HISTORICAL LAND-USE CHANGE EFFECTS ON THE BENGAL TIGER POPULATION IN NORTHERN INDIA AND NEPAL

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SUMMARY

In recent decades, it has become evident that human-induced land-use changes affect both the social and the natural world. As more area is claimed and converted for human use, natural areas which are home to an array of species slowly disappear. One such disappearing species is the Bengal tiger. They could be found throughout the Indian subcontinent with a population estimated to be more than 100.000 in 1900, to less than 4.000 in 2010. The largest populations today reside in protected areas such as the Terai Arc Landscape (TAL) in Northern India and Nepal.

This paper set out to find how historical land-use change has affected the Bengal tiger population in Northern India and Nepal and what kind of effect conservation efforts could have on the current and future populations. To find the answer to this question two different methodological approaches were used; (1) Land-use mapping for the years 1900, 2000 and 2021, and (2) literary research to discover why these land-use changes happened and how they were affecting the Bengal tiger population.

The results illustrated that throughout 1900-2000 rapid urbanisation and agricultural expansion took place, replacing grasslands and forest areas. These changes were driven by population growth, rural-urban migration, and a shift in food demand. Through this expansion of human-dominated land cover, the Bengal tiger's natural habitat decreased and simultaneously so did the habitat of their preferred prey. Moreover, although the poaching of the tiger was illegalised, the demand for body parts continued to grow. On the other hand, the progress between 2000 - 2021 shows that afforestation took place within the protected TAL area and here the population numbers started to increase slowly again.

However, there are still areas of concern regarding the conservation efforts and the survival of the Bengal tiger. Limited genetic diversity within the small populations and continued illegal poaching are threatening the success of the conservation efforts. Active safety monitoring and an increase of wildlife corridors connecting more protected areas and populations are needed. Ultimately, to protect the tiger is to protect entire ecosystems that all species, including ourselves, benefit from.

1. INTRODUCTION

This section will provide the reader with an overview of the background of the thesis topic, its research aim, and the structure the reader can expect from this paper.

1.1 BACKGROUND

The Bengal Tiger: Endangered

Today, anthropogenic pressure is causing changes in the environment and the natural balance of ecosystems. The growing lists highlighting endangered species of both flora and fauna give rise for concern. Indeed, one such species is the Bengal Tiger (*Panthera Tigris Tigris*) and can be found on the IUCN Red List of Threatened species (Goodrich et al., 2015). The IUCN report from 2015 outlined that the population was decreasing and emphasised that the population was severely fragmented. This is in accordance with Wikramanayake et al. (2010a) who evaluated that the Indian subcontinent Bengal tiger population decreased significantly from 100,000 in 1900s to less than 4,000 in 2010.

Luckily, in 2008 serious conservation efforts in the form of the Global Tiger Initiative were set in place to assure the survival of the Bengal tiger and are active today (GTI, 2013). 2016, a year after the last IUCN report was published, marked the first year that the population in some protected areas had slightly increased, and this trend has seemingly continued in the past few years (WWF, 2022). It seems that the conversation efforts have been effective and are providing the carnivore with room to not only stabilise but grow its numbers, an example of these conservation efforts is the Terai Arc Landscape (TAL) located in Northern India and Nepal (Wikramanayake et al., 2010b).

> *"Since the 1700s, tigers have been lost from two-thirds their former range countries including most recently Vietnam, Lao PDR and Cambodia" – World Wildlife Fund (WWF, 2022)*

However, the World Wildlife Fund does also emphasise that tigers remain to be endangered and are still facing threats (WWF, 2022). Where the conservation parks have been immensely successful, the carnivore has most likely gone extinct in what used to be their native countries (e.g., Cambodia) and its numbers are still declining in other regions. Another worrying concept is what can be referred to as 'bottleneck genetics', this refers to the phenomenon where a decreased population size results in a decrease in genetic diversity which may influence the survival potential of a species (Ali et al., 2008). Ali et al. further discusses the existing possibility of bottleneck genetics creating new viruses, which could also be potentially dangerous to other species.

Northern India and Nepal: Short Overview

Earlier subcontinental India was mentioned, this area consists of India and some bordering countries, amongst which is Nepal (figure 1). The reason why this research focusses on Northern India and Nepal is the Terai Arc Landscape, a collection of reservation areas on the countries' border, which will be explained in more detail in the following section. The aim of this short section, however, is to provide a short overview of the geographical and social area involved.

Figure 1. Countries included in the Indian subcontinent (World Atlas, 2021).

Northern India and Nepal are located in South Asia and are characterised by the Himalayan Mountain range. The climate is rather similar as here it is mostly influenced by the elevation and the monsoon conditions. A warm temperate climate is found in the lower elevation and contrasts the cool alpine climate in the mountains (Attri & Tyagi, 2010). Both countries experience heavy rainfall around July due to the Indian Monsoon carrying moisture heavy air from the Mediterranean Sea inward (Gadgil, 2003). These differences in altitude create ideal climate conditions for the existence of lower grasslands and mountainous forest areas which is the home to a diverse array of flora and fauna. In fact, Nepal covers less than 0.1% global land mass but is home to about 4% of the world's mammals (Paudel et al., 2012).

The most notable social aspect may be the immense population growth in both India and Nepal over the last few decades. More specifically, the urban populations are growing substantially quicker than rural populations (Regmi, 2014). Various literature sources have connected this growth to environmental degradation due to urbanisation, over-exploitation, and habitat fragmentation (Ray & Ray, 2011; Jodha, 1985).

Terai Arc Landscape: Reservation Area

Since 2000, WWF has been contributing to the protection of 14 areas in northern India and the bordering hills of Nepal in the TAL (Oglethorpe & Crandall, 2010). Here, among many other species, the Bengal tiger can be found. Their latest capture and release study done estimated a tiger population of 239 (Chanchani et al., 2014). Within the landscape various reserves and protected areas are connected through wildlife corridors as to stimulate movement for the populations within. Figure 2 shows the location of the TAL, the different reserves, and the various corridors connecting these areas. TAL lies within the similarly named Terai Arc region and is mostly situated at the foothills of the Himalayas.

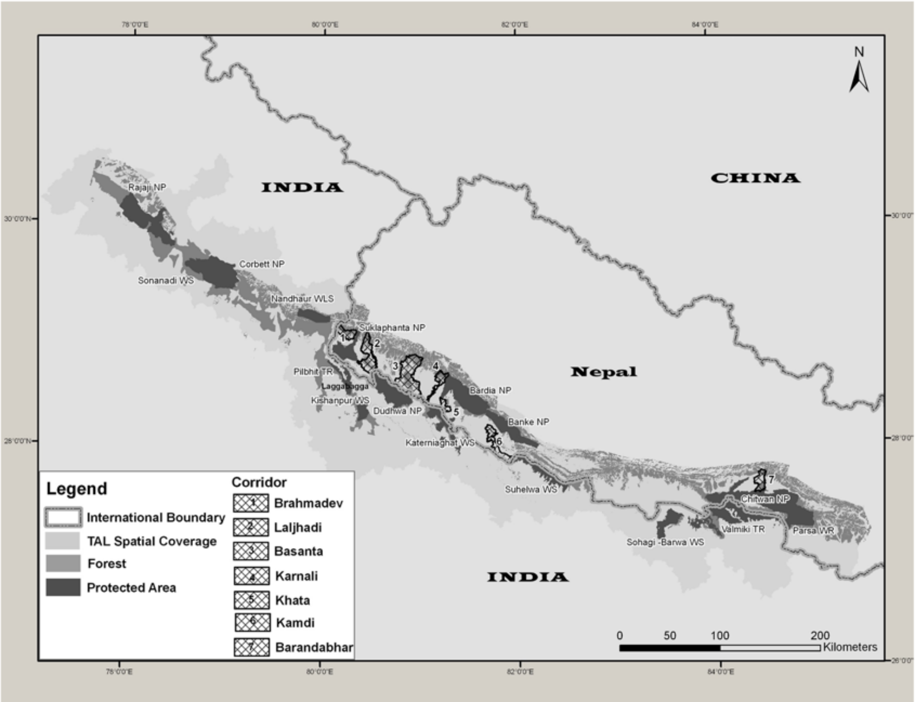


Figure 2. Map of the TAL (Kanagaraj et al., 2011).

The active participation of the WWF in this initiative was a response to the decline of flora and fauna in subcontinental India. Although some conservation efforts around the world have proven successful, factors such as habitat degradation and poaching remain a threat to the ecosystems within TAL (Ahmed et al., 2021). Recently, results of the conservation efforts have been published and possible further efforts are being discussed considering the 2022 Global tiger summit coming up this September (Subedi et al., 2021).

Problem Description

Thus, although it seems that the major decrease in the Bengal tiger population that took place from 1900-2010 has halted and it seems that some protected populations are slowly growing again, there is still a long road to go before the species are no longer considered endangered. Conservation efforts have already been implemented, mostly in the form of conservation areas, such as TAL, and it seems like there is ample of interest on expanding those efforts further (Kumar, 2021). However, to halt the disappearance of the species outside of the reservation areas and simultaneously combat further bottleneck genetic drift (or inbreeding), it would prove useful to see what exactly changed in the 20th century in Northern India and Nepal, and why these changes happened, to make sure we can prevent it from happening any further. Lastly, there are potential lessons to be learnt from conservation areas such as TAL for future conservation efforts.

1.2 RESEARCH AIM AND STRUCTURE

The research aim of this thesis is to understand historical land-use changes in Northern India and Nepal, what kind of drivers caused these changes, and how this could have affected the national Bengal tiger population. A further illustration of the current land-use in Northern India and Nepal will be presented and a closer look at conservation efforts (TAL) will be taken as to identify effective measures.

To achieve this aim, the following overarching research question is posed:

"What is the effect of historical (1900 – 2000) and current land-use changes on the *Bengal Tiger* population in Northern India and Nepal and what kind of effects could conservation efforts have?"

As to divide this research in comprehendible sections, three sub-questions were created to keep a structured overview throughout the paper:

1. What were the historical land-use changes (1900-2000) in Northern India and Nepal and what is the current state (2021)?
2. What could be the drivers of these changes and how could these changes have affected the livelihood of the Bengal Tiger in Northern India and Nepal?
3. To what extent has the Terai Arc Landscape initiative acted as an effective response and how is this different from other areas in Northern India and Nepal? (Minor case study).

By answering the above sub-questions, a concise answer will be found to the overarching research question.

Research Importance

The importance of the conservation of species such as the tiger, lies in the interconnectedness of its survival to the health and functionality of various ecosystems (Kumar, 2021). If the tiger population is in a well-maintained balance, this means that all ecosystem health indicators that are also related to its survivability are doing well. Therefore, saving the tiger would mean saving entire ecosystems along the way.

Furthermore, researching the relationship between land-use changes and species populations can prove useful for more species than just the Bengal Tiger. Ecosystems and the individuals living in them can be fragile when it comes to anthropogenic pressure, understanding how one simple action can cause an entire chain-effect, good or bad, could be useful for future land-use decisions but also for conservation efforts. Ultimately, it can be used in current and future studies such as the recently kickstarted project 'Save the Tiger', a project that aims to understand historical grassland dynamics in combination with hydrology and its effect on the tiger (Save the Tiger, 2022).

2. THEORY AND CONCEPTS

The survivability of the Bengal tiger is mostly dependent on the access to (1) its natural habitat, (2) sufficient prey availability, and (3) security from poaching for its survival (Sunquist, 1989; Karanth, 2001). Therefore, this research focusses on the relationship between these aspects and the influences that anthropogenic activities such as (historic) land-use change could have had on them.

Based on these three aspects, before the research on how (historical) land-use change has affected the Bengal Tiger in Northern India and Nepal can begin, a comprehensible overview of these indicators must be presented. First in section 2.1, an overview of the Bengal Tiger's living conditions is given, divided into (1) natural habitat, (2) prey species, and (3) social aspects. Second, in 2.2, a closer look is taken at what kind of drivers and pressures could alter these living conditions. Third, in 2.3, a visual overview of the research components is shown and explained in combination with an introduction to the DPSIR model.

2.1 OVERVIEW OF THE BENGAL TIGER'S LIVING CONDITIONS

Natural Habitat

The Bengal tiger can be found thriving in various habitats but mainly in different forest and grassland areas, however, they have also been found in mountainous (forest) areas such as the Himalayas (Kumar, 2021; Matthiessen, 2000). As for their habitat, the most important requirement is enough space to roam around in and medium to thick vegetation cover (Sunquist & Sunquist, 2017).

Prey Species

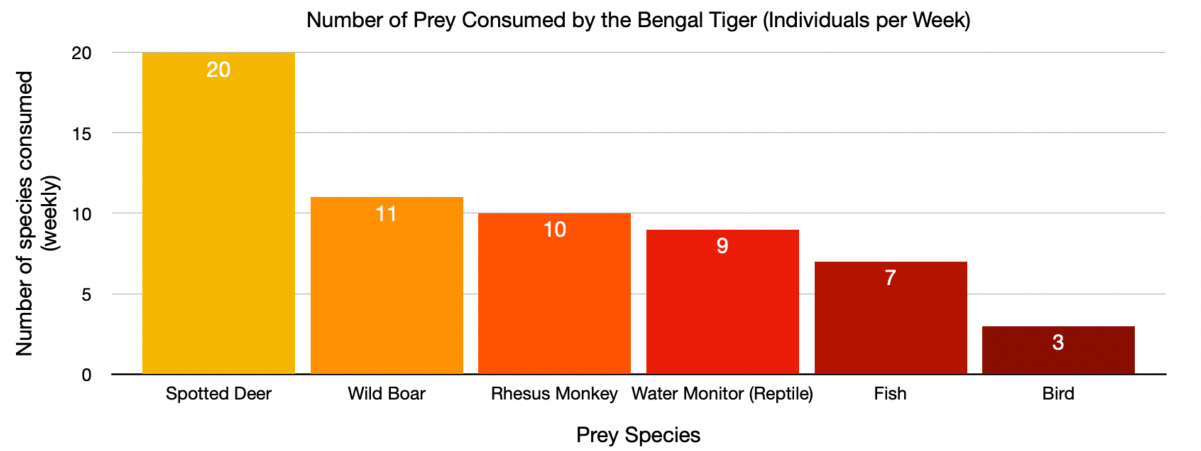


Figure 3. Weekly diet of the Bengal Tiger in individuals consumed (Adapted from Mukherjee & Sarkar, 2013).

As can be seen in figure 3, the average diet of the Bengal tiger consists primarily of ungulate species (grass grazing animals) such as deer and boar (Mukherjee & Sarkar, 2013). Ungulates are dependent on the availability of grass for their survival and can therefore mostly be found in grasslands or forests (Hobbs, 1996).

Social Aspects

Tigers are poached for their skin, body parts or as a trophy (Chapron et al., 2008). Furthermore, tigers can also be hunted if they pose a threat to a farmer's livestock. According to Check (2006), poaching poses the most prominent short-term danger to the Bengal Tiger.

2.2 POSSIBLE CAUSAL RELATIONSHIPS

Change of Habitat

As can be seen in figure 4, where the grey area represents the historic range and the white area the current range, the tiger range has drastically decreased since 1970.

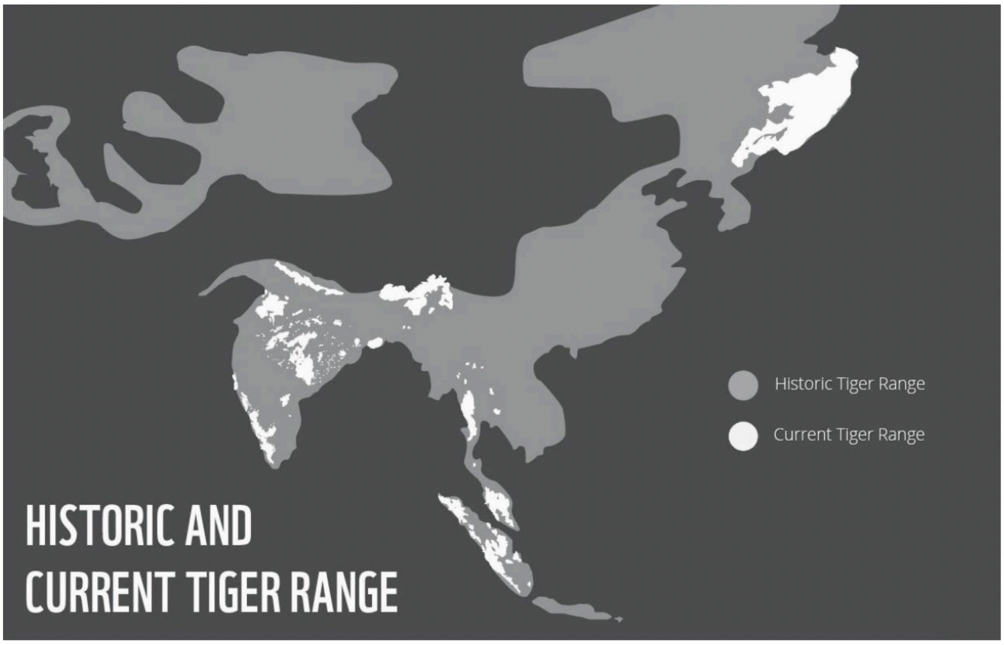


Figure 4. Historic and Current Tiger Range (1970-2022) (WWF, 2022)

There must be a reason why the tiger populations are no longer roaming around in those areas. One plausible cause for the decrease in tiger range is the loss of their natural habitats: grasslands and forests. Globally, trends show that we are increasingly losing those, and similar ecosystems, to anthropogenic activities (Bardgett et al., 2021). It is important to understand what these activities are and how they affect the ecosystems and particularly for this research, the Bengal Tiger.

Change in Prey Availability

The decrease in habitat mentioned before would not only be a challenge for the Bengal tiger but also for the species it preys on. As seen in the 2.1.2 Diet section, their diet mostly consists of ungulates. Ungulates are also dependent on the grasslands to provide them with the food that they need. The Lotka-Volterra model, see figure 5**,** used in ecology shows that prey and predator populations are dependent on each other in the sense that they keep the system in a balanced state.

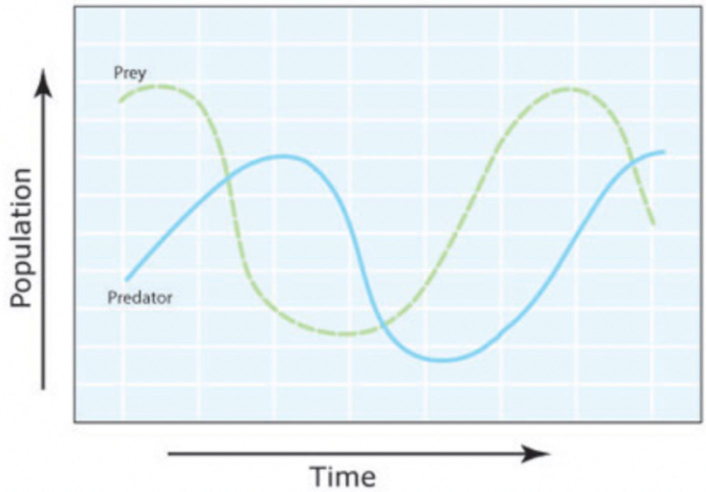


Figure 5. Lotka-Volterra model illustrates a balanced and closed prey-predator relationship (Stevens, 2010)

The idea behind the model is that as tigers decrease the ungulate number through hunting, they thrive for a short while but soon find their food resources lacking, causing a decrease in population. This, in turn, leaves room for the prey population to rebound until the tiger population grows large enough again to pressure the prey population once more.
Any outside pressure on the system, such as land-use change or altered competition, into this system, could throw off the balance entirely and as a result, affect the populations.

Change in Social Aspects

As mentioned in the introduction, an increasing focus on conservation efforts can be seen in the last decade or so. These large initiatives can bring awareness to the masses and through donations may become more extensive. However, local villages surrounding the conservation areas are experiencing disturbances, disproportionally affecting women who need to travel far distances to collect clean water daily, from the newly introduced tigers in their lives (Rubino & Doubleday, 2021). It seems that although from a global perspective the tiger has become a more beloved key species, on a local level the conservation areas may be less welcomed, and poaching may even increase.

2.3 OVERVIEW OF CONCEPTS AND THEIR RELATION: DPSIR FRAMEWORK

Below an overview of the discussed key concepts is given followed by a preliminary DPSIR model that was formed as a foundation for this paper its research.

Overview Key Concepts

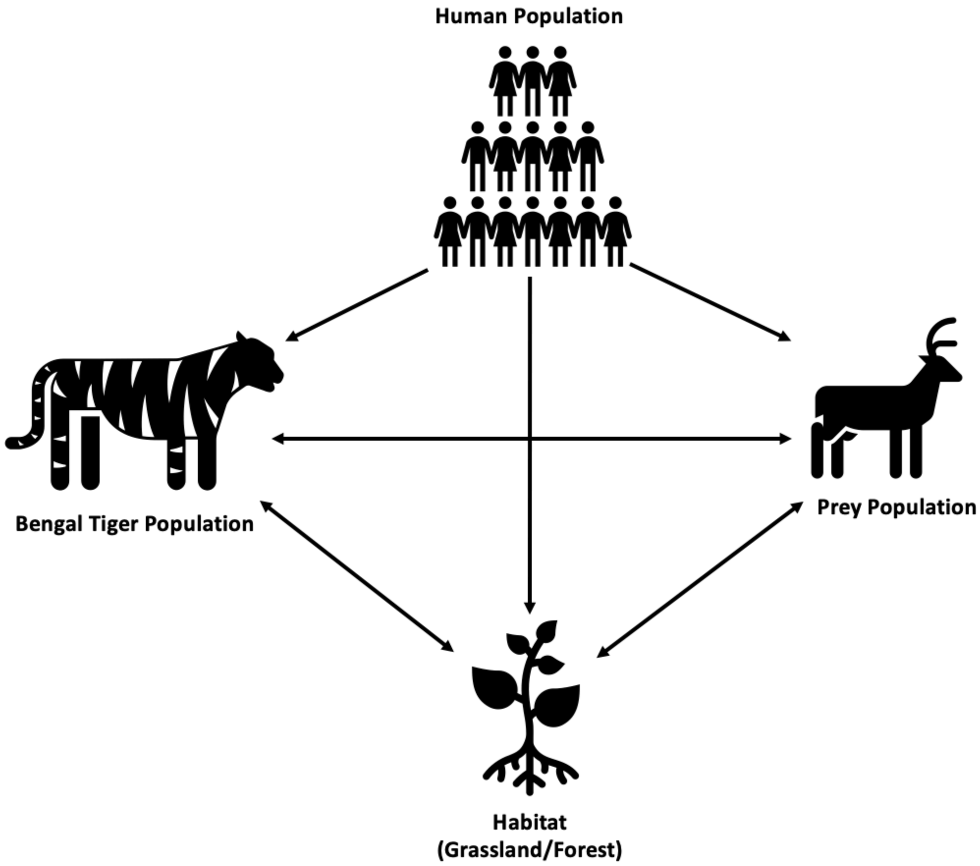


Figure 6. Illustrative overview of components interconnected with the survivability of the Bengal Tiger

From the literature found thus far, it becomes apparent that human activities such as land-use changes could be affecting the habitats, prey populations, and social views (e.g., poaching) of the Bengal tiger (figure 6).

As anthropogenic actions, land-use change here, is the starting point of this research no further look will be taken into how a change in the components will affect the human population, therefore, there are no arrows pointing towards the human population although it would realistically have some sort of effect. Although the importance of this research to both humanity and the environment has been stated and will be discussed again, this research is set up with the sole purpose of looking at how human-induced land-use change has affected the Bengal tiger (and its survivability components) and not vice versa.

DPSIR Model

This thesis will make use of the causal framework known as the DPSIR model. It is used to illustrate how certain anthropogenic **d**rivers can create **p**ressure on certain **s**tates which lead to **i**mpacts and can be remediated, if necessary, with **r**esponses (Ness et al., 2010). The basic theory and DPSIR-model can be found in Appendix I.

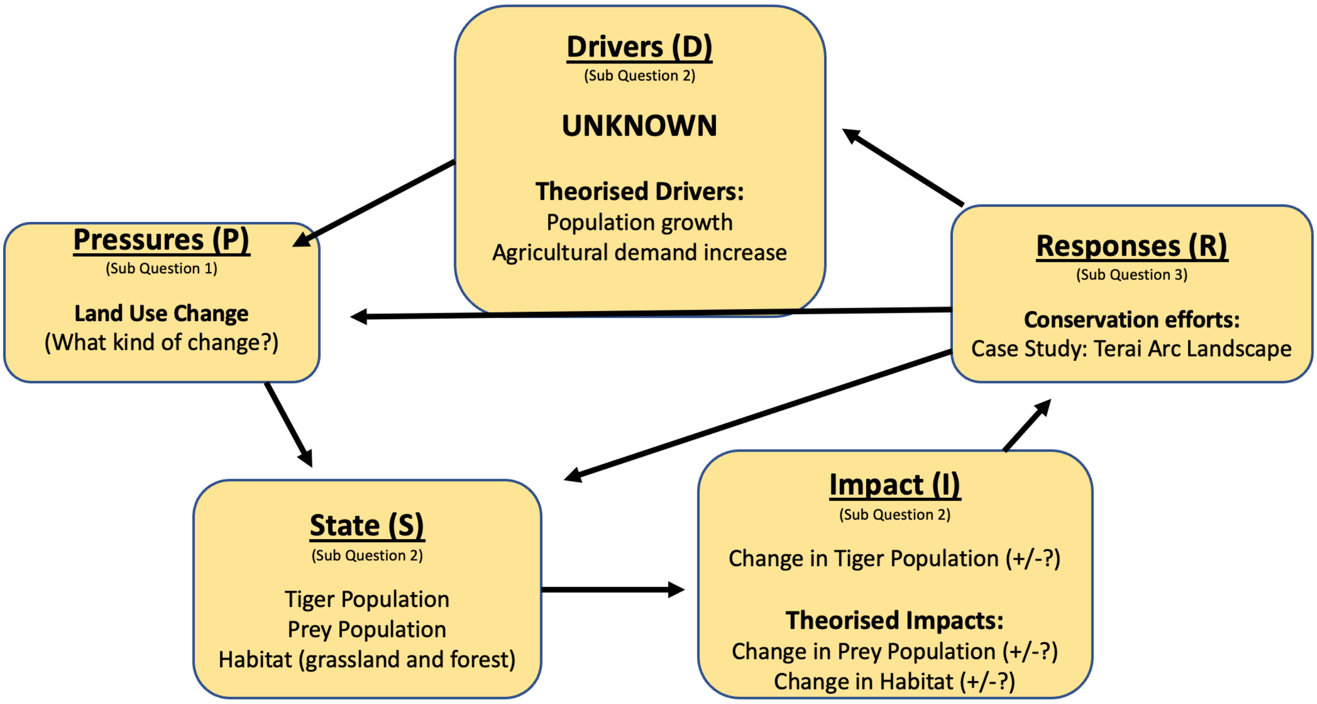


Figure 7. Preliminary DPSIR Model with Expected Results

As the three largest influences on tiger survivability have already been discussed in the previous section, a preliminary DPSIR model (figure 7) can already be created based on (1) human population, (2) prey population, and (3) habitat. The model illustrates the concepts that are to be researched and the gaps that have yet to be filled in through the results of the methodology introduced in the next section. Ultimately, the final DPSIR model is presented in the *Results*.

3. METHODS

A combination of two different methods was used to address the three different sub-questions, to answer the overarching research question, and create the final DPSIR model.

STEP 1. ARCGIS: LAND-USE MAPPING

To research the historical and current land-use changes in Northern India and Nepal (Q. 1), land-use mapping was used. ArcGIS was utilised to create different maps for the different time periods in these two areas. The chosen timespan is 1900 to 2000, as was discussed in the introduction, this period has seen a strong decline in Bengal Tiger population in subcontinent India.

The spatial datasets used for the land-use mapping part of this research are described below and can also be found in Appendix II. Both these datasets were used to map the (historical) land-use in Northern India and Nepal (Q.1), furthermore, the same data was later used to zoom into the location of the TAL to illustrate the land-use there as part of the minor case study (Q.3).

DATASET 1: Land-use Change (1900-2000) (Ellis et al., 2014A; 2014B).
Originally this dataset contained a total of nineteen classes. For the purposes of this research, these nineteen classes were divided into five land use/cover types, namely:

- Built-up area
- Agricultural area
- Rangeland
- Forest
- Barren

Figure 8 below illustrates how the 19 classes were allocated within each type. In Appendix II, the original allocation and class descriptions can be found.

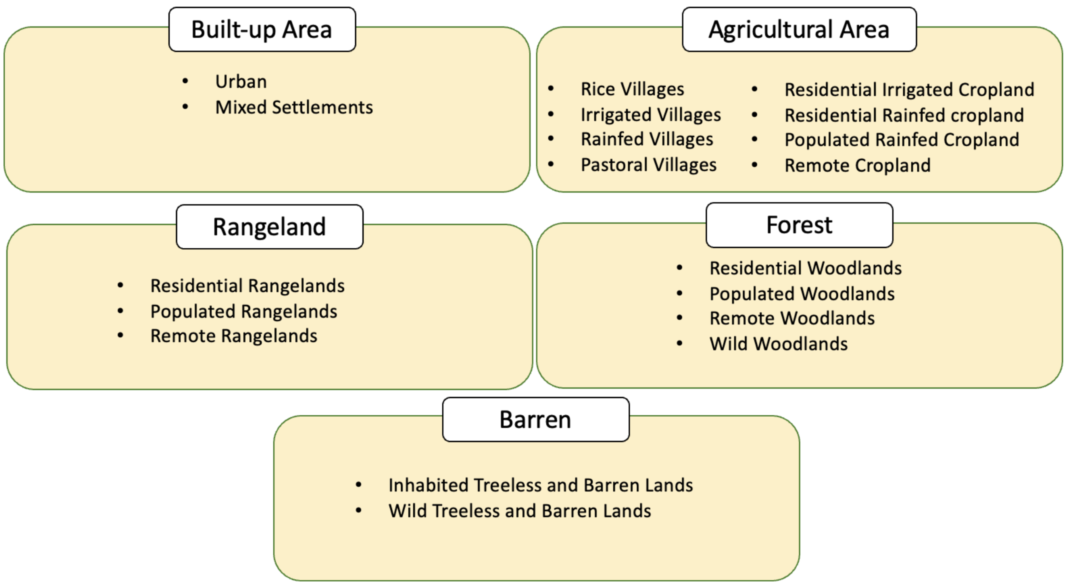


Figure 8. allocation of nineteen original dataset classes to five research-specific land-use/cover types

These types were chosen based on their potential influence on the Bengal tiger and its survivability. As outlined in the key concepts, both the Bengal tiger and its prey can be found in grassland and forest land cover. The change in size of these habitats proved a useful starting point for the literary research into the different states and impacts.

DATASET 2 (ESRI): Sentinel-2 10M Land-use/Land Cover Timeseries (2017-2021) (Karra et al., 2022)

From this dataset, the data for year 2021 was used to illustrate the current land-use in the research area. Whereas the previous dataset looks predominantly at historical changes, the conservation efforts for the Bengal Tiger started only a little over a decade ago. Therefore this 2021 dataset was mapped and illustrates the current land-use situation in Northern India and Nepal.

The dataset holds nine class definitions but have been re-categorised within seven land cover-types to better fit the historical dataset, one type is left out due to absence in the research area. The seven types used in mapping the land-use for 2021 are:

- Built-up area
- Agricultural area (new group including:)
    - Crops
    - Flooded Vegetation (agricultural purposes)
- Rangeland
- Forest
- Barren
- Water
- Snow/Ice

Not included as it was not present in the research area:
- Clouds: no data due to persistent cloud cover

A classification of all nine class definitions within this dataset can be found in Appendix II.

STEP 2. LITERARY RESEARCH AND DATABASES

To build upon the newfound pressure from the land-use mapping, literary research was conducted to compose a list of how the pressure affects the states and the consequent impacts (Q.2). The three aspects researched in relation to the land-use changes found are the ones essential for the survivability of the tiger:

1. Changes in habitat
2. Changes in prey availability
3. Changes in poaching

But also, which drivers caused the pressure (land-use changes) that have occurred in Northern India and Nepal. Here a closer look is taken at the human population and the changes in them and their activities. Phenomena that were investigated are:

1. Population growth
2. Food demand and changes

To conduct the literary research, the search engines Google Scholar, JSTOR, Science.gov, and BASE were used to find legitimate sources and explain the phenomena. More number specific data, such as population numbers or specific area size, was acquired through open databases such as the World Bank and FAOSTAT. Simple graphs will illustrate changes and suggest correlation (simplified example: population growth vs urbanisation).
The presentations of trends of suggested correlations were always done based on extensive literary research to be as transparent and justified as possible.

UNCERTAINTY

Although all databases present peer-reviewed papers and datasets, there is always a chance of error, especially with the use of historical spatial datasets. Although there is more certainty in historical data than future data, it is still not as reliable as current data can be. The historical dataset used, however, is used by the NASA Socioeconomic Data and Application centre and is therefore considered to be reliable enough for this research. However, as emphasised by GIS Lounge (2016), even current and verified spatial imaging can be unreliable due to for example label (/human-) or formatting (/computer-) errors. Therefore, all datasets were closely studied before they were chosen for the methodology and at multiple stages of the research were the land-use results compared to the literature results to assess their reliability.

One final aspect is the fact that it is rather recent that the Bengal Tiger population has increased again in certain protected areas. Therefore, it may be that many findings from papers dating back to 2010 may already be outdated and simply untrue. For this reason, the most recent findings are used, where possible, to portray the most accurate current state of research. Findings that are not as susceptible to change, such as (uninfluenced) natural phenomena, may be referenced from older sources.

4. RESULTS

The results of this research will be presented in different ways. First, each method section will be conducted separately, and the results will be shown and described through land-use maps and an in-depth overview of the literature reviews done based on the framework introduced in the *Concepts and Theory* section. Then, the results will be combined to fill in the DPSIR framework outlined earlier in this paper.

4.1 LAND-USE MAPPING: FINDING THE PRESSURES

This section showcases the land-use maps created through ArcGIS for the years 1900, 2000 and 2021 respectively. The former two illustrate the distribution of five different categories of land use/cover and the latter illustrates the distribution of seven different categories (containing the five prior ones as well).

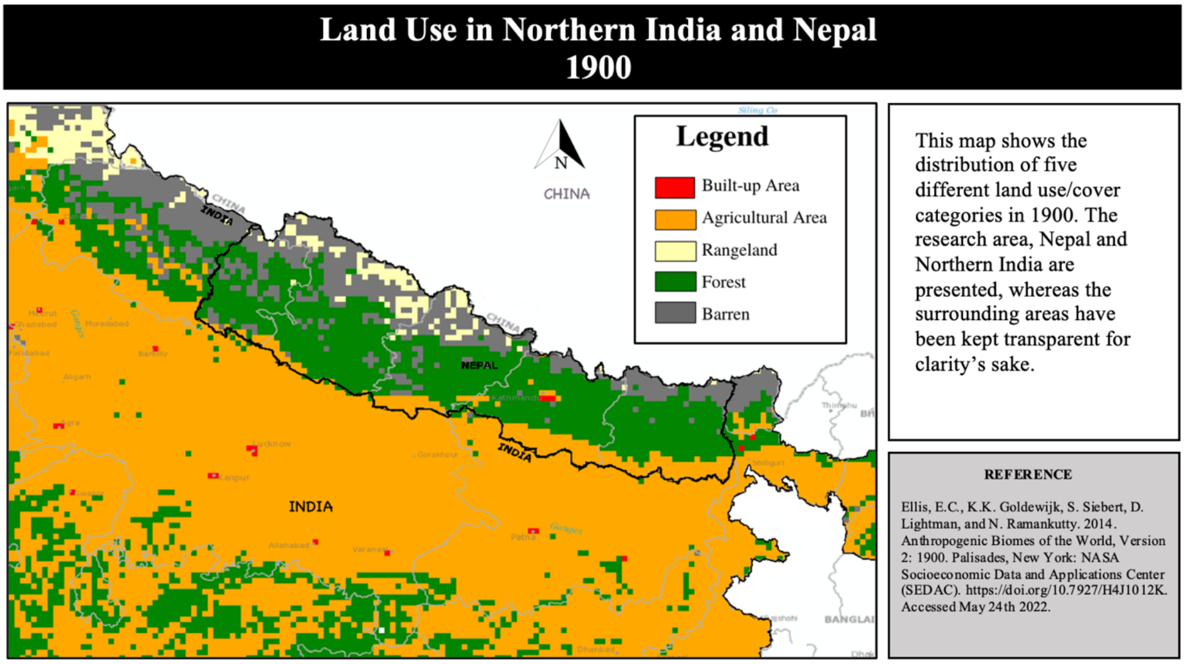


Figure 9. Land-use map of the research area in 1900 (five categories; dataset one)

Above in figure 9 the land use/cover of northern India and Nepal in 1900 is shown. Nepal has a rather high percentage of forest area compared to northern India and therefore seems relatively undisturbed. India shows large areas for agricultural purposes. Both in Nepal and India, some small built-up areas can be found.

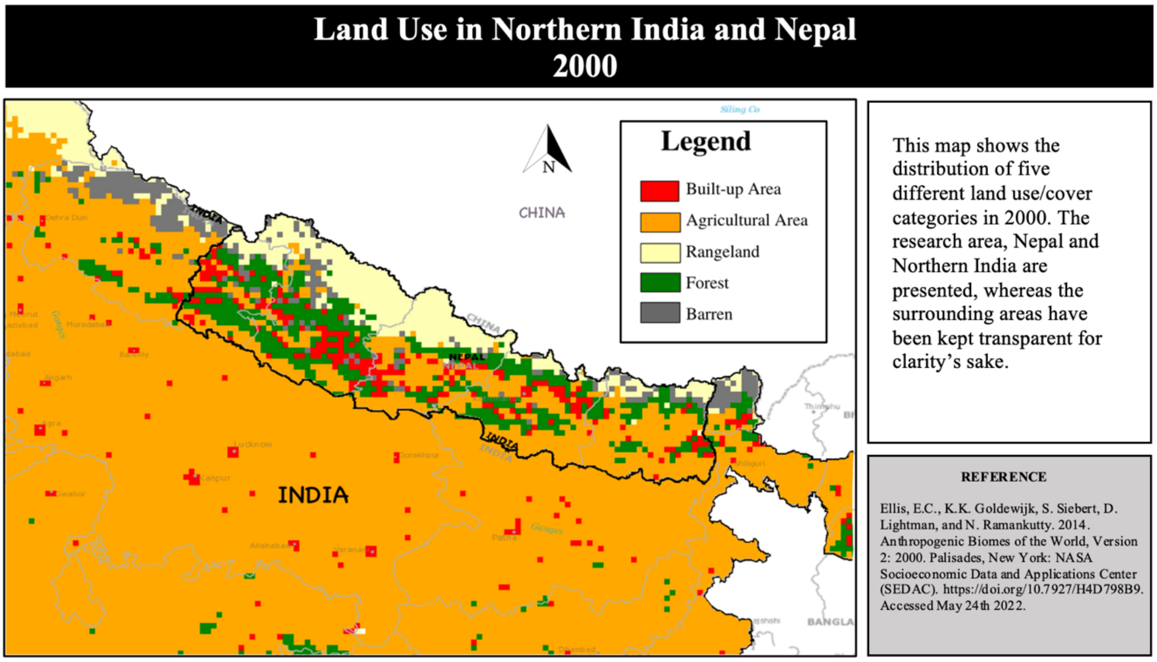


Figure 10. Land-use map of the research area in 2000 (five categories; dataset one)

Figure 10 showcases the land/use cover in northern India and Nepal in 2000. This land-use data is retrieved from the same dataset as the previous map. In this 2000 map, India seems to have lost forest area for the expansion of agricultural area and there is an increase in built-up area. There are seemingly more urban areas which are relatively spread out. The same is true for Nepal, although some barren land has been replaced by rangeland as well. Significant deforestation has taken place, and the built-up areas have grown larger and new built-up areas have been added, accompanied by adjacent agricultural areas.

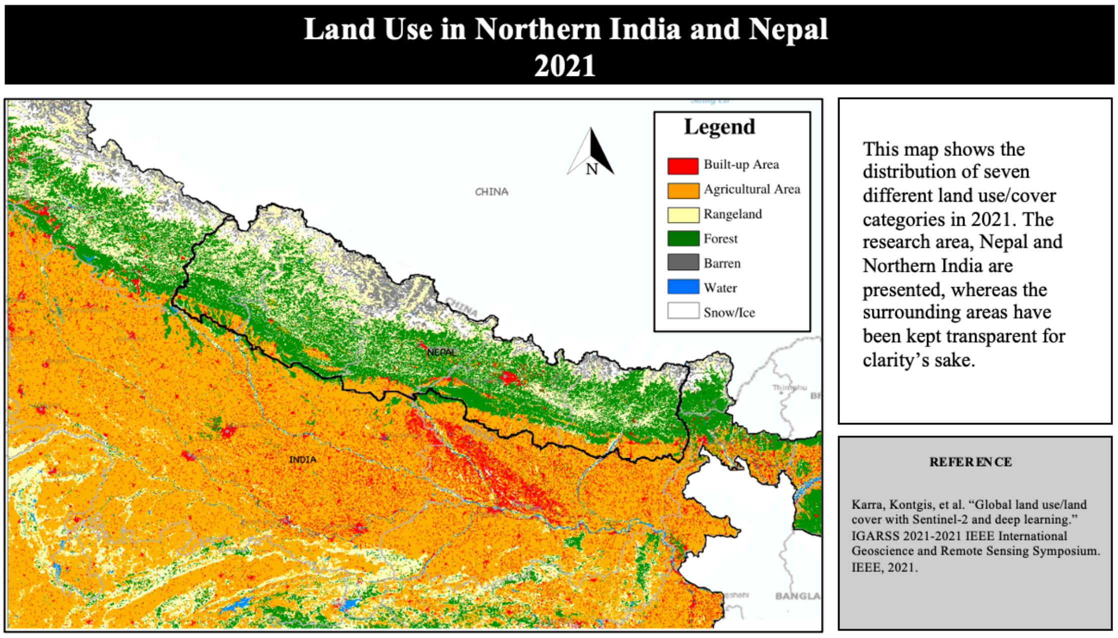


Figure 11. Land-use map of the research area in 2021 (seven categories; dataset two).

Figure 11 shows a more recent land use/cover map from 2021. This data was retrieved from dataset two as this one is from recent data instead of historical data such as set one. Therefore, this map is seemingly a little more detailed than the previous ones. Here snow/ice and water have also been illustrated. It seems that from 2000 onwards, forest areas have returned, and built-up area has mostly clumped together to form larger urban areas. This is true for both Northern India and Nepal, but India sees a specific observation where built-up area has mostly been structured around rivers such as the Ganges and other water bodies. The southwest of Nepal, which contains the Terai Arc-zone, has seen a decrease in built-up area between 2000-2021.

4.2 LITERATURE REVIEW: DRIVERS, STATES, AND IMPACTS

In the previous section the historical and current land-use changes were illustrated using land-use mapping. Here it became evident that over the last millennium, major forest and rangeland areas have given way to agricultural and urban areas. In this section, likely drivers for these changes are found through literary research and the states and impacts on the key survivability concepts described in *Section 2* are found.

4.2.1 Drivers

Population Growth

According to several research papers, population growth and rural-urban migration are the largest driver for urbanisation and deforestation (Prahdan, 2004; Bodo, 2019). Moreover, population growth often is a driver for increased agricultural area due to the increased food demand it brings (Agoramoorthy, 2008).

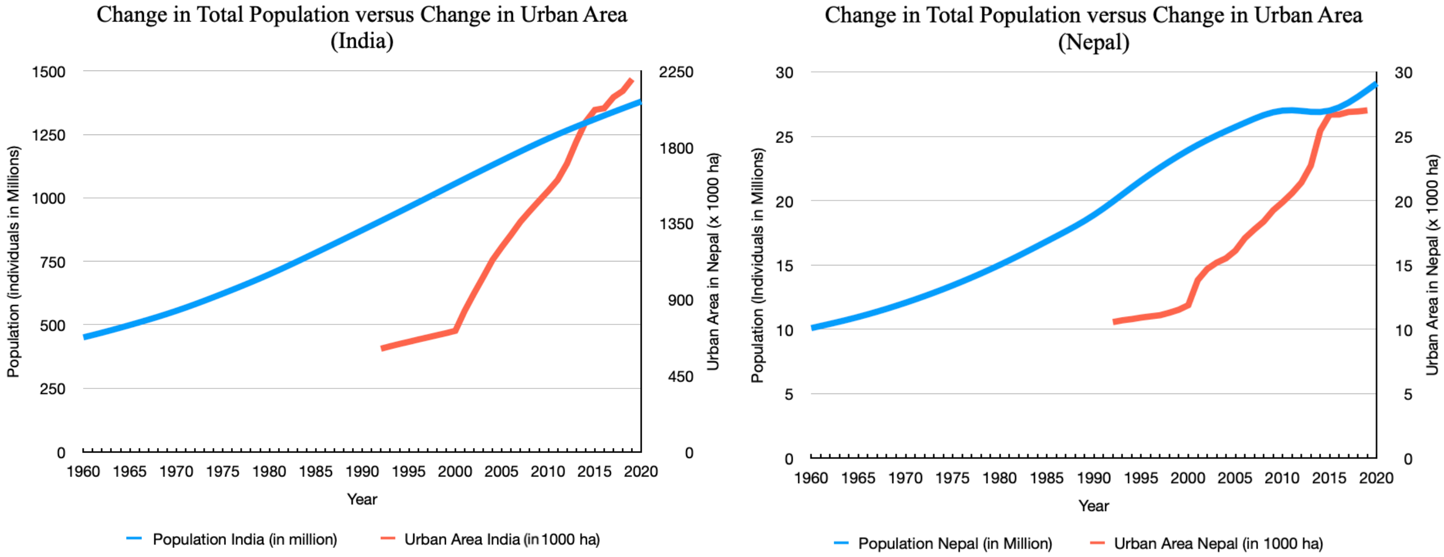
Below in figure 12, two tables showcase the population change for both India and Nepal from 1960 - 2020. Three categories are outlined: total population, urban population, rural population. The complete lists of World Bank Data used in this section can be found in Appendix III.

Country (Year)	Total Population	Urban Population	Rural Population
India (1960)	450,547,675	80,756,165	369,791,510
India (2020)	1,380,004,385	481,980,332	898,024,053
Change India (1960-2020)	**206,30%**	**496,80%**	**142,80%**

Country (Year)	Total Population	Urban Population	Rural Population
Nepal (1960)	10,105,060	351,656	9,753,404
Nepal (2020)	29,136,808	5,995,190	23,141,618
Change Nepal (1960-2020)	**188,30%**	**1604,90%**	**137,30%**

Figure 12. Change in Population (Total, Urban, and Rural) for both India (above) and Nepal (below) (Adapted from World Bank, 2020a; 2020b; 2020c).

It becomes clear that both countries see an increase in individuals for all categories. Similarly, the urban population sees the largest growth in both Nepal and India even though the overall urban populations are significantly smaller than the rural populations. Kumar et al. (2011), emphasise that the extraordinary numbers of individuals who work in agricultural employment have gone down, it still is the largest sector in India. Nepal has seen a similar trend over the past few decades (Upreti et al., 2016). However, the massive growth in total (and urban) population seems to be a likely driver of urbanisation. Figure 13 below illustrate the relationship in growth of overall population and urban area in India and Nepal respectively. The latter dataset was retrieved from the Food and Agriculture Organization Corporate Statistical Database (FAO) and was only available from 1992 onwards.



Figures 13. Change in total population versus change in urban area (ha) for both India (left) and Nepal (right) (Adapted from World Bank, 2020a ; FAO, 2022a)

Note here that the Y-axes in the left graph have different scales as the numerical values were too different to keep the same scales. The right figure has the same scale on both Y-axes as the values where similar. Both graphs show the population in individuals in millions and the urban area in 1000 ha. As urban area data for both the Asian countries have only been officially documented since 1992, we can compare the change over the same period of 1992-2019 for both datasets and countries:

- From 1992-2019, India saw a 50,3% increase in total population and a 261,6% increase in urban area
- From 1992-2019, Nepal saw a 43,5% increase in total population and an increase of 155.8% in urban area

Increased and Altered Agricultural Demand

Not only does population growth increase the national food demand in the sense that there are more people to feed, but there has also been a shift in the Indian diet where the demand for previously popular food, such as cereals, has decreased and the demand for meat, milk and eggs has increased (Kumar & Kathur, 1996). Livestock production is seen as a large threat to the survivability of grasslands due to habitat degradation and land-use conversion to pasture or cropland (Alkemade et al., 2013).

A food demand shift towards an increased total number of animal products would therefore come with the replacement of rangeland with cropland or pastureland. The following graphs, figure 14, show the change in numbers of livestock (combination of cattle, goats, and pigs) for both India and Nepal, the data was retrieved from FAOSTAT (2021b) and then altered to only showcase cattle, goats, and pigs. A more detailed table providing all data can be found in Appendix IV.

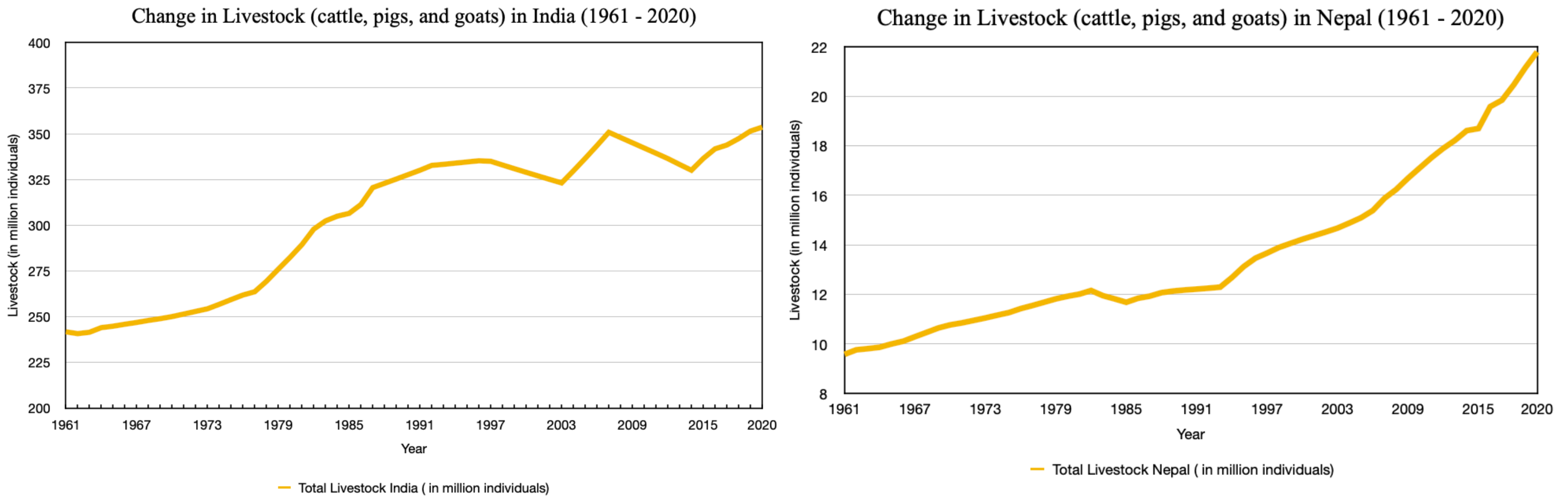


Figure 14. Change in Livestock Units (cattle, pigs, and goats) in India (left) and Nepal (right) from 1961 – 2020 (Adapted from FAO, 2022b).

This data seems in line with the findings that the demand for animal products within India has grown in the past few decades. From 1961-2022, India saw a 46% increase whereas Nepal saw a 127% increase in total livestock units. Regardless of if this increase is due to national demand only or also international import reasons, when livestock grazes pressure is put on native vegetation, possibly decreasing the grass availability for other animals dependent on similar rangeland areas (Chaikina & Ruckstuhl, 2006). Moreover, an increase in cattle also means an increase in food demand as they are large food sinks and the meat ultimately produced does not cover this gap in terms of caloric value (Singh & Singh, 2018).

4.2.2 States and Impacts

In the *Theory and Concepts* section, three different states were outlined as important to the survival of the Bengal Tiger in northern India and Nepal. Namely, (1) habitat availability, (2) prey population, and (3) poaching. Here, all three states will be reviewed considering the land-use map results in combination with literature collected.

Habitat availability

In the theory and concepts section it was established that both rangeland and forest area are the main habitat of the Bengal tiger. The previous section mapped the landcover changes which shows that these covers decreased leaving less habitat available for the tiger. Literature suggests that there are more factors than just the disappearance of total habitat and its fragmentation that are negatively affecting the tiger population. Namely, human-induced geographic isolation plays an important role in specifically the procreation of the Bengal tiger (Mondonaro et al., 2021). Geographic isolation usually can be any form of fragmentation that separates habitat patches from each other, either naturally or manually. In this case, based on the historical and current land maps from earlier, land-use change caused these habitat patches to be increasingly isolated from each other.

Therefore, not only do individual tigers need an abundance of space to roam around in, but they also need enough connecting habitats to find other individuals and reproduce. From the land-use maps shown above in figures 8, 9, and 10 can be concluded that not only the overall size of rangeland and forest area has shrunk, but the distance between these habitats has also only grown bigger due to an increase in agricultural land. Leaving individuals on metaphorical secluded islands of habitat with few to no other tigers near them to naturally collide paths with.

Furthermore, even relatively small fragmentation such as roads can be enough to discourage species such as the tiger to cross to another part of the forest (Carter, et al., 2022). Therefore, possibly missing yet another opportunity to encounter another individual of its species to procreate with and grow the population numbers. Lastly, although outside of the scope of this research, climate change plays an important role in altering hydrological systems such as precipitation trends with the potential of changing entire ecosystems (McCollum et al., 2017).

Prey Population

Within the Theory and Concepts section, the diet of the Bengal tiger was outlined in figure 3. Among many ungulate species, (spotted) deer seemed to be one of the main prey species of the Bengal tiger. The earlier mentioned livestock grazing (section 4.2.1) is seen as problematic for the survival of ungulate species, among which the deer species in the Himalayan areas and mountain forests in Northern India and Nepal (Khadka & James, 2016). Khadka and James, explain that due to the loss of rangeland and forest area in combination with overexploitation a significant decline in deer populations has occurred, with some species even being considered endangered. It appears that both the habitat loss to agricultural area and the pressure on native vegetation by livestock grazing is therefore influencing the availability of the Bengal tiger its preferred prey.

Poaching

While performing the literature review, an aspect that was discussed in the *Theory and Concepts* section returned multiple times, namely poaching. Although the phenomenon is not necessarily based on land-use changes, it is aggravated by especially urban population growth leading to urbanisation. For example, Breuer et al. (2016) explain that urbanisation has led to an increase in road construction which consequently created easier access to forest elephants and their habitats, increasing the poaching rates. Indeed, over a period of 20 years, the road density in Nepal grew five times its size including the mountain areas where the Bengal tiger can be found (Sudmeier-Rieux et al., 2019).

Although both India and Nepal have illegalised the poaching of the Bengal tiger, there is still a great deal of illegal trafficking (Nittu et al., 2022). Nittu et al. explain this has only gotten increasingly worse, as the demand for their body parts has been growing in the past few decades. They emphasise that especially India is at risk of illegal poaching as they have the largest tiger population globally and success rates are therefore much higher. The paper further explains that because China are the biggest importers of the illegal materials, Nepal bordering with both India and China is considered at risk and is known to have a popular illegal trafficking route. All these factors are threats to the conservation efforts mentioned in the introduction, such as the TAL area.

4.3 MINOR CASE STUDY OF TERAI ARC LANDSCAPE: RESPONSES

The TAL was created as a response to the decrease in flora and fauna in the effort to conserve them. Figure 2 showed how different corridors connected various protected areas to form the whole of the TAL.

Taking a closer look at the land-use maps from 1900, 2000 and 2021, there are some aspects that stood out and warranted further research. Below in figure 15, a zoomed-in version of the previous land-use maps is shown, within these maps the outline of the TAL can be seen.

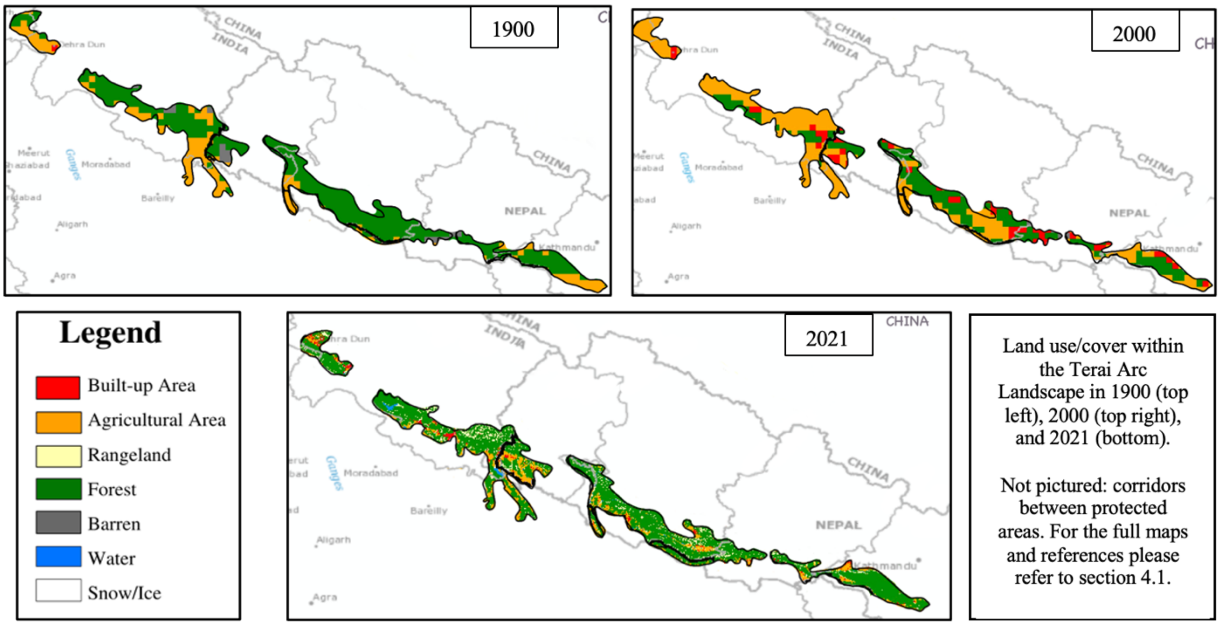


Figure 15. Land use/cover change in the TAL 1900 (top-left), 2000 (top-right), 2021 (bottom).

Please note that there are no TAL outline maps available due to the ambiguity of the exact area. Therefore, a generalised outline is created within the land-use maps created in section 4.1. The outline is based on figure 2 in combination with images from scientific papers referenced throughout this paper and was drawn in manually. The TAL itself is slightly larger than the outline above, but the outline showcases the protected conservation areas within, which are the areas of importance to this research.

In general, it becomes clear that the TAL area was relatively untouched up until 1900 as much of Nepal was in section 4.1 as well. In 2000, forest area was replaced by mostly agricultural area and built-up area. However, in 2021, a small area of built-up area and a large area of agricultural area has been restored to forest or rangeland. This is in accordance with the restoration and conservation efforts, mentioned in the introduction, that began between 2000-2010.

One important reason why the TAL area (and Nepal in general) was relatively undisturbed until 1900, saw a large rise in human-made land-use changes somewhere between 1900-2000 and recovered relatively quickly from the human-disturbance from 2000 up to 2021, is the disease Malaria (Dinnerstein, 1980). Dinnerstein explains that up until the 1950s, the Terai zone of northern Nepal was plagued by mosquitos and therefore the threat of the Malaria disease. With little to no interference from direct human impact, the original ecosystems remained largely intact and undisturbed. However, once successful prevention and treatment methods were installed by the government in the 1950s, the Nepalese population quickly came down from the mountainous areas to utilise the fertile flat plains made for excellent agricultural land that was needed to feed the rising population.

Policies protecting areas from significant human-alteration were already implemented as early as 1973, to conserve wildlife within Nepal (Aryal et al., 2021). Once the current TAL conservation policies were implemented in the early 21st century, it appears that no tipping point had been reached when it comes to the Bengal tiger. According to a governmental survey, Nepal has seen an increase of 62% in the Bengal tiger population within the TAL region from 2008 to 2018 (DNPWC, 2018) Therefore, protecting the forests, active afforestation, and relocation of urban areas proved immensely successful; the population saw a slow increase in numbers as its natural habitat slowly returned.

However, there are clear differences between regions within the TAL that are also predominantly caused by connectivity differences, loss of connectivity causes a decrease in ungulate population and lack of mating partners (Chanchani et al., 2014). Whereas properly connected regions often see an abundance of ungulates and a growing tiger population with a balanced gender ratio. However, as mentioned in the *Theory and Concepts* section, bottleneck genetics due to the small population size and geographical isolation are an area of concern when it comes to the future survivability of the Bengal tiger. Even though a population is growing within a region, sufficient regions need to be connected to make sure there is a diverse gene pool for high survival chances. Indeed, recent studies have found that bottleneck genetics is already occurring within the TAL tiger population (Thapa et al., 2018). Lastly, as was found during the literary research in section 4.2, illegalising poaching has not stopped the demand from growing and is therefore still an active threat to the conservation efforts within the TAL.

An interesting aspect that became apparent throughout this research is that similar species, such as the leopard, have seen increased living conditions due to the conservation efforts specifically for the (Bengal) tiger within and along the TAL (Thapa et al., 2021). This emphasises the status of the Bengal tiger as a key species; the conservation of the tiger alone is leading to conservation of entire ecosystems and its species.

4.4 DPSIR MODEL: OVERVIEW OF THE RESULTS AND THEIR RELATIONSHIP

Below in figure 16, a completed DPSIR model is shown that presents all the results found and how it all relates to each other. Encompassing all the research aspects and results, this model serves as a concise overview and summary of the entire thesis research.

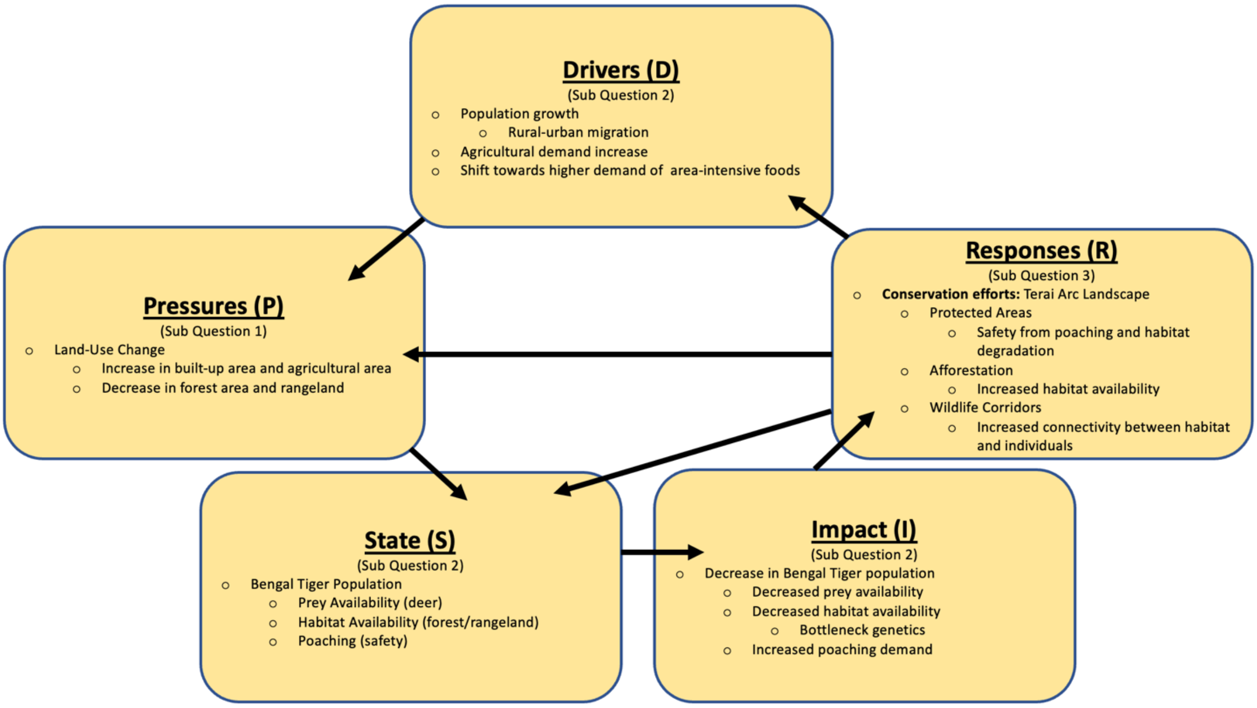


Figure 16. Finalised DPSIR model: Summary of Results

In the next sections, *Discussion* and *Conclusion*, the research questions will be answered one by one using the results found above.

5. DISCUSSION

As this research included methods that built upon results found within the research process quite a few links have already been made based on literature reviewing and confirmed through databases in the previous section. In this section, however, the results and links will be interpreted by concretely answering the sub-questions in relation to the framework and finally, the limitations and relevance of the findings are outlined.

ANSWERING THE SUB-QUESTIONS

Three bite-sized questions were created to give a complete answer to the research question of this paper. This section will discuss each sub-question individually based on the different methods and results introduced earlier on in the report. Ultimately, in the *Conclusion* (Section 6), the overarching research question will be answered in a concrete manner.

What were the historical land-use changes (1900-2000) in Northern India and Nepal and what is the current state (2021)?

The historical land maps in figures 9 and 10, illustrate that a large part of the forest land cover has been replaced by agricultural land and urban area over the period of 1900-2000. Nepal specifically has lost a high percentage of forest area. The reason why southern Nepal was barely affected by direct human impacts before 1900 but was quickly degraded between then and 2000 is due to the threat of malaria up until the 1950s. After the threat was (partially eliminated) the deforestation in preparation for altering the land for human-use quickly began. In 2021, however, it seems that some forest area has returned especially to Nepal (figure 11). At the same time, urban areas continued to grow in both areas and have clustered together over time in both regions.

What could be the drivers of these changes and how could these changes have affected the livelihood of the Bengal Tiger in Northern India and Nepal?

Drivers:
A combination of increased population growth, rural-urban migration, and a shift in food demand towards area-intensive products, has been responsible for the urbanisation and increase in agricultural area.

States and Impacts:
<u>Habitat availability</u> has decreased due to the replacement of forest and rangeland area by built-up area and agricultural area. The latter also giving rise to cattle grazing which pressures native vegetation of rangeland. This has decreased the habitat availability for both the Bengal tiger and the ungulates it preys upon. Furthermore, urbanisation has increased road connectivity adding to the geographic isolation between habitat patches. This makes it difficult for tiger individuals to find suitable mating candidates (specifically with sufficiently different genetics) causing implications for procreation and in some areas resulting in bottleneck genetics within the population. As discussed in the *Theory and Concepts* section, this gives rise to the possibility of new diseases and lowers the survival chances of an individual.

Prey availability has decreased due to the disappearance of its natural habitat. Especially for one of the preferred food species of the Bengal tiger, (spotted) deer. With some deer species even being considered endangered. As introduced in the *Theory and Concepts* section, the Lotka-Volterra theory holds that a drop in prey population is followed by a drop in predator population. Although in this theory the prey population slowly restores due to an absence in predator numbers, the lack of habitat availability for the prey is making this return challenging. This lack of prey availability is a limitation for Bengal tiger population growth.

Poaching has seen an increase in demand as parts of the Bengal Tiger are still wanted for multiple purposes such as medication and decoration, predominantly in China. From the *theory and concepts*, it became clear that poaching posed the biggest short-term threat to the Bengal Tiger. Now the numbers have decreased globally, each hunted down tiger could bring the population to a tipping point, making the disappearance of the species irreversible. Poaching has been illegalised in both India and Nepal; however, this has done little to halt the practice. As India has the biggest current Bengal tiger population globally, it is the most popular poaching area creating extra pressure on the already fragile population. Moreover, increased transport infrastructure due to urbanisation has increased accessibility to megafauna for poachers.

To what extent has the Terai Arc Landscape initiative acted as an effective response and how is this different from other areas in Northern India and Nepal?

Due to protective measures and afforestation, the TAL conservation efforts have been successful in stopping the decrease of the Bengal tiger population within its boundaries. Some years have even shown a very small increase in population numbers. However, the total area is limiting for the tigers and geographic isolation has led to the occurrence of limited genetic diversity among the TAL tiger population, leading to the phenomenon known as bottleneck genetics. As discussed in the *Theory and Concepts* and *Results* section, a lack of genetic diversity cannot only limit their survivability chances as a species but also possibly create new viruses that pose a threat to other (megafauna) species within the TAL. Therefore, wildlife corridors are essential to increase diversified contact within the population.

These wildlife corridors are the most promising response and lesson to be taken from the TAL in India and Nepal. The corridors and protective measures, for both deforestation and poaching, combined with the long absence of human interference due to malaria are the reason for why the tiger population is seemingly thriving in the TAL compared to other areas in Northern India and Nepal. However, safety from poaching through illegalising the activity might seem promising on paper but needs to be implemented and controlled correctly in practice as well for it to work effectively.

Conservation as a response in the DPSIR model (figure 16) does little to affect drivers such as population growth or a shift in food demand within a nation, however, it does limit the possibility of growth into protected areas. Thus, although the driver may not be limited in general, the consequences of the drivers will be limited and therefore have fewer negative influences on the conservation area.

RESEARCH LIMITATIONS AND IMPLICATIONS

Working with historical data always comes with some level of uncertainty, therefore this research was done in combination with literary research to see if the perceived changes in the land-use maps were also mentioned in other literature. Although the resulting maps and found data seem to be in line with each other, there was no comparative analysis done to see if the extend of the changes are the same. Therefore, even though the maps and literature both indicate a decrease in forest area, the maps may show a more optimistic or pessimistic view compared to the literature. However, as the historical datasets used are cited nearly 1400 times and both endorsed and implemented by NASA, they are considered reliable enough for the purpose of land-use change research.

Furthermore, the changing climate due to anthropogenic activities fell outside the scope of this research. As briefly mentioned in the results section, a change in the hydrological systems can alter ecosystems and therefore contribute to the degradation of grasslands and forests (McCollum et al., 2017). However, due to the limitations of time and word allowance only direct land-use changes were researched and indirect effects of land-use change such as possible increased greenhouse gas emissions were not included.

It is to be emphasised once more that the survival of the Bengal tiger correlates directly with the survival of its habitat and prey (Kumar, 2021). Therefore, actively protecting the Bengal tiger will protect entire ecosystems and the flora and fauna species that live within, such as the earlier discussed leopard who is coincidentally also benefiting from the conservation efforts aimed at tigers. If the restoration of ecosystems can be paired with sustainable resource use by future generations, the protection of the Bengal tiger will safekeep and sustain many species, among which is our own (Thapar, 2006).

6. CONCLUSION

ANSWERING THE RESEARCH QUESTION: KEY FINDINGS

The following question was posed at the start of this research:

What is the effect of historical (1900 – 2000) and current land-use changes on the *Bengal Tiger* population in Northern India and Nepal and what kind of effects could conservation efforts have?

During this report several discoveries were made:
The historical land-use changes between 1900 and 2000 in Northern India and Nepal included the disappearance of forest areas and a significant rise in urban and agricultural areas. Now, in 2021, some afforestation can be seen especially in Nepal. But not nearly to its previous levels. These land-use changes are predominantly driven by the extraordinary rise in (urban) population in both countries and the rise in animal product demand. The effect of these land-use changes has led to the disappearance of forests and grasslands leading to a decrease in habitat for both ungulate species and the Bengal tiger itself. This lack of space and food, in combination with increased poaching, is decreasing the survivability prospects of the Bengal tiger. Conservation efforts have proven effective, but the success is also partially due to the delayed disturbances in the Terai Arc-Zone in Nepal caused by Malaria up until 1950, making the initial restoration efforts possibly more efficient than ones applied in other heavily degraded areas. However, there are still areas of improvement. The continued development of wildlife corridors could minimise bottleneck genetics and well-executed protection policies can keep the tigers safe from poaching.

TAKE-HOME MESSAGES

- The Bengal tiger has seen a global decrease in population numbers due to a decrease in its prey availability and the safety and area of its native grass/forest habitat.
- This decrease is human-induced and caused by, among other aspects, population growth and change in agricultural demand leading to land-use changes such as urbanisation and agricultural area expansion.
- Recent conservation efforts, especially the Terai Arc Landscape, have proven fruitful in restoring some of the populations within its protected areas.
    - Both the tiger population and other species within the TAL have benefitted from the measures
    - However, poaching and bottleneck genetics are limiting the effectiveness.
- If the conservation efforts are improved and remain to be successful, entire ecosystems can be restored for the benefit of many species, among which our own.
- Future research should focus on finding effective locations for corridors and ways to improve monitoring of the protection policies in both India and Nepal.

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World Bank, World Development Indicators. (2020c). *Rural Population* [Data file]. Retrieved from https://data.worldbank.org/indicator/SP.RUR.TOTL

WWF. (2022). WWF's impact on tiger recovery (2010-2022). *Yearly*. Retrieved May 16, 2022, from https://app.yearly.report/newbuilder/#/from/wwf/wwfs-impact-on-tiger-recovery

9. APPENDIX

APPENDIX I: DPSIR MODEL

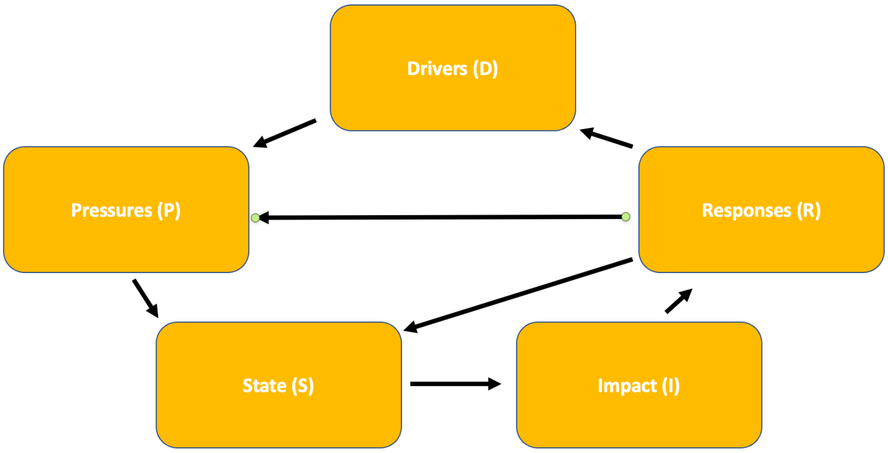

Figure I-A. Standard DPSIR Model (Adapted from Ness et al., 2010)

The DPSIR model (see figure I-A above for a basic model) is a framework that addresses the human-induced relationships between occurrences and/or systems. It starts with a driver that ultimately kickstarts a process this is often a human need such as increased tourism, which is followed by a pressure that takes form as a human activity which in this example could be littering from the newly attracted tourists. This pressure then impacts a certain state which could be the soil or water quality and leads to an impact such as health hazards due to polluted water. A response can influence the drivers, pressures, and states through taking an action that limits, alters, or mitigates the process (consequences). In this case, tourists might be told to pay a tourist tax which will be used to hire workers to clean the newly introduced pollution. Or new laws can be introduced that introduce a littering fine, to try and limit littering and pollution in the first place.

Through the use of the DPSIR model a system can be picked apart to see what is influencing or being influenced and how different responses can tackle the negative trends occurring.

APPENDIX II: SPATIAL MODELING DATASETS

Within this section further details of the datasets used within this research can be found.

DATASET 1: LAND-USE CHANGE (1900-2000) (ELLIS ET AL., 2014A; 2014B).

Below a table from the dataset paper can be found with the original description of the original different classes. For the purpose of the paper these classes were re-categorised to fit the research scope; the allocation can be seen in figure 8 in the *Methods* section.

Table 1 Description of anthrome classes.

Level	Class	Description
Dense settlements		Urban and other dense settlements
11	Urban	Dense built environments with very high populations
12	Mixed settlements	Suburbs, towns and rural settlements with high but fragmented populations
Villages		Dense agricultural settlements
21	Rice villages	Villages dominated by paddy rice
22	Irrigated villages	Villages dominated by irrigated crops
23	Rainfed villages	Villages dominated by rainfed agriculture
24	Pastoral villages	Villages dominated by rangeland
Croplands		Lands used mainly for annual crops
31	Residential irrigated croplands	Irrigated cropland with substantial human populations
32	Residential rainfed croplands	Rainfed croplands with substantial human populations
33	Populated rainfed cropland	Croplands with significant human populations, a mix of irrigated and rainfed crops
35	Remote croplands	Croplands without significant populations
Rangeland		Lands used mainly for livestock grazing and pasture
41	Residential rangelands	Rangelands with substantial human populations
42	Populated rangelands	Rangelands with significant human populations
43	Remote rangelands	Rangelands without significant human populations
Seminatural lands		Inhabited lands with minor use for permanent agriculture and settlements
51	Residential woodlands	Forest regions with minor land use and substantial populations
52	Populated woodlands	Forest regions with minor land use and significant populations
53	Remote woodlands	Forest regions with minor land use without significant populations
54	Inhabited treeless and barren lands	Regions without natural tree cover having only minor land use and a range of populations
Wildlands		Lands without human populations or substantial land use
61	Wild woodlands	Forests and savanna
62	Wild treeless and barren lands	Regions without natural tree cover (grasslands, shrublands, tundra, desert and barren lands)

For details of classification see Appendix S3.

Table II-A. Original class descriptions from Ellis et al. (2014a).

DATASET 2 (ESRI): SENTINEL-2 10M LAND-USE/LAND COVER TIMESERIES (2017-2021) (KARRA ET AL., 2022).

This map uses classification data (human-labelled) based on 400,000 earth observations each year. It is emphasised that the mapping of the year 2017 was based on slightly fewer images and therefore could be considered less accurate than the later years.

The following nine classes are present in the dataset:

1. Water
2. Trees
3. Flooded Vegetation
4. Crops
5. Built Area
6. Bare Ground
7. Snow/Ice
8. Clouds
9. Range Land

EXCERPT FROM DATABASE DESCRIPTION (**KARRA ET AL., 2022**)

Disclaimer:

The class definitions excerpt below was taken one on one from the database given above. Their preferred citation for it can be found in the reference list and is given here again:

Karra, Kontgis, et al. "Global land use/land cover with Sentinel-2 and deep learning." IGARSS 2021-2021 IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2021.

Direct link:
https://www.arcgis.com/home/item.html?id=d3da5dd386d140cf93fc9ecbf8da5e31

This excerpt contains all nine classes monitored and used in this dataset and exactly what is considered in each class:

Class definitions

1. Water
Areas where water was predominantly present throughout the year; may not cover areas with sporadic or ephemeral water; contains little to no sparse vegetation, no rock outcrop nor built up features like docks; examples: rivers, ponds, lakes, oceans, flooded salt plains.

2. Trees
Any significant clustering of tall (~15 feet or higher) dense vegetation, typically with a closed or dense canopy; examples: wooded vegetation, clusters of dense tall vegetation within savannas, plantations, swamp or mangroves (dense/tall vegetation with ephemeral water or canopy too thick to detect water underneath).

3. Flooded vegetation
Areas of any type of vegetation with obvious intermixing of water throughout a majority of the year; seasonally flooded area that is a mix of grass/shrub/trees/bare ground; examples: flooded mangroves, emergent vegetation, rice paddies and other heavily irrigated and inundated agriculture.

4. Crops
Human planted/plotted cereals, grasses, and crops not at tree height; examples: corn, wheat, soy, fallow plots of structured land.

5. Built Area
Human made structures; major road and rail networks; large homogenous impervious surfaces including parking structures, office buildings and residential housing; examples: houses, dense villages / towns / cities, paved roads, asphalt.

6. Bare ground
Areas of rock or soil with very sparse to no vegetation for the entire year; large areas of sand and deserts with no to little vegetation; examples: exposed rock or soil, desert and sand dunes, dry salt flats/pans, dried lake beds, mines.

7. Snow/Ice
Large homogenous areas of permanent snow or ice, typically only in mountain areas or highest latitudes; examples: glaciers, permanent snowpack, snow fields.
8. Clouds
No land cover information due to persistent cloud cover.

9. Rangeland
Open areas covered in homogenous grasses with little to no taller vegetation; wild cereals and grasses with no obvious human plotting (i.e., not a plotted field); examples: natural meadows and fields with sparse to no tree cover, open savanna with few to no trees, parks/golf courses/lawns, pastures. Mix of small clusters of plants or single plants dispersed on a landscape that shows exposed soil or rock; scrub-filled clearings within dense forests that are clearly not taller than trees; examples: moderate to sparse cover of bushes, shrubs and tufts of grass, savannas with very sparse grasses, trees or other plants.

APPENDIX III. WORLDBANK DATA (WORLDBANK 2020A; 2020B; 2020C)

Within this section the full table (Table III-A) of the used World Bank datasets can be viewed. This table is a collection of three different datasets namely total population, urban population, and rural population in from 1961 – 2020. Originally the three datasets include data for the world (with separate countries), but data from other countries were cut out for the sake of relevance to this research.

TABLE III-A. POPULATION FOR NEPAL AND INDIA (TOTAL, URBAN, RURAL) (1961-2020)

Year	India (Total)	Nepal (Total)	India (Urban)	Nepal (Urban)	India (Rural)	Nepal (Rural)
1960	450.547.675	10.105.060	80.756.165	351.656	369.791.510	9.753.404
1961	459.642.166	10.267.260	82.882.675	366.644	376.759.491	9.900.616
1962	469.077.191	10.433.147	85.456.483	376.845	383.620.708	10.056.302
1963	478.825.602	10.604.620	88.127.852	387.387	390.697.750	10.217.233
1964	488.848.139	10.783.958	90.901.311	398.467	397.946.828	10.385.491
1965	499.123.328	10.972.912	93.760.317	410.058	405.363.011	10.562.854
1966	509.631.509	11.172.530	96.712.771	422.322	412.918.738	10.750.208
1967	520.400.577	11.382.965	99.765.995	435.171	420.634.582	10.947.794
1968	531.513.834	11.603.921	102.932.969	448.724	428.580.865	11.155.197
1969	543.084.333	11.834.657	106.238.157	462.853	436.846.176	11.371.804
1970	555.189.797	12.074.628	109.705.504	477.672	445.484.293	11.596.956
1971	567.868.021	12.323.984	113.522.496	493.576	454.345.525	11.830.408
1972	581.087.255	12.583.142	118.082.741	528.240	463.004.514	12.054.902
1973	594.770.136	12.852.205	122.837.876	565.368	471.932.260	12.286.837
1974	608.802.595	13.131.260	127.793.753	605.351	481.008.842	12.525.909
1975	623.102.900	13.420.367	132.920.311	648.204	490.182.589	12.772.163
1976	637.630.085	13.719.466	138.219.074	694.342	499.411.011	13.025.124
1977	652.408.766	14.028.535	143.699.555	743.793	508.709.211	13.284.742
1978	667.499.815	14.347.653	149.379.784	796.725	518.120.031	13.550.928
1979	682.995.348	14.676.932	155.285.822	853.610	527.709.526	13.823.322
1980	698.952.837	15.016.408	161.444.126	914.649	537.508.711	14.101.759
1981	715.384.997	15.367.229	167.521.705	979.815	547.863.292	14.387.414
1982	732.239.498	15.729.431	173.152.674	1.040.659	559.086.824	14.688.772
1983	749.428.958	16.100.623	178.956.141	1.105.147	570.472.817	14.995.476

1984	766.833.411	16.477.488	184.906.540	1.173.362	581.926.871	15.304.126
1985	784.360.012	16.858.315	190.975.976	1.245.155	593.384.036	15.613.160
1986	801.975.250	17.239.677	197.165.615	1.320.559	604.809.635	15.919.118
1987	819.682.095	17.623.697	203.469.686	1.400.026	616.212.409	16.223.671
1988	837.468.938	18.020.755	209.894.840	1.484.550	627.574.098	16.536.205
1989	855.334.675	18.445.021	216.442.440	1.575.389	638.892.235	16.869.632
1990	873.277.799	18.905.480	223.096.279	1.673.891	650.181.520	17.231.589
1991	891.273.202	19.405.506	229.752.406	1.781.425	661.520.796	17.624.081
1992	909.307.018	19.938.322	236.274.336	1.910.490	673.032.682	18.027.832
1993	927.403.866	20.489.973	242.896.347	2.048.792	684.507.519	18.441.181
1994	945.601.828	21.040.899	249.629.427	2.195.197	695.972.401	18.845.702
1995	963.922.586	21.576.074	256.470.882	2.348.124	707.451.704	19.227.950
1996	982.365.248	22.090.352	263.440.889	2.507.255	718.924.359	19.583.097
1997	1.000.900.028	22.584.772	270.523.260	2.672.682	730.376.768	19.912.090
1998	1.019.483.586	23.057.875	277.707.329	2.844.419	741.776.257	20.213.456
1999	1.038.058.154	23.509.971	284.978.105	3.022.677	753.080.049	20.487.294
2000	1.056.575.548	23.941.099	292.322.757	3.207.389	764.252.791	20.733.710
2001	1.075.000.094	24.347.113	300.118.526	3.395.692	774.881.568	20.951.421
2002	1.093.317.187	24.725.625	308.796.506	3.520.929	784.520.681	21.204.696
2003	1.111.523.146	25.080.880	317.584.393	3.646.258	793.938.753	21.434.622
2004	1.129.623.466	25.419.337	326.495.070	3.772.484	803.128.396	21.646.853
2005	1.147.609.924	25.744.500	335.503.761	3.900.034	812.106.163	21.844.466
2006	1.165.486.291	26.066.687	344.622.641	4.030.431	820.863.650	22.036.256
2007	1.183.209.471	26.382.586	353.850.624	4.163.436	829.358.847	22.219.150
2008	1.200.669.762	26.666.581	363.154.576	4.294.653	837.515.186	22.371.928
2009	1.217.726.217	26.883.531	372.465.918	4.418.039	845.260.299	22.465.492
2010	1.234.281.163	27.013.207	381.763.164	4.529.575	852.517.999	22.483.632
2011	1.250.287.939	27.041.220	391.040.056	4.626.212	859.247.883	22.415.008
2012	1.265.780.243	26.989.160	400.416.922	4.711.768	865.363.321	22.277.392
2013	1.280.842.119	26.916.795	409.907.903	4.795.227	870.934.216	22.121.568
2014	1.295.600.768	26.905.982	419.567.353	4.892.046	876.033.415	22.013.936
2015	1.310.152.392	27.015.033	429.428.650	5.013.180	880.723.742	22.001.853
2016	1.324.517.250	27.263.430	439.501.314	5.164.239	885.015.936	22.099.191

2017	1.338.676.779	27.632.682	449.795.398	5.343.055	888.881.381	22.289.627
2018	1.352.642.283	28.095.712	460.304.169	5.546.094	892.338.114	22.549.618
2019	1.366.417.756	28.608.715	471.031.529	5.765.514	895.386.227	22.843.201
2020	1.380.004.385	29.136.808	481.980.332	5.995.190	898.024.053	23.141.618

APPENDIX IV. FAOSTAT DATA

Within this appendix the FAO databases are showcased.
Table IV-A illustrates the urban area in India and Nepal from 1992 – 2020 (in 1000 ha).
Table IV-B illustrates the livestock numbers in Nepal from 1961 – 2020 (in units).
Table IV-C illustrates the livestock numbers in India from 1961 – 2020 (in units).

TABLE IV-A. URBBAN AREA (1000 HA) IN INDIA AND NEPAL (1992-2020)

Year	Built-up area India (1000 ha)	Built-up area Nepal (1000 ha)
1992	608.8353	10.5677
1993	623.3732	10.7072
1994	636.9752	10.8002
1995	649.6471	10.9223
1996	662.9643	11.0153
1997	675.4851	11.1025
1998	688.221	11.3001
1999	700.707	11.5326
2000	714.745	11.8872
2001	832.4605	13.8287
2002	935.1731	14.6948
2003	1033.2064	15.1889
2004	1133.7741	15.5319
2005	1210.5382	16.1248
2006	1283.1927	17.0955
2007	1359.3931	17.7698
2008	1422.3692	18.3918
2009	1483.0086	19.2579
2010	1542.5145	19.8915
2011	1606.3742	20.589
2012	1702.6346	21.4203
2013	1832.0687	22.7398
2014	1949.1739	25.4544
2015	2020.1136	26.7041
2016	2029.8792	26.7099
2017	2095.3374	26.9076
2018	2131.8652	26.9483
2019	2201.7818	27.0354

TABLE IV-B. COMBINED LIVESTOCK (CATTLE, GOATS, AND PIGS) IN INDIA (1961 – 2020).

Year	India (Cattle) (in million individuals)	India (Goats) (in million individuals)	India (Pigs) (in million individuals)	Total Livestock (in million individuals)
1961	175,600000	60,864000	5,176000	241,640000
1962	173,900000	61,600000	5,135000	240,635000
1963	173,971008	62,334000	5,090000	241,395008
1964	175,800000	63,070000	5,050000	243,920000
1965	175,900000	63,800000	5,010000	244,710000
1966	176,212000	64,589008	4,975000	245,776008
1967	176,384000	65,066000	5,304000	246,754000
1968	176,731008	65,549000	5,588000	247,868008
1969	177,086000	66,036000	5,700000	248,822000
1970	177,442000	66,526000	6,000000	249,968000
1971	177,814000	67,026000	6,533000	251,373000
1972	178,384000	67,518000	6,896000	252,798000
1973	178,331008	69,000000	6,900000	254,231008
1974	178,580000	71,000000	7,100000	256,680000
1975	179,457008	72,500000	7,300000	259,257008
1976	180,350000	74,000000	7,400000	261,750000
1977	180,286000	75,620000	7,647000	263,553000
1978	181,992000	79,200000	8,100000	269,292000
1979	184,300000	83,000000	8,600000	275,900000
1980	186,500000	86,900000	9,000000	282,400000
1981	188,700000	91,000000	9,600000	289,300000
1982	192,453008	95,253008	10,072000	297,778016
1983	193,797008	98,300000	10,200000	302,297008
1984	195,154000	99,430000	10,300000	304,884000
1985	196,520000	99,490000	10,400000	306,410000
1986	197,895008	102,870000	10,500000	311,265008
1987	199,695008	110,207000	10,606000	320,508008
1988	200,650000	111,200000	11,000000	322,850000
1989	201,600000	112,200000	11,400000	325,200000
1990	202,500000	113,200000	11,900000	327,600000
1991	203,500000	114,200000	12,300000	330,000000
1992	204,584000	115,279000	12,788000	332,651000
1993	203,634000	116,700000	12,900000	333,234000
1994	202,684000	118,200000	13,000000	333,884000
1995	201,734000	119,700000	13,100000	334,534000
1996	200,784000	121,200000	13,200000	335,184000

1997	198,882000	122,721000	13,291000	334,894000
1998	196,535008	122,991000	13,328000	332,854008
1999	194,216000	123,262000	13,366000	330,844000
2000	191,924000	123,533000	13,403000	328,860000
2001	189,660000	123,805000	13,440000	326,905000
2002	187,422000	124,077000	13,478000	324,977000
2003	185,180992	124,358000	13,519000	323,057992
2004	188,570000	128,213000	12,878000	329,661000
2005	192,020992	132,188000	12,268000	336,476992
2006	195,535008	136,286000	11,686000	343,507008
2007	199,075008	140,540000	11,134000	350,749008
2008	197,444992	139,467008	10,967000	347,879
2009	195,815008	138,394000	10,802000	345,011008
2010	194,184992	137,320992	10,640000	342,145984
2011	192,555008	136,248000	10,481000	339,284008
2012	190,904105	135,173093	10,293695	336,370893
2013	189,000000	134,000000	10,130000	333,130000
2014	187,000000	133,000000	10,000000	330,000000
2015	188,166506	138,391040	9,851102	336,408648
2016	189,677730	142,335143	9,686420	341,699293
2017	191,054855	143,266764	9,465319	343,786938
2018	192,265451	145,771142	9,263549	347,300142
2019	193,462871	148,884786	9,055488	351,403145
2020	194,482355	150,248487	8,852111	353,582953

TABLE IV-C. COMBINED LIVESTOCK (CATTLE, GOATS, AND PIGS) IN NEPAL (1961 – 2020).

Year	Nepal (Cattle) (in million individuals)	Nepal (Goats) (in million individuals)	Nepal (Pigs) (in million individuals)	Total Livestock (in million individuals)
1961	5,800000	3,600000	0,180000	9,580000
1962	5,826000	3,750000	0,187000	9,763000
1963	5,830000	3,800000	0,180000	9,810000
1964	5,840000	3,850000	0,177000	9,867000
1965	5,850000	3,900000	0,250000	10,000000
1966	5,860000	3,950000	0,300000	10,110000
1967	5,985000	4,000000	0,307000	10,292000
1968	6,105000	4,050000	0,313000	10,468000
1969	6,226000	4,100000	0,320000	10,646000
1970	6,300000	4,150000	0,320000	10,770000
1971	6,350000	4,200000	0,300000	10,850000
1972	6,400000	4,250000	0,300000	10,950000
1973	6,450000	4,300000	0,300000	11,050000
1974	6,500000	4,350000	0,310000	11,160000
1975	6,550000	4,400000	0,315000	11,265000
1976	6,650000	4,450000	0,325000	11,425000
1977	6,703000	4,500000	0,348000	11,551000
1978	6,770000	4,550000	0,364000	11,684000
1979	6,850000	4,600000	0,370000	11,820000
1980	6,900000	4,650000	0,375000	11,925000
1981	6,930000	4,700000	0,380000	12,010000
1982	6,950000	4,750000	0,456000	12,156000
1983	6,750000	4,800000	0,400000	11,950000
1984	6,550000	4,850000	0,420000	11,820000
1985	6,356994	4,882335	0,441946	11,681275
1986	6,371743	5,016298	0,455724	11,843765
1987	6,362930	5,089933	0,476340	11,929203
1988	6,343108	5,211043	0,516059	12,07021
1989	6,284918	5,302344	0,547655	12,134917
1990	6,280852	5,323645	0,574197	12,178694
1991	6,254819	5,366946	0,591602	12,213367
1992	6,245682	5,405793	0,598955	12,25043
1993	6,237231	5,451710	0,604902	12,293843
1994	6,546177	5,524657	0,612027	12,682861
1995	6,837913	5,649056	0,636024	13,122993
1996	7,008420	5,783140	0,670340	13,461900

1997	7,024780	5,921960	0,723613	13,670353
1998	7,048660	6,080060	0,765718	13,894438
1999	7,030698	6,204616	0,825132	14,060446
2000	7,023166	6,325144	0,877681	14,225991
2001	6,982664	6,478384	0,912530	14,373578
2002	6,978690	6,606858	0,934461	14,520009
2003	6,953584	6,791861	0,932192	14,677637
2004	6,966436	6,979875	0,935076	14,881387
2005	6,994463	7,153527	0,947711	15,095701
2006	7,002916	7,421624	0,960827	15,385367
2007	7,044279	7,847624	0,989429	15,881332
2008	7,090714	8,135880	1,013359	16,239953
2009	7,175198	8,473082	1,044498	16,692778
2010	7,199260	8,844172	1,064858	17,10829
2011	7,226050	9,186440	1,108465	17,520955
2012	7,244944	9,512958	1,137489	17,895391
2013	7,274022	9,786354	1,160035	18,220411
2014	7,243916	10,177531	1,190138	18,611585
2015	7,241743	10,251569	1,203230	18,696542
2016	7,302808	10,986114	1,291308	19,58023
2017	7,347487	11,165099	1,328036	19,840622
2018	7,376306	11,647319	1,435369	20,458994
2019	7,385035	12,283752	1,488338	21,157125
2020	7,458885	12,811953	1,519593	21,790431