Locating a Wildlife Corridor for the Wild Tiger in India

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Locating a Wildlife Corridor for the Wild Tiger in India

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For

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Abstract

The tiger (*Panthera Tigris*) has been on the IUCN red list of endangered species since 1972 [1]. In the early 20th century, 100,000 wild tigers roamed Asia and today approximately 3,600 remain. India is home to over half of the remaining wild tigers and continues to struggle in creating effective conservation plans. Poaching, habitat destruction and prey depletion are several primary causes of tiger population degradation and remain major barriers to rejuvenation of healthy populations in the wild [2]. Wildlife corridors are essential to the process of repairing fragmented habitats. Through the use of GIS and remote sensing this research has located a wildlife corridor which has potential to connect several existing wild tiger habitats which would assist in conservation.
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Introduction

Most subject matter experts link the desperate situation of wild tiger populations to combinations of deforestation, poaching, lack of healthy population cores, dwindling food sources and the human tiger conflict. Wild tigers currently exist in about 7% of their original natural habitat which spans across 13 Asian countries. India is home to over half of the remaining wild tigers which number at approximately 1,700 [3] [4]. In the year 2010 at the Tiger Summit in St. Petersburg, the thirteen tiger range countries agreed to essentially double the wild tiger population by 2022 in turn increasing wild tiger populations to approximately 6,000 individuals [4]. In order to make this goal a viable possibility many successful efforts must come together in the form of decreasing poaching, expanding tiger habitats and education of local human populations.

India’s large geographic presence contains a plethora of ecosystems many of which are and/or previously were well suited to tiger activity [3]. The tiger’s natural habitat varies greatly to include areas such as the Himalayan Mountains in northern India and the humid wetlands of the Sundarbans in the state of West Bengal. Tigers can thrive in a range of landscapes, elevations and climates. During the 20th century, India’s human population grew dramatically. At the time of India’s independence from Great Britain in 1947, the population was only 376 million. Today, approximately 1.27 billion people live in India which averages 376 people
per square kilometer making it the most densely populated country in the world [7]. The rapid industrialization and population growth of India in the 20th century has taken a great toll on the indigenous flora and fauna throughout the country. Areas which were once forests filled with a multitude of wildlife species made way for agriculture, urban expansion and transportation networks. In the wake of this industrial and technological boom is an ever increasing amount of pollution and waste products. Oftentimes Indians lack the government support of proper waste disposal, water sanitation and recycling which further degrades the landscapes both urban and rural [8] [7] [9].

In 1972, the Indian government passed the Wildlife Protection Act which helped establish groundwork for many wildlife reserves and national parks. A great deal of attention has been given to the Indian wildlife crisis from scientists, to politicians to the global community. However, the reality remains that many of the established parks and wildlife reserves are drastically underfunded and understaffed. Additionally, the areas where wild tigers reside are oftentimes small and disjointed leading to little opportunity for healthy breeding and population expansion [8] [10] [11]. Figure 1 offers a visual of how the tiger's habitat range has dwindled throughout Asia in recent decades. The map in Figure 1 displays the tiger's historic range (in approximately the year 1850) in yellow and the current range in green. The historic range was fluid throughout much of Asia without fragmentation while
the current range is dispersed in pockets or small unconnected land masses [22].

While habitat decline has created many challenges for wild tigers, poaching oftentimes thwarts any small successes made in conservation. The tiger has been a cultural icon throughout Asia for centuries. Many cultures revere the tiger for its strength, power and majestic beauty. For over 1,000 years tiger parts have been used in Chinese medicine to treat ailments and restore energy. Chinese medicine is still commonly used today not only in China but in countries such as Nepal, South Korea, Japan and others. Tiger fur, teeth and heads are also sold through the black market and are revered by some to be ornamental status symbols. Asian countries are not the sole consumers of tiger products. Individuals in westernized countries such as the United States, Russia and Canada also participate in the illegal purchases of tiger products. A 2015 report stated that the US Fish and Wildlife Offices repository in Commerce City, Colorado held over 1.5 million illegal animal parts which have been confiscated by law enforcement. The office is a warehouse dedicated to keeping track of the illegal wildlife trade in the United States. They estimate the black market for illegal animals to be the fourth most lucrative in the world behind illegal drugs, weapons and human trafficking [23].

In the 1960’s, exotic pets became popular and many wealthy westerners bought tiger cubs and raised them in their homes. This created
an image of the tiger as something to be held as a pet or seen in a zoo and not a creature that should be in the wild and observed from afar. The cross cultural obsession with the tiger has led to the consistent breeding and raising of tigers in captivity as well as the hunting of wild tigers to the brink of extinction. Furthermore, captive tigers do not possess the same hunting and survival skills as wild tigers, they will not be able to replace tigers in the wild and therefore it is extremely important to conserve the wild tigers which remain [5][6][22].

One key element in reversing the damage inflicted on tiger habitats is to create corridors or pathways which will serve as a connecting habitat between two existing habitats. Connecting these habitats will not only allow for increased space for tiger populations but it will assist in encouraging healthy breeding and spur genetic diversity which is essential for maintaining healthy populations [3][6]. Importance should be placed on locating areas where habitat connection is not disrupted by a large human population and/or human presence such as railways, roadways and agriculture.

The goal of this research focuses on determining the best possibilities for creating corridors between existing habitats as well as finding a particular pathway and surrounding buffer corridor to serve as an ideal movement space for wild tigers. Secondary GIS vector data as well as classified satellite imagery will be utilized to yield the results and derive inferences.
Thesis Statement

With wild tigers losing 93% of their natural habitat to deforestation, urban expansion, poaching and human population growth it is imperative to allocate increased space for this species otherwise we risk losing them in the wild. By creating corridors between existing protected habitats we have a starting point to repair the wild tiger population and meet the goals of the 2010 Global Tiger Summit. GIS plays a key role in this effort which requires data analysis, imagery analysis and map production.

Literature review

Since the initiation of the wildlife protection act in 1972 saving the tiger has become a popular goal of conservationists. There are currently a multitude of scientific studies and journal articles regarding this topic. However, in spite of massive amounts of research the wild tiger continues to struggle. Significant obstacles are: widespread poaching, lack of funding and resources for tiger range countries, lack of education and support from local populations and the human expansion which persists throughout Asia. Lack of government funding in developing countries such as India means that while a wildlife reserve exists, it is very vulnerable to failure due to poaching and other illegal or legal human interference. The human tiger conflict continues to be a barrier to success since many villagers have little education and resources to manage tigers in their area. This conflict of geography oftentimes leads to rural people taking matters into their own
hands and killing the 'problem tigers' in their area. The literature review conducted centers around ways to mitigate these problems by creation of protected wildlife corridors and education.

Wildlife corridors and current reserve status

Large mammals such as the tiger require a great deal of territory in order to hunt, breed and grow healthy population cores. Even if they are located within a wildlife reserve, the disconnecting space between once large singular habitats have made the aforementioned tasks nearly impossible for many tigers. Additionally, many of the current core territories are small, lacking in food sources and riddled with human activity. In the past decade multiple conservation studies have evaluated tiger conservation from the landscape approach which seeks to evaluate habitat and identify areas for improvement. This research has spurred much conversation about the need for wildlife corridors and habitat connectivity.

Harihar and Padav state that if the heads of government of tiger range countries are to reach their goal of doubling tiger populations by the year 2022 then much work needs to be done to research the current state of tiger habitats. The author's primary goals of this study were to identify breeding cores, population data, habitat use data and prey availability for the wild tiger in the Terai Arc Landscape (TAL). (The TAL exists along the India - Nepal border and consists of 14 trans-border protected ecosystems at the
base of the Himalaya. Harihar and Padav spent approximately six months conducting on the ground research to identify and collect data in the TAL. The results of their data collection were that 4,109 km$^2$ of the 6,979 km$^2$ of potential habitat were being occupied by tigers and that areas of habitat not being occupied by tigers could be greatly attributed to habitat disturbances, lack of connectivity and lack of prey. Areas with less disturbances and greater amounts of prey are optimal however some tigers located in less optimal areas are forced to occupy territories where they come in greater contact with humans and have less access to food and water sources. The authors conclude that an overarching conservation plan should be implemented over the entire region to assess the ongoing status of the tigers and their ecosystems [12].

The authors of the article titled "Opportunities for Habitat Connectivity for Tiger (Panthera Tigris) between Kanha and Pench National Parks in Madhya Pradesh, India" researched habitat connectivity options for the wild tiger between Kanha and Pench National Parks. The authors argue that the fragmentation and loss of habitat especially for richly diverse ecosystems in the developing world is a major concern and define fragmentation as:

"Habitat fragmentation is usually a time driven process that is innocuously initiated by human habitation or man induced habitat alteration and which eventually accelerates and results in complete isolation of once contiguous habitat."
One way to undo the damage to these habitats is to reconnect them thus offering larger and more diverse habitats for wild animals. There is research which suggests that creating habitat space and corridors for large keystone species such as the tiger will in turn help smaller species gain habitat space as well. Therefore the tiger was selected as the species of focus for this study. The research was conducted by using GIS and remote sensing to find several potential pathways for the tigers in the designated area. Barriers to connectivity such as roadways, human population, forest density and waterways were considered in this analysis. Satellite imagery of the study area was collected and then classified in Erdas. The classified data was used to develop a least cost model in ArcGIS and a least cost path was run to show the most optimal pathways for the tigers in a corridor situation. The authors conclude that their findings represent potential corridors for the tigers and that more research should be done to validate assumptions and work with local communities to create an effective conservation plan. The authors also mention that no corridor is guaranteed to be successful and that it is ultimately up to the wildlife to choose whether to utilize the space. This aspect in particular makes wildlife corridor planning very difficult and essentially risky for conservationists in terms of funding [3].

In the paper titled “Prioritizing Tiger Conservation through Landscape Genetics and Habitat Linkages”, the authors describe the importance of wildlife corridors as a way to facilitate genetic diversity within the wild tiger
population. Genetic samples were collected and geoprocessed to search for linkages in genetic populations even though habitat polygons were fragmented. This study used a least cost and circuit theory analysis to prioritize the pathways between habitats. The cost path analysis yielded the optimal pathways for a tiger to cross sections of the area of interest. Remotely sensed imagery using forest cover and NDVI was applied to assist in creating a model of the likelihood of tiger presence in a given location. The results of the study concluded that optimal conditions for tiger habitat include large dense forests, low human footprint and abundance of ungulate populations. The authors note that to their surprise in spite of the disjointed habitats within the study area of central India, there still has been gene flow through the metapopulation in recent times. This is a positive sign for tiger conservation, however the overall prescription for this area is to legally confine existing and potential corridors, mitigate development and restore the habitat within the corridors [13].

The central themes of the paper "A Landscape-Based Conservation Strategy to Double the Wild Tiger Population" are wildlife corridors and habitat expansion. In this research, Wikramanayake and Dinerstein et al have concluded that both on site protection and landscape intervention are paramount in achieving healthy population growth of the wild tiger. The study used GIS to intersect tiger habitats with reserve locations and cross referenced them by biome type. The authors calculated the amount of tiger
population increase that each biome could sustain and the results displayed that over 15,000 more tigers could survive in the biomes studied. This paper discussed the implications of isolated reserves and stated that conservation efforts which only protect areas that are already protected are not enough. Habitat expansion and corridor creation is absolutely necessary as isolated habitats pose a risk for the tigers. Tigers located in small isolated territories are significantly more likely to die off due to lack of genetic diversity and breeding potential. A notable suggestion from this article is the idea of carbon credits allocated to regions or countries which designate large areas of land for forests and conservation. A tiger range habitat has approximately 3.5 times the carbon as a non-tiger range area in the same region. Since many tiger range countries do not have resources or financial motive to conserve forests the idea of carbon credits may be an excellent incentive [14].

In the article titled "Comparative Evaluation of Tiger Reserves in India" Post and Pandav used comparative effectiveness research to evaluate the current status of tiger reserves in India. Using subject matter experts and the Cambridge Conservation Forum's definitions of successful or failure as a reserve, the authors narrowed down the tiger reserves to determine the most successful and the least successful reserves. 'Successful' was defined as a reserve which increases the likelihood of tiger presence between the years of 1995 – 2005 while 'failure' was indicated by decline in tiger
populations over that same period. They then analyzed the socio-
demographic data surrounding the reserves being studied such as human
population density, agricultural activity and presence of an active
conservation champion. The results of the study were the labeling of seven
reserves as success and five as failure of the total 42 reserves in India. They
found that agricultural activities were seen near both successful and failed
reserves. The study also found that reserves which have a conservation
champion (someone that is a subject matter expert who is directly involved
with improving a conservation area) are more successful and may be able to
lead a failed reserve into becoming successful by increasing the prevalence
of tigers over a number of years. It is estimated that twenty of the reserves
studied can sustain a total of over 10,000 tigers, three times the current
global population. The most interesting aspect of the results from this study
are the findings that the more successful reserves have a higher human
population density while the most failed reserves have the lowest human
population. These results appear to be counterintuitive and seem to argue
against other research which states that tigers thrive in a low human density
area. However, one explanation could be the failed reserves are failing due
to lack of awareness for the reserve and lack of attention provided to a
particular reserve. Additionally, there is a difference between low human
density surrounding a reserve and the best types of habitat for a tiger to
reside [9].
One major issue to consider when researching wildlife corridors is the potential and ongoing concern for human animal conflict. This has been an area of concern for many rural people in India who deal with wild tigers traveling near their homes. Tigers have caused problems for humans by killing livestock as well as people and eliciting fear into local populations.

Nyhus and Tilson discuss the human tiger conflict in their article “Characterizing the Human-Tiger Conflict in Sumatra, Indonesia: Implications for Conservation”. The authors state the primary reasons for tiger population decline in the 20th century as: Habitat reduction, diminishing prey, Poaching and finally "Persecution by humans in response to real or perceived livestock predation and attacks on people".

Nyhus and Tilson make an effort to characterize and study the human tiger conflicts on this island using various records and Indonesian documentation. The conflicts were characterized and then plotted by location thus finding the primary areas where the greatest potential for conflict existed. It was discovered that solitary men working in agricultural settings during the daytime had the greatest risk of tiger attacks. This leads to a discussion regarding tiger food sources as they normally are not active during the daytime and prefer to remain away from human activity. Nyhus discusses the ongoing need for tiger conservation and the implementation of safe wildlife
corridors. He recommends that conservationists and communities work together to encourage "hard edges" of spatial separation by way of rivers and other natural environments in addition to educating local populations about ways to reduce conflict and properly manage livestock [11].

It appears that ideas similar to those of Philip Nyhus have been implemented in the Sundarbans of Bangladesh where human tiger conflict has been especially brutal in the past. A recent article in Earth Touch News Network describes an NGO called WildTeam which cooperated with the Bangladesh Forest Department and local villagers to provide education and training. Local response teams were created to educate their communities about how to manage a tiger's presence. The locals were trained to deal with tigers by gathering in groups and beating sticks on the ground. This tactic successfully scared the tigers back into the forest and also provided a non-violent solution to tigers entering the village. In the two years since the local response teams were created there have been no tiger killings by villagers. The article describes the way that villagers historically dealt with tiger intrusions was by killing and beating them. However, the villagers maintain that they respect tigers and do not want to have to kill them. Without strategies and education about tiger control the villagers had no other option than to kill or be killed. However, now that they have proper education and teams dedicated to tiger control there is hope for the human tiger conflict in this region [15].
Rural areas which are already dealing with human tiger conflict should be brought into the conversation regarding wildlife corridors to make sure they will be safe and able to have access to education and support from authorities. This will be an ongoing issue since humans and wildlife are increasingly occupying the same spaces.

**The Tiger as a Keystone Species**

It is sometimes argued that conservationists spend too much time focusing on conserving large mammals while other lesser known smaller animals are forgotten. Perhaps this is true and naturally humans focus on ‘saving’ big beautiful mammals before other species. Yet the tiger requires a vast amount of space particularly due to its solitary territorial nature. Therefore, by allocating space for the tiger we will also create much needed space for smaller species of animals as well as many indigenous fauna in any particular region. Being a large carnivore, the tiger sits at the top of the food chain. In his paper titled *Wildlife Conservation Strategies and Management in India: An Overview*, Swarndeep S. Hundal reviews the positive effects on the total environment by conserving a keystone species such as the tiger. Hundal states that

"Biogeographically representative areas of the tiger reserves have shown better signs of security and preservation".
Additionally, the creation of tiger reserves has improved the status of flora and fauna as well as served as an educational and enriching opportunity for locals and tourists alike [6].

The authors of the paper previously discussed titled Prioritizing Tiger Conservation through Landscape Genetics and Habitat Linkages also make note of the tiger as a flagship species which will assist in conservation efforts of many forested ecosystems across the tiger’s natural ranges in Asia. Typically in the case of large carnivores their conflict with humans is too high and thus leads to the degradation of the species. This is exactly what has been seen in the case of the wild tiger. Small landscapes have been conserved for the tiger but this species requires a vast amount of space. While allocating such large amount of precious land to the tiger may seem less than ideal, the authors note that by doing so we will be able to save and protect many other species of flora and fauna. [13] Finally, as mentioned previously, current tiger habitats have 3.5 times the carbon as non-habitat landscapes. The increase in carbon is likely due to the increase in flora within a tiger habitat as well as the low amount of human activity. Therefore, one can conclude that increasing tiger habitat will lead to an increase in carbon within any given area directly due to the increase in plant life, proving the point that increasing tiger habitat provides more opportunity for wildlife.

Poaching
The black market for poaching and trading endangered species is alive and well throughout the world today. It is not a thing of the past and continues to pose a grave threat to the conservation of many wild species. There is no exception for the tiger in this case as poaching has been a major barrier to success in maintaining healthy populations in the wild.

In their article titled "The Fate of Wild Tigers", Dinerstein, Loucks et al describe the confounding situation when a tiger census was conducted in India in 2005. India has long been a stronghold for wild tigers with more than 50% of the current wild population living in its borders. Indian wildlife reserves have a reputation for being well managed compared to those in their less fortunate neighboring countries such as Bangladesh and Nepal. However, when a tiger census found that rampant poaching had decimated the wild tiger populations in reserves like Sariska, Ranthambore and Bandhavgarh the Indian government was forced to learn the grave reality. These were considered well protected areas and the results of the census shocked conservationists and the Indian government into action, creating Project Tiger which aims to provide education, conservation and outreach in regard to the wild tiger crisis. The authors go on to describe several theories for how tiger parts continue to flood the black market in spite of much active legislation among Asian countries to ban this trade.

"Despite widespread trade bans, these medicines [made with tiger parts] are still coveted by enough consumers in China, Japan, South Korea,
Vietnam, parts of Southeast Asia, and even the United States to pose a grave threat to wild tigers."

One theory is that as the middle class grows in regions such as Tibet, China and Nepal, people have more money to spend on illegal tiger parts. Traditionally tiger fur, heads and teeth were something displayed by royalty but as people gain more disposable income it becomes increasingly possible for them to purchase these coveted items as well.

With the demand up and the punishments for poaching oftentimes being minimally enforced it creates an environment in which the activity of poaching outweighs the consequences. The authors explore one solution to tiger poaching as allocating more funds to these efforts. From 2000 – 2002 the amount of money donated to tiger conservation NGO’s in the Terai Arc Landscape [in northern India] was approximately $1.4 million. This money was supposed to be allocated to anti-poaching measures, park management and support, local education and resolving human tiger conflicts.

Additionally, tiger reserves across 17 tiger range states in India received about 17 million dollars of donation funds for the years 1997 – 2002. Yet it was discovered that much of the funds were misspent due to corrupt systems and tiger populations plummeted. Therefore, the conclusion of the authors is that the tiger crisis and poaching crisis won’t be solved merely by allocating money. Only by recognizing that this is a transnational, economic, scientific and public policy issue can we begin to move toward a solution.
The article calls for tiger range states to pledge resources toward intensifying on the ground protection, properly prosecuting poachers and breaking up their rings, finance economic incentives for encouraging conservation and very importantly allocate funds into effective and correct channels to mitigate corruption [22]

**Design and Implementation**

There are two core portions of analysis involved in this project. The first portion was to determine the area of interest (AOI) for the wildlife corridor and the second portion was to analyze the AOI and locate a viable pathway for wild tigers within a corridor.

**Step 1: Determining the Area of interest (AOI)**

Google Earth was utilized to create KML’s and subsequently shapefiles of the 51 potential areas of interest for the reserves in India. The shapefiles were used in ArcMap to display the locations alongside of other vector and raster data used in the analysis. These 51 locations consisted of existing tiger reserves, wildlife reserves and national forest regions. The rationale for adding to the 42 existing tiger reserves in India was to see if a forest reserve would prove to be a potential area for a wildlife corridor as well. Forest reserve land should not be discounted in this first level of analysis since it is ideal to incorporate as more data rather than less. At this stage of analysis we do not yet know where the data will lead and with the goal being
to find two optimal reserve areas to connect it is important to consider as many locations as possible. The task of accurate shapefile creation proved to be difficult as the topology of the reserve boundaries in Google Earth was not good and included loops, disconnected pieces and missing attribute information. For example, a reserve boundary may be clearly outlined in Google Earth using one easily discernable polyline to create a closed feature. In this case, the polygon was simply mimicked exactly to create the KML for this project. However, in other cases, polygon outlines in Google Earth were left unconnected and/or contained loops where the line backtracked into another feature without any explanation as to why. In these cases, the loops were ignored by creating KML outlines which attempted to draw straight lines through the loops. Unconnected polygons were connected by drawing a straight line from one unconnected piece to another. Therefore, the locations mapped to perform analysis one should be thought of as a general parameter for which a reserve is located and not to be taken as exact. (See Reference Map 1)

With the goal of creating a corridor between two existing wildlife regions, a selection criteria was developed to narrow down the 51 locations to several AOI's with the best potential for a wildlife corridor. The criteria is as follows and states that the corridor must not exceed 100 kilometers in length and must also be at least 20 kilometers in length. The goal is to create a viable corridor which is large enough to add substantial space to a
tiger habitat yet not be so large that it is impossible to realistically implement. Due to the population density in India it was thought that creating a corridor of over 100 kilometers would be difficult as the likelihood of running into large urban populations, agriculture and roadways is inevitable.

The next portion of criteria assigns a point value to each barrier or negative element already existing within a given corridor. The idea of assigning point values to land cover was also utilized in the article "Opportunities of Habitat Connectivity for Tiger (Panthera tigris) between Kanha and Pench National Parks in Madhya Pradesh, India" wherein the authors assigned values to various features in order to conduct their least cost path analysis for a potential wildlife corridor between Kanha and Pench National Parks [3]. This strategy is used in both step one and step two of the analysis in this project to determine the AOI and to find the pathways within a corridor.

Each possible AOI was assessed for the barriers and then points added together to create a list. The resulting list indicates each pair of wildlife areas that were considered. (See appendix 1) Those with the most points are the worst potential AOI’s and those with the least points are the best possible AOI’s. The points were assigned in the following manner: Roadways: The data used in this study listed roadways as major, minor and unclassified. Minor and unclassified roads were grouped together for the purpose of this
analysis. Major roadways were assigned a value of 10 points and minor roadways assigned a value of 2 points. Major roadways are absolutely a barrier to connectivity as directing wildlife traffic across a major highway would be counter-productive. However, minor roadways could be as small as a single dirt road and would not necessarily be detrimental to wildlife.

Railways: Multi-track railways were given a value of 5 points and single track given a value of one point. Similar to roadways, major multitrack railways areas are a large barrier while a single railway track would not necessarily be harmful depending on the type and frequency of trains running on it.

Waterways: any water body which would directly impede a corridor between two locations is 10 points. This would include a large lake or polygon of water located in between two wildlife areas. Smaller waterways such as streams and rivers were not considered as a barrier to connectivity as tigers will require access to water and the width of any given vector line waterway was not determinable with the data available. Population data was derived from NASA’s Socioeconomic Data and Applications Center in the form of a 2.5 minute grid with the 2010 population estimate for India. This grid was selected for its ability to estimate population density in a raster or surface area situation as opposed to using the population totals for each city point using vector data. The city point vector data has population numbers but from this data it was impossible to see how far the population extended out from the city point. The grid is a more accurate representation of population
over a particular geographical area. The grid was overlaid with the wildlife reserve locations and assessed similar to the vector data with the criteria being that areas with all grids in the 0 – 200 people range are zero points, areas with three or less grids above the 0 – 200 grids are one point. Areas with most grids in the 200 – 1000 range are 2 points and areas with three or more grids above the 1000 mark would be assessed with 5 points. Any areas with grids above 2000 would be automatically dropped from consideration. For reference, a 2.5 arc minute grid consists of approximately 5 square kilometers [16]. The numbers symbolizing the grid discussed above are equal to the human population density of a 5 square kilometer area.

The top three potential reserve pairs were Periyar/Shendurney, Parambikulam/Anamalai and Manas/Pakke (Pakhui). While Periyar and Shendurney had the least amount of points (6), it was decided that since they are already connected by other wildlife preserves between them, the efforts of this study would be better applied to one of the other top three pairs. Manas and Pakke (Pakhui) which had 7 points were decided upon as the area of interest. It was discovered that a third park called Sonai Rupai is located in between but not connected to the other two. This is an opportunity to connect three reserve locations with a wildlife corridor. The final results of this piece of analysis are that the AOI will be the area between Manas, Sonai Rupai and Pakke wildlife reserves in northeast India. (See reference map 2). This conclusion was made by way of a weighted
study to determine an optimal location for a wildlife corridor. This is not to say that this is the only location which would provide a potential corridor. Other AOI's could easily produce a viable corridor as well, they were just not chosen for this particular study due to the way the AOI's were evaluated here.

Describing the Area of Interest

At this point, it has been determined that a corridor will be placed to connect Manas, Sonai Rupai and Pakke Reserves. An official area of interest was drawn to encompass a space for a corridor to exist. This AOI is approximately 65 kilometers from west to east and approximately 45 kilometers from north to south. Therefore, the total area of interest consists of 2925 square kilometers. Administratively the AOI is uniquely located partially in the state of Assam, India and partially in the state of Arunachal Pradesh, India. Additionally, a small section of the central western area of the AOI sits within the border of Bhutan. It should be noted that Manas National Park of India is located in Assam, India, however, it is contiguous with Royal Manas National Park of Bhutan. These two areas as well as Khanding Wildlife Sanctuary of Bhutan are connected via wildlife corridors. The official boundaries of these national parks are quite unclear to discern given the shapefile and Google Earth boundary information available. That being said, throughout the remainder of this study, the term "Manas National Park" will refer to the area directly on the western border of the area of interest.
and may include Manas National Park of India, Royal Manas National Park of Bhutan and Khaing Wildlife Sanctuary. Sonai Rupai Wildlife Reserve is located in the western portion of the AOI and Pakke also known as Pakhui Tiger Reserve lays in the far northeast corner. After viewing the area of interest in Google Earth it is clear that a large portion of the area is forested and within the foothills of the Himalayas. The mountains make way for plains, agriculture and villages in the southern half of the AOI. (See Reference Map 3 and 4)

Of the 1700 estimated tigers in India for the 2010 tiger census, approximately 167 tigers are estimated to be in the Assam region. The 2001 census only found evidence of nine tigers in Pakke, however, the Principal Chief Conservator of Forests for Arunachal Pradesh states that 82% of this states forests have not been properly surveyed as of 2011 [17]. It should also be noted that while India has been conducting a tiger census in recent years the tigers by their nature are very difficult to quantify. They are solitary, illusive and prefer to hide in dense forested locations. The tiger censuses should be considered a rough estimate of tiger activity but not a definitive number. Many times researchers must rely on tiger scats collected to attempt to determine how many individuals have traversed an area [1].

Step 2 Analyzing the Area of Interest
The goal of the second part of analysis was to determine several possible pathways for a wildlife corridor using satellite imagery as well as ArcMap’s Spatial Analyst tools in the form of a cost path analysis. Landsat 8 satellite imagery for the AOI was downloaded from the USGS’s Earth Explorer site. The date of the imagery is October 1, 2014 and was selected due to its relatively small amount of cloud cover within the AOI and for the fact that most vegetation was still visible on this date. The imagery was stacked into a seven band .img file and classified using a supervised classification with Erdas Imagine 2015. The imagery was first classified with a band combination of 6, 5, 4 to represent red green and blue respectively. This combination was selected so that vegetation could be analyzed as accurately as possible. The image was then classified for a second time, this time using a band combination of 5, 4, 3 which displays color infrared [18]. (See reference map 3) The reasoning for completing two separate classifications was to determine if the cost path resulting from one classification would be similar to the least cost path from the other. If both paths are similar it makes a stronger case for the accuracy of the image classifications.

The items classified in both of the images were dense vegetation, light vegetation, other vegetation, water, clouds, agricultural and bare earth/urban. Once the images were classified in Erdas Imagine 2015, the reclassify tool was utilized in ArcMap to manually assign a cost value to each
class using the criteria described next. The cost value denotes the cost of a
tiger crossing that particular pixel of space and will be used to create the
cost path analysis. Dense vegetation was reclassified with a cost value of 1
which is the lowest cost value of the seven classes. Dense vegetation is the
most optimal space for the tigers as it will provide them with adequate
covering, increased prey options and less likelihood of encountering humans
[13]. Light vegetation was reclassified with a value of 2. Light vegetation is
the second best option for the tigers as it indicates areas which are likely
covered in grasses and brush. Other vegetation was assigned a cost of 3
since this type of vegetation might possibly be agricultural but from the
imagery it was not easily discernable. The water bodies within this AOI were
given a value of 4. Water is essential for tiger habitats but crossing a large
water body is not ideal. Clouds were present in the imagery and while they
were mostly covering what might be assumed to be dense forest, we do not
know for sure and cannot make an assumption. Clouds were given a cost
value of 5 as we do not have any way of knowing what land cover is
underneath them. Agricultural land should be avoided in order to minimize
human tiger conflict. Thus, agricultural land was given the second highest
cost value of 6. This AOI proved to be difficult to classify in terms of
distinguishing urban from bare earth. Many of the roadways and urban areas
appear to be unpaved and roads consist of dirt. Urban and bare earth were
classified together and given the highest cost value of 7. Bare earth is not
always a negative factor especially in terms of river beds and rocky areas of mountain slopes. However, the absolute last area that a wildlife corridor should exist is within an urban area thus this imagery class must be analyzed as the most costly. (See Reference Map 3)

Once the images were reclassified, the least cost path was developed. In order to accomplish this, a start and end point were first defined. The start point was placed at the eastern edge of Manas Reserve and the end point was placed at the northwestern edge of Pakke Reserve. A start and end must be defined to complete the cost analysis but of course in a corridor an animal might start from either end and it doesn’t make any difference. Sonai Rupai exists in between these two areas but leaves space on all sides of its border which are not currently protected habitat.

Using the start point and the reclassified imagery, a cost distance raster and a backlink raster were created using the ‘cost distance’ and ‘create backlink’ tools in Arc Toolbox. The cost distance and backlink are necessary inputs to create a final cost path. The cost distance determines the least accumulative cost for each cell to the nearest source while the backlink defines the neighbor that is the next cell on the least total cost path to the closest source. Both of these are required to compute a total cost path [25]. Finally, a cost path could be created from the cost distance and backlink while incorporating the desired end point. The result was the
creation of two pathways, one for each classified image. (See Reference Map 3 and 4)

Results

The analysis yielded two pathways which potentially could connect Manas Reserve with Pakke (Pakhui) Reserve in the locations of Bhutan, Assam, India and Arunachal Pradesh, India. The pathways are each approximately 64 kilometers long and travel primarily through the landscape classified as dense forest within the foothills of the Himalayan Mountains. The pathways are very similar with the exception of one area wherein one pathway diverts northwest while the other goes southeast. The two pathways merge back into the same pattern after approximately twelve kilometers. Finally, the pathways travel through 12 kilometers of space within the Sonai Rupai reserve but the majority of the length of the paths (approximately 45 kilometers) are located in areas which are currently not protected by a national park or wildlife reserve.

The pathway created from the first image classification will be called P1 and the pathway created from the second image classification will be called P2. Both P1 and P2 provide ample opportunities to connect several wildlife reserves by placing a protected corridor around them. Given that the pathways are very similar, a corridor of a 10 kilometer buffer was placed
around them and this corridor will be the primary area for further analysis and implementation. (See Reference Map 4)

Discussion and Areas for Further Research

The pathways presented here are merely a starting point for further investigation. The cost path analysis is a useful way to remotely study an area of interest. Through a cost path we can determine what areas to avoid and what direction the optimal pathway takes based on the imagery classifications. An analysis of each pixel in the Landsat imagery done through the algorithms in Erdas and ArcMap save valuable time compared to manually researching an entire AOI. Unfortunately, imagery classification and the cost path analysis are not without drawbacks. For example, classifying the water as a cost of 4 is to make a sweeping judgement. Water is essential to the tiger’s survival so in some senses it should be classified as a 1. It also can be a large barrier if the waterway is a deep fast moving river or large lake. Additionally, ‘bare earth’ could provide confusing results. As mentioned earlier, bare earth in this particular AOI could be a roadway, an urban location or a river bank. The roadways and urban bare earth are extremely negative while the riverbank could be classified as low as a cost of 1. Finally, cloud cover is inevitable in remote sensing and it must be dealt with in order to complete the analysis. Clouds have nothing to do with the success of the pathway and do hinder some of the results by blocking our knowledge of what lies beneath them. Further research of this area of
interest may include locating imagery without clouds and conducting the analysis for a second time.

To further refine this analysis and provide more accurate results the AOI could be broken into smaller segments or grids by which to classify individually. A grid with a large amount of urban area might classify ‘urban and bare earth’ with a cost of 7 while a grid in the forested region could classify ‘bare earth’ as a cost of one or two. The subsequent results will allow for a more granular view of the land cover in the AOI and how those reflect in the cost pathways.

Clearly, the analysis presented here is not the completed solution for connecting the three wildlife habitats of Manas, Sonai Rupai and Pakke. It is recommended that in order to be successful, several additional in-depth studies should take place. Since the corridor is located along the foothills of the Himalayan Mountains it will be necessary to gather additional information about the elevation and terrain of the pathway. Applying a digital elevation model (DEM) to the least cost path analysis has potential to help to narrow the scope of the corridor to areas with the least amount of slope. While it will be key to have the most desirable terrain accessible for the tigers within a corridor, elevation may or may not pose a barrier. Tiger’s natural habitat exists within the mountainous region of the Himalaya and BBC has reported sightings of tiger populations well above tree line. [19] The area of interest is below tree line but it is important to note that tigers
are capable of living and travelling through mountainous regions. It is more than likely that in a particular situation the tiger like all beings will take the path of least resistance when it comes to a choice of traveling over a mountain or down a valley. Therefore, elevation should be considered before assuming a tiger will choose to follow any one direction of a suggested path.

Abundance of prey should be of critical concern prior to implementing any wildlife corridor. Tigers thrive mainly upon smaller mammals indigenous to their specific habitat such as deer, rabbit and wild boar. They can and will hunt a variety of other types of prey but usually stick to the familiar species within their territory. The wildlife corridor should be assessed for adequate food sources and ease of finding fresh drinking water.

There appears to be some human activity within the area marked for the wildlife corridor in the form of mining, roadways and small settlements. In order to mitigate the human tiger conflict, the local populations should be involved and properly educated. These settlements should be first contacted and surveyed regarding the status of their current encounters with tigers. They should be provided with an education program as well as government forest officials. Many articles reviewed for this study mention that local people care for the tiger and they have a sense of pride connected with the species. However, when their lives or livelihood are threatened what else can they do but retaliate towards an aggressive tiger? If we are to keep wild animals in the wild we must be prepared to deal with the human and animal
conflicts. The tiger is no different from human bear conflicts in Alaska or human alligator conflicts in Florida. These issues must be met with education, awareness and caution for the safety of anyone located in a tiger habitat.

The problem with implementing an education program and providing adequate assistance is funding. India as a developing country with an incredibly high population is spread very thin on monetary resources. The Wildlife Protection Society of India classifies nearly all of the Indian tiger reserves as funding "insufficient and delayed" and the staff as "understaffed" [10]. One way to help solve this problem would be to train locals to either work or volunteer their time as forest rangers. Many of the communities in the Assam and Arunachal Pradesh states in India lack education and opportunity, and most individuals live very rural and impoverished lives. A program which offers wildlife education and training could prove to be beneficial for individuals interested. Additionally since the program would exist in land around their communities they would not have to travel far for this type of work and would have a vested interest in the location as it is their home. The locals who would work in the reserve areas would become subject matter experts. They could provide valuable feedback to researchers not only in regard to the wild tiger situation but about the local attitudes and sentiment. A position working or even volunteering as a forest ranger could lead to more prosperous jobs and education for people who otherwise may
not have the chance to expand their knowledgebase or work in an area they are passionate about.

Implementations of this corridor require the cooperation of both the Bhutanese and Indian governments. Bhutan and India traditionally have had friendly diplomatic relations and there is not presently any known hostile relations which would keep these two border areas from working together to achieve this goal. In a recent BBC documentary discussed in Bhutan’s Kuensel paper, Dr. Alan Rabinowitz discusses the critical role that Bhutan plays in tiger conservation. The tiger expert goes on to explain that Bhutan’s Himalayan Mountains are a key habitat for the tiger and calls for increased wildlife corridors and anti-poaching security. Of particular concern is the poaching activity in Royal Manas National Park and along Bhutan’s border with India [20]. Border regions of tiger range countries should be monitored more carefully as this is where tigers are illegally transported across international lines en route to tiger consuming countries such as China and Nepal. The AOI in this study is concerning as it is located along a border region which has been a hot spot for poaching [10]. It will be imperative for Bhutanese and Indian officials to agree on ways to conduct surveillance and protect the wildlife not only in their parks but throughout the biological corridors which cross international borders.

Most of the suggested next steps will require on the ground research, in person surveys and cooperation at a local level. It is important to note
that even with the most optimal research and budget there are no guarantees that a safe corridor will be traveled by the tiger population. The tigers have a final say as to whether they are interested in traveling through a corridor. It is possible that there will be some trial and error in locating areas where tigers are interested in moving. However, each successful biological corridor is valuable to global conservation efforts and can be utilized to learn how to implement corridors across various other species and ecosystems as well.

Final Thoughts

In discussing wildlife corridors, GIS and remote sensing are powerful tools which help put a structure in place to conduct further research. The need for wildlife corridors has never been more apparent as human populations continue to grow in number and expand over wider ranges of the earth's surface. Conserving wild animals particularly keystone species such as the tiger will allow these Asian ecosystems to remain healthy and are necessary for the vitality of the forests they occupy. Creating successful corridor habitats requires support from local and national governments, local citizens and the world population.

Based on a brief personal experience in India it is clear that this country has changed rapidly in recent decades. Middle class people are gaining access to technology, goods and services as these items become less
and less expensive in the global economy. While it is excellent to see a vast majority of people able to access these items, it is concerning to see the waste products created by the consumption of 1.2 billion people. Many local Indians do not have proper access to waste disposal, recycling and clean water. Plastic bags which are used one time are burned in piles because there is nowhere to recycle or dispose of them. Trash burning creates air pollution while unprocessed waste products clog streams and rivers. These things have an extremely negative impact on humans and wildlife alike. It is difficult to see how wildlife can be conserved effectively unless the Indian government and its citizens come together to adopt proper waste management and pollution controls [21]. Solving the wild tiger crisis is not a singular problem to be looked at in a vacuum. It is a global problem with many implications. Comprehensive solutions for pollution, poaching, deforestation, education and human population growth should be discussed alongside conservation. As progress is made on each of these fronts we can hope to see positive changes in wild tiger conservation.
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### Appendix 1

#### Analysis of the Potential AOI’s

The following reserves were excluded from analysis because they were more than 100 KM away from any other reserve area: Sariska, Ranthambore, Valmiki, Belta, Dampa, Namdapha, Sundarbans, Tadoba, Indravati, Sitanadi, Similipal, Sahyadri, Anshi, Nagarjuna Sagar, and Bhadra.

Analysis of the reserve pairs explained in the design and implementation section:

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<th>Buxa and Manas</th>
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Appendix 2

GIS Data, Software Citations & Metadata

GIS Data


Software

1. ESRI ArcGIS software version 10.3.1 utilized via the University of Denver student VPN.
2. Erdas Imagine 2015 utilized via the University of Denver student VPN.
3. Google Earth open source public version

GIS Metadata

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Appendix 3 – Project Overview Flow chart

1. Literature Review of Relevant topics
   - Conservation Planning
   - Wild Tiger Status
   - India – Areas of interest

2. Gather GIS Data
   - Shapefiles of reserves
   - Vector Data and Population Data
   - Landsat Imagery

3. Determine AOI and Data Processing
   - Classify Imagery
   - Conduct Cost Path Analysis
   - Create Final Maps

4. Write Paper as results from various elements are found
Appendix 4 – Project Analysis Flow chart

**Where should the AOI be located?**

- Collect KML locations from Google Earth and convert them to Shapefiles for use in ArcGIS
- Locations are current tiger reserves (42) and forested areas adjacent to current reserves (10)
- Establish weighted point criteria to measure barriers to connectivity for each potential AOI
- Choose AOI

**Where should the corridor be located?**

- Locate satellite imagery of the AOI with the criteria of minimal clouds and a time of year when vegetation is visible
- Choose image and download it
- Select cost value of each classification and reclassify in ArcMap
- Create corridor

**Collect KML locations from Google Earth and convert them to Shapefiles for use in ArcGIS**

**Locations are current tiger reserves (42) and forested areas adjacent to current reserves (10)**

**Establish weighted point criteria to measure barriers to connectivity for each potential AOI**

**Choose AOI**

**Locate satellite imagery of the AOI with the criteria of minimal clouds and a time of year when vegetation is visible**

**Choose image and download it**

**Select cost value of each classification and reclassify in ArcMap**

**Create corridor**

**Load location shapefiles into ArcMap with secondary sources such as: Railways, Roadways, Water, Administrative Boundaries and Population Grid.**
Figure 1
Representing the change in wild tiger habitat from historic (circa 1850) to present.

This map was copied from source 22, Dinerstein, Loucks et al "The Fate of Wild Tigers"
Reference Map 1

Displaying the 51 reserve areas studied in the analysis.

Tiger and wildlife reserve locations were plotted by creating KML files of location outlines found on Google Earth. The KML's were then exported into Shapefiles for ArcMap.

Note: Due to topology errors in Google Earth, the reserve boundaries are subject to some inaccuracies.
Reference Map 2

Displaying the Area of Interest and surrounding geography.
Reference Map 3

Displaying the image using two separate band combinations to produce classifications and the resulting pathways from each cost path analysis.
Displaying the wildlife corridor created from the results of the pathways. The corridor provides a connecting landscape for Manas National Park, Sonai Rupai Reserve and Pakke (Pakhui) Reserve.