal Region. Using a more advanced analysis technique, imagery type, and updated data, this study poses a similar question as Coen and Pollard, but builds on their assessment of Rainforest and Mangrove Forest as a singular category of LULC. Instead of asking how development LULCs impact forests, this study seeks to determine more specifically their impact on mangrove forests.

This study also contributes to the knowledge of development impacts on mangrove forests. There have been several studies published on the effects of shrimp farming on mangrove forests (Beland *et al.* 2006, Ramasubramanian *et al.* 2006), but few studies have been done to show how development other than aquaculture has impacted mangrove forests. More specifically, this study helps to fill the gap of knowledge on how mangrove forests are being affected by changing landscapes in the Panama Canal.

While mangrove forest area was not shown to decline in increasing rates from 1996 to 2008, a 13% overall loss is substantial, and the consequences of this depletion are nevertheless far reaching. Problems with flooding, coral reef depletion, and habitat loss will become increasingly pronounced as more mangrove forest is cut. Communities that rely on mangrove forests as a source of wood, medicine, tannins and a variety of other needs will find it more difficult to obtain these resources. Organisms that use mangrove forests as a nursery and as habitat will also likely suffer declines in their populations.

While these relatively small rates of decline do not appear to pose immediate concern, these rates extrapolated to 2030 provide alarming insight into the consequences of unchecked growth (Fig. 6). If the rate of depletion continues at the lowest annualized rate of decline experienced during this study (-0.51%), which occurred before U.S. Military withdrawal, 22% of 1996 Mangrove Forest area will be lost by 2030. If the rate of decline continues at its current state (-1.37%), 36% of 1996 Mangrove Forest area will be lost by 2030. Finally, if rate of depletion continues at the highest rate of decline experienced during this study (-2.59%), which occurred

2004-2006, 51% of 1996 Mangrove Forest area will lost by 2030. While these are hypothetical situations and rates are unlikely to be static throughout the next 22 years, these unhindered declines reveal a startling future for the Northeastern Panama Canal Region. In just over two decades, this site has the potential to become a severely degraded landscape in which the mangrove forest is unable to perform the same quality of unique ecological and social services that are needed by the inhabitants of the region.
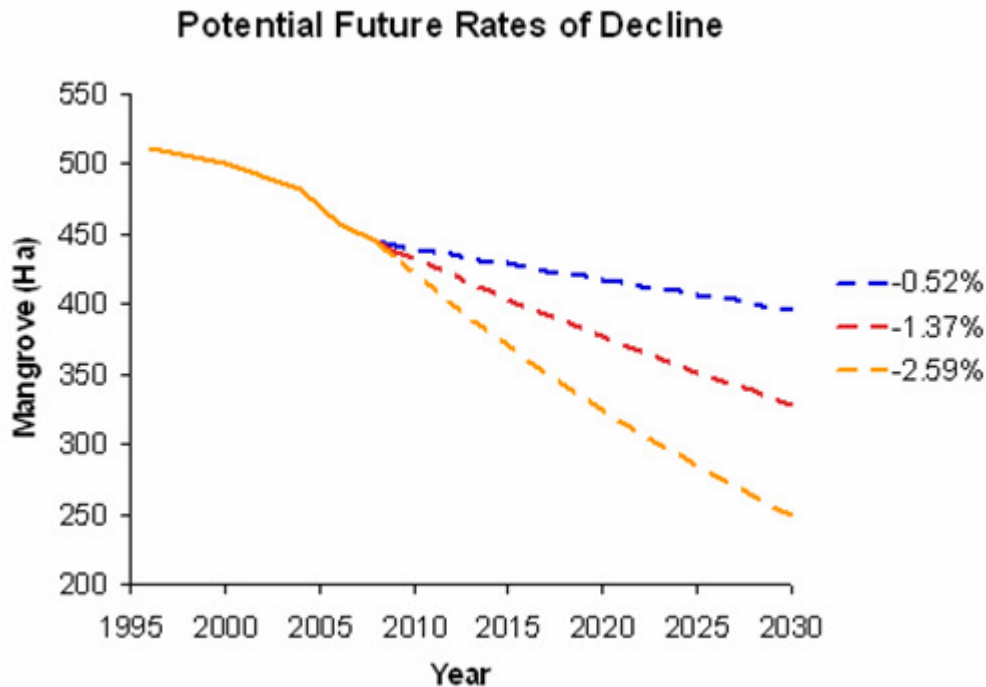

Figure 6. Extrapolated rates of mangrove decline. -0.52% is the lowest rate of decline (1996-2000), -1.37% is the current rate of decline (2006-2008), -2.59% is highest rate of decline (2004-2006).

   Developers and the Panamanian government can now understand how development is impacting mangrove forest in and around areas of development for the Northeastern Panama Canal Region, as well as potential future impacts, to make more informed development decisions. Given the findings of this study, the Environmental Impact Reports (EIRs) of proposed Port Development and Storage Yard areas should be critically examined with regards to how these development types will impact mangrove forests. This study should continue to be updated periodically to continue to monitor the rates of mangrove forest depletion and to see how the Panamanian government responds to this new information. The period of time that this

study examines is brief, and more data can produce increasingly accurate trends of the LULC changes occurring in the site. More time should be devoted to collecting accuracy assessment points in future studies, as the low amount collected in this study likely resulted in a less reliable assessment of map classification accuracy. Future advances in remote sensing technology could also lead to more accurate results. A related study on the secondary effects of mangrove depletion, such as coral reef degradation, frequency and level of flooding in the Province of Colón, and regional water quality could also be also performed.

This study proved effective to show that mangrove forest area in the Northeastern Panama Canal Region is declining and to identify which LULC is having the greatest impact. This information needs to be taken into consideration when future development plans are made for the region, and further research should be done to continue to monitor the effects of development on mangrove forests.

Acknowledgements

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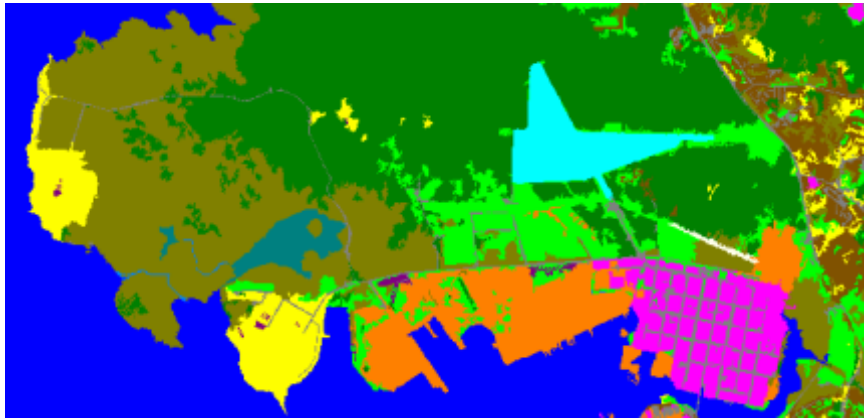
Appendix A: Total area (ha) for each LULC classification of Northeastern Panama Canal Region as determined by Definiens Professional classification of satellite maps for five years.

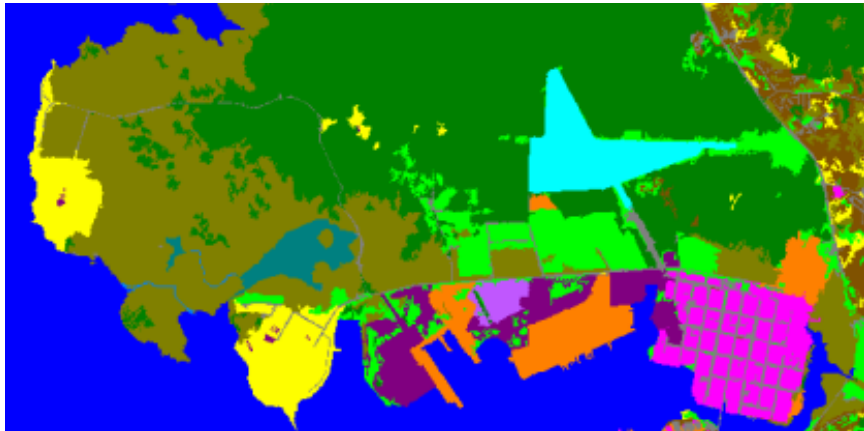| LULC	1996	2000	2004	2006	2008
Mangrove	510.59	499.95	482.08	457.04	444.48
Rainforest	804.59	776.94	738.64	705.17	698.13
Grassland	106.94	106.66	107.55	112.62	114.49
River	1.86	1.95	1.65	2.83	4.82
Lagoon	33.40	33.40	32.87	32.34	32.62
Port Development	91.69	173.83	172.58	214.04	223.89
Storage Yard	98.05	110.58	120.57	125.13	151.87
Cleared	164.89	202.15	241.55	241.95	246.94
Roads	59.79	61.95	62.36	74.77	74.04
Railway	0.00	3.46	7.23	9.14	10.95
Airport	73.59	73.59	72.99	74.28	70.24
Residential	4.51	7.75	4.81	7.68	10.32
Active Military	13.99	0.00	0.00	0.00	0.00
Decommissioned Military	81.86	6.02	5.51	5.93	5.36

Appendix B: Classified maps produced by Definiens Profession of Northeastern Panama Canal Region from years 1996, 2000, 2004, 2006, and 2008.
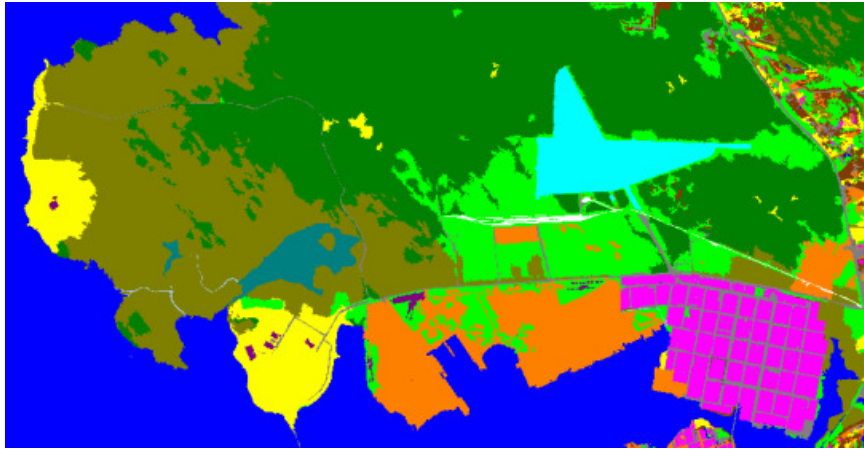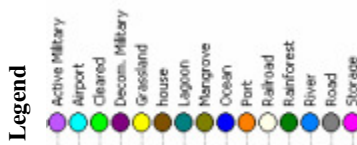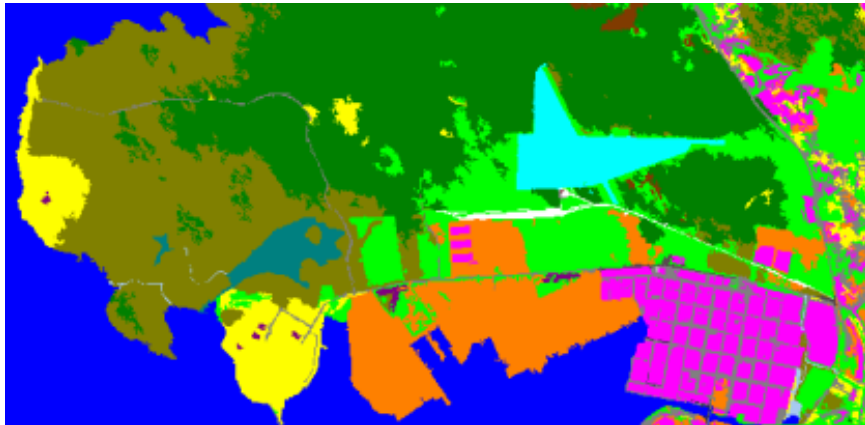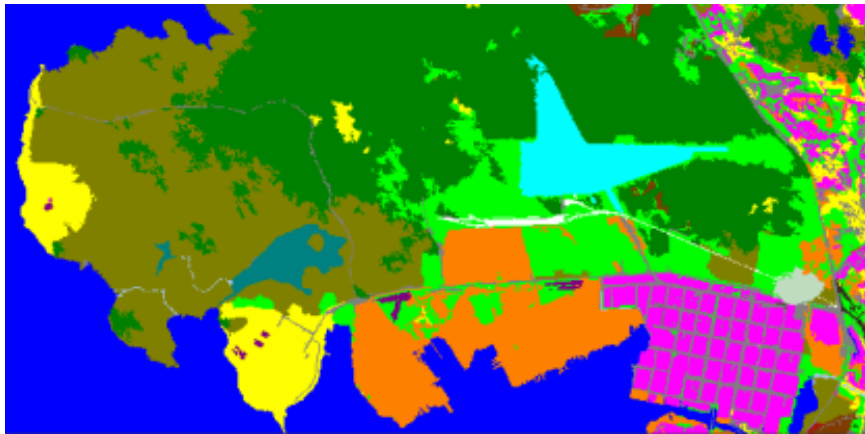
2008 Classified Map

2006 Classified Map

Legend

Active Military
Airport
Cleared
Decom. Military
Grassland
house
Lagoon
Mangrove
Ocean
Port
Railroad
Rainforest
River
Road
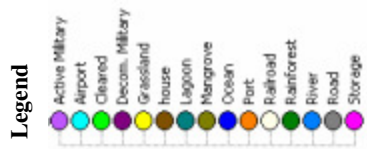Storage

Appendix C: R and p-values for the correlation coefficient analysis of percent development LULC area compared with percent Mangrove Area from 1996-2008.

Development LULC	R-value	p-value
Port	-0.89235	0.04171
Storage Yard	-0.95400	0.01176
Cleared	-0.83900	0.07565
Roads	-0.93222	0.02097
Railway	-0.96021	0.00947
Airport	0.69917	0.18888
Residential	-0.77569	0.12315
Active Military	0.63720	0.24755
Decommissioned Military	0.64126	0.24358