A Global Risk Assessment of Coastal Regions Based on the Disaster Mitigation Potential of their Mangrove Forests

By Lauren Mercado

An Undergraduate Thesis
Submitted in Partial Fulfillment for the Requirements of Bachelors of Arts
In
Environmental Science: Conservation and Ecology
And
Geography and Earth Science

Carthage College
Kenosha, Wisconsin
May 2018

Table of Contents

Abstract

Mangrove forests are found to lessen the impact of tsunamis, cyclones, and their subsequent flooding in nearby areas. Unfortunately, they are one of the most threatened ecosystems in the world. Due to their wide and dense vegetation, mangroves can reduce wave energy and prevent storm surge flooding, thus decreasing the cost of damages and loss of life that can result. The impact of this deforestation is particularly seen on coastlines where local communities have lost a source of livelihood as well as a protection against natural hazard events. As forest protection policy evolves around the world, mangroves' disaster mitigation properties could be a useful option in deciding conservation or restoration efforts. With this project's assessment of high-risk coastal areas using data analysis and GIS, the potential for mangrove conservation or restoration in mitigating natural disasters was further examined. Due to having high mangrove deforestation, high disaster frequency, history of greater disaster effects, and predicted high population density, the two regions of Asia and North and Central America should focus on mangrove restoration along with alternative protection strategies as a means of disaster mitigation.

Introduction

Forest loss has become a global environmental issue, resulting in both gradual and immediate consequences for humans and animals alike. Specifically, mangrove ecosystems are one forest type that has experienced a distinct amount of deforestation. Lost at a rate of 1% per year, mangroves are threatened twice as much as other forests (Thomas et al. 2017). This has devastated communities that rely on them. Coastal forests are a resource for food, medicine, and building materials as well as a provider of erosion and pollutant control (Osti et al. 2009). Another quality of mangroves are their ability to mitigate the damage to nearby places during and after natural disasters, which is potentially one of the ecosystem's most precious and increasingly important services. Assessment of communities that have been left vulnerable to these disasters due to the state of their mangroves is an important step in conservation policy and life-saving strategy. This study will evaluate risk based on three questions –

1) Where has most mangrove deforestation occurred?
2) Where do the most natural disasters occur?
3) Which areas hold the greatest risk based on these criteria?

Mangrove Forest Background

Mangroves are tropical and subtropical coastal ecosystems located around the globe in the middle of land and sea, particularly between latitudes 25° N and 30° S (Valiela et al. 2001). Figure 1 features a most recently available mangrove distribution, demonstrating the vast amount of land that these forests cover. They inhabit where rivers meets the ocean, creating a mixture of freshwater, saltwater, and river deposits in coastal areas called estuaries, lagoons, or deltas (Oyana et al. 2009). They consist of a variety of flora and fauna that have adapted to the tide changes and unique water chemistry. Most notably, there are the mangrove tree species from which the ecosystem gets its name. These trees have the ability to filter salt through their roots and leaves, allowing them to inhabit the coastline. (Estuaries n.d.). The reasons these forests have been targeted for clearance is largely due to coastal development, resource mining, and industries such as aquatic agriculture (Osti et al 2009). Of the harmful effects on mangroves, shrimp farming is cited as the greatest threat to coastal forest degradation (Quarto 2005). The subsequent decreased amount of vegetation and increased amount of urban land from these activities has left communities vulnerable to tsunamis and cyclones and their accompanying floods and storm surges.

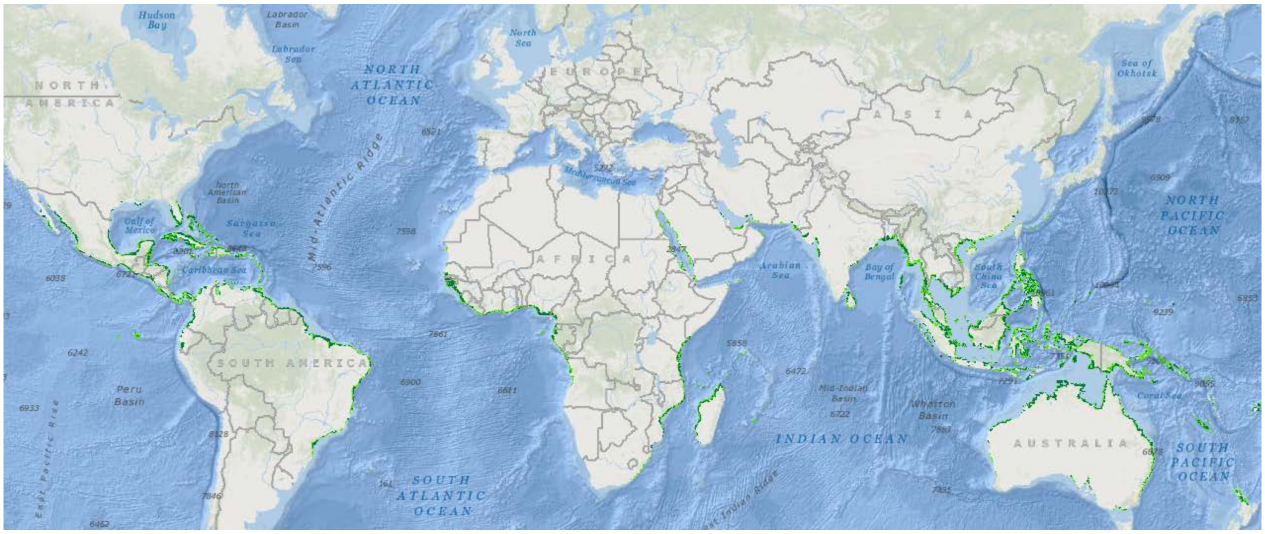


Figure 1. Global distribution of mangroves (Modified from map by USGS 2011, using data based on Giri *et al.* 2011).

Natural Hazard Background

Tsunamis are major, though sporadic, events that can absolutely devastate coastal communities, often where mangrove ecosystems are found. They are a series of large waves created by water disturbances, most frequently undersea earthquakes but also underwater volcanic eruptions and landslides (Oskin 2005). As energy from a disturbance flows through the deep ocean, it moves the water at up to 800 km per hour (*Tsunamis: Facts...* 2004). Eventually this energy reaches shallower water towards the coast and goes through a process called shoaling. Shoaling increases the height of the waves as the speed decreases, bringing this energy very destructively onto land. (*Tsunami…* 2006). This process of the wave contacting the coast tends to last from 10-60 minutes (Marois & Mitsch 2015), while the water can reach heights of 3 to 30 meters and strip an entire beach as it moves in and pulls back (*Tsunamis: Facts...* 2004). After the initial storm, intense flooding is also a possibility. Water can move inland 300 meters or more in a rush from the energy, destroying buildings and objects in the flood's path.

(*Tsunamis: Facts*... 2004). Though tsunamis can happen anywhere around the world, many occur in the Pacific Ocean where oceanic plates collide with continental crust to form what is called a subduction zone. The circling area in the Pacific Ocean of many subduction zones is known as the "Ring of Fire," and it stretches up from Australia, on the East coast of Asia, across the ocean to Alaska, and down the West coast of North and South America (Oskin 2015). Due to the increased potential of plate tectonic activity in this region, the deadliest tsunamis have occurred on the coasts of the "Ring of Fire," causing loss of life and property damage from the waves and flooding (Oskin 2015).

As mangroves are located in the tropics, cyclones are another threat to these communities. Cyclones, also known as hurricanes or typhoons depending on geographic location, are low-pressure storms that start over oceans and build into wind funnels (Marois & Mitsch 2015). The body of water must be warm to fuel the storm and form clouds, while the heat energy also combines with the rotation of the Earth to create the defining spinning motion of a cyclone (Kamenev & Pickrell 2011). Their strength can range from winds of 63 km per hour to over 290 km per hour; this range is broken into five categories of cyclone classification to label its severity based on the storm's speed (Kamenev & Pickrell 2011). Flooding also accompanies a cyclone, often in the form of a storm surge. The surge may even end up being the most destructive part of the event (Marois & Mitsch 2015). It describes the name for the rise in sea level caused by strong winds pushing water over the land. This phenomenon is measured by the height of the water level rise compared to the normal sea level for that location (*What is a storm surge?* 2016). A storm surge may reach heights of 1 to 3 m, with 9 m having been observed as an extreme case, and can last for up to several hours (Marois & Mitsch 2015). Modern development has reduced the loss of life associated with cyclones, yet property damage has shown a considerable increase for this hazard (Paul & Rahman 2006).

Referring to Figure 2, the most active cyclone and tsunami occurrence areas within the latitude of mangrove forest distribution are the Central America and upper South America region; the islands of the Gulf of Mexico, Caribbean Sea, and Atlantic Ocean; and Southeast Asia near the Indian and Pacific Oceans. To use mangroves’ disaster mitigation abilities to their fullest potential, the most vulnerable areas must be identified.

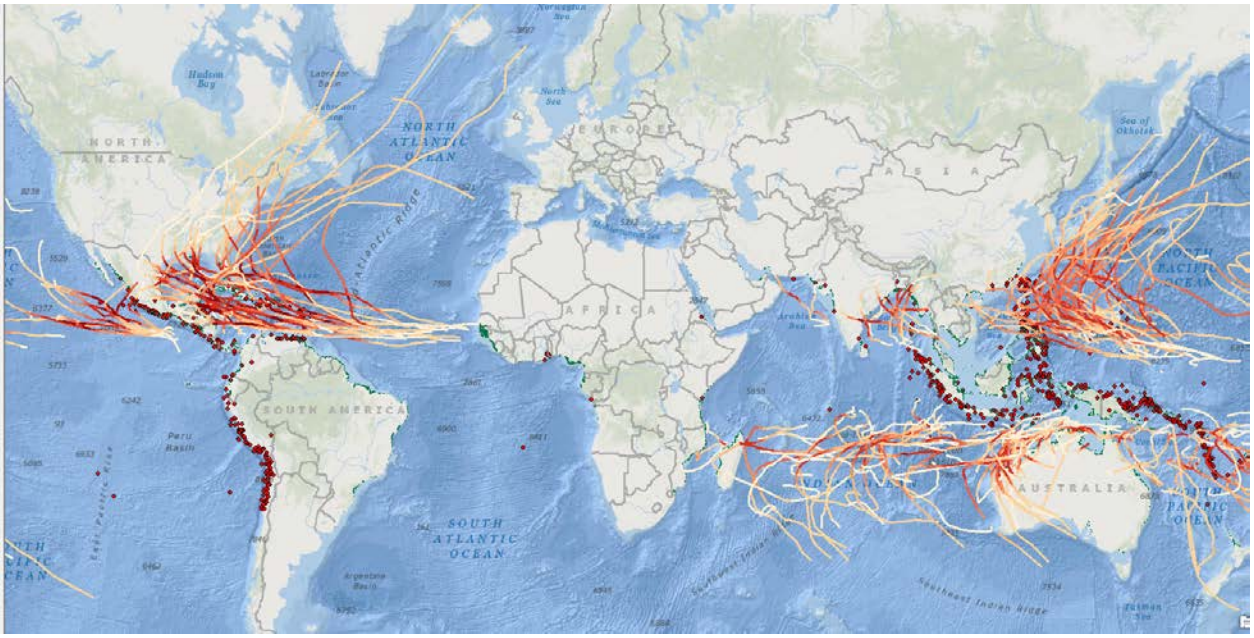


Figure 2. Tsunami events and cyclone paths occurring near global mangrove land cover (Modified from map by USGS 2011, using data based on Giri *et al.* 2011 and data from NOAA).

Mangrove Mitigation Properties

A natural disaster is defined when economic assets are destroyed by a natural process, such as the tsunamis or cyclones that threaten coastal regions; two variables contribute to the damage – the actual event itself and the level of vulnerability of the targeted community (Barbier 2007). Important factors that may determine the outcome are the strength of the storm, the density of the nearby community, the age of their infrastructure, disaster protocols, and more. As for mangrove forests, when acting as a protective barrier between coasts and a storm, they are able to reduce wave energy with their dense and wide vegetation (Osti et al. 2009). An example of this phenomenon was during the Indian Ocean Tsunami of 2004. As there were still healthy mangroves in Tamil Nadu, the Andaman Islands, and the Nicobar Islands, the number of deaths and the amount of inland property that was damaged was recorded lower than in deforested areas (Barbier 2007; Osti et al. 2009). Still, in total, 225,000 lives were lost and millions in dollars (US) in damages occurred to the coastal infrastructure (Osti et al. 2009). Research using satellite and field data to simulate mangrove forest density and its ability to handle tsunamis determined that there is a potential for the trees to reduce the maximum tsunami flow by about 90%; the appropriate density of the forest would have to be 30 trees per 100 square meters (Osti et al. 2009).

When it comes to cyclones, mangroves were also found to be an invaluable asset after the super cyclone of 1999 that hit eastern India. A study by the University of Delhi and Duke University showed an inverse relationship between the width of mangroves from the coastal community and the number of deaths. Still, many villagers died drowning in the storm surge that followed the disaster. Yet researchers predicted from a statistical model that there would have been 1.72 more deaths per each of the 409 villages if there were not a mangrove forest barrier (Duke University 2009).

Once either of these two hazards hit, the magnitude of the water can be deadly to areas without proper means to control it. With healthy mangroves, these forest ecosystems act as sponges to trap water and release it slowly into bodies of water (Lawrence 2007). They are also able to collect and emit water through soil absorption, evaporation, and transpiration. Countries who still have kept their habitats intact, like Costa Rica, have been better protected while other countries such as China, India, Nepal, and Bangladesh continue to be devastated by floods (Lawrence 2007). Too much development and not enough forestland creates a recipe for high floods and extreme surface run-off. A positive correlation has been described between the amount of forest and total water retention for a location. At 10% forest cover, there is around 25% water retention; if forest cover grows to just 30% or more, water retention can increase by 50% (EEA 2015).

For coastal protection, the composition of mangrove species in one forest may be better than the composition of another. There is a variety of mangrove tree species, often characterized by different types of aerial roots. Aerial roots are roots that expose themselves to the air and are typically above the Earth's surface. Mangrove trees use them because their moist and salty environments have low to no oxygen in the soil, so they must get it directly from the air (Spalding 2001). A diverse amount of aerial root types has evolved in mangroves; four main categories include – buttress, knee, pencil, and prop roots as shown in Figure 3 (Marek n.d.). The most prominent of the four are the buttress roots. These provide trees with a great amount of stability along with their breathing function. Knee roots are named after their knee like appearance, sticking out of the ground in an arch. Pencil roots are also named for their appearance as they stick straight out of the ground to a point. Lastly, prop roots prop the tree up by outgrowing the trunk and branches. As more grow, prop roots make the tree sturdy and designate the space the mangrove has to develop. These roots can even grow up to a radius of 10 meters around the trunk (Marek n.d.).

Not only do these unique roots help the mangroves themselves live in such a particular habitat, but also these same features are what gives the forest their strength against natural disasters. The protruding nature of these roots create obstacles that slow down the movement of water from tsunamis and cyclones along with the intense winds of tropical storms (Spalding et al. 2014). For the most productive forest systems, trees must be densely packed together so their roots and branches can create tough barriers; buttress and prop roots are best for this, as they are the largest and strongest of the aerial roots (Marek n.d.). In addition, a complex forest composition should be used throughout the whole coast. Any channels or open spaces give water the opportunity to flood areas at full strength. Dense, complex, and complete forests are necessary for the most successful disaster precautionary strategy involving mangroves (Spalding et al. 2014).

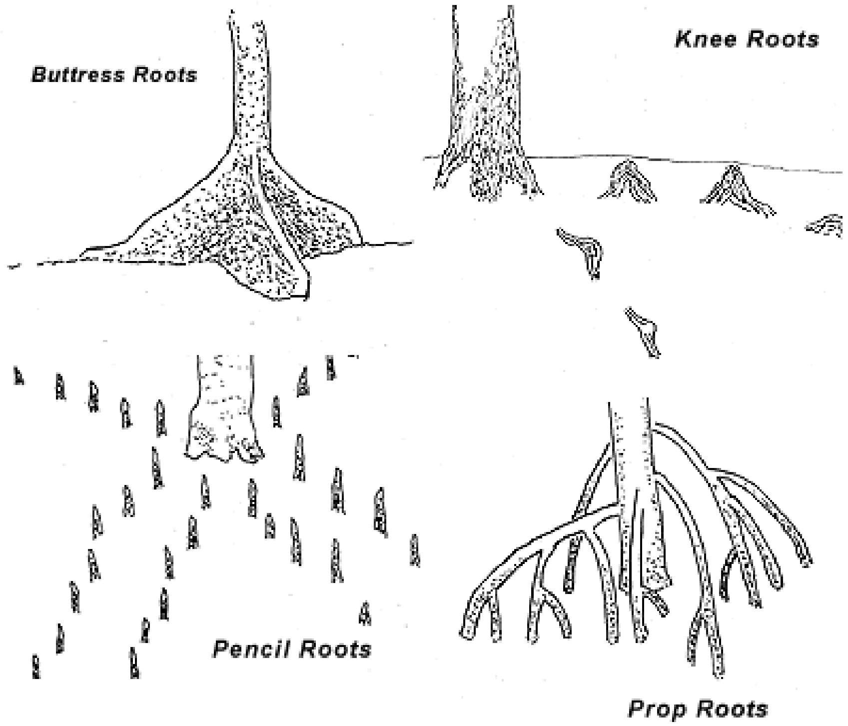


Figure 3. Four types of mangrove species aerial roots that show above the surface (*Source:* "Mangroves" n.d.).

Methods

Risk assessment consists of evaluating the intensity of the threat, the people exposed, and the extent of vulnerability (Spalding 2014). Threat was analyzed by the frequency and the amount of destruction of past tsunamis and cyclones; exposure was analyzed by population density. This study works off the assumption of mangrove forests' ability to mitigate natural disaster, and thus assesses vulnerability of an area by the degree of mangrove deforestation. The most at risk areas were determined by the consideration of the many different threat, exposure, and vulnerability variables.

To find global mangrove cover change, data was taken from the United States Geological Survey. Due to the difficulty of global surveying, only two full mangrove distribution sets were available; the early set had a temporal range from 1960 to 1996 and the later from 1997 to 2000 (Spalding et al. 1997; Giri et al. 2011). For analysis, data was broken up into five different regions where mangroves reside - Africa, Asia, North and Central America, South America, and Oceania. This organization method was influenced by the study of Osti *et al.* Proper area calculations for each distribution were done in ArcGIS through an equal area projection and calculating geometry tool, then the two layers were combined in an overlay using the Union tool for further analysis. Mangrove forest loss was represented as a percentage, found from the sum of area changes of smaller locations within each region. This was done by sorting locations into their subsequent region, adding the areas of mangroves within each region for the old and newer distributions, subtracting their before 1997 distribution area from their after 1997 distribution area, and dividing those sums by the earlier 1997 distribution area sum. The percent lost was used in a chi-square analysis to find if any region experienced more significant loss of mangrove forests. A layer was then made of the deforested areas to be used on various maps in a visual analysis.

For the disaster analysis, tsunami and cyclone data was found from the National Oceanic and Atmospheric Administration, NOAA (National Geo. n.d.; Knapp 2010). Tsunami data consisted of every major tsunami from 2000 B.C. to 2017; cyclone data consisted of every major cyclone from 1924 to 2017. Once again, this data was sorted into the five specified regions using the disaster event location, as well as by latitude location where mangrove habitat resides. Two chi-square tests were run based on the number of tsunami events and cyclone events per region. This test was used to evaluate region susceptibility, to see if any region experienced significantly more tsunamis or cyclones compared to the others. Totals and averages were compiled for the amount of deaths and houses destroyed by tsunamis per region and displayed in graphs; this was used to evaluate any differences in the effects of tsunami events per region. Then using ArcGIS, maps were made to represent the spatial frequency of the following disaster variables – total deaths, total houses destroyed, and cases of extreme damage (over $25 million). Maps were also created to show the frequency of cyclone paths moving through or within a dangerous distance of previously forested coasts to see any potential connection between mangrove-based vulnerability and hazard susceptibility. This was done with the select by location tool, using the within a distance spatial selection method at 200 km.

To assess the amount of exposure per region, a map from NASA predicting global population density by the year 2020 was obtained (NASA 2016). This map was modified by adding the mangrove deforestation layer previously made to find which coasts would have the most people and least amount of mangrove coverage.

Results

According to the mangrove distribution data, mangrove area changed drastically during the 20th century. The five regions studied lost a similar 98-99% of mangrove forest area, as shown in Figure 4. The chi-square statistical test resulted in a p-value of 0.99, over the significance interval of 0.05.

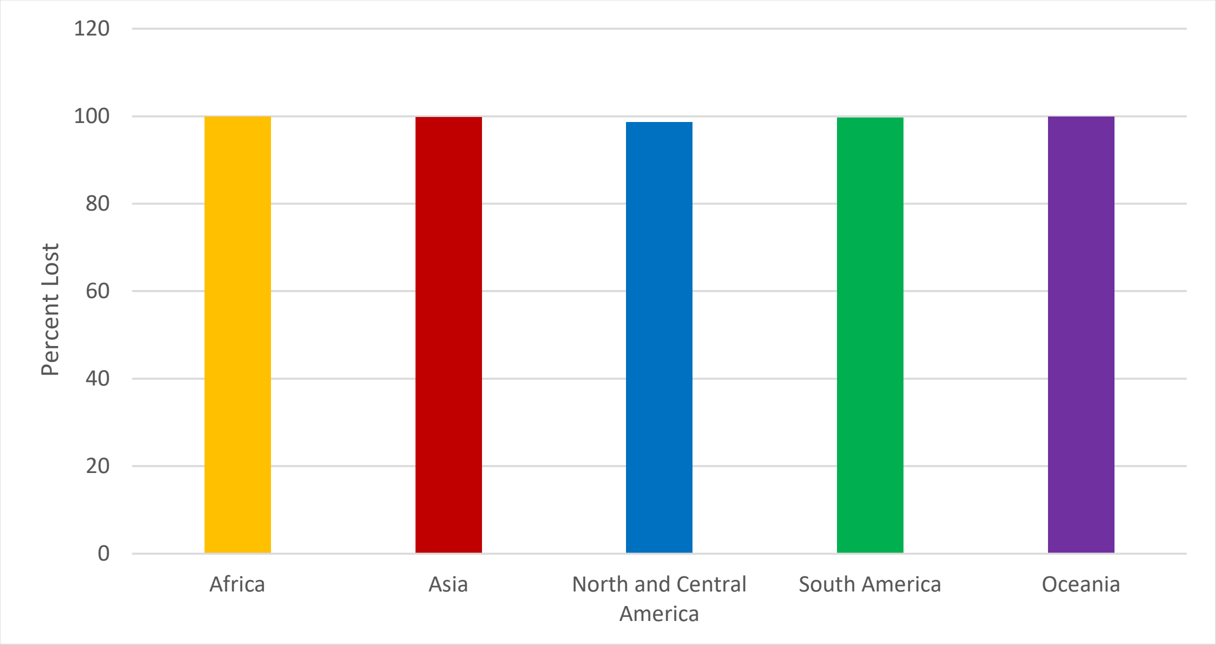


Figure 4. Percentage of mangrove area lost per region between 1960 and 2000 (Graph created using data from the USGS). Chi-square p-value = 0.99.

Historical records show that some regions experience more tsunami or cyclone events over others; their frequencies per region are displayed in Figure 5 and Figure 6, respectively. The chi-square tests for tsunami and cyclone frequency resulted in p-values less than .001. At a confidence level of 95%, these results show significant differences between the frequency of tsunami and cyclone events of the five regions. The Asia region has experienced the highest number of tsunamis; the North and Central America and Oceania regions have experienced the most cyclones at similar counts, with Asia in third.

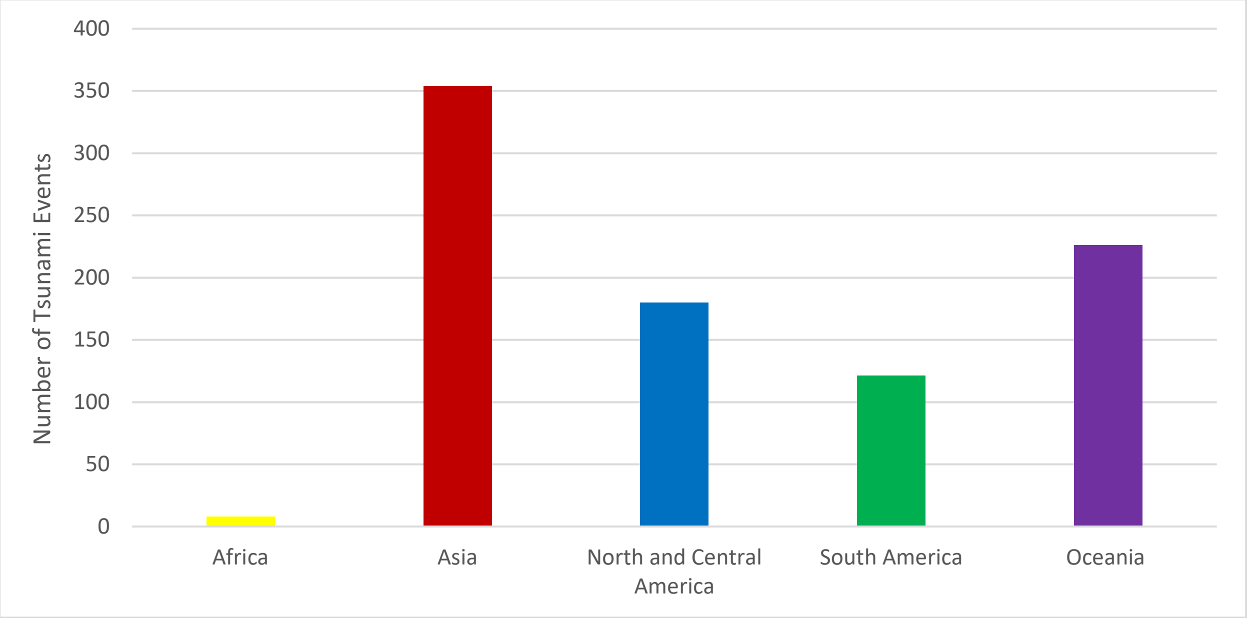


Figure 5. Frequency of tsunami events per region (Graph created using data from NOAA). Chi-square p-value < .001.

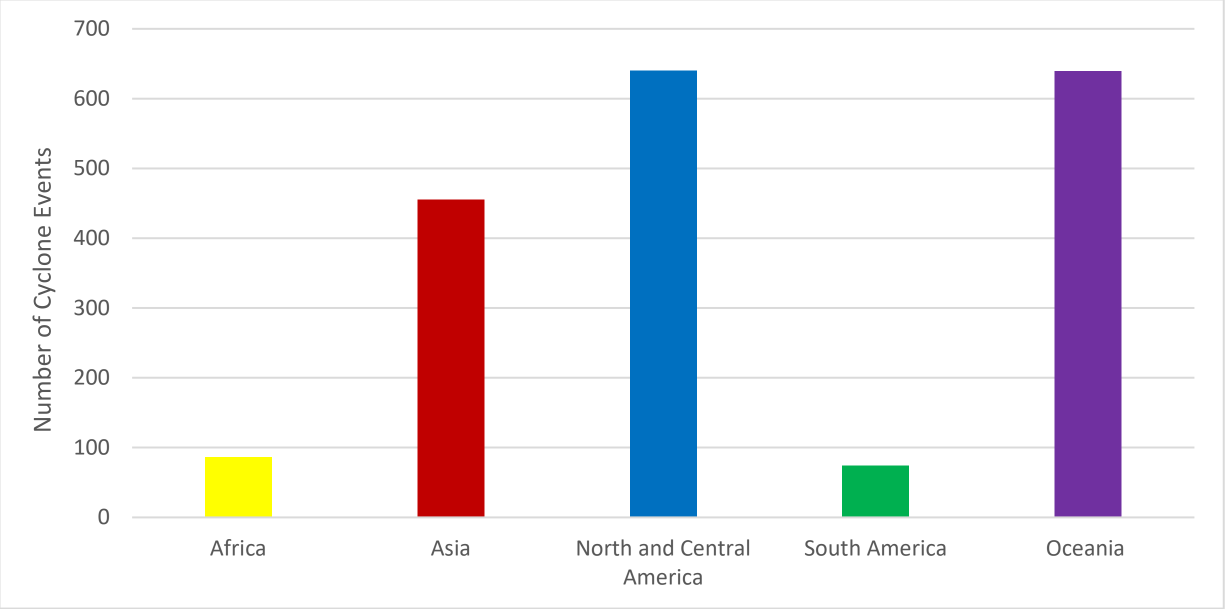


Figure 6. Frequency of cyclone events per region (Graph created using data from NOAA). Chi-square p-value < .001.

Breaking down the effects of these disasters in each region, the totals of deaths and houses destroyed by tsunamis are shown in graphs Figure 7 and 8. Asia has had the greatest number of deaths from tsunamis, closely followed by North and Central America. A map representing these values is found in Figure 11. North and Central America has had the most houses destroyed in their tsunami history by a large margin. The accompanying map to this data is shown in Figure 12. To represent the typical hazard event in each region, the average number of deaths and houses destroyed are displayed in Figures 9 and 10. The North and Central America region has both the greatest average number of deaths and average number of houses destroyed per tsunami event. In addition, North and Central America and Asia both have a notable amount of tsunami events that acquired damage equal to or over $25 million as shown in Figure 13.

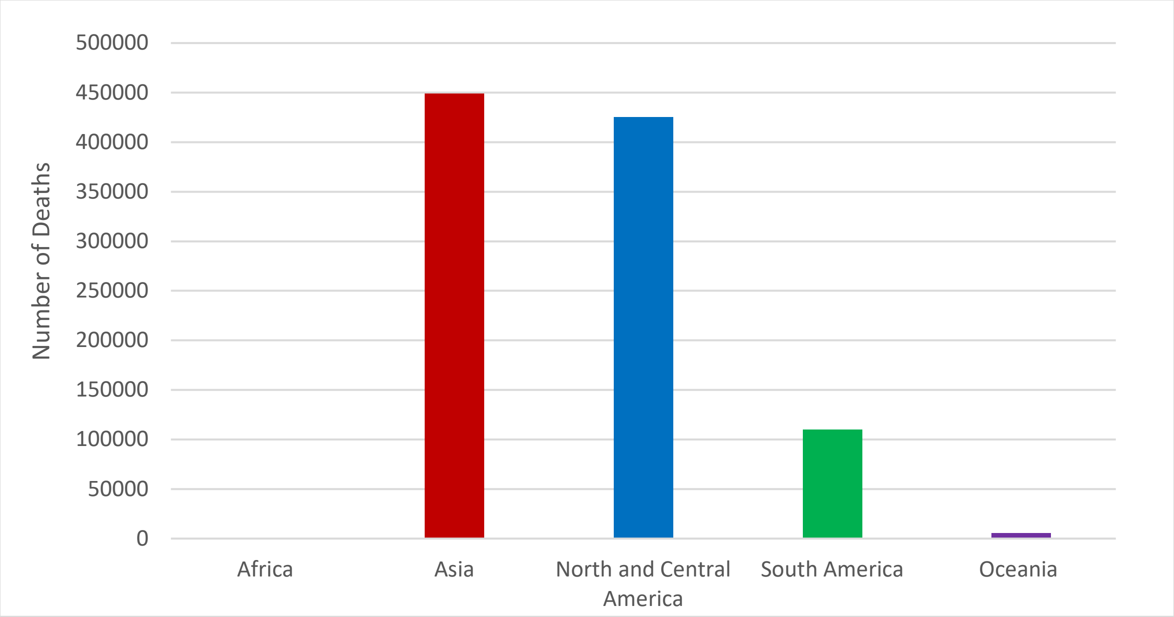


Figure 7. Total deaths from tsunamis per region (Graph created using data from NOAA).

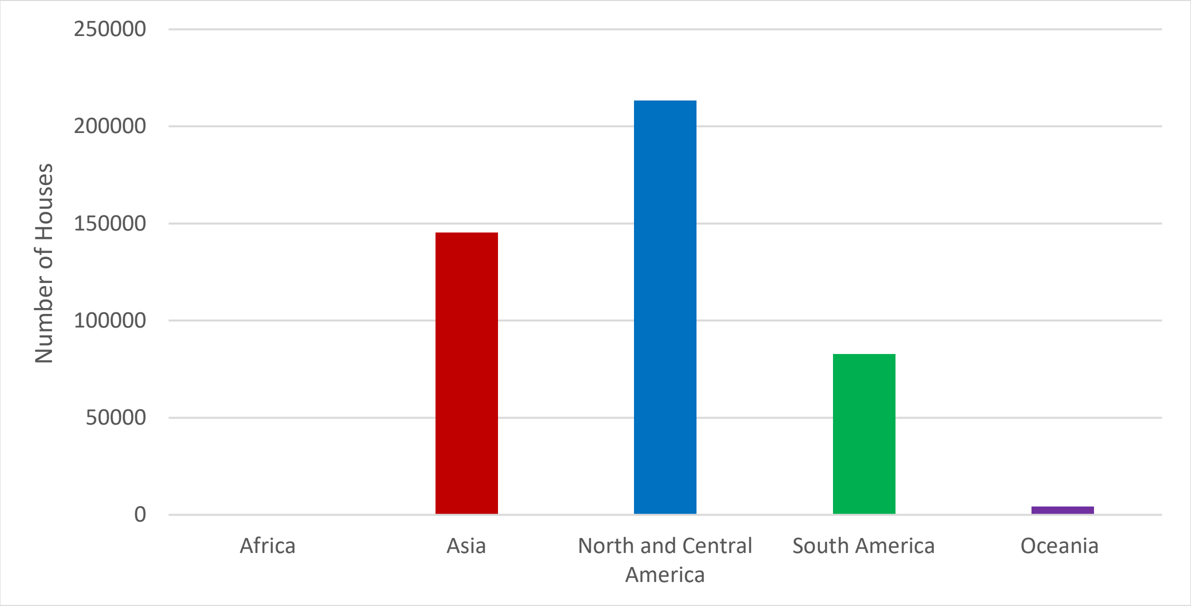


Figure 8. Total houses destroyed from tsunamis per region (Graph created using data from NOAA).

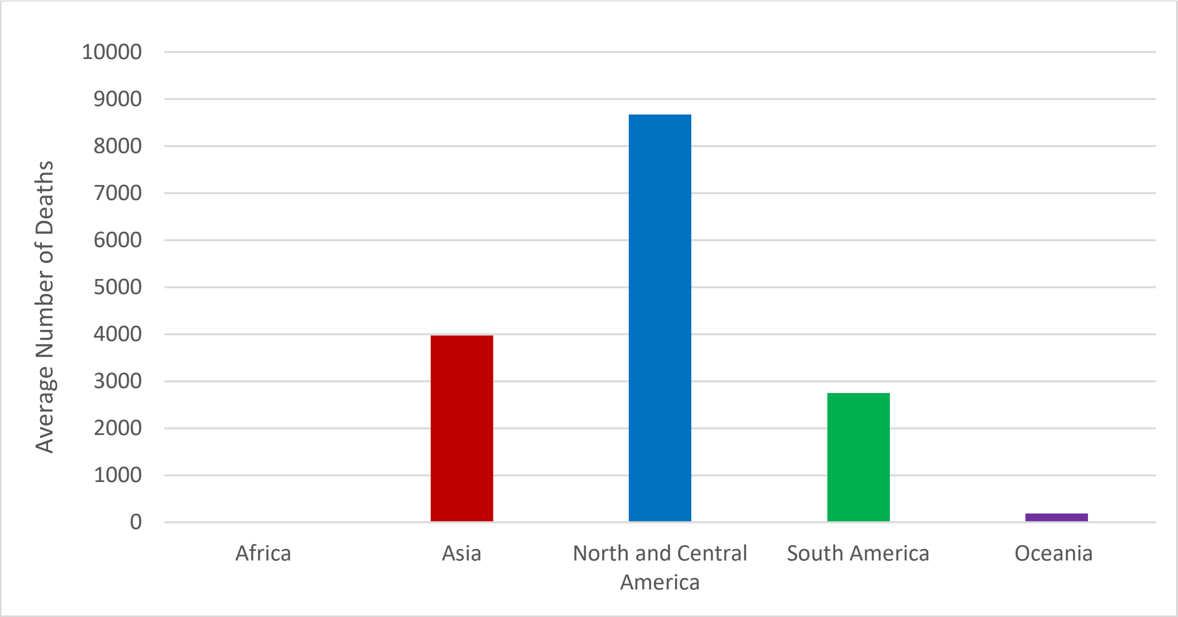


Figure 9. Average deaths per tsunami event by region (Graphs created using data from NOAA).

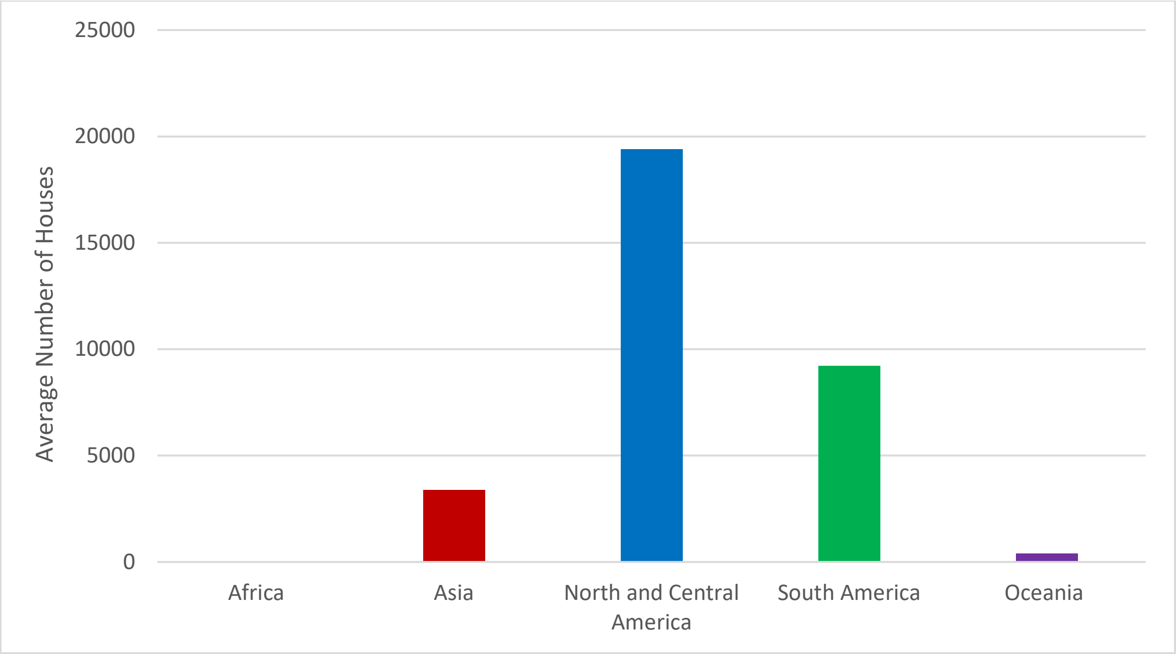
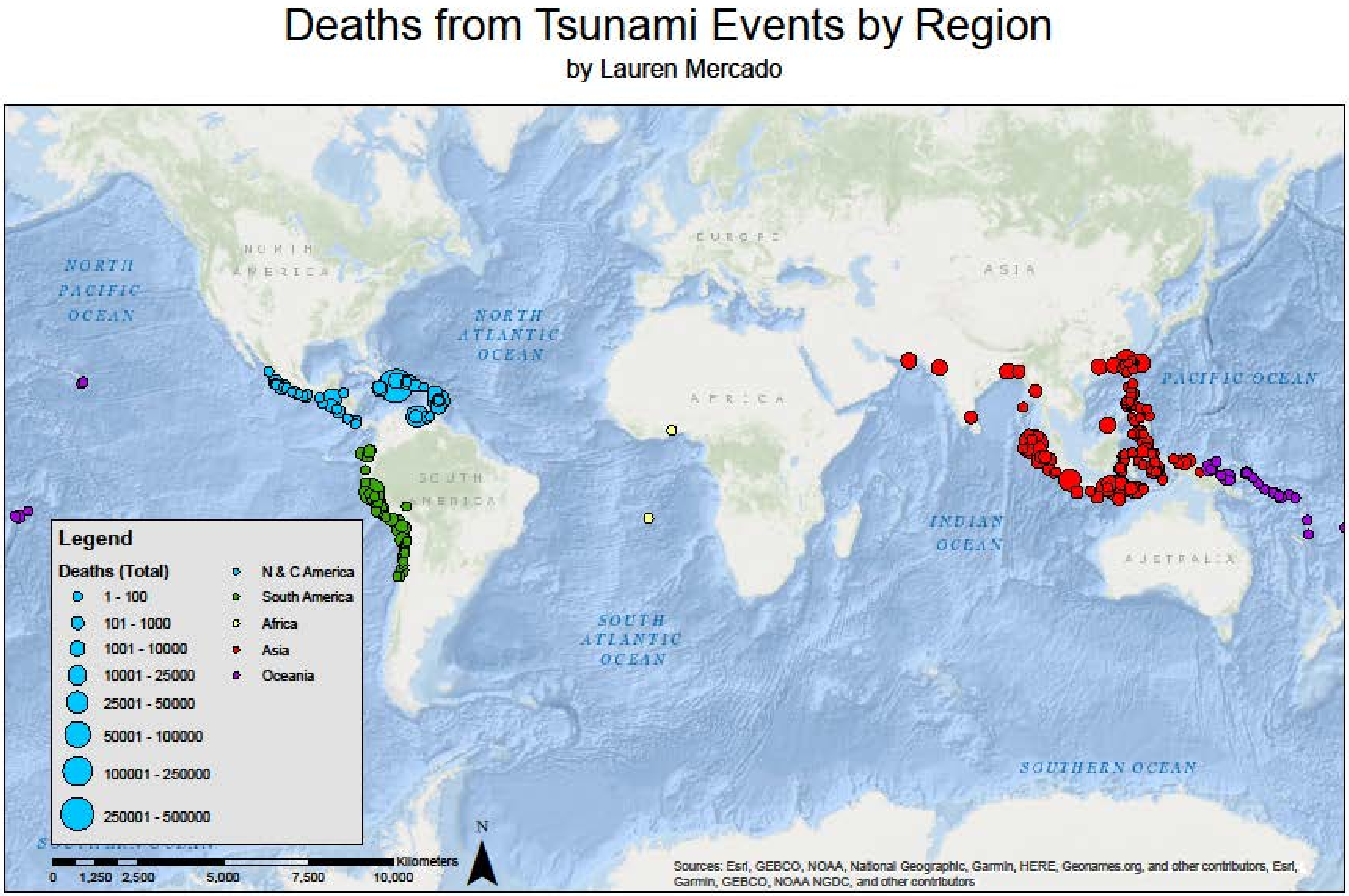


Figure 10. Average houses destroyed per tsunami event by region (Graphs created using data from NOAA).

The analysis of the disaster variables alone often resulted in Asia and North and Central America being prominent regions. With this focus, only the maps for these two regions featuring cyclone paths near deforested areas are included in the results. North and Central American had 640 incidents of intersection (Figure 14) and Asia had 455 (Figure 15).

Lastly, population density predicted for the year 2020 and the areas of deforested mangroves was used to assess exposure (Figure 16). Population density is predicted to be greatest in Southeast Asia, near the mangrove forests lost within the Asia region of this study.



Deaths from Tsunami Events by Region

by Lauren Mercado

Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 11. Total deaths from tsunami events by region within the latitudes of mangrove habitat (Map modified using data from NOAA).

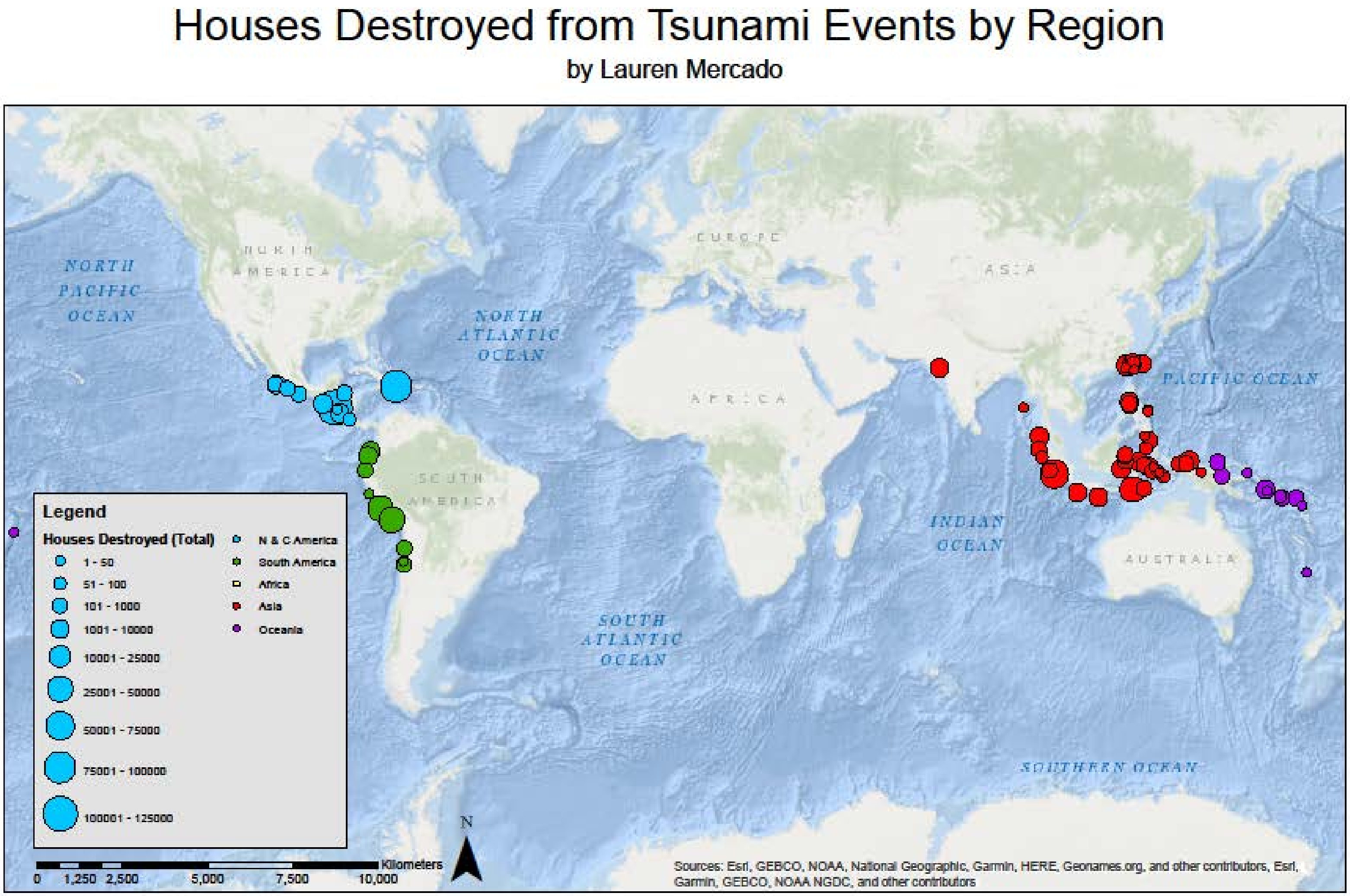


Figure 12. Total houses destroyed from tsunami events by region within the latitudes of mangrove habitat (Map modified using data from NOAA).

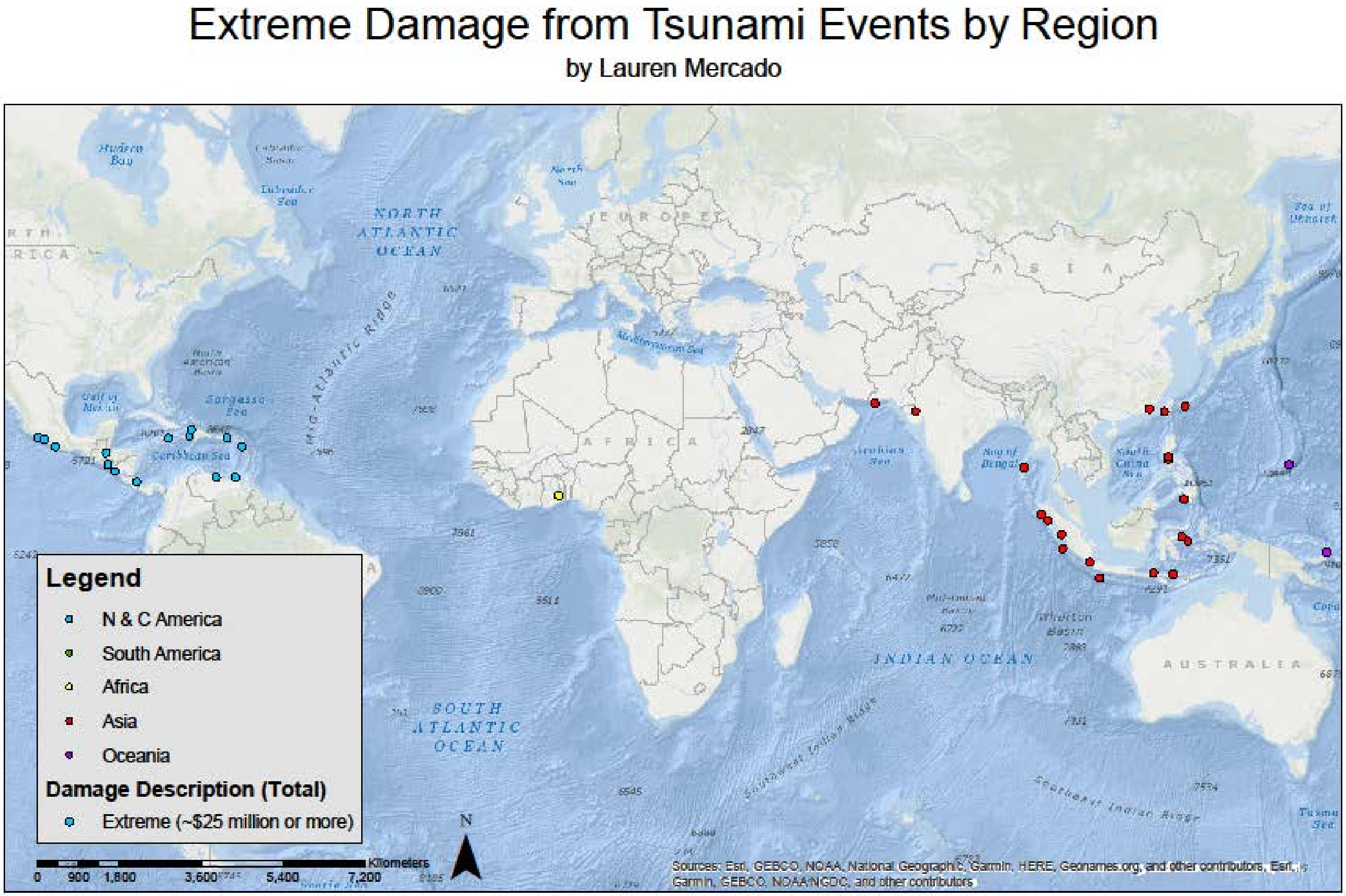


Figure 13. Tsunami events with extreme damage costing $25 million or more by region (Map modified using data from NOAA).

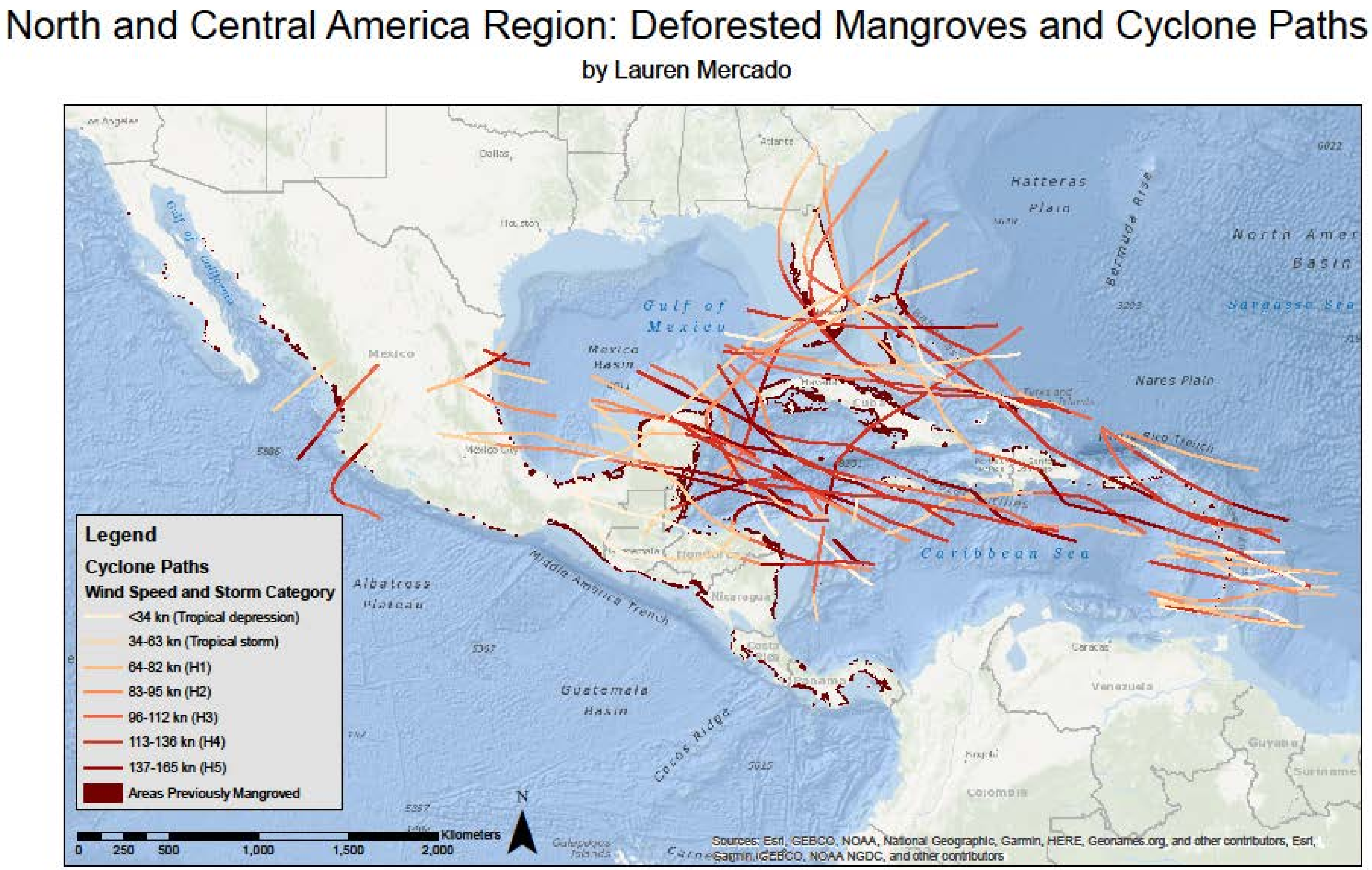


Figure 14. Intersection of cyclone paths and areas of deforested mangroves in the North and Central American region (Map modified using data from NOAA and USGS). Showing 640 cyclone path intersections within a deforested area.

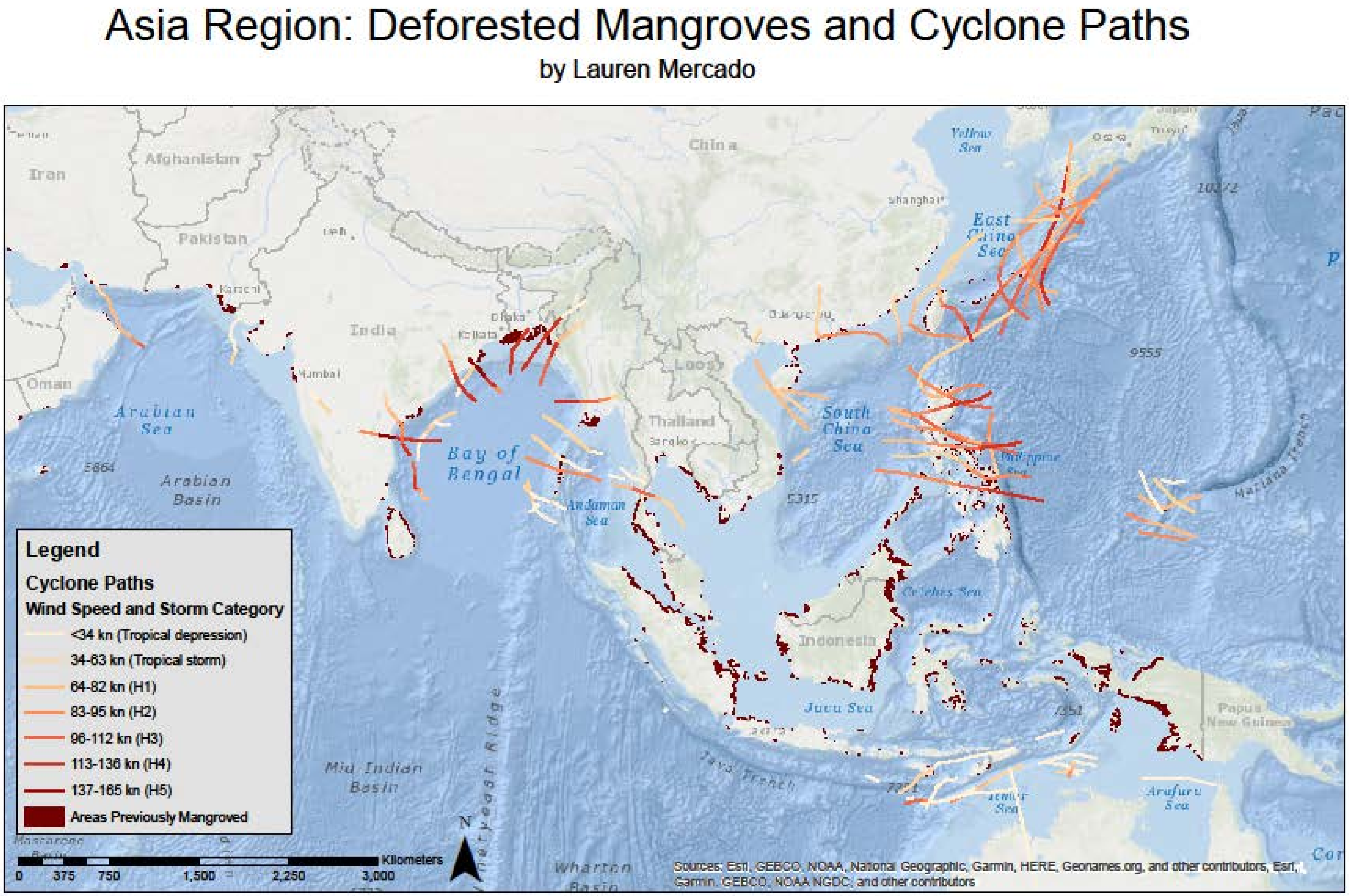
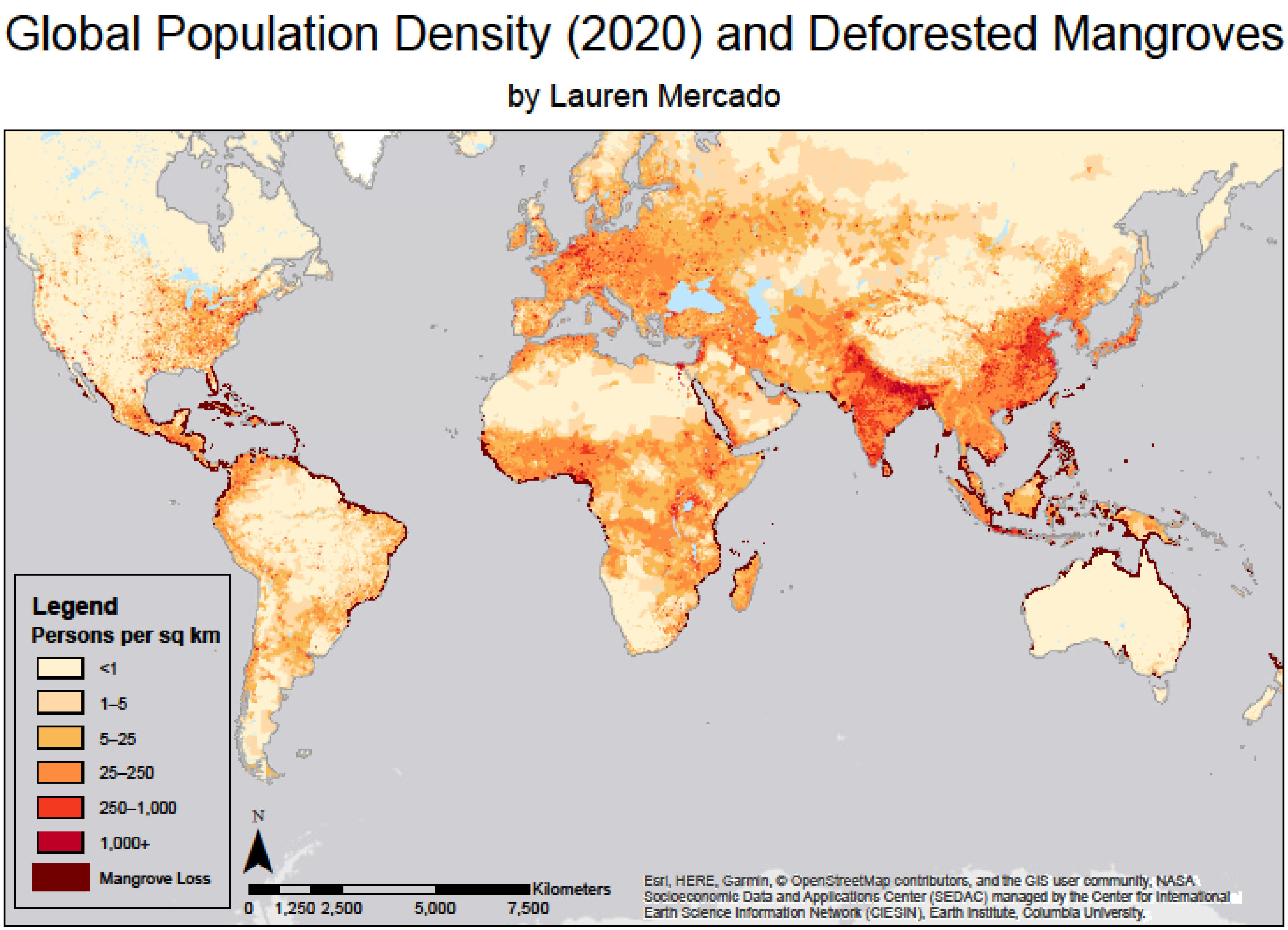


Figure 15. Intersection of cyclone paths and areas of deforested mangroves in the Asia region (Map modified using data from NOAA and USGS). Showing 455 cyclone path intersections within a deforested area.


Global Population Density (2020) and Deforested Mangroves

by Lauren Mercado

Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community, NASA Socioeconomic Data and Applications Center (SEDAC) managed by the Center for International Earth Science Information Network (CIESIN), Earth Institute, Columbia University.

Figure 16. Predicted global population density by the year 2020 and areas of mangrove deforestation (Map modified using data from NASA and USGS).

Discussion

The comparison of deforestation between areas concluded that no region experienced any significant mangrove forest loss different from the others because of the p-value being greater than 0.05. For the study, this find resulted in the assumption that all regions were at equal vulnerability to a natural hazard based on their similar lack of protection from mangrove forests (Figure 4). The risk assessment proceeded to take into higher account the results of the threat and exposure variables to decide on which regions need urgent disaster mitigation strategies.

At a significance level of 0.05 and a p-value lower than that, the disaster frequency analysis shows that the distribution of tsunami and cyclone events is not random. To answer the question of where do tsunamis most occur in locations with mangroves, it can be interpreted that Asia has significantly more tsunami events than the other regions (Figure 5). This is likely because of its location near the "Ring of Fire," which contains many subduction zones that can cause tsunamis. North and Central America, Oceania, and Asia have significantly more cyclone events occurring than South America and Africa (Figure 6). This pattern is likely due to the temperature of the waters near these coasts in combination with their climates, distance to the equator, and direction of global wind pattern that move the cyclones to these regions.

The totals and averages of the deaths and houses destroyed from tsunamis describe how this phenomenon affects the regions differently. Asia has the greatest number of deaths overall from tsunamis, likely because it has experienced the most occurrences (Figure 5, Figure 7). Yet, the North and Central America region has a similar number of deaths while experiencing a much lower frequency of tsunamis (Figure 5; Figure 7). The region also has the greatest number of total houses destroyed and the highest averages for deaths and houses destroyed (Figure 8, Figure 9, Figure 10). These discrepancies are probably due to differences in disaster intensity and tsunami preparation. Because Asia has experience a significantly greater amount of tsunamis, the region has likely become more prepared and better equipped in evacuation and infrastructure to handle such events compared to the North and Central America region. With less preparedness, there will be more fatalities and more property damage. Another potential reason is that North and Central America experience stronger tsunamis, which would also bring about greater destruction and more deaths per tsunami event. In addition, these results explain why both those regions have the most tsunami events costing $25 million or more (Figure 13), as there is more frequent, less prepared, and more intense activity occurring.

The isolated disaster analysis points to both Asia and North and Central America as being prominent areas of natural hazard activity and experiencing greater threats. This conclusion combined with their equal vulnerability due to non-significant mangrove deforestation differences puts both regions at similar risk. To further emphasize their vulnerability, Figures 14 and 15 display the potential interaction between deforested areas in these regions and the tropical cyclone storms. North and Central America has the highest occurrence of intersection, yet Asia also has a notable and dangerous amount. When considered with the predicted population density of 2020 in which Asia appears to have the greatest increase and the North and Central America region also has a critical amount, these factors stress further the risk of these regions to the effects of natural disaster. Overall, due to the greater frequency of tsunamis and cyclones, the amount of fatalities and property damage, and the predicted increase in population density, both Asia and North and Central America show elevated risk to coastal natural disasters.

Beyond Mangroves

Mangroves are key to the survival of the coastal communities they inhabit because of the many ecosystem services they provide. Yet when it comes to natural disasters, they are most effective when paired with other disaster mitigation techniques. A strong potential to reduce risk is first to evaluate location. Communities closer to the coastline will have greater damage during a natural disaster compared to ones further inland. A technique referred to as “building with nature” integrates the ideas of mangrove conservation and restoration with urbanization for the most effective protection as communities are developed. As places may rebuild after destruction or people migrate from high-risk areas, building farther from the coastline can help reduce death and damage to infrastructure in the future. When incorporating mangroves, the forests should be replanted in ways as not to expose cities to the coastline for the greatest benefit. This essentially creates a natural barrier between the population and any storm. (Spalding et al. 2014).

In addition to construction near the coast, construction away from it can still affect the ecosystem and be an important factor in risk reduction. Recalling that mangroves reside in estuaries where rivers meet the ocean, development such as dams on those rivers can impact the health of mangrove forests and thus their effectiveness in destruction mitigation. Rivers carry sediment that is vital to the forests’ soil and the trees’ health. Mangroves need renewed supplies of sediment to keep their growth rates up, their root structures strong to prevent erosion, as well as to protect themselves against rising sea levels due to storms, geological land change, or climate change. (Spalding et al. 2014). So if the mangroves are strong and stable, the force of storms is less likely to make an impact on the people and infrastructure in its path.

Another aspect of development that may influence the damages from natural disasters is the building of concrete coastal structures. These are used by some countries in defense of strong waves or as borders to aquaculture farms. Concrete infrastructure in those areas will need continual investment by these communities as they are withered down by water activity and must be repaired. This is unlike mangroves, which are likely to need only an initial investment because of their natural succession after ecosystem disturbances. In addition, hard structures are rarely tall enough to block all the waves that come with storms. They may actually end up reflecting waves and making them larger, bringing greater danger to people nearby (Spalding et al. 2014). Concrete also disrupts the previously mentioned important sediment flow. This means that excessive construction must be carefully examined or avoided completely in coastal areas near communities to prevent causing any extra damage during the disasters.

Lastly, the strongest mitigation technique countries can employ along with the protection of mangroves is proper warning systems and evacuation plans. Two unfortunate circumstances for people during a tsunami, cyclone, or flooding event are to be unaware until it hits or to know it was coming but be unsure what to do. As technology has improved, many places are able to make earlier predictions of incoming storms, allowing people more time to prepare and evacuate. Messages can be sent through the internet, television, phones, and radio or through warning tones when the threat is sudden. There should be private and public partnerships so warning broadcasts can reach the most amount of people. Also, the warnings should include knowledge on how serious the risk is, what to do, how to prepare, and where to evacuate. Informed people can make safer decisions when they properly understand the dangers. And because predictions are speculative, the area that is warned should be bigger than what is expected to account for inaccuracies with hazard predictions, as this will take more lives out of harm. Countries should also set up response teams to aid in evacuation attempts as well as be there during storms to help citizens under dangerous conditions. (National Research Council 1991). Plus, the effects of a storm linger long after the initial hit, so government organizations need long-term aid plans to properly rehabilitate affected areas (Paul & Rahman 2006). Taking these steps can be the difference between life and death for many people, in addition to the damage to livelihoods. Countries must actively involve all communities at the local level to see the best results and have an effective and long-term natural disaster plan (Early Warning Systems n.d.).

For mangroves to be seriously considered as a form of natural hazard protection, they must also be valued correctly. Because mangrove disaster mitigation provides a service and not a quantifiable good on the economic market, their values have long been difficult to estimate. More research of this is necessary to convince the policy makers of countries who could use the benefit of mangrove protection to take action to do so. Specifically, the EDF approach, which would assume the value of mangroves by measuring the reduction in expected damage, is the newly suggested way to estimate the monetary benefit of these coastal ecosystems (Barbier 2007). Estimates have shown that wetlands often have a total economic value for their functions greater than the value gotten from converting the land (Barbier 1994). This suggestion hopes to pave way to stop the encouragement of unsustainable deforestation based solely on the idea of economic growth, and instead achieve the conservation of mangroves for the benefit of all their ecosystem services.

Limitations and Future Studies

Data acquisition at the global scale can make analysis more difficult and less precise due to a limited amount of available resources. A study involving timeline correlation between the many disaster variables and specific mangrove loss locations was attempted. This would have made a more in depth risk assessment, yet had to be forfeited due to data size in exchange for an analysis involving separate considerations within a the whole of disaster risk assessment. For the future, analysis of specific locations within the concluded at risk regions of North and Central America and Asia would be best to suggest and potentially put into place proper mangrove management and disaster mitigation strategies.

Conclusion

Although there are other steps possible to improve disaster effect mitigation, mangrove forests provide a sustainable and resourceful solution to better protection. The North and Central America region and Asia region show an increased risk to disaster due to their frequency of tsunamis and cyclones, a greater amount of fatalities and property damage, a predicted increase in population density, and an equal loss of mangrove forests. Urgent mangrove conservation and restoration policies are suggested for these areas along with other strategies for the best mitigation. Planning and implementing mangrove restoration techniques wisely in light of the region's increased vulnerability can help reduce future loss of life and economic loss due to property damage. For greater effectiveness, mangrove restoration should be paired with warning systems and evacuation plans as well as an evaluation of current infrastructure.

Further research into restoration for specific communities and their unique mangrove habitat is needed to put this hazard mitigation technique into effect around the globe. A step to achieving this is to make sure the economic value of preserving mangroves is explicitly known, for accurate comparison to the market value of the ecosystem's deforested resources. This will help those places in numerous ways, as mangroves can also be a great and sustainable source economically and biologically when managed correctly. If countries and communities focus on conserving and restoring their mangrove forests, the benefits are likely to go beyond natural disaster protection.

References

Barbier, E. B. (2007). Valuing ecosystem services as productive inputs. *Economic Policy*, *22*(49), 177-229. doi:10.1111/j.1468-0327.2007.00174.x

Duke University. (2009, April 21). Mangrove Forests Save Lives In Storms, Study Of 1999 Super Cyclone Finds. *ScienceDaily*. Retrieved March 18, 2017 from www.sciencedaily.com/releases/2009/04/090414172924.htm

"Early Warning Systems" (n.d.) Policy and Practice. Practical Action. Retrieved December 15, 2017 from https://policy.practicalaction.org/projects/ews

"Estuaries, Salt Marshes, and Mangroves" MarineBio Conservation Society. Web. Retrieved February 19, 2017, from http://marinebio.org/oceans/estuaries-salt-marshes-mangroves/

"Forests can help prevent floods and droughts" (2015) EEA European Environmental Agency. Web. Retrieved October 2, 2017 from https://www.eea.europa.eu/highlights/forests-can-help-prevent-floods

Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011). Status and distribution of mangrove forests of the world using earth observation satellite data (version 1.3, updated by UNEP-WCMC). Global Ecology and Biogeography 20: 154-159. URL: http://data.unep-wcmc.org/datasets/4

Kamenev, M.; Pickrell, J. (2011, February 02). Cyclones: facts and figures. Australian Geographic. Retrieved September 21, 2017, from http://www.australiangeographic.com.au/topics/science-environment/2011/02/cyclones-facts-and-figures

Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann. (2010). The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data. Bulletin of the American Meteorological Society, 91, 363-376. non-gonvernment domain doi:10.1175/2009BAMS2755.1. Retrieved September 20, 2017, from https://www.ncdc.noaa.gov/ibtracs/

Laurance, W. F. (2007). Forests and floods: one strategy for reducing catastrophic floods invokes protecting or regenerating forests that lie upstream of a threatened region. Support for this approach comes from a global-scale analysis of flood risk. *Nature*, *449*(7161), 409+. Retrieved from http://carthage.idm.oclc.org/login?url=http://go.galegroup.com/ps/i.do?p=EAIM&sw=w&u=waicu_carthage&v=2.1&it=r&id=GALE%7CA189796636&asid=fd7f9c7d453cad5825cb16377ca3df3d

"Mangroves." Wet Tropics Management Authority. Retrieved November 11, 2017 from http://www.wettropics.gov.au/mangroves-info

Marek, Paul. “Mangrove roots.” Retrieved November 11, 2017 from http://www.mangrove.at/mangrove_roots.html#cone-roots

Marois Darryl E., & Mitsch William J. (2015) Coastal protection from tsunamis and cyclones provided by mangrove wetlands – a review, International Journal of Biodiversity Science, Ecosystem Services & Management, 11:1, 71-83, DOI: 10.1080/21513732.2014.997292

Mersereau, D. (2016, July 25). Why are Hurricanes and Typhoons More Common in the Pacific? Retrieved March 17, 2017, from http://mentalfloss.com/article/83562/why-are-hurricanes-and-typhoons-more-common-pacific

NASA. (2016). Socioeconomic Data and Applications Center (SEDAC) managed by the Center for International Earth Science Information Network (CIESIN), Earth Institute, Columbia University. Retrieved April 10, 2018 from http://dx.doi.org/10.7927/H4NP22DQ

National Geophysical Data Center / World Data Service (NGDC/WDS): Global Historical Tsunami Database. National Geophysical Data Center, NOAA. doi:10.7289/V5PN93H7 Retrieved September 21, 2017 from https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.ngdc.mgg.hazards:G02151

National Research Council. (1991). A Safer Future: Reducing the Impacts of Natural Disasters. Washington, DC: The National Academies Press. https://doi.org/10.17226/1840

Oskin, B. (2015, May 6). What is a Subduction Zone? Retrieved March 17, 2017, from http://www.livescience.com/43220-subduction-zone-definition.html

Osti, R., Tanaka, S., & Tokioka, T. (2009). The importance of mangrove forest in tsunami disaster mitigation. *Disasters*, *33*(2), 203-213. doi:10.1111/j.1467-7717.2008.01070.x

Paul, A., & Rahman, M. (2006). Cyclone Mitigation Perspectives in the Islands of Bangladesh: A Case of Sandwip and Hatia Islands. *Coastal Management*, *34*(2), 199-215. doi:10.1080/08920750500531371

Spalding, M.D. (2001). Mangroves. UNEP World Conservation Monitoring Centre and Cambridge Coastal Research Unit, Cambridge, UK. *Encyclopedia of Ocean Sciences, volume 3, pp 1533–1542.* Retrieved November 1, 2017, from http://www.sciencedirect.com/science/article/pii/B9780123744739000898

Spalding M.D., Blasco F, Field C.D. (Eds.) (1997). World Mangrove Atlas. Okinawa (Japan): International Society for Mangrove Ecosystems. 178 pp. Compiled by UNEP-WCMC, in collaboration with the International Society for Mangrove Ecosystems (ISME). (version 3). URL: https://archive.org/details/worldmangroveatl97spal ; http://data.unepwcmc.org/datasets/6

Spalding M, McIvor A, Tonneijck FH, Tol S and van Eijk P (2014). Mangroves for coastal defense. Guidelines for coastal managers & policy makers. *Wetlands International and the Nature Conservancy*. Retrieved October 2, 2017 from https://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf

Thomas N, Lucas R, Bunting P, Hardy A, Rosenqvist A, Simard M (2017) Distribution and drivers of global mangrove forest change, 1996–2010. PLoS ONE 12(6): e0179302. https://doi.org/10.1371/journal.pone.0179302

T. J. Oyana, W. Sun, & P. Sirikulchayanon (2009) Buffering functions of mangroves in the 2004 tsunami, International Journal of Digital Earth, 2:3, 257-274,DOI: 10.1080/17538940902870668

"Tsunami Facts and Information" (2006). Australian Government Bureau of Meteorology. Web. Retrieved September 28, 2017, from http://www.bom.gov.au/tsunami/info/

"Tsunamis: Facts about killer waves" (2004). National Geographic. Web. Retrieved September 28, 2017, from http://news.nationalgeographic.com/news/2004/12/1228_041228_tsunami_2.html

"What is a storm surge?" (2016). NOAA National Ocean Service. Web. Retrieved September 28, 2017, from https://oceanservice.noaa.gov/facts/stormsurge-stormtide.html