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Prospects of Amur tiger recovery in China and Kazakhstan using GIS and Remote Sensing

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:

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According to the Global Tiger Initiative (GTI), the population of the tiger is planned to increase. Up to date, successful conservation initiatives in Russia have led to the increase of the Amur tiger in the wild and the change of its status from "Critically Endangered" to "Endangered".

The planned Northeast Tiger and Leopard National Park (NTLNP) is aiming to recover the population of the Amur tiger in China. An even more ambitious tiger initiative is taking place in Central Asia. Kazakhstan with the support of WWF Russia is planning to reintroduce the currently extinct Caspian tiger by bringing its closest extant relative, the Amur tiger to the territory of the newly established Ile-Balkhash Nature Reserve (IB).

The current thesis focuses on Amur tiger restoration in China and the restoration prospects of Caspian tiger in Kazakhstan, comparatively analyzing their nature reserves with the Amur tiger habitat suitability model in the Russian Far East within the Sikhote-Alin Nature Reserve (SA). A multi-scale approach used to analyze habitat suitability includes the use of Geographical Information System (GIS) that shapes a predictive research model incorporating ecological data on relevant spatial and temporal scales. Methods include analysis of the remotely sensed data, secondary data, and an interview. According to the final suitability maps, the territory of the Northeast Tiger and Leopard National Park is highly suitable for tiger conservation and the initiative has prospects for the restoration of the Amur tiger population in China. The territory of the Ile-Balkhash Nature Reserve has a low habitat suitability level, while the need to restore the local ecosystem and tiger prey to ensure successful reintroduction raises doubts about the success of the initiative.

Keywords: Amur tiger, recovery of large carnivores, biodiversity conservation, GIS, remote sensing.

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Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

The loss of biological diversity and Earth's sixth mass extinction has turned out to be significantly more severe to both invertebrate and vertebrate populations, causing a global environmental problem. Among terrestrial vertebrates, mammals have experienced 30% or greater decline in their geographic range with more than 40% of species experiencing severe population declines (Ceballos *et al.* 2017). Global decline in the number of species caused by habitat loss/fragmentation, over-exploitation, invasive species, pollution, toxification, and climate change has a cascading negative effect on ecosystems in general.

Tigers (*Panthera tigris, P.t.*) are the largest feline carnivores. Historically, tigers used to occupy much of the territories of Asia, including the Caspian and Aral Seas, southeastern Russia, and the Sunda islands (Luo *et al.* 2004). However, starting from the 20th century due to habitat loss and poaching, the population has declined from over 100,000 in 1900 to only 3,500 in 2014, among which only 2,500 are mature breeding individuals (IUCN 2014). In general, within the last 14 years, the population in the wild has declined by 20% and the decline continues (IUCN 2014).

Wild tigers are under threat across the tiger range. The current status of the most iconic Asian animal, according to IUCN statistics, is endangered (EN) (IUCN 2014). There are tiger populations in the following countries: Bangladesh, Bhutan, India, Indonesia, Malaysia, Nepal, Thailand and Russia. The list of the governments of the tiger range countries, apart from the already mentioned states includes: Cambodia, China, Lao, Myanmar, and Vietnam (Global Tiger Recovery Program 2018).

Taxonomy and phylogenetic relations between tiger subspecies are still under review of the International Union for Conservation of Nature Species Survival Commission (IUCN SSC) Cat

Specialist Group. For this moment, based on Luo *et al.* (2004), *Panthera tigris* can be divided into six extant subspecies (IUCN 2014):

- Amur Tiger (*P. t. altaica)*: Russian Far East and northeastern China
- Northern Indochinese Tiger (*P. t. corbetti)*: Indochina north of the Malayan Peninsula
- Malayan Tiger (*P. t. jacksoni*): Peninsular Malaysia
- Sumatran Tiger (*P. t. sumatrae*): Sumatra
- Bengal Tiger (P. *t. tigris*): Indian sub-continent
- South China Tiger (*P. t. amoyensis*)*: subspecies have not been directly observed in the wild since the 1970s and are possibly extinct.

The following three tiger subspecies are currently extinct in the wild (IUCN 2014) and they used to occupy the following territories:

- Bali Tiger (*P. t. balica*): Bali
- Javan Tiger (*P. t. sondaica*): Java
- Caspian Tiger (*P. t. virgate*): dry river valleys of the Takla Makan, western slopes of the Tianshan mountains, Amudarya and Syrdarya river valleys, shores of the Caspian Sea, Elburz mountains, eastern Turkey, Tigris and Euphrates river valleys.

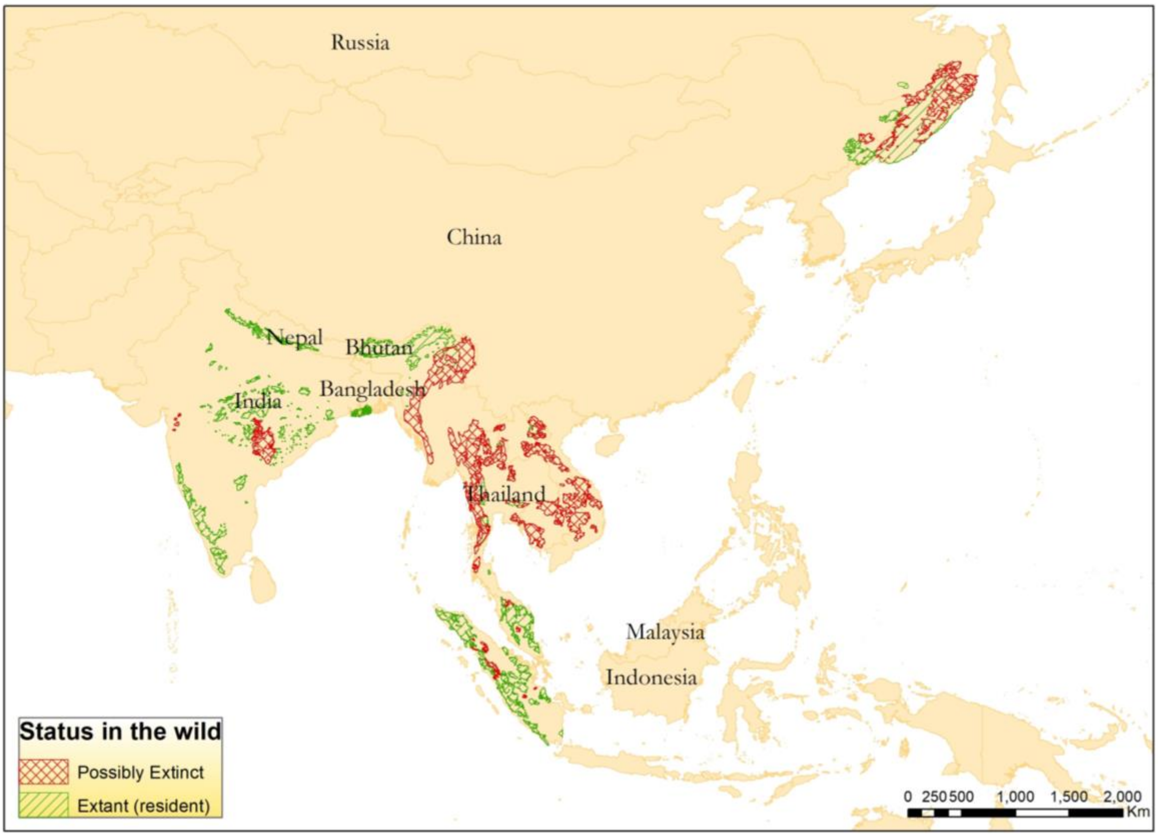


Figure 1 Distribution map of Panthera tigris based on IUCN Red List of Threatened Species (IUCN 2018)

Figure 1 shows the tiger range based on IUCN statistics on terrestrial mammals. Currently, the suitable habitat for tigers across the whole Asian tiger range is around 1.2 million km^2 (Global Tiger Recovery Program 2010). The map in *Figure 2* is part of the Global Tiger Recovery Program research initiatives, and it shows tiger landscapes divided into five categories, namely: global priority, regional priority, long-term priority, some parts with insufficient data, and, lastly, historical tiger range.

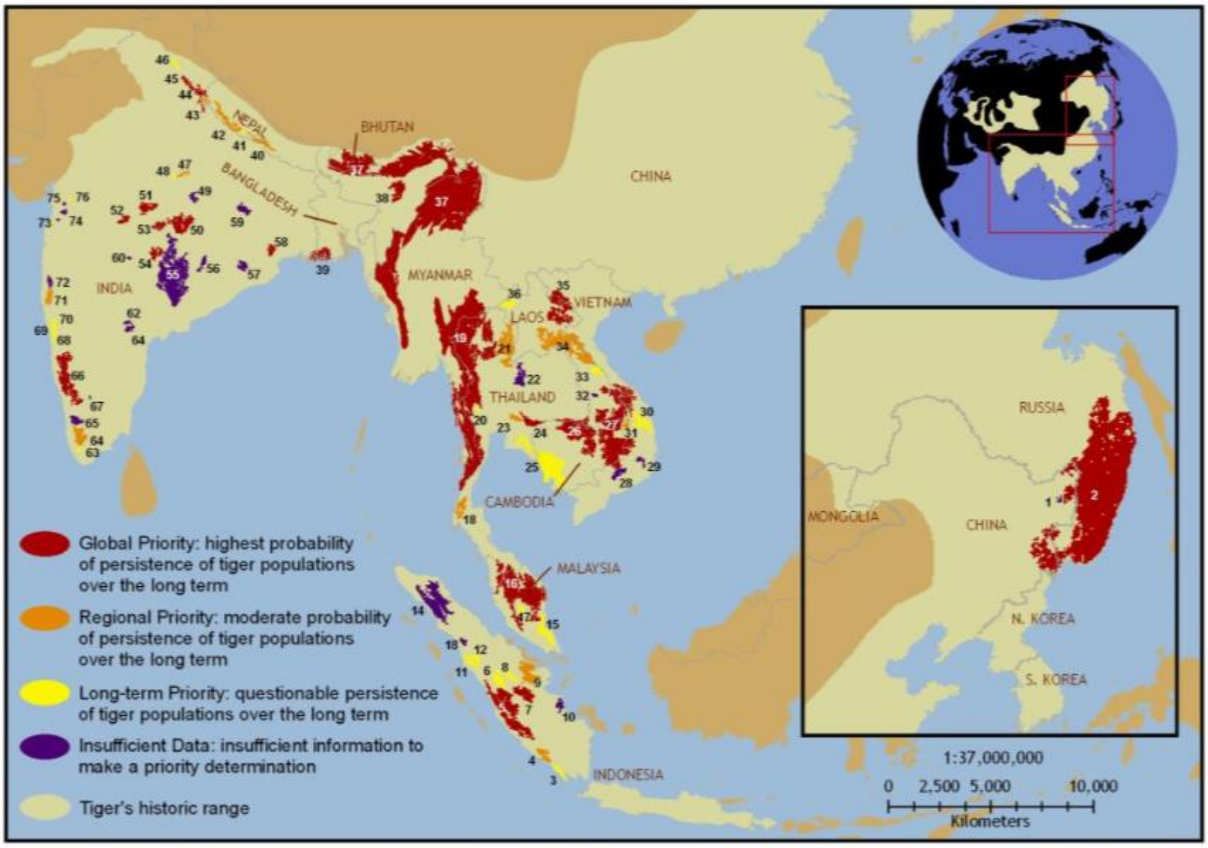


Figure 2 Tiger Conservation Landscapes (Global Tiger Recovery Program 2010)

In *Figure 2*, we can observe that one of the global priority areas (in red color) shows a significant presence of tiger population in the Russian Far East (RFE) and Northeast China. Russia was taking significant actions to protect the tiger population starting from 1947 in its Sikhote-Alin and Lazovsky nature reserves, successfully bringing back the Amur tiger population (Matyushkin *et al.* 1996). From Russia, tigers migrate to neighboring China, which will start tiger protection scheme with the new Northeast Tiger and Leopard National Park in year 2020 (McLaughlin 2016). One of the historical tiger countries – Kazakhstan – is pioneering with tiger reintroduction program in the newly created Ile-Balkhash Nature Reserve with the aim to reintroduce the extinct Caspian tiger using Amur tigers from RFE (WWF Russia 2018a).

The present thesis takes a closer look at already assigned priority areas in Russia, China and Kazakhstan and is aiming to identify local factors/stressors that might influence the effectiveness of tiger conservation. For that reason, the habitat suitability model based on 7 factors/habitat suitability characteristics is developed. The current habitat suitability model includes vegetation types, topography, tiger prey, proximity to roads and population density, deforestation, and presence of the already existing protected areas.

1.2 Research aim and objectives

My project's aim is to contribute to the Amur tiger recovery program by investigating the application of geospatial analysis tools and remote sensing in the habitat suitability analysis. The application of geospatial analysis is shown on the case study of habitat suitability for Amur tiger recovery in Northeast Tiger Leopard National Park in China and Ile-Balkhash Nature Reserve in Kazakhstan, which will be comparatively analyzed with the Amur tiger habitat suitability model in the Russian Far East.

Current thesis aims to answer the following research question: What are the prospects of Amur tiger restoration in China in the Northeast Tiger and Leopard National Park and prospects of Caspian tiger reintroduction in the Ile-Balkhash Nature Reserve in Kazakhstan?

To achieve the stated aim and answer the research question, the following objectives will be accomplished:

- To review existing methods applied in the large mammal's conservation
- To identify the current status of the Amur tiger in the wild (using secondary data and expert knowledge)
- To identify the main characteristics of a suitable habitat for tigers and develop a conceptual framework for habitat suitability;
- To review existing technologies that are applicable for habitat suitability analysis;
- To analyze using geospatial analysis tools and remote sensing the territory of the existing park in Russia and planned parks in China and Kazakhstan.

1.3 The scope of the research

The research will include analysis of the territories of existing and proposed nature reserves and national parks in Russia, China, and Kazakhstan. The boundaries of the parks will be mapped and drawn based on open-source datasets and already existing maps showing the boundaries of the proposed and existing parks.

Spatial data will be downloaded from open source datasets. Data on Amur tiger trails is gathered on the territory of the Northeast Tiger and Leopard National Park and Sikhote-Alin Nature Reserve with the use of camera traps. The exact tiger distribution and individual trails are not mapped due to the absence of open-access data. However, the exact trails of individual tigers are not essential. For the purpose of the research, boundaries of protected areas with buffer zones are sufficient.

1.4 Roadmap

The thesis consists of six chapters. *Introduction* provides general information about tigers, their current range and status. This chapter has the main aim, research question and objectives, as well as identifies the scope of the current research. *Chapter 2* includes a literature review on the Amur tiger status in the wild. Chapter 2 elaborates on Amur tiger restoration factors, which include habitat characteristics, necessary legislation, and introduce successful restoration case in Russia. This chapter also introduces the Caspian tiger and reintroduction initiatives. Chapter 2 concludes with the general theory on the application of geospatial technologies in wildlife conservation. *Chapter 3* presents the research methodology including study area locations, data collection and data analysis methods, pointing at certain problems and limitations of the research in the end of the chapter. *Chapter 4* focuses on habitat suitability analysis focusing at habitat characteristics that define Russian Far East and contribute towards the growth of the tiger population. This chapter includes geospatial data processing steps and preliminary maps of

Russia, China, and Kazakhstan. *Chapters 5* presents prospects of the Amur tiger recovery in China and prospects of the Caspian tiger reintroduction in Kazakhstan based on habitat suitability and current legislation. Chapter also highlights relevant impediments to successful tiger recovery in relevant countries. *Chapter 6* presents the conclusion of the thesis. It discusses implications of the research to conservation of large carnivores and provides an overview of the future research directions.

2. Literature review

2.1 Conservation of large carnivores

Conservation biology is a relatively new topic, which gained its current definition around the mid-1980s (Sodhi *et al.* 2011). Current rhetoric around conservation biology is based on Western science, yet there are other important conservation traditions rooted in local and indigenous knowledge and practices. The recognition of the acceleration and global loss of species, i.e. sixth mass extinction, was the major drive behind the emergence of conservation biology (Van Dyke 2008). Convention on Bilogical Diversity (1992) defines biodiversity as the "variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." The definition is inclusive and can be shared and interpreted to local issues by various nations to support biodiversity conservation.

The major goal of conservation biology is saving species. Yet, as Van Dyke (2008) stresses, when we talk about saving "species" as fundamental units of biodiversity, we must (1) understand how various conservation schemes will affect different groups, and (2) clearly define those groups to show their place in biodiversity to speak to both scientists and general audience about them.

In general, to ensure conservation of large carnivores, a set of ecological and cultural characteristics should be taken into account. Clark *et al.* (1996) suggest viewing large mammals' conservation not as a myriad of problems like habitat loss and human poaching but look for reasons behind those problems and identify their origin to successfully tackle it. He puts a strong emphasis on how we define a problem, since definition will drive further solutions. Subsequent management schemes will reflect the aforementioned problem definition, i.e. ecological, social, political and economic factors behind it (Clark *et al.* 1996).

Clark *et al.* (1996) identified five variables that will help to understand the problem of large carnivores' conservation; they are the following: management system reasons, historical/cultural reasons, valuational reasons, ecological reasons, and policy process reasons. These reasons have their own subdivisions, but due to the limited time and resources, which is usually the case for conservation science, focusing on larger variables seems more practical and feasible.

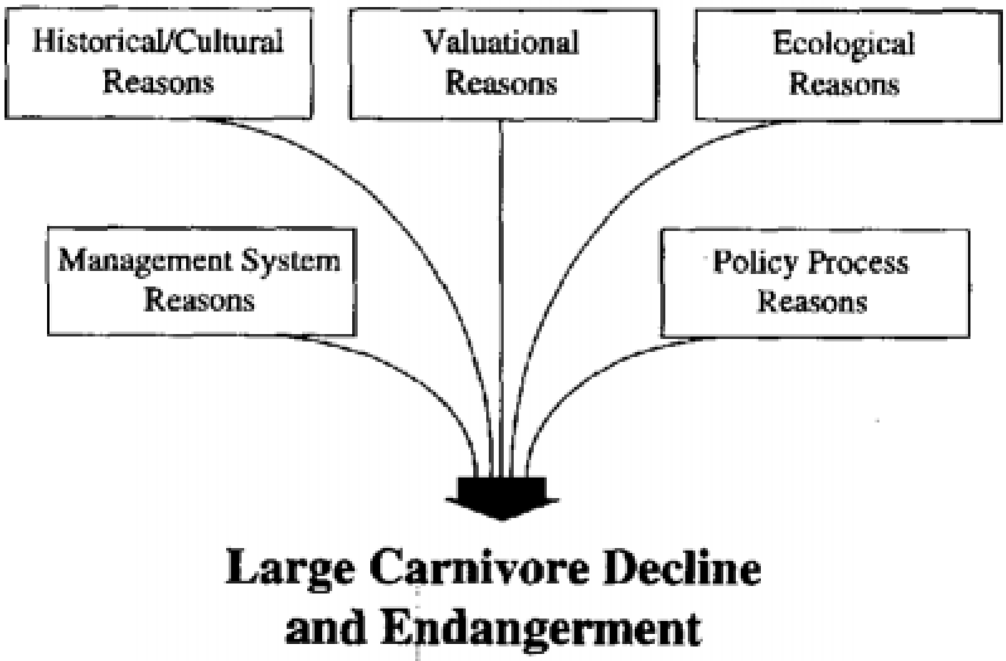


Figure 3 Schematic representation of the five-part problem definition for large carnivore conservation in North America (Clark et al. 1996)

Figure 3 can be a helpful tool for conservation planners and policy makers, since they can map the problem with minimal social contention and achieve species conservation. Yet, there is no blueprint for a successful conservation plan; each case should be adapted to local needs and resources on the adequate scale.

Protected areas play a significant role in the conservation of biodiversity. According to IUCN, protected area is "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (Convention on Bilogical Diversity 2018).

IUCN has also developed a categories system to classify different types of protected areas according to the management objectives. They include six categories, ranging from Category Ia and Ib, which are Strict Nature Reserve and Wilderness Area respectively, to Category VI, which is Protected area with sustainable use of natural resources (Protected Area Categories 2016). These categories are accepted by the United Nations and its member countries and serve as a reference point to define and manage protected areas in national legislations.

Protected areas play a vital role in conserving ecosystem services, like food, clean water, medical care, protection from natural disaster as well as mitigation of climate change effects. Protected areas, especially categories I and II, serve as last refuges for extinct and endangered species to survive in the wild. They also serve as examples of wilderness areas, where natural evolution without any human impact can take place. Finally, protected areas have a certain cultural meaning in a nation's heritage, like Machu Pichu in Peru (Stolton *et al.* 2010).

The map in Figure 4 shows protected areas on land and in the oceans listed in the World Database on Protected Areas. Currently, around 14% of land surface and small area of ocean is covered by protected areas (Stolton *et al.* 2010). WDPA is the most comprehensive database, which includes both terrestrial and marine protected areas and is regularly updated (Protected Planet 2018). Being a joint project between UN Environment and IUCN, WDPA extensively collaborates with governments, non-governmental organizations, academia and industry to inform decision making and enhance action.

Figure 4 Protected areas of the world (Protected Planet 2018)

Different categories of protected areas require different management actions and even within one category various management approaches can be employed. The ownership models also vary across protected areas from state-run to community managed areas and their combination. Stolton *et al.* (2010) in a report for the World Bank on valuing protected areas specify that to make protected areas effective, territories should not only be properly managed, but they should also be part of the larger conservation scheme supplemented by ecological corridors, buffer zones, and sustainable management.

According to the theory of island biogeography on species-area relationship, the larger the "island" of protected area the more species diversity is likely to take place (Van Dyke 2008; Stolton *et al.* 2010). Large territory allows managing a habitat large enough to maintain the natural habitat for selected species. Therefore, connectivity between ecosystems (buffer zones, ecological corridors) is crucial to ensure species diversity and, subsequently, successful conservation. In the context of the conservation of large carnivores, like tigers, buffer zones and ecological corridors are crucial, because Amur tiger never lives inside the designated protected areas, they usually roam around in the quest for food and new territory.

Last, but not least, transboundary protected areas can facilitate transnational cooperation. Current national borders are delineated based on land surface's natural features, like mountains, rivers, and else. However, the existence of political borders (ideally) should not limit wild animals from migration. Transboundary conservation of natural resources has both political and social benefits. Spatial requirements of large carnivores, like wolves and tigers, has made them flagship species for transboundary cooperation (Linnell *et al.* 2016). Transboundary cooperation between Russia and China to protect the endangered Amur tiger and allow species to roam between two countries' national parks, can be a future example of a successful transboundary management (WWF 2013).

2.2 Status of the Amur tiger in the wild

Panthera tigris altaica, commonly known as Amur or Siberian tiger used to occupy the entire Korean Peninsula, the northern provinces of China, the Amur river bank in Russia to Transbaikalia and Yakutia (Pikunov 2014). This range was occupied by tigers till the beginning on the 19th century.

Starting from 20th century, the range and number of Amur tiger species has varied significantly. Numbers of Amur tiger started to fluctuate across Russia, from high at the beginning of the 20th century to getting very low by the 1930s and 1940s. According to Matyushkin et al. (1996), around 30-40 animals were roaming around the Russian Far East in 1940.

A turning point in the faith of the Amur tiger in Russia was the implementation of protective legislation in 1947 (Matyushkin *et al.* 1996). Since then, protection of the critically endangered Amur tiger was the priority for the Russian Far East region. Around 80-90% of the world population of the Amur tiger resides in the Russian Far East (Matyushkin *et al.* 1996). For that reason, in July 1996, the Russian Federation Ministry of Environmental and Natural Resources

Protection started conservation initiatives approving the "Strategy for Amur Tiger Conservation in Russia" and adopted Resolution #795, "On the conservation of Amur tigers and other rare and endangered species of wild flora and fauna on the territory of Primorsky and Khabarovsky Krais" (Matyushkin *et al.* 1996).

Overall, Russian initiatives towards Amur tiger conservation, have led to the gradual increase in the number of tigers in the wild. Census conducted by Pikunov (1990) in 1984-1985 found around 250 tigers in the entire Russian Far East region. While census conducted by Mescheryakov and Kucherenko (1990) five years later, indicated at least 350 tigers in the Primorsky region alone. The implementation of protective legislation towards tigers from Soviet Union and later Russia has stopped human persecution and helped to raise the population of tigers from critically low to 300-400 individual species (Matyushkin *et al.* 1996). Another 20 tigers are roaming in the northern-eastern region of China, which is the neighboring part of the Primorsky krai despite the presence of a fence along Russia-China border (Russian Border Protection Zone). The number of tigers in the Korean peninsula is not confirmed.

Assessing the number of tigers and conducing censuses is important to develop adequate conservation programs. The need to conduct annual censuses was highlighted during International symposium "Amur tiger – problems of population conservation" (1993), in the "Amur Tiger Program" (1994) as well as during the international conference "Ecology and Conservation of Amur tiger" (1995) (Matyushkin *et al.* 1996). Yet, such monitoring methods are costly and ineffective, since Amur tigers roam across vast territories and significant amount of man power is required to continue in situ monitoring. Luckily, with the advance of geospatial technologies and the use of remote sensing in conservation, environmental monitoring has become more feasible.

Factors influencing the size of the tiger population include availability of prey, integrity of the habitat, weather conditions, and poaching of tigers and their prey. Territories of *zapovedniks* in Russia (Sikhote-Alin, Lazovsky, and Ussurisky Reserves) show the highest density of tigers. However, the problem with relying solely on nature reserves and national parks is the limited territory that they cover and the actual territorial requirements of Amur tiger. According to Carroll *et al.* (2006), strictly protected areas cover only 3.4% of the region, which is not sufficient to ensure successful conservation.

However, it is important to specify that territories that Amur tigers occupy in the Russian Far East are one of the most sparsely populated areas of the world with less than one person per square kilometer (Russian Census 2010), which has a positive effect on the tiger presence, their habitat and prey.

It is important to bear in mind that forests of Northeast China and Russian Far East serve as a home for another felid carnivore – Amur or Far eastern leopard (*Panthera pardus ssp. orientalis*). According to IUCN Red List, Amur leopard is Critically Endangered (Stein *et al.* 2016). Species have experienced the same stressors as Amur tigers. Prey availability is the driving factor behind the decline in the number of Amur leopards in the wild, yet they could peacefully coexist with Amur tigers in one habitat in the presence of sufficient amount of their prey (Yang, Dou, *et al.* 2018).

The status of Amur tiger in China was assessed during surveys in Heilongjiang province in 1974-1976, 1984-1986, and 1988-1991 (Stein *et al.* 2016). In the 1970s, the population of tigers was around 81 individuals. By the 1980s, the quality of tiger habitat degraded significantly, and the number of felids dropped to 20-30 individuals in northeastern China. The last survey in the 1990s, identified no more than 20 individual species and noted a significant decline in prey densities, which is the reason the behind low number of tigers in the region.

There was a series of surveys in Jilin province as well. The last survey in 1998, helped to determine up to six nomadic tigers roaming between China and Russia, close to the border with the Russian Far East (Baogang *et al.* 1999).

Current range of Amur tiger habitat is shown in *Figure 5* below. IUCN Red List of Threatened Species mapped the distribution of the *Panthera tigris* species. Out of this dataset, the Amur tiger range was extracted. We can observe that Amur tigers roam throughout the entire Sikhote-Alin range in the Russian Far East and Provinces of Jilin and Heilongjiang in Northeast China.

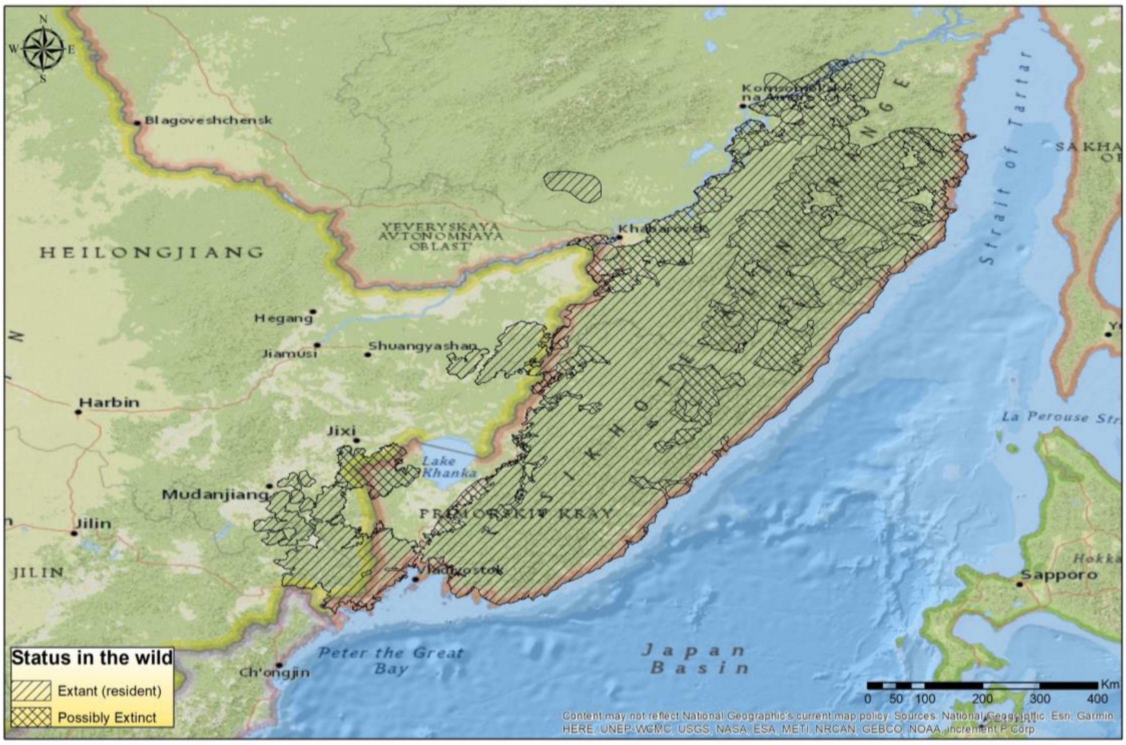


Figure 5 Amur tiger distribution range based on the dataset from the IUCN Red List of Threatened Species

2.3 Reintroduction of the Caspian tiger

Kazakhstan's government is planning novel and ambitious plan to bring back currently extinct Caspian tiger or Turan tiger (*Panthera tigris virgata*) to Central Asian steppes. Being a part of the global tiger initiative to double tiger population in the wild by the year 2022, Kazakhstan will restore the habitat and prey for wild tigers.

Historically, the Caspian tiger had the largest geographic range of around 800,000-900,000 km^2 with 2-3 tigers per 100 km^2 (Chestin *et al.* 2017). Tugay- and reed-dominated ecosystems of shores of the Caspian Sea, Elburz mountains, eastern Turkey, Tigris and Euphrates river valleys were the primary habitat for the Caspian tiger (IUCN 2014). Currently, sub-species are marked as "Extinct" by IUCN Red List.

Extensive and aggressive agricultural development in Central Asia during the Soviet times coupled by poaching and trapping have led to the extinction of the Caspian tiger in the wild. However, the collapse of the Soviet Union and decline in the agricultural activities in Kazakhstan are leading to the natural restoration of the habitat (Chestin *et al.* 2017). Moreover, recent study on tiger phylogenetics by Driscoll *et al.* (2009) has revealed that currently extant Amur tiger can serve as genetic source for the reintroduction of the extinct Caspian tiger in Central Asia.

Certainly, reintroduction of large carnivores is an ambitious plan. Yet, wolves (*Canis lupus*), bears (*Ursus arctos*), and African wild dogs (*Lycaon pictus*) were already successfully reintroduced using translocation of "behaviorally competent" individuals from the wild (Driscoll *et al.* 2012). Repatriating tigers to their historical range using "analog" species requires a thorough ecological research. Specifically, species should be recognized in the national legislation, protected area status should be given to the assigned region, agriculture and livestock activities should be stopped, habitat and wild prey should be re-established as well (Jungius *et al.* 2009).

WWF Russia explored the possibilities for restoration in Central Asia and marked delta of the Ile river as a potentially suitable region (Chestin *et al.* 2017). In this light, the government of the Republic of Kazakhstan has signed a Memorandum with WWF in 2017 on joint initiative to reintroduce the Caspian tiger (WWF Russia 2017). This year, Ile-Balkhash Nature Reserve was created as a first step towards the initiative (WWF Russia 2018a).

2.4 Restoration factors

The rate of decline of Amur tigers in the wild recent decades has pushed tiger range countries to implement new policies and develop tiger action plans. Successful restoration scheme should have several phrases and receive significant support from respective governments and local communities. The tiger action plan developed by 13 tiger range countries mentions its main aim called Tx2 goal to double the current population of tigers by year 2022, which is the next Chinese Year of the Tiger (WWF Russia 2017). Effective management and protection schemes will help to recover the endangered population of tigers in the wild and enlarge the current tiger range.

2.4.1 Suitable habitat characteristics

An important factor in conservation biology and species conservation is protection of the core habitat. Habitat includes the necessary living units for a given wild species, including space, food, water, etc. (Xiaofeng *et al.* 2011). Species' ecological niche, which is a set of conditions necessary for species survival and reproduction, is the result of a combination of external (ecological conditions) and internal (population size, density, reproduction rate) factors (Lauria *et al.* 2015). A useful tool in habitat protection schemes is habitat suitability models developed by conservation planners to map the likelihood of the occurrence and density of threatened species in a given ecosystem and analyze species-environment relationships.

Ecological characteristics across the Amur tiger range in Russia and China were evaluated during the Survey of Amur tigers and leopards by Baogang *et al.* (1999). The survey has identified two separate population of Amur tigers: the Tumen River population (southwest Primorsky Krai, Jilin Province, south Heilongjiang, and North Korea), and Sikhote-Alin population.

Therefore, any conservation scheme should aim to protect both tiger populations and ensure their connectivity.

Xiaofeng *et al.* (2011) has identified tiger-specific habitat demands to explain species distribution. The main driving factor behind Amur tiger population occurrence and density is tiger prey density. Habitat loss and degradation caused by human activities and continuous poaching have significantly reduced the population of tigers. Human-related factors include human population density and distance from major roads and railways. Certain elevation (400-800 m) and specific vegetation are more comfortable for tigers and their prey. Temperate deciduous broad-leaved forests of Korean pine and mixed wood make the most suitable vegetation for tigers and their wild prey like sika deer and wild boar (Xiaofeng *et al.* 2011).

Based on the impact level of various factors, Xiaofeng *et al.* (2011) assigned five values to habitat suitability evaluation factors that can be seen on *Table 1* below. Factors are ranging from rating 1, which includes high suitability and low disturbance, to rating 5, which is low suitability and high disturbance level. These factors supplemented by other secondary data and expert knowledge will serve as a future reference for the current research's habitat suitability analysis.

Table 1 Standardized rates of habitat suitability evaluation factors

Factors	Ratings				
	1	2	3	4	5
Vegetation suitability	Deciduous broad-leaved forest mainly including Betula platyphylla and Populus davidiana	Temperate deciduous broad-leaved forest mainly including oak trees and Fagaceae	Coniferous forest	Artificial forest and Swamp Meadow	Agricultural areas, residential regions and rivers
Prey density (number/km2)	3.23-9.10	1.99-3.23	1.24-1.99	0.57-1.24	0-0.57
Elevation (m)	400-800	800-1100	200-400	0-200	>1100
Slope (°)	15-30	-	0-15	30-45	>45
Aspect	Southerly Exposures	-	Other	-	-
Population density (person/km2)	0-15	15-99	99-208	208-344	344-518
Distance from main roads (m)	> 1000	-	500-1000	-	0-500

2.4.2 Legislation

Globally, more and more countries are adopting national biodiversity inventory and wildlife monitoring strategies to trace and report changes in biodiversity indicators (Lee *et al.* 2005). There is a rising pressure from the international community to adopt biodiversity strategies coming from international agreements, such as the Convention on Biological Diversity (1993), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1975), the Ramsar Convention on Wetlands (1971), etc.

The main parts of the national biodiversity inventories include species, abundance, and distribution of biota (Lee *et al.* 2005). The main purpose of monitoring status, condition, and changes in biodiversity indicators is to equip managing agencies with adequate and updated information that will enhance understanding of ecosystems. Environmental monitoring requires long-term commitment and investment from the government. As a result, funding of biota monitoring and development of reports is usually not consistent.

Countries within tiger range adopt tiger action plans to protect charismatic predators. Realizing the importance of tiger as umbrella species within the forest ecosystem and their symbolical value in national cultures facilitated management. Protecting umbrella species leads to protection of other species and their habitats. Symbolizing independence, royalty and protection in some cultures, like Malaysia, tiger itself is in the urgent need of protection by countries.

Global Tiger Recovery Program (GTRP) is ambitious initiative among 13 Asian tiger range countries (TRCs), namely Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Russian Federation, Thailand, and Vietnam (Global Tiger Recovery Program 2018). The main aim of the program is to achieve doubling of the tiger population by year 2022, improving quality of critical tiger habitats across tiger range, bring significant reduction in poaching and illegal trade, as well as to sustain continuous monitoring across tiger landscape.

Member countries of GTRP believe that current initiative is the last and most important step to ensure the survival of *Panthera tigris* as a type. Multilateral and successful action will ensure tiger recovery, while inaction will lead to the extinction of tigers in the wild. Current plan highlights that to ensure survival of the animal in the wild, tiger prey, significant amount of tiger range and, subsequent biodiversity and ecosystems should be supported. Loss of apex predator taking top position in the food chain will influence Asian ecosystems at all levels.

2.5 Geospatial technologies and remote sensing

2.5.1 Remote sensing and geospatial technologies

The first use of remotely sensed data goes back to the military during the World War I and World War II. At first, aerial images and remote sensing were raising concerns in public due to association with the "eye in the sky" and "Big Brother" concepts (Khorram *et al.* 2016). However, as technologies advanced, social acceptance of the remote sensing grew and now it is part of our daily lives through Google Earth engine, global positioning systems (GPS), weather forecasts and environmental monitoring.

Remote sensing can be defined as "acquisition and measurement of information about certain properties of phenomena, objects, or materials by a recording device not in physical contact with the features under surveillance" (Khorram *et al.* 2016). While Environmental Systems Research Institute (ESRI) in geographic information system (GIS) vocabulary defines remote sensing as "collecting and interpreting information about the environment and the surface of the earth from a distance, primarily by sending radiation that is naturally emitted or reflected by earth's surface or from the atmosphere, or by sending signals transmitted from a device and reflected back to it" (Thenmabail 2015). Remote sensing is broadly used in various areas, such as agriculture, forestry, hydrology, oceanography, and environment (*Figure 6*).

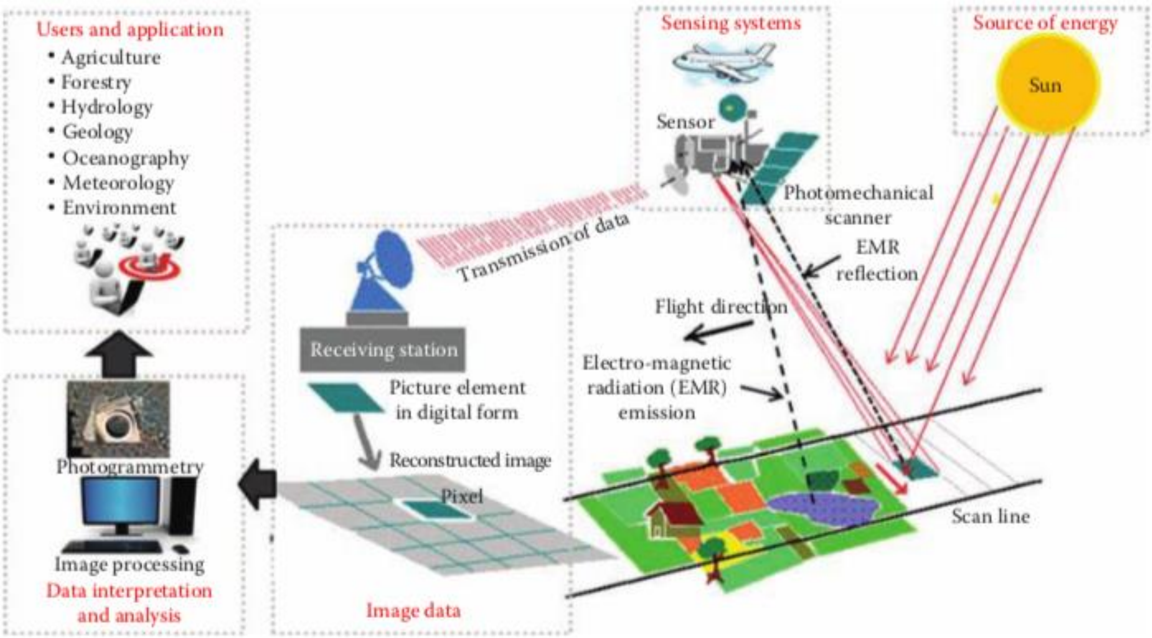


Figure 6 An illustration of the remote sensing concept (Thenmabail 2015)

Remotely sensed data can be divided into active and passive data. Passive remote sensing data is acquired when reflected or transmitted electromagnetic radiation from the sun across the electromagnetic spectrum recorded by sensors. Usually, it involves measurement of solar energy reflected from Earth's surface (*Figure 7*). The source of active remote sensing data is a pulse of energy emitted from and measured by a sensor (Thenmabail 2015). Google Earth engine is an example of passive system using digital elevation model (DEM) images obtained from satellite imagery, aerial photography, and GIS. Active remote sensing measures man-made energy signals and records reflected signals. Among the most widely used sensors are Radio Detection and Ranging (RADAR) and Light Detection and Ranging (LiDAR). Another common example of active remote sensing is global positioning systems (GPS) that is widely used by public in the everyday life.

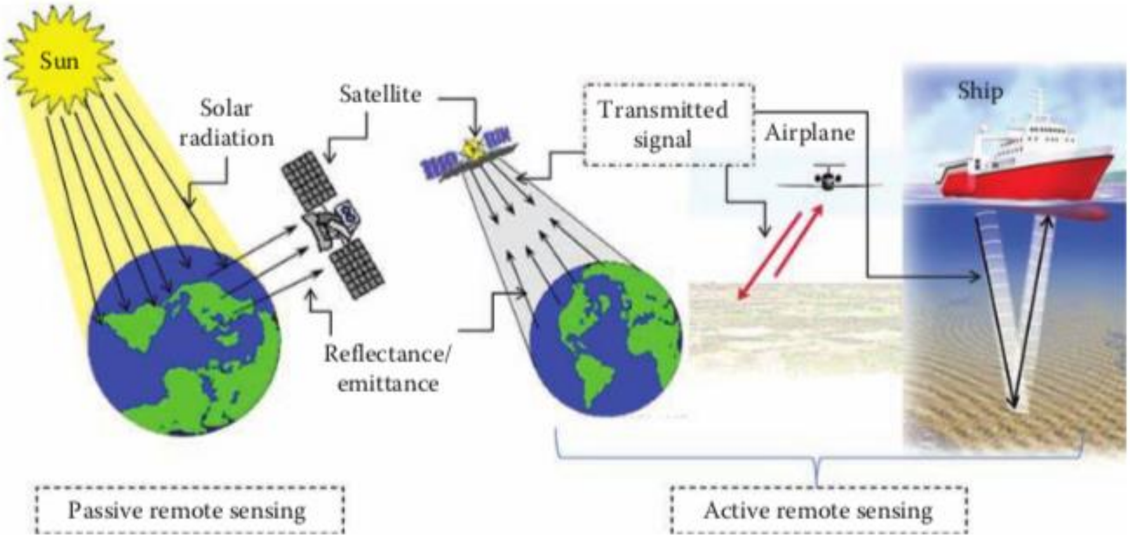


Figure 7 Illustration of passive vs. active remote sensing with different platforms (Thenmabail 2015)

The nature of the remotely sensed data is essentially *geospatial*, meaning that observed area is referenced on the map according to its location in a geographic coordinate system (Khorram *et al.* 2016). This feature of the remotely sensed data allows to merge data with geospatial data sets representing administrative divisions, roads, rivers and so forth. Data obtained from remote sensing is a primary source of GIS data and directly influences the quality of the data.

Electromagnetic energy (EME) that areas and objects reflect includes visible light, infrared, radio waves, heat, ultraviolet rays and x-rays (Thenmabail 2015). Electromagnetic radiation (EMR) can also be defined as all energy that moves with the speed of light in a harmonic wave pattern (Khorram *et al.* 2016). EMR travels in the sinusoidal fashion at the speed of light; where distance from one wave peak to another is a wavelength, while the number of peaks per unit of time is wave frequency (Thenmabail 2015). Depending on the wavelength and frequency of various forms of EMR they are distributed along the electromagnetic spectrum (*Figure 8*).

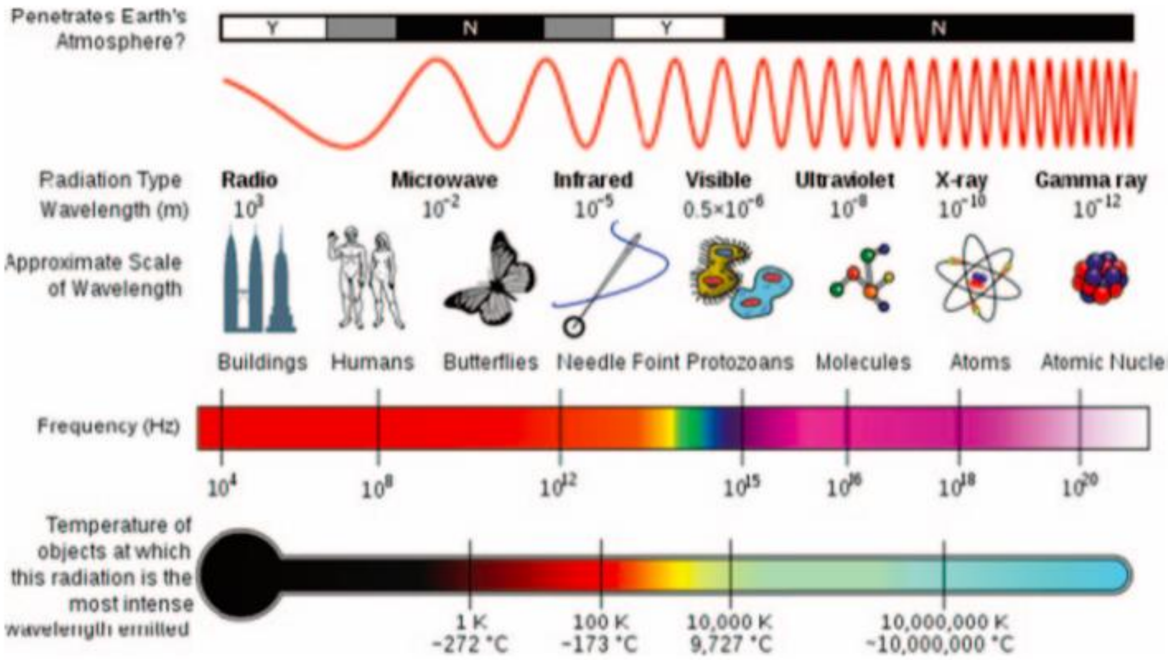


Figure 8 The electromagnetic spectrum (Thenmabail 2015)

Visible light that human eye can distinguish represents only a small portion of the electromagnetic spectrum. When electromagnetic radiation contacts with area or object, it interacts with it though absorption, reflection, scattering, emission, and transmission through the matter (Khorram *et al.* 2016). Every object and material have unique emission/reflection properties, which are called *spectral signature*. For instance, in agricultural monitoring, different types of soil reflect light differently allowing scientists to distinguish healthy soil from unhealthy ones.

ESRI defines a *geographic information system* (GIS) as “a specialized computer database program designed for the collection, storage, manipulation, retrieval, and analysis of spatial data” (Steinberg *et al.* 2015). GIS is used in various disciplines as a tool for data collection, organization, exploration, and analysis. Spatial or map-based data means that it is linked to a specific geographic location. GIS allows holistic understanding of the problem by integrating multiple data forms and analyzing multiple layers of information.

Having all the aforementioned advantages, it is important to bear in mind that remote sensing and geospatial technologies have certain limitations. Remote sensing provides relevant spatial, spectral, and temporal information; yet, it cannot provide all information to conduct physical, biological, and social science research (Jensen 2007). In general, passively recorded data is not disturbing to the observing object of interest. However, active remote sensing can disturb the phenomenon of interest by electromagnetic radiation from sensors (Jensen 2007). Finally, remotely sensed data is expensive and requires highly qualified image analyst to process the information.

2.5.2 Geospatial technologies and remotes sensing for wildlife conservation

Continuous development of geospatial technologies and remote sensing significantly enhanced our understanding of environmental issues. In the light of the environmental changes that the world experiences today, it is of a crucial importance to correctly map, monitor, analyze the changes and to respond in a timely manner. Deforestation and fragmentation affect the habitats of many species leading to biodiversity loss at an alarming rate. IUCN Red List classified 42% of terrestrial invertebrate and 25% of marine species are threatened with extinction (Ceballos *et al.* 2017). Geospatial technologies and remote sensing offer effective mechanisms to observe and monitor relevant changes at local as well as global scale (Ban 2016).

Land use and land cover maps are one of the most widely used types of terrestrial application of remote sensing. Natural and artificial features are categorized in groups and classes. Land use and land cover maps help to understand changes in vegetation and the reasons behind the changes (Khorram *et al.* 2016). Satellite images of various resolution are used for various purposes, for instance, Landsat provides images at 30-meter resolution that can be used for analysis of agricultural productivity, while commercial satellite like GeoEye 1 has a ground sample distance of 0.41 meter providing accurate high-resolution imagery that can be used during the disaster management.

Movement of large animals, migration patterns, as well as utilization of the habitat are related to the landscape and fall within terrestrial application of remote sensing. Tracking of animals is usually performed using tagging, bio-logging, with audio and video recordings, global positioning systems, and remote sensing (Khorram *et al.* 2016). Yet, direct observation of large animals though aerial images can be time consuming, costly, and limited to a few numbers of individual animals. Most often, satellite imagery analyzed to track the use of land and vegetation by certain species.

Pioneers in using Normalized Difference Vegetation Index (NDVI) in environmental monitoring were Verlinden and Masogo (1997), who were searching for correlation between habitat greenness with species density. The results of the research showed positive correlation between NDVI and grass greenness. Even though the correlation between NDVI and species distribution was not proven, NDVI estimates allow us to evaluate overall habitat suitability illustrating the global distribution of vegetation in various shades of gray (*Figure 9*). The most commonly used formula to calculate NDVI is the following:

$$NDVI = \frac{\mathrm{B2-B1}}{\mathrm{B2+B1}},$$

where B2 corresponds for brightness values from near-infrared band of the image, and B1 corresponds to values in the red band of the image (Khorram *et al.* 2016).

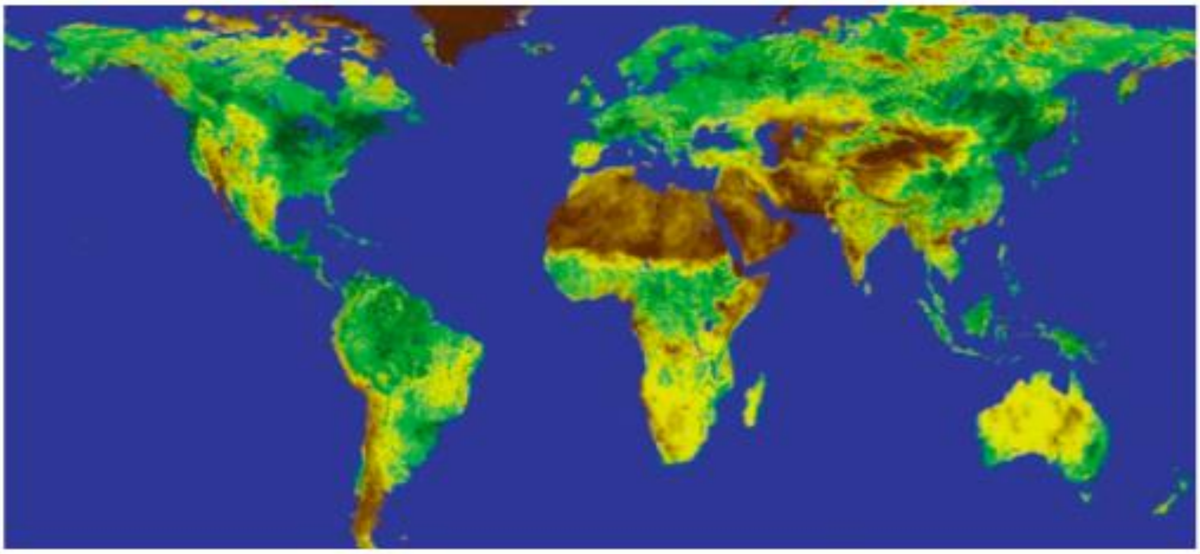


Figure 9 Normalized Difference Vegetation Index (NDVI) image depicting global vegetation cover in various shades of green (Khorram et al. 2016).

Traditional wildlife monitoring methods involving capture-mark-recapture of wild animals is effective, but highly labor intensive and disturbing to the wildlife being monitored (Verma *et al.* 2016). Moreover, the high impact of human factor, i.e. training, accuracy of gathering methods and limited scale, raise question about the reliability of the traditional wildlife monitoring techniques. New methods involve networks of technical sensors and satellite linked tracking terminals, and camera traps with motion detectors, which certainly allow for a more unobtrusive monitoring (Verma *et al.* 2016). Technologies became more autonomous and can be connected to mobile devices with the advance of Global Positioning System (GPS) and Global System for Mobile Communication (GSM). For instance, researchers from the Tiger-Leopard Observation Network (TLON) monitor tiger movement in the Jilin and Heilongjiang provinces being based at Beijing Normal University extracting information from camera traps every month (Wang *et al.* 2017).

3. Research Methodology

Comprehensive habitat suitability analysis requires a multi-scale approach, because analysis of habitat suitability is related to various factors on different spatial and temporal scales (Store *et al.* 2003). Geographical Information System (GIS) in this case will help to shape a predictive research model incorporating ecological data on relevant spatial and temporal scales. My three main methods are analysis of remotely sensed data, secondary data, and the interview.

Information about tiger habitat preferences as general theoretical guidance will be taken from already existing literature. Extensive research on the Amur tiger habitat preferences is carried out by scholars from the Tiger-Leopard Observation Network in China (TLON) based in Beijing Normal University (ResearchGate 2018). Information on the Caspian tiger will be gathered during the interview with the tiger expert from the Association for the Conservation of Biodiversity of Kazakhstan. The main objective is to gather sufficient information on suitable habitat for Amur tiger and Caspian tiger and map it using ArcGIS 10.2.2 (Environmental Systems Research Institute) software and relevant extensions.

3.1 Selection of the case study areas

The Amur tiger range extends throughout the Amur-Heilong region, which includes the Russian Far East, specifically territories of national parks, and occasionally Northeast China, which neighbors the Russian Far East. The case study area includes Sikhote-Alin Nature Reserve (SA) in Russia and the Northeast Tiger and Leopard National Park (NTLNP) in China. Since Kazakhstan is planning to reintroduce the already extinct Caspian tiger bringing the Amur tiger as the closest phylogenetic relative to newly created Ile-Balkhash Nature Reserve, the territory of the reserve is included as the case study as well.

3.2 Data collection

3.2.1 Remotely sensed data

The current research uses geospatial analysis working with spatial information. Digitized data will be either downloaded from open-source datasets or digitized data will be created.

To reach one of the main aims of the research, namely to analyze with the use of geospatial analysis tools and remote sensing territories of protected areas, various spatial and remotely sensed data is required. The following data sources were used (*Table 2*):

Table 2 Data sources used in the research

Data	Purpose	Source
MODIS	Land surface	https://lpdaac.usgs.gov
MERIS	Global cover 300m	http://due.esrin.esa.int/page_globcover.php
Landsat	Land surface	https://glovis.usgs.gov
SPOT	Vegetation	https://www.vito-eodata.be/
ASTER	Elevation	https://gdex.cr.usgs.gov/gdex/

3.2.2 Secondary data

The present research will rely on the already existing body of primary data collected during Amur tiger monitoring in the Russian Far East and Northeast China, which will serve as a general theoretical guidance. Secondary data will include GIS layers and tabular data representing environmental and demographic information. The data will be taken from government agencies, research institutions, nonprofit organizations, and private sources. GIS, in turn, will allow to integrate all data units serving both as a data collection and data analysis tool (Steinberg *et al.* 2015).

Tigers roam between national parks. Both the Russian Far East and Northeast China are extensively studied by scholars and relevant research groups like Tiger-Leopard Observation Network (TLON). However, a closer look at the territory of the existing and planned national parks is scarce. Existing maps (Hebblewhite *et al.* 2014; Yang, Zhao, *et al.* 2018; B. Wang *et al.*

2018) provide an overview of the whole tiger range; yet, study of the habitat within national parks is of great importance and will be conducted in the current thesis.

Habitat suitability rating used in the current research relies on the standardized rates of habitat suitability evaluation factors developed by Xiaofeng *et al.* (2011). Variables were compared with existing data on habitat suitability in Russia and synchronized accordingly to generate new patterns. The exploratory data analysis approach is used to generate new context-appropriate 3-scale scheme, which ranges from (1) Highly suitable to the (3) Least suitable areas.

In case of Kazakhstan, the newly created Ile-Balkhash Nature Reserve presents completely different habitat for the Amur tiger, because initially territories were occupied by the currently extinct Caspian tiger. The research on this region is even more scarce. Preliminary analysis of the tiger management unit has been conducted (Chestin *et al.* 2017), but the area of the national park has not been analyzed separately.

Secondary data includes analysis of vegetation suitability, topography (elevation, slope), and human disturbance factors (population density, distance from main roads and railways). Exact data on tiger prey density is absent and will be mapped based on the expert's estimations.

Lastly, reference to the planned management schemes on the territories of nature reserves will be presented. The success of conservation initiatives is closely correlated with the willingness of Chinese and Kazakhstani government to invest time and money. Moreover, it will also require extensive cooperation with local communities, since their support is of paramount importance.

3.2.3 The interview

For the purpose of research, the vice-president of Kazakhstan National Geographic Society and head of the Centre for Conservation Biology Dr. Sergei Sklyarenko was interviewed in person. An open information about newly established Ile-Balkhash Nature Reserve is sparse, as during the interview I got sufficient information about the Caspian tiger habitat preferences and had access to the project's plans and relevant maps.

The interview followed a semi-structured format. Firstly, a few questions about the history behind the development of the new national park, size and planned conservation management approaches were asked. Then, the details about the Caspian tiger habitat preferences were discussed. The purpose of the interview was gathering sufficient data to model suitable habitat for the Caspian tiger based on the Amur tiger's habitat preferences. The results are summarized in Table 3 and *Table 5*.

3.3 Data analysis

3.3.1 Processing geospatial data

For the purpose of research, ArcMap 10.2.2 mapping and analysis platform and its extensions developed by ESRI were used. Unification and standardization of habitat suitability factors was an important step in the data analysis. Data on the same parameters was downloaded from the same sources or classified in a similar way to homogenize all the parameters and produce habitat suitability map. All vector data was rasterized for the subsequent analysis. All maps in the current thesis without a reference to an author were produced in ArcMap.

3.3.2 Combining geospatial data with secondary data and expert knowledge

Based on the secondary data and expert knowledge, a set of criteria for successful conservation will be developed to analyze the habitat suitability in the territory of the proposed national park using geospatial methods.

The data used in the present thesis includes digitized GIS vector maps/layers, raster layers, remotely sensed images from satellites (*Table 2*), secondary data from field research, and expert knowledge. All characteristics were classified based on the criteria in *Table 4*.

The general framework of the method for the present thesis that shows all operations performed in ArcGIS 10.2.2 is illustrated in *Figure 10*. The framework was used to compare areas of Sikhote-Alin Nature Reserve (SA), the Northeast Tiger Leopard National Park (NTLNP), and Ile-Balkhash Nature Reserve (IB).

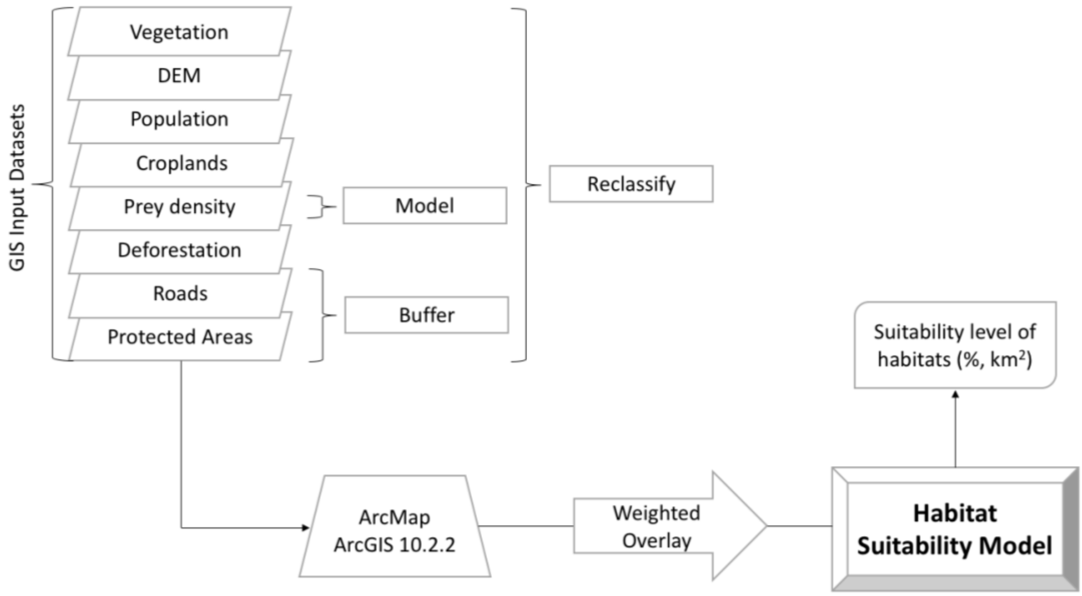


Figure 10 A general framework for the thesis.

GIS input datasets are in vector and raster format, and the Spatial Analyst Tools extension for ArcGIS allows analysis of both of them (*Figure 11*). There are over 170 tools and 23 toolsets that allow Spatial Analyst to work with natural resource analysis, statistical analysis and to perform modeling (Steinberg *et al.* 2015). For the current thesis the following geoprocessing toolsets were used: distance, extraction, generalization, interpolation, overlay, map algebra and reclass.

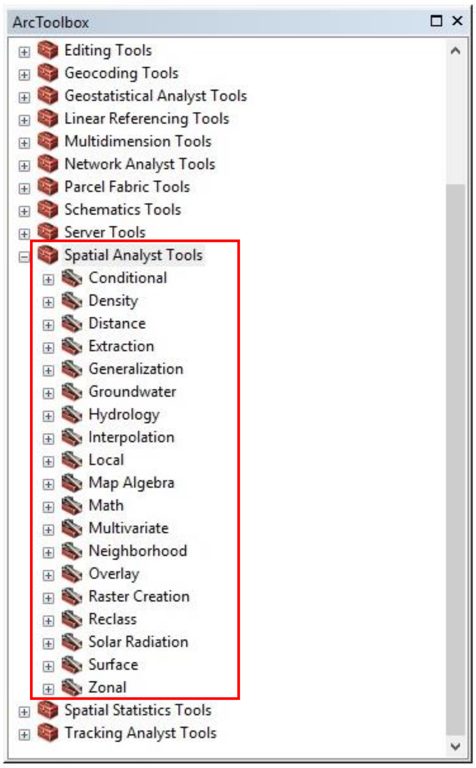


Figure 11 Spatial Analyst Tools

Spatial interpolation tool is usually used to estimate values between sampled locations predicting surface from point values from the sample. Interpolation is used when it is hard or impossible to provide a complete census, and instead data values in various locations between sample points are estimated (Steinberg *et al.* 2015).

Buffer feature creates a polygon around input feature on a specified distance (ESRI 2018a). Depending on the input feature and the desired result, buffers can be constructed differently (*Figure 12*). The current thesis uses Euclidean buffering. Euclidean buffers are useful for analyzing distances around specific features in a projected coordinate system; here it is Global Coordinate System (GCS_WGS_1984). Despite the fact that there are areas where the distance between the objects is distorted, because the actual shape of the earth is included only in geodesic buffers, the data is still accurate.

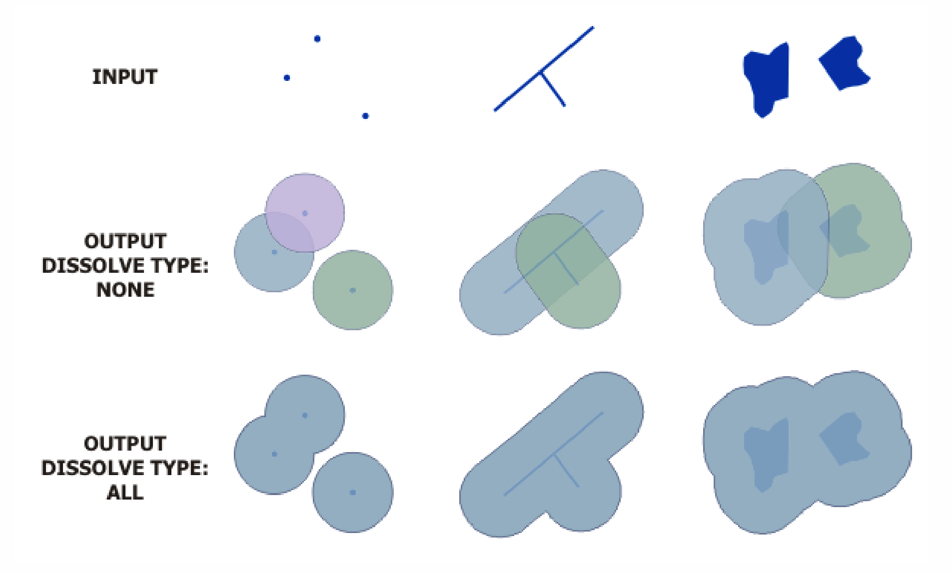


Figure 12 Buffer Illustration of three input data types (ESRI 2018a)

One of the crucial tools for habitat suitability analysis is Overlay analysis, which refers to a group of methodologies in the Spatial Analysis Tools. Overlay analysis is used in the optimal cite selection as well as habitat suitability modelling (ESRI 2018b). As it can be seen in *Figure 13*, values of a common scale are integrated into one raster depending on their value and importance. Multicriteria analysis that involves classification of different factors, like prey density, surface analysis and human disturbance, requires the use of another feature – Reclass, to ensure that value scales are the same.

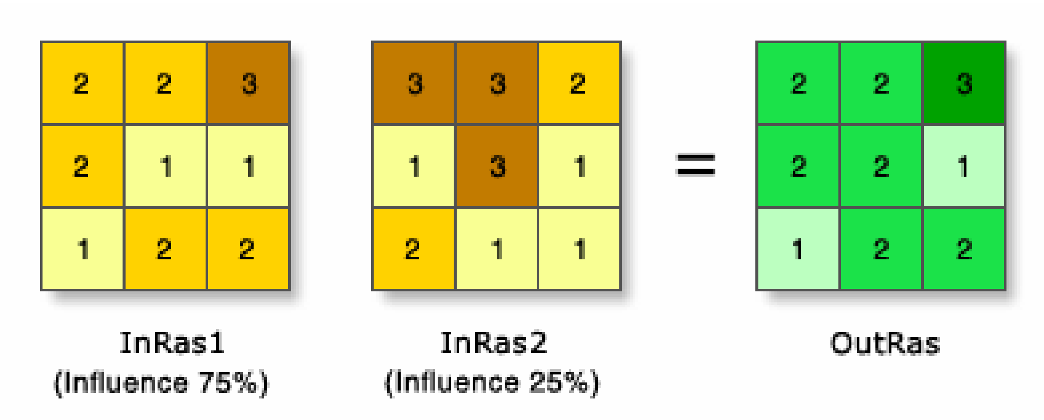


Figure 13 Weighted Overlay (ESRI 2018b)

Some parameters in the model were classified to have a greater impact on the overall habitat suitability. For instance, tiger's prey density is the most important factor in the presence of felids in the selected territories and Weighted Overlay function allows to set a greater percentage influence of this factor. Weighted Overlay method gives an advantage, since all values and all layers have their relative importance.

3.4 Problems and limitations of the research

The main problem during the research arises from the lack of open-source data. To make valuable comparisons, data on case study states should be derived from the same data source or have the same format. Additionally, data on the exact tiger range is not accessible due to long history of poaching. The data on exact number of tiger prey (wild boar, Bukhara deer, and roe deer) is not available either. Tiger prey will be modelled based on expert knowledge with a provision of a rough approximation of the number and location of tiger prey.

Tiger poaching and retaliatory killing are not included in the research since the territories analyzed are national parks and nature reserves protected under IUCN and guarded by security forces. Data on illegal actions is out of the scope of the research.

The present thesis does not take into account the climate change scenario. Yet, with climate- and environment-related change, trends like biodiversity loss and wildfires can significantly impact the habitat of the Amur tiger and their prey, considerably disrupting the conservation efforts of the respective countries.

Visa-related problems prevented me from doing field research in China. Initially, I was planning to attend a conference and present a poster with maps of the Northeast Tiger and Leopard National Park and meet with researchers from the Tiger-Leopard Observation Network.

Another problem appeared during the research: some scholars were not willing to meet or ignored my inquiries. I got important contacts from vice-president of Kazakhstan National Geographic Society, but did not arrange meetings due to a shortage of time and unwillingness of scholars to meet.

4. Habitat suitability analysis

4.1 Case study area description

Russia: Sikhote-Alin Nature Reserve

The current thesis focuses on population of Amur tigers in the Sikhote-Alin nature reserve. The map in *Figure 14* shows the territory of Sikhote-Alin and the Northeast Tiger and Leopard National Park. Shapefile with borders of Sikhote-Alin was downloaded from the Protected Planet website (Protected Planet 2018). The shapefile represents Sikhote-Alin UNESCO Biosphere Reserve borders, which includes the territory of Sikhote-Alin *zapovednik*.

The reported area of the park is approximately 4,014 km^2 (401,428 ha) with 626 km^2 (62,550 ha) buffer zone (Williams 2018). Established in 1935 in the northeastern part of Primorsky Krai, the nature reserve is located in the watershed of Central Sikhote-Alin's eastern slopes on the Sea of Japan's coast. Steep mountains are covered with rocks, while more shallow slopes are covered by evergreen forests.

Created in 1935 to protect a population of the sable, currently, the nature reserve protects endangered Amur tigers. Compared to the initial territory, the area of the nature reserve was reduced by the Soviet authorities six-fold in 1951, which has led to weaker protection of Amur tigers. In general, conservationists call to enlarging the territory of the reserve two-fold including the Dzhigitovka River valley south of the reserve (Williams 2018).

The most common evergreen trees are Korean pine (*Pinus koraiensis*), mountain pine, Yeddo spruce (*Picea ajanensis*), and Khingam fir (*Abies nephrolepis*), altogether they comprise coniferous forest (Center for Russian Nature Conservation 2018).

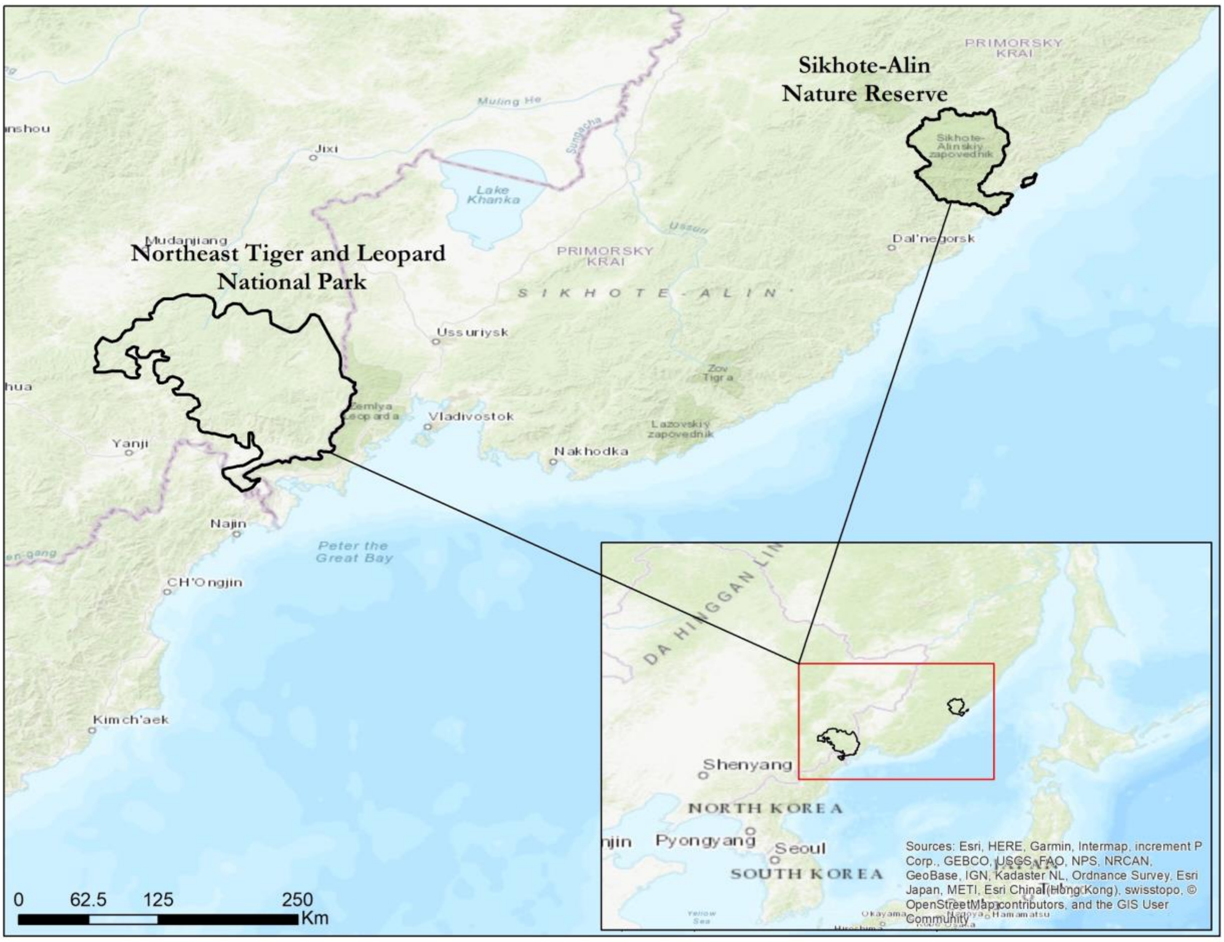


Figure 14 Sikhote-Alin Nature Reserve (Russia) and Northeast Tiger Leopard National Park (China)

Located in the Eastern Asian temperate zone, its territory is almost fully (99%) comprised of forests. Starting from the sea level, vegetation 'belts' can be clearly distinguished with the rise in altitude. Seaside oak forests are replaced by mixed broadleaf and pine forests higher up, that are higher replaced by fir-spruce vegetation. Mountain tops are covered by mountain pine (*Pinus pumila*) and alpine tundra vegetation. The forests of Siberian pine (*Pinus sibirica*) and broadleaf forests are endemic to the region (Williams 2018).

China: The Northeast Tiger and Leopard National Park

Under Xi Jinping's "Ecological Civilization" auspices, China has pledged to protect endangered Amur tiger and Amur leopard creating The Northeast Tiger and Leopard National Park in Jilin and Heilongjiang Provinces in Northeast China (Standaert 2018). On the map above

(*Figure 14*), we can see that the national park will neighbor North Korea to the south and Russian Far East to the northeast. The planned territory will be around 14,600 km^2, which is 60% larger than Yellowstone National Park.

The territory of the national park was delineated by Limin Feng from the Tiger-Leopard Observation Network. Due to the absence of the open-access shape file, the territory of the park has been digitized from map using Georeferencing toolbar in ArcGIS with the projection of the data frame GCS_WGS_1984. The result can be seen on Figure 14. The final boundaries of the park will be approved by year 2020.

In Northeast China, the main topographic features include high and steep mountainous areas, low mountains and flat gradient areas (Xiaofeng *et al.* 2011). Vegetation includes coniferous forest, broad-leaved mixed forest, secondary forest, woodland shrub and marshy grass areas, and contains more than 2500 plant species (Xiaofeng *et al.* 2011). In general, the area is a cold and sparsely populated industrial area of China. The humid forest is sustained due to its temperate continental monsoon climate.

Kazakhstan: Ile-Balkhash Nature Reserve

Kazakhstan is aspiring to become the first country that has successfully reintroduced tigers who went extinct in the wild over half of a century ago. In September 2017, the Memorandum on the implementation of the tiger reintroduction program in Kazakhstan was signed between the Ministry of Agriculture of Kazakhstan and WWF Russia (WWF Russia 2018a). The program will contribute to the aforementioned Tx2 global initiative to double the population of tigers in the wild by year 2020. However, to start tiger reintroduction initiative, a designated national park was needed. On 27th of June 2018, Ile-Balkhash Nature Reserve was created by the Decree #381 of the Government of the Republic of Kazakhstan. The territory of the park is 415,000 hectares.

There are no open-source shape files of the nature reserve. Boundaries of the park were delineated using Georeferencing toolbar based on maps from Kazakhstan National Geographic Society (*Figure 15*). The Amur tiger will be brought on the territory of the park as the closest relative of the already extinct Caspian tiger.

Figure 15 Ile-Balkhash Nature Reserve

The territory includes the Ile river delta covered with floodplain and saxaul forests and wetlands on the south-eastern coast of the Lake Balkhash (WWF Russia 2018a). The whole ecosystem will be revived to create a suitable habitat for tiger. The reintroduction program will also include the restoration and conservation of ungulates population (kulan, tugai deer) to ensure prey for tigers. Overall, the initiative will help to restore the local ecosystem and protect Lake Balkhash from drying out.

4.2 Amur tiger habitat requirements

Table 3 specifies Amur tiger habitat requirements in Russia and China with the necessary sources and links for the GIS layers. The data is based on information presented by Xiaofeng *et al.* (2011) and expert knowledge. Secondary data and expert knowledge helped to add more factors to model the habitat suitable for Amur tigers. Complete data from *Table 3* will be classified for the further analysis.

Table 3 Amur tiger: habitat suitability factors

Factor	**Characteristics**	**Data**
Vegetation suitability	Deciduous broad-leaved forest, temperate deciduous broad-leaved forest	https://lpdaac.usgs.gov http://due.esrin.esa.int/page_globcover.php
Prey density (number/km^2)	3-9	Expert knowledge
Elevation (m)	400-800, 800-1100	https://gdex.cr.usgs.gov/gdex
Slope (°)	15-30	https://gdex.cr.usgs.gov/gdex
Aspect	Southerly exposures	https://gdex.cr.usgs.gov/gdex
Population density (person/km^2)	0-15, 15-99	http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-density
Distance from main road (m)	> 1000	http://www.diva-gis.org/gdata
Deforestation	No deforestation	https://www.globalforestwatch.org/map
Habitat fragmentation	No fragmentation	https://databasin.org/datasets/f88b2b0d922642e689864cbd3409c177
Agricultural development	No croplands	http://sedac.ciesin.columbia.edu/data/set/aglands-croplands-2000/data-download
PAs	Already existing PAs	https://www.protectedplanet.net

Based on *Table 3*, future habitat suitability analysis is going to be performed. All values are going to be grouped into three categories of habitat suitability, ranging from the most to the least suitable area. Russia and China are evaluated together, because national parks are topographically more similar and are in close geographic proximity. The Northeast Tiger and Leopard Nature Reserve and Sikhote-Alin are connected by ecological corridors and share the same population of wild tigers moving back and forth searching for food and territory. *Table 3* was supplemented by the data from secondary sources and the interview and reclassified to perform habitat suitability analysis. The results can be seen in Table 4.

Table 4 Environmental variables used in the model for the Amur tiger

#	Factors	Rating*		
		1	**2**	**3**
1	Vegetation suitability	Closed broadleaved deciduous forest, Open needle leaved deciduous or evergreen forest, Closed to open mixed broadleaved and needle leaved forest	Mosaic forest or shrubland/grassland, Mosaic grassland /forest or shrubland, Sparse vegetation	Artificial surfaces and associated areas, Bare areas, Water bodies
2	Prey density (number/km2)	3.0-10.0	1.5-2.9	0-1.49
3	Elevation	400-1100	0-400	>1100
4	Deforestation	No deforestation	-	-
5	Population density (person/km2)	0-99	100-199	>200
6	Distance from main roads (m)	>1000	500-1000	0-500
7	Agricultural development (%)	0-25.0	25.1-50.0	50.1-100
8	Protected areas	Inside the reserve	-	-

Rating*:
1 – Most suitable elevation, vegetation type, low altitude, low population density and far away from roads, no agricultural development
2 – Relatively suitable elevation, vegetation type, medium population density, distance to roads, and relatively low altitude
3 – Least suitable elevation, vegetation type, high population and close to the road, high altitude, croplands

The data on habitat suitability factors in Kazakhstan should be analyzed separately. Despite the fact that Amur tigers will be brought to Ile-Balkhash, they will adapt to the local vegetation and topography, which differs from the Russian Far East and Northeast China. In the same manner as during the analysis of the habitat suitability for the Amur tiger, data is classified into three similar classes from the most to the least suitable areas. The result of the classification can be seen in *Table 5*.

Table 5 Environmental variables used in the model for the Caspian tiger

#	Factors	Rating*		
		1	2	3
1	Vegetation suitability	Mosaic forest or shrubland/grassland; mosaic grassland/ forest or shrubland; open needleleaved deciduous or evergreen forest; closed to open mixed broadleaved/ needleleaved forest	Closed to open herbaceous vegetation, sparse vegetation	Post-flooding or irrigated croplands; rainfed croplands; mosaic cropland; mosaic vegetation/cropland; waterlogged soil; artificial surfaces; bare areas; water bodies; permanent snow and ice
2	Prey density (number/km2)	3.0-10.0	1.5-2.9	0-1.49
3	Elevation (m)	0-500	-	>500
4	Deforestation	No deforestation	-	-
5	Population density (person/km2)	0-99	100-199	>200
6	Distance from main roads (m)	>1000	500-1000	0-500
7	Agricultural development (%)	0-25.0	25.1-50.0	50.1-100
8	Protected areas	Inside	-	-

4.3 Data processing

The data used in the thesis includes GIS vector and raster maps, remotely sensed images, secondary data, and knowledge of tiger experts. *Table 7* summarizes all preliminary results of the geospatial analysis and remotely sensed data.

Data on the global land cover is taken from the European Space Agency. Data on the land cover was produced for year 2009 and it was developed using input observation from the 300m MERIS sensor on the ENVISAT satellite mission (ESA 2010). The preview of the Global Land Cover map is presented in *Figure 16*. The land cover data of the territories of the selected national parks was extracted using Extract by Mask tool in the Extraction toolset, and then reclassified through the Reclassify function in Reclass toolset (*Figure 17*).

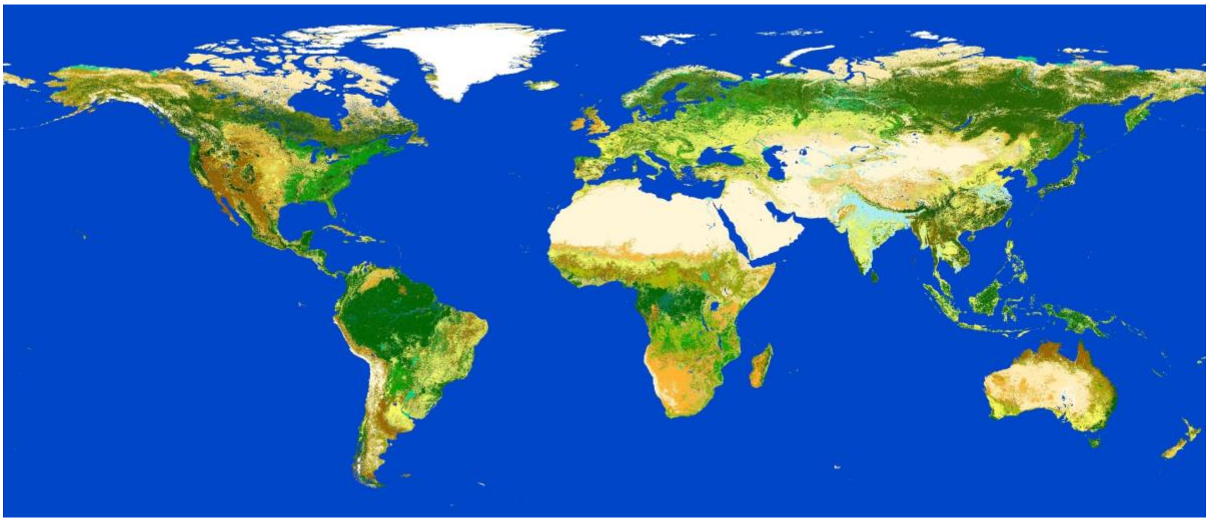


Figure 16 Global Land Cover Map

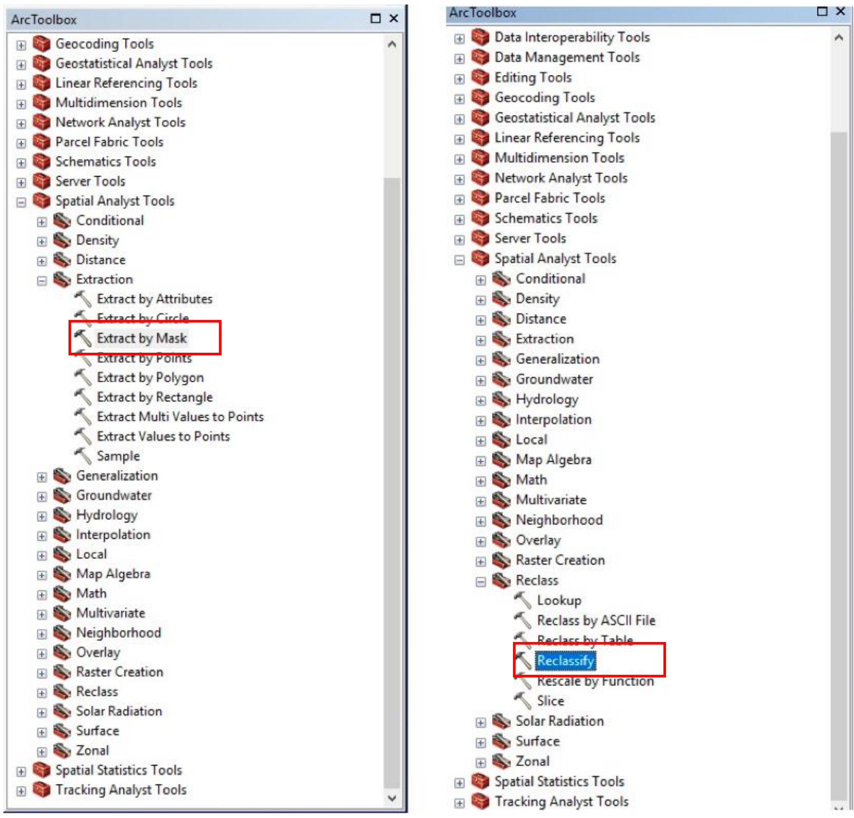


Figure 17 Data processing steps

The prey distribution and abundance have direct effect on the presence of Amur tigers. The primary prey species are wild boar, roe deer, red deer, sika deer and spotted deer (Xiaofeng *et al.* 2011). Food habits of the Amur tiger and their prey selection was studied based on kill sites, and for the sake of research, it was assumed that tigers prefer species of their own size (Yang, Dou, *et* *al.* 2018). Thus, small animals were excluded from the model. To track prey preferences and estimate prey number, some researchers (Yang, Dou, *et al.* 2018) have collected tiger scats, while other researchers have analyzed data from camera traps (Xiaofeng *et al.* 2011; Yang, Zhao, *et al.* 2018).

Xiaofeng *et al.* (2011) modelled prey density in the Northeast China according to the suitability level of vegetation types to prey animals developed earlier by Guo *et al.* (2008). Thus, prey density was modelled based on the assumption that the relative ratio of prey density in shrub, broadleaf forest, meadow, and cropland/water is 10:8:5:0. To include this data into the current thesis' model, the land cover data is classified in the following way:

Table 6 Prey density

Ratios	**10**	**8**	**5**	**0**
Sikote-Alin	Mosaic forest or shrubland/grassland; mosaic grassland/ forest or shrubland	Closed broadleaved deciduous forest; open needleleaved deciduous or evergreen forest; closed to open mixed broadleaved/ needleleaved forest	Sparse vegetation	Bare areas, water bodies
NTLNP	Mosaic forest or shrubland/grassland; mosaic grassland/ forest or shrubland	Closed broadleaved deciduous forest; open needleleaved deciduous or evergreen forest; closed to open mixed broadleaved/ needleleaved forest	Sparse vegetation	Artificial surfaces (urban), bare areas, water bodies
IB	Mosaic forest or shrubland/grassland; mosaic grassland/ forest or shrubland	Open needleleaved deciduous or evergreen forest; closed to open mixed broadleaved/ needleleaved forest	Closed to open herbaceous vegetation, sparse vegetation	Post-flooding or irrigated croplands; rainfed croplands; mosaic cropland; mosaic vegetation/cropland; waterlogged soil; artificial surfaces; bare areas; water bodies; permanent snow and ice

Data on the global elevation is taken from Global Data Explorer by the US Geological Survey (U.S. Geological Survey 2016). The ASTER Global Digital Elevation Model (ASTGTM) was developed by the US National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI). The ASTER GDEM is presented as

Geographic Tagged Image File Format (GeoTIFF) on a 1 arc-second grid (*Figure 18*). On the equator the accuracy is up to 30m, which makes data too large to download as one file.

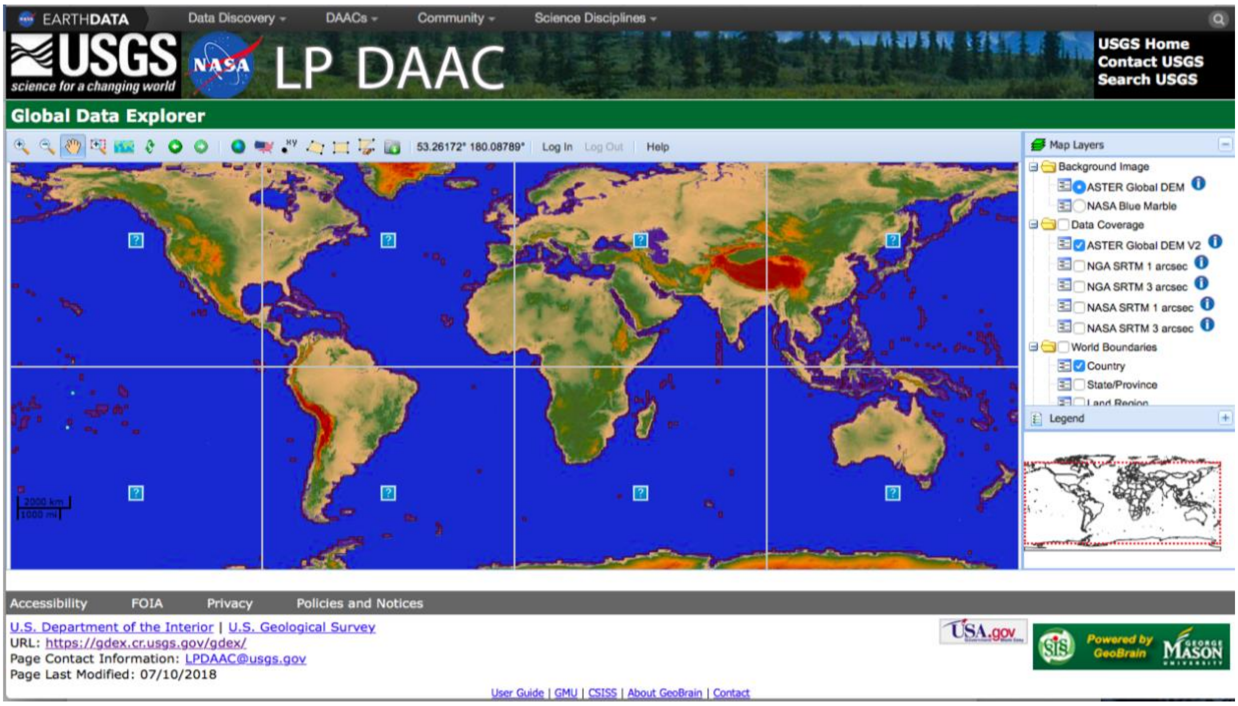


Figure 18 Data on Elevation from Global Data Explorer

Several GeoTIFF files of each national park were downloaded and combined into one layer. Initially, I wanted to combine raster files using Raster Calculator tool in the Map Algebra toolset. However, merging raster layers in the Raster Calculator has failed several times, so I have used Data Management Tools, specifically, Mosaic to New Raster tool in the Raster toolset (*Figure 19*). Then, the data was processed as in the *Figure 17*.

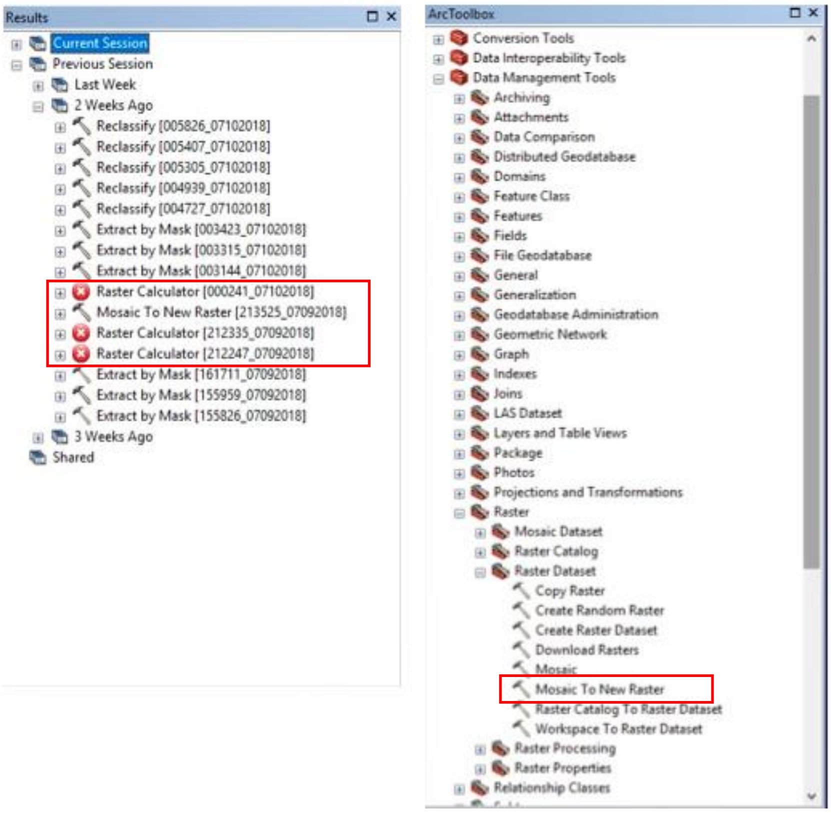


Figure 19 Manipulations with Terra ASTER

Data on the population density plays an important role in the habitat suitability for tigers, since human population density has proven to be inversely related to the presence of felids in the wild (Yang, Zhao, *et al.* 2018). The data on human population density is taken from the Global Population Density Gird v1 (1970-2000) from NASA Socioeconomic Data and Applications Center (SEDAC) shown in *Figure 20*. The resolution of this raster dataset is of 30 arc-seconds. Population density grid per square kilometer is the result of the division of the population in each grid cell by the area (in square kilometers) of each grid cell (CIESIN 2017). Data processing steps as in *Figure 17* were taken to model suitable human population density.

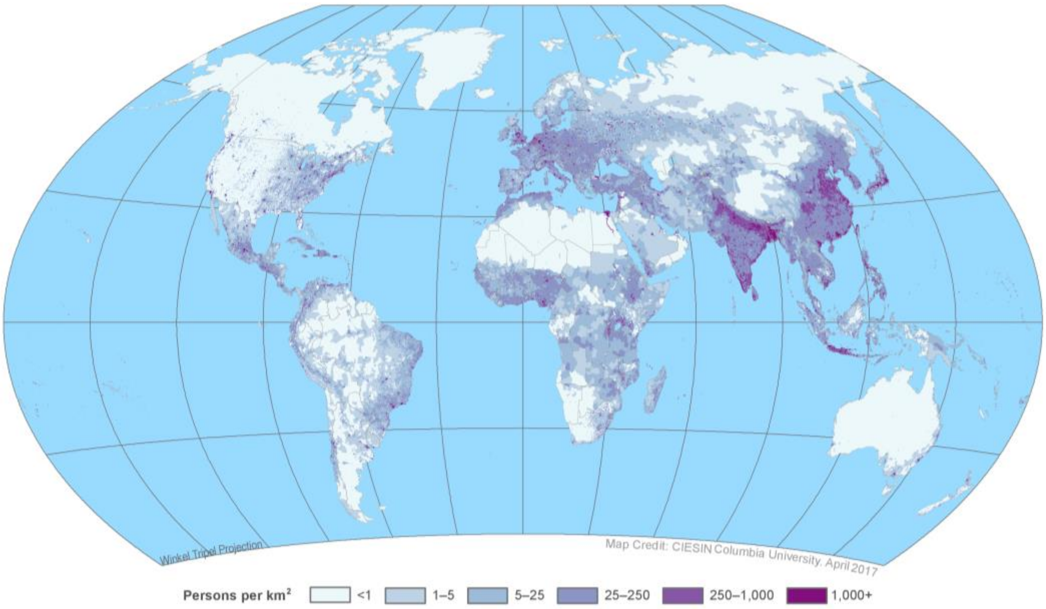


Figure 20 Global Population Density Grid Time Series Estimates, 2000

Another negative effect of human presence on the tiger's population would be shown in the proximity to major roads and the agricultural development. Major roads divide the initial habitat of large mammals like that of tigers. Moreover, the mere existence of roads gives poachers the opportunity to access tigers and their wild prey (Kerley *et al.* 2002). Within the close radius, poaching is higher, and no tiger cubs are born due to the human disturbance. The vector dataset on the roads as ESRI shapefile is downloaded from DIVA-GIS website, which is coming from the Digital Chart of the World. A 1-km buffer zone is created around the major roads since at this distance detrimental effects of human disturbance are tolerable.

Another pressing factor negatively affecting the Amur tiger's habitat is deforestation. Continuous logging and land conversion across the whole tiger population range has created patches of primary forest, secondary forest, and human disturbance areas that have pushed the tiger range countries towards creation of new protected areas (Smith *et al.* 2018). However, other than assigning special status to designated areas, sufficient control over the territories of the protected areas is needed. For instance, illegal logging in the Russian Far East destroys the Amur tiger's primary habitat (World Wildlife Fund 2018).

The data on deforestation within each national park is taken from the Department of Geographical Sciences of the University of Maryland. Global forest loss was mapped with the use of Landsat 8 OLI data and presents changes from 2000 to 2017 (Hansen *et al.* 2013). In the results (*Table 7*), we can see that deforestation within the last 17 years has not been that high. However, if we take a look at the whole region of China's Northeast, and especially, Russia's Far East, we see that a significant amount of primary forest was lost (*Figure 21*).

To analyze the data, 10x10 degree granules for China (50N 120 E), Russia (50N 130E), and Kazakhstan (50N 70E) were combined with the use of Mosaic to New Raster function and reclassified for subsequent use. Red dots in *Figure 21* indicate deforestation from 2000 to 2017.

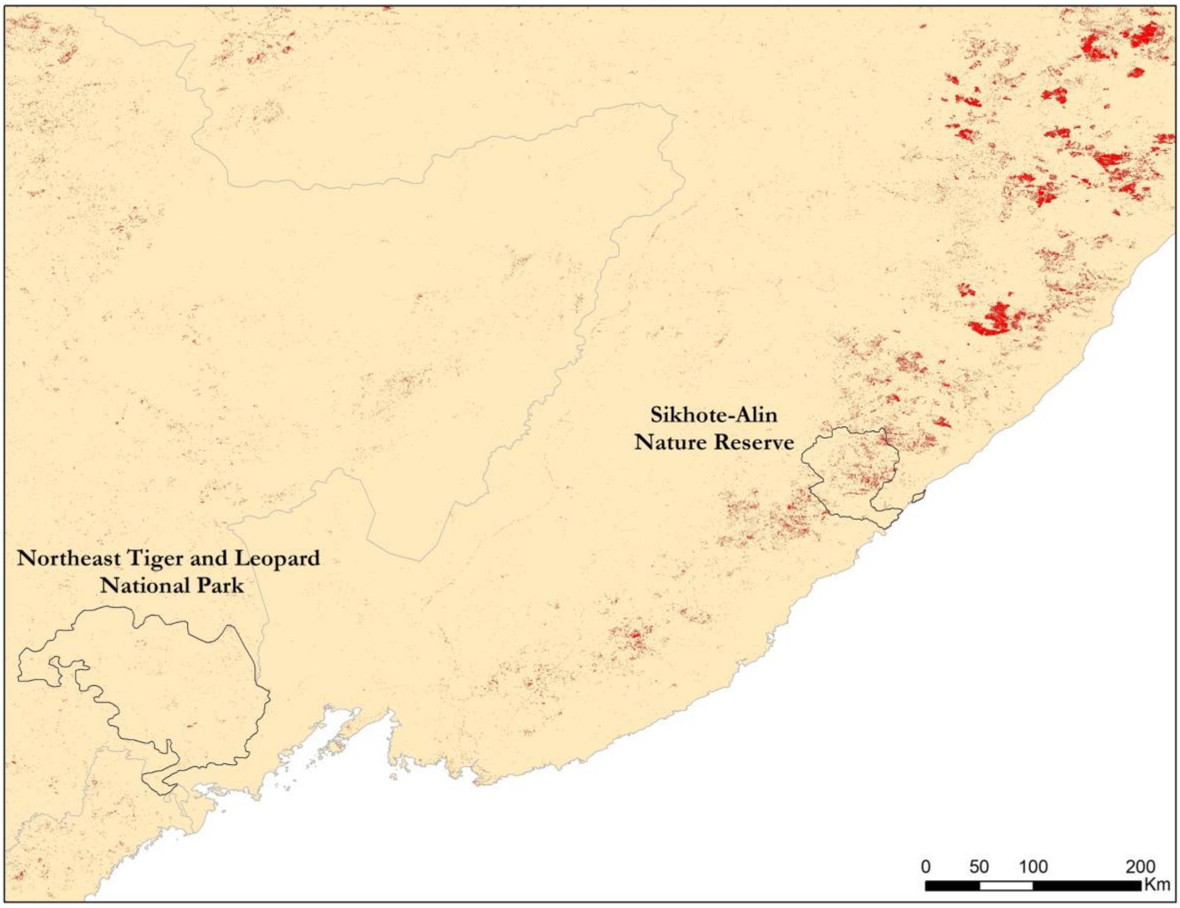


Figure 21 Deforestation in Russia and China from 2000 to 2017

Apart from deforestation, conversion of habitat to croplands to meet agricultural needs degrades the habitat for carnivores and their wild prey. Agricultural areas along with residential regions are one of the least suitable habitats for the Amur tiger (Xiaofeng *et al.* 2011). Data from the Earth Stat provides a global dataset of croplands circa 2000. It is presented as five-arc minute grid cells in GeoTIFF that combine data from MODIS and SPOT satellites. According to the dataset, 15 million km^2 (around 12% of the Earth's ice-free surface) covered by croplands, see *Figure 22* (Ramankutty *et al.* 2008).

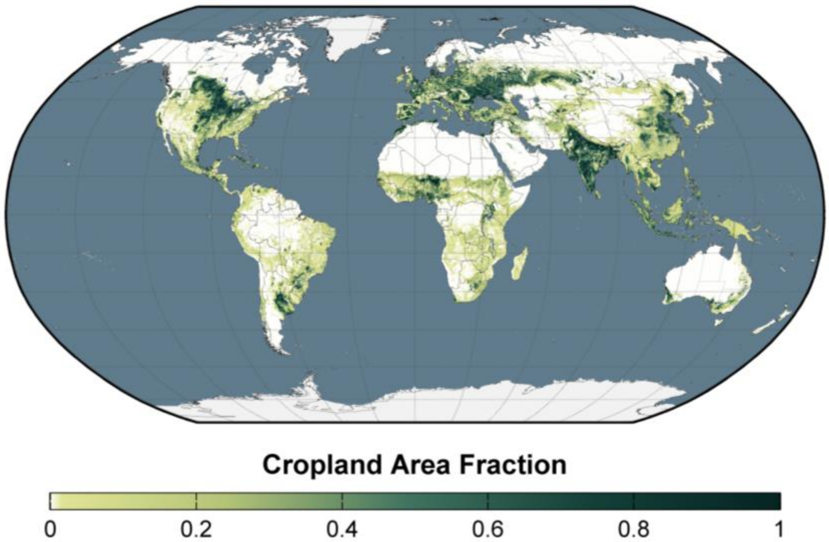


Figure 22 Cropland Area in the Year 2000

The last but not least significant factor in the current habitat suitability model is the presence of the already existing protected areas on the territory of the newly created national parks. Carroll *et al.* (2006) suggest that the presence of the protected areas within the tiger range only marginally increases tiger viability. However, in the long-term perspective, the population model suggests that low human presence on the territories of protected areas and the continuity of the habitat dramatically increases the tiger population and distribution. Therefore, already existing and planned protected areas play an important factor in tiger conservation initiatives.

The World Database on Protected Areas (WDPA) has helped to map terrestrial protected areas. In the final habitat suitability map, only the territory of the national park is analyzed. However, a quick glimpse at the Sino-Russian border and Kazakhstan would help to make more informed decisions.

In *Figure 23*, we can see that Russia has a well-developed network of protected areas all over the Russian Far East. However, the proposed Northeast Tiger and Leopard National Park seems to be isolated from current protected areas on Chinese territory. Therefore, the success of the NTLNP will be determined by the level of cooperation with Russian protected areas. The research on Amur leopards and transboundary cooperation between China and Russia by Vitkalova *et al.* (2018) suggests that sharing data on species population helps to make more precise calculations on the number of species in the wild. As a result, appropriate conservation schemes can be applied. Continuous monitoring and synchronization of the data allowed to estimate transboundary movement of Amur leopards and has highlighted the need to protect habitat continuity despite the presence of the international border (Vitkalova *et al.* 2018). Yet, connectivity and ecological corridors to the Sikhote-Alin mountain range should be secured both for tigers and leopards.

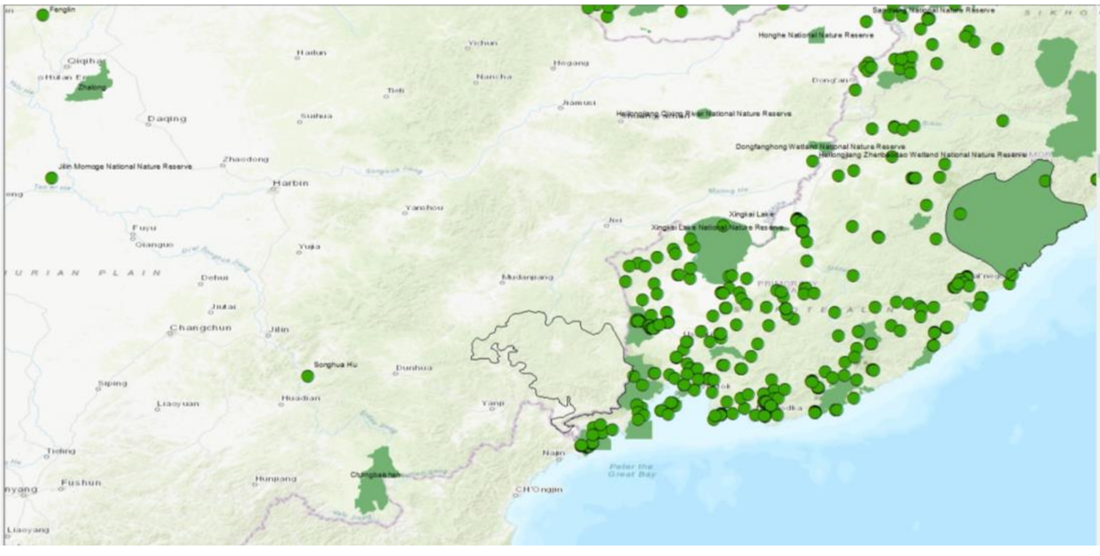


Figure 23 Protected Areas in Russia and China (polygons and dots represent PAs)

In the case of the newly established Ile-Balkhash Nature Reserve in Kazakhstan, we can observe that IB is created in the territory of the already existing Karoiskiy reserve (*Figure 24*). Moreover, as Dr. Sklyarenko from Kazakhstan Geographic Society has mentioned during the interview, the already existing Karoiskiy and Pribalkhashskiy sanctuaries create favorable conditions towards the establishment of the new national park. Moreover, the population of Bukhara deer and roe deer from Altun Emel national park could be connected to IB though ecological corridors to ensure wild prey for tigers.

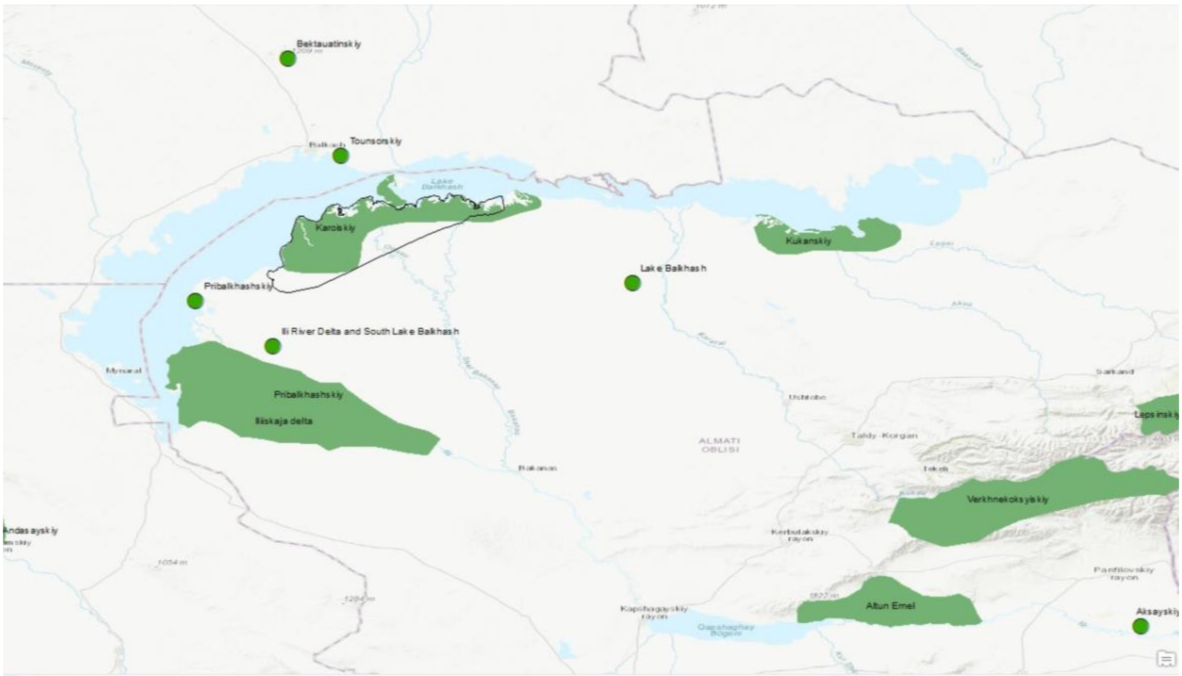
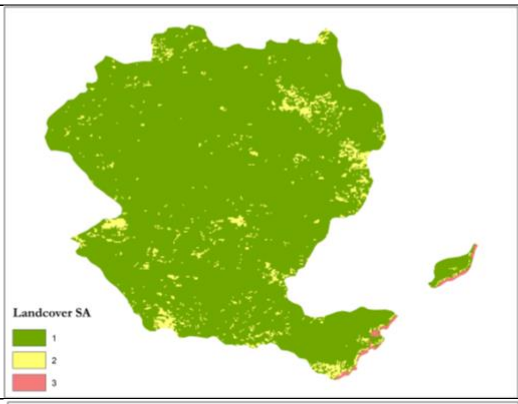
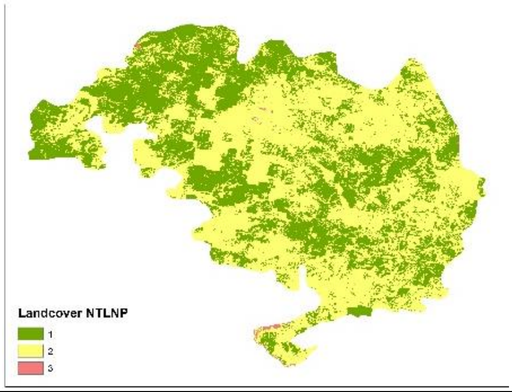
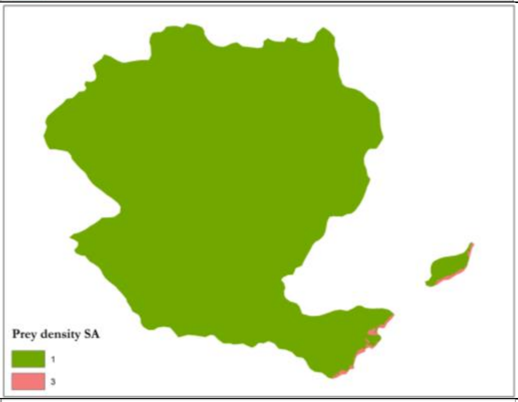
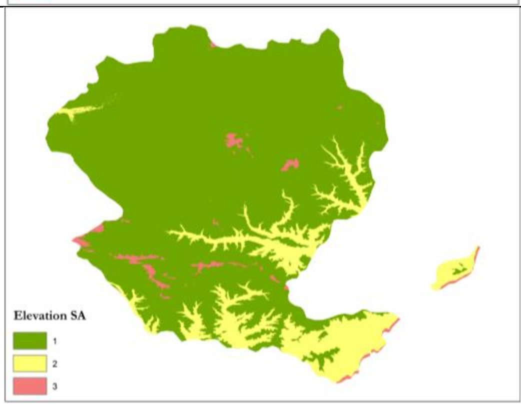
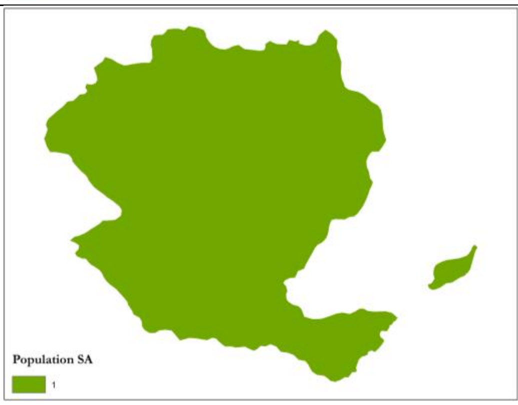
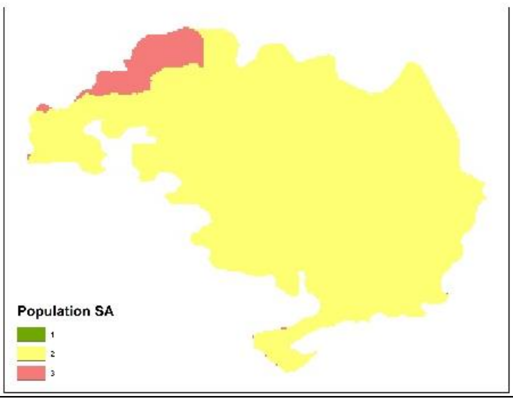


Figure 24 Protected Areas in Kazakhstan (polygons and dots represent PAs)

4.4 Preliminary results

Table 7 provides preliminary maps on vegetation suitability, prey density, elevation, population density, major roads, deforestation, croplands, and protected areas on the territories of the Sikhote-Alin Nature Reserve in Russia and the Northeast Tiger and Leopard National park in China. These maps will be merged later to provide a full picture of the suitable habitat for the Amur tiger.

Table 7 Amur tiger: Results

	Sikhote-Alin Nature Reserve	Northeast Tiger Leopard National Park
1. Landcover		
2. Prey density		
3. Elevation		
4. Population density		

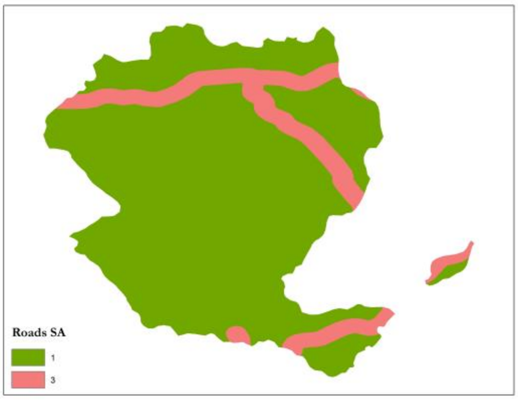
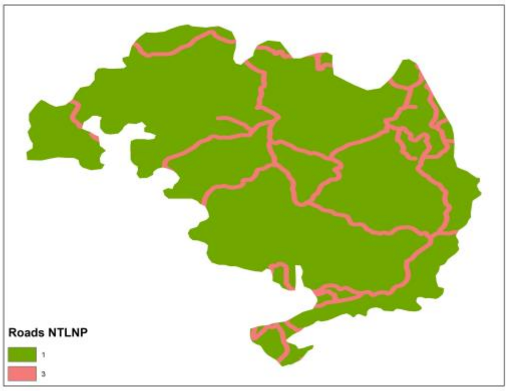
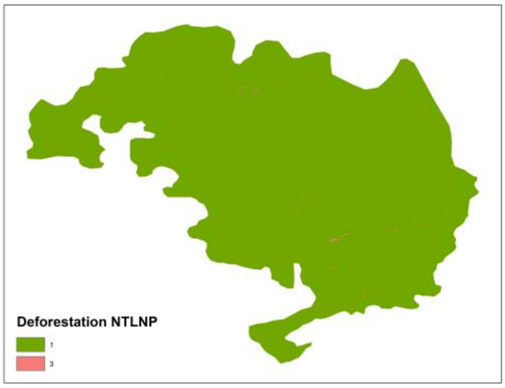
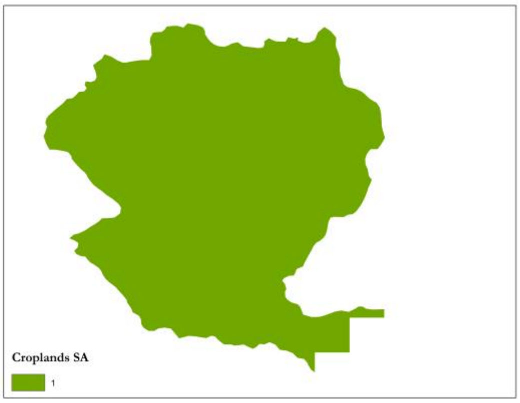
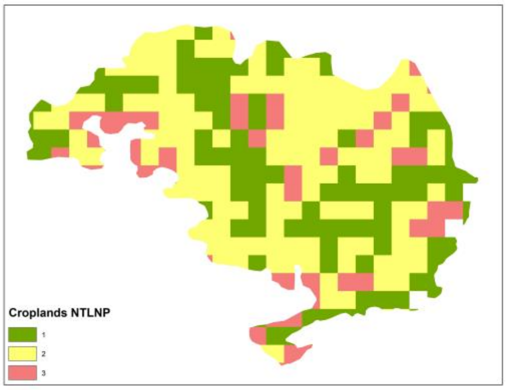
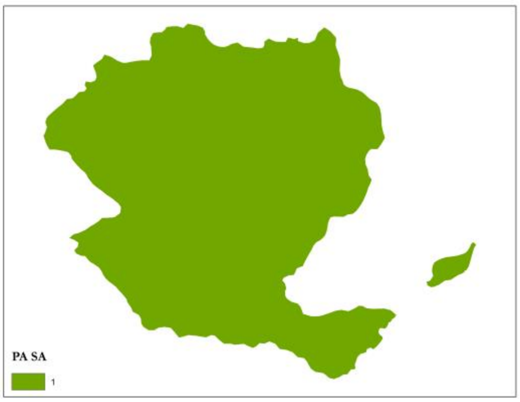
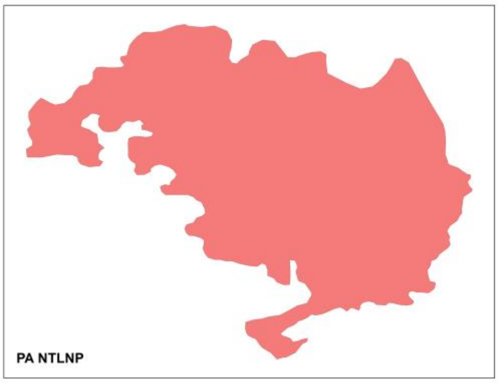
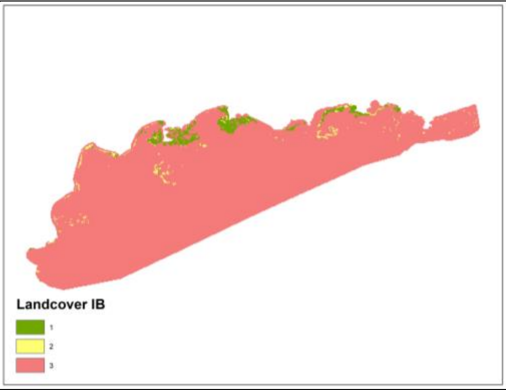
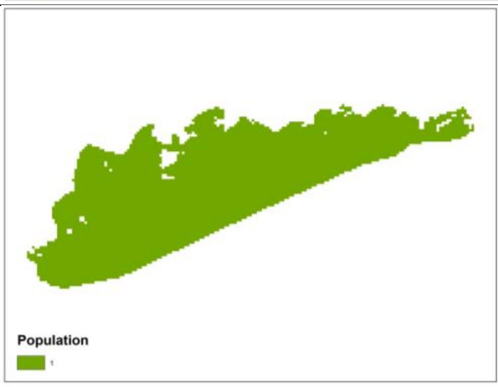
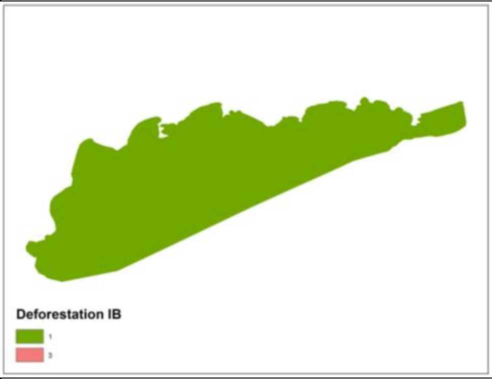
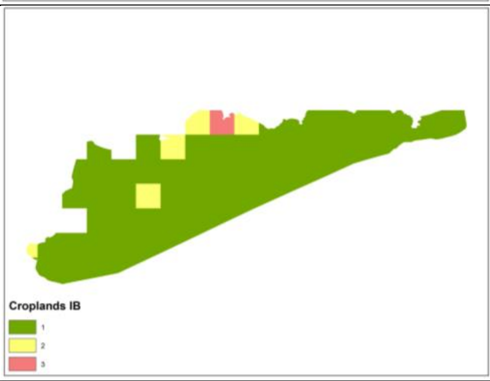
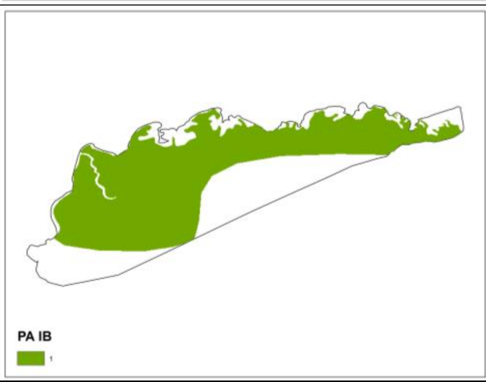
<table>
<tr><td>5. Major roads</td><td>
</td><td>
</td></tr>
<tr><td>6. Deforestation</td><td>
</td><td>
</td></tr>
<tr><td>7. Croplands</td><td>
</td><td>
</td></tr>
<tr><td>8. PAs</td><td>
</td><td>
</td></tr>
</table>

Table 8 provides preliminary maps on the same habitat suitability factors as *Table 7* only for the Caspian tiger on the territory of the Ile-Balkhash Nature Reserve in Kazakhstan.

Table 8 Caspian tiger: Results

<table>
<tr><td></td><td>Ile-Balkhash Nature Reserve</td></tr>
<tr><td>1. Land cover</td><td>
</td></tr>
<tr><td>2. Prey density</td><td>
</td></tr>
<tr><td>3. Elevation</td><td>
</td></tr>
<tr><td>4. Population density</td><td>
</td></tr>
</table>

5. Major roads	
6. Deforestation	
7. Croplands	
8. PAs	

To produce the final habitat suitability map for each national park merging of all preliminary maps is required. The current model has 8 layers; however, in the final habitat suitability analysis seven factors will be used. The presence of the already existing protected areas (PAs) had positive/negative effects on newly created nature reserves in Kazakhstan and China, respectively. However, it the case of Russia, this variable does not affect the final map, since Sikhote-Alin Nature Reserve was established in 1935.

ArcGIS allows to perform suitability analysis or optimal site selection with the use of the overlay analysis. ESRI defines overlay as a "technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis" (ESRI 2018c). To perform meaningful analysis, inputs in the overlay function should have the same value scale. For that reason, habitat factors were reclassified and ranked earlier according to suitability levels (*Table 4* and *Table 5*). Weighted Overlay function of the Overlay toolset allows to set different 'weight' to each parameter according to its importance

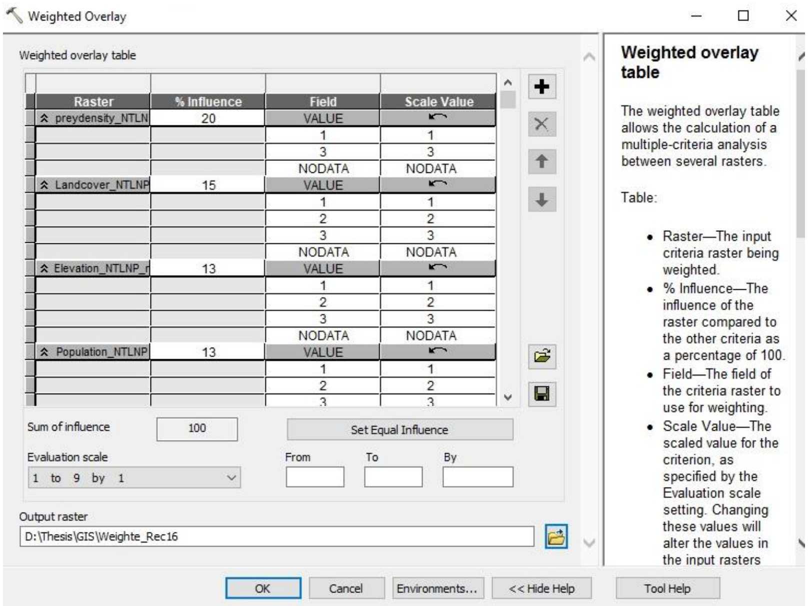


Figure 25 Weighted Overlay function

Figure 25 shows that raster files have different values in "% Influence" graph. Prey density has the greatest effect on tiger presence; therefore, the value assigned for this parameter is 0.2. The second most important factor is landcover, because it ensures presence of tiger prey on the designated territory. The assigned value is 0.15. The rest of parameters have approximately equal effect and their assigned value is 0.13. The sum of the percent influence of all factors is 100. The result of the Weighted Overlay function showing habitat suitability levels within protected areas in Russia (*Figure 26*), China (*Figure 27*), and Kazakhstan (*Figure 28*) is presented below.

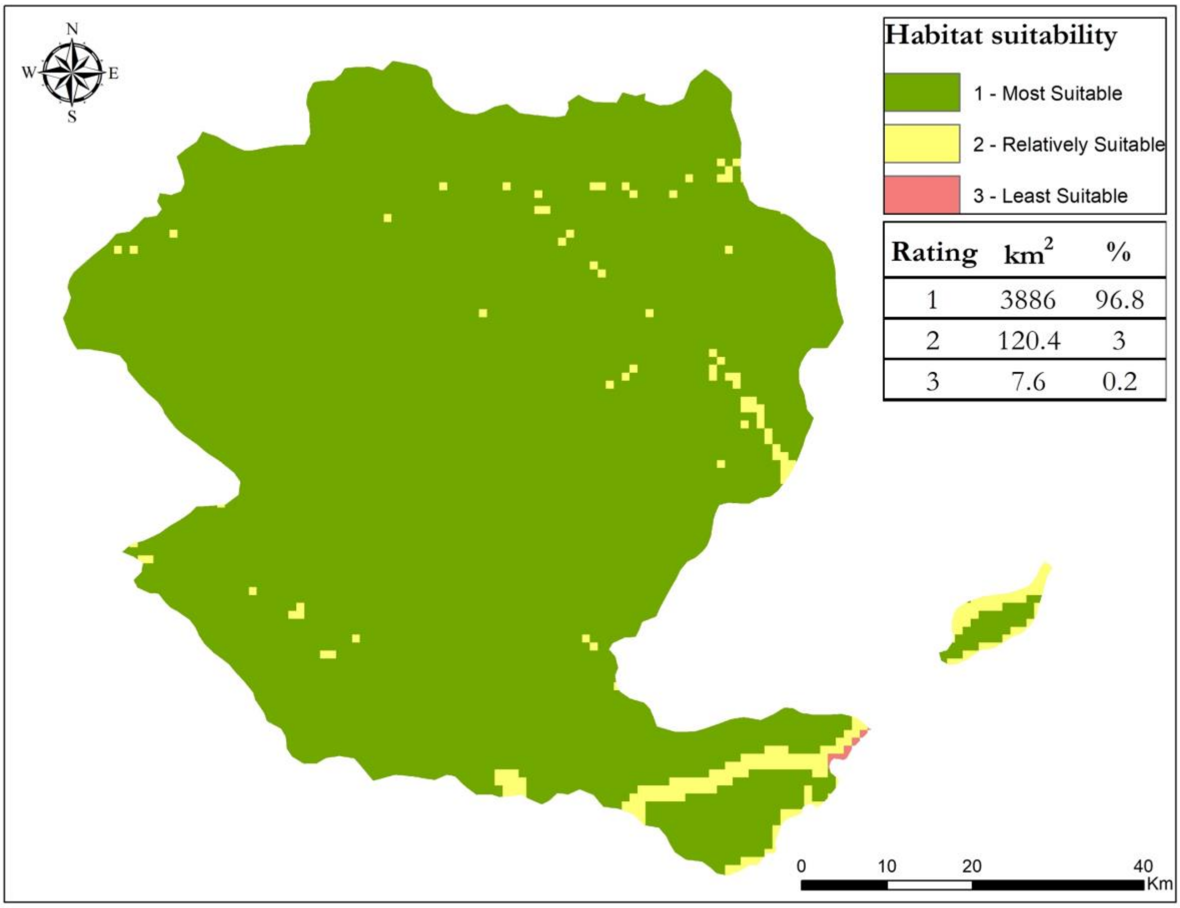


Figure 26 Habitat suitability for Amur tiger in the Sikhote-Alin Nature Reserve (Russia)

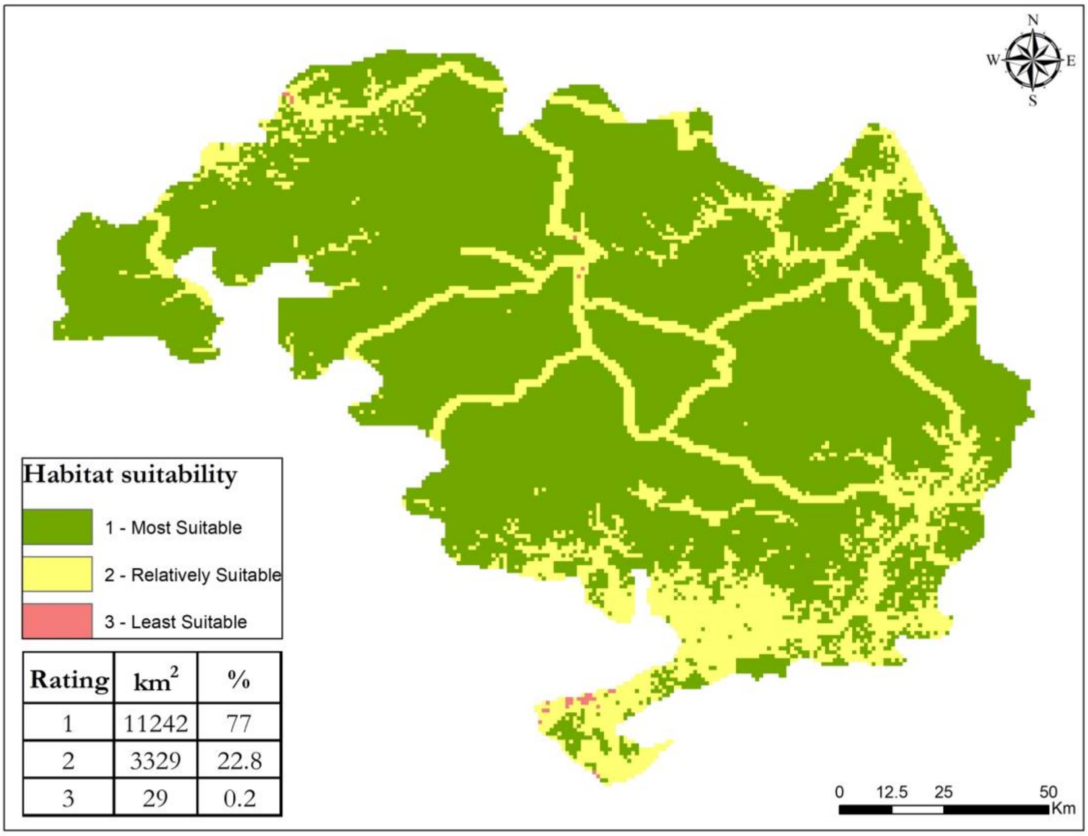


Figure 27 Habitat suitability for Amur tiger in the Northeast Tiger and Leopard National Park (China)

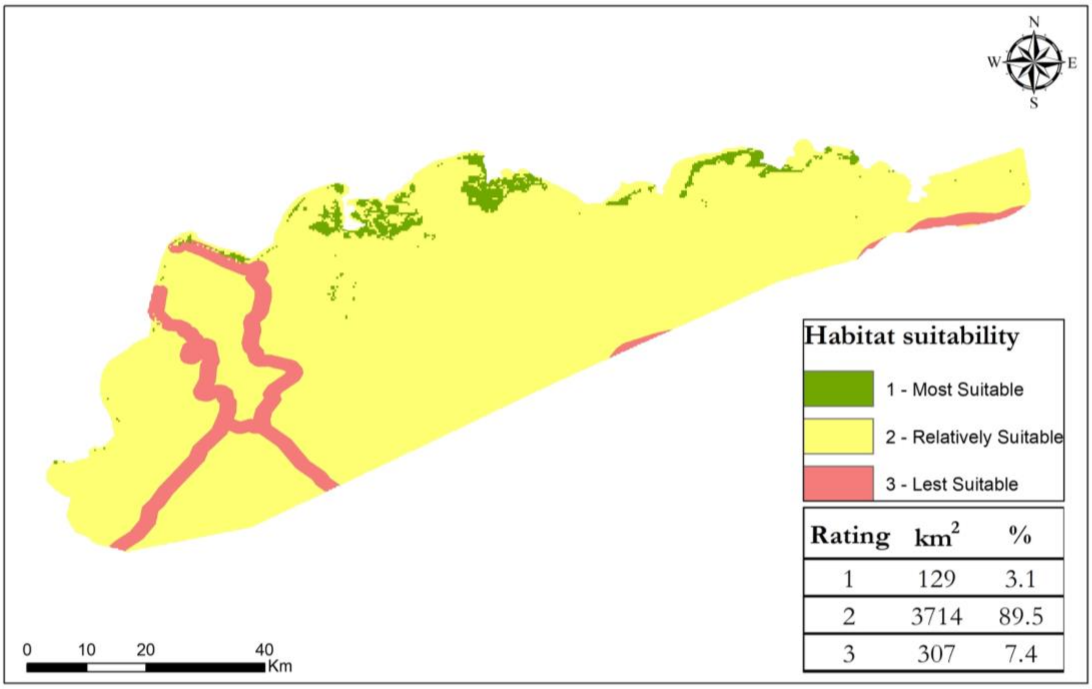


Figure 28 Habitat suitability for Caspian tiger in the Ile-Balkhash Nature Reserve (Kazakhstan)

For further analysis and subsequent policy-making the area and percentage of the suitable area for each nature reserve are presented in *Table 9*.

Table 9 Suitability level of habitats

	Rating	**km²**	**%**
SA	1	3886	96.8
	2	120.4	3
	3	7.6	0.2
	Total	4014 km²	
NTLNP	1	11242	77
	2	3329	22.8
	3	29	0.2
	Total	14600 km²	
IB	1	129	3.1
	2	3714	89.5
	3	307	7.4
	Total	4150 km²	

5 Prospects of Amur tiger recovery in China and Kazakhstan

The territory of the Sikhote-Alin Nature Reserve has the greatest amount of suitable territory (96.8%) and perfect conditions since it is a historical Amur tiger range. Ecological and topographic factors are the most suitable. More importantly, the Russian Far East is a sparsely populated region. Low human density and minimal human disturbance play an important role in the preservation of the primary habitat for felids, both Amur tigers and leopards. In general, the Sikhote-Alin mountain range contains around 90% of the total population of the Amur tiger.

It was noted by Xiaofeng *et al.* (2011) that the biggest success factor on the Russian territory is determined by the size of the nature reserve and large-scale protection. Single breeding female tiger with cubes require a territory of 400 km^2, while male tiger requires around 1200-2000 km^2. The conditions from the Sikhote-Alin National Park are regarded as the most suitable for Amur tigers because it is the only region where the population of tigers is increasing.

In the proposed Northeast Tiger and Leopard National Park, the most suitable territory for the Amur tiger takes around 77% of the park (Figure 27). Almost 23% of the territory is relatively suitable. Only minor 0.2% percent of the territory of the park is not suitable for the population of the Amur tiger. Based on the results, environmental factors are highly suitable for the recovery of the Amur tiger in China. Moreover, dispersal of the tiger population from the Russian Far East gives a good chance of tiger recovery in China (Hebblewhite *et al.* 2012). Tiger expert Miquelle estimates that the newly proposed park could provide enough habitat for a population of 75 Amur tigers (Standaert 2018), while the Russian Far East in general sustains a population 480 to 540 of adult tigers.

However, it is important to pay attention to the points 4 and 7 in *Table 7*, which represent population density and croplands respectively. High population density negatively affects the tiger population. To prevent human-tiger conflict the Chinese government is planning to relocate residents out of the national park. Standaert (2018) mentions that Chinese authorities are planning to relocate around 70,000-80,000 of locals either outside of the national park or into few settlements within the park to prevent future human-tiger conflict.

Another factor is a high presence of croplands within the boundaries of the nature reserve. Almost 66% of the planned nature reserve is covered by croplands with 'relatively suitable' and 'not suitable' types of soil (*Table 7*). Even after the stop of any agricultural activities, it will take some time for the soils to return to the initial state.

In general, one of the crucial factors ensuring the success of the initiative is the willingness of the Chinese government to invest time and money to properly manage the reserve and sponsor further research. Effective management scheme will help to regulate and eliminate possible human-tiger conflicts that might arise due to high population density. Continuous monitoring and adequate protection will help to prevent tiger capture and illegal poaching.

The last important factor is the creation and preservation of ecological corridors. Appropriate width, direction, and management of corridors will help to link tiger population in China to the Russian population. Continuous tiger landscape will increase the survival chances of the Amur tiger.

In the case of Kazakhstan, the situation is different. The 'most suitable' territory takes only 3% of the whole territory, while 'least suitable' territory takes 7% of the territory. Yet, almost 90% is 'relatively suitable'. This factor gives hope for the reintroduction of the Caspian tiger in the Ile-Balkhash Nature Reserve. Preliminary analysis of the habitat was performed by researchers from WWF Russia (Chestin *et al.* 2017). Yet, the result of my habitat analysis was inconsistent with the results of WWF Russia.

One of the reasons behind inconsistency might be the use of different dataset for the land cover than the one used by researchers from WWF. I was not able to download the dataset due to some technical issues on the site that they have used. Another reason is simply that the territory indeed is not particularly suitable for the reintroduction of the Caspian tiger. However, the Kazakhstani government is aware of that and already is taking steps to improve the habitat. According to the program for the Ile-Balkhash Nature Reserve, it will take up to 15 to 25 years restore the ecosystem and prey, and only then the Amur tiger will be brought on the territory of the reserve (WWF Russia 2014).

Within this period, first of all, local tugay and reed ecosystems will be revived. The next step would be the reintroduction of Bukhara deer and wild boar to provide sufficient prey for tigers. The relocation of the Amur tiger on the territory of the reserve would be the last step of the program.

One of the most important steps, apart from designating the territory for reintroduction of the Caspian tiger, would be inclusion of this species into the Red Book of Kazakhstan. As Dr. Sklyarenkno has mentioned during the interview, the program is quite ambitious and will involve big investment and government commitment. Financial help from international donors is possible only if the species are officially recognized. However, the Red Book of Kazakhstan does not have a section on species that are extinct in the wild.

The support from the local population plays a significant role in the reintroduction and further conservation initiatives. Preliminary consultations with the local population have revealed significant concerns associated with the reintroduction of wild carnivores in the nature (WWF Russia 2014). As a result of a series of meetings, it was agreed to fence the territory of the national park. However, long-term consequences of fencing on the migration of the Caspian tiger were not addressed during the consultations.

Many other factors will determine the success of reintroduction of the Caspian tiger. However, as Dr. Sklyarenkno has said, even if the project will stop at one of the stages and reintroduction will not be successful, it still would be a positive outcome. The multi-stage process of the revival of the ecosystem in the delta of River Il and Lake Balkhash that were degraded during the years of extensive agriculture will bring a positive outcome.

Therefore, the same as in the Northeast Tiger and Leopard Nature Reserve, the success of tiger survival and increase of the tiegr population are determined by the combination of suitable environmental characteristics and effective management schemes. The Caspian tiger reintroduction initiative is supported by WWF Russia that already has helped to restore decreasing population of tigers in the Russian Far East (WWF Russia 2018b). A combined initiative of the Kazakhstani and Russian governments can be a determinant factor in the future success.

Despite the fact that geospatial technologies and remote sensing are modern and sophisticated technologies, the analysis had certain limitations and uncertainties. Some of the datasets used for the analysis were outdated. For instance, land cover data was from the year 2000. Other data is modelled by tiger experts. For example, data on the prey density was based on the prediction that a certain vegetation can sustain a certain amount of prey species. More accurate data can be gathered through the use of camera traps.

6. Discussion and conclusion

The main aim of this thesis was to show the application of GIS and remote sensing for habitat suitability analysis. The current thesis has made an attempt to evaluate the habitat suitability for the Amur tiger in the prospected Northeast Tiger and Leopard National Park in China and the restoration prospects of the currently extinct Caspian tiger in the Ile-Balkhash Nature Reserve in Kazakhstan, comparatively analyzing them with the Sikhote-Alin National Park in Russia. Habitats in China and Kazakhstan are compared to Russia because intensive conservation efforts in the Russian Far East have increased the tiger population to 540 individual species in 2015. Therefore, the habitat within the Sikhote-Alin National Park is used as a reference point for Amur tiger conservationists.

The final habitat suitability map for the Northeast Tiger and Leopard National Park (*Figure 27*) has shown high suitability level for tigers with 77% of the planned territory being highly suitable. If the Chinese government follows its commitment to become an "Ecological Civilization" and create for Amur tigers a "room to roam", the initiative can be a great success. (Standaert 2018). The long-term success would also be determined by the connectedness of the Chinese population of tigers to the Russian population of Amur tigers. Therefore, the trans-boundary conservation scheme to protect populations of both Amur tigers and leopards is essential.

In the case of Kazakhstan, despite the fact that researchers from WWF Russia have proven the habitat suitability, the final habitat suitability map for the Ile-Balkhash Nature Reserve (*Figure 28*) has shown low habitat suitability for the successful reintroduction of the Caspian tiger. Yet, if Kazakhstan acts according to its commitment and revive the ecosystem of the Ile-Balkhash region, and ensure sufficient prey, the initiative may be the first tiger reintroduction success story.

The methodology used in the research could be used in the habitat suitability analysis of different species. The steps can be replicated for the same territory on a larger scale with the inclusion of the buffer zone around national parks and ecological corridors between Russia and China.

The results may be used by conservation planners and politicians to guide the restoration process. The maps developed may also be used by social and educational organizations to inform the general audience of the importance of the environmental management and conservation of the ecosystem. Public participation can be useful to identify the suitable habitat for conservation, allowing social science methods to enrich wildlife management (Cox *et al.* 2014).

Lastly, we should keep in mind that restoring endangered species is not a linear process. Continuous improvement of the existing maps is required as new data and new field knowledge become available. The restoration of the Amur tiger population in China and the reintroduction of the Caspian tiger will contribute to the Global Tiger initiative and its goal to double the current population of tigers.

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Appendix

Land cover data

Russia (Sikhote-Alin Nature Reserve):

Value	Label	Red	Green	Blue
50	Closed (>40%) broadleaved deciduous forest (>5m)	0	160	0
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	40	100	0
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	120	130	0
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	140	160	0
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	190	150	0
150	Sparse (<15%) vegetation	255	235	175
200	Bare areas	255	245	215
210	Water bodies	0	70	200

China (Northeast Tiger Leopard National Park):

Value	Label	Red	Green	Blue
50	Closed (>40%) broadleaved deciduous forest (>5m)	0	160	0
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	40	100	0
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	120	130	0
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	140	160	0
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	190	150	0
150	Sparse (<15%) vegetation	255	235	175
190	Artificial surfaces and associated areas (Urban areas >50%)	195	20	0
200	Bare areas	255	245	215
210	Water bodies	0	70	200

Kazakhstan (Ile-Balkhash Nature Reserve):

Value	Label	Red	Green	Blue
11	Post-flooding or irrigated croplands (or aquatic)	170	240	240
14	Rainfed croplands	255	255	100
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	220	240	100
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	205	205	102
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	40	100	0
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	120	130	0
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	140	160	0
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	190	150	0

140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	255	180	50
150	Sparse (<15%) vegetation	255	235	175
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	0	220	130
190	Artificial surfaces and associated areas (Urban areas >50%)	195	20	0
200	Bare areas	255	245	215
210	Water bodies	0	70	200
220	Permanent snow and ice	255	255	255