# *The fate of free-ranging tigers in an Eastern Himalaya biodiversity hotspot*

## The effects of historical land use and associated drivers on the tiger population in Namdapha National Park and Tiger Reserve, India.

**Thesis**

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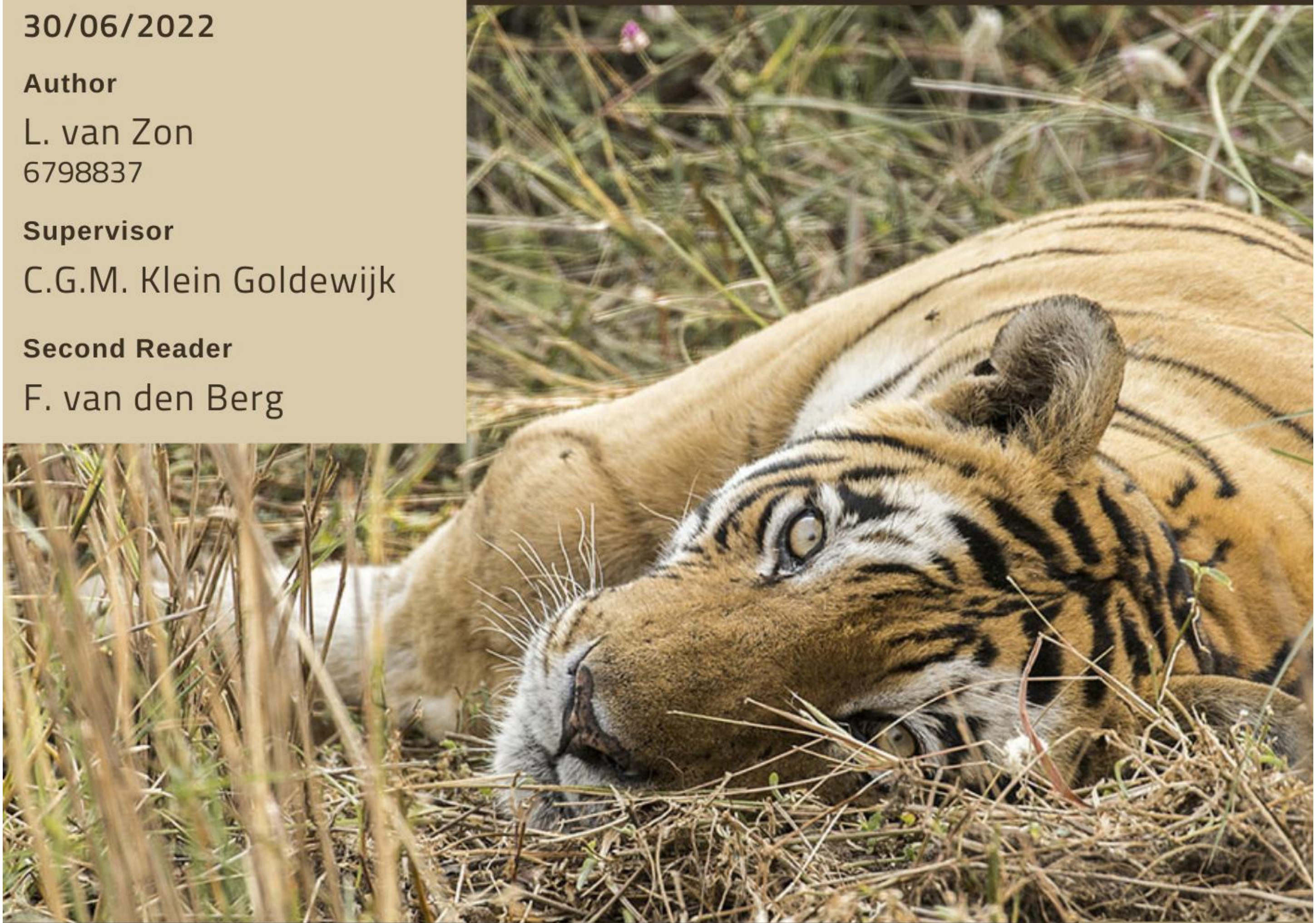

https://www.seymourwildlife.com/bengal-tiger-panthera-tigris-tigris-ranthambhore-np-india-may-2016.html

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## Glossary

| | |
|---|---|
| HI-LIFE | Far-Eastern Himalayan Landscape Initiative |
| LU | Land-use |
| NPTR | National Park and Tiger Reserve |
| P.t. tigris | Panthera tigris tigris |
| PA | Protected area |
| TCP | Tiger Conservation Plan |
| UoM | University of Minnesota |

## Executive summary

In less than a century, the Bengal tiger, Asia's largest predator, has been relegated to fragmented habitats and confined to isolated populations in less than 7% of its historical range. Free-ranging tigers are in a precarious state, despite large areas dedicated to their conservation. Tiger populations are plagued by organized poaching, prey depletion, and natural habitat degradation, extirpations either directly or indirectly precipitated by anthropogenic activities.

The study area of this report, Namdapha National Park and Tiger Reserve (NPTR), represents an excellent case study of the abundance of challenges associated with tiger conservation. This dissertation aims to investigate land-use changes in proximity to the park using GIS analysis. Subsequently, interdisciplinary literature is analyzed to place the land-use changes in the context of a DPSIR framework. Finally, both the land-use changes and their drivers are connected to the tiger population in the study area.

The key findings from this study show that agricultural expansion, human encroachment, and urbanization form the most prominent threats to tiger populations in Namdapha NPTR since tigers require large contiguous areas of habitat with limited anthropogenic disturbance.

# 1. Introduction

## 1.1. Background and Relevance

The Bengal tiger (*Panthera tigris tigris*), Asia's largest predator, has been regarded as a prevalent cultural symbol for centuries (Lamichhane & Jha, 2015; Jhala, Qureshi & Nayak, 2020). This flagship species is a conservation icon, serving as the apex predator in the food chain (Jhala, Qureshi & Nayak, 2020). The Bengal tiger acts as an effective umbrella species for the conservation of wildlife in the Indian subcontinent and strongly shapes ecological interactions within ecosystems (Dinerstein et al., 2007; Jhala, Qureshi & Nayak, 2020). The 2018 status report on tigers states that "ensuring the conservation of this top carnivore guarantees the well-being of forested ecosystems, the biodiversity they represent as well as water and climate security" (Jhala, Qureshi & Nayak, 2020). This is in accordance with Sustainable Development Goal (SDG) 15: 'Life on land', which emphasizes the importance of healthy ecosystems and the services they provide (FAO, 2022).

India houses more than 80% of all free-ranging tigers, the largest population across the global range of tiger species (Jhala, Qureshi & Nayak, 2020; Rastogi et al., 2012). Despite the debatable nature of the exact number of tigers (Karanth et al., 2011), the Indian tiger population harbors over 60% of the extant genetic variation of the species (Mondol, Karanth & Ramakrishnan, 2009; Jhala, Qureshi & Nayak, 2020; Rastogi et al., 2012). Therefore, India holds the key to tiger conservation from both an ecological and genetic perspective and offers a unique context in which to comprehend illustrative challenges associated with the conservation (Rastogi et al., 2012; Jhala, Qureshi & Nayak, 2020). Internationally, India can serve as an outstanding case study that demonstrates the difficulties facing tiger conservation programs (Rastogi et al., 2012) and shows commitment to these protection endeavors, exhibited by large monetary contributions (Walston et al., 2010). The Project Tiger, established in 1973, aims to "harness the functional role of the tiger and its charisma to garner resources and public support for conserving representative ecosystems" (Jhala, Qureshi & Nayak, 2020). Under its stewardship, India increased its tiger reserves from 9 to 50 over the span of a few decades (Jhala, Qureshi & Nayak, 2020).

Some of these reserves have a higher conservation potential than others. The 2018 status report of The National Tiger Conservation Authority and Wildlife Institute of India states that the tiger populations in the Northeastern Hills get the highest conservation rating (see *Figure 1*) because they are arguably "most likely to share their gene pool with the most critically endangered subspecies, i.e., *P.t. corbetti*, that exists in Myanmar" (Jhala, Qureshi & Nayak, 2020). The Northeastern Hills accommodate three tiger reserves: Namdapha National Park and Tiger Reserve (NPTR), Kamlang Tiger Reserve, and Dibang Wildlife Sanctuary, where conservation investments have become of 'paramount priority' (Jhala, Qureshi & Nayak, 2020).

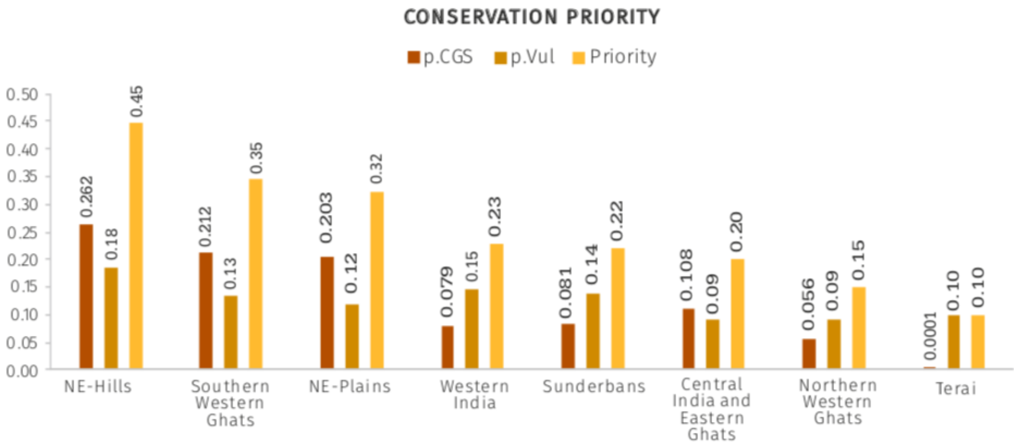


*Figure 1: "Conservation priority computed based on population vulnerability, genetic diversity, and distinctiveness for tiger populations in India". P.CGS is an index for "population genetic diversity and divergence". p.Vul represents the "vulnerability of a population to extinction based on population size". (Jhala, Qureshi & Nayak, 2020).*

This research will regard Namdapha NPTR, which is situated in the Changlang district of Arunachal Pradesh, as depicted in *Figure* 2, and covers an area of 2053 km$^2$ (Jhala, Qureshi & Nayak, 2020). It was established in 1983 and is the only Protected Area (PA) in the state that has the dual status of National Park and Tiger Reserve (Shakya et al., 2021; Lodhi et al., 2013). The park contains the highest species richness out of all PAs in India (ICIMOD, 2021a; Sarkar et al., 2021) and is globally recognized as a biodiversity hotspot (Jhala, Qureshi & Nayak, 2020). It is the only park in the world that harbors all four big cats: tigers, lions, leopards, and jaguars (Cary, 2019; Khorozyan, 2015). In addition, Namdapha NPTR serves as a confluence zone for two genetically unique P.t. subspecies (Jhala, Qureshi & Nayak, 2020), which accentuates the conservation priority of this area.

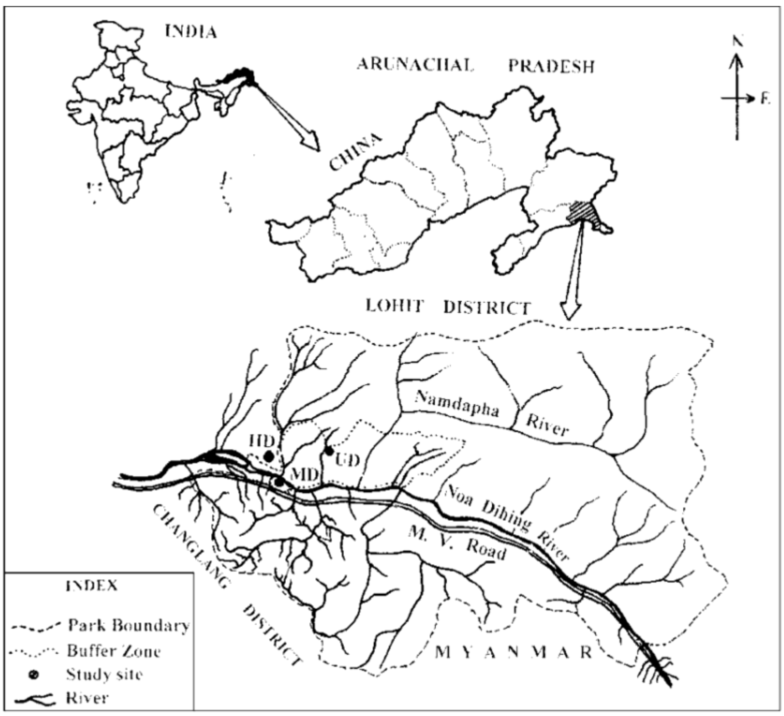


*Figure 2: Location of Namdapha National Park in Arunachal Pradesh, Northeast India. (Nath et al., 2005)*

## 1.2. Problem statement

Despite formal protection and regional and national conservation support, the tiger has been classified as endangered on the IUCN Red List for Threatened Species for more than a decade, and tiger populations continue to dwindle (Dinerstein et al., 2007; Karanth, 2014). The extant tiger populations are relegated to fragmented habitats and confined to disengaged populations in less than 7% of their historical range (Jhala, Qureshi & Nayak, 2020; Dinerstein et al., 2007). The iconic species is plagued by threats like habitat destruction, poaching, overexploitation, and inbreeding depression, extirpations either directly or indirectly precipitated by anthropogenic activities (Dinerstein et al., 2007; Jhala, Qureshi & Nayak, 2020; Basnet et al., 2019).

Namdapha NPTR also suffers the consequences of anthropogenic pressure. According to the 2018 status report on tigers and co-predators, Namdapha NPTR has a tiger density of less than 1 tiger per 100 $km^2$, which is remarkably low when compared to other PAs in the state (Jhala, Qureshi & Nayak, 2020). This gives rise to concern because tigers have recently disappeared from what were considered two well-protected sanctuaries in India: The Sariska and Panna Tiger Reserves (Project Tiger, 2005; Dinerstein et al., 2007). This incident is illustrative of the problems associated with tiger conservation; even in areas that are dedicated to conservation, external factors degrade the tigers' territory (Rastogi et al., 2012). In a sense, PAs in India can be compared to conservation islands in a far-reaching sea of hostile habitat (Jhala, Qureshi & Nayak, 2020; Basnet et al., 2019).

## 1.3 Research aim

Thus, in a country with an ever-growing population, threats of range contraction and other unprecedented challenges remain prominent. The gravity of the situation calls for renewed attention to the conservation of free-ranging tigers in PAs. As aforementioned, Namdapha NPTR will be the focus of this research. Its vulnerability to active and passive pressures and persisting low tiger density combined with its high conservation value makes this tiger reserve an excellent case study. An analysis of land-use changes in the surrounding area will provide insight into the biotic and abiotic drivers that affect Namdapha's tiger population, both on a temporal and spatial scale.

The aim of this research is threefold: to understand the historical land-use changes (1900-2015) in the area surrounding Namdapha NPTR; to describe the associated drivers and analyze their interaction with the land-use changes; and to investigate how these two aspects have affected the *Panthera tigris tigris* (*P.t. tigris* henceforth) population within the park. To carry out this aim, the following overarching research question is posed:

*What is the effect of historical land-use changes (1900-2015) and associated drivers on the Panthera tigris tigris population in Namdapha National Park and Tiger Reserve?*

To break down this overarching question, two sub-questions will organize this research into comprehendible segments, representing two important aspects of the research aim:

1. What are the major changes in land-use during the period of 1900-2015 surrounding Namdapha National Park and Tiger Reserve?
2. What are the main drivers behind these land-use changes?

# 2. Theory

This section is concerned with outlining the living conditions of the Bengal tiger. The survivability of a single specimen depends predominantly on the availability of prey and accessibility to its natural habitat (Sunquist & Sunquist, 1989; Global Tiger Forum, 2019). Therefore, diet will be discussed as an essential part of an organism's ecological niche (Mukherjee & Sen Sarker, 2013; Lamichhane & Jha, 2015). Subsequently, the predator-prey and predator-predator interactions will be reviewed, which is fundamental to understanding the general ecology of a species (Mukherjee & Sen Sarker, 2013; Lamichhane & Jha, 2015). Thereafter, the natural habitat of the Bengal tiger will be described. Finally, having established the tiger's living conditions (with more details in *Appendix A*), the existing body of scientific literature will be interrelated in the form of a conceptual DPSIR framework. This framework is by no means said to encompass all relevant aspects, but it is meant to visualize the most important ones in a comprehensible diagram.

## 2.1. *Panthera tigris tigris* living conditions

### 2.1.1. Prey selection

Prey selection preferences of large carnivores are relatively poorly understood in the tropical forests of North-eastern India (Karanth & Sunquist, 1995; Selvan et al., 2013). Generally, however, tigers prefer large mammalian herbivorous prey species (Mukherjee & Sen Sarker, 2013; Selvan et al., 2013; Karanth & Sunquist, 1995). Namdapha NPTR houses many prey species (Namdapha Tiger Reserve, n.d.a), but the distribution of the tiger seems to be predominantly determined by the availability of large ungulates (Bhandari, 2014), as they are preferential prey (Hayward & Jedrzejewski, 2012).

### 2.1.2. Predator interactions

In reality, many other considerations and interactions complicate this issue. According to Mukherjee and Sen Sarker (2013), "… prey selection of tigers in any area is ultimately the cumulative effect of different ecological, behavioral, and habitat factors which delineates the availability and vulnerability of prey species at any particular time". Anthropogenic disturbances could potentially distort the predator-prey balance, leading to shifts in prey selection. The predator-prey interaction goes both ways; on one hand, tigers are affected by prey availability because they are specialized hunters, but on the other hand, tigers play a pivotal role in shaping the prey communities (Karanth & Sunquist, 1995). The reality of these interactions is complex, but generally, "direct positive correlations exist between habitat richness, prey-base diversity/biomass, and tiger density" (Reddy, Srinivasulu & Rao, 2004). Simply put, the greater habitat richness, the greater the abundance and diversity of wild prey, and the greater tiger density. Moreover, interspecific competition does not seem to play a large role in determining tiger density, which seems to be predominantly determined by prey abundance (Karanth et al., 2004)

### 2.1.3. Habitat

The *P.t. tigris* can reside in varied habitats: grasslands, (sub-)tropical rainforests, mangroves, and wet or dry deciduous forests, among others (Wild Cats World, 2022). This subspecies can cope with a wide range of environmental conditions, as long as three conditions are met: ample prey, cover, and limited human disturbance (Global Tiger

Forum, 2019). Changes in these factors could potentially lead to breeding suppression (Krishna et al., 2013). To meet all conditions, a large contiguous area of undisturbed habitat is required (Mallick, 2019). This large range is also needed to raise young and support the long-term genetic viability of the population (Karanth & Sunquist, 1995; Jhala, Qureshi & Nayak, 2020). *Appendix A* provides an extensive overview of several indicators of habitat suitability in Arunachal Pradesh, as well as a more detailed overview of the tiger's diet and interspecific relations.

## 2.2 Conceptual framework: DPSIR

The overarching conceptual framework that will be utilized in this paper is the Driver-Pressure-State-Impact-Response (DPSIR) framework. This framework describes a causal chain from driving forces to responses while interlinking the socio-economic and ecological system (Gessesew, 2013). This framework facilitates systems thinking to gain a holistic overview and conceptualizes complex challenges in a simplified manner (Allen, 2022; Smeets & Weterings, 1999)). The DPSIR framework used in this research deviates slightly from the conventional DPSIR approach because a sixth component called 'barriers for effective management' is included. The incorporation of this component is inspired by Mangi, Roberts & Rodwell (2007) and Roura-Pascual et al. (2009). It is included in this analysis because it emphasizes a practical, social aspect of the problem, which aids in conceptualizing the broader context of the problem.

Within this framework, three threats are considered most prominent to free-ranging tigers: habitat degradation (range contraction, fragmentation, etc.), prey depletion, and direct poaching (Lamichhane & Jha, 2015; Ranganathan et al., 2008; Rastogi et al., 2012; Jhala, Qureshi & Nayak, 2020). Most of the components in this framework will be related to these prevailing challenges, either directly or indirectly.

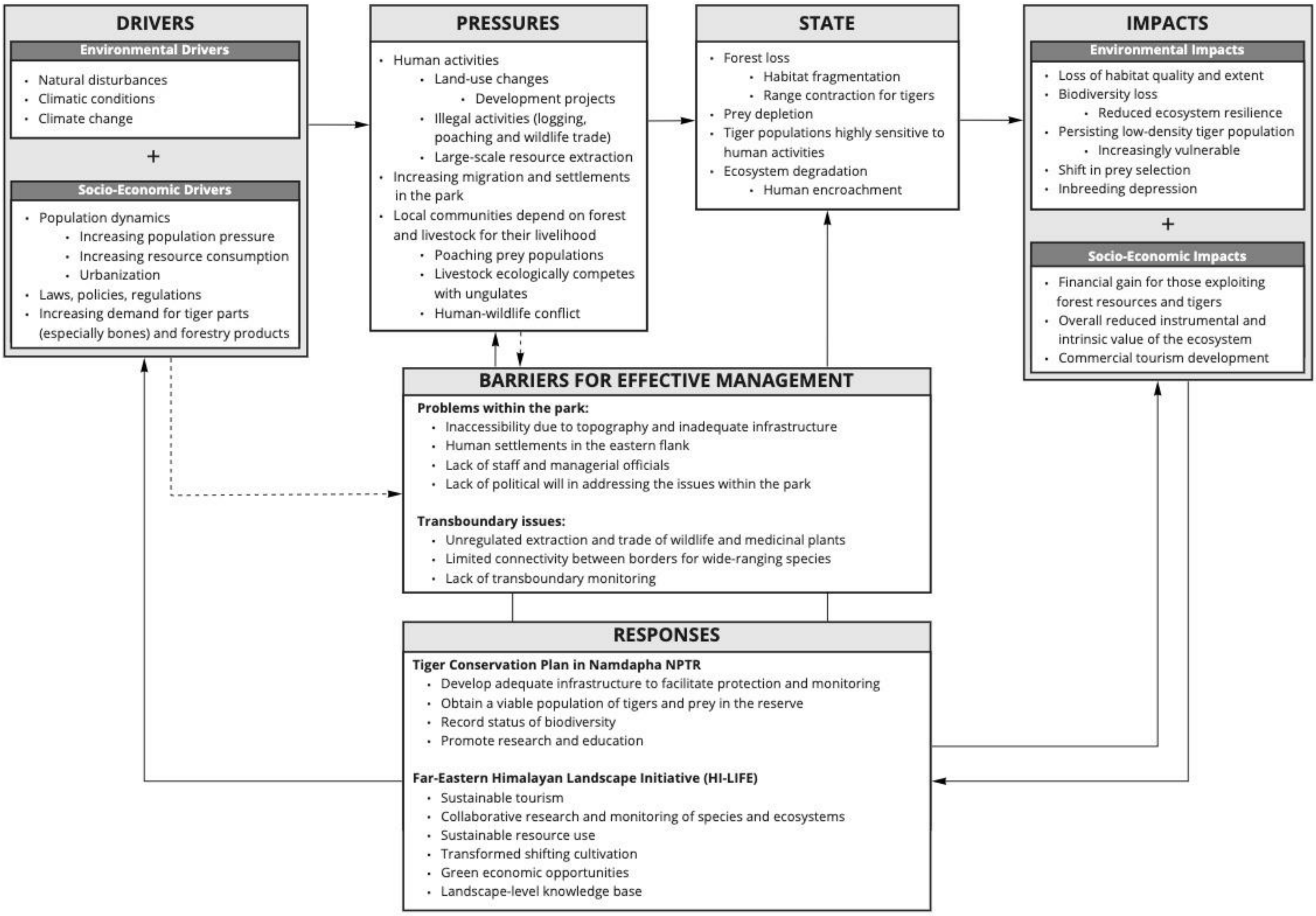


*Figure 3: DPSIR-framework*

## Drivers (D)

"Driving forces are the factors that cause changes in the system" (Gessesew, 2013). Some environmental drivers include natural disturbances such as forest fires, climatic conditions, which are variable and monsoon-influenced, and climate change, which will ultimately affect the frequency and intensity of the natural disturbances and the climatic conditions in Arunachal Pradesh (Saikia et al., 2017; Sangomla, 2021). These environmental drivers do not necessarily exert direct pressure on the tiger population within Namdapha NPTR, because this subspecies can endure an array of environmental conditions, as mentioned in section 2.1.3. However, they can play a role by amplifying or subduing the pressures exerted by socio-economic drivers, via positive or negative feedbacks.

The drivers that exert the most direct pressure on tiger populations are socio-economic in nature (Rastogi et al., 2012). The ever-growing Indian population with rising affluence pressures the tigers, their habitat, and prey in many ways (Lamichhane & Jha, 2015; Sunquist, Karanth & Sunquist, 1999; Rastogi et al., 2012). Human activities like logging, agricultural expansion, and developmental projects adversely impact wildlife and nature (Lamichhane & Jha, 2015). Increased resource consumption and demand for land and forestry products expand the human enterprise, resulting in range contraction (Rastogi et al., 2012). Urbanization further aggravates ecosystem degradation because it promotes road development, and subsequently increases vulnerability to deforestation and poaching (Etter et al., 2006; Breuer, Maisels & Fishlock, 2016; Krishna et al., 2013).

A specific increase in demand for tiger parts is driven by the traditional Chinese medicine market, in which the animal is "ground down and separated into various medicines" (Raaj, 2009). Throughout Asia, there are stringent laws that ought to protect tigers and other wildlife from threats like poaching. In reality, however, offenses under the Wild Life (Protection) Act, 1972, seldom lead to convictions due to insufficient enforcement and attract minor fines with little to no jail time (Dinerstein et al., 2017)

## Pressures (P)

"Pressures are the human activities that directly affect the system and are generated by the driving forces" (Gessesew, 2013). These pressures are transformed into natural processes, which manifest themselves in shifting environmental conditions eventually affecting the tiger population (Lemmons, 2022). Increasing population pressure combined with rising affluence and specific demand for forestry and tiger products generates unsustainable, and often illegal, human activities (Lamichhane & Jha, 2015; Rastogi et al., 2012). Large infrastructure development projects increase the pressure on the ecosystem by creating more opportunities for commercial tourism, business, and settlement (Shakya et al., 2021; Krishna et al., 2013; The Arunachal Times, 2022).

Several ethnic communities reside in the buffer zone of Namdapha NPTR and its surroundings (The Arunachal Times, 2022), and are fully dependent on the nature reserve for their livelihood. During the 20$^{th}$ century, the human influx into the park increased with the migration of native forest dwellers moving from Myanmar to Arunachal Pradesh (Arunachalam et al., 2004). This creates a challenge since tigers are drastically affected by anthropogenic disturbances and require a large habitat that is free of human encumbrances (Rastogi et al., 2012; Arunachalam et al., 2004). Besides this, the local communities also exert further direct and indirect pressures on the tiger population. For instance, they have been reported to poach on tiger and prey populations (Rastogi et al., 2012). Moreover, they keep domestic livestock that ecologically competes with ungulates, which serve as prey species for tigers, potentially resulting in a dwindled ungulate population (Rastogi et al., 2012; Damania et al., 2002; Madhusudan, 2005). This, in turn, affects tiger density. Since the native communities have limited options for their livelihood, they can be severely impacted if crop or cattle is lost to wild animals. Subsequently, local communities can retaliate and harm the animals, so both sides suffer in the process (Rastogi et al., 2012; Madhusudan, 2005). Fortunately, tigers do not show any preference for livestock if there is ample prey biomass available (Reddy, Srinivasulu & Rao, 2004; Lamichhane & Jha, 2015; Khorozyan, 2015).

## State (S)

"State is the condition of the system at a specific time" (Gessesew, 2013). In this case, land-use changes and other anthropogenic disturbances impact the state of the environment. The habitat richness and quality – and thus the prey-base and tiger density – suffer the consequences of fragmentation, range contraction, and human encroachment (Reddy, Srinivasulu & Rao, 2004; Rastogi et al., 2012). These threats are prevailing because tigers require a large continuous habitat that is free of human encroachment (Rastogi et al., 2012; Arunachalam et al., 2004; Mallick, 2019), as outlined in section 2.1.3.

## Impacts (I)

"Impacts are consequences of environmental state change in terms of substantial natural or socio-economic effects which could be either positive or negative" (Allen, 2022). One of the environmental impacts is that dwindling prey populations affect the prey selection and distribution of the tiger and exacerbate its vulnerability to poaching (Dinerstein et al., 2007). The persistently low density of tigers and co-predators within Namdapha NPTR is worrisome for the biodiversity of the park since top carnivores shape ecological interactions within the metapopulation framework (Vasudeva et al., 2022; Dinerstein et al., 2007; Jhala, Qureshi & Nayak, 2020). The combination of biodiversity loss and increased human encroachment in the park forms a potential threat to the longer-term resilience of the ecosystem (Oliver et al., 2015), which subsequently causes a plethora of potential other challenges in the future. Another factor influencing the viability of the tiger population is related to genetic diversity. Habitat fragmentation sequesters the tiger population into smaller, isolated populations. This ultimately hinders genetic exchange between subspecies, increasing the chances of extinction (Khan et al., 2021).

The socio-economic impacts are variable and difficult to predict in the long run. However, from a short-term perspective, those who exploit the ecosystem benefit financially. Much of the poaching is organized by sophisticated operators, who exploit both wildlife and the local communities. Much of the hunting is done by native forest dwellers with the appropriate knowledge and skillset. However, traders pay them a meager amount of money and make substantial profits themselves (WPSI, n.d.). Hence, profits can be gained from exploitation on a short timescale. However, in the long run, the overall instrumental and intrinsic value of the ecosystem will suffer and even the traders will be confronted with the adverse impacts associated with this. Besides this, the currently nature-based ecotourism that focuses on local culture is threatening to be replaced by commercial tourism due to the development of infrastructure (Shakya et al., 2021), which might further accelerate ecosystem degradation and interfere with the livelihood of native forest dwellers.

## Responses (R)

"Responses are the efforts made by society as a result of the changes manifested in the impacts" (Gessesew, 2013). Following the Project Tiger Guidelines, Namdapha NPTR set up a Tiger Conservation Plan (TCP) in 2014. The park's objectives are to obtain a viable tiger and prey population, record biodiversity, promote research and education, and develop more infrastructure to foster protection and monitoring (Namdapha Tiger Reserve, n.d.b).

In addition to this regional initiative, the governments of India, Myanmar, and China have initiated the Far-Eastern Himalayan Landscape Initiative (hereafter: HI-LIFE), which focuses on biodiversity conservation and improved livelihoods (Basnet et al., 2019; ICIMOD). Several PAs in the Far-Eastern Himalayan landscape, including Namdapha NPTR, form a contiguous ecological landscape (depicted in *Figure 4*), which has potential for integrated conservation and management (Shakya et al., 2021). HI-LIFE strives to find a balance between conservation and development. Some of the objectives are sustainable tourism, collaborative research and monitoring of species and ecosystems, sustainable resource use, transformed shifting cultivation, green economic opportunities, and a landscape-level knowledge base (ICIMOD, 2018b). Moreover, the transboundary collaboration between India and Myanmar has led to the signing of a memorandum of understanding (MoU) in February 2020, to tackle issues related to illegal wildlife trafficking and take collective action to facilitate the conservation of tigers and other wildlife (ICIMOD, 2021b).

## Barriers to effective management

In addition to the management objectives, Namdapha NPTR outlined specific problems in achieving them, which include the inaccessible, rugged terrain and lack of decent infrastructure, growing settlements in the buffer zone and permeation into the core area, lack of staff and managerial officials, and a lack of political will (Namdapha Tiger Reserve, n.d.b).

The International Centre for Integrated Mountain Development (ICIMOD, 2021a) and partners in the Far-Eastern Himalayas have highlighted some additional transboundary issues that hamper the effectiveness of the conservation efforts: lack of transboundary monitoring, unregulated trade of wildlife and medicinal plants, and limited connectivity between conservation sites, which lack in the TCP of Namdapha NPTR. For a wide-ranging, low-density species like the tiger, a landscape approach to conservation is essential (Walston, 2010). Furthermore, drivers tend to operate at a larger, transboundary scale (Basnet et al., 2019). PAs will remain of paramount importance in tiger conservation efforts but facilitating a landscape that is permeable for tigers should be part of the solution (Walston, 2010). HI-LIFE is a step in the right direction, but the full potential of landscape conservation has not yet been realized. Namdapha NPTR namely provides the promising opportunity to be connected with ecological corridors in Hponkan Razi Wildlife Sanctuary, Hkakabo Razi National Park, and Gaoligongshan National Nature Reserve (Basnet et al., 2019; ICIMOD, 2018a).

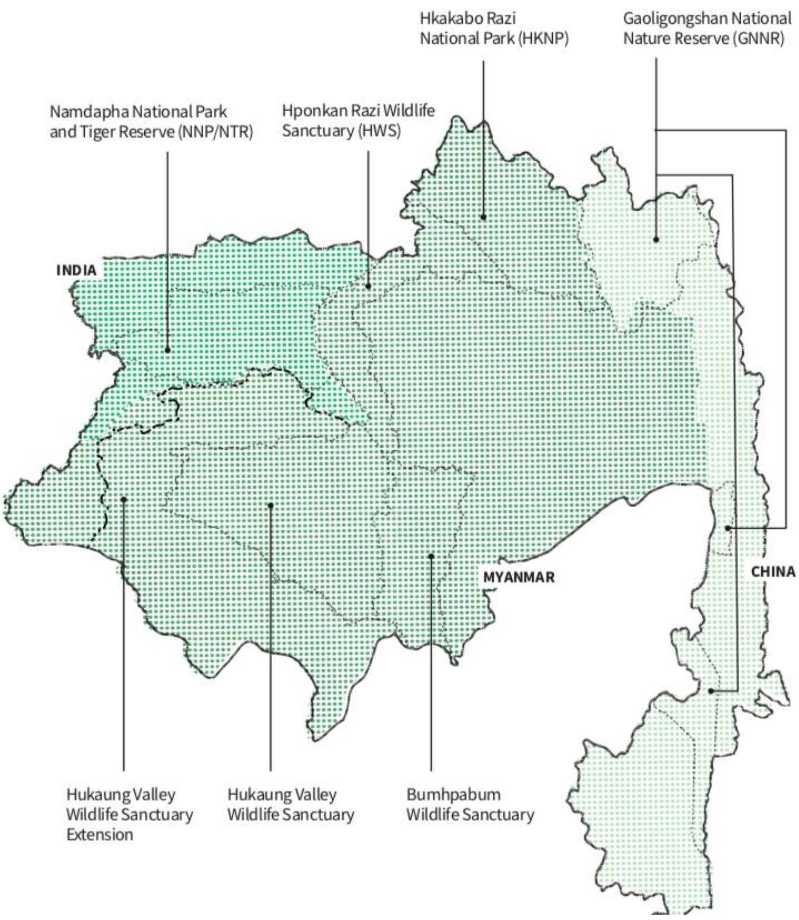


*Figure 4: The Far Eastern Himalaya Landscape (ICIMOD, 2018b)*

# 3. Methodology

To allow for replicability of the discoveries and to amplify transparency, the following section will outline the proposed methodological approach of this paper. The approach consists of two fundamental steps; a qualitative literature review sheds light on the drivers affecting the tiger populations, and mapping of geospatial data in GIS identifies significant changes in land use. To properly explain land-use (hereafter: LU) dynamics, an interaction containing two basic aspects ought to be followed; firstly, major changes in land use should be identified; secondly, those changes ought to be connected to their drivers (Lambin & Geist, 2006). Both elements are considered in the methodological approach, in addition to a third element: placing the LU changes and the associated drivers in the context of the *P.t. tigris* population of Namdapha NPTR, which will be outlined in the discussion. This section will start with an overview of the study area, Namdapha NPTR, after which the aforementioned two aspects of the approach will be introduced.

## 3.1. Study area

This dissertation will cover Namdapha NPTR, which accommodates a wide array of habitat types (see *Appendix B*), including the world's northernmost tropical rainforest, alpine meadows, subtropical pine and temperate broad-leaved forest, and perennial snow (Sarker et al., 2021; Jhala, Qureshi & Nayak, 2020; Basnet et al., 2019). The vast habitat heterogeneity is due to the low latitude and substantial altitudinal differences, ranging from 200m to 4571m above MSL (Krishna et al., 2013). In *Figure 2*, the location of Namdapha NPTR within India and Arunachal Pradesh is depicted. In this figure, a buffer zone in the northwest corner is also depicted. This area was added to the park later in 1986 because there used to be many human settlements. Part of the inhabitants was resettled, but the majority of the communities still depend on the park for resources and even encroach into the park's core zone (Arunachalam et al., 2004).

## 3.2. Literature research

The results of the literature review are depicted in both the DPSIR framework and discussion. To assess the drivers of historical and current LU changes, various publications pertaining to the effects of LU and associated drivers on tiger populations were compared with one another to establish patterns and trends. Primary and secondary data were extracted from peer-reviewed literature, journal articles, books and chapters, grey literature, and institutional reports from organizational websites, among others. Initially, Google and Google Scholar were utilized to get an outline of what kind of articles are available. Broad search terms like 'tiger population', and 'land use changes' provide a general overview of peer-reviewed publications. More refined search terms were derived from the initial search premise to track down additional relevant articles. More narrowly defined search terms were selected based on this paper's research question and include the following keywords: 'Panthera tigris tigris', 'Bengal tiger', 'Namdapha National Park', 'Namdapha Tiger Reserve', 'demographic pressure', 'anthropogenic', land use driver', 'agricultural intensification', 'agricultural expansion', 'deforestation', 'urbanization', 'LUCC', 'biodiversity conservation' and 'Indian Eastern Himalayas'. Publications were considered if one or multiple keywords appeared in the title, keywords, or abstract. Combinations of these keywords were used to find the most pertinent publications. In addition to the search engines Google and Google Scholar, metadata services like Worldcat, ResearchGate, PubMed, and Mendeley were utilized. Academic publishers include JSTOR, BioOne, ScienceDirect, Public Library of Science (PLoS), and Springerlink. Moreover, publications were derived using the so-called 'snowball method', in which sources are located using the bibliography of relevant articles.

To evaluate the quality and credibility of the information sources, a set of selection criteria was utilized to act as guidance. The selection criteria are the following: (1) how relevant is the information to the research question? (2) what are the author's credentials? (3) when was the information published? (4) is the information verifiable? (5) primary or secondary source? (6) is the information presented clearly? (Adapted from Mandalios, 2013).

## 3.3. Land-use mapping using GIS

To assess significant changes in land use over time, geospatial raster data was analyzed using a Geographic Information System (GIS) analysis. This analysis provides synoptic information on LU change due to its ability to assess both temporal and spatial components (Parth & Arijit, 2010). The data was processed using the Environmental Systems Research Institute's (ESRI's) ArcGIS application Arcmap (version 10.8.1), which is a free, open software that is particularly helpful in geospatial data analysis and visualization. The spatial range of the GIS analysis is not limited to the study area, Namdapha NPTR, but also includes the surrounding area of Arunachal Pradesh and part of Myanmar. Hence, LU changes are analyzed in a wider, transboundary landscape because their drivers and impacts also operate on larger scales.

### 3.3.1. Data collection

The History Database of the Global Environment (HYDE, version 3.2.000) serves as the primary tool in this assessment. HYDE is "an internally consistent combination of updated historical population estimates and enhanced allocation algorithms with weighting maps for land use which are time-dependent" (Klein Goldewijk et al., 2017). The dataset covers a period of 10,000 BCE to 2015 CE (Klein Goldewijk et al., 2017), but in accordance with the research question this dissertation focuses on the period 1900-2015. HYDE is a useful tool for long time series and trends, so it serves as a baseline in this analysis to establish the state of the system in 1900 and compare this with the state in 2015. There are two main categories: cropland and grazing lands. For this analysis, a selection was made regarding the LU types and population categories, based on their relevance and proximity to Namdapha NPTR. Regarding the land use types, grazing lands were excluded from the analysis because the agricultural sector in Arunachal Pradesh is dominated by cropland (Lodrick, 2019), see also *Appendix C* for further substantiation. The data files used for this analysis are "cropland1900AD" and "cropland2015AD". For the population estimates, only the population density ("popd_1900AD" and "popd_2015AD") is included, because it provides the best insights into the interactions with the selected land types and allows for a broad comparison of settlement intensity and migration patterns across a spatial scale (US Census Bureau, 2021).

Moreover, to accommodate the relatively small spatial and temporal range of this research, two additional datasets were used: "Land Use 1900" (University of Minnesota, 2017a) and "Land Use 2000" (University of Minnesota, 2017a). These datasets contain seven land types: agriculture, inhabited and uninhabited forest, inhabited and uninhabited barren land, urban, and rangeland. The data from both datasets is sourced from NASA

Socioeconomic Data and Applications Center (Sedac) and retrieved via ArcGIS Online. The nominal data in these datasets can provide a qualitative, synoptic overview of the patterns and trends associated with LU change and provide information regarding the conversion of certain land types. It also includes natural vegetation types, which is a useful addition to the anthropogenically transformed land types that are described in the HYDE database.

| DATASET | TYPE OF DATA | DESCRIPTION OF DATA |
|---|---|---|
| HYDE (3.2) | Raster, Ratio | The History Database of the Global Environment provides geospatial information about historical land types and population estimates on a continuous time series with a spatial resolution of 10km. |
| Land Use 1900 | Raster, Nominal | This dataset is from the University of Minnesota (UoM) and contains global land use as of 1900. It includes the following categories: agriculture, inhabited and uninhabited forest, inhabited and uninhabited barren land, urban, and rangeland |
| Land Use 2000 | Raster, Nominal | This dataset is from the University of Minnesota (UoM) and contains global land use as of 2000. It includes the following categories: agriculture, inhabited and uninhabited forest, inhabited and uninhabited barren land, urban, and rangeland |

*Table 1: Collected data*

### 3.3.2. Qualitative data analysis

The HYDE database was analyzed separately from the two UoM datasets. For the HYDE database, a geographical coordinate system (GCS_WGS_1984) was defined, and data was manually classified by altering the class breaks. In addition to the HYDE datafiles, 'Indian Admin Boundary' was used to trace the border of Arunachal Pradesh, and Wildlife Protected Areas in India was used to trace Namdapha NPTR. These shapefiles are depicted in all maps to clarify the spatial distribution of the different LU types. Hence, the UoM and HYDE maps became comparable for qualitative analysis, which was conducted with the naked eye.

# 4. Results

This section will outline the findings of the GIS analysis. Trends and patterns are described, and further interpretation of the data will be reviewed in the discussion section. Firstly, an elevation map will show the major altitudinal zones, which will be subsequently compared with the general LU maps that were created using the UoM datasets. From the HYDE dataset, cropland and population density will be highlighted (see also *Appendix D*).

*Figure 5* depicts the elevation model of Northeast India with three major subdivisions. The division is as follows: [1] Arunachal Pradesh forest zone; [2] Brahmaputra river basin in the neighboring state Assam; and [3] forest zone in the northeastern hills (Pawar et al., 2007). Both the UoM and HYDE maps show distributions that correlate with the elevation map.

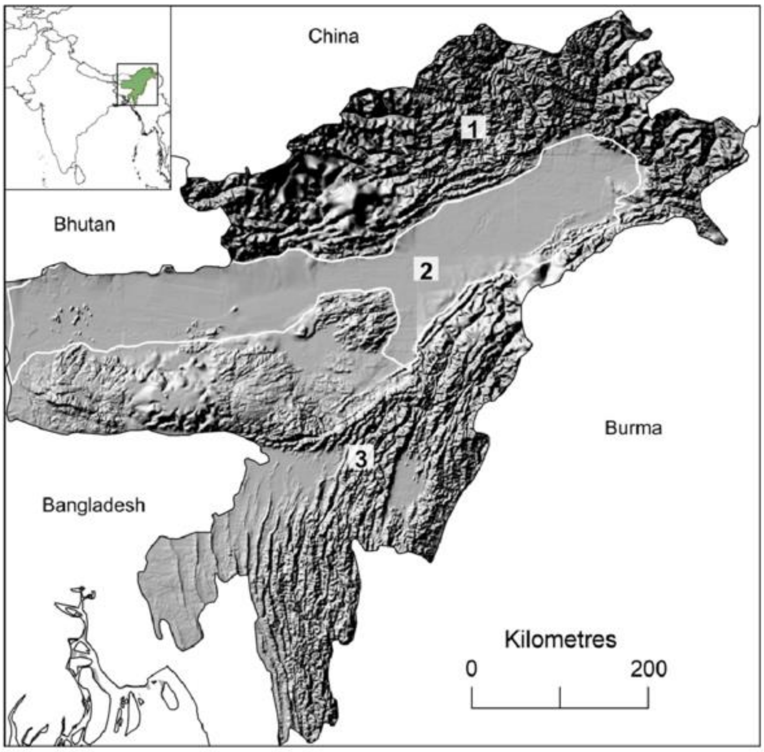


*Figure 5: Digital Elevation Model (DEM) of Northeast India with major subdivisions (Pawar et al., 2007).*

## 4.1. Land use analysis

*Figure 6* shows that in 1900, several zones can be distinguished. The north is dominated by rangeland, with some agriculture and barren land. There is a large tract of forest in Arunachal Pradesh (subregion 1 of the elevation map), with a strip of agricultural land in the Brahmaputra river valley (subregion 2).

*Figure 7* shows that in 2000, the same division is noticeable. However, shifts have occurred in the distribution and extent of the land use types. A large share of barren land has been replaced by rangeland, agriculture, or forest, and concurrently some extent of the rangeland has been converted to agricultural land. Especially the conversion of barren to agricultural land is striking, since barren land is usually classified as having a natural vegetation status that is scarce and scattered (FAO, 2001; Güler, Yomralıoğlu & Reis, 2006) or even unculturable (Narain, n.d.), while agricultural land is classified as land where vegetative cover is extensive and predominantly anthropogenic of origin (FAO, 2001; and

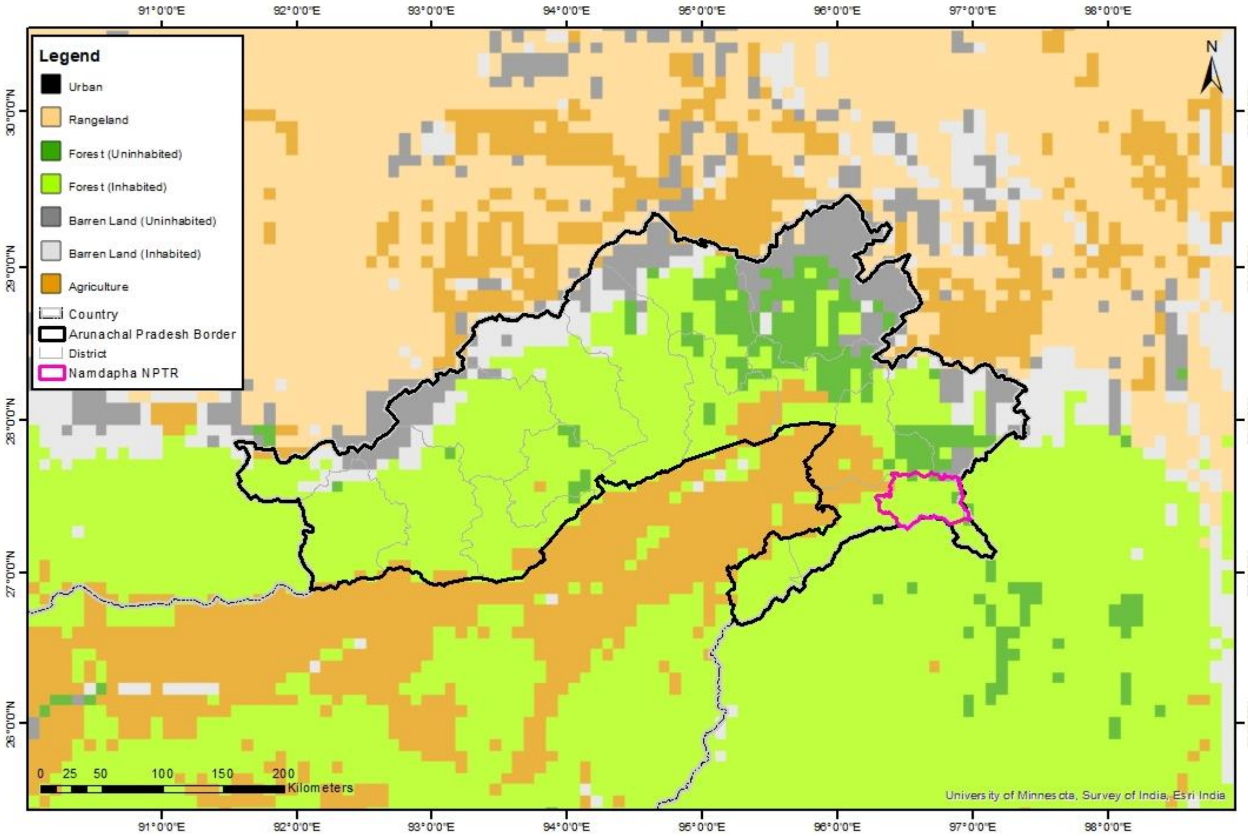


*Figure 6: Land use in Arunachal Pradesh (1900). Created with ArcMap, from UoM dataset.*

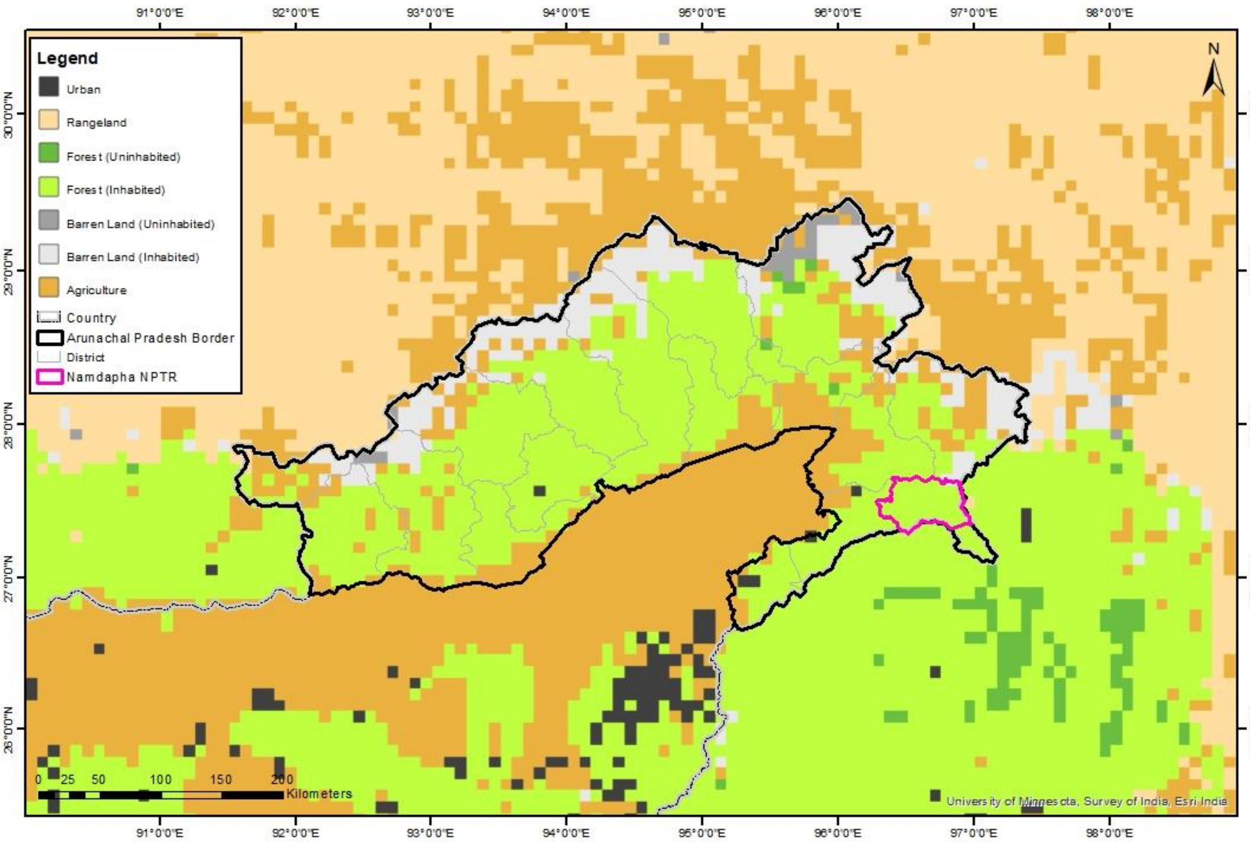


*Figure 7: Land use in Arunachal Pradesh (2000). Created with ArcMap, from UoM dataset.*

Güler, Yomralıoğlu & Reis, 2006). One possible explanation for this is reviewed in section 5.2. Other noticeable transitions are that of uninhabited to inhabited barren land and forest and the development of urban area. In addition, there is an expansion of agricultural area at the expense of forest in the lower elevations. Lastly, an interesting phenomenon distinguishes the land use trends of India and Myanmar: almost all uninhabited forest in India has disappeared, while that of Myanmar has slightly expanded.

#### 4.1.1. Cropland

Generally, there is expansion and intensification of cropland, which is in line with the trend in the UoM maps. One major difference between the graphs is the absence of a significant amount of cropland to the north of Arunachal Pradesh, while agricultural land is present in the UoM maps. In *Appendix C3* it becomes clear that the agriculture in this area is in the form of grazing lands, as opposed to cropland. Evidently, there is a correlation with elevation since cropland is almost exclusively present at lower elevations. In *Appendix D* the UoM and HYDE maps are put side to side for comparison.

### 4.2. Population density

*Figures 10 and 11* display the population density in Arunachal Pradesh in 1900 and 2015. These maps show similar patterns to the maps that are previously discussed in this chapter, namely concentration in the Brahmaputra that intensifies throughout the century. Once again, there seems to be a correlation with the elevation pattern of the area. When comparing these figures with *Figures 6 and 7*, it is striking that the transition from uninhabited to inhabited barren land on the northernmost border of Arunachal Pradesh is not reflected in the population figure. Moreover, when comparing those same four figures, the areas with the greatest population growth in *Figure 11* do not necessarily parallel the areas of urban development in *Figure 7*. However, some scattered communities can be distinguished at higher elevations, similar to where cropland has expanded.

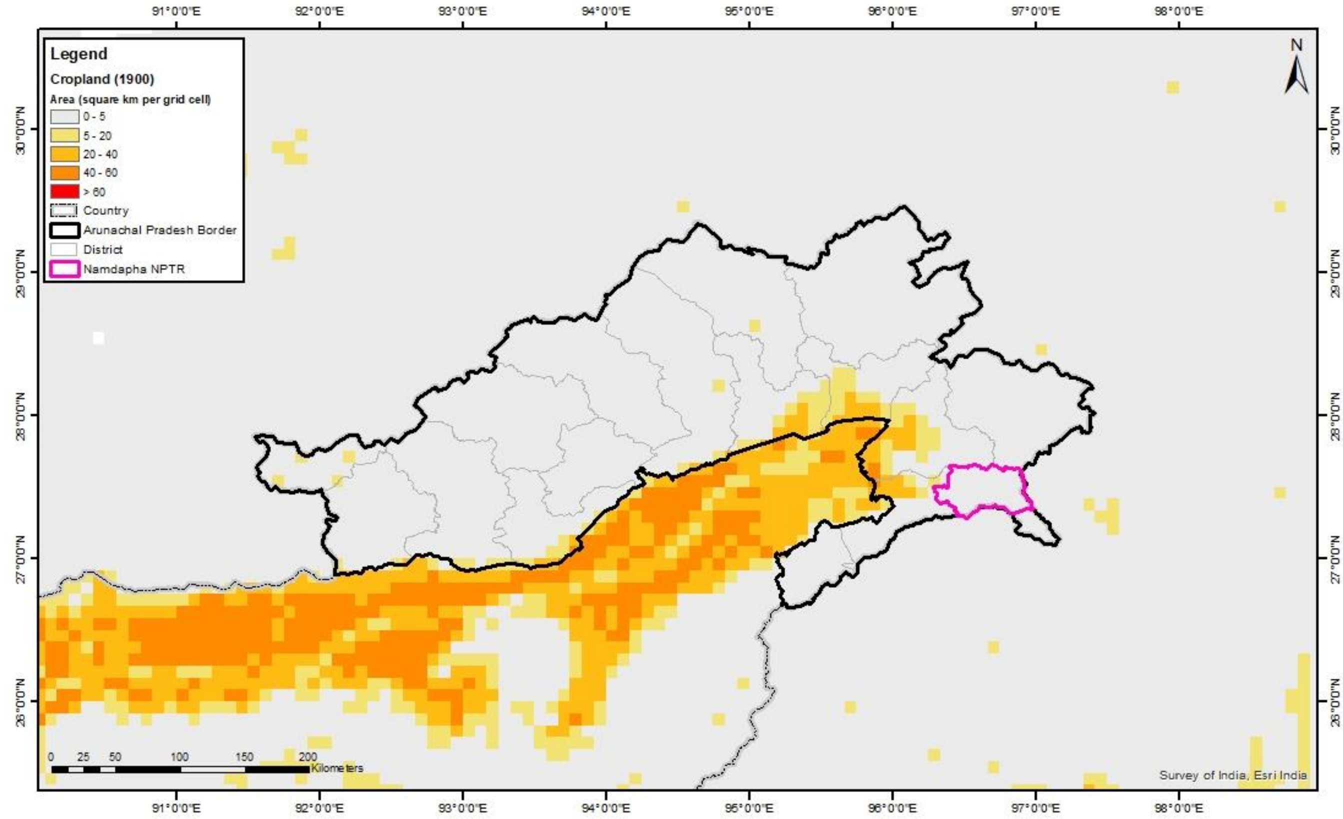


*Figure 8: Cropland in Arunachal Pradesh (1900). Created with ArcMap, from HYDE dataset.*

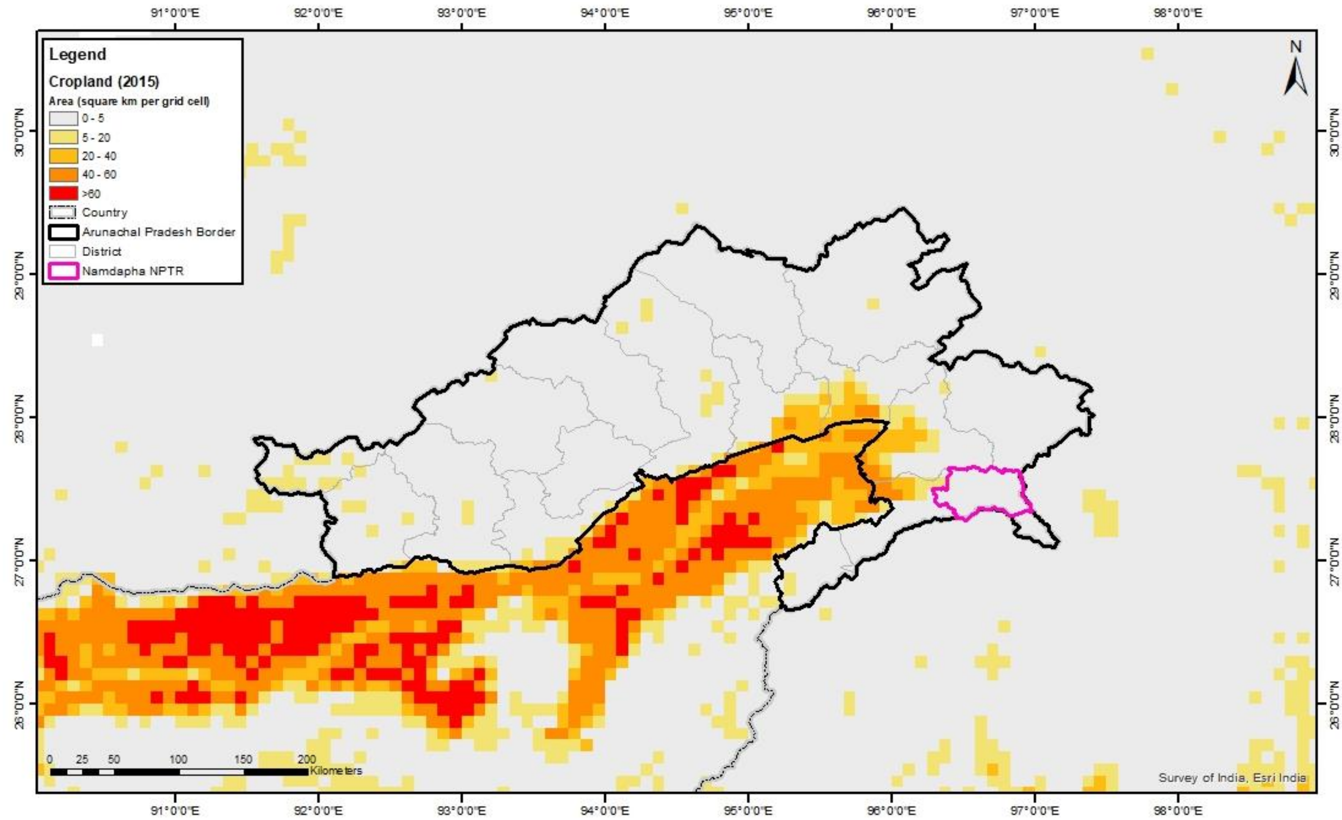


*Figure 9: Cropland in Arunachal Pradesh (2015). Created with ArcMap, from HYDE dataset*

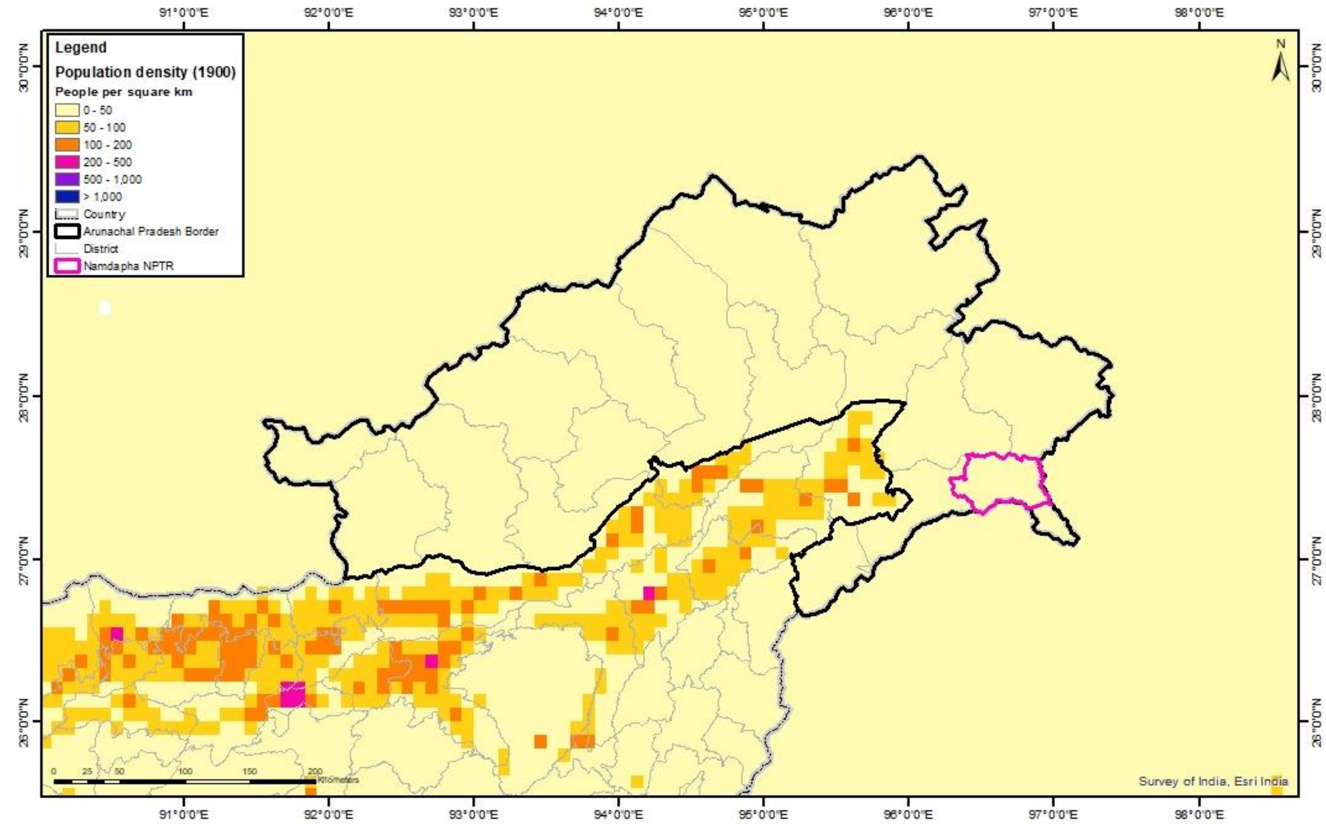


*Figure 10: Population density in Arunachal Pradesh (1900). Created with ArcMap.*

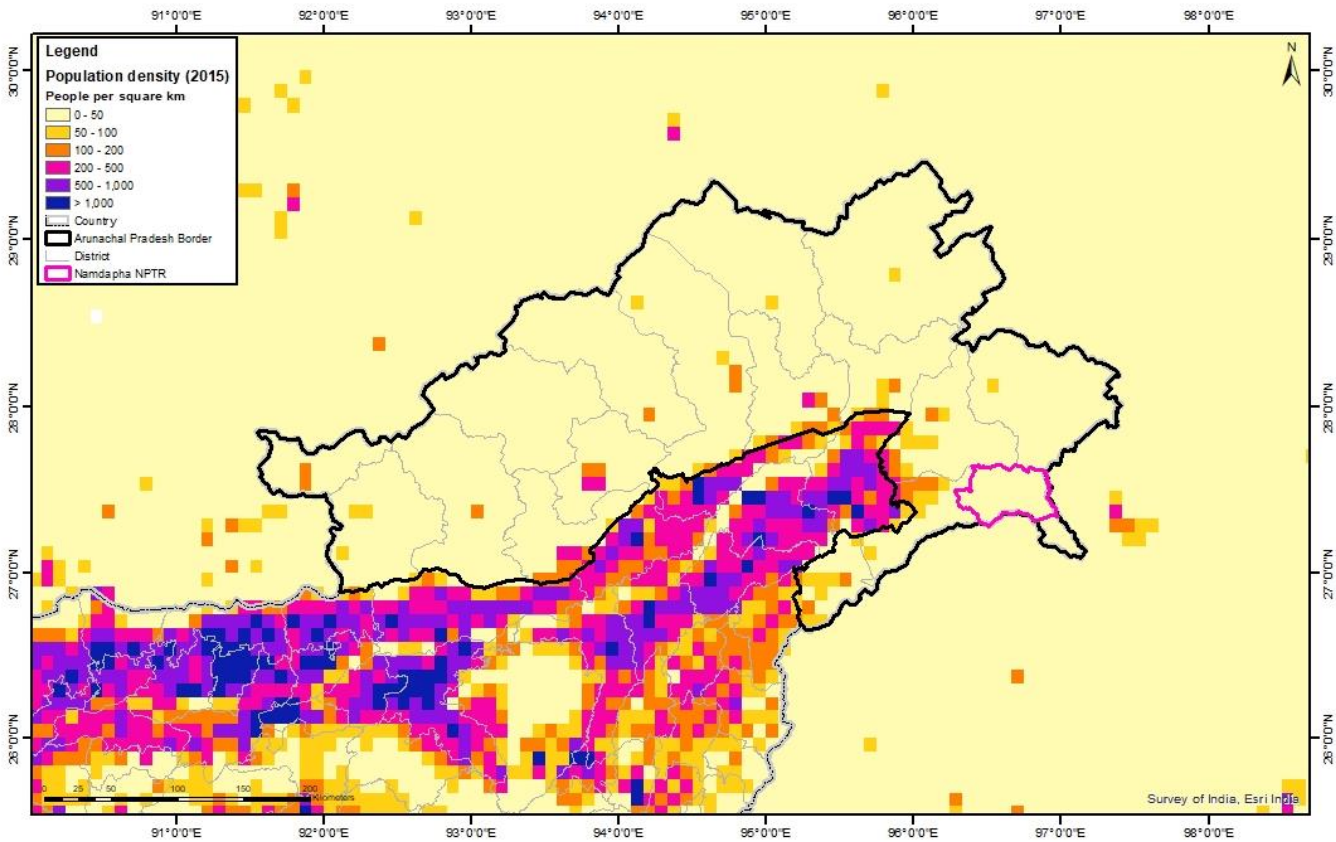


*Figure 11: Population density in Arunachal Pradesh (2000). Created with ArcMap.*

# 5. Discussion

This section provides the interpretation of key LU changes and subsequently the impacts on the Bengal tiger population. Additionally, the limitations of this research are outlined, as well as implications and recommendations.

## 5.1. Interpretation of the findings

Following the methodological approach, this chapter will be structured in two sections. First, major LU changes (1900-2015) will be linked to their drivers. Then, the effect of these two elements will be used to analyze their impact on the *P.t. tigris* population in Namdapha NPTR.

### 5.1.1. Land use changes and associated drivers

This section will address and explain major LU trends in Arunachal Pradesh. The results section has revealed clear similarities between the maps from UoM and HYDE and the elevation map depicted in *Figure 5*. Agriculture, specifically settled rain-fed cropland (see *Appendix C1/C2*), develops in the river valley area just outside of Arunachal Pradesh, because this valley is situated on ancient alluvial sediments, which are very suitable for crop cultivation (Lodrick, 2019; Das & Lodrick, 2020). Agricultural suitability, alongside other factors such as accessibility to fresh water and opportunities for transportation, explains why the expansion and intensification of croplands and population density go hand in hand.

In most cases, agricultural expansion is correlated to an increasing food demand associated with population growth and rising affluence (Amarendra & Narayanan, 2015). However, population-driven cropland expansion is only slightly relevant in this case. Despite the abundance of natural resources in the Far-Eastern Himalayas, most of the farmers, especially those that reside on the hillside, practice agriculture on a subsistence level because they lack decent infrastructure and facilities (Kumar et al., 2021). Moreover, farmers are constrained by increasing vulnerability to natural disasters in this fragile ecosystem, which is ravaged by landslides and erosion during the monsoon season (Kumar et al., 2021; Rao & Pant, 2001). The extant natural disturbances are likely to be amplified by environmental drivers in the future, as mentioned in section 2.2, facilitating an even greater demand for land.

As can be seen in the UoM maps (Figures 6 and 7), urban areas establish near agricultural areas, which is a common settlement pattern (Ramankutty, Foley & Olejniczak, 2002). Rangeland and forest give way to urbanization and agriculture, which compete from a LU perspective (Amarendra & Narayanan, 2015). As a result, agricultural lands are pushed towards more marginalized areas (Ramankutty, Foley & Olejniczak, 2002), in this case those under greater inclinations where tigers and prey reside. Despite the vulnerability of the hillside, shifting cultivation is generally practiced at higher elevations. This practice, also known as *jhum*, is an inherently unsustainable practice whereby natural vegetation is burned to clear the land, which is then cultivated for several years and later abandoned (Lodrick, 2019). This gives rise to further encroachment of pristine forest.

Despite the agricultural expansion and human encroachment, large tracts of natural forest remain (Basnet et al., 2019), as depicted in the UoM maps (Figures X and X). Logging and forestry used to make up a signification portion of the gross state product of Arunachal Pradesh, but since 1970 production has dropped, largely due to environmental legislation (Lodrick, 2019). Environmental laws possibly also explain the preservation of uninhabited forest in Myanmar. However, the extent and coherence of this forest area are under threat from illegal logging and development projects, driven by increasing demographic pressure.

### 5.1.2. Impacts on the *P.t. tigris* population

Two of the established trends put significant pressure on the *P.t. tigris* population in Namdapha NPTR: human encroachment and agricultural expansion. Both trends relate to the three most apparent threats highlighted in the DPSIR framework: direct poaching, prey depletion, and habitat degradation. Increasing demographic pressure and urbanization induced a pushing effect of anthropogenic influences toward Namdapha NPTR for land and food, resulting in encroachment in different areas of the park. The forest dwellers hunt and trap tigers and their prey (deer, wild boar, sambar, gaur) for bushmeat and hide. Moreover, the virgin forest is cleared for settlements, (shifting) agriculture, and resource extraction (Arunachalam et al., 2004; The Arunachal Times, 2022), causing fragmentation and range contraction. According to Reddy, Srinivasulu, and Rao (2004), "direct positive correlations exist between habitat richness, prey-base diversity/biomass, and tiger density". Hence, reduced habitat quality causes a lower prey density, which leads to a persistently small tiger population in Namdapha NPTR. The extant tiger population becomes even more vulnerable because of a subsequent shift in prey selection (Dinerstein et al., 2007) and the direct and indirect impacts of tiger and prey poaching, respectively.

Further anthropogenic disturbances aggravate the hostility of the environment for tigers and their prey, partly due to large development projects and associated LU changes. Arunachal Pradesh's rugged terrain used to make for limited accessibility, but connectivity in the state is increasing, partly as a response to urbanization (Lodrick, 2019). The large tracts of intact forest in Arunachal Pradesh are threatened by projects such as the 157 km Maio-Vijoynagar Road that passes through Namdapha NPTR. This road, which was constructed in 1972 and widened in 2011, exacerbates the three most prominent challenges for tigers: habitat degradation, prey depletion, and direct poaching. Roads can cause habitat fragmentation and loss of canopy, thereby reducing habitat quality and gene flow (Kirshna et al., 2013; Carter et al., 2022). According to Carter et al (2022), even small linear openings, such as a road, can be enough to significantly reduce population connectivity, posing a threat to the long-term viability of the population. Moreover, clearing hillside vegetation increases vulnerability to erosion and landslides, which affects the overall health of the ecosystem. Road development can also distort faunal behavioral patterns due to traffic noise and lights, such as breeding and migration, and lead to roadkill (Krishna et al., 2013). Additionally, prey depletion is apparent near infrastructure, and new roads portend increased human encroachment. As a result, there is easier access to illegal activities, such as logging and poaching, and human settlement (The Arunachal Times, 2022; Krishna et al., 2013; Carter et al., 2022). Human access to remote areas in combination with an increased demand for tiger products greatly intensifies hunting pressure.

However, the road helps in patrolling and monitoring the PA, thus curbing encroachment and illegal activities (The Arunachal Times, 2022), and is included in Namdapha NPTR's TCP (see section 2.2). Moreover, it might aid in the development of the local communities that reside on the PA's fringes (Krishna et al., 2013). Therefore, a trade-off exists between socio-economic and environmental interests.

In conclusion, Namdapha NPTR is facing multiple threats of agricultural expansion, habitat fragmentation, encroachments, development projects, poaching, large-scale resource extraction, and LU change, all of which have impacts that will potentially be amplified by environmental drivers. However, it is important to note that LU changes rarely follow standard ecological theories because they are often directly influenced by human activities (Roy & Roy, 2010), so the exact implications for the *P.t. tigris* population might be difficult to predict and susceptible to change.

## 5.2. Limitations

Although nearly all publications and datasets in this research are peer-reviewed, the data might be subject to some uncertainty or bias. For the GIS analysis, potential sources of error are labeling, formatting, generalizing, or digitizing. Moreover, the use of historical data is often affiliated with more uncertainty than current, measurable data. Specifically for Arunachal Pradesh, the illegal logging and inaccessibility due to rugged terrain might reduce the accuracy of the data, which potentially influenced the findings. Furthermore, both the HYDE and UoM datasets have a relatively low resolution, which limits the amount of detail in this study. The data is generalized over coarse grains, which does not give an accurate representation of the reality on a human scale. In addition, HYDE is intended for analysis over long time series. Nevertheless, these datasets can provide insight into the distribution of different LU types and the changes that occur over a span of 100 years, which makes them suitable for this kind of research.

A specific limitation of the UoM dataset is that each grid is only labeled as a certain LU type, without insight into the intensity. Hence, the created maps provide an overview of the distribution of different land types, but, for example, they do not provide information about a potential intensification of agriculture or thinning out of forestland, complicating data interpretation. This is partly compensated for with the HYDE dataset, which shows the intensity of cropland, among others. For this research, however, distribution and general trends over time are most important. Another limitation associated with the UoM datasets regards the classification of different LU types. The datasets, being sourced from ArcGIS, do not specify definitions of the LU classifications, which also complicates the interpretation of the data. For example, part of the barren land in 1900 has been transformed into agriculture in 2000. However, this same trend is not reflected in the HYDE cropland map. One possible explanation for this is that there are classification differences between the datasets, meaning that land classified as barren in UoM might contain some elements needed for agriculture. However, the class definitions were not mentioned with the rest of the metadata.

In general, research ought to be as objective as possible, but total objectivity is often difficult to achieve, especially in qualitative research. This does not only apply to this thesis, but also the publications used in this research, despite being peer-reviewed and carefully selected using the criteria mentioned in section 3.2. In this thesis, personal bias could have affected the interpretation of the findings or the demarcation of this thesis scope, for example. Subjectivity could also have been involved in the labeling of different processes in the DPSIR framework since the different components are quite broadly defined. For example, this research has classified 'human activities' as a pressure, while others might classify it as a driver. Nevertheless, DPSIR remains a useful tool for communicating science, partly because of its simplicity. This simplicity, however, is also subject to some criticism. Svarstad et al. (2008) state that this framework lacks complexity and does not properly exhibit cause-consequence relationships. According to them, this results in a bias towards the physical, human-induced side of the problem, while the social dimension is less pronounced and non-human drivers are ignored. To capture more of the social issues, 'Barriers to effective management' was added as a component in the DPSIR framework.

## 5.3. Implications

By linking interdisciplinary literature, an overview was created of the most prominent challenges facing tiger conservation in Namdapha NPTR. As mentioned in the introduction, this study area provides a unique context in which to investigate conservation implications, because it is a biodiversity hotspot, which is situated in a fragile landscape with great conservation value and yet faces a plethora of challenges. This research can be seen as a valuable addition to the existing body of literature, by providing an overview of the predator's ecology, and connecting this with regional LU changes and the associated chain of causal links.

The importance of tiger conservation lies in the interconnectedness of this top predator with the functionality of the ecosystem. Therefore, researching the cause-effect relationships of anthropogenic pressure on umbrella species such as the tiger can prove useful for lower taxa as well. This is especially relevant in fragile landscapes such as the Far Eastern Himalaya, where maintaining balance is of utmost importance to increase resilience and safeguard essential ecosystem services.

The findings of this research can provide useful insights for administrating both short-term solutions within the existing managerial regime and formulating long-term trajectories on a transboundary scale. However, there are still major gaps in our understanding of such a landscape approach.

## 5.4. Recommendations

Using the anthropogenic biomes in HYDE and DPSIR-framework, this research has focused primarily on the role of humans in the dwindling tiger populations in Namdapha NPTR. Future research could try to capture more complexity regarding non-human drivers, possibly by adopting another conceptual framework. This research also argues for more integration between science and management, especially with regard to transboundary issues. There are promising initiatives in the Eastern Himalaya Landscape, like HI-LIFE, but future research ought to work towards the functionality of such initiatives because in poaching and many other transnational problems the practical dimension is lacking. Therefore, the barriers to effective management could be further studied to better frame the socio-political context of the problem. To devise a better conservation policy, the options of traditional knowledge inclusion and involvement of local communities in decision-making should be explored. Lastly, an interesting addition to the extant literature would be to have a deeper look into the temporal dimension of tiger conservation and investigate the time lags associated specifically with drivers of tiger decimation.

## Concluding remarks

This dissertation aimed to assess the effect of land-use changes (1900-2015) and associated drivers on the *P.t. tigris* population in Namdapha NPTR. It is important to note that the tiger requires a large contiguous habitat with ample prey and cover and limited human disturbance. Tiger density seems to be primarily determined by prey diversity which, in turn, is influenced by habitat quality. According to the results of the GIS analysis, forest and rangeland give way to agricultural and urban area, hence reducing habitat quality. Further human encroachment, driven by population growth and increasing demand for food and land, aggravates the disturbance regime in the park. Urbanization incentivizes connectivity within Arunachal Pradesh, leading to deforestation for resource extraction and settlements, and increasing the tiger's vulnerability to poaching. Moreover, demographic pressure induces a pushing effect of agricultural land into previously undisturbed, marginalized areas, where tigers and their prey reside. The most prominent threats for tigers can thus be subdivided into three major challenges: natural habitat degradation, prey depletion, and direct poaching.

The unique context of Namdapha NPTR has shown that PAs are fundamental for restoring tiger populations. However, proper transboundary management is required to ensure a tiger permeable landscape. Without this, PAs would be like conservation islands in a vast sea of hostile habitat, hence increasing vulnerability and forming a threat to the long-term viability of this flagship species.


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## References


Allen, W. (2022, 4 April). *Using a DPSIR framework to support good natural resource management and policy*. Learning for Sustainability. Retrieved 8 May 2022, from https://learningforsustainability.net/post/extended-dpsir/

Amarendra, A., & Narayanan, K. (2015). Agriculture intensification, population growth and cropland expansion: evidence from post-Green Revolution Andhra Pradesh.

Arunachalam, A., Sarmah, R., Adhikari, D., Majumder, M., & Khan, M. L. (2004). *Anthropogenic threats and biodiversity conservation in Namdapha nature reserve in the Indian Eastern Himalayas* (Vol. 87, Issue 4). https://www.jstor.org/stable/24109174

Basnet, D., Kandel, P., Chettri, N., Yang, Y., Lodhi, M. S., Htun, N. Z., Uddin, K., & Sharma, E. (2019). Biodiversity Research Trends and Gaps from the Confluence of Three Global Biodiversity Hotspots in the Far-Eastern Himalaya. *International Journal of Ecology*, *2019*, 1–14. https://doi.org/10.1155/2019/1323419

Bhandari, S. (2014). Prey selection by Bengal Tiger (Panthera tigris tigris, Linnaeus 1758) in Chitwan National Park, Nepal. https://www.researchgate.net/publication/311431546_Prey_selection_by_Bengal_Tiger_Panthera_tigris_tigris_Linnaeus_1758_in_Chitwan_National_Park_Nepal

Breuer, T., Maisels, F., & Fishlock, V. (2016). The consequences of poaching and anthropogenic change for forest elephants. *Conservation Biology*, *30*(5), 1019–1026. https://doi.org/10.1111/cobi.12679

Carter, N. H., Pradhan, N., Hengaju, K., Sonawane, C., Sage, A. H., & Grimm, V. (2022). Forecasting effects of transport infrastructure on endangered tigers: a tool for conservation planning. *PeerJ*, *10*, e13472. https://doi.org/10.7717/peerj.13472

Cary, Z. (2019, 16 December). *Top 10 Biggest Cats in the World*. Earth and World 2022. Retrieved 7 June 2022, from https://earthnworld.com/biggest-cats-in-the-world/

Damania, R., Stringer, R., Karanth, K. U., & Stith, B. (2002). The Economics of Protecting Tiger Populations: Linking Household Behaviour to Poaching and Prey Depletion. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.295494

Das, H., & Lodrick, D. O. (2020). *Assam | History, Map, Population, & Facts*. Encyclopedia Britannica. Retrieved 22 June 2022, from https://www.britannica.com/place/Assam

Dinerstein, E., Loucks, C., Wikramanayake, E., Ginsberg, J., Sanderson, E., Seidensticker, J., Forrest, J., Bryja, G., Heydlauff, A., Klenzendorf, S., Leimgruber, P., Mills, J., O'Brien, T. G., Shrestha, M., Simons, R., & Songer, M. (2007). The fate of wild tigers. In *BioScience* (Vol. 57, Issue 6, pp. 508–514). https://doi.org/10.1641/B570608

Etter, A., McAlpine, C., Wilson, K., Phinn, S., & Possingham, H. (2006). Regional patterns of agricultural land use and deforestation in Colombia. *Agriculture, Ecosystems & Environment*, *114*(2–4), 369–386. https://doi.org/10.1016/j.agee.2005.11.013

FAO. (2001). *Land Cover Classification System (Lccs: Classification Concepts and User Manual).* Food & Agriculture Organization of the United Nations.

FAO. (2022). *SDG 15. Life on land | www.fao.org*. Food and Agriculture Organization of the United Nations. Retrieved 10 May 2022, from https://www.fao.org/sustainable-development-goals/goals/goal-15/en/

Gessesew W. S. (2013). *Application of DPSIR Framework for Assessment of Land Degradation: A Review*. https://doi.org/10.31031/APDV.2017.01.000522

Global Tiger Forum. (2019). *Status of Tiger Habitats in High Altitude Ecosystems of Bhutan, India and Nepal (Situation Analysis)*. http://globaltigerforum.org/wp-content/uploads/2019/09/Final-HAT-VERSION-28-AUGUST-20191.pdf

Güler, M., Yomralıoğlu, T., & Reis, S. (2006). Using landsat data to determine land use/land cover changes in Samsun, Turkey. *Environmental Monitoring and Assessment*, *127*(1–3), 155–167. https://doi.org/10.1007/s10661-006-9270-1

Hayward, Matt & Jedrzejewski, Wlodzimierz (2012). Prey preferences of the tiger. Journal of Zoology. 221-231.

ICIMOD (2018a). *Regional workshop on planning transboundary technical collaboration for landscape management*. ICIMOD Workshop Report 2018. Kathmandu: ICIMOD https://www.researchgate.net/publication/327305055_Regional_workshop_on_planning_transboundary_technical_collaboration_for_landscape_management_ICIMOD_Workshop_Report_2018

ICIMOD. (2018b). Landscape Initiative for Far-Eastern Himalayas (Hi-LIFE). *International Centre for Integrated Mountain Development*. https://doi.org/10.53055/icimod.891

ICIMOD. (2021a). *Namdapha National Park and Tiger Reserve | HimalDoc*. Retrieved 11 May 2022, from https://lib.icimod.org/record/35342

ICIMOD. (2021b, July 15). *A shared landscape for tigers*. Retrieved 16 May 2022, from https://www.icimod.org/success-stories/annual-report-2020/a-shared-landscape-for-tigers/

Jhala, Y.V., Qureshi, Q. and Nayak, A.K. (2020). Status of tigers, copredators and prey in India, 2018. National Tiger Conservation Authority, Government of India, New Delhi, and Wildlife Institute of India, Dehradun.

Johnsingh, A.J.T. (1992). Prey selection in three large sympatric carnivores in Bandipur. *Mammalia*, *56*(4). https://doi.org/10.1515/mamm.1992.56.4.517

Karanth, K. U. (2014, 20 April). *The*. IUCN Red List of Threatened Species. Retrieved 11 May 2022, from https://www.iucnredlist.org/species/15955/50659951#habitat-ecology

Karanth, K. U., & Sunquist, M. E. (1995). Prey Selection by Tiger, Leopard and Dhole in Tropical Forests. In *Source: Journal of Animal Ecology* (Vol. 64, Issue 4).

Karanth, K. U., Gopalaswamy, A. M., Kumar, N. S., Delampady, M., Nichols, J. D., Seidensticker, J., Noon, B. R., & Pimm, S. L. (2011). Counting India's Wild Tigers Reliably. *Science*, *332*(6031), 791. https://doi.org/10.1126/science.332.6031.791-a

Karanth, K. U., Nichols, J. D., Kumar, N. S., Link, W. A., & Hines, J. E. (2004). Tigers and their prey: Predicting carnivore densities from prey abundance. *Proceedings of the National Academy of Sciences*, *101*(14), 4854–4858. https://doi.org/10.1073/pnas.0306210101

Khan, A., Patel, K., Shukla, H., Viswanathan, A., Van der Valk, T., Borthakur, U., Nigam, P., Zachariah, A., Jhala, Y. V., Kardos, M., & Ramakrishnan, U. (2021). Genomic evidence for inbreeding depression and purging of deleterious genetic variation in Indian tigers. *Proceedings of the National Academy of Sciences*, *118*(49). https://doi.org/10.1073/pnas.2023018118

Khorozyan, I., Ghoddousi, A., Soofi, M., & Waltert, M. (2015). Big cats kill more livestock when wild prey reaches a minimum threshold. *Biological Conservation*, *192*, 268–275. https://doi.org/10.1016/j.biocon.2015.09.031

Klein Goldewijk, C.G.M., Beusen, A., Doelman, J., & Stehfest, E. (2017). Anthropogenic land use estimates for the Holocene – HYDE 3.2. *Earth System Science Data*, *9*(2), 927–953. https://doi.org/10.5194/essd-9-927-2017

Krishna, M., Kumar, A., Ray, P. C., Sarma, K., Devi, A., & Khan, M. L. (2013). *Impact of road widening on wildlife in Namdapha National Park, Arunachal Pradesh, India: a conservation issue*.

Kumar, P., Sharma, P., Kumar, P., & Butail, N. (2021). Agricultural Sustainability in Indian Himalayan Region: Constraints and Potentials. Indian Journal of Ecology. 42. 649-662.

Lambin, E. F., & Geist, H. (Eds.). (2006). Land-Use and Land-Cover Change. *Global Change - The IGBP Series*, 42-45. https://doi.org/10.1007/3-540-32202-7

Lamichhane, S., & Jha, B. R. (2015). Prey selection by Bengal Tiger Panthera tigris tigris (Mammalia: Carnivora: Felidae) of Chitwan National Park, Nepal. *Journal of Threatened Taxa*, *7*(14), 8081. https://doi.org/10.11609/jott.2424.7.14.8081-8088

Lemmons, R. (2022, 7 January). *The Dpsir Analytical Framework - Sustainable Development*. Climate Policy Watcher. Retrieved 16 May 2022, from https://www.climate-policy-watcher.org/sustainable-development/the-dpsir-analytical-framework.html

Lodhi, M. S., Samal, P. K., Chaudhry, S., Palni, L. M. S., & Dhyani, P. P. (2013). Land Cover Mapping for Namdapha National Park (Arunachal Pradesh), India Using Harmonized Land Cover Legends. *Journal of the Indian Society of Remote Sensing*, *42*(2), 461–467. https://doi.org/10.1007/s12524-013-0326-8

Lodrick, D. O. (2019, 27 May). Arunachal Pradesh. Encyclopedia Britannica. Retrieved 13 June 2022, from https://www.britannica.com/place/Arunachal-Pradesh

Madhusudan, M.. (2005). Of Rights and Wrongs: Wildlife Conservation and the Tribal Bill. Economic and Political Weekly. 40. 4893-4895. 10.2307/4417419.

Mallick, J. (2019). Panthera tigris: range and population collapse in Northern West Benal, India. Biodiversity International Journal. 3. 10.15406/bij.2019.03.00135.

Mandalios, J. (2013). RADAR: An approach for helping students evaluate Internet sources. *Journal of Information Science*, *39*(4), 470–478. https://doi.org/10.1177/0165551513478889

Mandal, R. K., Alam, M. A., Baba, U., Raiula, T., & Kumar, S. (2020). Status and velocity of urbanization in Arunachal Pradesh, India: a new direction. *Ilkogretim Online*, *19*(4), 3040–3054. https://doi.org/10.17051/ilkonline.2020.04.764679

Mangi, S. C., Roberts, C. M., & Rodwell, L. D. (2007). Reef fisheries management in Kenya: Preliminary approach using the driver–pressure–state–impacts–response (DPSIR) scheme of indicators. *Ocean & Coastal Management*, *50*(5–6), 463–480. https://doi.org/10.1016/j.ocecoaman.2006.10.003

Mondol, S., Karanth, K. U., & Ramakrishnan, U. (2009). Why the Indian Subcontinent Holds the Key to Global Tiger Recovery. *PLoS Genetics*, *5*(8), e1000585. https://doi.org/10.1371/journal.pgen.1000585

Mukherjee, S., & Sen Sarkar, N. (2013). The Range of Prey Size of the Royal Bengal Tiger of Sundarbans. *Journal of Ecosystems*, *2013*, 1–7. https://doi.org/10.1155/2013/351756

Namdapha Tiger Reserve. (n.d.a). *Fauna*. Retrieved 9 May 2022, from https://namdaphatigerreserve.org/Fauna.php

Namdapha Tiger Reserve. (n.d.b). *Namdapha Tiger Reserve*. Retrieved 16 May 2022, from https://namdaphatigerreserve.org/view%20TCP.php?a=CORE%20Part%20-%20B%20Proposed%20Management.pdf&b=CORE%20Part%20-%20B%20Proposed%20Management

Narain, P. (n.d.). *LAND USE CLASSIFICATION: CONCEPTS & METHODS - Towards an improved information basis* [Presentation slides]. FAO. https://www.fao.org/fileadmin/templates/ess/documents/meetings_and_workshops/ICAS5/PDF/ICASV_4.2_031_PPT_Narain.pdf

Nath, P., Arunachalam, A., Khan, M., Arunachalam, K., & Barbhuiya, A. (2005). Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, northeast India. *Biodiversity and Conservation*, *14*(9), 2109–2135. https://doi.org/10.1007/s10531-004-4361-1

Oliver, T. H., Heard, M. S., Isaac, N. J., Roy, D. B., Procter, D., Eigenbrod, F., Freckleton, R., Hector, A., Orme, C. D. L., Petchey, O. L., Proença, V., Raffaelli, D., Suttle, K. B., Mace, G. M., Martín-López, B., Woodcock, B. A., & Bullock, J. M. (2015). Biodiversity and Resilience of Ecosystem Functions. *Trends in Ecology & Evolution*, *30*(11), 673–684. https://doi.org/10.1016/j.tree.2015.08.009

Parth, R. & Arijit, R. (2010). Land Use and Land Cover Change: A Remote Sensing & GIS Perspective. Journal of the Indian Institute of Science. 90. 489-502.

Pawar, S., Koo, M. S., Kelley, C., Ahmed, M. F., Chaudhuri, S., & Sarkar, S. (2007). Conservation assessment and prioritization of areas in Northeast India: Priorities for amphibians and reptiles. *Biological Conservation*, *136*(3), 346–361. https://doi.org/10.1016/j.biocon.2006.12.012

Project Tiger (2005). Joining the Dots: The Report of the Tiger Task Force. New Delhi (India): Government of India, Union Ministry of Environment and Forests.

Raaj, N. (2009, 8 August). *This may be the last time you see a tiger*. The Times of India. Retrieved 16 May 2022, from https://timesofindia.indiatimes.com/home/sunday-times/deep-focus/this-may-be-the-last-time-you-see-a-tiger/articleshow/4872542.cms

Ramankutty, N., Foley, J. A., & Olejniczak, N. J. (2002). People on the Land: Changes in Global Population and Croplands during the 20$^{th}$Century. *AMBIO: A Journal of the Human Environment*, *31*(3), 251–257. https://doi.org/10.1579/0044-7447-31.3.251

Ranganathan, J., Chan, K. M., Karanth, K. U., & Smith, J. L. D. (2008). Where can tigers persist in the future? A landscape-scale, density-based population model for the Indian subcontinent. *Biological Conservation*, *141*(1), 67–77. https://doi.org/10.1016/j.biocon.2007.09.003

Rao, K., & Pant, R. (2001). Land use dynamics and landscape change pattern in a typical micro watershed in the mid elevation zone of central Himalaya, India. *Agriculture, Ecosystems & Environment*, *86*(2), 113–124. https://doi.org/10.1016/s0167-8809(00)00274-7

Rastogi, A., Hickey, G. M., Badola, R., & Hussain, S. A. (2012). Saving the superstar: A review of the social factors affecting tiger conservation in India. In *Journal of Environmental Management* (Vol. 113, pp. 328–340). https://doi.org/10.1016/j.jenvman.2012.10.003

Reddy, H.S., Srinivasulu, C., & Rao, K.T. (2004). Prey selection by the Indian tiger (Panthera tigris tigris) in Nagarjunasagar Srisailam Tiger Reserve, India. *Mammalian Biology, 69*, 384-391.

Roura-Pascual, N., Richardson, D. M., Krug, R. M., Brown, A., Chapman, R. A., Forsyth, G. G., Le Maitre, D. C., Robertson, M. P., Stafford, L., Van Wilgen, B. W., Wannenburgh, A., & Wessels, N. (2009). Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making. *Biological Conservation*, *142*(8), 1595–1604. https://doi.org/10.1016/j.biocon.2009.02.029

Roy, P. & Roy, A. (2010). Land Use and Land Cover Change: A Remote Sensing & GIS Perspective. Journal of the Indian Institute of Science. 90. 489-502.

Saikia, P., Deka, J., Bharali, S., Kumar, A., Tripathi, O. P., Singha, L. B., Dayanandan, S., & Khan, M. L. (2017). Plant diversity patterns and conservation status of eastern Himalayan forests in Arunachal Pradesh, Northeast India. *Forest Ecosystems*, *4*(1). https://doi.org/10.1186/s40663-017-0117-8

Sangomla, A. (2021). *Climate change in North East: Arunachal's Seijosa shows connect between shifting patterns, declining biodiversity*. DownToEarth. Retrieved 12 May 2022, from https://www.downtoearth.org.in/news/climate-change/climate-change-in-north-east-arunachal-s-seijosa-shows-connect-between-shifting-patterns-declining-biodiversity-75016

Sarkar, M. S., Amonge, D. E., Pradhan, N., Naing, H., Huang, Z., & Lodhi, M. S. (2021). A Review of Two Decades of Conservation Efforts on Tigers, Co-Predators and Prey at the Junction of Three Global Biodiversity Hotspots in the Transboundary Far-Eastern Himalayan Landscape. *Animals*, *11*(8), 2365. https://doi.org/10.3390/ani11082365

Selvan, K. M., Veeraswami, G. G., Lyngdoh, S., Habib, B., & Hussain, S. A. (2013). Prey selection and food habits of three sympatric large carnivores in a tropical lowland forest of the Eastern Himalayan Biodiversity Hotspot. *Mammalian Biology*, *78*(4), 296–303. https://doi.org/10.1016/j.mambio.2012.11.009

Shakya, B., Uddin, K., Yi, S., Bhatta, L. D., Lodhi, M. S., Htun, N. Z., & Yang, Y. (2021). Mapping of the ecosystem services flow from three protected areas in the far-eastern Himalayan Landscape: An impetus to regional cooperation. *Ecosystem Services*, *47*, 101222. https://doi.org/10.1016/j.ecoser.2020.101222

Sunquist, M.E., K.U. Karanth & F.C. Sunquist (1999). Ecology, behavior and resilience of the tiger and its conservation needs, pp. 5–18. In: Seidensticker, J., S. Christie & P. Jackson (eds.). Riding the Tiger: Tiger Conservation in Human-dominated Landscapes. Cambridge University Press, Cambridge, UK.

Sunquist, M. E., & Sunquist, F. C. (1989). Ecological Constraints on Predation by Large Felids. *Carnivore Behavior, Ecology, and Evolution*, 283–301. https://doi.org/10.1007/978-1-4757-4716-4_11

Smeets, E., & Weterings, R. (1999, 7 September). *Environmental indicators: Typology and overview*. European Environment Agency. Retrieved 16 Mei 2022, from https://www.eea.europa.eu/publications/TEC25

Svarstad, H., Petersen, L. K., Rothman, D., Siepel, H., & Wätzold, F. (2008). Discursive biases of the environmental research framework DPSIR. *Land Use Policy*, *25*(1), 116–125. https://doi.org/10.1016/j.landusepol.2007.03.005

The Arunachal Times. (2022, 28 February). *Namdapha National Park threatened by encroachment*. The Arunachal Times. Retrieved 16 May 2022, from https://arunachaltimes.in/index.php/2022/03/01/namdapha-national-park-threatened-by-encroachment/

University of Minnesota. (2017a, 27 January). *Land Use 1900* [Dataset]. NASA Socioeconomic Data and Applications Center (Sedac). https://www.arcgis.com/home/item.html?id=426b954b5be74d599b6ce85f2ad10642

University of Minnesota. (2017b, 27 January). *Land Use 2000* [Dataset]. NASA Socioeconomic Data and Applications Center (Sedac). https://www.arcgis.com/home/item.html?id=5d4a0f170e8e4858b8142ffc2057feb6

US Census Bureau. (2021, October 8). *Understanding Population Density*. The United States Census Bureau. Retrieved 16 June 2022, from https://www.census.gov/newsroom/blogs/random-samplings/2015/03/understanding-population-density.html

Vasudeva, V., Upgupta, S., Singh, A., Sherwani, N., Dutta, S., Rajaraman, R., Chaudhuri, S., Verma, S., Johnson, J. A., & Krishnamurthy, R. (2022). Conservation Prioritization in a Tiger Landscape: Is Umbrella Species Enough? *Land*, *11*(3), 371. https://doi.org/10.3390/land11030371

Walston, J., Robinson, J. G., Bennett, E. L., Breitenmoser, U., Da Fonseca, G. A. B., Goodrich, J., Gumal, M., Hunter, L., Johnson, A., Karanth, K. U., Leader-Williams, N., MacKinnon, K., Miquelle, D., Pattanavibool, A., Poole, C., Rabinowitz, A., Smith, J. L. D., Stokes, E. J., Stuart, S. N., . . . Wibisono, H. (2010). Bringing the Tiger Back from the Brink—The Six Percent Solution. *PLoS Biology*, *8*(9), e1000485. https://doi.org/10.1371/journal.pbio.1000485

Wild Cats World. (2022, January 11). *Tiger (Panthera Tigris)*. Wild Cats World - Official Sanctuary. Retrieved 9 May 2022, from https://www.wildcatsworld.org/wild-cat-species/tiger-panthera-tigris/

WPSI. (n.d.). *WPSI Legal Programme*. Wild Life Protection Society of India. Retrieved 16 May 2022, from http://www.wpsi-india.org/tiger/poaching_crisis.php

# Appendices

## Appendix A

Diet

No specific ecological analysis about the tigers in Namdapha NPTR was located via the search engines used in the methodological approach. Therefore, alternative literature about the living conditions of the *P.t. tigris* was consulted to provide a general overview that will aid this research. The publications used for this section give estimates based on scat analysis. They cover study areas that resemble the conditions in Namdapha NPTR, namely PAs within the Eastern Himalayas or North-eastern India with comparable prey species composition. Moreover, additional literature is used to substantiate the statements. Namdapha NPTR houses species that are repeatedly mentioned in the selected publications as significant contributions to the tiger's diet, including sambar (*Rusa unicolor*), barking deer (*Munticus muntjak*), gaur (*Bos gaurus*), and wild boar (*Sus scrofa*) (Namdapha Tiger Reserve, n.d.a; Mukherjee & Sen Sarker, 2013; Selvan et al., 2013; Reddy, Srinivasulu, Rao, 2004; Karanth & Sunquist, 1995). The figure below displays the prey preferences for tigers in Pakke Tiger Reserve, which is located in the same area as NNPTR, Arunachal Pradesh in the Eastern Himalaya, and resembles Namdapha NPTR with regard to key mammalian species.

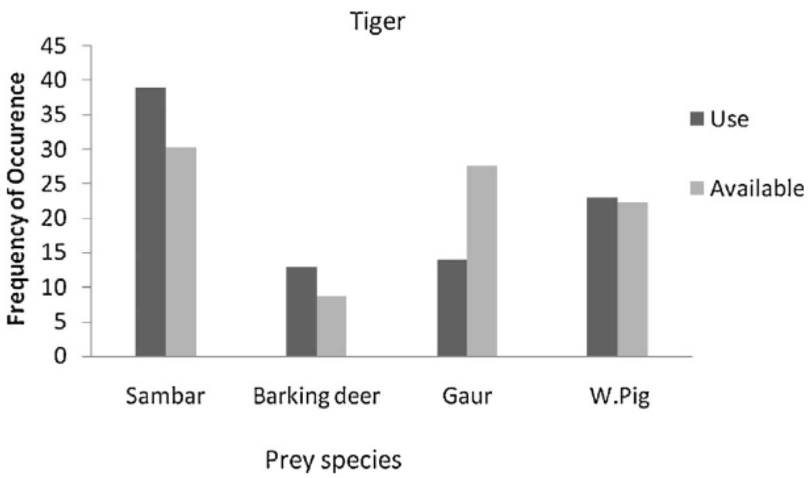



*Figure A1: "Comparison of expected observed and expected proportion of prey in tiger scats" (Selvan et al., 2013)*

Interspecific competition

Besides the aforementioned predator-prey interactions, interspecific predator-predator interactions should also be shortly mentioned. Co-existence of sympatric carnivores is facilitated by niche differentiation, for example in the selective predation of different species, body size and age classes of their prey (Karanth & Sunquist, 1995; Johnsingh, 1992; Selvan et al., 2013). In addition, tigers are socially dominant over sympatric carnivores. Therefore, interspecific tiger density seems to be predominantly determined by prey abundance rather than interspecific competition (Karanth et al., 2004).

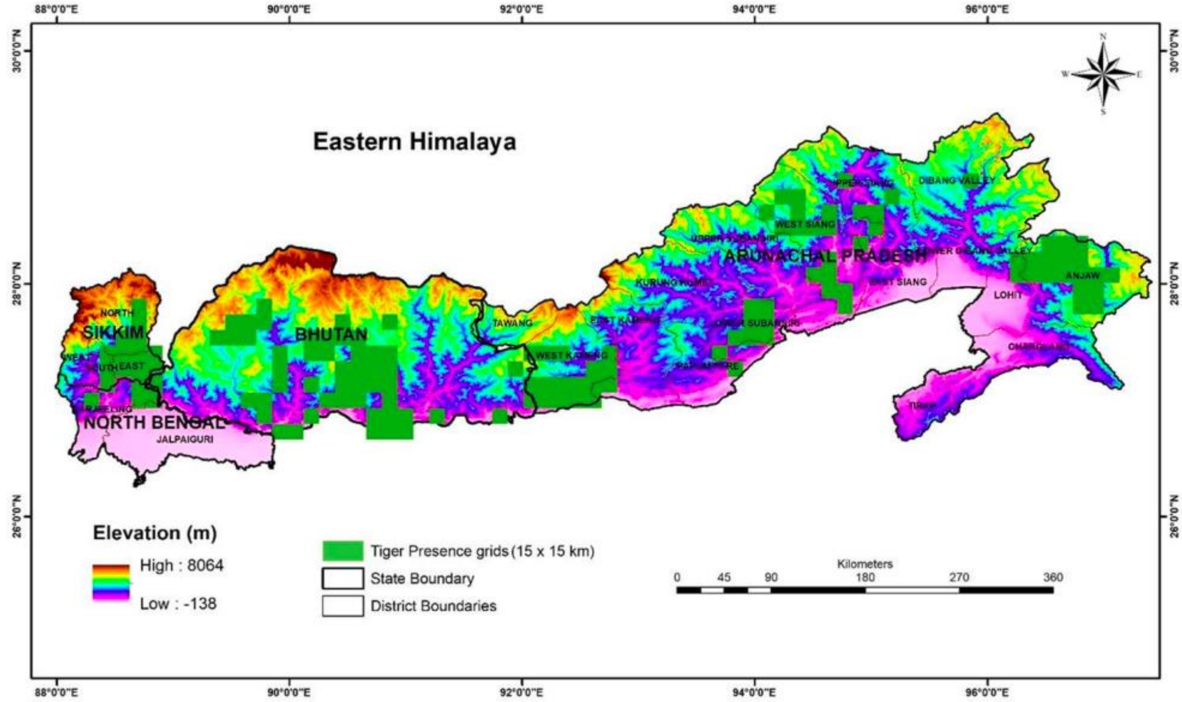
Habitat

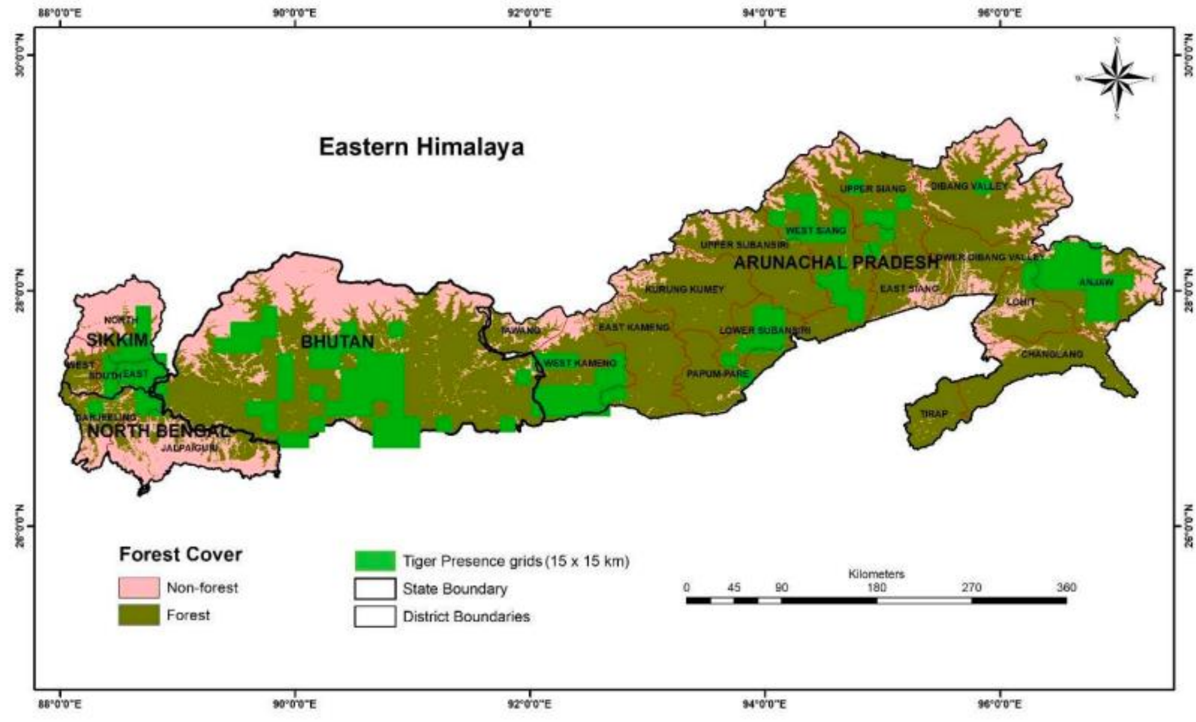
Global Tiger Forum (2019) mentions several factors that foster tiger presence in Arunachal Pradesh:

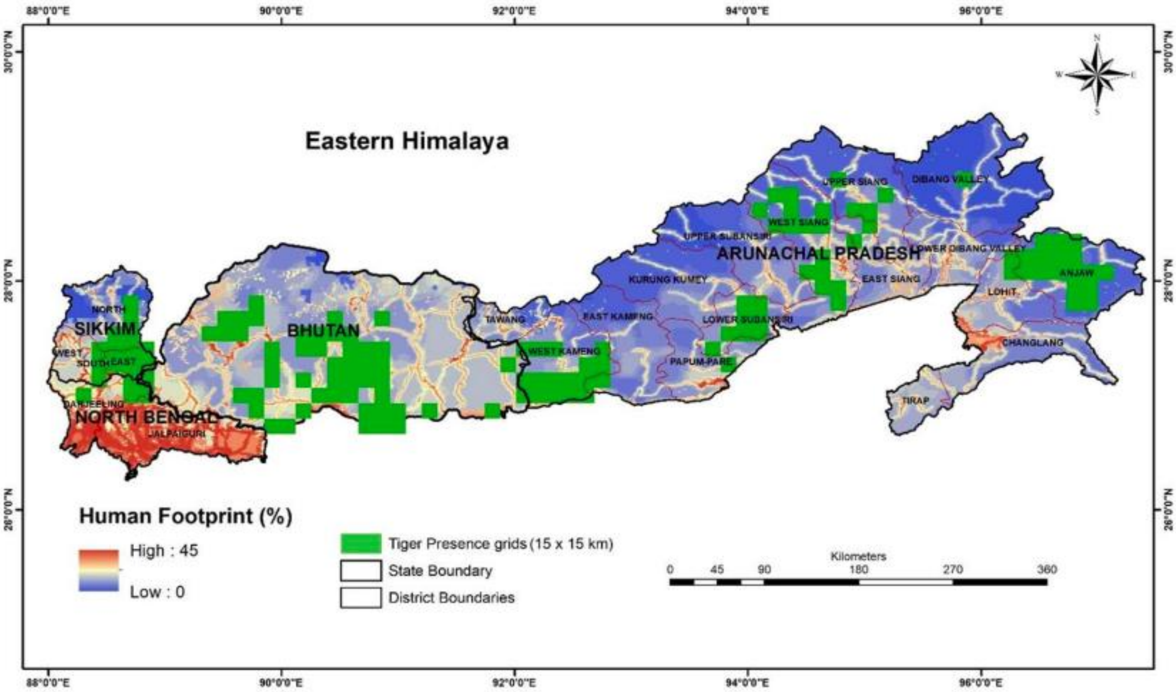
- Moderate Elevation Complexity
- Moderate Forest Cover
- Gentle Slope
- High Drainage Density
- Low Human Footprint
- Low Temperature Condition
- Moderate Dry Condition

To visualize this, several graphs show the current status of each of these factors:

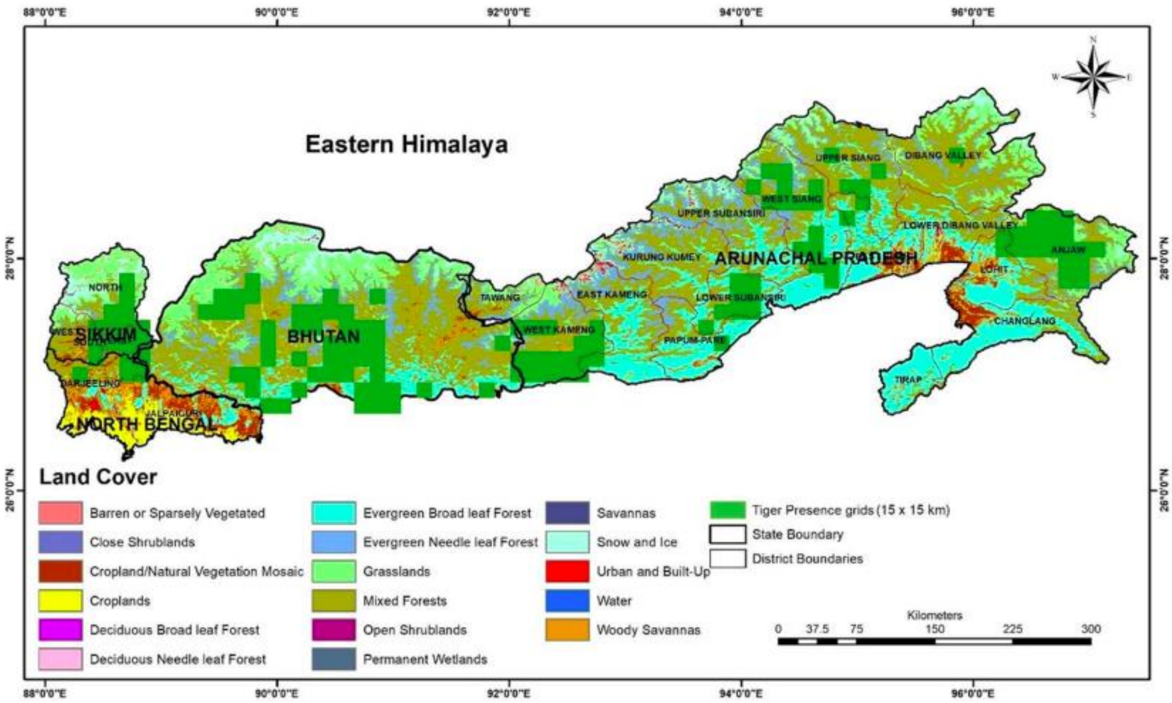
NOTE: these graphs are directly derived from the Global Tiger Forum report (2019). Tiger presence was measured using camera trap analysis, in which Namdapha NPTR was not included.


Eastern Himalaya
88°0'0"E
90°0'0"E
92°0'0"E
94°0'0"E
96°0'0"E
30°0'0"N
28°0'0"N
26°0'0"N
SIKKIM
NORTH
WEST
SOUTH
EAST
DARJEELING
NORTH BENGAL
JALPAIGURI
BHUTAN
TAWANG
WEST KAMENG
EAST KAMENG
KURUNG KUMEY
ARUNACHAL PRADESH
WEST SIANG
UPPER SIANG
DIBANG VALLEY
EAST SIANG
LOWER SUBANSIRI
PAPUM PARE
LOHIT
ANJAW
TIRAP
Elevation (m)
High : 8064
Low : -138
Tiger Presence grids (15 x 15 km)
State Boundary
District Boundaries
Kilometers
0 45 90 180 270 360

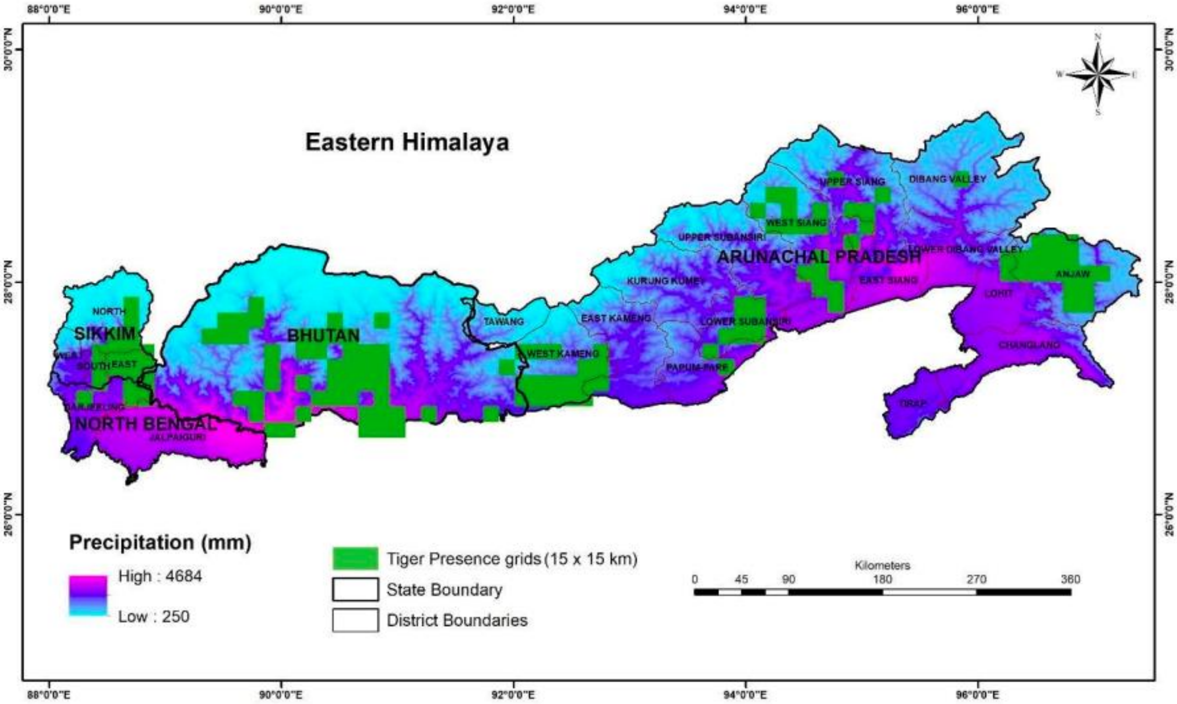

Eastern Himalaya
88°0'0"E
90°0'0"E
92°0'0"E
94°0'0"E
96°0'0"E
30°0'0"N
28°0'0"N
26°0'0"N
SIKKIM
NORTH
WEST
SOUTH
EAST
DARJEELING
NORTH BENGAL
JALPAIGURI
BHUTAN
TAWANG
WEST KAMENG
EAST KAMENG
KURUNG KUMEY
UPPER SUBANSIRI
ARUNACHAL PRADESH
WEST SIANG
UPPER SIANG
DIBANG VALLEY
LOWER DIBANG VALLEY
EAST SIANG
LOWER SUBANSIRI
PAPUM-PARE
LOHIT
ANJAW
CHANGLANG
TIRAP
Forest Cover
Non-forest
Forest
Tiger Presence grids (15 x 15 km)
State Boundary
District Boundaries
Kilometers
0 45 90 180 270 360

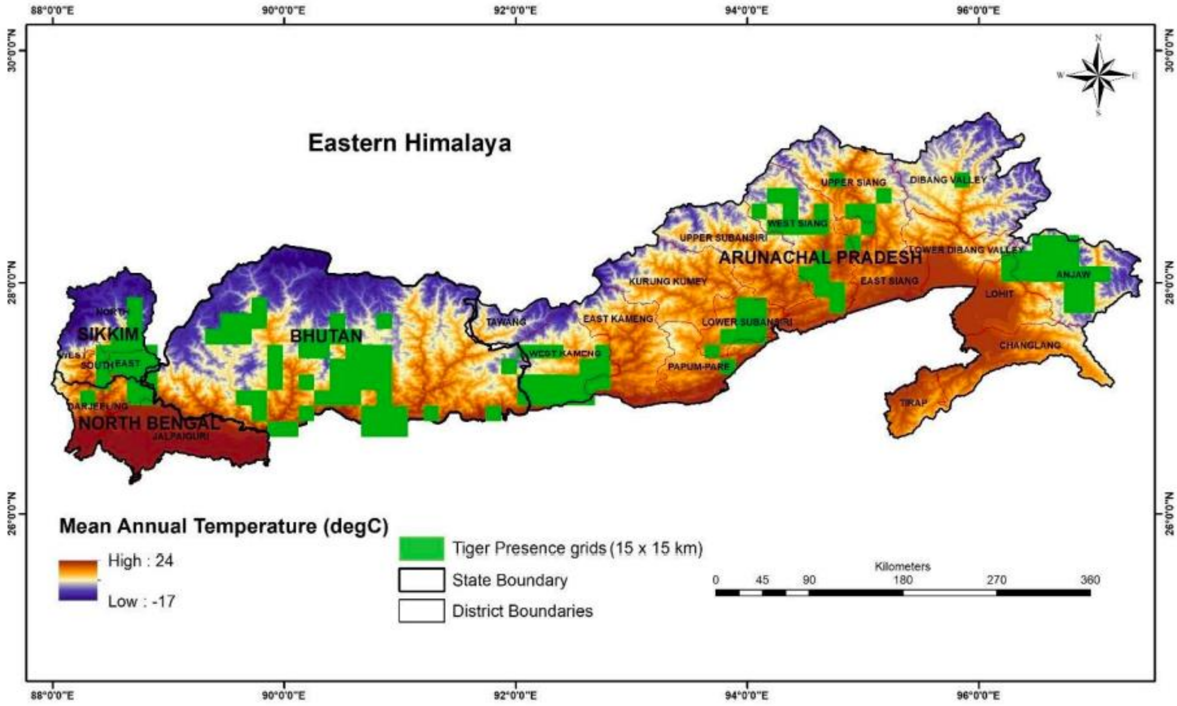


Eastern Himalaya
SIKKIM
BHUTAN
ARUNACHAL PRADESH
NORTH BENGAL
Human Footprint (%)
High : 45
Low : 0
Tiger Presence grids (15 x 15 km)
State Boundary
District Boundaries
Kilometers
0 45 90 180 270 360

Eastern Himalaya
SIKKIM
BHUTAN
ARUNACHAL PRADESH
NORTH BENGAL
Land Cover
Barren or Sparsely Vegetated
Close Shrublands
Cropland/Natural Vegetation Mosaic
Croplands
Deciduous Broad leaf Forest
Deciduous Needle leaf Forest
Evergreen Broad leaf Forest
Evergreen Needle leaf Forest
Grasslands
Mixed Forests
Open Shrublands
Permanent Wetlands
Savannas
Snow and Ice
Urban and Built-Up
Water
Woody Savannas
Tiger Presence grids (15 x 15 km)
State Boundary
District Boundaries
Kilometers
0 37.5 75 150 225 300


Eastern Himalaya
SIKKIM
NORTH
SOUTH
EAST
DARJEELING
NORTH BENGAL
JALPAIGURI
BHUTAN
TAWANG
WEST KAMENG
EAST KAMENG
KURUNG KUMEY
UPPER SUBANSIRI
LOWER SUBANSIRI
PAPUM-PARE
ARUNACHAL PRADESH
WEST SIANG
UPPER SIANG
EAST SIANG
DIBANG VALLEY
LOWER DIBANG VALLEY
LOHIT
ANJAW
CHANGLANG
TIRAP
Precipitation (mm)
High : 4684
Low : 250
Tiger Presence grids (15 x 15 km)
State Boundary
District Boundaries
Kilometers
0 45 90 180 270 360
88°0'0"E
90°0'0"E
92°0'0"E
94°0'0"E
96°0'0"E
30°0'0"N
28°0'0"N
26°0'0"N


Eastern Himalaya
SIKKIM
NORTH
SOUTH
EAST
DARJEELING
NORTH BENGAL
JALPAIGURI
BHUTAN
TAWANG
WEST KAMENG
EAST KAMENG
KURUNG KUMEY
UPPER SUBANSIRI
LOWER SUBANSIRI
PAPUM-PARE
ARUNACHAL PRADESH
WEST SIANG
UPPER SIANG
EAST SIANG
DIBANG VALLEY
LOWER DIBANG VALLEY
LOHIT
ANJAW
CHANGLANG
TIRAP
Mean Annual Temperature (degC)
High : 24
Low : -17
Tiger Presence grids (15 x 15 km)
State Boundary
District Boundaries
Kilometers
0 45 90 180 270 360
88°0'0"E
90°0'0"E
92°0'0"E
94°0'0"E
96°0'0"E
30°0'0"N
28°0'0"N
26°0'0"N

## Appendix B

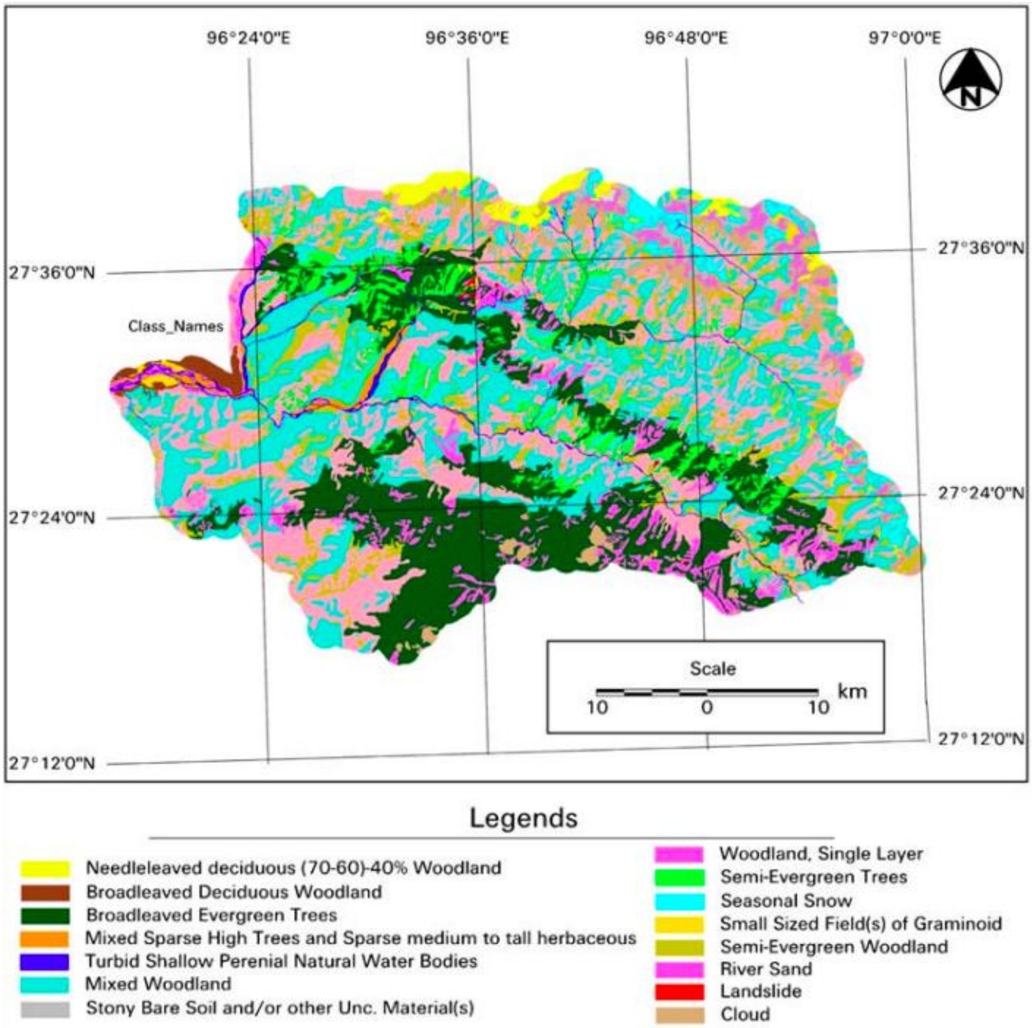



*Figure B: Land cover in Namdapha NPTR (Lodhi et al., 2013)*

## Appendix C

As mentioned in the methodological approach, HYDE contains two main categories: cropland and grazing lands. The former includes a distinction between irrigated and rain-fed crops (other than rice) and irrigated and rain-fed rice. The latter distinguishes between more intensively used pasture and less intensively used converted or natural rangelands. The historical population estimates are represented as total, rural, and urban population, and in the form of population density and built-up area (Klein Goldewijk et al., 2017). Grazing lands are excluded from the analysis because the agricultural sector in Arunachal Pradesh is dominated by cropland (Lodrick, 2019), specifically the cultivation of rain-fed crops (see *Figure C1*). A large variety of livestock is reared in the area (Lodrick, 2019), but there are little spatial implications of its significance to Namdapha NPTR since most of the grazing lands are north to Arunachal Pradesh (see *Figure C2*).

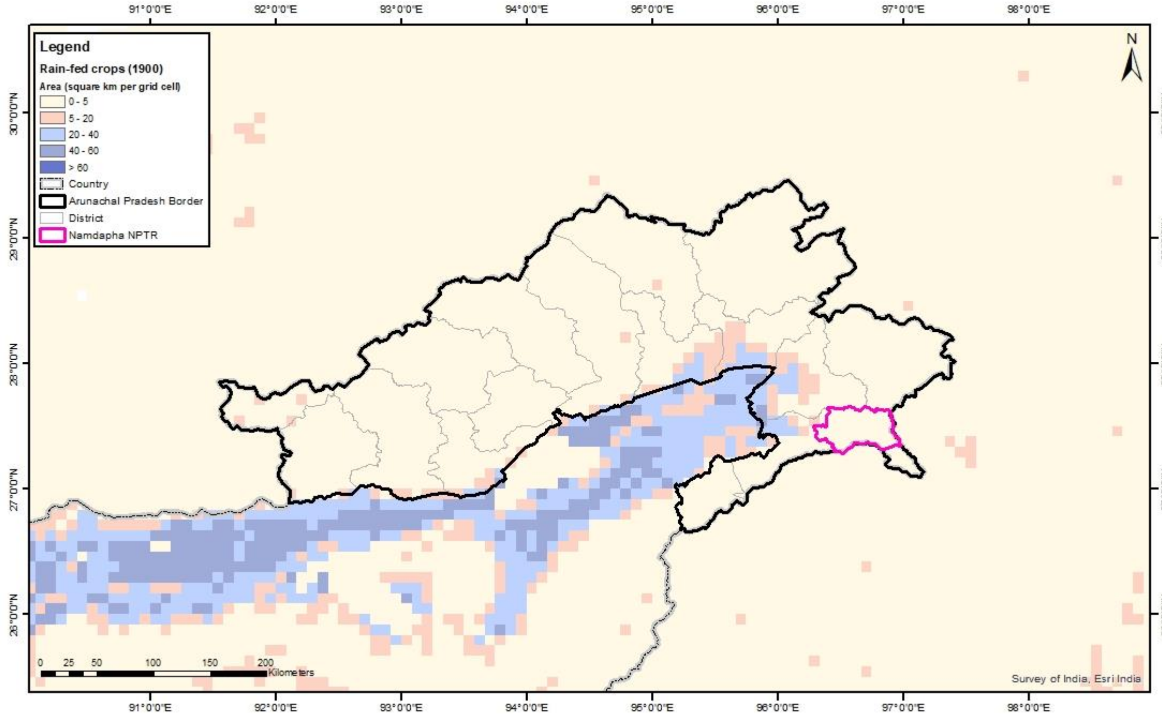



*Figure C1: Rain-fed crops, other than rice, in Arunachal Pradesh (1900). Created with ArcMap, using HYDE dataset.*

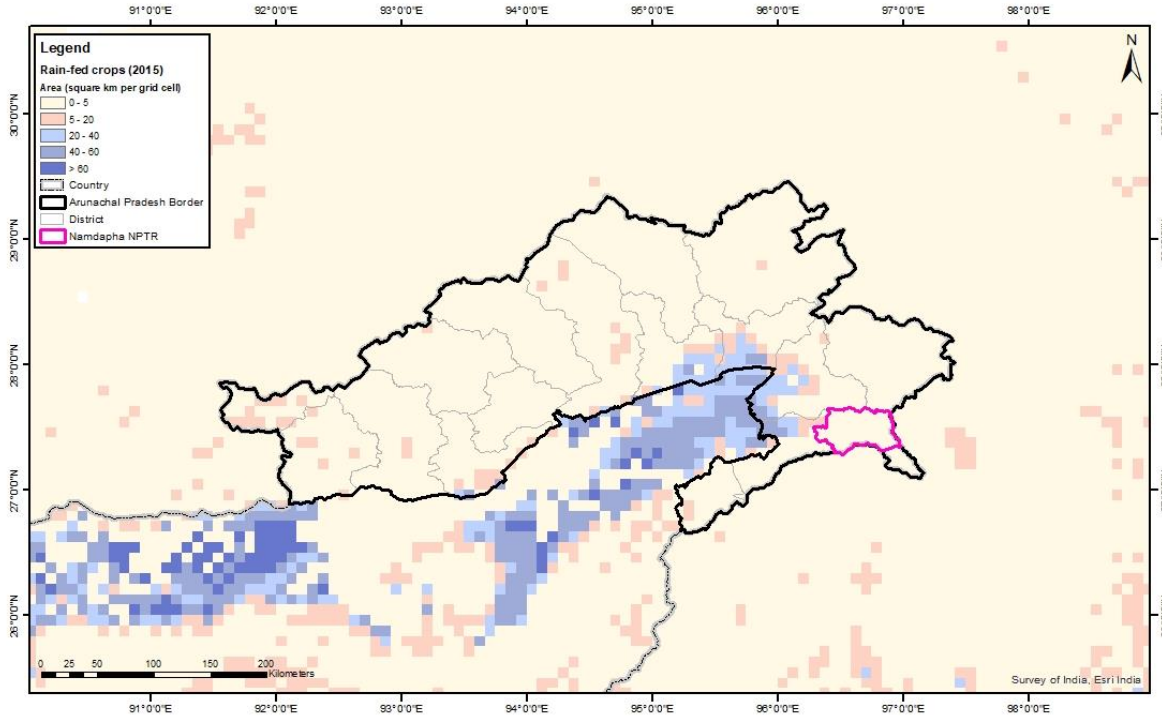



*Figure C2: Rain-fed crops, other than rice, in Arunachal Pradesh (2015). Created with ArcMap, using HYDE dataset.*

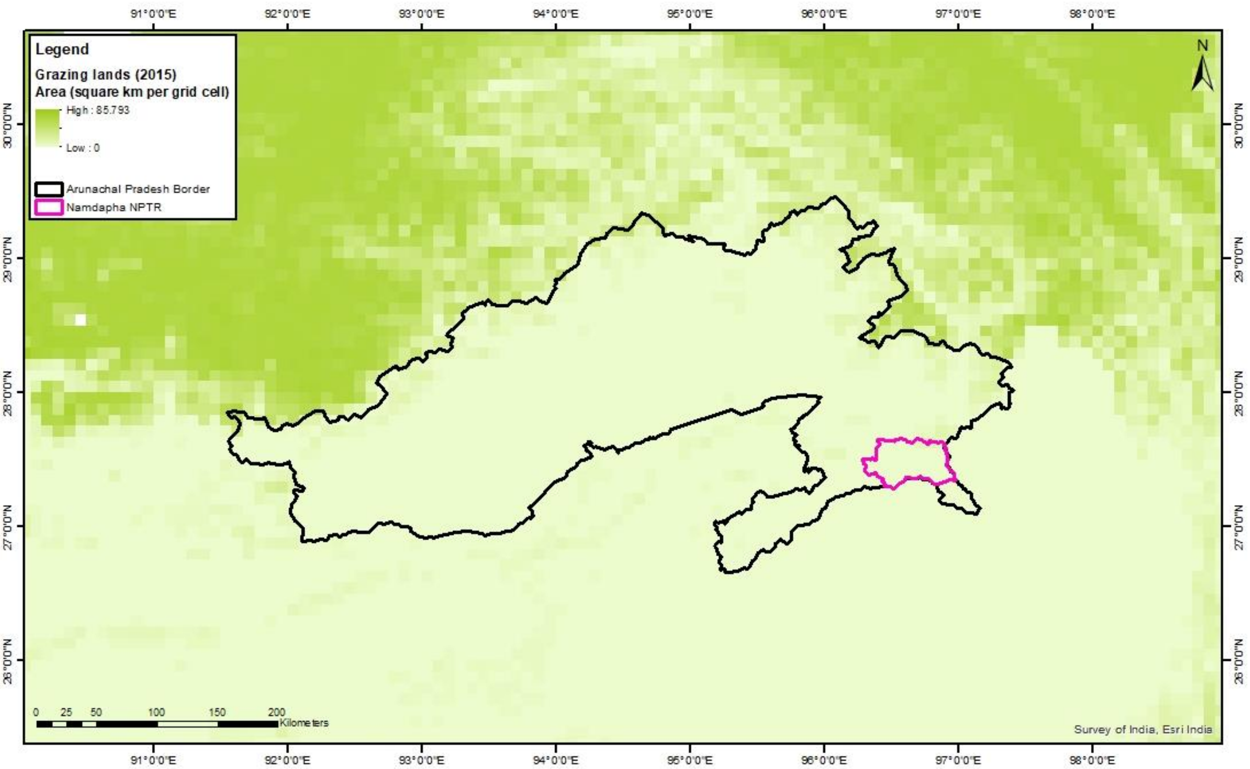
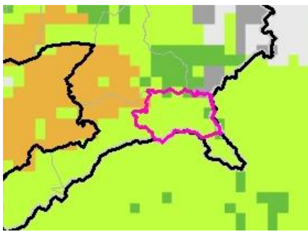
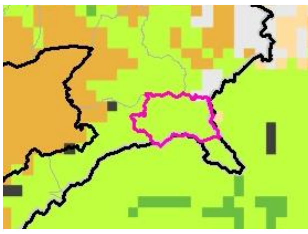
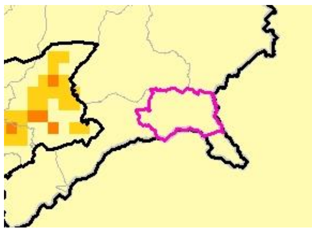


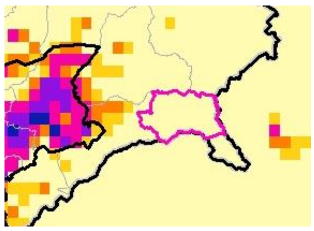

*Figure C3: Grazing lands in Arunachal Pradesh (2015). Created with ArcMap, using HYDE dataset.*

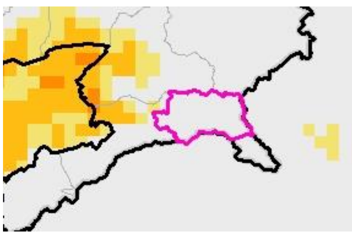
## Appendix D

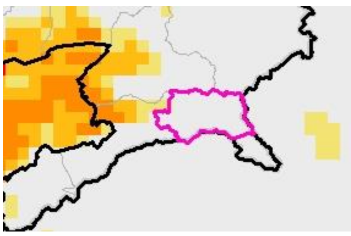

Land Use 1900


Land Use 2000


Population density 1900


Population density 2000


Cropland 1900


Cropland 2000

There is some inconsistency: in the UoM maps, agricultural land seems to retreat from Namdapha NPTR as time passes, while the cropland from the HYDE data seems to stay relatively the same. There are many possible explanations for this, including errors in data or classification differences, as discussed in the limitations section (5.2). Another explanation would be that the agricultural land is replaced by urban area, because these two LU types are usually in competition with each other. Moreover, development of urban area can lead to loss of fertility in nearby cropland (Mandal et al., 2020), which can also partly explain the retreat of agriculture witnessed in the UoM graphs.