CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF ENVIRONMENTAL SCIENCES

Diploma Thesis

2021 **Bc. Marina de Souza Faria**

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

FACULTY OF ENVIRONMENTAL SCIENCES

Department of Landscape and Urban Planning

Spatiotemporal Changes in Krkonoše Mts. Alpine Tundra

Diploma Thesis

Supervisor: Mgr. Jana Müllerová, Ph.D

Author: Bc. Marina de Souza Faria

Prague, 2021

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Bc. Marina Souza Faria

Landscape Engineering
Landscape Planning

Thesis title

Spatiotemporal changes in Krkonose Mts alpine tundra

Objectives of thesis

Alpíne tundra represents the most valuable parts of KRNAP. Eventhough it seems to be stable, on a long-term the tundra undergoes significant changes mainly due to the global change and local disturbances including human impact. Fine grain mosaic of vegetation above the treeline and its relatively slow changes are difficult to capture only using traditional field mapping techniques, and remote sensing methods, especially historical aerial imagery, can help.
The main aim of the theses is to assess the long-term changes of alpine tundra vegetation above the treeline in Krkonoše Mts.

Methodology

Detailed spatially-explicite analysis of historical and current aerial photography (available for most of tundra since 1936) and standard GIS processing will be complemented by historical sources and field work. The detected changes will be related to environmental conditions and placed in historical context.

The proposed extent of the thesis

60 pages

Keywords

Krkonoše, tundra, vegetation, long-term change, aerial imagery, human impact, disturbances, history

Recommended information sources

Lokvenc, T., 2001. History of Giant Mts.'dwarf pine (Pinus mugo Turra ssp. pumilio Franco). Opera Corcontica, 38, pp.21-42.

Treml, V., Wild, J., Chuman, T. and Potůčková, M., 2010. Assessing the change in cover of non-indigenous dwarf-pine using aerial photographs, a case study from the Hrubý Jeseník Mts., the Sudetes. Journal of Landscape Ecology, 3(2), pp.90-104.

Expected date of thesis defence

2020/21 SS – FES

The Diploma Thesis Supervisor

Mgr. Jana Müllerová, Ph.D.

Supervising department

Deans Office of FES

Electronic approval: 2. 3. 2021

Ing. Pavla Kohoutová

Head of Institute

Electronic approval: 2. 3. 2021

prof. RNDr. Vladimír Bejček, CSc.

Dean

Prague on 13. 03. 2021

AUTHOR'S DECLARATION

I hereby declare that this thesis is a presentation of my original research work done under the guidance of Mgr. Jana Müllerová, Ph.D. All sources that were used are listed. The thesis was not previously presented to another examination board and has not been published yet.

Prague, 30th March 2020.

Acknowledgements

I want to express my sincere appreciation to my supervisor Mgr. Jana Müllerová, Ph.D. for her guidance. From the very beginning as well as during the field trips, and the pandemic situation, she was always patient and supportive. Moreover, I would like to thank the Department of GIS and Remote Sensing of the Institute of Botany at the Czech Academy of Science for the financial support of the project I was a part of. Thanks to Professor Peter Kumble MLA Ph.D. of the Faculty of Environmental Sciences, (CULS) for his motivation and teaching style which are both very inspiring to me.

I'm thankful to Zdeněk Havel, for his love and for encouraging me to pursue my dreams, as well as his family to always help me when it was possible, for the attention, care, and be a family to me since I'm abroad.

Even far away from my family, I'm grateful for their love, bravery, and faith that they always remind me of, thank my mom, daddy, Camila, Vitor, Laurinha and my aunt Marcia for strengthening our ties. We are very strong, and we will never feel lonely since we have each other.

ABSTRAKT

Cílem této Diplomové práce je analýza časoprostorových změn v arkto-alpínské tundře Krkonoš ve srovnání s montánním pásem reprezentovaným třemi krajinnými výřezy. Výzkum kombinuje historický kontext, práci s leteckými snímky a mapami a analýzu krajinné struktury, což umožnilo připravit doporučení pro ochranu přírody a krajiny. Oblasti zájmu jsou: alpínské pásmo - západní arkto-alpínská tundra, a montánní pásmo - výřez 1 - Horní Malá Úpa; výřez 2 - Růžohorky u Pece Pod Sněžkou, a výřez 3 - Špindlerův Mlýn. Prostorová analýza studovaných území byla provedena za využití historických a současných leteckých snímků z let 1953 a 2018, a softwaru eCognition a ArcGIS. Statistické a grafické zpracování proběhlo v programech MS Excel a Power BI.
Byly nalezeny čtyři hlavní trajektorie změn land cover/land use: za prvé, šíření lesa/keřů (všechny studované plochy) v tundře ve spojení s umělými výsadbami; za druhé, opouštění lučního hospodaření (výřezy 1 a 2); za třetí, přeměna tradičních zemědělských sídel na turistické resorty (výřezy 1 a 3); a dále vliv sjezdového lyžování na krajinu (výřez 3).
Výsledky ukazují značně vyšší stabilitu tundry ve srovnání s montánním pásmem, kde jsou změny více dynamické. Celkově byl zaznamenán výrazný trend šíření lesa ve výřezech a keřové vegetace v tundře. Také bylo zaznamenáno snížení plochy luk a rostoucí urbanizace. Z toho lze vyvodit, že turismus a související opouštění tradičního hospodaření a zarůstání lesem ovlivnilo, ať přímo či nepřímo, environmentální podmínky v obou zónách, nicméně vliv je více zřetelný v montánním pásmu. Oproti tomu v alpínské tundře byly změny způsobeny převážně historickým vysazováním dřevin, ale pravděpodobně také globálními změnami podporujícími spontánní expanzi keřů. Detailní časoprostorová analýza prezentovaná v této studii umožnila vyvodit následující doporučení pro ochranu přírody a krajiny. V tundře by měla být prováděna opatření proti expandující kleči s ohledem na historii území a cenné reliktní půdy. V montánním pásmu by hlavní strategií měla být prevence další degradace a fragmentace krajiny, ale také regulace turismu a ochrana tradičního lučního hospodaření.

Klíčová slova: Arkto-alpínská tundra; Dlouhodobá časoprostorová analýza; Krkonoše; Letecké snímky; Turismus; Zarůstání dřevinami; Změny land use/land cover

ABSTRACT

The Diploma Thesis aims to analyze the spatiotemporal changes of the arctic-alpine tundra in the Krkonoše mountains and compares it with the changes in the montane belt represented by three landscape subsets. The research embraces the historical context, analyses of aerial imagery, maps, and assessment of landscape structure to allow the development of recommendations for nature conservation and landscape protection. The areas of interest are: alpine belt - western part of arctic-alpine tundra, and montane belt - Subset 1 - Horní Malá Úpa; Subset 2 - Růžohorky in Pec Pod Sněžkou and Subset 3 - Špindlerův Mlýn. Using the historical and current aerial imagery from 1953 and 2018, the spatial analysis of the study sites was made in eCognition and ArcGIS software. The statistics and graphics we processed in MS Excel and Power BI programs.

Four main trajectories of land cover/land use changes were found: Firstly, the forest/shrub encroachment (all study sites), in tundra related to the afforestation plan; secondly, the land abandonment of grassland farming (Subset 1 and 2); thirdly, the transformation of traditional agricultural villages to tourist resorts (Subset 1 and 3); and lastly, the impact of skiing on the landscape (Subset 3).

The results show that the alpine tundra demonstrates considerably higher stability compared to the montane belt where the changes were much more dynamic. Overall, I detected a strong trend of increasing forest in subsets and shrubby vegetation in the tundra. Moreover, a decrease in grasslands in all study sites, as well as growing urbanization has been observed. To conclude, the tourism and related abandonment of traditional farming and afforestation impacted, directly and indirectly, the environmental conditions of both zones, nevertheless, it is more prominent in the montane belt. Whereas in the alpine tundra, the changes can be attributed mainly to the historical planting of woods, however, they were most likely affected also by global change promoting spontaneous shrub encroachment. The detailed spatiotemporal analysis presented in this study enabled me to derive the following recommendations for conservation. In tundra, management of expanding dwarf pine should be carried with respect to the site history and valuable relict soils. As for the montane belt, the main strategy is to prevent further landscape degradation and fragmentation, but also regulate tourism and preserve traditional grassland management.

Key words: Aerial imagery; Arctic-alpine tundra; Krkonoše Mountains; Land use/land cover change; Long-term spatiotemporal analysis; Tourism; Wood encroachment

CONTENT

1. INTRODUCTION

1.1. MOTIVATION AND OBJECTIVE OF THE STUDY

This research is a part of the project “Vegetation of Krkonoše tundra - past, present, and future” CZ.05.4.27/0.0/0.0/17_078/0009044 from the Department of GIS and Remote Sensing of the Institute of Botany at Czech Academy of Science.

The Krkonoše National Park (KRNAP) is one of the most important protected areas in the Czech Republic. It hosts many significant and rare species and habitats, especially the arctic-alpine tundra, which is fragile, unique, and irreplaceable. The region underwent many historical and natural events during the years, and today, the Krkonoše Mts are the place where the interests of nature conservation and human society meet. This research aims to understand the changes in the Krkonoše in time.

The mountain landscape is marvelous and fascinating, especially for foreign students that have never seen such a unique ecosystem before. The mountains, tundra biome, climatic conditions are authentic particularly for this area, and make an exciting study area for research, to examine how the physical geography and the historical context sculpted and designed the national park that we have nowadays.

The Thesis will first present the basic concepts of the mountain ecosystem and the tundra biome in an overall view, and then apply the knowledge on a microscale; the changes in the park, exemplified and explained by three chosen subsets and studied in detail at the most valuable part of the park, the arctic-alpine tundra.

There are two areas of the arctic-alpine tundra in Krkonoše: western and eastern, this study will focus on the western one. Besides the tundra, three more subsets in the Montane belt were chosen: (1) Horní Malá Úpa (2) Růžohorky, Pec Pod Sněžkou and, (3) Špindlerův Mlýn. The first one is located in a traditional agricultural village area, the second, in a steep area of grasslands abandonment and the third, in the most famous skiing resort of the mountain range. Three subsets were selected to enable comparison in the landscape changing trajectories in different locations throughout the time.

With the assistance of the remote sensing approach, the Thesis will be able to analyze landscape changes of historical aerial images and current orthophotos. The workflow combining the object-based image analysis with Geographic Information System (GIS) automates and improves the change detection and its interpretation.

This study can contribute to better management and preservation of natural values. Thus, the detailed study of spatio-temporal changes in the park including the most fragile area of the tundra will help to improve planning the tourist and recreational activities and protective measures. It will also help to preserve the unique nature and minimize the human impact in the park, providing the best experience for visitors.

The objective of this Master Thesis is to test the following hypotheses:

H1. The Krkonoše Mountains are a subject of human-induced long-term changes, and the changes show different dynamics depending on elevation.

H2. The alpine belt shows considerably more stability compared to the montane belt.

H3. Effects of the site history are important for the current state of ecosystems and landscape.

Therefore, in this Thesis, I performed the long-term assessment of vegetation changes in the Krkonoše Mts. along the elevational gradient, specifically in the tundra of the alpine belt and in the montane belt, identifying the main trajectories and conservation issues.

Specific objectives of this Master Thesis are to:

1. Define the main changes, trajectories, and human impact in the Krkonoše Mts. during the last 70 years in both montane (three selected subsets) and alpine belts (tundra).

2. Carry a detailed analysis of trends in vegetation change of Krkonoše alpine tundra with a specific focus on the shrub encroachment

3. Analyze the potential of aerial photography to provide relevant information about the changes

4. Evaluate the changes using the remote sensing approach: eCognition and ArcGIS

5. Derive recommendations for the conservation of the area

2. LITERATURE REVIEW

2.1. MOUNTAIN ECOSYSTEM

This chapter will explain the basic concepts related to the mountain ecosystems and describe the mountain's importance from both the natural and human viewpoint. The mountains are integrated systems responsible for providing survival resources for human beings and serving as an important hotspot of biodiversity (Sayre, 2020; Korner, 2017). Over time, the anthropogenic pressure is exhausting this fantastic but fragile bioecological system, thus it is important to understand its past and current state and functioning, to adopt efficient conservation policies.

2.1.1. Biogeography - Geodiversity Importance

Biogeography is one of the fields in geographical science that answers questions such as: "Why are there so many living things, why are they distributed in the way they are and are these patterns being affected by human activity?" (Hominick, 2002). For the mountain's case, their biogeography is a function of geographic isolation that contributes to speciation and influences the patterns of colonization and species distribution (Knowles L, et al. 2017).

Korner (2004) stratified mountains into elevational belts (**Figure 1**). Each belt has specific climatic conditions and particular biogeography: flora, and fauna. This thesis focuses on the montane zone and the tundra in the alpine zone.

The part from mountain foothills up to the treeline is called the "montane" belt. It is mostly forested, and partly covered by semi-natural grasslands and human settlements. The vegetation-covered belt above the treeline is termed "alpine", which by definition has no trees because of harsh climatic conditions. Human activities above the tree line are rather recent and mostly related to tourism. Thus, the alpine zone is mostly natural and extremely sensitive to disturbances and/or changes in environmental conditions. The belt above the alpine, glacial area with permanent snow cover, is called the "nival" belt, which also has biodiversity including several species growing in favorable microhabitats.

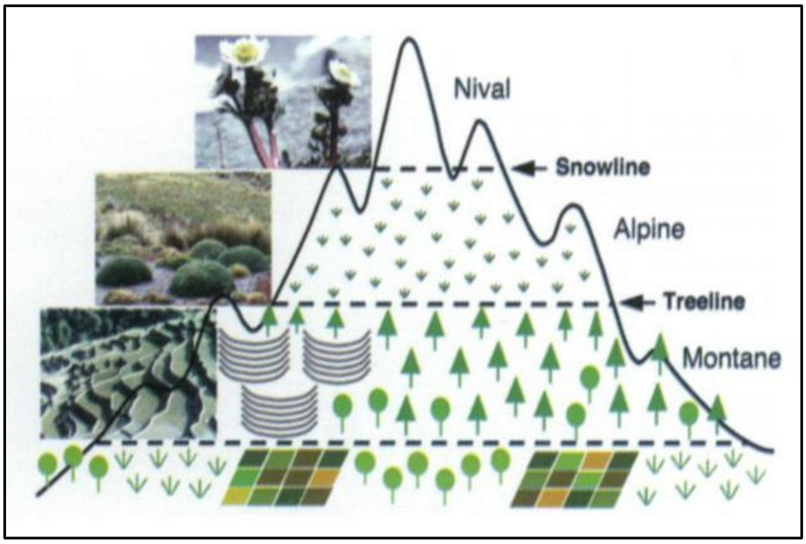


Figure 1: Biogeographical nomenclature of elevational belts (Korner, 2004).

This stratification thus creates several climatically different life zones over short distances, and therefore, the mountains serve as hot spots of biodiversity and priority regions for conservation. The mountain biodiversity mirrors the geodiversity from topography. The geomorphology of the steep slopes generates various microclimate situations which together with substrate types, water, and nutrients regime turn into different microhabitats that can show differentiation depending on herbivorous, wildfires, or other disturbances. Together with the biogeography stratification, habitat isolation and fragmentation are increasing biodiversity as they provide local or regional diversification (Korner, 2004).

Korner (2004) observes the trend of an increase in diversity with elevation. Because of high altitudes, vegetation in the alpine belt is very diverse at fine scales, having mostly small size species, and most of them endangered. For example, in the cloud forest of Peru, 30 % of the 272 endemic species are found in the alpine belt. The high diversity does not necessarily reflect an absolute number of species but the number of endangered and rare ones.

The richness of plant species observed in mountains is particularly important. In it, the diverse vegetation is crucial for preventing soil erosion on steep slopes, thereby contributing to the protection of landscape and humans against natural hazards and the impact of extreme events (Korner, 2002). Steep slopes and the sharp climatic gradients make the mountains a very fragile bioecological system susceptible to changes in a rapidly warming world. Mountain ecosystems show slow rates of recovery after disturbances, both natural and/or anthropic ones (Nilsson, et al., 1995). High-altitude ecosystems are inherently fragile and characterized by low resiliency and therefore they are particularly susceptible to human interference, especially according to land use and management applied which have a high and significant impact on the soil and vegetation (Buckley et al., 2002).

2.1.2. Geosystem Services

In contrast to the ecosystem services, which are related to abiotic nature and their viewpoint is more biocentric, this study will be using the term and concept of geosystem service (Gray, 2019). According to the Millennium Ecosystem Assessment (MEA, 2005), ecosystem services provide regulating, supporting, provisioning and cultural services. However, no mention of the geological resources of the planet, on top of that the view is more biocentric. On the other side, there is a wider point of view that is the geosystem services (**Figure 2**) which means all the services come from the geodiversity and includes the importance of geology for evolution and its living system (Gray, 2019).

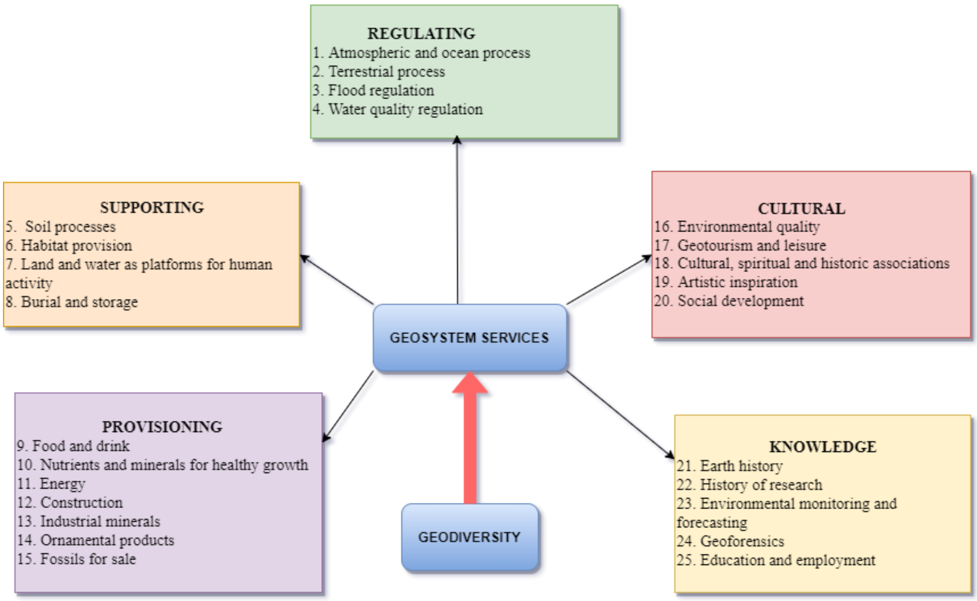


Figure 2: The 25 major geosystem services, all of which are related to the planet's biodiversity. Adaptation by Marina de Souza Faria (Gray, 2019)

Gray (2019) suggests an attempt to examine the goods and services related to geodiversity (**Figure 2**) combining MEA classification, "knowledge services", the importance of geography and geology. The topography that designs the landscape has the potential to attract tourists, for example, caves, coastal, and mountain views can be attractive. The land surface also provides a platform for unique flora and fauna, which means that different topographies are suitable for different wildlife, as alpine tundra plant species that grow on cold mountain tops or some species of birds that prefer to nest on soft sediment cliffs.

The first services used by humans in the mountains were due to topography, soil (substrate material), and/or vegetation. According to Young et al (2007), in the central and eastern European countries (CEEC) (the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovenia, and the Slovak Republic), agriculture was the most important land use during the period between World War II and 1989, covering approximately 48% of their total national land. That intensification brought the common use of fertilizer and biocides, land draining, irrigation, and the loss of biodiversity and landscape features.

Agriculture is driven by climate, terrain (topography), and soil conditions. In the mountains, development was connected to cattle and sheep grazing since the Middle Ages, utilizing alpine pastures. As for agriculture, since the 18th century, most crop production was potatoes, some fruits, and vegetables just in small quantities for subsistence, still, grazing was the most important activity until the tourism boom in the 20th century (MAB, 2011).

For the west Carpathian mountain in Czechoslovakia, Plesnik (1978) states that the increase of the grazing activity was due to the petrographic composition of the substratum, soil, relief conditions, vegetation, and ownership. This is because the best conditions for alpine grazing are on the basic substrates, rich in nutrients, and minerals, with a consolidated and consistent soil cover and smooth slopes with few rock outcrops.

The drop of cattle and sheep breeding started in the second half of the 19th century because of the industrialization process. The grazed area in the alpine pastures was gradually diminished by land reclamation of more accessible and high-quality sub-montane pastures and meadows.

In the high and western Tatry Mountains (Slovakia), similarly to the Czech Republic, there were also mining activities (MAB, 2011) since the 15th century, such as iron, copper, silver and gold mining in some valleys. After 1871, open-pit mines (sand-pits and quarries) were opened as a consequence of the construction activities (roads, railroads, hotels and so on). All the mining activities (subsurface) were closed before the founding of Tatry National Park (TANAP) in 1949. After the improvement of scientific researchers in the park to provide knowledge on rehabilitation of the degraded ecosystems, the TANAP authorities decided to focus on environmental monitoring (long-term impacts from the high number of visitors, air and water pollution) and environmental education, guiding activities with cultural and educational proposes in cooperation with national and international media and organizations (MAB, 2011).

Similarities between TANAP and KRNAP mountains is that tourism is one of the most important activities that cause increasing impact nowadays. All the mountain resources, such as steep slopes, poor and shallow soils, extreme climate conditions, etc; provide high geodiversity, cultural diversity and biodiversity because of biogeographical and traditional adaptation, unique and beautiful landscapes, and rare species of flora and fauna. Thus, in the summer, hiking and cycling in the mountains are very popular. In winter, the sports and tourist activities include downhill and cross-country skiing, snowboarding, ski alps, and others. These seasonal attractions support the visiting of people from the European lowlands and far beyond and cause a lot of pressure on fragile mountain ecosystems (MAB, 2011).

Another example, as illustrated in the Alps, the main pressure on mountain biodiversity is caused by the tourism and related construction facilities, such as infrastructure development (hotels, skiing slopes, restaurants, shopping mall, etc), unsustainable tourism, fragmentation of habitats, and overexploitation of natural resources (EEA, 2010).

The impact of tourism in TANAP started to be stronger in the period from 1980 to 1982, because of not well-planned development of touristic activities, the crises in the economic sector affected the transport and sewage system the most. The first damage occurred around the settlements (camping sites, chalet areas, touristic trails, etc.), such as caused by motor vehicles in the forest and alpine zones (MAB, 2011).

The impacts of tourism differ according to the mountain range, depending on the past land use, e.g. agriculture, grazing, cattle, pasture, mining, etc. Therefore, the conservation of mountain biodiversity should be managed on both regional and local scale. History thus affects policies for the conservation and sustainable management of mountain biodiversity and wilderness: mountain areas are one of the last remaining pieces of wilderness in Europe (EEA, 2010).

2.1.3. Environmental Issues and Conservation

One of the issues brought by infrastructure development in the mountains is the fragmentation caused by the construction of roads and trails. Skiing slopes and ski lifts cause substantial damage to the soil by trampling and other disturbances, and they turn more vulnerable to water erosion. Ski slopes with low vegetation cover have higher water runoff levels, increasing the risk of flooding lower areas, and damaging the ecosystem (MAB, 2011).

The high number of tourists in specific seasons, as mentioned before, delivers some consequences such as endangering biodiversity by supporting invasive species, disturbing fauna, trampling etc. For example, in the Caucasus ecoregion, the wood harvesting for fuel and timber trade are the activities that threaten biodiversity (MAB, 2011). In the Carpathians mountains, the hunting and poaching activities target the rare species, and since their population is small and isolated, they may not maintain long-term viability and become extinct (UNEP, 2007).

The synergy between human and mountain ecosystems in low-intensity farming activities: the livestock rearing and traditional cultivation methods. Those activities can be done sustainably, creating semi-natural habitats that support a range of species, such as species-rich grasslands, hay meadows, and grazed wetlands. Fifty-one per cent of Europe’s High Nature Value (HNV) farmland is situated in mountain areas (EEA, 2010). Thus, those differences between environmental issues require specific conservation policies for each mountain range. However, they should be encouraged by international documents that embrace and support local management and conservation approaches.

Messerli, B. (2012) organizes in chronological order the global changes and the world’s mountains according to the policies. Messerli, B. (2012) emphasizes the three most important events: the global UN conferences in Stockholm in 1972, Rio de Janeiro in 1992, and Johannesburg in 2002. They had a huge impact on the global change policies and programs and thus also on a wide range of mountain initiatives at the regional, national, and local levels. This can be seen in 2002 when the Mountain

Partnership (MP) was founded as a voluntary alliance of government, intergovernmental organizations, and civil society. The aim of MP is sustainable mountain development by exchanging knowledge, information, and expertise between members around the whole world. The committee supports initiatives at all levels to improve the quality of life and sustain healthy environments in the mountain ecosystems (MP, 2015).

The Food and Agriculture Organization (FAO) of the United Nations embraces sustainable mountain development together with watershed management, declaring even an international year of the mountains in 2002 and an international mountain day on December, 11. Manuelli et al. (2017) mention that every three years, FAO prepares the secretary-general's report to the General Assembly of the United Nations (UN), which explains the status and progress of sustainable mountain development at national and international levels and provides suggestions for consideration by the Assembly. Within the FAO, there is a commission that covers the topics of water and mountains. The team at FAO Forestry Department is responsible for developing, implementing, and promoting integrated landscape management. FAO also presents the Secretariat of the Working Party on the Management of Mountain Watershed, which is a technical committee that has the task to improve the understanding of mountain ecosystem services in a changing world and to promote inclusive stakeholder´s dialogue in headwater regions (Manuelli et al., 2017).

Mountain Research Initiative (MRI) is a collaboration for researchers and it works as a network to contribute to the studies about the drivers and processes concerning the mountain ecosystem approaches (MRI, 2020). The initiative's goals are to identify the relationship between social-ecological systems defined by sustainable targets and to enable the authorities' decisions, policies, and actions.

Funded in October of 2003 by the European Commission and sponsored by UNESCO-MAB in collaboration with the MRI and the University of Vienna (Austria), the GLOCHAMORE - Global Change in Mountains Regions is a worldwide network to study the environmental challenges. GLOCHAMORE was planned to work in a synergy way with ongoing research activities, with the explicit long-term goal of implementing the research strategy in Mountain Biosphere Reserves (MBRs) and other protected areas in both developed and developing countries (Bugmann et al, 2007).

Among other mountain's initiatives are the Global Observation Research Initiative in Alpine Environments (GLORIA) and Mountain Invasion Research Network (MIREN). Both of them are focused on the vegetation changes caused by climatic-global change. GLORIA works in long-term observation of permanent plots in the fragile alpine ecosystems (GLORIA, 2021) and MIREN supports the research of non-native species (invasions), their redistribution, and the impacts in the mountain biodiversity, trying to find the best management (MIREN, 2020).

Bugmann et al., (2007) explain that drivers of global and climate change in mountain biosphere reserves (MBRs) can differ according to their impact. They can have a direct impact and particular importance for snow and ice, ecosystem composition, biodiversity, and function. In the article, the authors highlight two key drives of such change: climate and land use (**Figure 3**).

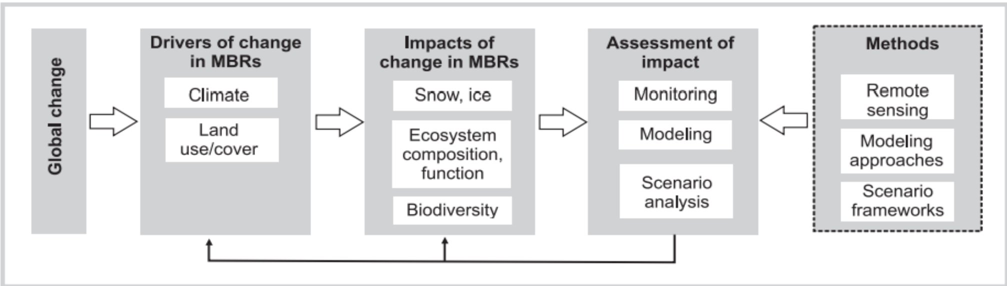


Figure 3: Proposed elements of a strategy for modeling and assessment of global change impacts on Mountains Biospheres Reserves, (Bugmann et al, 2007).

Land use and land cover change are revealed by agriculture, resource extraction, and urbanization regarded impacts in park boundaries. Bugmann et al., (2017) say that natural resource managers often see land use and land cover changes as a more immediate concern as compared to climate change, maybe because the land use and land cover are more immediately subject to policy control, contrasting to climate change. The knowledge about land use and land cover might be divided into natural, socio-economic, and political. That information is essential to understand the local factors and process of changes, and to be able to analyze it by modeling and estimation (Bugmann et al, 2007).

For climate, in brief, Bugmann et al., (2007) suggest providing scenarios of climate change that are specific to mountain regions. The GLOMOCHAMORE strategy focuses on a selection of key elements that make it possible to describe and predict climate change with minimal effort and thus in MBRs around the globe (Bugmann et al, 2007). Because the scenarios can be global, the data is efficient to explain the changes in fragile mountain ecosystems according to goods and services, and list so-called "valued ecosystem components" (VECs) that are sensitive to climate change (Bugmann et al, 2007).

The research (modelling and scenarios) for specific VECs supports the management of protected areas. Baugmann et al., (2007) highlight the importance of climatic parameters concerning other drivers of global change, such as human populations, land use, atmospheric CO2 concentrations, and nitrogen depositions.

The following chapters on the tundra will be focusing more on climatic drivers because the alpine belt clearly demonstrates the negative consequences of global climate change. The land use and land cover drives are easily seen in the montane belt because of the historical context and also, due to seasonal tourism nowadays. Of course, both belts (the alpine and the mountain) are affected, directly or indirectly by both drivers (climate and land use/cover). Still, regarding the magnitude, scale, duration, and direction of the impacts and in the term of research, the montane belt receives more of the land use and land cover impacts, whereas the alpine belt receives more of the climate change impact.

The wide geographical distribution of mountains comes up with the possibility to compare inter and intra-regional research of global impact changes to merge interests of both, the natural and social science communities, and to become a joint research framework. The assessment of land use and climatic conditions hence supports the best management strategies to maintain multiple functions for biodiversity. It thus supports the decision-making of policies to conserve and protect the mountain areas.

2.2. KRKONOŠE MOUNTAINS - HISTORICAL CONTEXT

From the first civilization in the Middle Ages passing through the foundation of Czechoslovakia to nowadays. This subchapter is an overview of the human occupation and main activities in Krkonoše Mts (Giant Mountains). How did the study area become Krkonoše national park (KRNAP) and one of the most important reservation areas in the Czech Republic? I will describe the important events and processes through the years that were responsible for the landscape changes.

2.2.1. Middle and Modern Ages

The first settlements in the foothills of Krkonoše Mts date to the middle of the 13th century. Those people came after the second wave of Germanic settlers' occupation. They moved to the area close to the river Úpa and river Elbe. Besides the hunters, there were prospectors for gold, silver, precious stones, and ore (HK Region, 2015). Similarly, to other mountain ranges, during the middle ages, the mining of minerals and timber was used as a source of income (Bašta, 2013).

Areas where the ore mining was an important part of their history since 16th century were the mines in Herlíkovice, Hanapetrova Paseka, Svatý Petr above Špindlerův Mlýn, Horní Rokytnice, Bárta's forest (Bártův les) at Rýchory, Obří důl, and in the valley of the river Čistá, called Černý Důl nowadays. Iron, copper, arsenic, silver, and gold were the main commodities to be mined (HK Region, 2015).

The mining activities weakened during both wars, and when revived in the 18th and 19th century it was not of the same importance as before. The only exceptions were Obří důl and "Berghaus" in Černý Důl, both during the old period and from the 1920s. Both are tourist attractions now. The visitors just need good shoes and warm clothes because of high humidity and cold temperatures (HK Region, 2015).

It was in the depths of Sněžka, where the ore mining was most widespread, looking like a labyrinth of corridors, pits, tall chimneys, etc. For example, the deposit of Harrachov began to be used in the middle of the 19th century for the chemical industry as the main seams containing fluorite, barite, galenite, and quartz. However, later was found not so profitable, and the mining work was deactivated by the end of the 19th century. In the underground of Sněžka Mountain, there is also the Kovárna Historic Mine in Obří důl. Nowadays, it is a popular tourist place with a good infrastructure where visitors can go to 50 meters deep inside of the mountain and see unique geological structures and remains of ore (HK Region, 2015).

Since the 16th-17th centuries, the mountain communities were mostly living from cattle herding (chalet farming). This mode of grazing was practised on some chalets until the 18th century. At such places, forests were replaced by meadows and pastures, supporting the development of wealthy biodiversity comparable to the forest-free areas, for example at the edges of the cirques or the avalanche slopes. The forest-free areas mean a naturally developed ecosystem inaccessible for human activities (Bašta, 2013).

The so-called “cabin”/ “chalet” or “*bouda*” farming came from the German word *baude* meaning activity of land of pastoral farming and livestock keeping for their livelihood. The farmers constructed their houses at the upper edge of the forest, also establishing communications, driveways, and extended pastures and meadows (HK Region, 2015; Lokvenc 2001). Those activities had a significant impact on the local landscape and major damage was done to shrub pine stands.

Lokvenc (2001) explains the history of the Giant Mountains in parallel with the dwarf pine vegetation (*Pinus mugo*). The author says that Silesia became part of the Czech Kingdom in the early 13th century. The major part of the region above the alpine belt was covered with dwarf pine and a mixture of spruce and other shrubs species. The dwarf pine wood was valuable and essential fuel for chalet dwellers because it has one of the highest heating capacities, that’s the reason why it was more appreciated than spruce wood.

Wood exploitation was essential for the living in the mountain, even during summers, especially in the chalets above the forest limit. Lokvenc (2001) mentions that during an archaeological expedition the scientists found a fireplace of summer chalet near the Labe headspring. Those wood consumptions resulted in the deforestation of shrubs and wood stands in the dwarf pine zone. Firewood was necessary and it was acquired by cutting spruce and dwarf pine stands above the forest limit, cutting paths and driveways for livestock, and extension of agricultural areas (Lokvenc, 2001). Also, shrubs were removed mechanically, sometimes even by their roots, and the ground surface was trampled by the livestock and fertilized by their excrements.

Alpine farming expanded all over the mountains during the 18th century. Later on, other smaller areas were used, often situated on slopes where soils were already devastated by grazing livestock and erosion. This happened because after villages were abolished and following other political and economic changes, most feudal chalets were sold to serfs at low costs (Lokvenc, 2001).

Each of those chalets held an easement and right of pasture, grass cutting, timber extraction, and other benefits. According to Lokvenc (2001), the literature sources show that the numbers of grazing livestock were high at the beginning of the 19th century, e.g Bílá Louka was grazed by 32 head of cattle and 12 goats from the Luční Bouda, and the same numbers were at Rennerovky area. Even though only a part of the livestock grazed in the dwarf pine, it is sure that grazing was common there and had a significant influence on plant communities and soil.

Grazing stimulates eutrophication by increasing nitrogen and phosphorus content, causes important gradual changes in the composition of vegetation cover. It also contributes to the development of *nitrophilous phytocoenosis*, creates damage to plants by trampling the ground surface (hills, contour footways on slopes) and promotes local soil erosion. Such activities were reduced significantly after WWI, the only exception being the 1950s when a small herd of cattle and horses grazed in the surroundings of Luční Bouda (Lokvenc, 2001; HK Region, 2015).

2.2.2. Foundation of Czechoslovakia - 1918

The first thinking about conservation measures started around 1919 with the first Czechoslovak Decree on the Protection of the Krkonoše Flora under the Ministry of Education. The Decree says that destroying the flora could be punished by a fine of up to 200 CZK or 3 weeks in prison (Bašta, J., 2013). However, the botanist František Schustle proposed the idea of establishing a national park covering the whole area and buffer around the Krkonoše Mountains in 1923. During his studies, he realized that it is more efficient to protect extensive areas than individual species. The proposal was analyzed by the Minister’s, but only fragmentary measures were adopted before WWII (Bašta, 2013).

Figure 4: Haymaking at the Luční bouda Chalet, the first half of the 20th century. Cultivation of the Bílá Louka Meadow ceased in 1945 (Collection of Museum of Krkonoše in Vrchlabí). (Bašta, 2013).

It is also important to note other significant changes in the landscape: the years 1937-38 brought the construction of permanent fortifications along the border with Germany and at the same time, haymaking in some meadows as **Figure 4**. Those defensive bunkers were built in the tundra at Bílá Louka meadow and below Mt. Kotel. Besides that, some trenches below Rýchory were filled with concrete (Bašta, 2013). Even nowadays, it is possible to see some of the military structures due to slow montane ecosystem regeneration.

The whole mountain range experienced huge changes after WWII when German inhabitants were forced to leave and the new Czech settlers did not have an interest in traditional farming. Traditionally, many places such as steep slopes had to be cut by hand, and thus such places difficult to access became afforested, many of them with low-quality spruce monocultures (Bašta, 2013).

In contrast to those abandoned farms were increasing tourism activities in the mountains. Wealthy families were going to high altitudes for recreation to enjoy the fresh air. It was a fancy hobby for a minority wealthy group that was quickly replaced by recreation for the masses. An important milestone was the construction of the cable cabin and lifts in Jánské Lázně in 1928; Pláně in 1947 and 1949-50 to Mt. Sněžka (Bašta, 2013). Those lifts and cable cabins attracted new people to the Krkonoše Mts. because of the easier and more comfortable access without exhausting hiking, and the sledges were also used during the winter. In Norway at the end of the 19th century, Dr Krause from Hirschberg saw the ski for the first time and brought them back to

Krkonoše. Ski made it easier for foresters to get to the snow-covered mountain forests. Later on, skiing started to grow as a sport, and the first skiing clubs and competitions were founded (HK Region, 2015).

After thorough research, a group of naturalists was to establish eight State Nature Reserves (SNR) from western of Krkonoše to eastern, by a Decree from the Ministry of Education on 4th March 1952. After a few years, the highest part of the mountain, the alpine belt, was protected by law *Act No. 41/1956 Coll.,* on the State Nature Protection. Unfortunately, this protection had its limitations because the focus of protecting nature and the landscape was only anthropocentric (Bašta, 2013). Even with all those conservation measures growing, some completely unsustainable activities happened, for example in 1949 - 1959, there was a uranium mine in Mt. Medvědín. This mining was realized for the Soviet Union, and no environmentally oriented mines reclamation project existed (Bašta, 2013; Pasek et al., 2015).

2.2.3. Foundation of The Krkonoše National Park

In 1962, the first *Land Use Plan for the Krkonoše Region* mentioned that the area should be declared a national park. The Krkonoše National Park (KRNAP) was nominated by *Government Regulation No. 41/1963 Coll.* on 17th May 1963 (**Figure 5**). During the first period, the institution was organizing the responsibilities crucial for the future of the mountain landscape, inhabitants, and visitors. In cooperation with Poland and the *Karkonoski Park Narodowy* (KPN), the region was established as a National Park on 16th January 1959. The first agreement concerned tourism and other mutual issues (Bašta, 2013).

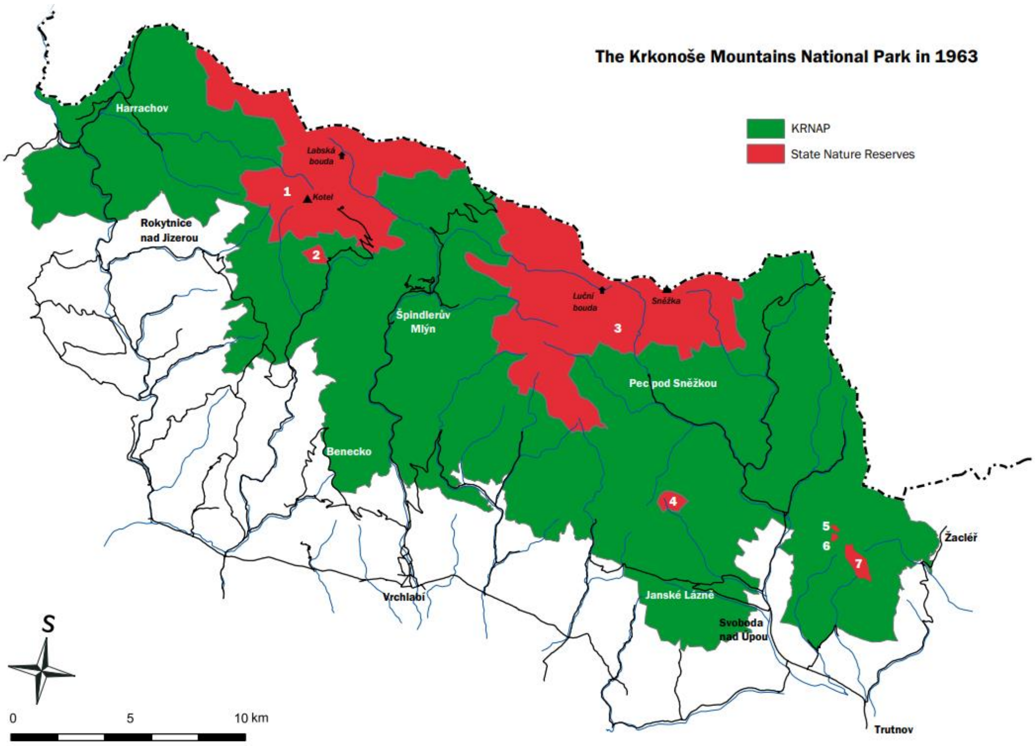


Figure 5: KRNAP in 1963, in red the most valuable territories continue to be protected as State Nature Reserves (SNR); (Bašta, 2013 - Map Kalenska, 2013).

The KRNAP Administration brought up new spheres to contribute to the park in 1964: The Scientific Council, Voluntary Ranger Corps, and later, the Architect’s Group. KRNAP also established a scientific journal - *Opera Corcontica*. The Voluntary Ranger Services grew to 85 members by 1965 and had a big influence. Most of the members were also part of the Mountain Rescue Service. The KRNAP was divided into seven districts for protection and started zoning the nature reserves in 1967 (Bašta 2013).

The population in Krkonoše Mts. decreased by 40-80% between 1930-1961. Among other reasons, it was caused by the end of traditional meadow farming (Bašta, 2013). On the other hand, the number of visitors has been increasing since the middle of the 1960s.

As for the roads, Bašta (2013) mentions that until 1974 it was allowed to drive freely in the KRNAP. After 1989, regulation of transportation was not always effective, and in some periods, NP Authorities supported motor vehicles just for pleasure. In 1992 the number of permits to drive in the park was 5,544, but in 2000 it grew up to 26,000, and in 2012 this number decreased again to 9,900. One of the solutions to regulate cars inside the park was the increased capacity of parking (in 1965). However, the guests accommodated in the Špindlerova chalet had permission to drive up until the end of the 1980s.

There were significant changes during the period of normalization, in Czech "*normalizace"* that ran from the Warsaw Pact invasion to Czechoslovakia in August 1968 to the *"glasnost"* era during 1987. At KRNAP administration, the director Miroslav Klapka and his Deputy Josef Fanta were removed from their positions for political reasons, and KRNAP was directed by Václav Veselý, who passed away in 1973. During this period, the KRNAP administration grew from 81 employees in 1973 to 200 in 1983. Moreover, the Department of the Chief Architect for the Krkonoše Region was separated from KRNAP in 1974, This decision had negative consequences to nature protection as there was increased pressure by the massive construction activities for recreational purposes (Bašta, 2013).

In the post-revolution year of 1990, the new Ministry of the Environment re-declared the KRNAP Administration, creating the Action Programme and providing changes in the institution. In March 1990, the national park was re-declared by *Government Regulation No. 165/1991 Coll.* along with *Act No. 114/1992 Coll.*, on Nature and Landscape Protection, defining the conditions for its protection (Bašta, 2013).

The new zoning was made, and the KRNAP's territory was divided into three zones according to the natural value and the level of protection (**Figure 5)**: 1st zone – strictly natural (4,400 ha) – covered relatively undisturbed ecosystems which should be left to natural processes; 2nd zone – directed natural (4,000 ha) – including the sections which had been somewhat modified but where near-natural management was allowed but only with the aim of gradually return to natural conditions; 3rd zone (27,900 ha) covered heavily modified ecosystems and inhabited areas (Bašta, 2013).

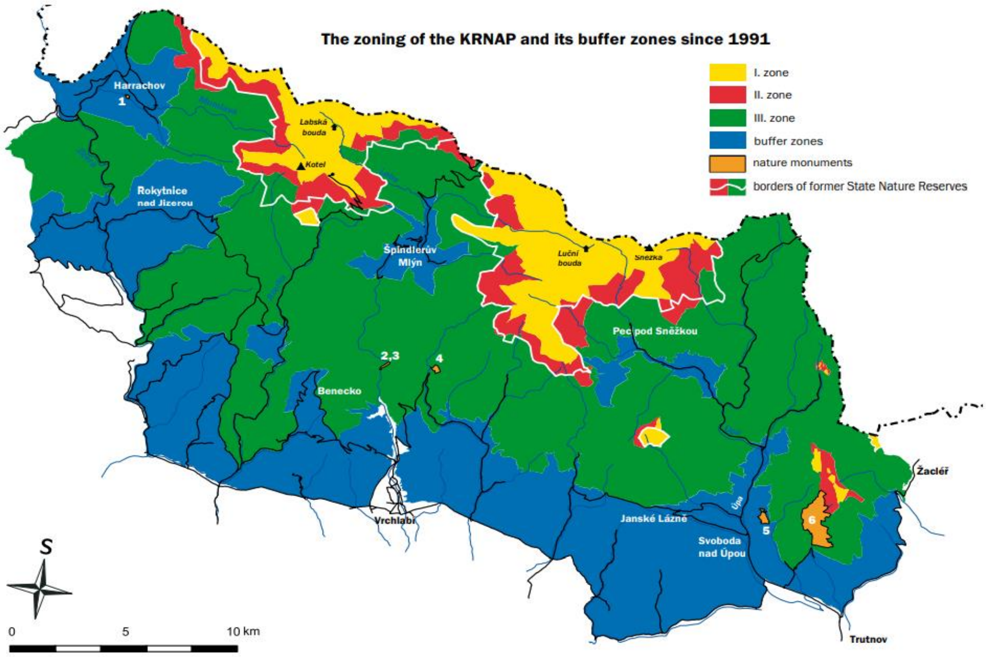
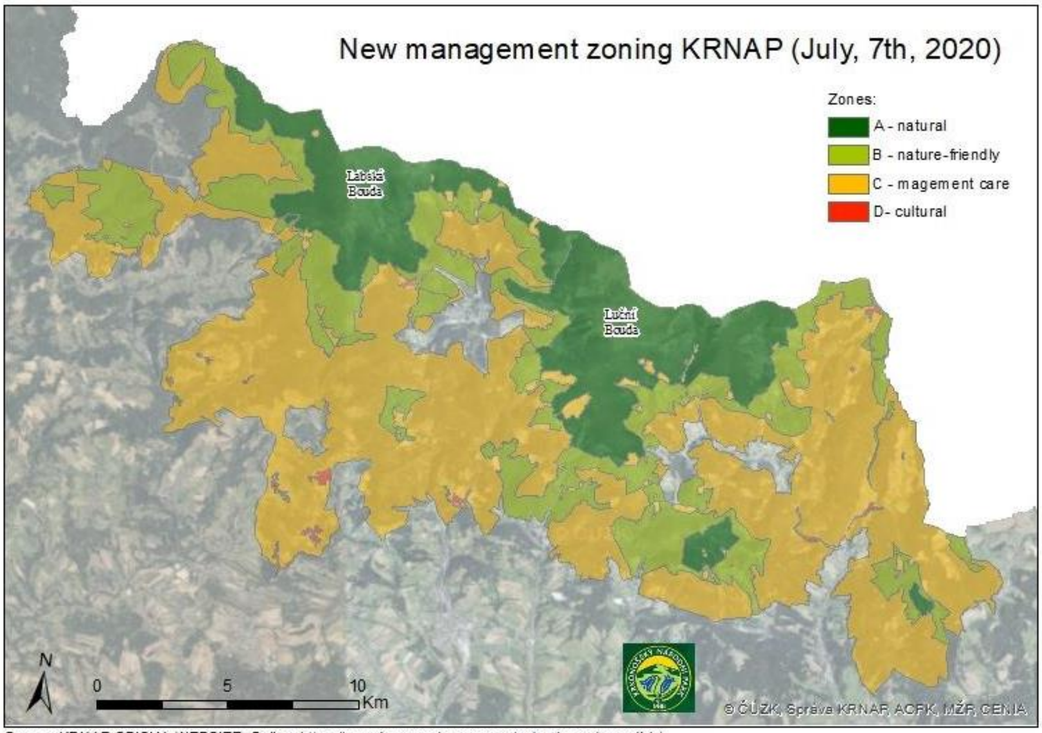


Figure 6: The zoning of the KRNAP and its buffer zones since 1991 in Bašta, 2013 (Map Kalenská and Bašta, 2013). The most valuable uppermost areas above the tree line (tundra) are included in the 1st zone and marked with yellow.

The zoning of KRNAP since 1991 **(Figure 6**) highlights the SNR (State Nature Reserves), marked with a white line. The park has a total of 36,000 ha with a buffer zone covering 18,4000 ha, including urban and ski areas (Harrachov, Vítkovice, Špindlerův Mlýn, and Pec pod Sněžkou).

The new zoning established on the 7th of July in 2020 (**Figure 6)** will guide the management for the next 15 years. It determines which parts of the National Park will be left to natural development and in which interventions will be carried out to restore damaged ecosystems towards their natural state or try to preserve and improve the state of habitats important for biodiversity, especially Krkonoše meadows (KRNAP, 2020). According to Robin Böhnisch, Director of the KRNAP Administration, the zones differ in their scientific value and combine the rules and care with various regulations and purposes (KRNAP, 2020).



Source: KRNAP OFICIAL WEBSITE. Online: https://www.krnap.cz/zonace-v-otazkach-a-odpovedich/
ArcGIS Server: ČÚZK Coordinate System: S-JTSK_Krovak_East_North. Projection: Krovak. Geographic Coord Sys: GCS_S_JTSK. Datum: D_S_JTSK
Author: Marina de Souza Faria

Figure 7: Map of new management zoning in KRNAP. (KRNAP, 2010). Organized by Marina de Souza Faria.

Concerning visitors in the park, the new zoning does not contain any additional restrictions, the regulation of the number of people will be more restrictive only in quiet areas. The three main ones include the two largest areas on the ridges of the Giant Mountains, and one on the top of Světlá and Černá hora (KRNAP, 2020).

Explaining the legend of the zoning (**Figure 7**), the **natural zones** (dark green) are defined as areas where natural ecosystems predominate, which is to leave these ecosystems to their natural development without disturbing them; the **nature-friendly zones** (light green) includes man-made ecosystems managed to gradually help nature return to its natural state; the **management care zones** (yellow) include man-made ecosystems, and the purpose here is to maintain or improve the condition of these objects of protection, and therefore typical activities here include mowing and grazing in grasslands and forest management supporting biodiversity.

The last zone is the **cultural** (red), defined on the territory of the Krkonoše municipalities and their vicinity, it is intended for sustainable development and the management aims is to keep the achieved quality of the environment. This zone is relatively small in the Giant Mountains, because most municipalities are excluded from the national park since 1991, but are located in the protection zone (KRNAP, 2020). All those changes in the zoning can be seen in the light of the historical events and the progress of the KRNAP administration. The historical timeline (**Figure 8**) summarizes this chapter and shows us the main events and important dates.

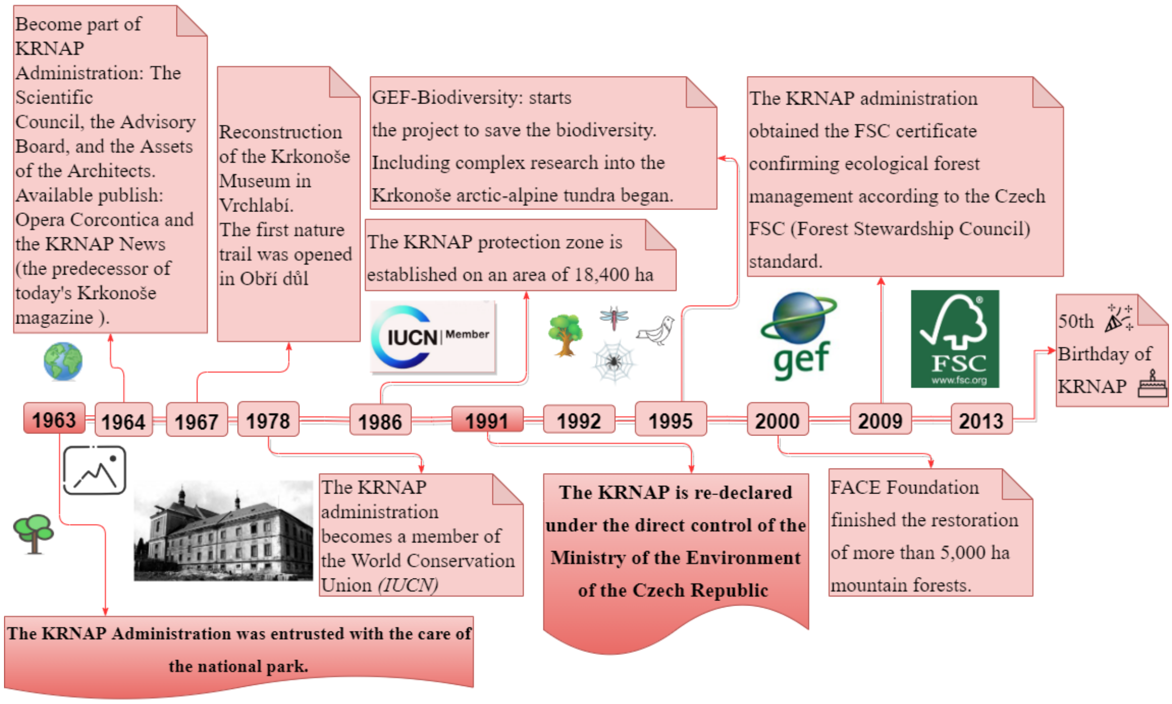


Figure 8: Historical timeline of the main events in KRNAP. Online: https://www.krnap.cz/vyznamna-data-krnap/. Accessed on 02.04.2021. Organized by: Marina de Souza Faria

2.3. TUNDRA BIOME

The concept of the tundra biome covers two main types of tundra in the world: arctic and alpine. Both differ in the description of biodiversity (soil, climate, flora, and fauna), but also have similarities that affect the flow of the whole ecosystem. It's essential to understand the basic knowledge about the tundra, to be able to understand the climatic issues and the consequences in the nutrients cycling for the future conservation approaches.

2.3.1. Types of Tundra: Arctic And Alpine

The arctic tundra is found in polar latitudes in the far northern hemisphere. **Figure 9** highlights the arctic zone and the subdivisions which include mountains, glaciers, and forest-tundra vegetation (Moore, 2006). The fauna has a peak of activity in the summer, the species migrate from lower latitudes, such as *caribous* and birds migrating northward from the coniferous forest zone because of the high amount of food (grasses, insects) during this season (Moore, 2006).

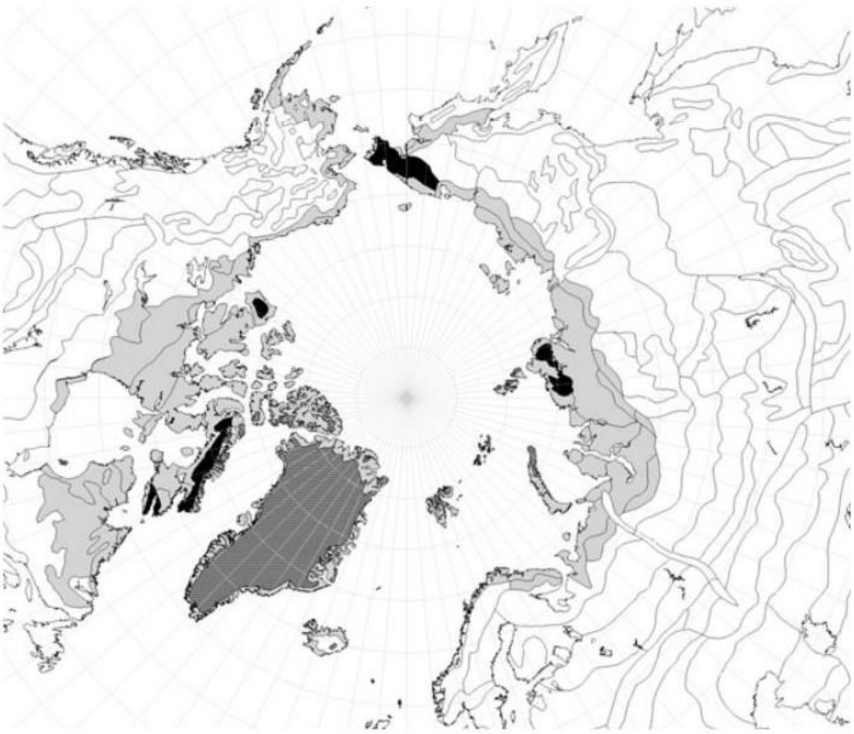


Figure 9: ARCTIC ZONE. Black - mountain areas. Dark Grey - glaciers. Light Grey - forest-tundra ecotone vegetation types and polar desert. (Moore, 2006).

The alpine tundra is located in the high mountains, for example (**Figure 10**), it is possible to find huge portions of alpine tundra in the North American Cordillera, in the Alps and Pyrenees of Europe, in the Himalaya and Karakoram of Asia, in the Andes of South America and even in the Eastern Rift mountains of Africa (Nagy, L., et al 2009).

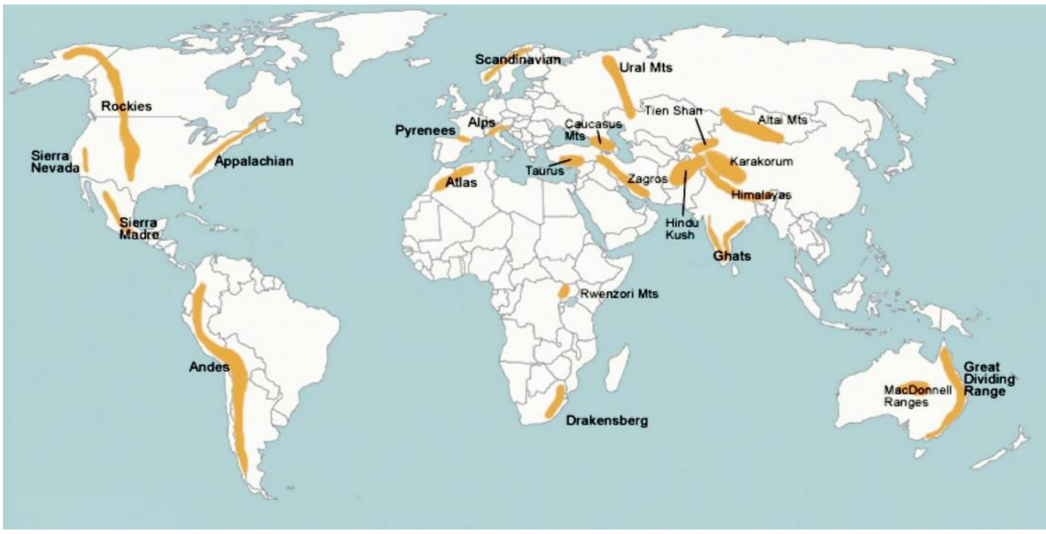


Figure 10: Main mountain ranges in the world. Online: https://brainly.in/question/6061205 accessed on 25.01.2021

The climate is one of the most important drivers to understand the soil, vegetation and the physical-geographical aspects of tundra biomes. Arctic tundra is only present in the northern hemisphere. The climate in the arctic tundra at the south pole, which has the biggest ice sheet, receives the influence of the oceans and it is not able to let the tundra grow (Moore, 2006). The regions of North Atlantic and North Pacific bear tundra vegetation, which is bounded by boreal forests of birch, pine, spruce and larch (Moore, 2006).

In general, the climate of the arctic tundra consists of long extremely cold winters and short, cool summers. Because of the low temperature in the tundra biome, some areas are covered by snow and/or ice, which causes a loss of further energy, since the sunlight is reflected off the surface and not absorbed; the degree to which a material reflects light is called *albedo* (Moore, 2006). Dark stones on the ground can be used as heat absorbers, and thin layers of gradually melting ice can behave like miniature greenhouses, raising the local temperature near to the ground (Moore, 2006).

The length of the summer season is very important for tundra plants and animals as they have to complete their reproductive cycles in a limited period. An important and sometimes neglected characteristic of the climate is that the arctic tundra is dry, especially in the polar regions. The annual total precipitation (including rain and snow) is 250mm in maximum, including melting snow. The soil receives humidity mainly in summer. Snow and ice are also present during the winter, but there are very low levels of evaporation due to low temperatures. For these reasons, the arctic regions are known as *"cold deserts"* or *"polar deserts"* (Moore, 2006).

In the zone called *forest-tundra,* tree growth becomes difficult because of the climate explained before; the short summer season, intense cold and wind blasting. In the southern limit of the low arctic, the trees are scattered and stunted. Pines are rare to find in the arctic timberline of Alaska or Canada, however, they are widespread in Europe and Asia, especially the Scots pine (*Pinus sylvestris*). At the ecotone between the boreal forest or taiga and the true tundra, a dense layer of shrubs and herbs can be found in the forest understorey (Moore, 2006).

Compared to the arctic tundra, the climate in the alpine one is more complex because there are more factors to affect the altitude of the timberline above which tundra vegetation can grow. The rate at which temperature drops with altitude is called the *lapse rate* and is driven by atmospheric conditions and geographical location. In high latitudes, the tundra habitats are occurring at lower altitudes compared to the mountains in the Tropics which need to be very high to provide conditions to let the tundra grow (Moore, 2006).

Another very important climate driver in both tundra is the wind. High wind speed modifies the microclimate by removing a layer of air close to the ground; often the warmest air due to absorption by dark surfaces (*albedo*). This way, the warm air can change the altitude of the timberline in the mountains (Moore, 2006). The microclimate of mountains varies according to topography and the barriers for the wind, and thus the steepness and aspect of the slope facing influence how much sunlight reaches any particular area and determines the vegetation that will be supported there (Moore, 2006).

The dryness which is common in arctic tundra is not a problem in the mountains (i.e. in alpine tundra). The air from lowlands regions or the oceans are often pushed upwards by wind, and after getting colder, the water-holding capacity is reduced and its water content condenses as clouds and subsequently becomes precipitation (raindrops) or snow in case the temperature is too low (Moore, 2006).

In alpine habitats, it is important to consider the low air pressure and consequently the low availability of oxygen. This influences animals and even humans because breathing becomes more difficult there. Most mammals, even wild sheep and ibex are limited to altitudes below 5,800 m, whereas birds and some cold-blooded invertebrate animals can exist even higher (Moore, 2006).

Therefore, the tundra as a biome is a complex and very variable ecosystem, especially according to landscape and topography. It is found in those parts of the Earth where conditions are very cold at average temperature, but still support life, including rare species of flora. Tundra vegetation of both polar and alpine habitats is close in its basic structure. It is formed by a mosaic of stunted dwarf tree and shrub species, grasses, sedges, mosses and lichens. This vegetation is capable of withstanding cold, abrasive winds and periodic burial by snow and thus has to take advantage of short vegetation seasons. Its plants, animals and microbes have been selected by nature to cope with the highly stressed conditions. Extreme environment and cold also have an impact on the rocks and the soils of the tundra region, depending on the mountain range (Moore, 2006).

2.3.2. Global Changes and Its Consequence

The energy in the tundra biome, as the majority, is related to solar radiation (Nagy et al. 2009) and can be explained by the formula: $Rn = H + G + L\ x\ Et + p$ which Rn is the sum of all incoming short-and long wave radiation; H is the convective, sensible or thermal heat exchange of the soil with the atmosphere; G is the conducted heat through the soil; L is the latent heat of vaporization; Et is the mass of water evaporated, and; p is the energy from biological processes (photosynthesis, respiration) (Nagy et al. 2009).

Heat balance can be related to climate at several spatial scales. In the mesoscale, topography and prevailing wind determine snow distribution and soil humidity. At the micro-scale, the vegetation types themselves are important components of heat (Nagy et al. 2009). Latent heat of the vaporization complements the heat and water systems, which is crucial for defining plant growth conditions as this hydrological cycle brings various chemical compounds to the soil and vegetation from the air (Nagy et al. 2009).

Because temperature is one of the most limiting factors for tundra vegetation establishment and growth, global warming has a substantial effect on the tundra vegetation. It is reducing the snow cover and prolonging vegetation season, mildening temperature extremes, changing the water cycle and availability, melting glaciers and permafrost, altering soil chemistry and more (Soukupová et al., 1995).

It is important to mention that the atmospheric chemistry factors are connected to other drivers of vegetation patterns (precipitation and temperature) and have an impact on the radiative heat balance, and those changes affect the biogeochemical cycle (Nagy, L. et al., 2009). Walker et al. (2001) illustrate that the atmospheric nitrogen deposition provides fertilizer input and is thought to be a regionally important factor for biodiversity change in the alpine zone.

However, since the 1960s, the global change, due to modifications in land use and largely human-induced impacts on atmospheric chemistry, has increased inorganic nutrients in the air such as nitrogen compounds and carbon dioxide (Walker et al., 2001). The most drivers of global change that impact alpine biodiversity are in hierarchy and synergy: land use together with climate change, nitrogen deposition, carbon dioxide enrichment and biotic interactions (Walker et al., 2001).

An important study to understand the nitrogen supply in the tundra ecosystem due to global warming was made by Rien (2009) in the Arctics. He analyzed concentrations of nitrogen and phosphorus that can be transferred to the soil horizon O (plant litter) after increased nitrogen supply was added to the soil system. The results were planted species-specific. In general, the nitrogen alteration increased the amount of nitrogen and phosphate in dead leaves, and consequently the amount of organic nitrogen and phosphate transported to the soil because of the input from leaf litter (Rien, 2009). Since nitrogen is often a limiting nutrient, it is very relevant to examine the role of nitrogen fertilization, and thus increased atmospheric CO2 on soil microbial activity and respiration. This kind of studies results in findings that the response of tundra soil microbial communities to elevated nitrogenous compounds is complex, with evidence that nitrogen might suppress some microbial functional groups showing depression of overall microbial biomass and activity in tundra soils (Gutierrez. et al., 2010).

To conclude, climate change is affecting Europe's mountains in different ways. At the regional level, changes in temperature and precipitation result in changes in snow cover, glacier volume and extent, and permafrost and surface runoff (EEA, 2010). Nitrogen from the atmosphere turns into deposit either in a wet or a dry form; the data on nitrogen deposition at alpine altitudes are still rare (Nagy et al., 2009).

In brief, the climatic parameters are changing in concord with other drivers of global change, such as the above mentioned: human population, land use, atmospheric CO2 concentrations, and nitrogen deposition. Thus, they need to be studied as a set of systematic simulation with impact models, where scenarios for each driver are applied in isolation and, also to be able to combine those with other scenarios that include the full set of drivers. Such an approach is highly valuable because it allows us to determine the relative importance of specific drivers for a given system/service and to assess their importance in comparison with other areas (Bugmann, 2007).

2.4. THE ARCTIC-ALPINE TUNDRA IN KRKONOŠE MOUNTAINS

2.4.1. Principles of the Unique Arctic-Alpine Tundra

European arctic-alpine tundra is unique; however, it is important to notice that depending on the localization. It presents some changes in the vegetation composition, species diversity, species ranges and altitudinal limits of trees and shrubs (Kupková et al., 2017). The lithology of the mountains supported the conservation of the arctic-alpine tundra and the frost-resistant flora and fauna (Soukupová et al., 1995). These species which can be found in KRNAP will be described in the next chapter.

Arctic-alpine tundra of Krkonoše Mts. represents a unique ecosystem. Here in Central Europe, a particular ecosystem developed above the tree line, showing affinities to two natural words; alpine and Scandinavian which normally lay thousands of kilometres away from each other. This is due to the glaciation history. During the cooling of the entire northern hemisphere at the end of the tertiary period, more than two and a half million years ago, the cold glacial periods were interspersed with warmer interglacial periods; this process gradually gave birth to the Krkonoše Mts. as we know it nowadays. Unlike the regions stretching hundreds of kilometres to the north and south, it was never covered by the continuous glacier (Soukupová et al., 1995).

When the continental ice-sheet reached the piedmont of the Krkonoše Mts., periods of icy-arid desert climate were altering with a more humid climate. The humid periods were marked by frost-weathering caused by fissure and ground ice, the former resulting in stony fields, the latter affecting solidification and segregation of weathering material. Besides the retreat of the ice-sheet in warmer interstadials and at the beginning of the Holocene, the tundra phenomena in lower altitudes degraded or were superimposed by immense fluvial and/or aeolian erosion, sedimentation and establishment of vegetation cover (Soukupová et al., 1995; Lokvenc, 2001).

Therefore, the arctic-alpine tundra from Krkonoše Mts. is a consequence of the past and current impact of regelation (Soukupová et al., 1995). Since the last Glacial period approximately 10.000 years ago, the climate does not fluctuate as much and the paleoecologists recorded data that suggest a certain ascend of the treeline. During the warmest Holocene period when closed-canopy was suspected to reach the summits, the vegetated-cryogenic structures in the arctic-alpine tundra would have disappeared during the long Post Glacial period, but they are maintained due to current regelation that acts as a conservation factor of “fossil” landforms (Soukupová et al., 1995).

The polygonal soils and rocky stripes were formed by the natural effects of frost and ice. The process of freezing and thawing caused the muddy layers of soil to slide across each other and formed eye-catching banks covered with mosses and lichens. In Krkonoše Mts., it is possible to find a rich gallery of forms that are the result of frost, wind glacial and water erosion in the ancient past. These processes are still taking place today although less intensively; polygons, striped soils, inclination terraces, boulder fields as well as fractured rocky outcrops together with living nature remind the geological history of the Krkonoše Mts. (Soukupová et al., 1995).

From the north of Europe, the continental ice sheet advanced as far as the northern foothills of Krkonoše Mts. which blocked their advance several times. Similarly, the alpine glaciers crept northwards as far as the bohemian basin. The huge masses of ice pushed in front of them from the south and the north, though the living world of the arctic-alpine tundra plants and animals found a “refugee” on the frozen, never glacier-covered mountain ridges of Krkonoše Mts. Under the command of wind, ice, snow and avalanches, this unique vegetation of the arctic-alpine tundra was formed (Soukupová et al., 1995).

Lithological and anemo-orographic predisposition supported the conservation of the arctic-alpine tundra, including the existence of frost-resistant flora and fauna (Soukupová et al., 1995). This kind of European arctic-alpine tundra is unique, however, it is important to notice that it is subject to changes in the vegetation composition, species diversity, species ranges and altitudinal limits (Kupková et al., 2017). Changes caused by anthropogenic use in arctic-alpine tundra existed significantly since the 9th century. During the 18th and 19th century, activities connected to chalet farming, such as grazing and mowing in summer, affected the vegetation-cryogenic zone. Fortifications built-in 1938 caused big disturbances, still, the formation of very recent cryogenic structures has been observed on anthropogenic grounds around the fortifications (Soukupová et al., 1995). In the early 1990s, the airborne pollution produced by surrounding industrial areas heavily affected Krkonoše Mts. ecosystems including the tundra landscape (Lokvenc, 2001). The tourist activities such as hiking, biking, skiing and building tourist facilities caused profound changes in plant composition affecting the dispersal of anthropophytes from foothills and valleys to the summits, into the arctic-alpine tundra as a result of seed dispersal eutrophication, acidification and disturbance of plant cover (Soukupová et al., 1995, Müllerová et al., 2011).

In brief, it is possible to relate two main threats for the arctic-alpine tundra of Krkonoše Mts: firstly, the abandonment management and urbanization process of surroundings. Secondly, the increase of the speed in the climate change causes nitrification, eutrophication and consequently, disturbances as Müllerová et al. (2011) mentioned, e.g. roads and pathways can spread seeds of non-native species. Besides that, pollutants from vehicles can change the concentration of the nutrients in the air that affects the plants (soil) and precipitation content.

2.4.2. Fauna and Flora

The main focus of this thesis is on the flora, however, I will briefly mention some representatives of tundra's fauna as they are an important part of the ecosystem and because many of them are rare or endemic species, that can be only found on the Krkonoše Mts. ridges. Their adaptation was successful in life in the rocky soils where natural processes shape them into characteristic forms over several millennia (KRNAP, 2010).

These tenacious organisms are remarkable for their colours and different forms. Reptiles, such as the adder, find a sanctuary in the rocky tailless. Lithobious and lithophilous arthropods are typically found there. The spider (Araneida) *Acantholycosa norvegica ssp. sudetica*, has grey-brown colours. The wolf spider uses rocks to be camouflaged and can grow up to 10mm. Both can be found at lower elevations, such as the periglacial rocky talus and hunt insects and other invertebrates (Soukupová et al., 1995; KRNAP, 2010).

Among butterflies (*Lepidoptera*), several glacial relicts and endemites can be traced, such as *Erebia epiphron silesiana*. It only occurs naturally in the Czech Republic in the Hrubý Jeseník Mountains, where it has formed an endemic subspecies. To the Krkonoše Mts. it was introduced in the 1930s. Another endemic subspecies is *Psodos quadrifaria ssp. sudetica,* occuring on the Krkonoše fringes of talus fields and peat bogs above the upper treeline (Soukupová et al., 1995; KRNAP, 2010).

The dragonfly *Anisoptera* **(Figure 17)**, is considered a glacial relict with the range scattered from the mountains of central Europe (in the Alps above 1,000 m a.s.l.) to the Caucasus in the east. Considering its restricted range in the Czech Republic, even though it is quite common in parts of Krkonoše, it is included in the national Red List of Animals as critically endangered. From beetles (*Coleoptera*) should be highlighted the ground beetle - *Nebria rufescens* that live in the surface of the soil (epigeon), and as the dragonfly is also classified as a glacial relict, a survivor from the ice ages. In Krkonoše, it can be found in the forest level in damp places, gravel and boulder alluvia around streams, under the rocks, driftwood, etc (Soukupová et al., 1995; KRNAP, 2010).

The last to mention here are the birds, the rare bluethroat *Luscinia svecica* (**Figure 11**) which nests in the shade of the dwarf pine. The beautiful blue colour is characteristic of males, while the females have a cream-coloured throat (KRNAP, 2010). From the air, the peat bogs, mat grass meadows and dwarf pine scrubs look like camouflage nests spread across the mountain plateau. Another rare species that nest in the Czech Republic since the Middle Ages are the peregrine falcons. *Falco peregrinus* nests on the cliffs. After a long absence, the falcon has returned to Krkonoše and chosen this rugged place as its home, that's the reason why climbing in some rocky areas has been forbidden (Soukupová et al., 1995; KRNAP, 2010).

Figure 11: Male of Red-spotted Bluethroat - *Luscinia svecica ssp. svecica.* Source: KRNAP, 2010.

To describe vegetation of the arctic-alpine tundra, Soukupová et al. (1995) (**Figure 12**) divided the vegetation into four zones: (1) flower-rich tundra, niveo-glacigenic relief with avalanche tracks and ecosystem of the *Juncion trifidi* (2) lichen tundra - cyo-eolian zone, (3) grassy-tundra vegetated-cryogenic zone, bogs, fens and springs, on mineral bedrock short-grass communities forming dense uniform stands (vegetated pattern grounds), and (4) wet, wind-protected-dense krummholz of mountain pine (*Pinus mugo*), tall grass and flowering herb communities.

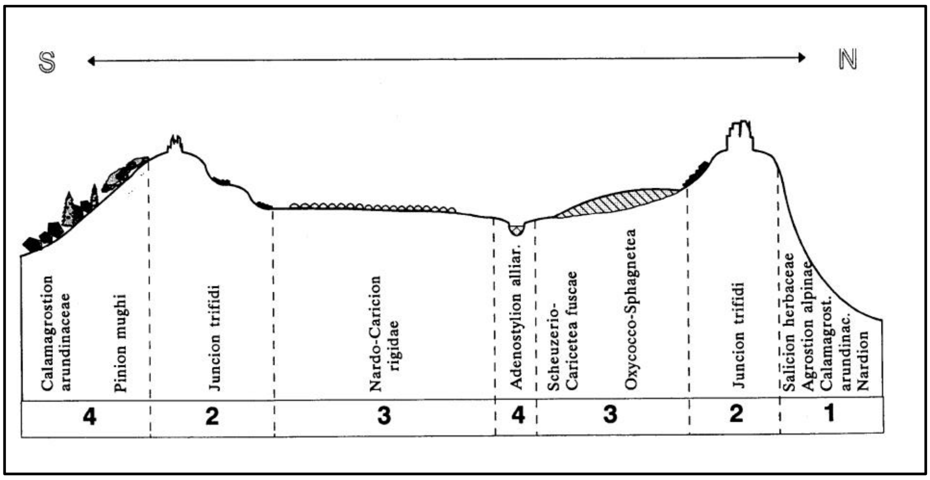


Figure 12: Schematic N to S profile through the Krkonoše arctic-alpine tundra. (Soukupová, 1995).

On the extensive plateau around the Luční and Labská bouda chalets, we can find typical grassy tundra. The most common plant species include: *Nardus stricta* **(Figure 13a)**, a typical grass dominant of dense uniform stands of alliance *Nardo-Caricion rigidae* at the localities of high snow cover and deeper humus podzol soils based on granites; *Molinia caerulea* **(Figure 13b)** and *Calamagrostis villosa* forming acidophilus communities of tall grasses and flowering herbs on wet, wind-protected soils with long-lasting snow cover; *Deschampsia cespitosa* **(Figure 13c)**, found on mesotrophic to eutrophic deeper, permanently humid soils; peat mosses; and *Baeothryon cespitosum subsp. cespitosum* forming oligotrophic communities of boreal arctic and alpine raised bogs with the prevalence of shrub form and peat mosses (Müllerová, 2004).

Figure 13: ***(a)*** *Nardus stricta* ***(b)*** *Molinia caerulea* ***(c)*** *Deschampsia cespitosa.* Source: Field Trip, July 2020.

The short-stemmed alpine grasslands, quaking peat bogs as well as dense growths of twisted dwarf pine, *Pinus mugo*. Shrubs (**Figure 14**) creating "krummholz" are perfect archives of the ancient and recent past. KRNAP peat bogs are the spitting image of those in Scandinavia therefore, it is no surprise that they are home to some of the so-called glacial relics. Since the 16th century, human colonization of the Krkonoše Mts. related to continuous deforestation in the montane belt and reduction of krummholz in the summit regions. Where the area was liable to afforestation, extensive plantation of dwarf pine took place between 1897 and 1916 (Lokvenc, 2001). The results were that *Pinus mugo* successfully prospered, showing mortality of less than 10%, however, unfortunately, part of these plantations affected also the cryo-eolian zone and vegetated-cryogenic zone with relic soils and geomorphological features, such as patterned grounds, solifluction benches, ecotonal zone of mires and spring sites. Thus, the presence of krummholz promoted the spreading of expansive grasses like *Deschampsia flexuosa* **(Figure 13c)**, *Calamagrostis villosa* and *Anthoxanthum alpinum*, which found refuge under the canopy of the dwarf pine (Soukupová et al., 1995).

Figure 14: Peat bog and dwarf pine (*Pinus mugo*) krummholz. Source: Field trip, July 2020

In the peat bogs, other species that are easy to find and very often together are *Trichophorum cespitosum* and *Eriophorum vaginatum* **(Figure 15)** and *Sphagnum* **(Figure 16)** which is a peat moss very common in this area. They are well adapted to wetlands, the one with a brown top is *Trichophorum cespitosum* belonging to the *Cyperaceae* family. The one with the white top which looks like cotton is *Eriophorum vaginatum*, belonging to the same family. It has structures called cottongrass that can aerodynamically support the wind spreading the seeds (KRNAP, 2010).

Figure 15: *Trichophorum cespitosum* and *Eriophorum vaginatum*. Source: Field Trip, July 2020

Sheltered from the wind in the deep glacial circles, it is possible to find rare preserved glacial lakes and glacial moraines. It is a world of flower-rich tundra, which is one of the richest habitats that can be seen in the Czech nature; these circles are called "Botanical gardens" in Czech, such as *Krakonošova zahrádka.* Only several of the highest summits host the unusual environment of lichen tundra; this is the kingdom of arctic-alpine lichens

Figure 16: Sphagnum mosses. Source: Field Trip, July 2020.

Besides being a glacial relic, the *Sudetic Lousewortis*, *Pedicularis sudetica subsp. sudetica*, **(Figure 18)** and *Dactylorhiza fuchsii* **(Figure 17*)*** both are endemic orchids species. Unfortunately, *Pedicularis* is one of the Krkonoše critically endangered endemic species. When the continent began to warm up around 10-15,000 years ago, the vast lowlands to the north of Krkonoše were covered by thick forests, which cut off the escape route for these arctic organisms. However, this species found a sanctuary on the ridges of Krkonoše Mts., which were never glaciated. They made themself at home here, and still belong to the eye-witnesses of nature which is long gone as the glacial relics; as experts call these ancient emissaries of the arctic tundra. Although the Sudetic lousewort primarily grows in the arctic belt of North America and Siberia, it was discovered for the scientific world in 1800 by the German botanist Willdenow in Krkonoše (KRNAP, 2010).

Figure 17: *Dactylorhiza fuchsii* and dragonfly *Anisoptera*. Source: Field trip, July 2020.

Figure 18: *Pedicularis sudetica subsp. sudetica.* Source: Field trip, July 2020.

Fortunately, for the field trip in July 2020, it was possible to bring a photographer, Zdeněk Havel, who was instructed by me and my supervisor to take pictures of species that are important for this thesis. Moreover, he was able to capture several rare species such as *Pedicularis sudetica* and others.

To conclude this chapter four last species should be highlighted, three of them are endangered. These are *Aconitum plicatum* (**Figure 19a)**, endangered and highly poisonous species due to the presence of alkaloids like aconitine. The second one is *Luzula luzuloides* (**Figure 19b)**, belonging to the family *Juncaceae.* It is a perennial, sparsely bushy grass with underground protrusions, 30–70 cm high, often forming stands. *Sedum alpestre* (**Figure 20)** growing at the rock outcrops can only be found in the Czech Republic in Krkonoše and Jeseníky Mts. It belongs to the endangered species of the country, similarly to *Drosera rotundifolia,* a tiny carnivorous plant that takes from the insects the supplement which poor mineral nutrition of the soil in which the plants grow, cannot provide (**Figure 21)** (KRNAP, 2010).

Figure 19: (a) *Aconitum plicatum* (**b)** *Luzula luzuloides*. Source: Field trip, July 2020.

Figure 20: *Sedum alpestre.* Source: Field trip, July 2020.

Figure 21: *Drosera rotundifolia*. Source: Field trip, July 2020.

2.5. REMOTE SENSING APPROACH

Remote sensing is the science of obtaining and gathering spatial information about the Earth's surface from a distance, typically using low altitude (unmanned aircraft), high altitude (aerial) or satellite data (**Figure 22**) (Lillesand et al., 2000, Gergel et al., 2017). When applying remote sensing, it is important to choose the right setup of data acquisition and interpretation techniques. The most commonly, automatic methods supported by Geographic Information System (GIS) are currently being used because they allow the analysis, synthesis and communication of virtually unlimited sources and types of biophysical and socioeconomic data (Lillesand et al., 2000).

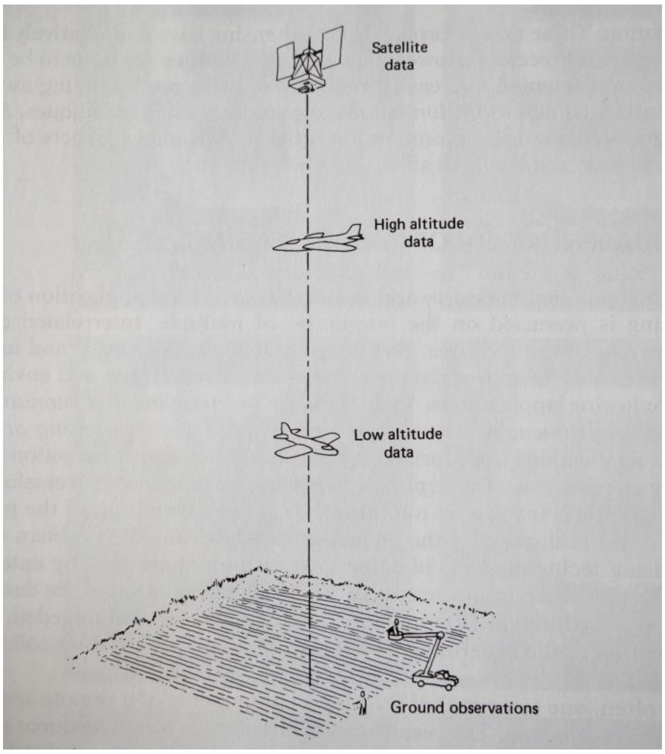


Figure 22: Multistage remote sensing concept. (Lillesand et al, 2000).

Scientists were first using remote sensing to understand forest extent and condition around the 1910s. The arrival of aerial photographic cameras in the 1920s resulted in the support by many countries to get the images for cartography reasons, to survey agricultural lands and map land cover and land cover changes (Gergel et al., 2017). Satellite-based remote sensing began in the late 1950s and early 1960s, and since then more than 100 satellite-based sensors have been launched as part of national and international remote sensing programs (Gergel et al., 2017).

Some of the remote sensing basics to consider for designing the study can be divided into the four key elements (1) size of a pixel (spatial resolution), (2) an overall spatial extent, (3) a timing (time of acquisitions and the interval between acquisitions), and (4) regions of the electromagnetic spectrum the sensor can acquire (spectral resolution) (Gergel et al., 2017).

The spatial resolution is the size of the minimum area that can be resolved by the sensor and is generally equated to the pixel size (Strahler et al., 1989). The spatial resolution defines how much detail the image can provide, for example, a high (or fine) spatial resolution imagery (<1m) can provide information on small objects such as individual trees, buildings, and cars, whereas low or coarse spatial resolution (>100 m) is more appropriate for observing broadscale phenomena such as ocean colour, broad vegetation phenological responses, and cloud patterns (Gergel et al., 2017).

The temporal resolution means the time required for a sensor to return to the same location on the Earth's surface, which differs from spectral resolution (**Figure 23**) that includes three components: the number, width, and location of the spectral wavelength bands detected by the sensor (Gergel et al., 2017). The last one to be described is the radiometric resolution which provides an indicator of the information content of an image and the reflectance (Gergel et al., 2017).

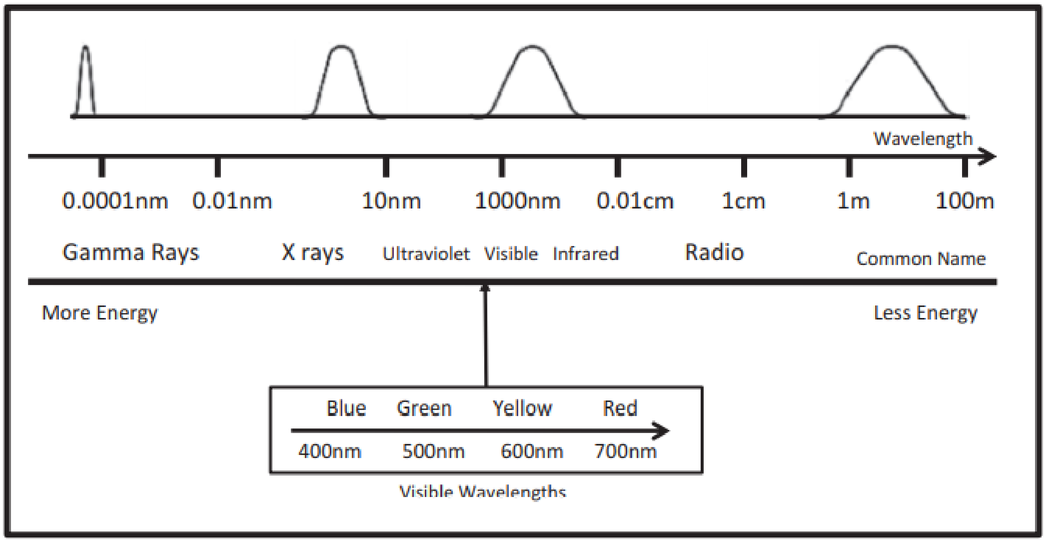


Figure 23: Schematic representation of the electromagnetic spectrum. (Gergel et al., 2017).

2.5.1. Aerial Photography and Image Interpretation

One of the first aerial photographs was taken by a balloon flying over Boston in 1860 by James Wallace Black (Lillesand et al., 2000). The aeroplane, which had been invented in 1903, was not used for camera photography until 1908: Afterwards, during World War I, the military expressed a high interest in this technology for purposes of mapping, planning and management. In 1934, the American Society of Photogrammetry was founded in the USA as a scientific and professional organization dedicated to advancing this field (Lillesand et al., 2000).

Aerial photographs provide higher spatial resolution information compared to the universally available satellite imagery, for example, Landsat, Sentinel or Spot. Moreover, aerial photography has a unique value for mapping historical landscape baselines and assessing long-term landscape changes (Gergel et al., 2017).

In the past, aerial photographs were commonly made with either *panchromatic* or (later) *colour* and *infrared-sensitive* film (IR). Panchromatic film has long been the "standard" film type for aerial photography. As shown in **Figure 24**, its spectral sensitivity extends over the UV light and the visible portions of the spectrum, however, the spectrum is not separated into individual channels. The infrared-sensitive film is sensitive not only to UV light and visible energy but also to near-IR energy (Lillesand et al., 2000).

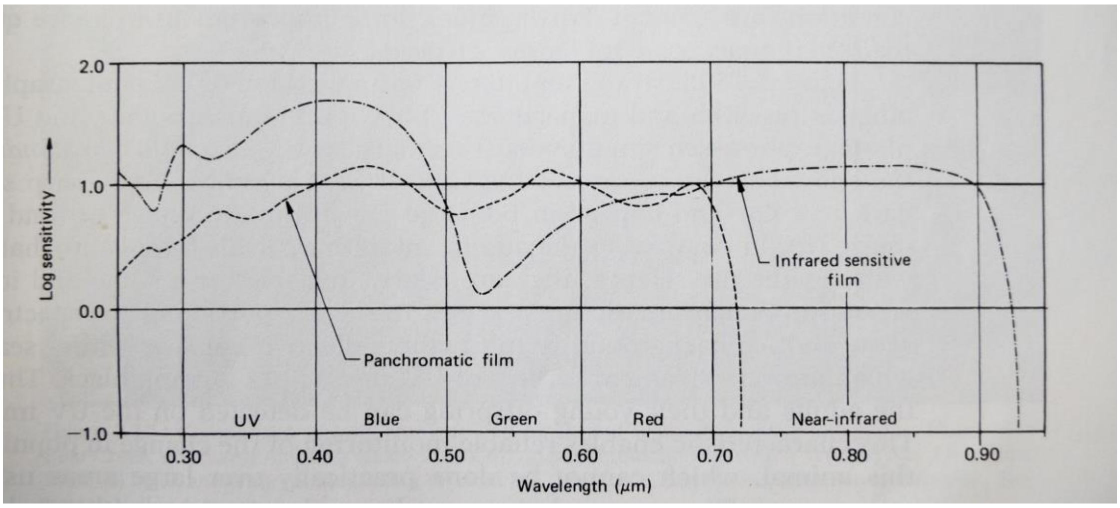


Figure 24: Generalized spectral sensitivities for panchromatic and IR-sensitive films (Lillesand et al., 2000).

For example, the author (Lillesand et al., 2000) illustrates the use of a black and white image to distinguish deciduous and coniferous tree species in panchromatic and infrared photograph films (**Figure 25**). In the upper part of **Figure 25(a)**, it is virtually impossible to distinguish between tree species, nonetheless, the conifers have a distinctive conical shape whereas the deciduous trees have rounded crowns. In the IR photo in the lower part of **Figure 25(b),** the coniferous trees have a distinctly darker tone because they show lower IR reflectance. On such an image, the task of differing the two tree types becomes almost trivial (Lillesand et al., 2000).

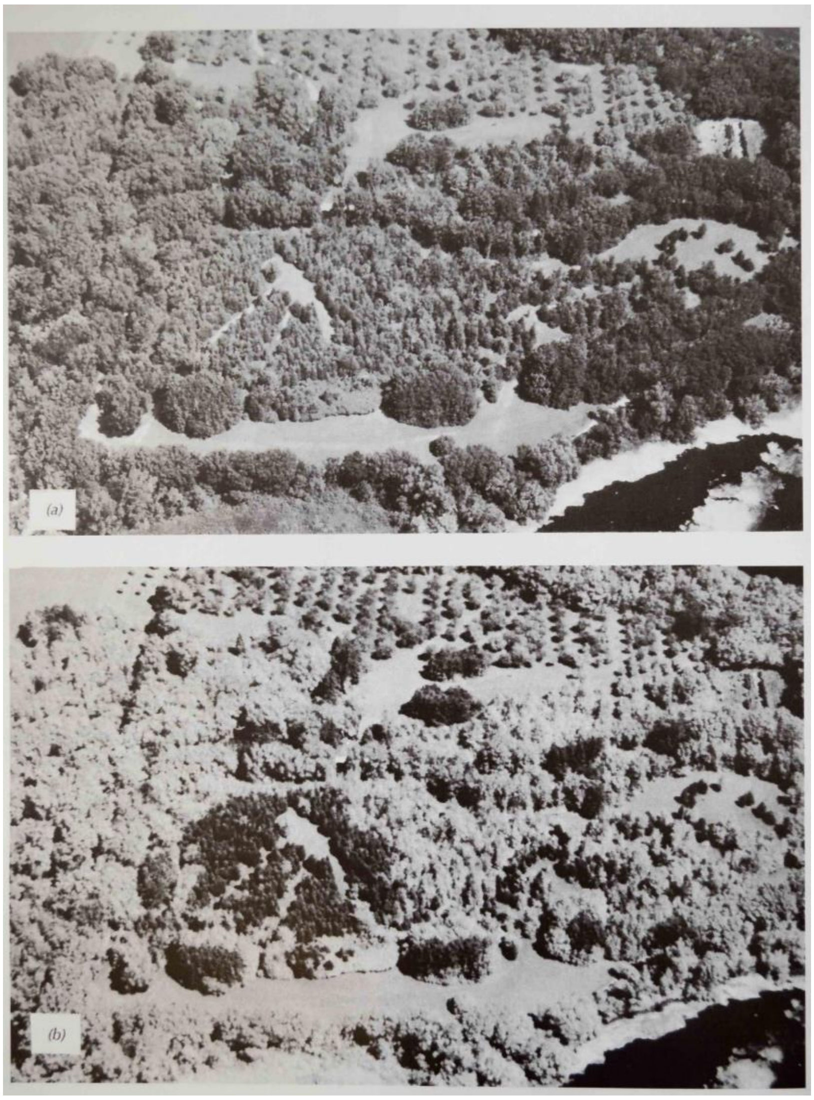


Figure 25: Low altitude oblique aerial photographs illustrating deciduous versus coniferous trees. (a) Panchromatic photographic recording reflected sunlight over the wavelength band 0.4 to 0.7 µm. (b) Black and White infrared photograph recording reflected over 0.7 to 0.9 µm wavelength band (Lillesand et al., 2000).

For the colour film, several proportions of yellow, magenta, and cyan dye are superimposed to control the proportion in the amount of blue, green, and red light that reaches the human vision. Consequently, the subtractive mixture of yellow, magenta, and cyan dyes on a photograph is used to control the additive mixture of blue, green, and red light reaching the eye of the observer (Lillesand et al., 2000). To improve this, colour film is manufactured with three emulsion layers that are sensitive to the blue, green, and red light but contain yellow, magenta and cyan dye after processing (Lillesand et al., 2000).

The colour IR film differs from a normal colour film in this recorded manufacturing process of green, red and the photographic portion (0.7 to 0.9 μm) of the near-IR scene energy in three emulsion layers (yellow, magenta, and cyan). The result is a "false colour" film in which blue images result from objects reflecting primarily red energy, and red images result from objects reflecting primarily in the near-IR portion of the spectrum (Lillesand et al., 2000). This tool was developed and much improved during World War II to detect painted targets that were camouflaged to look like vegetation since healthy vegetation reflects IR energy stronger than green colour does. The real healthy vegetation reflects tones of red on colour IR film, in contrast to low IR reflectance that appears blue (Lillesand et al., 2000).

The process of interpretation of aerial images requires minimizing the uncertainties from the visual interpretation, the training and practice make this journey easier and specific knowledge in research is essential during the classification process (Brus et al, 2018). Automation of the image classification brings objectivity and repeatability into the interpretation process. The interpretation covers the meaning of the image content but also goes forward of what can be seen on the image to recognize spatial and landscape patterns, depending on the expertise of the interpreter, algorithms used and the field of application (Lillesand et al., 2000; Brus et al., 2018). Overall, most of the applications follow basic variations such as shape, size, pattern, tone, texture, shadows, site, association (context) and resolution. I will briefly describe each one below (Olson, 1960).

Shape refers to the outline of individual objects, also *height* defines its shape; *pattern* describes the spatial arrangement of objects, e.g. the spatial arrangement of trees in an orchard is different from that of forest tree stands; *tone* relates to the brightness or color of objects; *texture* is the frequency of tonal changes, when the features unit is too small to be discerned individually on the image, e.g. such as tree leaves and leaf shadows, it is the result between shape, size, pattern, shadow and tone that produces how much "smoothness" the image will have; *shadows* results from slope and terrain elevation and sunlight, that might be determined by various geologic landforms; *site* is the topography or geographic location; *association* (context) relates to occurrence of certain features in relation to other; *resolution* lean on many factors, since some objects are too small or have too little contrast with their surroundings to be clearly seen on the image, thus other factors as image scale, image color balance affect the success of image interpretation (Olson, 1960; Lillesand et al., 2000; Blaschke et al. 2008).

The image interpretation with the purpose of analyzing the land cover and/or land use data is essential for landscape ecology applications in a wide range of planning and management fields (Brus et al., 2018). *Land cover* refers to the type of feature present on the surface of the Earth, for example, lakes and highways, whereas *land use* relates to the human activity or economic function associated with a specific piece of land, e.g. pasture or ski slope (Lillesand et al., 2000).

This is particularly important because the concepts are completely different. However, they can be connected, for example, land use is the sum of arrangement activities and inputs which people attempt in a specific type of land cover. The socioeconomic analysis of changes in land cover makes it possible to evaluate retrospective landscape development, assess the influences, study the capacity and ecological sustainability of the territory, and predict trends of changes (Brus et al., 2018).

In Europe as well as in the Czech Republic, there are historical archives with original aerial images. The films and negatives were used for military purposes until 1990, however, these Czech archives were not available for public use. Nowadays, they are being processed (digitalization and scanner) and available under CUZK - State Administration of Land Surveying and Cadastre, thus they are responsible for new orthophotos and new data acquisition (Müllerová et al., 2011; 2013).

2.5.2. Object Based Image Analysis

The traditional method to assess the remote sensing imagery, and to detect the landscape changes that are the most used since remote sensing was widely recognized, is the *pixel-based classification*. The pixel is the atomic analytical unit in this technique, where spectral characteristics are employed to classify the imagery and assess the changes mostly without considering the spatial context (Hussain et al., 2013). This is particularly problematic for historical panchromatic imagery that only provides limited spectral information (Müllerová et al., 2013). But recently the powerful computer systems and efficient software algorithms have boosted the opportunities for segmentation and feature extraction from the images. Such progress enabled the implementation of a new remote sensing approach of image classification, called *object-based image analysis (OBIA)*, also called a *geographic object-based image analysis (GEOBIA)* (Blaschke et al., 2008). This approach copies the human analytical decision and adds spatial and contextual information on top of the spectral one. It can also make it easier to integrate the raster-based image processing and vector-based GIS.

The unit to analyze in OBIA is an object which summarizes the information including the above-mentioned elements for image interpretation, such as texture, shape, and spatial relationship with neighboring objects. The progress and development of software like eCognition, IMAGE Objective, and ENVI's Feature Extraction module help bring OBIA to the mainstream (Blaschke, 2010; Hussain et al., 2013).

Chen et al. (2012) compare the object and pixel-based classification, mentioning some problems especially if high-spatial-resolution imagery is used. **Figure 26** is shown a typical example of change detection using multiscale OBIA which results in highly accurate classification, in contrast to the pixel perspective, where it is more difficult to define a unique spatial resolution to monitor the changes according to all types of geographic objects. **Figure 26a),** represents a wildland-urban interface area that has been classified using a two-scale OBIA; a small scale was applied to delineate houses, while a large scale was more appropriate to capture vegetation patches (Chen et al., 2012). The classification accuracy increased by 18% compared to using the pixel-based approach (**Figure 26b)** (Chen et al., 2012).

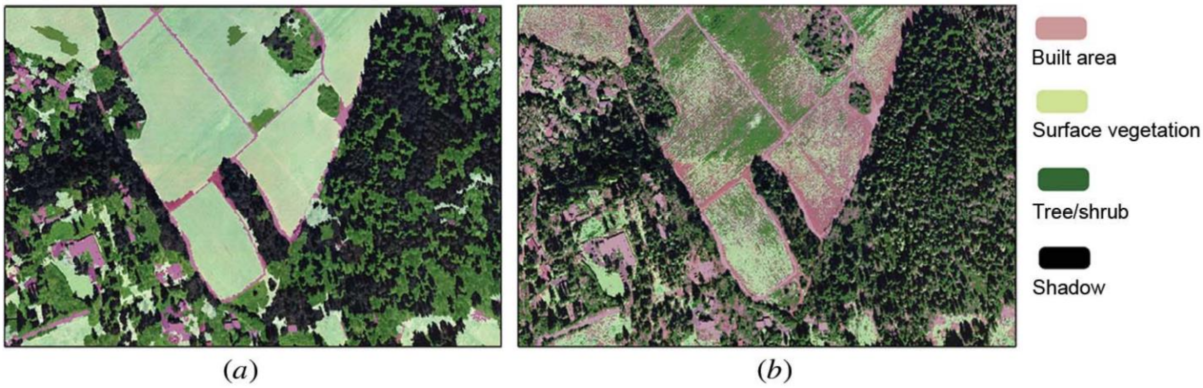


Figure 26: Comparison of classified maps using (a) a multiscale object-based and (b) a pixel-based approach (Chen et al., 2012)

After the research which compares different data sources, spatial and spectral resolutions and image processing techniques and their potential to monitor the invasive species *Heracleum mantegazzianum* (giant hogweed) by pixel and object-based image analysis, Müllerová et al. (2013) and other authors mentioned in this chapter concluded that for panchromatic as well as colour very high spatial resolution (VHR), the best results were provided by OBIA approach with average accuracies. Pixel-based methods gave very poor results for such low spectral resolution data and were excluded from further analysis.

For multispectral VHR aerial data, acquired at the time of the species fruiting, the OBIA approach yielded better results but the accuracy was still lower compared to the previously mentioned results. The medium resolution satellite data showed comparably higher accuracies for pixel-based methods, with supervised (maximum likelihood) classification achieving the best results but still much lower compared to VHR data (Müllerová et al, 2013).

Therefore, OBIA was considered to be particularly beneficial for analyzing low spectral resolution imagery, such as historical panchromatic aerial imagery, because it relies on both spectral and spatial information (Müllerová et al., 2013).

3. METHODOLOGY

3.1. STUDY AREA

The Krkonoše Mts. are located in the North along the border with Poland, forming bilateral Czech-Polish National Park of Krkonoše (KRNAP) and Karkonosze (KPN). It belongs to the Hradec Králové and Liberec Regions (**Figure 27**), being part of the so-called “Black Triangle”, which means heavy industrialization and environmental damage from Poland, Germany and the Czech Republic. It includes the highest mountain of the country (Sněžka, 1603 m. a.s.l.) and the source of river Elbe, one of the major rivers in Europe and the largest river of the country. The Elbe rises at the western plateau of Krkonoše tundra near Labská bouda. In the East, Krkonoše borders Jizerské hory Landscape Protected Area (EU.CZ 2009).

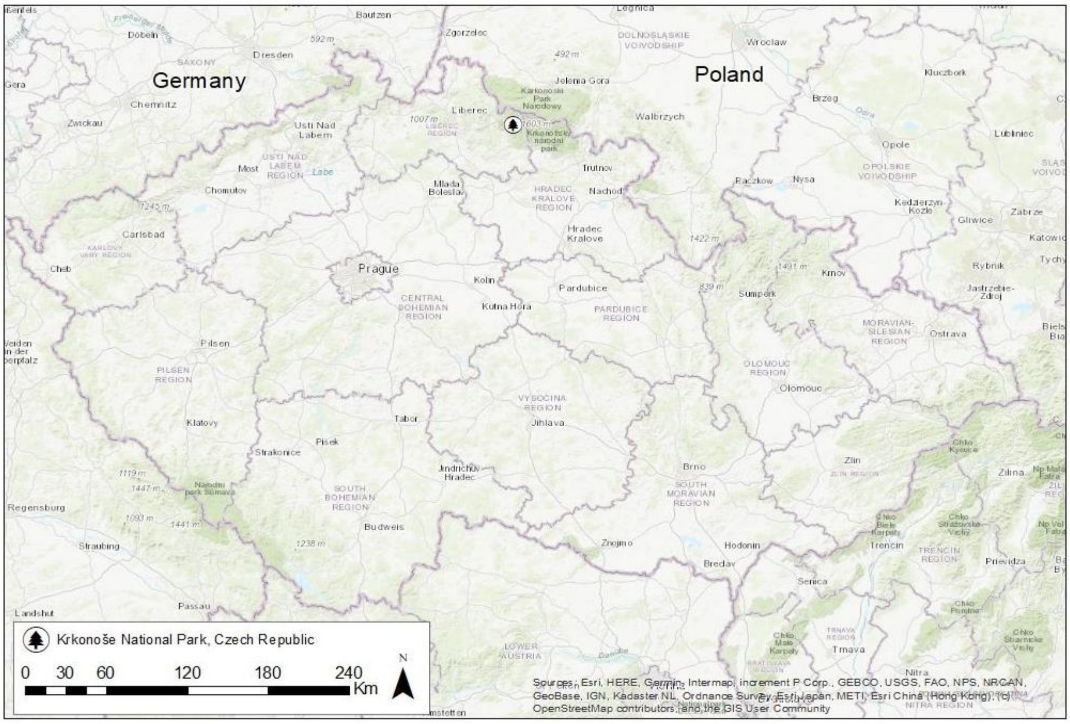


Figure 27: Map of the regions in the Czech Republic and the Krkonoše National Park. Source: ESRI GIS, Marina de Souza Faria

3.1.1. Environmental Conditions

The physical geography elements such as geomorphology, geology, climate and soil will be described to understand the background on the environmental conditions in Krkonoše Mts. The focus will be placed on pattern ground soils and their importance for the High Sudetes. The physical and ecological aspects of the Krkonoše Mts. comprise a huge variety of meteorological phenomena, landforms and biotic communities, which in a balanced proportion reflect the treeless ecosystem in both the far-north and high mountains (Soukupová et al., 1995).

Geology of Krkonoše Mts. is a combination of Proterozoic and Paleozoic crystalline schist, primarily mica schist, phyllite and ortho gneisses, dating between 600 million and 1 billion years ago (KRNAP, 2010). In the Carboniferous era, about 300 million years ago, a massive granite body suffered orogenesis and resulted in on-called the Krkonoše-Jizera Pluton. This geological formation is bordering the Silesian Ridge of Krkonoše from the foot of Sněžka Mountain as far as Harrachov, almost the entire Jizera mountain range and the Polish slopes of Krkonoše. The unique morphology and undulation shape of Sněžka is related to the metamorphism aureole contact that emerged from the orogenesis process. Notably the contact with carbonate rocks brought about an area boasting some of the Krkonoše region's mineral deposits – Harrachov, Medvědín, Svatý Petr, Herlíkovice, Obří důl and others already mentioned in the historical context in the literature review chapters (KRNAP, 2010).

Some geological differences are the volcanic cliffs in the Krkonoše tundra caused by small intrusions of neovolcanic (balsam of tertiary age), they can also be found around Harrachov. They represent the highest emergence of neovolcanica not only in Krkonoše but in all Central Europe. The Basalt Ravines are hosting the highest species diversity in all KRNAP, forming some important so-called “gardens” (Soukupová et al., 1995; KRNAP, 2010).

The geomorphology was under more intense transformation during the Tertiary and Quaternary periods, the peneplains and etchplains that can see in the undulation of two large plateaus are remnants of such periods. The differences in the modelling of the northern slopes of Krkonoše and those to the south happened because of the geology explained before, which evidence comes from the lowest geological formation – the Quaternary, and the eastern compared to western part does not have such a huge difference. (KRNAP, 2010). During several alternating glacial and interglacial periods, the higher altitudes of Krkonoše were transformed into glacial cirques, through glacial valleys, such as Labský důl and Obří důl, which has already been mentioned in the historical context of the mining (KRNAP, 2010).

The cryogenic factors strongly operate particularly on emergent convex relief e.g. peaks, custodied, ridges, frost cliff, cryoplanation terraces and tors, which are exposed to a higher frequency of regelation and enhanced wind action (Soukupová et al., 1995). Evidence of recurring glaciation in some parts of the mountains is in the form of glacial moraines and lakes.

Glacial, frost and river erosion developed the typical pyramidal shape of the Sněžka mountain top. The flat relief found in summit plateaux and adjacent depression in the Krkonoše (Bílá Louka, Pančavská Louka, etc) mostly extends over deeply weathered medium-grained and coarse-grained granites, and over remains of fossil alteration mantle. These areas never experienced glaciation which led to the emergence of a unique collection of land contours determined by periods of frost-sorting, one that is unmatched by other medium-sized European mountains. However, there were exposed to low air temperature due to altitude, regelation due to temperature fluctuations and wind action due to topography, all those features compose the geodiversity for which the mountains are renowned (Soukupová et al., 1995; KRNAP, 2010).

The long-term climate measurements are being recorded on top of Szrenica (1331 m) and Sněžka (1603 m). The mean values calculated from records of these meteorological stations indicate per humid cold climate, marked mainly by very low temperature, prevailing western SW, W and NW winds, high annual precipitation, with a prominent share of snow, normally deep and long-lasting snowpack covering and, prominent deposition of rime causing enormous load on any emerging structure above the ground (Soukupová et al., 1995).

The temperatures are comparable with northernmost Scandinavia and characterized by annual temperatures below 1°C and daily averages below zero. Krkonoše's peaks are colder than lower locations in valleys, although the latter is, in turn, colder than those in the foothills. When temperatures invert, the higher altitudes are sunny and warm whereas the valleys accumulate cold air, fog and low cloud cover. This typically takes place in this territory, especially in autumn and winter, when it lasts several days but rarely can even draw on for weeks (Soukupová et al., 1995; KRNAP, 2010).

The topoclimate could better represent the explanation of those concepts because it changes due to the diversity of relief, slope aspect, inclination and topographic situation (Soukupová et al., 1995). The most important factors are the pattern of wind direction and distribution of snowpack, this is a topic to be studied in a long-term perspective but is very difficult due to the danger of avalanches (Soukupová et al., 1995).

Therefore, according to the environmental conditions described above, Krkonoše Mts. developed different kinds of soil. The most prominent aspects that influenced pedogenesis were the acidic and mineral-deficient geological bedrock and the cool and very humid climate. The types of soil found in Krkonoše are large of acidic form, with prevailing types being brown forest soil and humus soil with peaty podzol and podzolic ranker in the lowest and higher altitudes, respectively (KRNAP, 2010).

The podzolization and accumulation of raw humus, are related to nordic/subarctic humus podzols. With increasing altitude, the degree of podzolization declines (Soukupová et al., 1995). Under the periglacial climate of the cool period in the Pleistocene, new exo geodynamic processes acted in a deeply weathered mantle, particularly basic cryogenic processes such as congelifraction, cryogenic segregation, solidification, and nivation. They were induced by the existence of permafrost and intensive regelation, generating cryoplanation, terraces, frost cliffs, slack tips, block fields and spectacular tors. This resulted also in pattern ground, marked by cryogenic segregation into polygons, stripes and furrows, which were identified at the latitude of Krkonoše by the Swedish geologist Arvid Högbom (1914) and will be explained further in more detail (Soukupová et al., 1995).

The most valuable types of soil in the park are relict pattern-grounds which are very shallow, rocky frost-sorted alpine soils at the highest elevations above the treeline. Along the streams, there can be found alluvial and gley soil of varied thickness. In forest and sub-arctic peat bogs of both plateaus, peaty soils occur, the depth is around 2–3 metres. These are very original natural habitats that allow the unique northern ecosystems to flourish. To conclude, the acidity of Krkonoše's soils could be explained by the geological features, however, the decrease of pH is also happening since the late 20th century through exposure to air pollution (acid rain). Past large-scale clearings of dying forest stands caused massive erosion and soil degradation through what is called *intraskeletal* erosion (Soukupová et al., 1995; KRNAP, 2010).

3.1.2. Study Sites

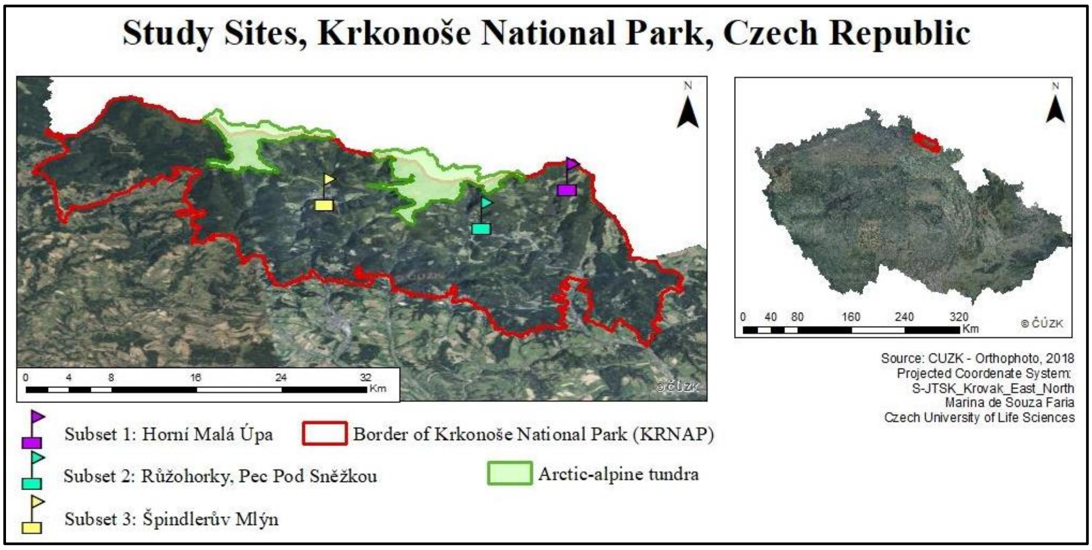


Figure 28: Study Sites at Krkonoše National Park. Source: CUZK, 2018.
Map: Marina de Souza Faria

The literature review explained the historical context of the Krkonoše Mts. and revealed the main changes in the land use and land cover, caused by the cessation of traditional management on one hand, and increasing human pressure due to tourism on the other. The main changes can thus be expected in the settlements, meadows (deforestation/afforestation) and tourist (mostly skiing) facilities. To study the effect, I carried out the detailed landscape spatio-temporal analysis of the most valuable areas above the treeline (alpine tundra), and at three small scale subsets in the montane zone (**Figure 28**). According to the literature review, the supervisor and I chose those subsets to represent the main trajectories of changes in the landscape (cessation of the management, increasing tourism - skiing, changes in settlements). For that reason, the physical descriptions of the study sites are very important information to auxiliary us to interpret the results and analyse the most important information for the discussion.

3.1.3. Alpine Belt

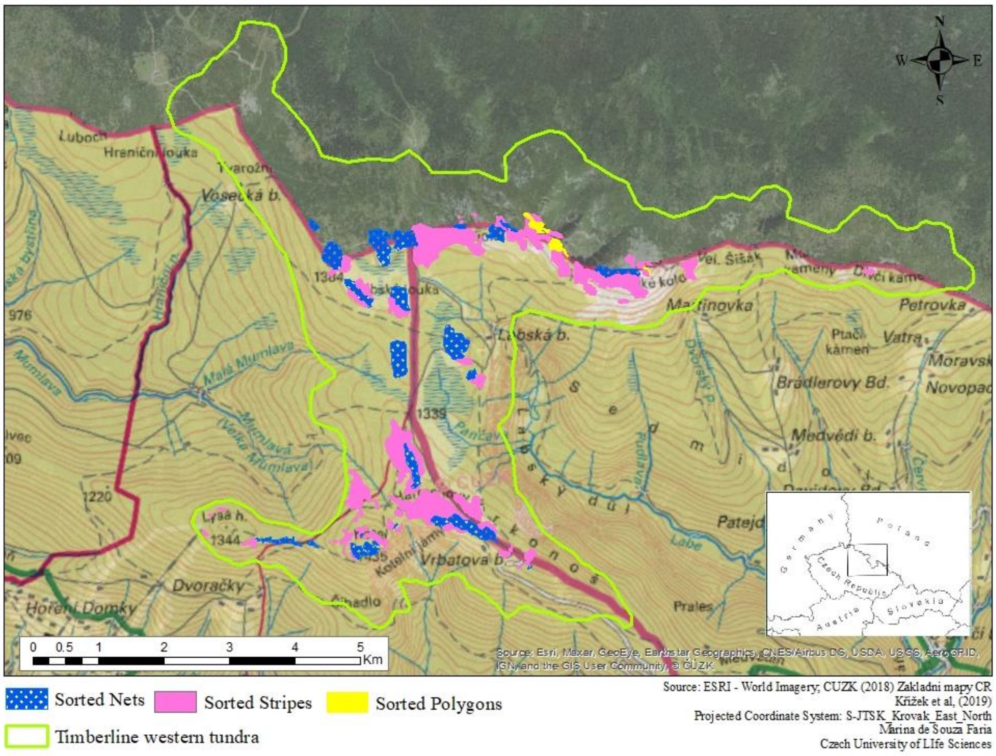


Figure 29 – A: Patterned ground in western tundra of Krkonoše Mts. Source: ESRI; CUZK; Křížek et al, 2019. Digitized by Marina de Souza Faria

The alpine tundra covers an area of 47 km²; 32 km² in the Czech part of the park and 15 km² in the Polish land. The topography is basically two plateaus formed by cryogenic, nivation, eolic and glacial processes during the geological eras (Křížek, 2019). The western plateau 50°46’ N; 15°32’E, with Labská bouda chalet (**Figure 29 - A**), and the eastern plateau, with Luční bouda chalet (50°44’ N; 15°42’ E), have the same size of 16 km² (**Figure 29 - B**). Both tundra plateaus are comparable and in this research, the focus will be the western part. The patterns in environmental conditions and the consequences of natural and anthropic disturbances were studied by many authors (Soukupová et al., 1995; Lokvenc, 2001; Müllerová et al., 2011; Kupková et al., 2016).

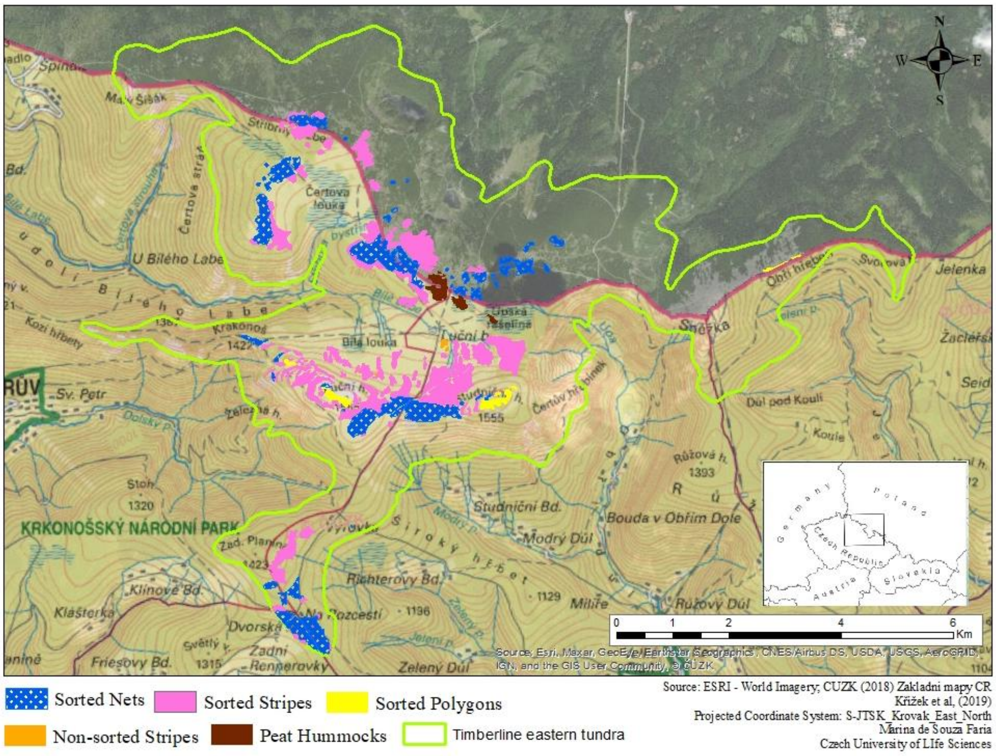


Figure 29 - B: Patterned ground in western tundra of Krkonoše Mts. Source: ESRI; CUZK; Křížek et al, 2019. Digitized by Marina de Souza Faria

To illustrate the uniqueness of the tundra ecosystem, **Figures 29 (A and B)** show the relict pattern ground in the Krkonoše arctic-alpine tundra region (the Czech Republic and Poland). This term refers to a wide group of periglacial landforms that presents almost regular surface geometric patterning in the form of circles, polygons, irregular nets or strips (Křížek et al., 2019). Soukupová et al. (1995) explain that the most prominent cryogenic structures of the arctic-alpine tundra in Krkonoše are developed on quartzites and fine granite. In Pleistocene stadials, the uppermost area of the Krkonoše was occupied by a stone hamada (Soukupová et al., 1995). Less exposed sites on coarse-grained granites with a thicker weathering mantle were covered by stony-sand tundra. Its frost-sorted polygons and striped soils, covered later with vegetation, are continually preserved by current cryogenic processes (Soukupová et al., 1995).

The legend on the map (**Figure 29 - A and B**) are covered with more sorted nets and stripes (colour blue and pink), the nets are characterized by irregular cells and the stripes consist of up-domed fine-grained bands overgrown by vegetation between narrower coarse stripes elongated downslope. Also, there are a few small areas classified by yellow colour: sorted polygons which are characterized by their regular polygonal morphology with straight stony borders, slightly depressed relative to the centres. And on the western side, even peat hummocks (colour brown) are distinguished because they undergo the shape changes connected with the segregated ice core expansion. In the center of the eastern tundra is visible one orange dot, which corresponds to non-sorted stripes, this class consists of an up-domed centre, which is an elongated downslope (Křížek et al., 2019).

To characterize the climate which contributes to still develop this particular soil is very difficult due to the high diversity of the topographic levels and wind direction factors, the overall KRNAP at altitudes of 1350–1600 m (arctic-alpine tundra) is characterized by the average annual temperature from 0.2°C (Sněžka Mt.) to 2.1°C (Labská bouda chalet) and the annual sum of 1300–1400 mm precipitation (Harčarik, 2002).

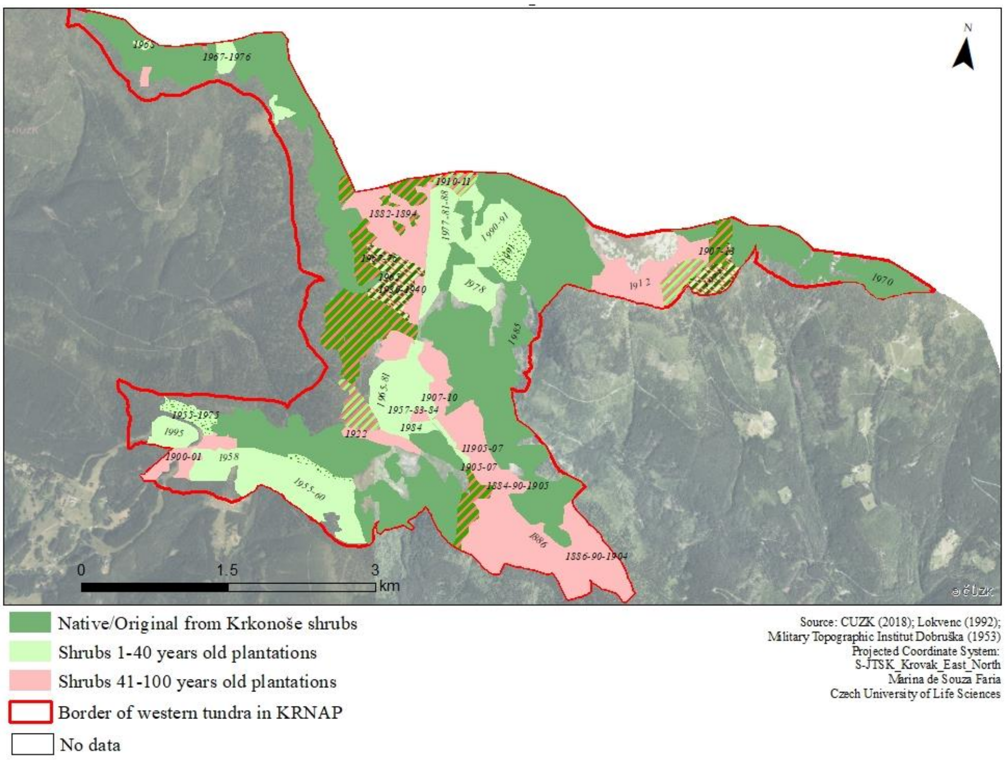


Figure 30: Origins of dwarf pine (*Pinus mugo*) in KRNAP. Source: (Military Topographic Institute, Dobruška, 1953; Lokvenc, 1992; CZUK, 2018). Digitized by Marina de Souza Faria

Concerning climate topic it is important to mention the microclimate in the area, because is one of the favored conditions that are offered thanks to the topography, so it can contribute to analyzing the conditions which support or not the vegetation growth. The map (**Figure 30**) shows the vegetation of dwarf pine (*Pinus mugo*) in the western tundra. The dark green colour represents the original shrubs. The light green colour shows the dwarf pine that was planted 1- 40 years ago, and the pink shows 41-

110 years old shrubs planted in the area. All those mixed colours are shown on the map (**Figure 30**) imply that those three classes mixed between each other. For example, in the southeast, close to the border (marked by red colour), there are dark green and pink together. This means natively planted dwarf pine species mixed with species planted around 41-110 years ago (Lokvenc, 1992).

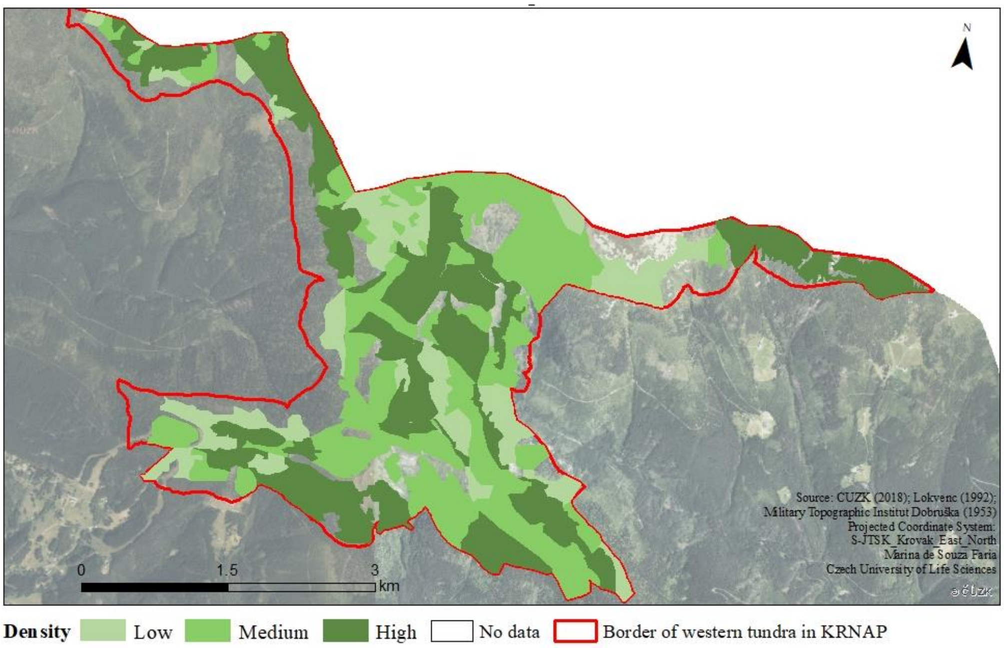


Figure 31: Density of dwarf pine forest in the tundra. Source Source: (Military Topographic Institute, Dobruška, 1953; Lokvenc, 1992; CZUK, 2018). Digitized by Marina de Souza Faria

To complement the information on the map (**Figure 30**) Lokvenc (1992) also gives information about the density of dwarf pines in the area. Another map (**Figure 31**) shows the density of those pines during the plantations and which of them are more established in the area. When the Krkonoše landscape suffered floods and landslides in the 19th/20th centuries, the first plans for reforestation of parts of the ridges with dwarf pines were promoted; instead of improving local water and soil conservation conditions. (Bašta, 2013). The planning for plantation of dwarf pine started in Jilemnice dominion in the western Giants Mts. in 1970. Gradual afforestation was accomplished in the area of 439 ha in the whole Sudetes (Lokvenc, 2001). Between 1870-1913, 110 ha of dwarf pine, 13ha of spruce and 30 ha of cembra pine were upgraded.

The reforestation work was initiated by Count Jan Harrach in several stages, which continued until the second half of the 20th century by Ing. Theodor Lokvenc and Forest Drainage workers. After the declaration of Krkonoše National Park in 1963, the NP Administration staff had the opportunity to review the plans submitted by the ten-year development plan for high mountain afforestation (Bašta, 2013). They tried to prevent the reforestation of peat bogs, fen sites and localities where rare or endangered plant species occur. However, high-mountain afforestation with pine shrub was terminated in 1990 and several scientific studies were carried out in the following two decades to evaluate the influence of these plantings on the environment of the arctic-alpine tundra (Lokvenc, 2001; Bašta, 2013)

3.1.4. Montane Belt - Subsets

The Subsets represent the three main trajectories. These are: (i) transformation of settlements (Subset 1), (ii) grassland abandonment (Subset 2), and (iii) impact of skiing (Subset 3). The Subsets have an area of 3.4 km² or 671 ha. The rectangular shape measure's length is 1,972m x 1,722 m. All of these topographical maps are in the same coordinate systems (WGS - 1984) unlike the one used in the analysis (S-JTSK Krovak); for that reason, the rectangular shapes appear not centralized.

SUBSET 1:

The first subset is located on the border with Poland (50°44'N; 15°49'E) (**Figure 32**). It represents an example of changes in the settlement related to population changes and changes in a lifestyle, cessation of traditional forms of management and transforming the traditional village into a tourist area (**Figure 33**).

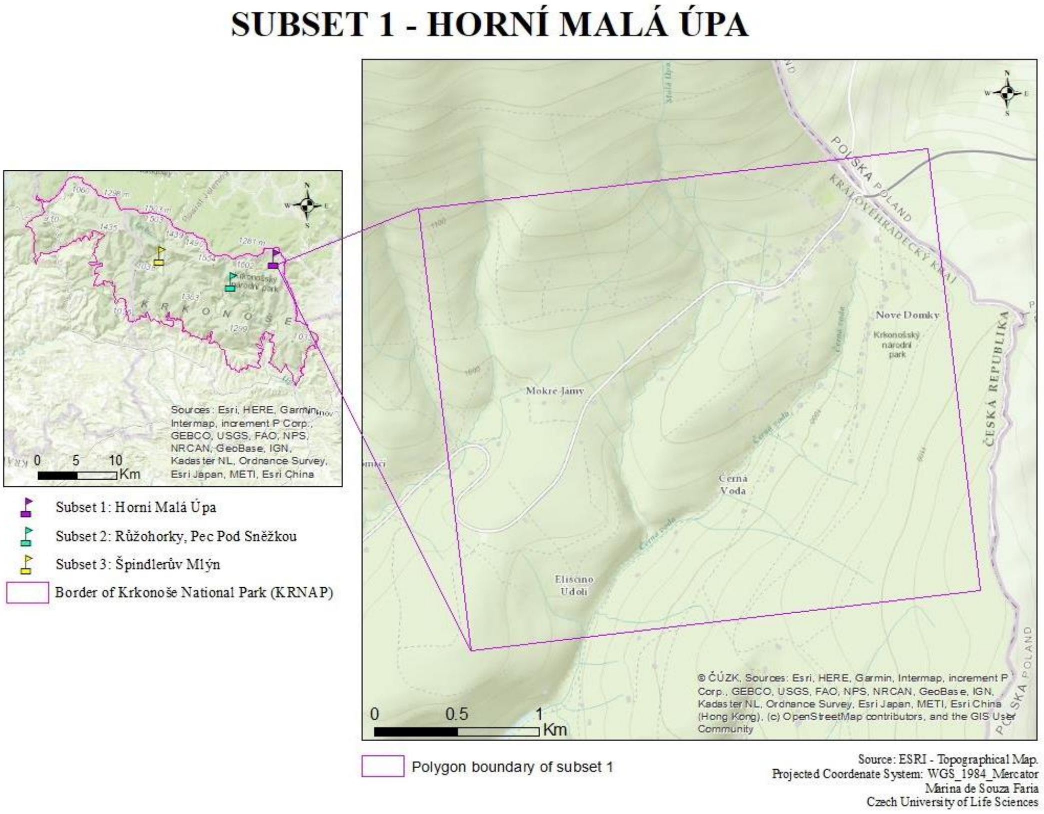


Figure 32: Topographical map of Subset 1. Source: ESRI. Author: Marina de Souza Faria.

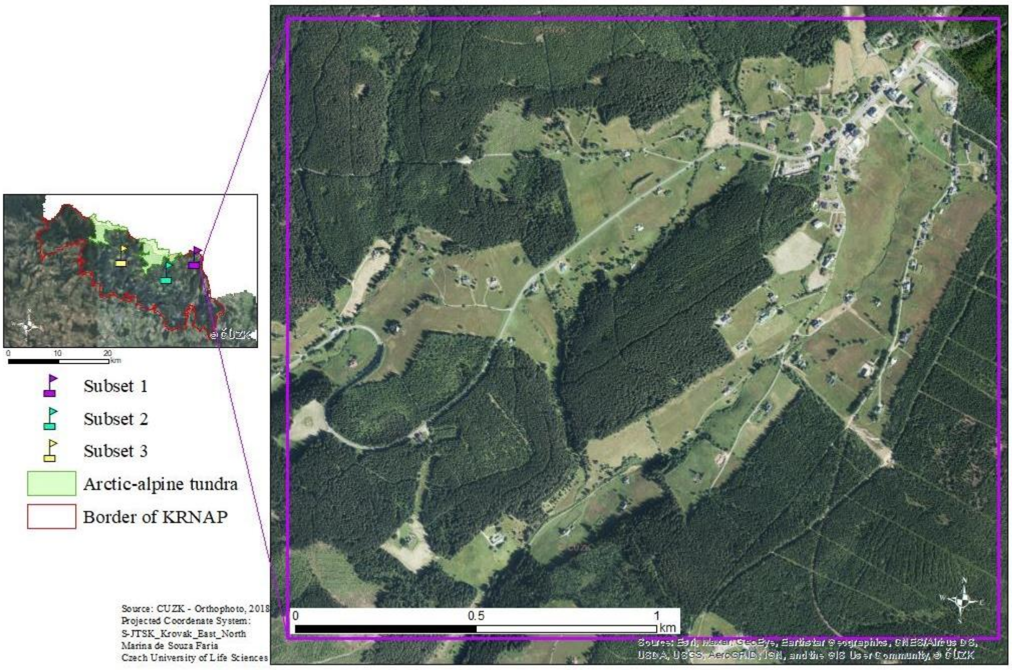


Figure 33: Aerial imagery of Subset 1. Source: CUZK, 2018; ESRI. Marina de Souza Faria

The village Horní Malá Úpa is dated back to 1748 and is an important example of the settlements that were developed concerning grazing, mowing and trading since the village lie on one of the few trade roads at the border with Poland (Lokvenc, 2001). The settlement started in the 16th century, firstly for the extraction of minerals and wood for the silver mines in Kutná Hora. The extraction of wood and minerals was already declining at the beginning of the 17th century, but the settlers established meadows on the felled clearings as soon as they arrived and built the first mountain huts (**Figure 34**). They improved the land to allow the grazing of cows and goats. Each family was given their location to be felled, which consequently created enclaves that were inhabited mainly by members of one family for several more centuries (Malá Úpa, 2020).

Figure 34: Settlements in Horní Malá Úpa. Source: Foto Historie. Online: http://www.fotohistorie.cz/Kralovehradecky/Trutnov/Horni_Mala_Upa/Default.aspx Accessed in 03.08.2021

The ores were mined in the 16th century in the settlement of Smrčí and Lví důl. Mining returned there in 1735 and then mainly in the years 1841 to 1866. The mined iron ore and arsenic were then processed in Pec pod Sněžkou (around the Subset 2). In 1779, the future Emperor Joseph II visited Malá Úpa and, as part of a policy, he had a church built by the locals. On February 22, 1791, the Stand of God, at that time the highest church in Bohemia (975 m), was dedicated to the patrons St. Peter and Paul (**Figure 35**). The church was accidentally burned, but it was reconstructed and still is an important touristic point nowadays. Many events happen around it including fairs, street markets and other recreational purposes (Malá Úpa, 2020).

Figure 35: St. Peter and Paul church in the 19th Century and 21st Century. Source: http://www.staretrutnovsko.cz ; (Malá Úpa 2020). Accessed in: 03.08.2021

Those huts/chalets started to change their function to tourism facilities in the 18th century, so they can provide the necessary services to visitors. However, in Malá Úpa, tourism grew the most with the development of winter sports after World War I. In

1945, the village of Malá Úpa had about 1,000 permanent residents. At that time, both parts - Dolní a Horní Malá Úpa already had 1120 beds for guests, compared to today's 2500 beds (Malá Úpa, 2020). In comparison with the number of permanently settled inhabitants, it is clear that Malá Úpa already had the character of a recreational mountain resort. Nowadays, most of the former farms serve as tourist facilities. There are two car parks for the visitors, several ski lifts, restaurants and a small brewery (Malá Úpa 2020).

SUBSET 2:

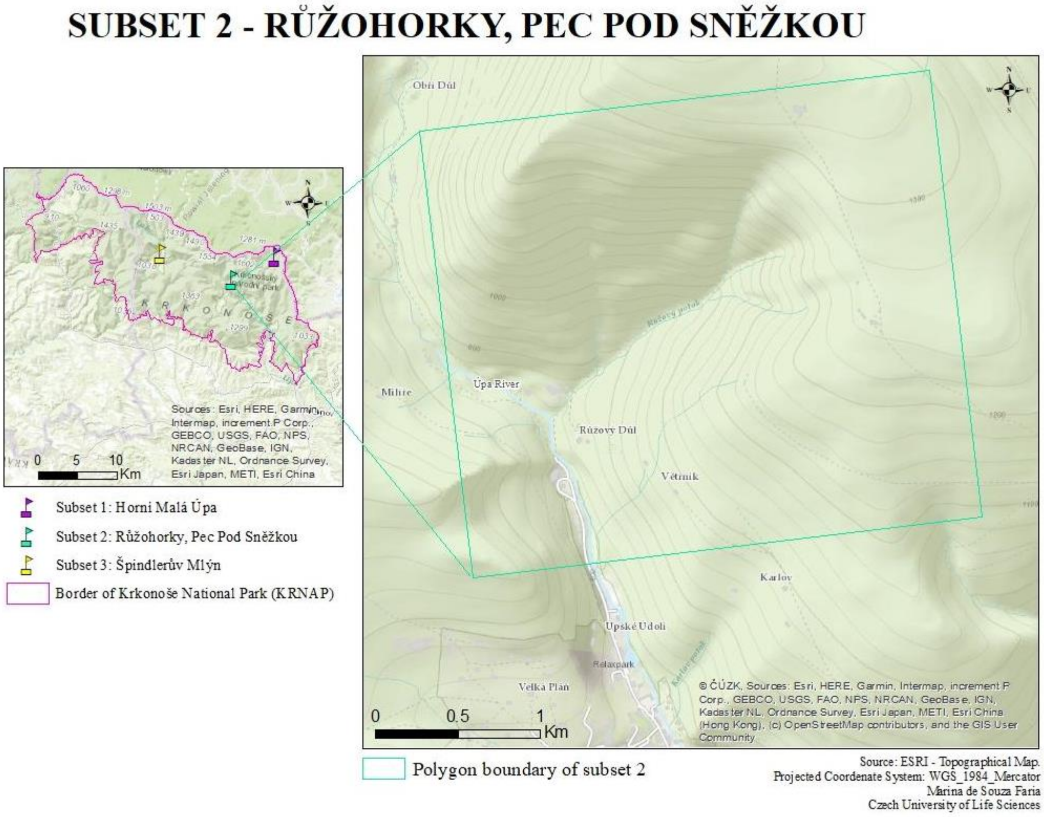


Figure 36: Topographical map of Subset 2. Source: ESRI. Author: Marina de Souza Faria.

The second subset (50°42'N; 15°40E), representing the grassland abandonment, is located between Pec Pod Sněžkou and the highest mountain in the Czech Republic, Sněžka (1603m). The Úpa river passes through the Subset. It is a left tributary of the river Elbe with the confluence in the Obří důl (**Figure 36**) (EU.CZ, 2009). The land cover is prominent by the meadows and forest; the way how they change according to altitude is a valuable analysis of the map of topography and the aerial imagery (**Figure 37**).

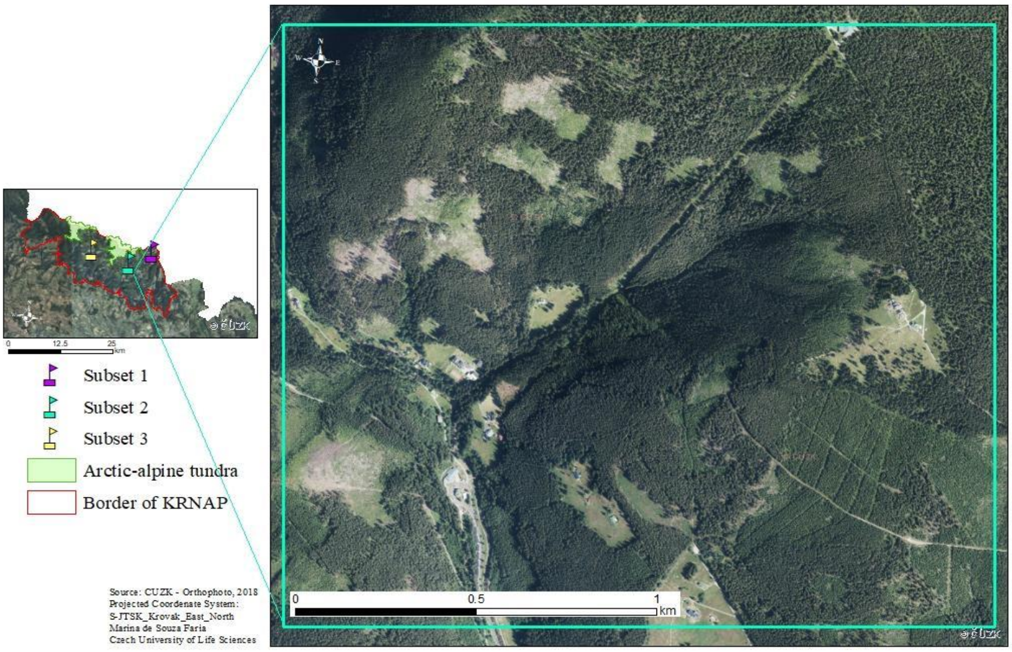


Figure 37: Aerial imagery of Subset 2. Source: CUZK, 2018. Marina de Souza Faria

The human impacts on this area have started with the mining of copper, ores and arsenopyrite around the year 1511 in Obří důl (Giant Mine), and the region was at first settled as part of today's Pec pod Sněžkou. Růžohorky and Pec Pod Sněžkou stood out firstly because of the extensive logging for the needs of the Kutná Hora during the 17th century. Woodcutters, who were invited to Krkonoše from Styria, Carinthia and Tyrol, founded the meadow enclaves in forest clearings, built dwellings (called huts) and bred cattle and goats (Pec pod Sněžkou, 2020).

Figure 38: Pec pod Sněžkou's valley in the 18th Century and 21st Century. Online: http://www.pecpodsnezkou-velkaupa.cz/cz/velka-upa/historie/ Accessed in 03.08.2021

The landscape started to change towards tourism already in the 19th century (**Figure 38**). The settlers realized a new source of livelihood, they accommodated tourists in their dwellings, renting the rooms and gave the rise to huts, afterwards started the construction of hotels and pensions (Bašta, 2013; Pec pod Sněžkou, 2020). The traditional way of farming was gradually abandoned.

Already before World War II, Krkonoše was an important centre for vacation activities, including winter hiking and skiing, therefore around the boom of tourism, the authorities proposed to build a chairlift to the summit of Sněžka (Bašta, 2013). The investor soon pushed through the current route through the Růžový důl Glacial Valley, across Mt. Růžová hora, and up to the summit of Sněžka. The construction was authorised by the Ministry of Education, which at that time was responsible for conservation policies and measures. Despite protests by some of the prominent personalities, the construction was supported by the Local People´s Committee in Pec pod Sněžkou. In the end, the chairlift was built in 1947–1950 (Bašta, 2013).

The concern for the landscape planning of the region started as soon as the new Town Council took control and started to promote the reconstruction of the old, and the construction of a new chairlift. The Council also wanted to recover and re-open the Czech Chalet. In 1994, with the new direction of KRNAP, the administration started looking for a new alternative route for the chairlift, with a lower station near the dam in the centre of Pec pod Sněžkou and intermediate station at Růžohorky (Bašta, 2013).

The Town of Pec pod Sněžkou had to ensure the processing of EIA documentation, which would analyse all possible impacts of several variants of this investment project on the environment. It is also important to mention that significant damage done to spruce and dwarf pine growths during its construction and the upper parts of the Sněžka massif were subjected to gross interference. Summarized, after years of negotiations and compromises, the construction of a new chairlift began in the autumn of 2011 and was completed in 2015 (Bašta, 2013; Pec pod Sněžkou, 2020). Thus, the traditional way of farming was abandoned and today it is kept only via subsidies from The Landscape Natural Function Restoration Programme.

SUBSET 3:

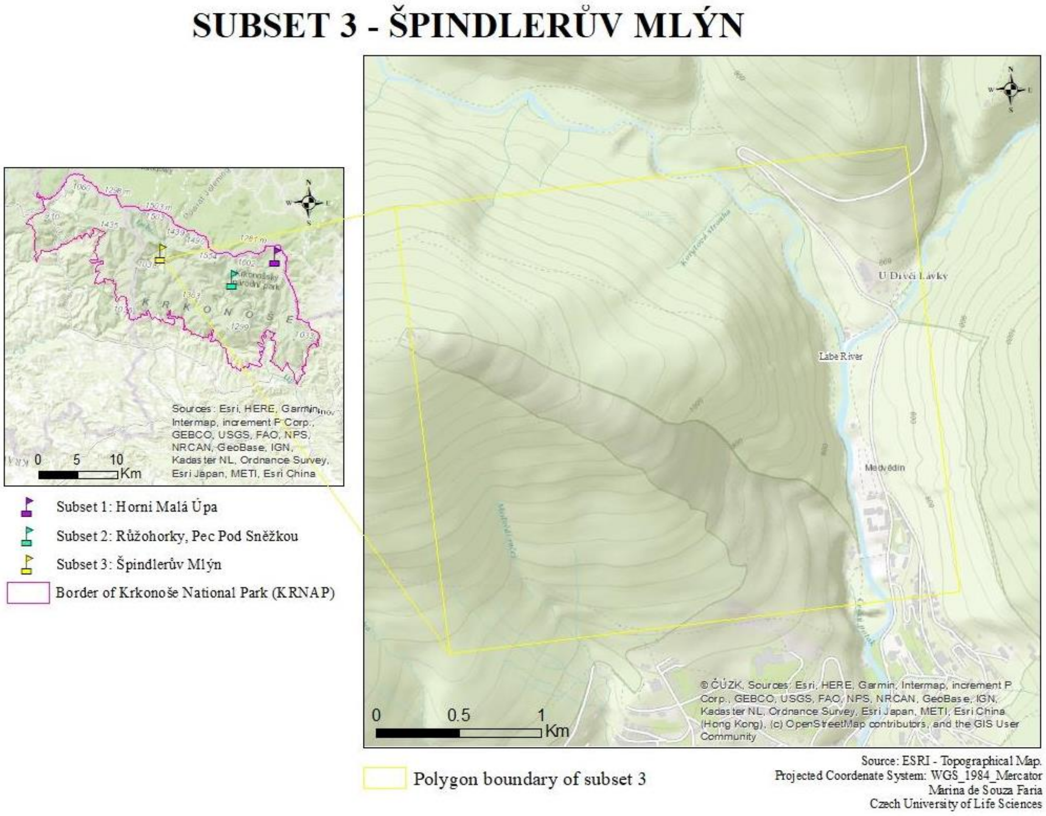


Figure 39: Topographical map of Subset 2. Source: ESRI. Author: Marina de Souza Faria.

The third subset is located in Špindlerův Mlýn (50°44’N; 15°36’E), on the Medvědín mountain of 1235 m a.s.l. (**Figure 39**). The area is surrounded by mountains, including Luční hora at 1555 m a.s.l. in the east, the second-highest mountain of the Czech Republic. The Elbe River flows through surrounding valleys. This river is one of the major rivers in Central Europe, nevertheless, 33.7% is in the Czech Republic (EU.CZ 2009).

In the valley, the settlement of Špindlerův Mlýn was established in the early 16th century under the rule of King Louis II Jagiello. First settlers were mostly attracted by the underground wealth such as mining and ore. To help with the mining, experts from Alpine countries were called. They were very experienced with high altitudes and knew how to breed cattle. Therefore, they began farming in the clearings, slowly turning them into meadows and pastures (**Figure 42**), thus forming typical meadow enclaves in the middle of forests, as they are known nowadays (Špindlerův Mlýn, 2020).

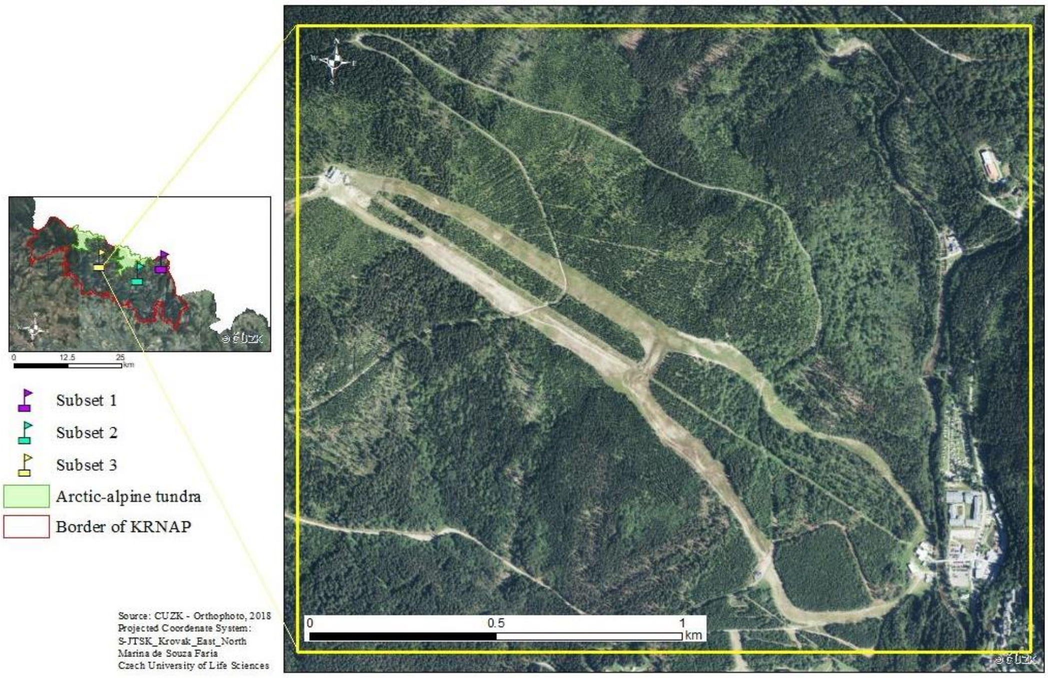


Figure 40: Aerial imagery of Subset 3. Source: CUZK, 2018. Marina de Souza Faria

Over time, miners were gradually replaced by builders. The management of buildings increasingly became an important activity in the area and the landscape started to change (Špindlerův Mlýn, 2020). The construction of the road in 1872 contributed significantly to the higher number of visitors. New professions were created, such as guides and porters of the Krkonoše Mountains, they even used wooden backpacks since they significantly helped tourists to carry their luggage uphill (Špindlerův Mlýn, 2020).

Figure 41: Riverside in Špindlerův Mlýn. Landscape changes in 1840 and 2019.
Online: http://www.fotohistorie.cz/Kralovehradecky/Trutnov/Spindleruv_Mlyn/Default.aspx ;
Špindlerův Mlýn (2020). Accessed in 03.08.2021

Figure 42: Skiing slope in Špindlerův Mlýn in the 19th century and 21st century. Source: (Špindlerův Mlýn 2020)

Starting from the mid-19th century, the place started to develop into a tourist resort. At first, the main season was summer, but in the second decade of the 19th century, other activities took place, such as sledging. The attraction took place in Špindlerův Mlýn and Petrovka. Another facility which helped to improve the area for the tourists was the construction of the hydroelectric power plant. In 1909, one year later, an electric sledge lift was set up (Špindlerův Mlýn, 2020).

In 1880, Dr Krause from Hirschberg appeared on Petrovka with the skis for the first time and nobody imagined that it would have a touristic potential. It took approximately another twenty years for skiing to become a practical means of transport and a new sport (**Figure 42**) (Špindlerův Mlýn, 2020). Guido Rotter donated skis to all-mountain schools in Vrchlabí in 1899. Moreover, it was Count Jan Harrach, who equipped foresters with them (Špindlerův Mlýn, 2020). Nowadays, Špindlerův Mlýn is one of the most visited skiing resorts in the Czech Republic (Boori et al., 2014).

Currently, the most wanted winter sports activities are snowboarding, downhill and cross-country skiing, ski touring, snowshoes or fun in the snow, snow tubing and sledge slide. From spring to autumn, the visitors have these options: nature trails around the town, mountain hiking or cycling trips through the mountain's nature. In the summer, cyclobuses help to connect several mountain resorts of the Krkonoše (Špindlerův Mlýn, 2020).

3.2. DATA SOURCES

The orthophoto map of the Czech Republic comes from the first country-wide aerial survey from the 1950s. The historical panchromatic aerial images are stored at the Military Geographical and Hydrometeorological Office (VGHMÚř) Dobruška. The historical orthophoto map of the Czech Republic includes layers of aerial photographs from the years 1949-1955, whereas, for the Krkonoše area, they come from 1953. The panchromatic orthomosaic at a resolution of 0.5 m was created by GEODIS BRNO within the methodological part (1st stage) of the National Inventory of Contaminated Sites (NIKM) project (Geo Portal, 2015), and is freely available.

The current colour orthomosaic from 2018 is freely available at the geoportal of the State Administration of Land Surveying and Cadastre (CUZK). It is the colour seamless orthomosaic of the Czech Republic in an 8-bit colour scale. Raster image pixel of the Orthophoto ČR displays approximately 0.20 m of the territory in the medial terrain plane. The positional accuracy characterized by a standard error in coordinates in flat terrain is 0.25 m, in rugged terrain 0.5 m. Orthophoto ČR has distributed in graphic raster formats JPG in export units displaying 2.5 x 2 km of terrain in division into map sheets of the State Map 1: 5,000 (ČUZK, 2018).

3.3. ANALYSIS

This study used two main software to analyze the data: *Trimble eCognition Developer* (version 9.3.0) and *ArcMap* (version 10.7.1) from ArcGIS/ESRI. Besides these, two main other software were used: Excel from Microsoft Office and Power BI. Excel was used to export the attribute tables for the analysis of the area (m^2) and percentage of changes, and Power BI to make the graphics.

The analysis required training and practice concerning image interpretation skills and learning how to operate the eCognition software. This was possible since the Institute of Botany in Průhonice has the license for eCognition and I processed the data with the supervision of Mgr. Jana Müllerová, Ph.D. Moreover, she has also explained to me the components of the image interpretation, and how to set up the classification values.

Overall, the visual image interpretation is to identify what is seen in the images and communicate this information to others; before that, it is just data. After the human interpretation, this data becomes useful information (Lillesand et al., 2000). Therefore, the accuracy is the responsibility of the interpreter and also depends on the data resolution, because this factor indicates the degree and value of details that are in the area of interest distinguished by space, time and topic (Brus et al., 2018). When the resolution is too low, it does not have enough details and the interpretation becomes less accurate (Brus et al., 2018).

According to the choice of the classification system or list of land cover/land use categories to be mapped, the process is dependent on the scale, image characteristics and analytical methods available (Anderson et al., 1976). For this Thesis, we chose to adapt to the U.S Geological Survey (USGS) land use/land cover classification system (Level I).

This classification is the basic concept and structure which is still valid, and the new studies are still following it (Lillesand et al., 2000). USGS consists of a series of nested hierarchical levels which are increasing categorical detail. Categories from one or more levels can be selected which should be appropriate for any scale of analysis, from global to local (Lillesand et al., 2000).

The USGS land use/land cover classification system was designed according to several important criteria:

"(1) The minimum level of interpretation accuracy using remotely sensed data should be at least 85 per cent, (2) the accuracy of interpretation for the several categories should be about equal, (3) repeatable results should be obtainable from one interpreter to another and from one time of sensing to another, (4) the classification system should be applicable over extensive areas, (5) the categorization should permit land use to be inferred from the land cover types, (6) the classification system should be suitable for use with remote sensor data obtained at different times of the year, (7) categories should be divisible into more detailed subcategories that can be obtained from large-scale imagery or ground surveys, (8) aggregation of categories must be possible, (9) comparison with future land use and land cover data should be possible, and (10) multiple uses of land should be recognized when possible" (Lillesand et al., 2000).

For those reasons, Level I of USGS was used and adapted to our study sites. It allows comparing the classes between them, as explained in criteria 2, 4, 5, 6 and 9. Thus, consider the capacity of a beginner in image interpretation of such a new biome. For illustration, **Figure 43** gives an example of aggregation of land use/land cover types at USGS methods.

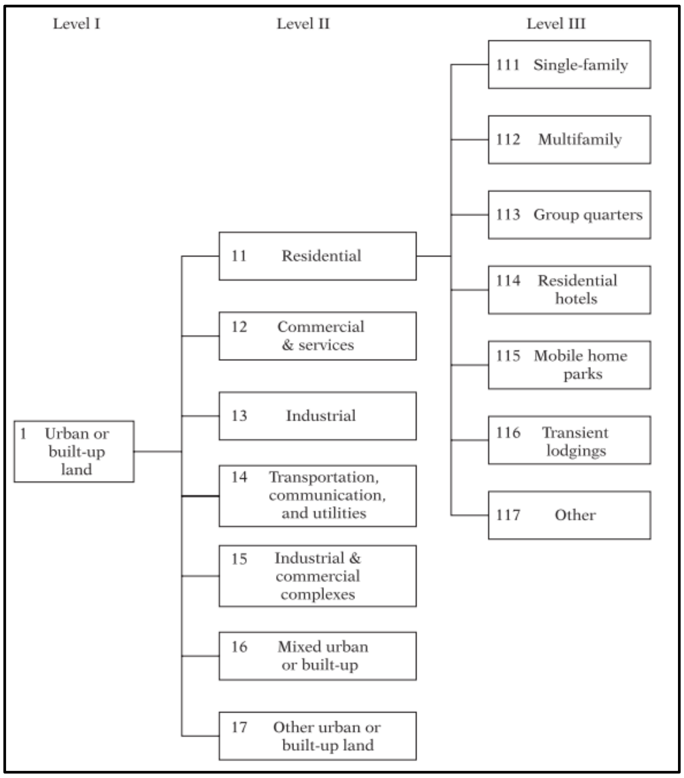


Figure 43: Example of aggregation of land/use/land cover types at USGS. (Lillesand et al., 2000).

However, to be classified as "Urban or built-up land" in a National park where most of the study sites do not have an urban area, would block the comparison between them or at least make it more difficult. For this reason, we decided as "built-up" which includes any constructed structures (buildings). This is just one explanation, what can be seen in the wider description of each of the USGS methods of classification and the ones that were set-up for us to adapt to the study area. **Table 1** shows the USGS definition of some of the classes we use in our classification **(Table 2),** to be functional for comparison between the study sites:

Table 1: Description of some of the classification USGS in Level I, organized by Marina de Souza Faria (Lillesand et al., 2000)

LEVEL I OF USGS LAND USE/LAND COVER CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA	
Name of the Classe	**Description**
Forest Land	Represents areas that have a tree-crown areal density (crown closure percentage) of 10% or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime. Lands from which trees have been removed to less than 10% crown closure but that have not been developed for other uses are also included. For example, lands on which there are rotation cycles of clearcutting and blockplanting are part of the forest land category. Forest land that is extensively grazed, as in the southeastern United States, would also be included in this category because the dominant cover is forest and the dominant activities are forest related. Areas that meet the criteria for forest land and also urban and built-up land are placed in the latter category. Forested areas that have wetland characteristics are placed in the wetland class.
Rangeland	Rangeland historically has been defined as land where the potential natural vegetation is predominantly grasses, grasslike plants, forbs, or shrubs and where natural grazing was an important influence in its presettlement state.
Urban or built-up land	Urban or built-up land is composed of areas of intensive use with much of the land covered by structures. Included in this category are cities; towns; villages; strip developments along highways; transportation, power, and communication facilities; and areas such as those occupied by mills, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be iso lated from urban areas. This category takes precedence over others when the cri teria for more than one category are met. For example, residential areas that have sufficient tree cover to meet forest land criteria should be placed in the urban or built-up land category
Water	The water category includes streams, canals, lakes, reservoirs, bays, and estuaries.

Table 2: Classification used for the study sites, organized by Bc. Marina de Souza Faria and Mgr. Jana Müllerová, Ph.D.

NAME OF THE CLASSES	DESCRIPTION
Forests	Shrubs and trees, mostly coniferous (Norway spruce, and dwarf pine in case of tundra)
Grasslands	Grasses and herbs, for tundra see description in subchapter 2.4.2 FAUNA and FLORA.
Built-up	Buildings (houses, hotels, pesions, chaltes, restaurantes), parking lots, buckers.
Roads	Main and secondary roads, including touristic trails.
Water	All identify water bodies: lakes, wetlands, peat lakes, rivers and streams.
Rocks	Rocky outcrops and screes mostly without vegetation (except lichens).

After setting-up the classification legend, a rule-based classification was processed in eCognition; the application of this process will be further explained step by step. Moreover, GIS was used to improve the classification performance, combining remotely sensed data with ancillary information on topography and landcover development in other periods. Those GIS tools were used to enhance image classification in three ways, pre-classification stratification, post-classification sorting, manual editing (Lu, D et al., 2007).

3.3.1. eCognition

The scheme below (**Figure 44**) summarizes the steps that were made in eCognition to process the aerial images (historical panchromatic imagery from 1953 and current RGB imagery from 2018). It also shows how it was converted into object-based segmentation and shapefile format which will be able to be exported to ArcGIS. All the steps and main tools were chosen will be described.

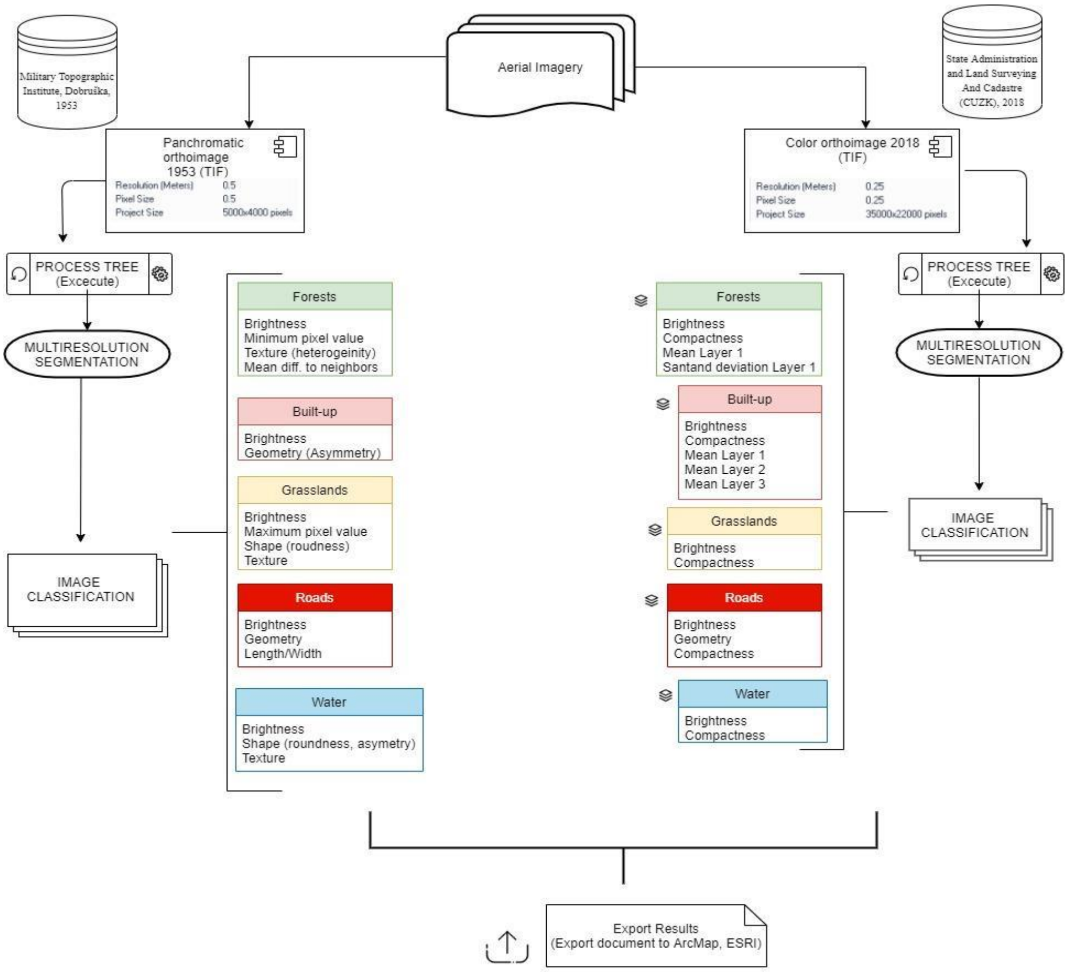


Figure 44: Scheme of the classification process in eCognition until the data are exported to ArcGIS. Organized by Marina de Souza Faria

First (i) each image was imported to the eCognition in TIFF format which includes a specific description of resolution and pixel size (**Figure 44**); (ii) the multiresolution segmentation was run at the following parameters - shape 0.5 for panchromatic and 0.1 for colour imagery, compactness for both 0.5; (iii) the process tree (rule-based classification) was set up and standardized in two versions for panchromatic and colour imagery, defining each target class using parameters such as spectrum (e. g. mean brightness as the main parameter used for panchromatic orthomosaic), shape (asymmetry, roundness, ratio of the object height and width), texture heterogeneity, and context (mean difference to neighbors) see **Figure 44** for more details.

As the whole process was explained in **Figure 44**, there are more details about the steps and the concepts behind it. Firstly, to understand the rule-based classification used in the project, the classification was prepared in a way that based on the expert knowledge, for each class specific rules were prepared to assign each pixel to one of the classes. To import the aerial image to eCognition is quite simple: before the import, a project is created (**Figure 45**), and an image imported. After the *process tree* is prepared, it can be copied to the following projects to facilitate the process when importing other images (Trimble, 2017). The idea is to use the first file as a master file in which the rules are defined. After the *process tree* is already set up (**Figure 45**), it just needs to rerun (*execute*) the whole process including segmentation and classification.

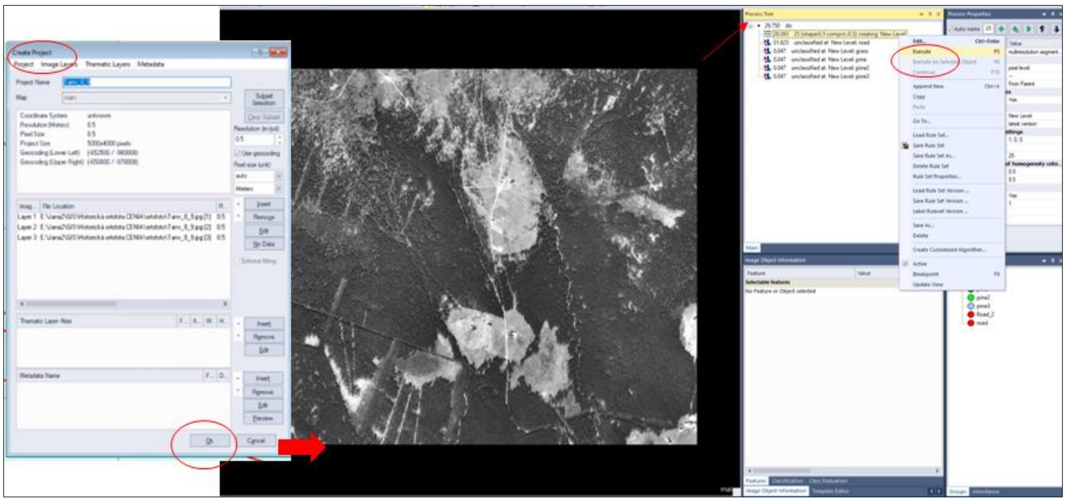


Figure 45: Import the aerial image and create a new project at eCognition, then *execute* the process tree already set up to start the *segmentation process*. Screenshots made by Marina in September 2020.

The *execute* tool in the *process tree* starts, in my case, with the *multiresolution segmentation*. This is the main step in eCognition when the image is cut into pieces-segments (**Figure 46**) which serve as building blocks for further analysis. **Figure 46** with those segments (polygons) in blue colour shows the result right after finishing the *execute segmentation.* After that, we can classify - label those objects with a specific class to start the interpretation and analyze the segmentation.

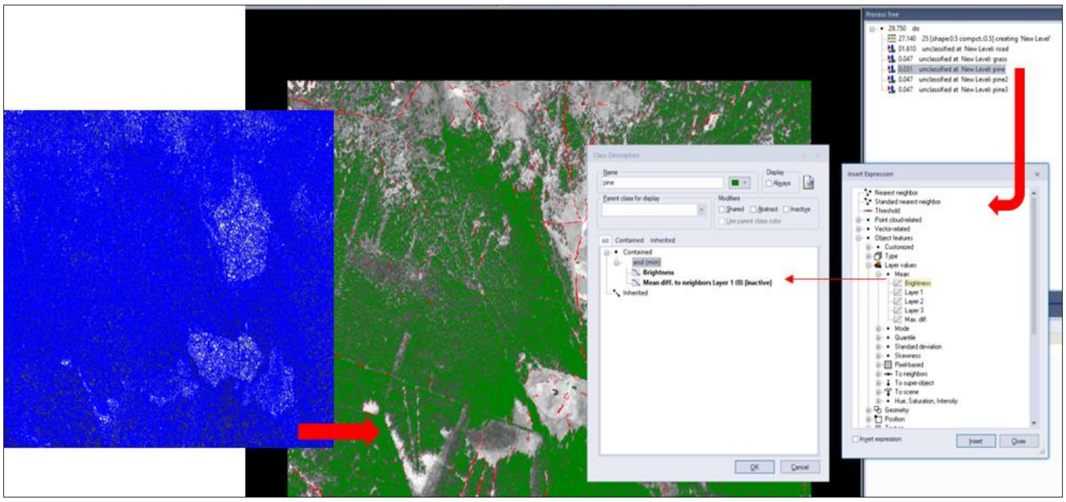


Figure 46: First *segmentation process* and the class description window. Screenshots made by Marina in September 2020.

At the *process tree,* which uses an eCognition language to create ruleware, it is possible to click on a specific class to open an option to *insert expression.* It is very important to set the rule according to the image type and check the performance, because even though the rules created above the master file can recognize most of the objects, sometimes it is necessary to adjust the rules and/or add news *expressions*. A variety of parameters is available in eCognition. It is possible to adjust values in the *class hierarchy* > *image object* information window, especially in the case of an image taken in a different period of the day as sunlight can create shadows and other barriers that make interpretation difficult.

To illustrate, let's continue with the example of these screenshots, where I noticed a couple of trees that were not recognized (**Figure 47**). It can be noticed that I have three classes called "pine" (*pine, pine2, pine3*), but just the first one (*pine - dark green*) was executed correctly. When I click on the object at the *Image Object Information* window, it can see the feature values of those classes. Said that it is possible to set up that information in the *expression window* which englobes the values of these objects that need to be classified. When this is done, the new objects will be recognized and classified as requested (*pine2 - light green*), **Figure 47**.

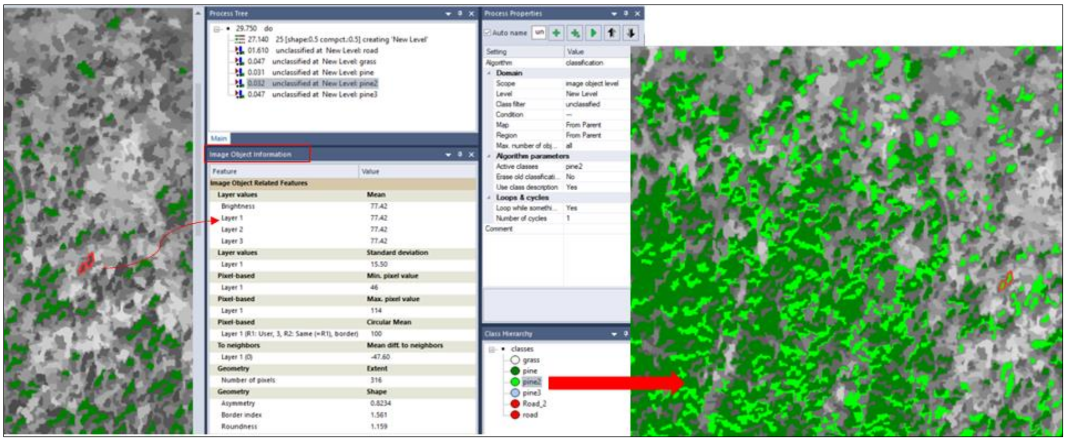


Figure 47: Analyzing the image object information of specific objects that was not classified yet. Screenshot made by Marina in September 2020.

The most important expression used for both aerial image types (historical and current orthophoto) was the brightness as mentioned in the scheme (**Figure 44**), however, it is possible to play with all the options as visible in (**Figure 46**). Besides that, it is also important to analyze the *membership functions* for classification, which allows you to define the relationship between feature values and the degree of membership to a class (Trimble, 2017).

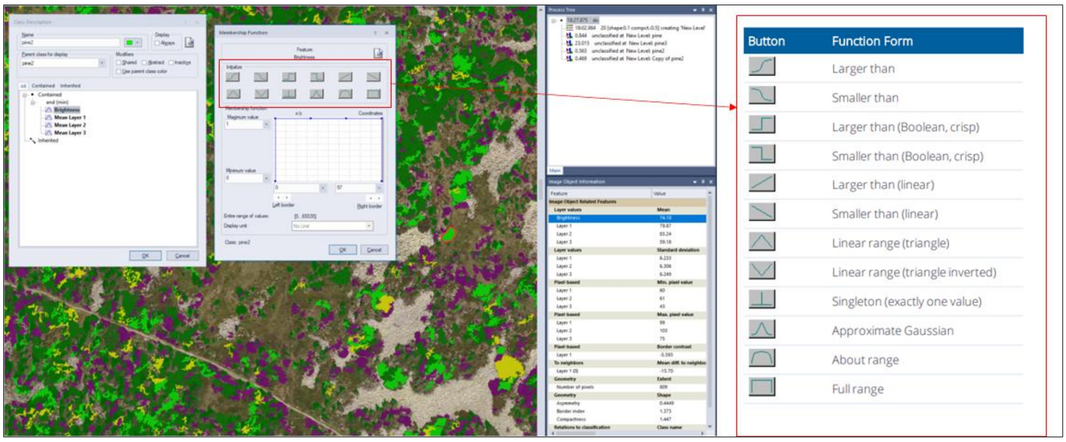


Figure 48: Infrared RGB orthophoto with *membership function* of *brightness* for each layer Screenshots made by Marina in September 2020; Trimble, 2017.

This function is important in both kinds of an image but requires more attention to the coloured imagery since it shows different features values for each image layer (**Figure 48**). The final step in eCognition is to analyze the results and there is also a possibility to manually edit the results. Since the software was only available at the Institute of Botany in Průhonice and due to the difficult pandemic situation I only used this opportunity in some cases, and prefer to export results as a shapefile to ArcMap and made most of the editing manually in my computer.

The manual editing, I was using in eCognition was shown in **Figure 49.** These were: **(a)** single selection mode - selecting an object with a single click, **(b)** polygon selection, which selects all objects that are located within the border of a polygon, **(c)** line selection done along a line, and **(d)** rectangle selection, selects all the objects within a rectangle. After the selection of the polygons, it is possible to (1) change one class to another; (2) merge selected objects, or (**Figure 49 e**); (3) cut the selected object in more parts (**Figure 49 f**). Selection can be done on the whole classification or solely on some of the classes.

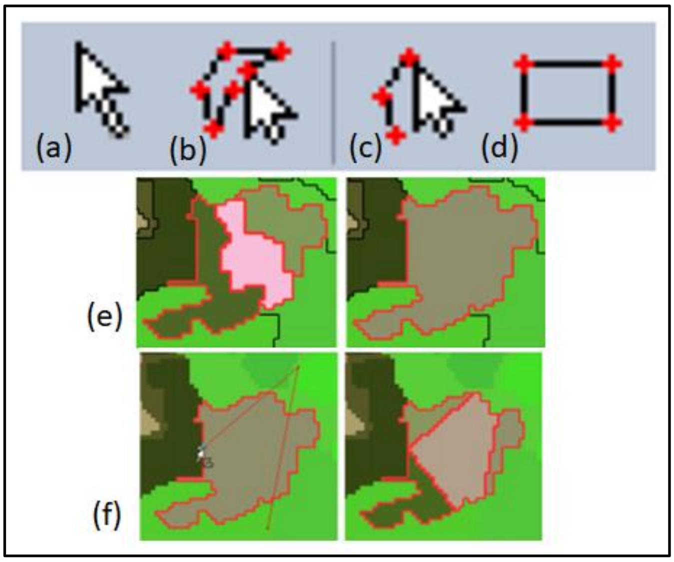


Figure 49: Manual editing tool. (Trimble, 2017)

The last step of the analyses was to export the results. eCognition enables exporting results as shapefiles, such as polygons, lines, or points. Also, only selected classes can be exported as shapefiles together with selected attributes and classifications. As with the *Export Raster File* option, image objects can be exported in common raster formats such as GeoTIFF. Any georeferencing information as provided when creating a map is exported as well (Trimble, 2017).

3.3.2. ArcGIS

ArcMap is a software I am more familiar with from my previous studies. The manual editing flows better with it and it is more independent. However, it is a laborious task consisting mostly of manual editing of objects that were misinterpreted by the eCognition. Therefore, it demands a lot of attention to the details. The process is summarized in the scheme below (**Figure 50**).

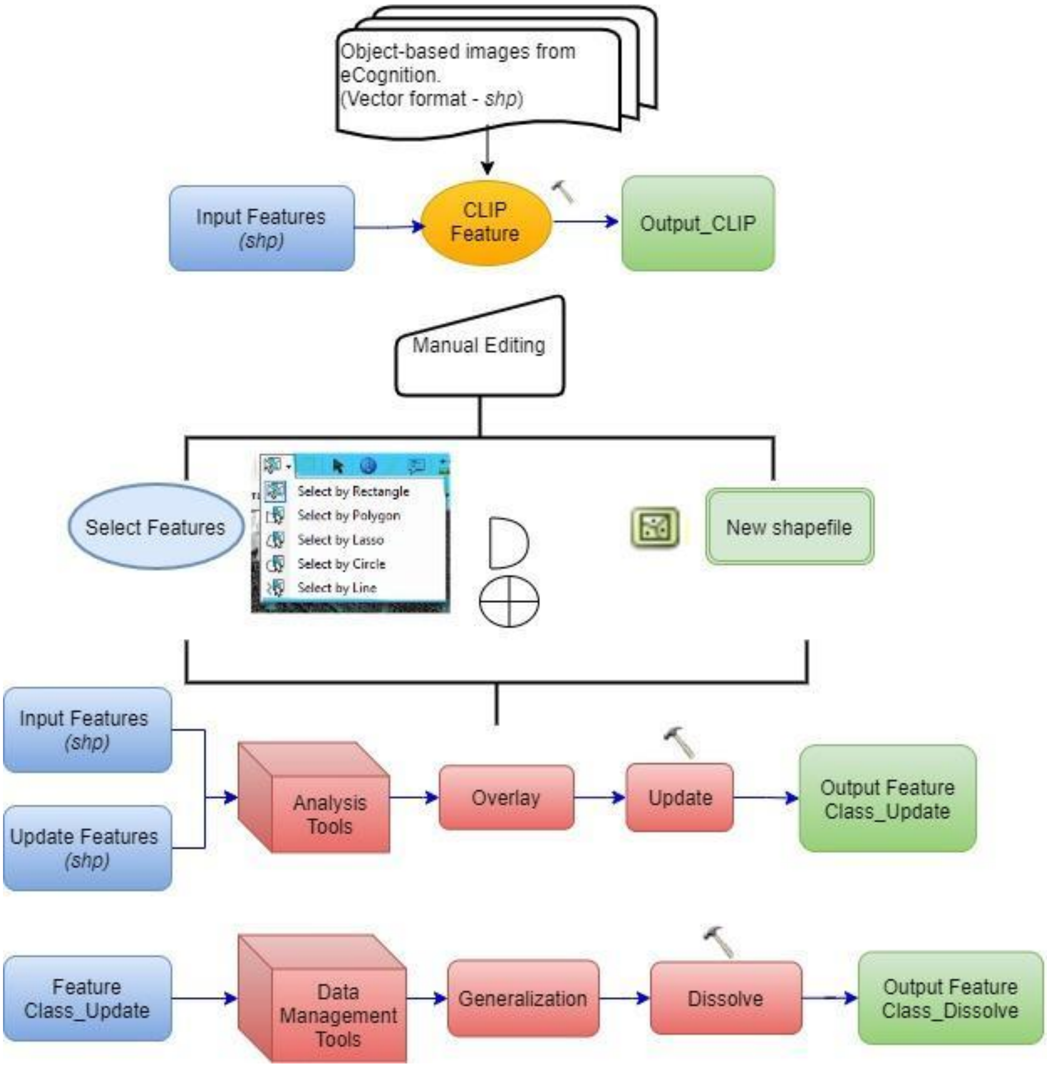


Figure 50: Scheme of the tools that were used in the image processing in ArcMap. Organized by Marina de Souza Faria

Firstly, the exported document was *clipped* within the border of the study sites. For the manual editing, I had two options: either correct the attributes of exported polygons using the *selected feature* which is very similar to the selected option of the eCognition (**Figure 49**) but not as easily enables to choose a particular class for the selection, and/or to make new polygons/features by creating a *new shapefile*. To speed up the process, I needed to use the *new shapefile* sometimes, e.g. some parts of the roads that were in the shadows of spruces.

After making the manual edits, the new shapefile needs to be joined in the same classification. To do that I used the tool *update* (**Figure 51**) which computes a geometric intersection of the *Input Feature* and *Update Feature*.

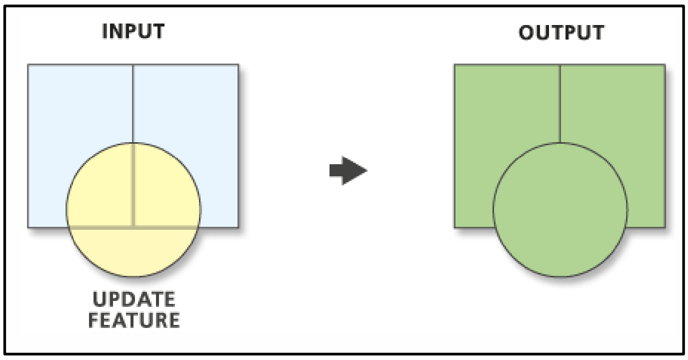


Figure 51: Illustration of the *Update* tool.
Online:https://desktop.arcgis.com/en/arcmap/10.3/tools/analysis-toolbox/update.htm
Accessed on 3.11.2021

The polygons in ArcMap, thus the new polygons created and updated in the image have the same classification but are not connected. This way the image takes a long time to display, therefore, the attribute table carries many repetitive values that could be connected to be easier manipulated afterwards. For that reason, it was chosen the *dissolve* tool **(Figure 52)** to aggregate features based on specific attributes.

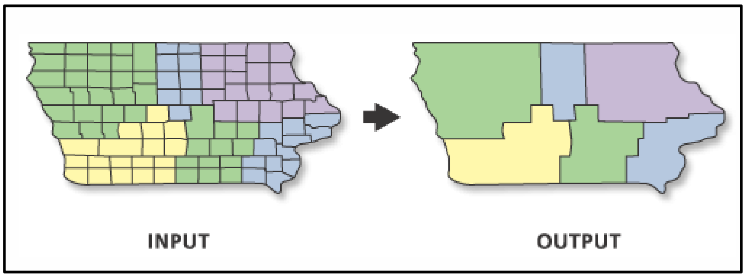


Figure 52: Illustration of the *dissolve* tool.
Online:https://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/dissolve.htm.
Accessed on 3.11.2021

The results and discussion were necessary to overlap the data. For that, I digitized the maps of pine plantations (Lokvenc, 1992) and relict soils (Křížek et al., 2019) using *Georeferencing tools*, created a *new shapefile* and with vectors *designing* the polygons of the features with their information at the *attribute tables*. After that I was able to compare their data with my results by *intersect tool* (*ArcToolbox* > *Analysis Tools* > *Overlay* > *Intersect*), which also improved the assessment of spatio-temporal changes in land cover because just the features that are in the same locality are selected as the illustration (**Figure 53**).

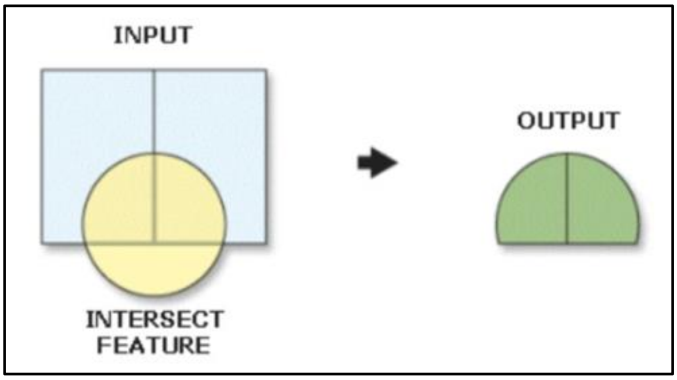


Figure 53: Illustration of the *Intersect* tool.
Online: https://pro.arcgis.com/en/pro-app/latest/tool-reference/analysis/an-overview-of-the-overlay-toolset.htm. Accessed on 3.17.2021.

Analysis of changes in landscape fragmentation and complexity was carried out using the attribute tables of ArcMap shapefiles. Again, it was used *dissolve tool* (**Figure 52**), however this time with the *created multipart features* not enabled (**Figure 54**). It was run to assure an individual polygon for each spatially separated land cover feature. This was followed by an assessment of attribute tables using functions to *calculate geometry* (area, perimeter), and *statistics* to acquire the counting, mean values and standard deviation.

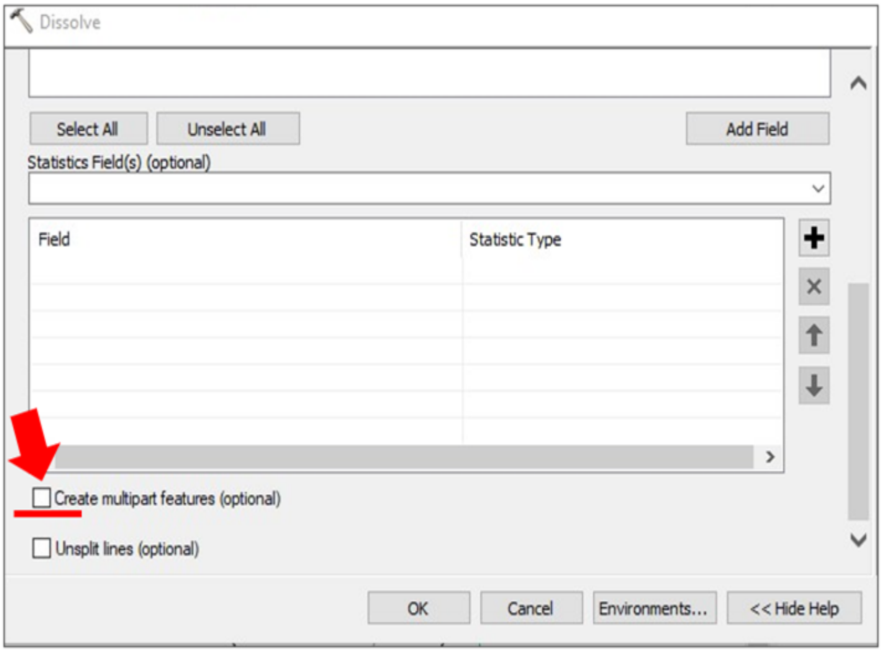


Figure 54: *Dissolve* window highlighting that creates multipart features is not enabled. Screenshot by Marina de Souza Faria on 3.17.2021.

The *statistics* provide to us the values from landscape metrics. At the *attribute table*, it is possible to choose the values for each class and for the overall (**Figure 55**). The first one is to click at *class field > summarize...* and enable all the metrics that are important, in my case: *count, mean, standard deviation and sum*. For the overall data as displayed in **Figure 55** *right-click at the area or perimeter field > statistics.* Exporting those values in text and open in Excel I was able to create the tables to compare the landscape metrics between the study sites: *count* is the number of patches, *mean* is the mean patch area, *the standard deviation* is the patch size heterogeneity and *sum perimeter* is the total edge length. All of them are important parameters to understand landscape distribution.

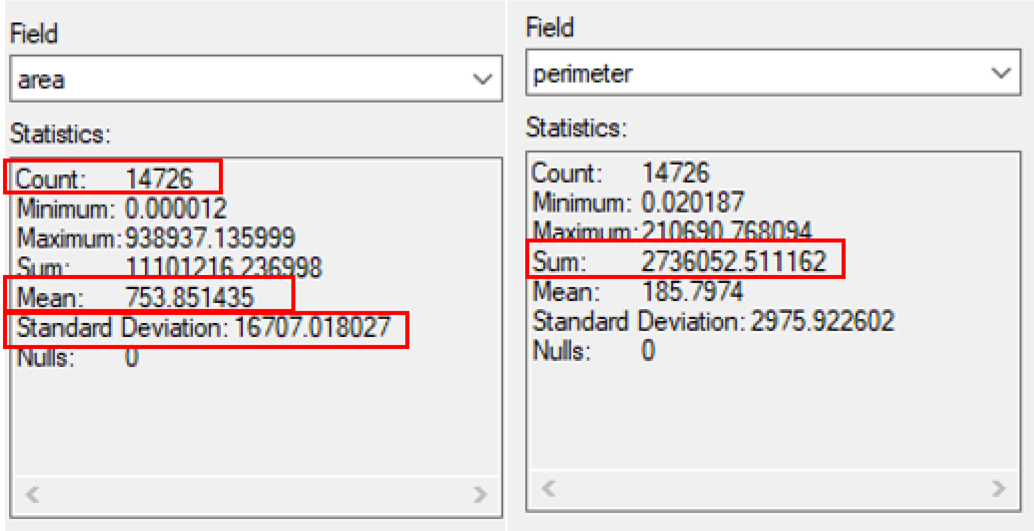


Figure 55: *Statistics* highlighting used values. Screenshot by Marina de Souza Faria on 3.17.2021

4. RESULTS

4.1. ALPINE BELT - WESTERN ARCTIC-ALPINE TUNDRA

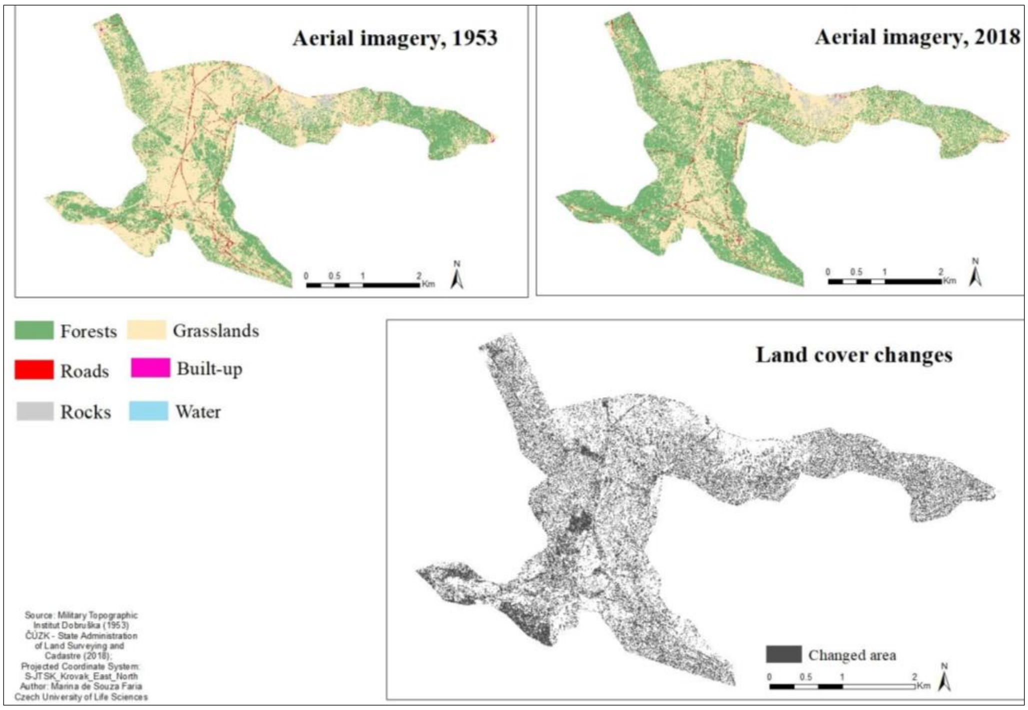


Figure 56: Map of land cover in 1953 and 2018, thus the result of spatial-temporal land cover changes during this range of time in western arctic-alpine tundra. Original Map in A3 format Appendix A1.

The arctic-alpine tundra is located in the western and eastern part of the Krkonoše Mountains. As mentioned before, the thesis focuses on the western arctic-alpine tundra. Nevertheless, in the discussion, I will compare the similarities between both parts. On the map (**Figure 56**), the increase of forested area and consequently the decrease of grasslands is noticeable.

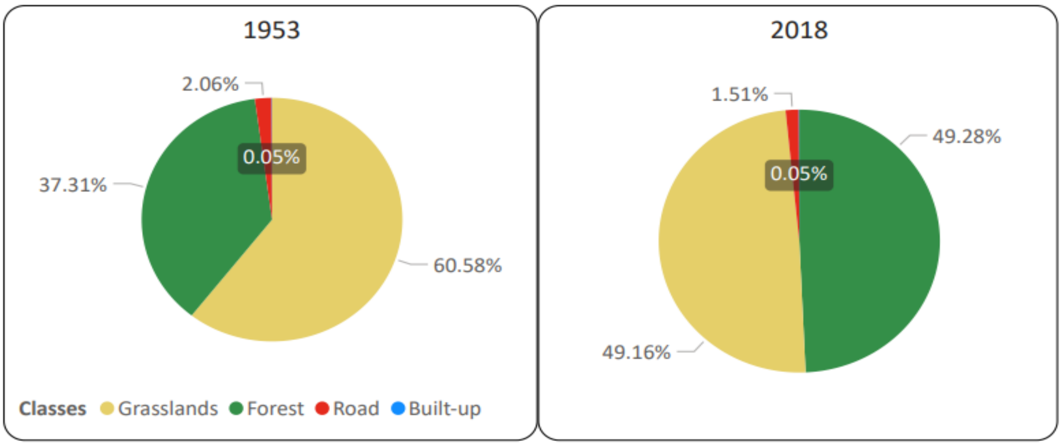


Figure 57: Graphics of percentage of the total area in 1953 (historical data) and 2018 (current data).

In the graphic (**Figure 57**), complementary to the map (**Figure 56),** it is possible to visualize the strong increase in forest class; in the past 37% of the area was forested and currently, it is 49%. In 1953, the grasslands were covering 60.5%, and in 2018, 46.1%. Also noticeable is a decrease in roads, from 2.06% to 1.51%. The other classes such as built-up, rocks and water were the same throughout the years (1953-2018): the built-up (0.05%) is made-up mostly of main chalets and the bunkers (**Figure 58**); the rocks are covering 0.03% of the area, and the water 0.03% (mainly streams and peat lakes).

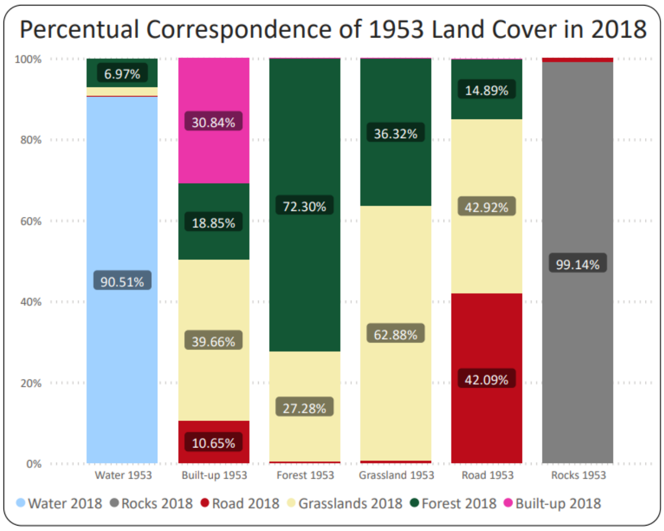
Figure 58: Plot within the tundra (south area) with road, bunker and increase of the density of the forest (pines and spruces). (Military Topographic Institute, Dobruška, 1953; CZUK, 2018)

Table 3: Matrix of landscapes changes from historical (1953) and current data (2018).

HISTORICAL DATA	Built-up 2018	Grasslands 2018	Forest 2018	Road 2018	Rocks 2018	Water 2018
Built-up 1953	**30.84%**	39.66%	18.85%	10.65%	0.00%	0.00%
Grassland 1953	0.05%	**62.87%**	36.32%	0.76%	0.00%	0.00%
Forest 1953	0.01%	27.28%	**72.30%**	0.40%	0.00%	0.00%
Road 1953	0.10%	42.92%	14.89%	**42.09%**	0.00%	0.00%
Rocks 1953	0.00%	0.00%	0.00%	0.86%	**99.14%**	0.00%
Water 1953	0.00%	2.14%	6.97%	0.38%	0.00%	**90.51%**

CURRENT DATA	Built-up 1953	Grassland 1953	Forest 1953	Road 1953	Rocks 1953	Water 1953
Built-up 2018	**29.75%**	56.62%	9.56%	4.07%	0.00%	0.00%
Grasslands 2018	0.05%	**76.62%**	20.43%	2.90%	0.00%	0.00%
Forest 2018	0.02%	44.58%	**54.59%**	0.81%	0.00%	0.00%
Road 2018	0.36%	24.15%	7.37%	**67.16%**	0.95%	0.00%
Rocks 2018	0.00%	0.00%	0.00%	0.00%	**100.00%**	0.00%
Water 2018	0.00%	0.00%	0.00%	0.00%	0.00%	**100.00%**

The details between the changes of the classes can be seen in **Table 3 upper part,** which displays the percentage of change from the old class (1953) to the new class (2018), the diagonal axis in bold is the percentage of stable areas that did not change. The most stable classes were rocks and water (99 and 91%, respectively), forests (72%), and grasslands (63%). Now, I will describe the historical data of the areas that have changed. The former built-up area was 40% converted into grasslands, 19% to the forest and 10% to roads. The 1953 grasslands were mostly changed to the forest (36%), while the forests from the past were 27% changed to grasslands. The roads became grasslands (43%), forest (15%), and built-up areas (0.1 %). The rocks remained the same as mentioned and the water showed a low change to grasslands (2%), forest (6%) and roads (0.4%).



Land Cover Areas in Sq m

Classes	1953	2018
Forest	4,071,821.70	5379782.16
Grasslands	6,611,666.09	5366364.34
Rocks	183,584.19	182003.68
Road	225,085.07	164547.05
Built-up	5,470.72	5681.84
Water	3,673.55	3324.82

Figure 59: Graphic of percentual correspondence of 1953 Land Cover in 2018. The historical data from the matrix shown graphically.

The graphic (**Figure 59**) illustrates the matrix of historical data **(Table 3)**, with the x-axis representing the data from 1953, and the y axis the current data (2018). It is easier to understand since it displays the total historic area of a specific class divided into the new classes that now belongs. The water from 1953, for example, stayed 90.5% as water in 2018. The next one, built-up turned into different classes, but 30.8% did not change. The forest remained as a forest at 72.3% and the stable area for grasslands was 63%. The permanent roads stayed the same at 42.09%, and the rocks almost 100%, but a small percentage of 0.9% developed to roads.

From the six classes the forest (green colour) appeared in five, which means that most of the classes have a certain area that developed into the forest, also notice the map **(Figure 56)** and analyze those historical statistics. Consequently, looking at the matrix of changes in the current data (**Table 3 low part**), the current grasslands are mostly stable (formed of former grasslands - 77%), or used to be forests (20%), while current forests are from 45% developed from former grasslands. It means these two classes show high dynamics in time. Furthermore, 9.5% of the current built-up areas used to be forest, as well as the current roads which used to be forest in the past (7.3%).

However, the forest class showed a total increase of 30% as is illustrated in **Figure 60** below.

Figure 60: Plot within the central area of the western arctic-alpine tundra, which illustrates some stable area of the road, and a huge difference of planted forest of dwarf pine with few spruces. (Military Topographic Institute, Dobruška, 1953; CZUK, 2018)

Figure 60 shows an example which contributes to significant changes in the class of forest and grasslands. The change matrix of current data (**Table 3**) shows that 44.5% of current forest used to be grasslands in the past, and the current built-up area also occupied a huge area of former grasslands, 56.6%. The current roads used to be grasslands in the past (24.1%). All of these changes contributed to the total decrease in the class.

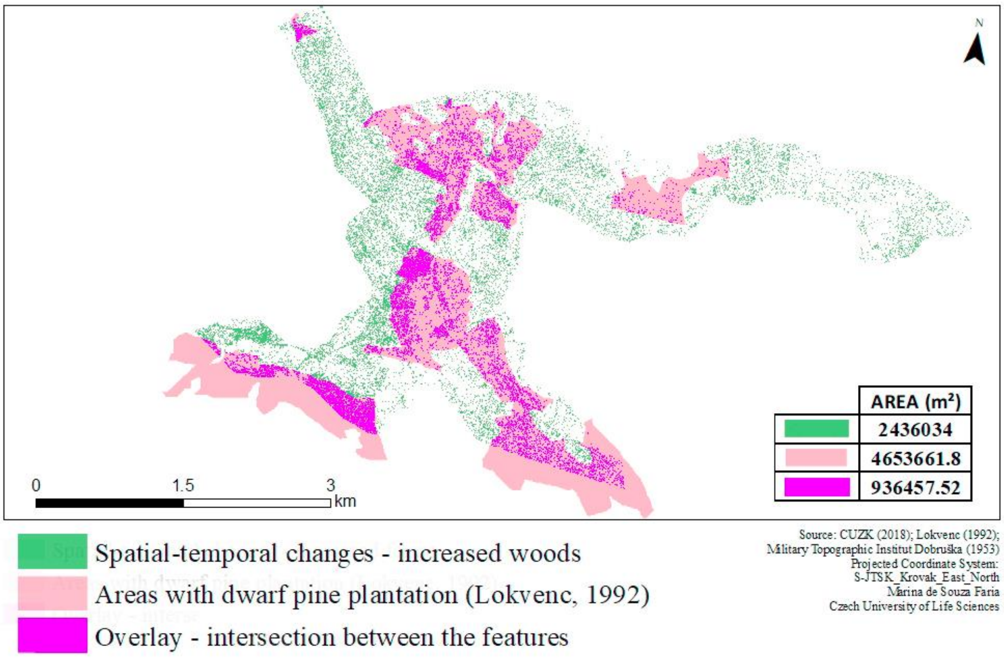


Figure 61: An overlay between the pine plantations (Lokvenc, 1992) and detected land cover changes from 1953 to 2018, specifically the increase in woods at the western tundra Plateau.

Overall, the tundra experienced a large woody encroachment (called forest in the general statistics). This is partly due to the artificial planting of *Pinus mugo*. To analyze the direct human influence on shrub encroachment of grassy tundra I overlaid the detected increase in wood cover (**Figure 56**) with the map of Lokvenc (1992) showing the historical extent of pine plantations, described in the study area chapter (**Figure 30**). The analysis can be seen on the map (**Figure 61**) where 936 457.52 m² or 9 364 hectares (38.4%) of the total increase of pine happened on the areas that were identified by Lokvenc as dwarf pine plantations. Besides, 5 537 041.78 m² or 55370 hectares of the increase happened at areas classified as *"native/original Krkonoše shrubs"* (**Figure 30**), and 2 668 926.14 m² or 26 689 hectares of increase belong to areas that were not mapped by Lokvenc as covered by conifers.

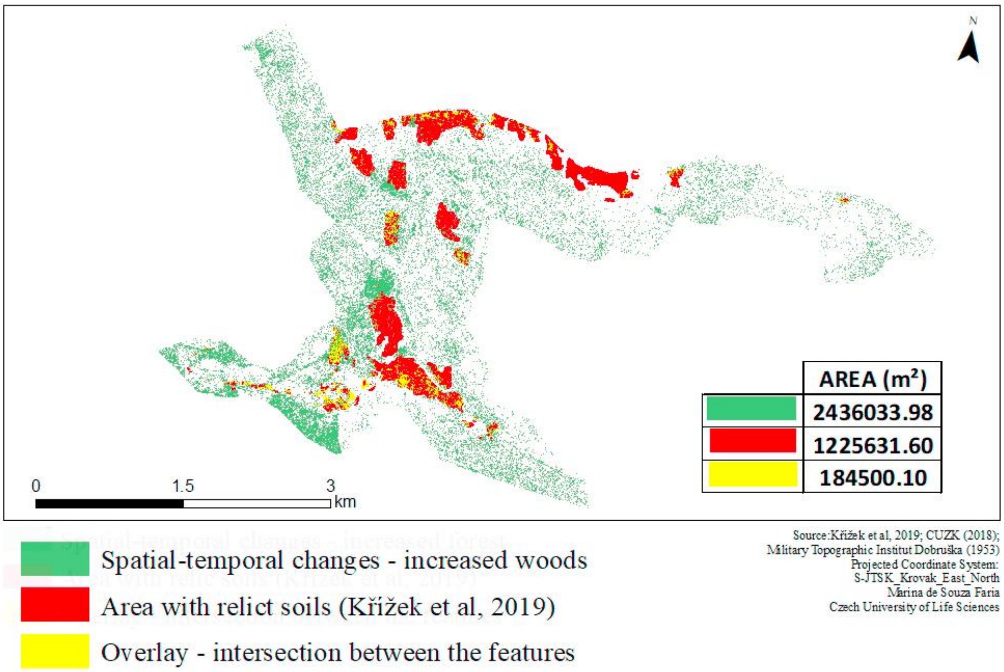


Figure 62: An overlay between the relict soils (Křížek et al., 2019) and detected land cover changes from 1953 to 2018, specifically the increase in woods at the western tundra Plateau

To further determine the origin of the shrub encroachment (natural or planted) and enable me to draw conclusions for the nature conservation of fragile tundra, I overlaid the spatio-temporal changes in tundra also with the map of relict soils prepared by Křížek et al. (2019) available in **Figure 29** at study area chapter, for more details. This is relevant because relict periglacial soils could not possibly develop under the shrub/tree cover. Therefore, in the tundra, areas where such extremely valuable soils are present must have been free of woods in the past. The analysis (**Figure 62**) shows that 15% of the pines have overgrown in the relict soils in the last sixty years. However, already in 1953, (**Figure 60**) the central area of the tundra was overgrowing spontaneous shrubs by the dwarf pine, contributing largely to the disturbance of such unique geomorphological features of Krkonoše tundra.

For scientific purposes, shrubs and woods in the tundra are called *forest* in the general data; map (**Figure 56**) and matrix (**Table 3**). The reason for that is to enable comparison between the tundra and subsets (subchapter 4.3). The data must have the same terminology (name of the classes) in all the study sites. However, it is clear that the tundra ecosystem does not support the development of forest and the recommended nomenclature should be wood or shrubs. Therefore, the word *forest* in the tundra area is purely informative and allows a better comparison of the Thesis result.

4.2. MONTANE BELT

The three subsets are showing the most common trajectories of changes in the Krkonoše landscape. These are changes from traditional agricultural villages towards tourism (Subset 1), abandonment of grasslands (Subset 2), and the impact of skiing on the landscape (Subset 3).

4.2.1. Subset 1: Horní Malá Úpa

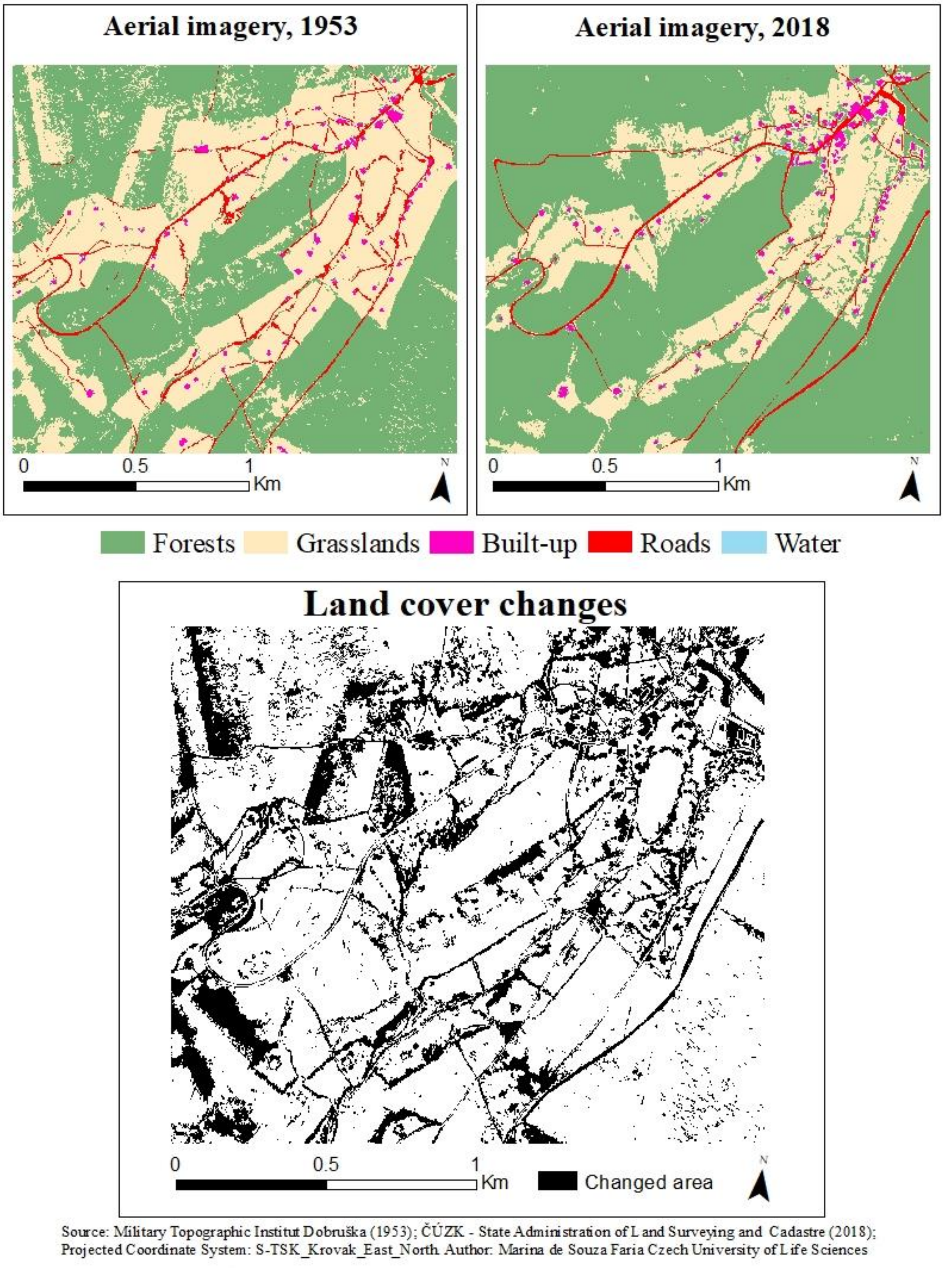


Figure 63: Map shows the land cover in 1953 and 2018, together with the result of spatial-temporal analysis of cover changes in the last sixty years in Horní Malá Úpa.

This subset is located on the border with Poland. It covers a village where locals could grow crops and livestock for themselves and did grazing and mowing in the past. Both the map and the graphs (**Figure 63** and **Figure 64**) complement each other and show us that the grassland class is markedly decreasing. In percentage respectively from 41.9% in 1953 to 26.2% in 2018. Also, the roads become slightly smaller from 3.5% to 2.8%. In contrast, the forest increased from 53.6% in 1953 to 69.4% nowadays. The built-up structures slightly increased from 1% to 1.5% and the water that was an absent class in the past, appears just in a small portion of 0.02%.

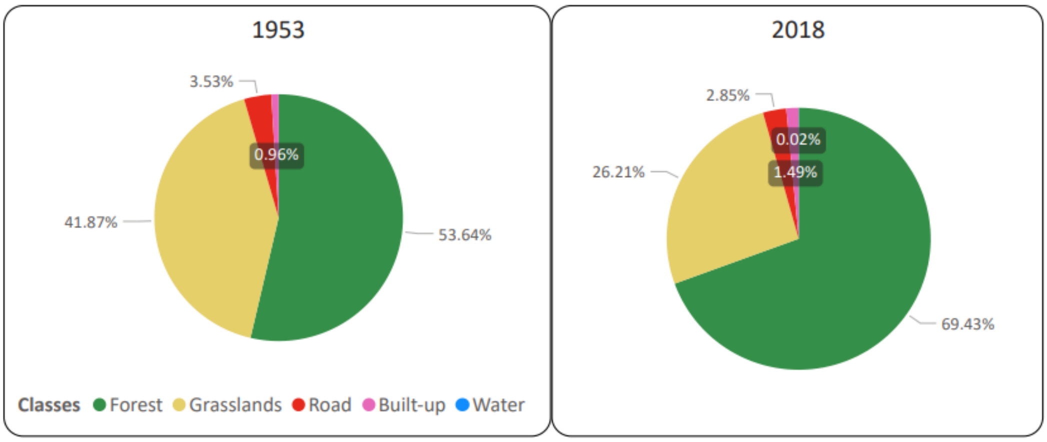


Figure 64: Graphic in the percentage of the total area in 1953 and 2018 (historical and current data)

The water class did not appear in the past as seen in the aerial imagery (**Figure 65**) and cover a very small percentage nowadays since there is only one water body recognized in the Subset. Thus, the picture represents very well the landscape changes in this study site as few buildings still existed in the past. The built-up area increased by 1.6 times.

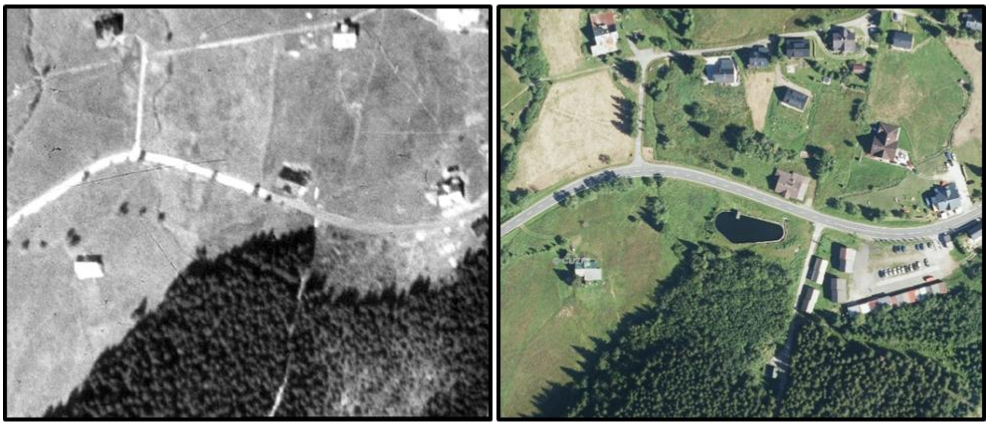


Figure 65: The plot within Subset 1 shows the most common trend in the distribution of features in Horní Malá Úpa. New houses, an increase in scattered trees in the gardens, a small water body and tourist facilities such as a parking lot (Military Topographic Institute, Dobruška, 1953; CZUK, 2018)

Table 4: Matrix of landscapes changes according to historical (1953, upper part) and current data (2018, lower part).

HISTORICAL DATA	Built-up 2018	Grasslands 2018	Forest 2018	Road 2018	Water 2018
Built-up 1953	**51.40%**	25.71%	19.35%	3.53%	0.00%
Grassland 1953	1.85%	**56.57%**	39.47%	2.06%	0.04%
Forest 1953	0.29%	1.93%	**96.40%**	1.37%	0.00%
Road 1953	2.00%	35.11%	28.45%	**34.44%**	0.00%
Water 1953	0.00%	0.00%	0.00%	0.00%	**0.00%**
CURRENT DATA	Built-up 1953	Grassland 1953	Forest 1953	Road 1953	Water 1953
Built-up 2018	**32.99%**	51.97%	10.28%	4.75%	0.00%
Grasslands 2018	0.94%	**90.38%**	3.95%	4.73%	0.00%
Forest 2018	0.27%	23.80%	**74.48%**	1.45%	0.00%
Road 2018	1.18%	30.26%	25.85%	**42.70%**	0.00%
Water 2018	0.00%	88.37%	11.63%	0.00%	**0.00%**

In detail, the matrix (**Table 4, upper part**) shows the percentage of changed areas from old to a new class. The numbers in bold on the diagonal axis represent the stable area that did not change. However, I want to highlight the changes, firstly: 51% of the former built-up area stayed unchanged, 28% developed into grasslands, around 19% changed to the forest, and 3% to roads. The former grasslands either stayed as grasslands (57%) or converted to forest (40%), built-up (2%), 2% in roads and 0.04% to water (**Figure 63**). The forests were mostly stable (96%), and very small parts were transformed into built-up areas (0.3%), grasslands (2%) and roads (1.3%). 34% of past roads stayed unchanged, 35% changed into grasslands, 28% into forests, and 2% to built-up.

The current data (**Table 2, lower part**) from the water were classified as grasslands (88%) and forest (11%). This class did not appear in the historical data; the value is zero (0%). Therefore, for statistical analysis, this data was not used to be shown in the graph (**Figure 66).** However, it is shown in the matrix of the land cover areas next to the graph.

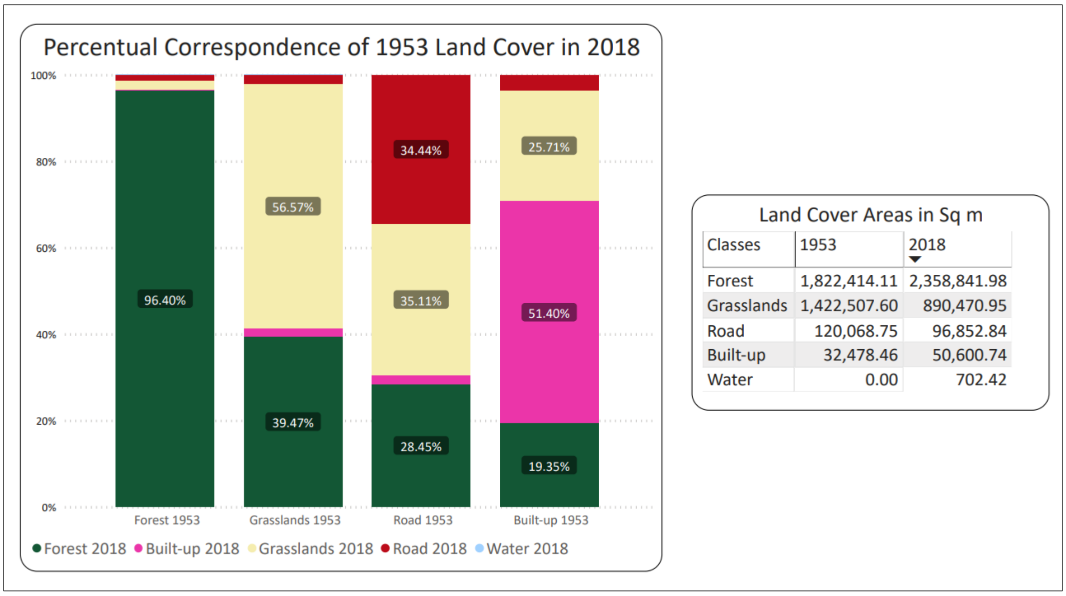


Figure 66: Graphic of percentual correspondence of 1953 Land Cover in 2018. The historical data from the matrix shown graphically.

Figure 66 displays the historical data from the matrix of **Table 4** being easier to visualize the stable areas. The "x" axis represents the historical data from 1953 and the "y" axis corresponds to the current data from 2018. The stable areas of each class range from 34% to 96%, representing no changes in the land cover. The forest is the class with the highest percentage of stability, 96% (**Figure 66**). The grasslands stability is 56%, however, this class also contributes the most to the changes, mostly growing into the former forest (39%). The roads have 34% of non-changed areas. Moreover, 51% of buildings are still present till now in Subset 1, but most of them changed the function from housing/farms to touristic facilities.

In the graphic (**Figure 66**) the forest cover (green colour) appears in all classes and increased 1.3 times. The area has grown significantly. The history of current forests, available in **Table 4**, shows that 24% of the recent forest used to be grasslands in 1953, and from the current roads, 26% of them were forest in the past. It is important to notice that the built-up area has the highest rate of increase (1.6 times), but in absolute numbers (**Figure 66**), the forest shows the biggest increase of approximately 540 m².

4.2.2. Subset 2: Růžohorky, Pec Pod Sněžkou

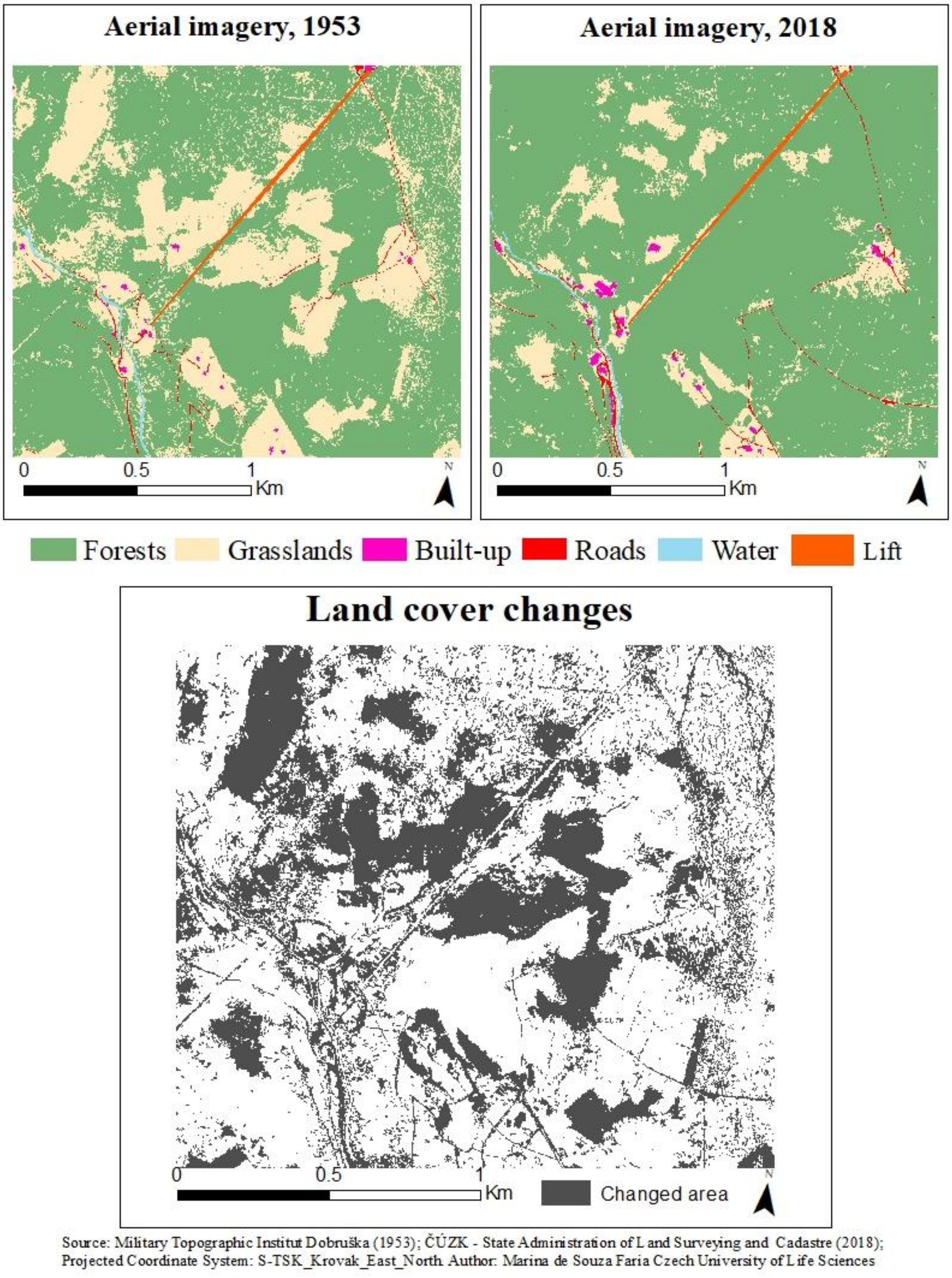


Figure 67: Map of land cover in 1953 and 2018, thus the result of spatial-temporal land cover changes during this time frame in Růžohorky, Pec Pod Sněžkou

This Subset represents the process of abandonment of traditional grassland and meadow farming. This is a central area of the Krkonoše Mts. The word “central” implies two different meanings. Firstly, there are connections to important facilities and touristic points of the area, e.g. the chairlift to the top of Sněžka Mt., one of the parking lots with the highest capacity, access to a variety of restaurants and shops. Furthermore, it is also a bio center that supports the interconnection between the bio corridors in the National Park.

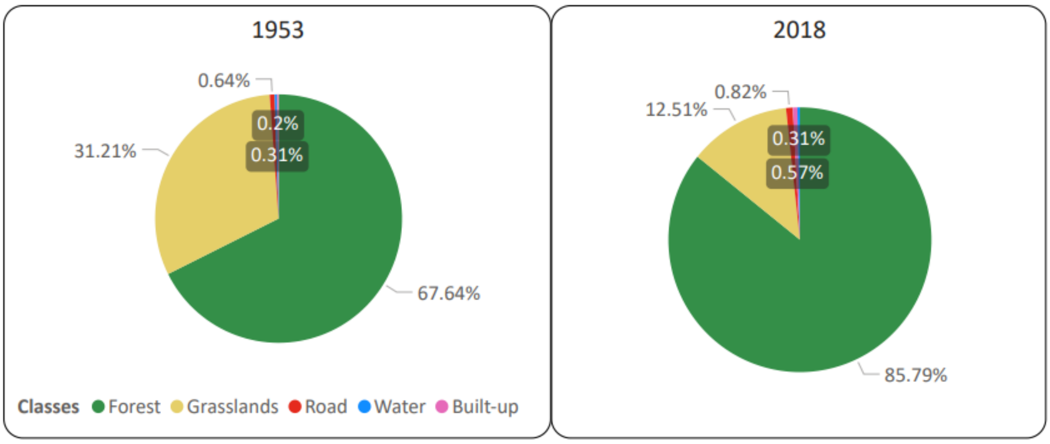


Figure 68: Graphic in the percentage of the total area in 1953 and 2018 (historical and current data).

As analyzed by the map (**Figure 67**) and in the correlation with the graphic (**Figure 68**), the forest increased from 68% to 86% (**Figure 69**). Moreover, the built-up area increased as well from 0.2% in 1953 to 0.6% in 2018, together with roads that increased too, from 0.6% to 0.8%. The decrease in the area happened in grasslands class, from 31% to 12% and the water remained very similar, without significant change.

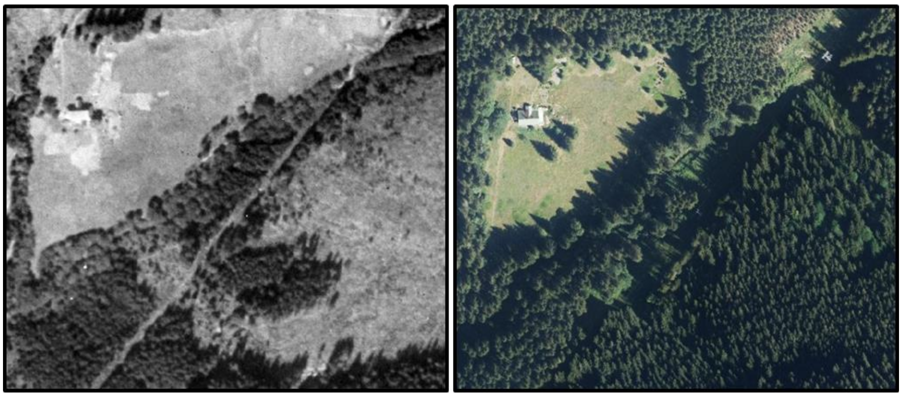


Figure 69: Plot within Subset 2 shows the development of a forest over meadows in the area around the chairlift to Sněžka (Military Topographic Institute, Dobruška, 1953; CZUK, 2018).

Table 5: Matrix of landscapes changes according to historical data (1953, upper part) and current data (2018, lower part).

HISTORICAL DATA	Built-up 2018	Grasslands 2018	Forest 2018	Road 2018	Water 2018
Built-up 1953	**68.93%**	23.19%	6.81%	1.07%	
Grassland 1953	1.10%	**16.96%**	80.61%	1.19%	0.15%
Forest 1953	0.10%	10.38%	**89.04%**	0.40%	0.09%
Road 1953	3.03%	20.47%	48.56%	**27.73%**	0.16%
Water 1953	0.00%	7.37%	27.90%	0.24%	**64.49%**

CURRENT DATA	Built-up 1953	Grassland 1953	Forest 1953	Road 1953	Water 1953
Built-up 2018	**24.31%**	60.59%	11.63%	3.44%	0.00%
Grasslands 2018	0.37%	**42.31%**	56.09%	1.05%	0.18%
Forest 2018	0.02%	29.32%	**70.20%**	0.36%	0.10%
Road 2018	0.26%	45.16%	32.71%	**21.77%**	0.09%
Water 2018	0.00%	14.80%	20.04%	0.33%	**64.83%**

More information about the changes is available in **Table 5**, which describes the changes from the point of view of historical (1953, upper part) and current data (2018, lower part). The diagonal values mean no changes in class occurred and it will be described later. First, I will describe the changes in each class in historical data. The most stable was the forest class, up to 90% of the former forest did not show any change. This is in contrast with the grasslands which were, to the largest extent, overgrown by forest (81%). The built-up area turned into grasslands from 23% to forest from 7% and roads from 1%. The forest changed from 10% to grasslands, from 0.1% to built-up and from 0.4% to roads. Finally, the former roads became grasslands from 7%, forest from 28% and water from 0.2%.

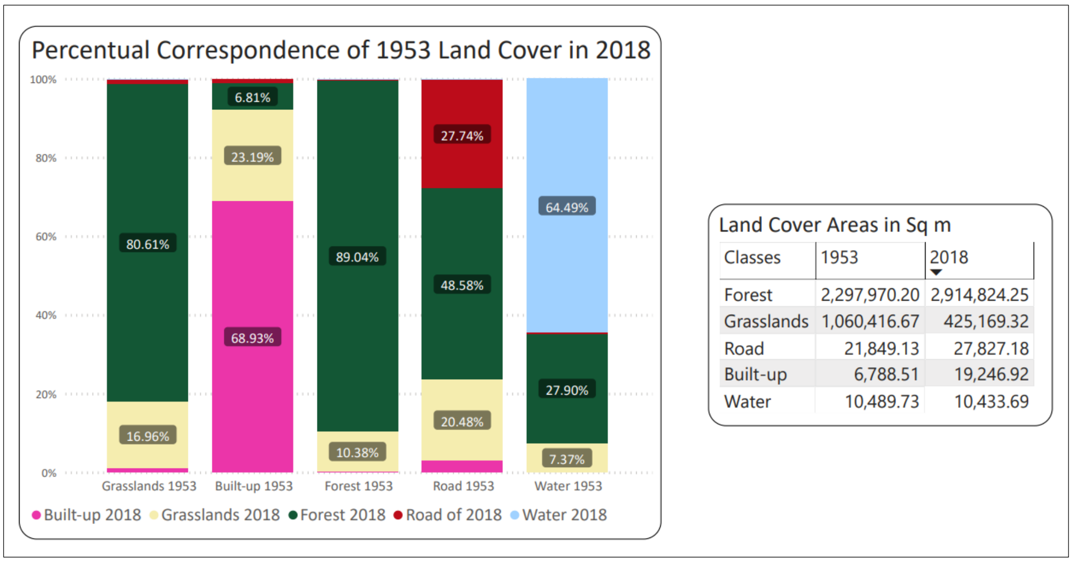


Figure 70: Graphic of percentual correspondence of 1953 Land Cover in 2018. The historical data from the matrix shown graphically.

The graphic which displays the percentage of historical data (**Figure 70**) makes it easier to notice the classes that did not show changes, for example only 17% of the grasslands from 1953 are still the same today. In the built-up area, this number is significantly higher at 67%. The most stable area is the forest which did not experience any changes at 89% did not experience changes. The stable area for roads is 27% and for water 64%.

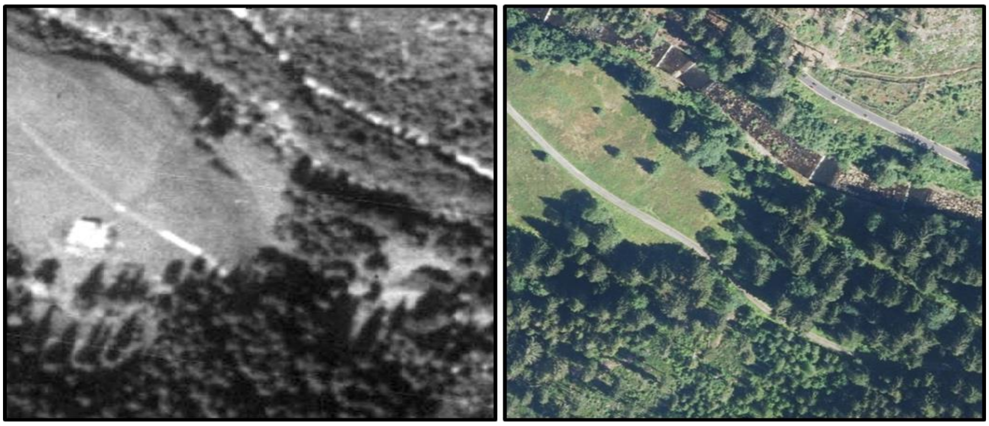


Figure 71: Plot within Subset 2 and the development of forest and meadows growth in the area around the lift to Sněžka (Military Topographic Institute, Dobruška, 1953; CZUK, 2018).

The changes in the data for water class can be puzzled out from detailed matrix tables (**Table 5**) which show that from the current regulated water body, the Úpa river, 14% was classified as grasslands, and 20% as forest in the past. **Figure 71** shows the changes around the Úpa river. The increased riparian forest trees and canalization as a consequence of the floods in the 19th century, thus the construction of the weir in Pec Pod Sněžkou, consequently modifying the amount of water in the river.

In both aerial images (**Figure 69 and 71**) is notable the increase of buildings, roads, and forests. The graphic (**Figure 70**) presents that all historic classes have a certain amount of green colour, which means that the class changed to a new forest.

Comparing that information with the current data (**Table 5 lower part**), 56% of current grasslands, and 33% of current roads and 12% of the current built-up area used to be a forest. This explains the total increase in the forest of 1.3 times. However, the built-up area increased even more, i.e. 2.8 times (almost by 13.000 m²) to support growing touristic demand in the area. Although it looks like a low percentage change in Figure 68, it is a change of significant impact.

Those impacts most occur in the grasslands. The decrease in this class is easier to understand in comparison with current data. As seen in the graphic (**Figure 70**), 81% of the grasslands have overgrown by forests. Moreover, the current data (**Table 5**) presents that 61% of the built-up area was previously grasslands in 1953 as well as 29% of the current forests, 45% of the roads and even 15% of the water used to be grasslands. Therefore, most of the built-up areas came from former grasslands.

4.2.3. Subset 3: Špindlerův Mlýn

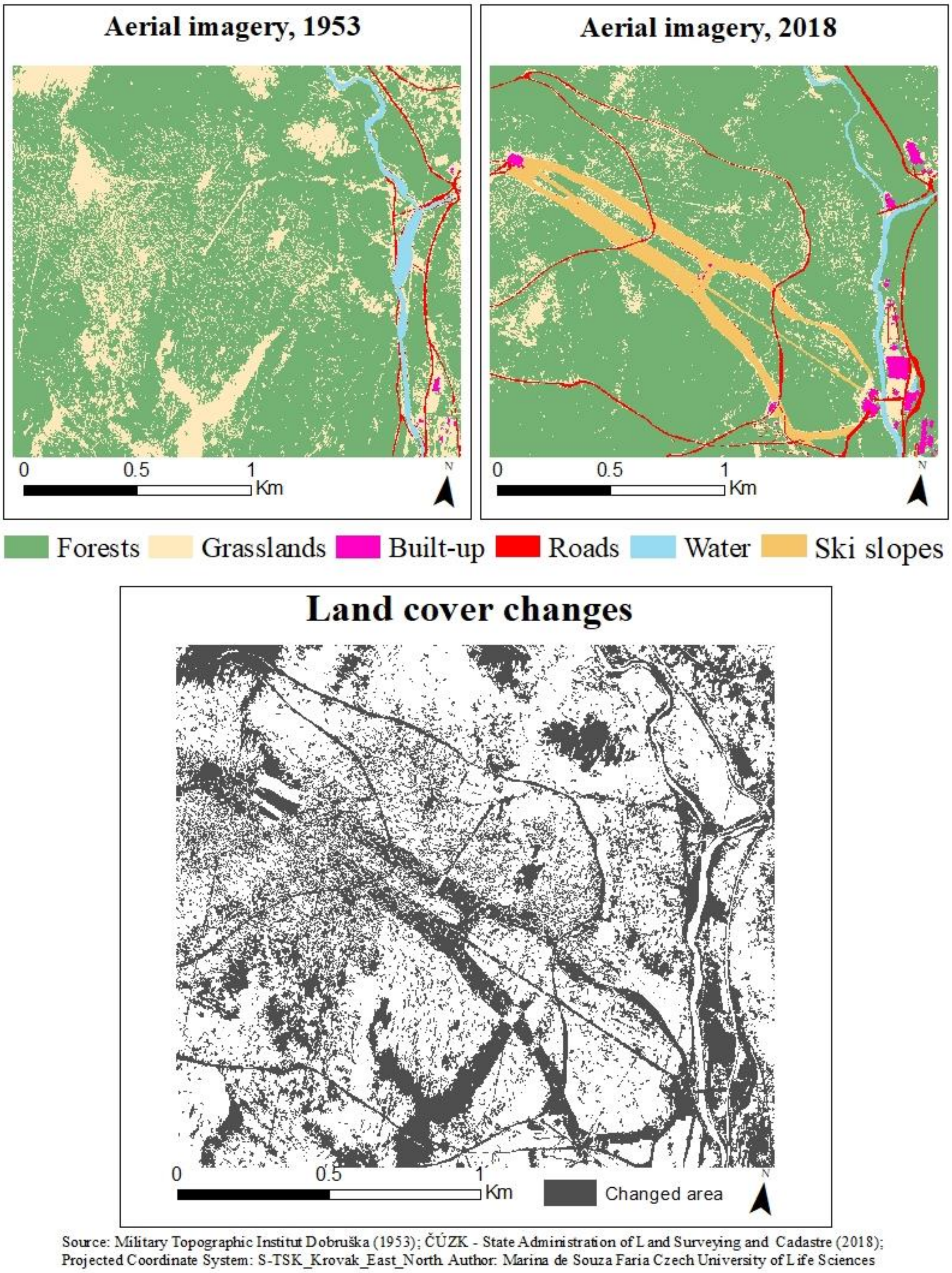


Figure 72: Map of land cover in 1953 and 2018, thus the result of spatial-temporal land cover changes during this range of time in Špindlerův Mlýn

This subset represents a tourist phenomenon, and one of the most popular activities that appeared in KRNAP: skiing and other winter sports activities. The map of land cover changes for Subset 3 (**Figure 72**) presents the most prominent changes compared with the other study sites. It is due to one of the biggest ski slopes which were constructed there. For the purposes of data analysis, the slope was integrated as grassland to avoid misinterpretation of the land cover changes.

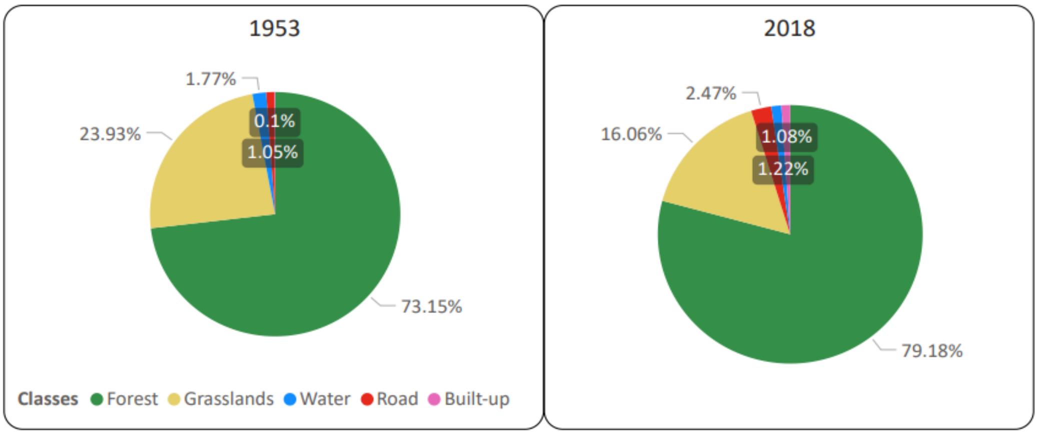


Figure 73: Graphic in the percentage of the total area in 1953 (historical data) and 2018 (current data).

What captures our attention the most on the map are the ski slope and the roads. **Figure 73** shows that grasslands (including the ski slopes) decreased from 24% in 1953 to 16% in 2018. On the other hand, the water increased slightly from 1.7% to 1.2%. The increase can be also seen in the forests from 73% to 79%; in the built-up area from 0.1% to 1%; and finally, the roads increased from 1% in 1953 to 2.5% in 2018.

Table 6: Matrix of landscapes changes according to historical data (1953, upper part) and current data (2018, lower part).

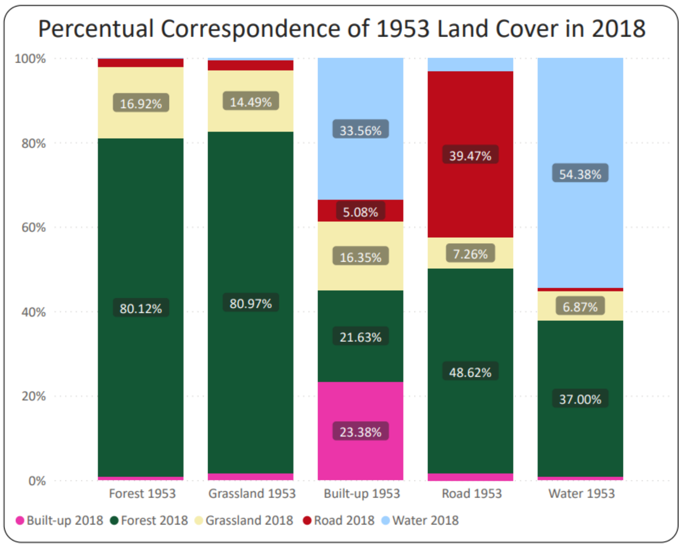
HISTORICAL DATA	Built-up 2018	Grasslands 2018	Forest 2018	Road 2018	Water 2018
Built-up 1953	**23.38%**	16.35%	21.63%	5.08%	33.56%
Grassland 1953	1.66%	**14.49%**	80.97%	2.46%	0.43%
Forest 1953	0.85%	16.92%	**80.12%**	1.98%	0.12%
Road 1953	1.59%	7.26%	48.62%	**39.47%**	3.06%
Water 1953	0.93%	6.87%	37.00%	0.83%	**54.38%**

CURRENT DATA	Built-up 1953	Grassland 1953	Forest 1953	Road 1953	Water 1953
Built-up 2018	**2.06%**	36.95%	57.91%	1.55%	1.53%
Grasslands 2018	0.10%	**21.59%**	77.09%	0.47%	0.76%
Forest 2018	0.03%	24.47%	**74.03%**	0.64%	0.83%
Road 2018	0.20%	23.81%	58.65%	**16.76%**	0.59%
Water 2018	2.62%	8.39%	7.21%	2.63%	**79.14%**

Table 6 shows a detailed matrix of changes in historical and current data. Describing the historical data, the built-up area in 1953, 16% was converted to grasslands, 21% to the forest and 5% to roads. A total of 80% of former grasslands developed into forests, and an extremely low area of former grasslands, only 14%, experienced no change. Thus, the forests were mostly stable (by 80%), or became grasslands (17%) and roads (2%). The roads were transformed from 7% to grasslands, from 49% to forest and from 1.5% to built-up area. The last class is the water which, in the comparison with the past, shifted to the class of built-up (0.9%), 7% to grasslands, 37% to forest and 0.8% to roads.

Figure 74: Plot within Subset 3 and the changes in the Elbe river, building facilities, parking lot and aqua park. (Military Topographic Institute, Dobruška, 1953; CZUK, 2018).

The facility structures for the visitors (**Figure 74**) made noticeable changes in the building's layout, e.g. the aquatic park. **Figure 74** focuses on features that might be more difficult to understand. To illustrate why it is tough, the change from roads to built-up can be difficult to distinguish, e.g. roads to a parking lot. Moreover, the canal of the river became wider, therefore it blends with the surrounding vegetation, making its interpretation also difficult.



Land Cover Areas in Sq m

Classes	1953	2018
Forest	2,485,407.39	2,690,030.63
Grasslands	813,085.69	545,649.25
Road	35,596.64	83,854.12
Water	60,237.28	41,390.94
Built-up	3,230.53	36,632.58
Classes	1,953.00	2,018.00

Figure 75: Graphic of percentual correspondence of 1953 land cover in 2018. The historical data from the matrix (Table 4, upper part) shown graphically

The graphic (**Figure 75)** helps us to identify which new class increased and also shows which class did not change and therefore can be considered as more stable. From the forest area, 80% did not change. However, for the grasslands the stable area is much smaller when only 14.5% of former grasslands are still used as grasslands in 2018, On the other hand, 80% of it became a forest. In the built-up area, there are 23% of buildings or structures that are still there in 2018. The roads remained the same from 39.4% and the water from 54.3%.

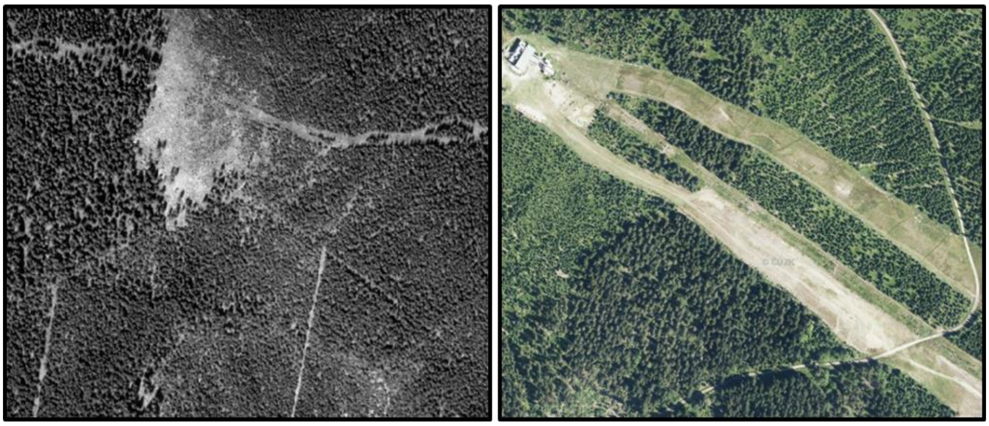


Figure 76: Plot within the Subset 3, the forests and grasslands change into building facilities and roads around the ski slope. (Military Topographic Institute, Dobruška, 1953; CZUK, 2018)

Figure 76 helps us to visualize the most important changes, especially in the grasslands class. The historical aerial imagery (**Figure 76**) is covered with forest vegetation. Few areas are cleared by freshly cut forest or young forest. Both are detected in huge amounts in Subset 3. In the current orthophoto, these areas were replaced with the building, ski slope and roads. The detailed spatio-temporal matrix of the current data in **Table 6, lower part,** complements the analyses because it clarifies that the current grasslands used to be forest from 77%, causing the decrease of the grassland area by 0.7 times. Also, the water decreased by 0.7 times since the river in this area underwent canalization and became narrow for the purposes of amenities as it was necessary to tolerate a higher number of people and building constructions.

The current forest (**Table 6, lower part**) was from 24% formed by grasslands in the past, whereas the current built-up area used to be also grasslands (37%) and forest (58%). It shows us the reason for why the grasslands decreased, i.e. mostly to be included in built-up, forests and roads classes. The built-up area increased significantly by 11.3 times. This is the highest magnification/increased rate compared with all the study sites. Also, the roads enlarged 2.4 times. In the past, roads were occupying 24% of grasslands and 58% of forests. To conclude, the forest increased 1.1 times, most of that is due to the young forest that grew up and was classified as a grassland class on historical imagery.

4.3. COMPARISON AMONG THE SITES

The collected data are embracing. Therefore, they provide us with several possibilities for discovering more information about the land cover changes. To conclude the results and the chapter, and to improve the following discussion, it is important to compare all the study sites. In the graphic (**Figure 77**), the comparison of the class by magnification rate among the sites is shown. It is calculated as the class area of 2018, divided by the class area of 1953. Hence, the graphic nicely illustrates which classes decreased over time, and which ones increased. The value of 1 signifies no change, whereas values below 1 show the decrease, and above 1 indicates the increase, showing us the magnitude of how much a specific class changed.

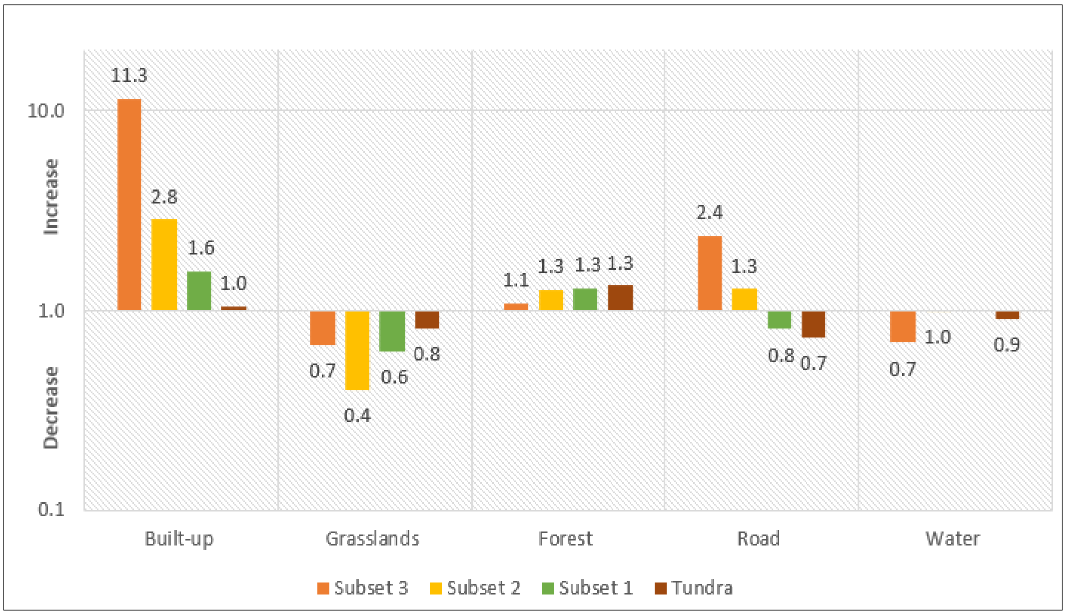


Figure 77: Magnification changes in the land cover in all the study sites.

Overall, as it is shown in the graphic, the tundra was significantly more stable compared to the mountain belt areas. The largest differences among the sites were found in the built-up class. Except for tundra that showed no changes in this class, the built-up area experienced the largest increase at all montane subsets, being the most pronounced in Subset 1, which for the most part, contained a mountain village. Therefore, it is a result that can be expected. Consistently, all the study sites experienced a decrease in grasslands and an increase in the forest area. As for the roads, the Subset 1 and arctic-alpine tundra decreased, in contrast to Subsets 2 and 3 which experienced an increase in the amount of roads inside the areas, mainly because of tourist facilities. The water did not change in Subsets 1 and 2, on the other hand, in Subset 3 and the tundra it slightly decreased.

Talking specifically about each study site, the largest changes happened in Subset 3 (the skiing resort) where the built-up area magnified 11.3 times, and roads 2.4 times. In contrast, the least changes happened in the arctic-alpine tundra, where the largest decrease was detected for grasslands (0.7 times), and the largest increase of 1.3 times was found in the forest (woods and shrubs). For Subsets 1 (the village) and 2 (abandoned farming), the largest decrease was detected in grasslands (0.4 and 0.6 times), whereas the largest increase was recorded for built-up areas (2.8 and 1.6, respectively).

Looking at the landscape metrics values allow us to analyze the interactions between spatial patterns in the past (1953) and the current time (2018). It will substantially help us to compare the sites between themselves and interpret the landscape patterns and ecological processes in the discussion. For this reason, the following tables (**Table 7, 8, 9 and 10**) will describe these parameters: (1) number of patches, (2) mean patch area, (3) patch size heterogeneity, and (4) total edge length for each class in each year (1953 and 2018). On top of that, the magnification rate (values from 2018 divided by values from 1953) shows the increase and the decrease of each class.

Table 7: Landscape metrics for Subset 1, the upper table shows the historical data (1953), the middle table the current data (2018), and the lower table the comparison between the two by the magnification rate (detailed for each class, and overall).

SUBSET 1				
Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 1953	90.00	360.87	357.31	11908.12
Grasslands 1953	1552.00	916.56	26985.45	204592.91
Forest 1953	594.00	3068.04	30859.85	159989.16
Roads 1953	169.00	710.47	2894.82	58971.91

Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 2018	280.00	180.72	338.40	20246.63
Grasslands 2018	789.00	1128.61	8778.74	123397.76
Forest 2018	845.00	2791.53	30974.13	118357.35
Roads 2018	4.00	24213.21	38488.15	30710.95
Water 2018	1.00	702.42	0.00	117.59

MAGNIFICATION RATE	Number of Patches	Mean Patch Area	Patch Size Heterogeneity	Total Edge Length
Built-up	3.1	0.50	0.95	1.70
Grasslands	0.5	1.23	0.33	0.60
Forest	1.4	0.91	1.00	0.74
Roads	0.0	34.08	13.30	0.52
Overall	0.8	1.3	0.8	0.7

Table 8: Landscape metrics for Subset 2, the upper table shows the historical data (1953), the middle table the current data (2018), and the lower table the comparison between the two by the magnification rate (detailed for each class, and overall).

SUBSET 2				
Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 1953	81.00	83.81	150.41	3110.21
Grasslands 1953	2660.00	398.65	6603.71	262712.69
Forest 1953	715.00	3213.94	50077.14	252534.74
Roads 1953	80.00	273.06	526.94	13808.66
Water 1953	6.00	1748.00	1505.88	2480.99

Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 2018	86.00	223.49	564.45	6302.92
Grasslands 2018	1876.00	226.62	1699.71	125016.76
Forest 2018	379.00	7690.83	105705.74	121851.09
Roads 2018	51.00	545.62	1124.03	16363.87
Water 2018	5.00	2086.71	1844.56	2718.67

MAGNIFICATION RATE	Number of Patches	Mean Patch Area	Patch Size Heterogeneity	Total Edge Length
Built-up	1.06	2.67	3.75	2.03
Grasslands	0.71	0.57	0.26	0.48
Forest	0.53	2.39	2.11	0.48
Roads	0.64	2.00	2.13	1.19
Water	0.83	1.19	1.22	1.10
Overall	0.7	1.5	1.8	0.5

Table 9: Landscape metrics for Subset 3, the upper table shows the historical data (1953), the middle table the current data (2018), and the lower table the comparison between the two by the magnification rate (detailed for each class, and overall).

SUBSET 3				
Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 1953	94.00	34.37	134.72	1783.68
Grasslands 1953	3795.00	214.25	2706.97	374860.06
Forest 1953	672.00	3698.51	82423.83	367659.82
Roads 1953	204.00	174.47	1883.53	14691.39
Water 1953	2.00	30118.64	39068.01	4656.04

Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 2018	58	631.5962186	1461.686443	8493.131958
Grasslands 2018	3801	143.5541267	1898.516921	211945.476
Forest 2018	466	5772.526702	49167.3197	193848.1046
Roads 2018	1199	69.90512297	1059.492591	37010.5386
Water 2018	4	10347.53061	9601.625341	4798.861052

MAGNIFICATION RATE	Number of Patches	Mean Patch Area	Patch Size Heterogeneity	Total Edge Length
Built-up	0.62	18.38	10.85	4.76
Grasslands	1.00	0.67	0.70	0.57
Forest	0.69	1.56	0.60	0.53
Roads	5.88	0.40	0.56	2.52
Water	2.00	0.34	0.25	1.03
Overall	1.2	0.9	0.5	0.6

Table 10: Landscape metrics for Tundra, the upper table shows the historical data (1953), the middle table the current data (2018), and the lower table the comparison between the two by the magnification rate (detailed for each class, and overall).

TUNDRA				
Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 1953	29	188.65	332.05	1750.77
Grasslands 1953	4217	1567.84	28365.77	1348983.63
Forest 1953	9807	415.19	8401.34	1209694.94
Roads 1953	421	534.64	6965.13	133898.18
Rocks 1953	232	791.31	2677.92	39966.08
Water 1953	20	183.68	148.98	1758.91

Classes	Number of Patches	Mean Patch Area (m²)	Patch Size Heterogeneity	Total Edge Length (m)
Built-up 2018	40	142.05	335.70	3256.19
Grasslands 2018	36042	148.89	6849.18	3468768.94
Forest 2018	51664	104.13	4281.19	3405719.38
Roads 2018	20	8227.35	29222.38	65690.90
Rocks 2018	244	745.92	2258.90	40428.59
Water 2018	19	174.99	137.30	1686.80

MAGNIFICATION RATE	Number of Patches	Mean Patch Area	Patch Size Heterogeneity	Total Edge Length
Built-up	1.38	0.75	1.01	1.86
Grasslands	8.55	0.09	0.24	2.57
Forest	5.27	0.25	0.51	2.82
Roads	0.05	15.39	4.20	0.49
Rocks	1.05	0.94	0.84	1.01
Water	0.95	0.95	0.92	0.96
Overall	6.0	0.2	0.3	2.6

.

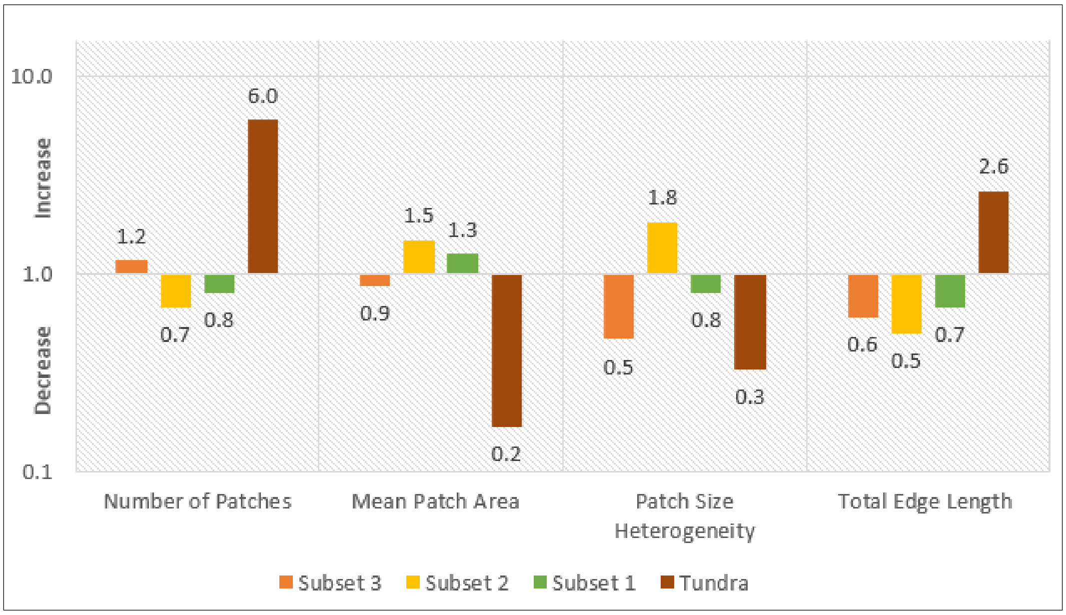


Figure 78: Magnification rate of landscape metrics. The overall class of tables 7, 8, 9 and 10 displayed graphically.

Figure 78 displays the overall magnification rate of the classes. Subset 1 shows a slight decrease in the number of patches, e. g. grasslands (from 1552 to 789). However, detailed **Table 7** shows that the number of patches increased in the forest area from 594 to 845. The number of patches also decreased in Subset 2. In this case, in both grasslands and forest from 2660 and 715 to 1876 and 376. A slight increase in the number of patches occurs in Subset 3 which includes grasslands (from 3795 to 3801) but not forest (from 672 to 466). In the arctic-alpine tundra, there is a noticeable increment in the number of patches. It increased 8.5 times in grasslands and 5.3 times in the forest (**Table 10**).

The mean patch area increased in both, Subset 1 and 2. On the other hand, in the arctic-alpine tundra, five classes out of six show a certain decline in the mean patch area, hence the reason for the lowest magnification rate (0.2). In Subset 1 and 2, the magnification graph (**Figure 78**) should be analyzed together with the tables, in Subset 1, it is **Table 7**. It shows that roads enlarged 34 times, however, the decrease in the number of patches from 169 to only 4, indicates an error affected by the manual editing as explained in the analysis in subchapter 3.3 and it will be discussed thoroughly in the discussion as well. This error was recorded only for the road class. For the analysis of the landscape matrix, grasslands and forest are more important data sources since they represent more reliable data that did not have any manual editing and data processing.

As for the patch size heterogeneity, it increased only in Subset 2. **Table 8** shows that the increase happened in the classes of forest (2.1 times), roads (2.1 times), water (1.2 times), but by far the highest increase of 3.7 was recorded in the built-up area (150 to 564). The built-up area increased in Subset 3 (10.8) and did not change in tundra even though these sites had an overall magnification rate less than 1 (Grasslands 0.24; Forest 0.51; Rocks 0.84; Water 0.92).

The last parameter is the total edge length which increased only in the tundra area. Overall, as well as in most of the other classes (built-up, grasslands, forest and rocks) a decrease was recorded (**Table 10**). Moreover, all the subsets present drop off in the total edge length Subset 1 - 0.7 times; Subset 2 - 0.5 times; and Subset 3 - 0.6 times (**Figure 77**). The cause behind it can be easily traced as values in grasslands and forest declined significantly by 0.6 and 0.7 times (respectively) in Subset 1 (**Table 7**), 0.4 times in both classes in Subset 2 (**Table 8**), and 0.5 times also in both classes in Subset 3 (**Table 9**).

5. DISCUSSION

This research assesses the long-term spatial-temporal changes of land cover from 1953 to 2018 using the aerial imagery interpretation. In the discussion, the reason for those changes according to their location will be highlighted, focusing to answer the question: Where those changes happened in the landscape, and what are their possible underlying reasons?

The analysis of *where* and *why* are the key questions of spatial science. It contributes to creating future research directions, and the conclusions serve to support decisions on conservation approaches and best management avoiding wasting time, and money. Therefore, the main changes demonstrated in the results will be summarized, placed in the context of other papers and studies. Moreover, the ideas on possible drivers will be developed according to the literature and the site history and context. Based on the findings, recommendations for conservation will be derived as well.

5.1. MAIN LANDSCAPE TRAJECTORIES

The study revealed profound changes in the land-cover of Krkonoše Mts. during those sixty-five years (1953-2018). According to hypothesis H1, the changes showed different dynamics depending on elevation, with the montane belt being much more dynamic compared to the rather stable arctic-alpine tundra (hypothesis H2). Still, the same trends could be observed throughout the area. According to the hypothesis H3, at both elevation zones, the site history played an important role in shaping the landscape and ecosystems, and the long-term analyses such as the one presented in this Thesis, are therefore important to interpret the current state, inform the management and derive recommendations for the conservation.

In the arctic-alpine tundra of the alpine belt, the increase in woods was the most prominent change. This happened partially because of the active planting of dwarf pine, and partly due to the natural shrubs encroachment. The same trend could also be observed in the montane belt subsets, however, in this case, it can mostly be attributed to the land-use changes. In the montane belt, other trajectories which are even more noticeable can be highlighted, e.g. urbanization in Subsets 1 and 3 that happened due to the need to support growing tourism with new infrastructure. Subset 2 shows the biggest decrease in grassland areas. This can be explained in part by the abandonment of traditional grassland management. Subset 3 which demonstrates the highest increase in the built-up area, includes the skiing facilities and a set of tourism structures to support the visitors such as parking lots, restaurants, and hotels.

Nevertheless, both the montane and alpine belts suffer from two kinds of disturbances: (i) global, such as climate change including global warming and increase of nitrogen, CO2, and other greenhouse gases, and (ii) the local effects, such as the changes in land use and increasing tourism. Both (i and ii) bring consequences to the landscape. Even though it is difficult to disentangle the local and global effects, based on the finding, it was possible to conclude that in the montane belt, the main driver of the change is caused by land use. This conclusion is derived from the fact that the land cover was very unstable. The changes in land use were very dynamic and related mostly to the transformation of the traditional farming landscape to tourism. On the other hand, in the considerably more stable and less populated alpine belt, it can be assumed that most of the change was due to the global change, although the direct human influence is also an important driver (Soukupová et al., 1995; Lokvenc, 2001; Theurillat et al., 2001).

The review made by Theurillat et al. (2001) points out that the global change factors are in synergy with climatic factors such as atmospheric CO2 concentration, eutrophication, ozone, or changes in land-use. This fact is connected to the study area of the KRNAP since the intensification of the industrial activities in Poland, Germany, and the Czech Republic, the area is also known as the “Black Triangle”, created pollution and overall damaged the environment (contamination of rivers and water bodies, chemical waste of materials stored in soil, and other). The high emissions are responsible for the decline of spruce forests and the deterioration of the tundra ecosystem (Štursa, 1998).

Theurillat et al., (2001) affirm that there are three basic vegetation’s consequences to a climatic change: the first, persistence of the new climate; the second, migration to a more suitable climate; and the third, extinction. The same rule can be applied to the local disturbances. In the Krkonoše tundra, the competitive local species favored by the road disturbances (e.g. *Calamagrostis villosa, Campanula bohemica*) showed resilience to those changes. However, some low-stress-tolerant rare species and low competitive species tend to disappear (Müllerová, 2011). The reasons are the use of limestone and melaphyre in some hiking trails. Unfortunately, it altered the soil and accelerated the eutrophication and ecotone effect, which facilitated the invasion of non-native species (Štursa, 1998). Besides, Theurillat et al., (2001) also considered that other influences, such as fragmentation or plant interaction might affect the plant species as it was also observed in the western arctic-alpine tundra in Krkonoše Mts. by the landscape metrics (**Figure 78**), where the decreased mean patch size and increased number of patches indicate the increase in landscape fragmentation.

5.2. AFFORESTATION

These two main drivers, land use and global changes, are correlated to many other studies concerning land cover, e.g. Chauchard et al. (2010) analyzed the changes in silver fir (*Abies alba*) in the subalpine forest of the west-central Alps which was located 2000 m a.s.l. and nowadays is moving upwards. According to Theurillat et al. (2001), in the case of silver fir, the consequence of climate change was the migration of the species. The hypothesis for the increase in the upper tree-limit is explained by land use changes and current climatic warming. The authors used dendrochronology of 31 plots and the results showed an increase of about 300 m since 1950. This followed the abandonment of low-productivity land, and they estimate that it might continue to happen since global warming continues and land use is based on new agricultural and forestry practices. The same can be applied to the Krkonoše Mts. Focusing on the land abandonment effect in the study sites of KRNAP, especially Subset 2 shows similarities with the paper (Chauchard et al., 2010), both Subset 2 and their research, demonstrated changes in the forest diversity (tree population dynamics) and properties, but this topic of land abandonment will be more developed in chapter 5.3.

All study sites present similarities in two phenomenons: (i) decrease in grasslands, and (ii) increase in forest/shrub areas. As already mentioned, these changes can be partly attributed to the active planting, but, especially in the alpine belt, also to the spontaneous shrub encroachment due to the global change. This phenomenon was studied by Cannone et al. (2007) through historical data from the European Alps between 1953 and 2003, using dendrological techniques and remote sensing methods, and their results indicated that even air temperature warming of 1-2°C might have altered the vegetation community dynamic (Cannone et al., 2007).

The afforestation plan in the Krkonoše alpine belt happened in several different time periods, Soukupová et al. (1995) explained that after the large floods in 1882, 1897, and 1900, extensive planting of dwarf pine, Norway spruce, and arolla pine was carried between 1897 and 1916. Another planting occured between the 1960s and 1990s, this time by *Pinus mugo* (71%), *Picea excelsa* (28%), *Sorbus aucuparia* (1%), and *Salix lapponum* (1%). The *Pinus mugo* is well adapted to the growth above the treeline, and its mortality was less than 10%. Those plantations negatively affected patterned grounds, the relict soil, besides that, other habitats such as solifluction benches, ecotonal zone of mires and spring sites, and organisms living in such habitats were also affected (Soukupová et al., 1995).

Štursa (2013) stated that after the declaration of Krkonoše National Park in 1963, the Administration staff had an opportunity to review the plans, and one of their conclusion was to prevent the reforestation of peat bogs, fen sites, and localities where rare or endangered plant species occur. At that time, certain errors which were threatening the unique tundra were made. For example, they did not realize that the dwarf pine might cause the gradual extinction of other highly valuable natural phenomena. Moreover, the growth of young dwarf pine seedlings is increasingly influencing the microclimatic conditions in the afforested areas.

Another consequence was that the presence of krummholz promoted the spreading of expansive grasses like *Deschampsia flexuosa, Calamagrostis villosa* and *Anthoxanthum alpinum,* which found shelter below the canopy of the dwarf pine (Soukupová et al., 1995). The afforestation residue also modified the snow cover distribution and the processes of its melting, as well as reducing the fluctuations between day and nighttime temperatures. These fluctuations are essential for the genesis and survival of several frost landforms, for which the Krkonoše mountain ridges are so famous in the context of Central Europe (Štursa, 2013).

Harčarik (2002) studied three localities in the tundra, focusing on differences in temperature during the seasons and the effect of snow cover. In that study, he mentions that the data collected from the 1999–2001 period were elaborated on the basis of the microclimatic and the snow measurements realized in three localities of pattern ground and relict soils of the arctic−alpine tundra. In his results, he claims that dwarf pine could cause the complete elimination of the frost processes in the soil of patterned ground (vegetated-cryogenic zone) of the Krkonoše Mts. tundra.

5.3. THE IMPACT OF TOURISM AND LAND ABANDONMENT

Different land use was established by the historical context in the mountains, therefore, the Thesis results should be analyzed together with the findings of the literature review. In Krkonoše Mts., human colonization happened in the 16th century and it is connected with progressive deforestation in the montane belt and krummholz in the alpine belt (Soukupová et al., 1995). The consequence can be seen in the disturbance of the ecosystem functions. It started with alpine farming at the end of the 19th century. The aim of the deforestation was to create the largest possible areas of pastures and hay meadows and use the dwarf pine for firewood and equipment for chalet dwellers (Lokvenc, 2001).

In Krkonoše Mts., the alpine farming declined during World War II, nevertheless, it brought new disturbances due to the building of the fortification system (e.g bunkers) and highways (Soukupová et al., 1995; Lokvenc, 2001). Farming was gradually transformed to become adapted to tourism which caused other disturbances to nature. Hiking, trekking, and recreation brought a migration of plants from the foothills and valleys to the summits where even more severe microclimate conditions did not prevent their establishment and spreading due to the permanent supply of diaspores (Soukupová et al., 1995; Lokvenc, 2001; Müllerová et al., 2011).

During this transition between farming and tourism, large areas of land were abandoned. Treml et al., (2016) states that the enlargement of the tree establishment was mainly due to agricultural land abandonment. The authors believe that the effect of land use changes was more important in the lower than in the upper part of the treeline ecotone of the Sudetes Mountains (Central Europe). From data of *Picea abies* at elevations ranging from 1250 to 1490 m.a.s.l, and plots set up at lower and upper timberline, the authors created a model using climatic variables and land use intensity for each of the plots. Their results showed a gradual increase with some plots undergoing thinning.

This phenomenon was presented in Subset 1 where most of the buildings remain until nowadays, but the land use changed. In the past, those cottages/chalets used open land to support grazing, mowing, and hay meadows. It is in contrast to the present when the population opted to have tree alleys between properties and afforest some of the former grasslands. On top of that, some of the buildings were reconstructed, mostly to fit the tourists' needs.

The boom of tourism in the Czech Republic happened in the early 90s, when most of the foreigners were curious about the culture of the country behind the Iron Curtain, even without investment in advertisements, its fall brought to the country around US$ 4 billion per year (Boori et al., 2014). However, even before 1989, the tourism in Krkonoše Mts. was important because Czech tourists always formed the majority of visitors in the area. Nowadays, tourism is the main economic activity in the Krkonoše Mountains, thus today, approximately 80% of the locals depend on tourism (UNESCO, 2016). Boori et al. (2014) studied the disturbances of tourism in Jeseníky Mountains, in the Northeastern part of the Czech Republic, by using LANDSAT imagery from 1991, 2001, and 2013. The intensity of disturbances related to the distance from the villages, hence areas closer to the village showed more disturbances.

The most comprehensive global map of human pressure, available at UN Biodiversity Lab and Jones et al. (2018), explained that currently, the world has more protected areas (6 million square kilometers) compared to times before the Earth Summit Rio 1992. However, 55% of them are suffering from increased human pressure. This pressure is classified from low to high, and the biome of tundra globally shows *low pressure,* of approximately 20%.

It is possible to free download the data and apply a more detailed scale to the area of interest. Therefore, I downloaded the data for the Czech Republic and Poland to have this information about the Krkonoše and Karkonosze Mts (KRNAP and KPN) (**Figure 79**). The legend indicates the percentage of each square kilometer of protected area that has been converted from “natural” to “human-dominated” landscape with intense human pressure. In the area of KRNAP in the Czech Republic, the percentage is around 98-100, while in KPN in Poland the percentage decreased to 52-76. It indicated the Czech side of the mountains is more affected by humans compared to the Polish one.

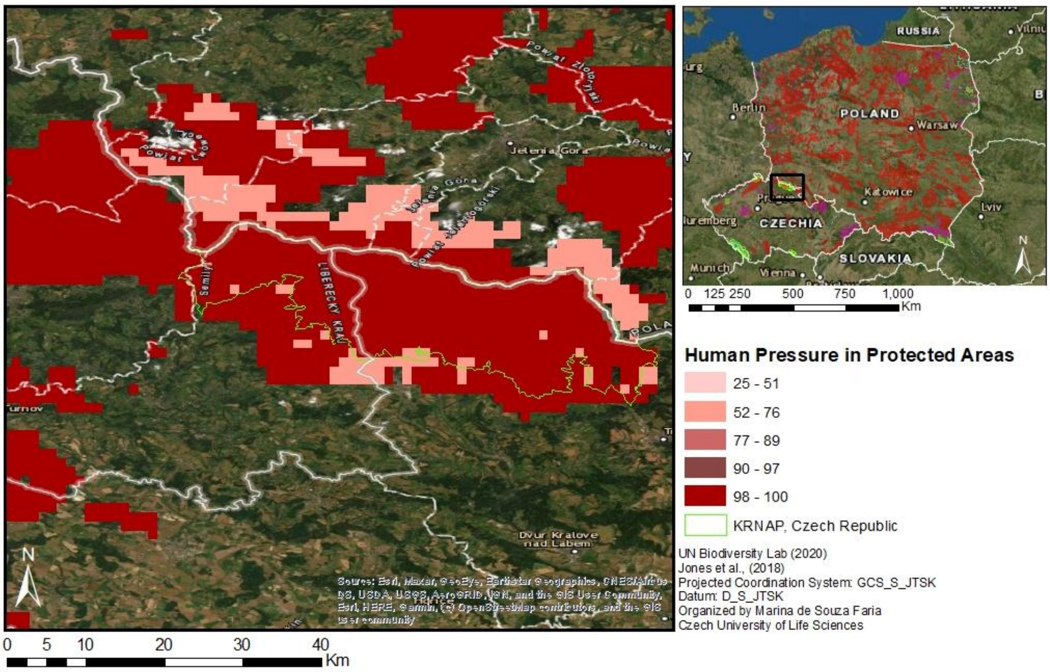


Figure 79: Human pressure in protected areas in the Czech Republic and Poland in a 1km² resolution. Source: UN Biodiversity Lab, organized by Marina de Souza Faria

This might partly happen because of the difference in geomorphology between the Polish and the Czech national park. On the Polish side, the mountains are generally much steeper and the KNP is smaller compared to the KRNAP. From the state border, the steep slopes go quickly down to the lowlands that are not part of KNP. It means that all Polish tourist facilities are either at the border on the ridge or in the lowlands outside the National Park. In contrast, in the Czech Republic, the topography is much more gradual, facilitating human activities, which were present there for a long time (Bašta, 2013).

For example, at Subset 3, the ski slope for touristic recreational proposes is visible. Moreover, the construction of roads is pronounced, as the road area increased 2.4 times. This is connected to the process of urbanization which can be visualized in both, Subset 1 and 3, such as the increase in the built-up area to which the roads are connected to.

Back to the transition of farming to tourist facilities that were followed by land abandonment. A few farmers are still trying to carry on the traditional farming supported by subsidies from the Landscape Natural Function Restoration Programme (Pec pod Sněžkou, 2020). Around 40% of the EU budget is designated to The Common Agricultural Policy (CAP) which has the function to certificate the appropriate life quality for farmers and to preserve the European heritage (Střeleček, et al., 2009). The CAP impacts in a positive way the agricultural sector, e.g. in Slovakia the farmers would generate losses without these subsidies. In the Czech Republic, the Less Favoured Area (LFA) payments support the profit of LPA agriculture enterprises, especially in the mountain areas where the share of the LPA payments is at 20% of the Gross Farm Income (Střeleček, et al., 2009).

5.4. LANDSCAPE STRUCTURE

After the classification, it was possible to assess the landscape structure using the landscape metrics. The structure is very important to understand the spatial distribution of the landscape because it might be important for the movement of a particular organism, the spread of species, disturbances, or redistribution of nutrients (Gergel et al., 2017). Landscape metrics are quantitative indexes which support the description of landscape patterns and specific characteristics of the landscape composition and configuration, e.g. the land evaluation, geosystems services, forest monitoring, urban sprawl control, and regional biodiversity conservation (Yu, et al., 2019).

The attributes used in this Thesis to analyze the landscape fragmentation were the *number of patches*, the *mean patch area, patch size heterogeneity,* and the *total edge length.* Whereas the increase in patch number and the decrease in its average area signify increasing fragmentation and diversity of habitats, the heterogeneity of patch size informs about the variability in patch area; lower the value, more even the patches are in size. The *total edge length* gives information concerning the edge effect with a higher number signifying a higher share of ecotones.

The ecological meaning of the parameters can be different according to the context, and it is the reason why it is essential to know the landscape history of the area of interest. In general, for natural land cover types such as forests or grasslands, increasing edges mean increasing ecotone habitats that can be sources of biodiversity, while increasing fragmentation means decreasing the core area inside one patch that can be important for some species such as birds. On the other hand, for anthropic habitats such as roads or urbanized places, more edges mean more disturbed natural habitats because roads can serve as traveling corridors of non-native species including the invasive ones; in the case of the Krkonoše Mts. they support the altitudinal drift of lowland species (Štursa, 1998, Müllerová et al., 2011).

The Thesis is not explicitly focussing on a landscape patterns analysis, however, I want to show that the basic information of the parameters is already helping to make conclusions, especially when combined with the other provided data which are the aim of the research. Moreover, I want to show the importance and potential for future work, where the values of landscape structure can be improved, processed, and provide more detailed information to be related to environmental conditions, such as Munroe, et al. (2007) mentioned in their research. Their study analyzes the land fragmentation in a mountain park in Honduras, with Landsat ™ images from 1987, 1991, 1996, and 2000 using remote sensing and GIS. They found out that in their case, the patch fragmentation was correlated with slope, elevation, and distance to roads.

The study sites at KRNAP show an increase in landscape fragmentation and ecotone effects in the tundra, whereas the opposite trend was observed in the montane belt. Munroe, et al. (2007) present that fragmentation was lowest in the central zone and highest in the surroundings, indicating that pressure on forests around the settlements is higher than expected, thus stating that statistical analyses show certain limitations since it does not imply causality, so care must be taken during the interpretation of the results. They also support the idea that is essential to consider the landscape trajectories (history context).

5.5. UNCERTAINTY IN AERIAL IMAGERY INTERPRETATION

During work on the Thesis, I encountered several difficulties in interpreting the imagery, especially in case of historical panchromatic imagery. The uncertainty in the visual interpretation of land cover is certainly a problem, as stated by several authors. Munroe, et al. (2007) referred that the biggest challenge during the image interpretation was to distinguish between the clearings for different purposes. So, they used elevation as a support for the decision, however even this way it was difficult to presume and they considered that the study should be combined with *in situ* research. That is similar to this Thesis, where I also encountered challenges concerning the image interpretation.

Brus et al. (2018) explained different methods on how to interpret an image, such as (1) grid, (2) geometry, (3) semi-transparent circles, and (4) transparency. They described which method is suitable for a specific kind of image, and stated that since full automation is never possible, all methods show a level of uncertainty depending on the interpreter. They pointed out that the biggest problem of the whole concept is how to distinguish different uncertainties and merge them in an understandable visualization together, showing the need to study the topic in more detail, because there is no methodology which covers all the bias caused by real interpreters working with this kind of data (Brus, et al., 2013).

Different studies, even those specialized in imagery interpretation, present some scale of difficulty, especially those concerning black and white aerial photos. Halounová (2004) classified black and white aerial orthophotography and other monochromatic remote sensing data using object-oriented analysis (OBIA) for automatic classification. As in my Thesis, she also used eCognition software for image segmentation. She identified some difficulty in urban areas, and she also says that the low accuracy values were in the case of two classes - deciduous and coniferous forest. Therefore, the tree class could not distinguish the tree types. Moreover, she explains that it is difficult to distinguish these two classes even during visual interpretation for forests younger than 40 years (Halounová, 2004).

I had the same problem distinguishing between pine/shrubs/spruces, even with the advice of an expert, I could notice different types of trees just on the color aerial imagery, but not on the black & white. The panchromatic imagery provides us the information about land cover, however not in detail and the land use can be confused (Halounová, 2004). For example, the brightness of roads and watercourses is very similar, similarly, it is not possible to distinguish the pavement type for the road class (**Figure 71 and 74**). The overlay of topographic or other color imagery might help with better recognition since the water bodies are not expected to present significant changes in the National Park.

I noticed that some roads were hidden under the shadows of big spruce or even pines. Most of these errors were modified by manual editing, but this might be a reason for decreasing magnification rate for roads in Subset 1 (**Figure 64**). Therefore, the results should be interpreted together with the maps (**Figure 63**) and the historical context, since I expect that in some cases, there were more field roads in the past because of the agriculture activity. Those field roads were used for farming, transportation of products, and increasing land fragmentation in the area. Nowadays, the citizens and tourists tend to use mostly the main roads and those old field roads were either deactivated or very well hidden within forests.

Treml et al. (2011) assess the changes in land cover of dwarf pine in Hrubý Jeseník Mountains, using aerial photographs from 1971/1973 and 2003. They chose the OBIA since this approach covers not only spectral resolution but also spatial, shape, and texture properties of objects. As already mentioned, the authors also recognize that black & white imagery has limited spectral resolution. To solve that, they used Halounová (2004) method which consists of a median filter layer with a 3x3 pixel window before the segmentation process in order to suppress local inhomogeneities in the image and to increase poor signature space provided by scanned panchromatic imagery (Halounová, 2004; Treml et al., 2011). Still, such an approach decreases the spatial detail of the source, bringing the smoothing effect.

According to the other studies, the OBIA followed by manual editing is an important approach that I've been using and is very often opted for. In this diploma thesis, I used the rule-based classification, which is based on expert knowledge, creating your own rules in assigning each class in eCognition. Therefore, it can possibly contain errors caused by uncertainty, however, they were mostly solved by the subsequent manual editing in ArcGIS. The manual editing was also applied by Treml et al. (2011), and the authors stated that the correction was quite high because of two main reasons: firstly, the sophisticated methods of classification used, and secondly, the limitations in image quality. However, the automatic classification improved by following manual editing is still much faster and reliable than only manual image interpretation, such as delineation of huge amounts of dwarf-pine patches in my case.

5.6. RECOMMENDATIONS FOR CONSERVATION MEASURES

The goal of the comprehensive literature review at the beginning of the Thesis was to cover the historical context that helps to understand and interpret the Krkonoše landscape changes. Marcucci (2000) says that landscapes are constantly changing over many time scales, not just from the ecological point of view but also from the cultural one, and claims that to develop a proper landscape planning, the historical proposal has the potential to improve the description, prediction, and prescription.

Each keystone process that affects landscape changes such as geomorphology, climate change, colonization patterns, disturbances, and cultural processes has different lengths of time (Marcucci, 2000), which should be reflected in the research by a compilation of different researches covering various spatial-temporal scales. This Thesis emphasizes the importance of the historical context for both, landscape planning and conservation measures, being efficient and sustainable for future generations.

One of the most important recommendations is the improvement and support of long-term monitoring and detailed research of all abiotic and biotic processes because they are the most effective for the management and landscape planning of the Krkonoše Mts., especially for the arctic-alpine tundra (Štursa, 1998). However, this can also be applied to other mountain ecosystems. Investment in scientific research is crucial nowadays because of the global occurrences across all latitudes. Steep and small-scale environmental and climatic gradients in the mountains can support understanding of the global change and help to derive possible solutions (Payne et al., 2017).

There are several opportunities for research on mountain biodiversity highlighted by Payne et al. (2017), for example, there is no comprehensive biological inventory of the world's mountains which contains species and ecosystem types and the effects of global change. Another field that requires research is a better mapping of global mountain biodiversity to improve the understanding of changes between the species and ecosystem types. Overall, it is necessary to increase the knowledge of spatiotemporal processes and patterns at multiple scales, and whereas ecological and social processes do not operate at the same scales, linkages must be developed (Payne et al., 2017).

The detailed spatially explicit analyses of long-term changes in Krkonoše Mts. coupled with the literature review allowed me to derive the following recommendations for the nature conservation of the area. For the tundra, the management towards reducing the pines in the relict soil should be provided with respect to the site history, and such measures are already realized by the KRNAP Authorities (Soukupová et al., 1995; Lokvenc, 2011; Bašta, J., 2013). Still, since the *Pinus mugo* species is rare and protected in the country, and the tundra ecosystem is very fragile and sensitive to any disturbance, the shrub removal should be carried with extreme caution and restricted solely to places specifically indicated (cf. Treml et al., 2010; Štursa, 2013). For the montane belt, solutions should be applied towards preventing further landscape degradation and fragmentation, regulating the tourism, preserving traditional grassland management with the help of the dedicated subsidy programs and the aim of preserving the landscape diversity, and controlling the pressure from the surroundings (cf. Štursa, 1998, Payne et al., 2017; Müllerová et al., 2011).

6. CONCLUSIONS

To conclude, this Diploma Thesis presents spatial-temporal changes in Krkonoše Mountains between 1953 and 2018 by comparing the aerial imagery provided by public databases and processed using remote sensing methods. According to my hypotheses, throughout the years, the mountain landscape in lower elevations has been transformed for economic and social reasons, whereas at the alpine zone above the treeline, natural processes are still dominating. Although the Krkonoše tundra suffers from increasing human impacts, it is still more stable compared to the montane belt. The Thesis proved that to correctly assess the landscape change, it is essential to understand the historical context that allows to reveal the main trajectories of the land cover change, disturbances and propose solutions for the best management.

The first revealed trajectory is the afforestation - the increase of forest/woods in all the study sites, and consequently the decrease of grasslands which mostly became encroached by forest/woods. The artificial afforestation was aiming at soil and forest conservation and erosion measures, but also at the tourists so the visitors have a more pleasant and "green" place to visit in summer seasons.

The excessive plantation caused disturbances in the relict soils of the arctic-alpine tundra, which is an important and unique geomorphological feature. Therefore, it now requires research to manage the best way to restore and protect such rare vegetated-cryogenic zones-soils. Secondly, the urbanization process is an important factor, i.e. transition from traditional low-intensity farming towards tourism. This process generated an increase in built-up areas in all study sites except the tundra, where it remained the same.

Regarding changes in the landscape structure, the research shows that the tundra experienced an increase in both landscape fragmentation and ecotone effects, whereas the opposite trend was observed in the montane belt where the landscape shows homogenization. The effects of tourism and abandonment of traditional farming are higher in the montane belt, caused by the urbanization processes, while in the tundra the disturbances and changes are more subtle, except for past plantations. Transformations there are happening at smaller scales and are probably mainly driven by global effects such as climate change.

Therefore, it is more difficult to detect the tundra changes in detail from relatively coarse aerial imagery. Concerning the software analysis, eCognition is very efficient and reliable in mapping vegetation, especially historical images (panchromatic orthophotos). Still, manual editing is necessary, and the results must be interpreted considering possible errors.

The potential direction of further research may be in a more detailed use of the examined data within the landscape structure and the application of other methods of remote sensing to compare the results. For the conservation of such fragile mountain ecosystems, it is important and necessary to adopt specific measures depending on the location. This is only possible if the historical approach covering longer periods of time is performed. In tundra, management in the relict soil should be done with respect to the site history. Besides that, measures such as further landscape degradation, regulation of tourism, preservation of traditional grassland management, and controlled pressure of the surroundings should be applied for the montane belt.

7. REFERENCES

Anderson, J.R., et al., “A Land Use and Land Cover Classification System for Use with Remote Sensor Data,” Geological Survey Professional Paper 964, U.S. Government Printing Office, Washington, DC, 1976.

Austrian MAB Committee. (2011). Biosphere Reserves in the Mountains of the World.

Bašta, J., (2013) Krkonose Mountain National Park In: Bašta, J., Štursa, J., eds. 50 years of the Krkonose Mountains National Park. Published by Krkonoše National Park Administration in Vrchlabí in 2013, 06-61.

Boori, M. S., Voženílek, V., & Choudhary, K. (2015). Land use/cover disturbance due to tourism in Jeseníky Mountain, Czech Republic: A remote sensing and GIS based approach. The Egyptian Journal of Remote Sensing and Space Science, 18(1), 17-26

Blaschke, T., Lang, S., & Hay, G. (Eds.). (2008). Object-based image analysis: spatial concepts for knowledge-driven remote sensing applications. Springer Science & Business Media.

Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS journal of photogrammetry and remote sensing*, *65*(1), 2-16.

Brus, J., Pechanec, V., & Machar, I. (2018). Depiction of uncertainty in the visually interpreted land cover data. Ecological Informatics, 47, 10-13.

Bugmann, H., Gurung, A. B., Ewert, F., Haeberli, W., Guisan, A., Fagre, D., ... & Participants, G. (2007). Modeling the biophysical impacts of global change in mountain biosphere reserves. *Mountain Research and Development*, 66-77.

Buckley, Ralf C.; Pickering, Catherine M.; Warnken, J. Environmental Management for Alpine Tourism and Resorts in. Tourism and development in mountain regions, 2000, 27-45.

Cannone, N., Sgorbati, S., & Guglielmin, M. (2007). Unexpected impacts of climate change on alpine vegetation. Frontiers in Ecology and the Environment, 5(7), 360-364.

Chauchard, S., Beilhe, F., Denis, N., & Carcaillet, C. (2010). An increase in the upper tree-limit of silver fir (Abies alba Mill.) in the Alps since the mid-20th century: A land-use change phenomenon. *Forest Ecology and Management*, *259*(8), 1406-1415.

Chen, G., Hay, G. J., Carvalho, L. M., & Wulder, M. A. (2012). Object-based change detection. *International Journal of Remote Sensing*, *33*(14), 4434-4457.

CUZK. State Administration and Land Surveying and Cadastre (2018), Geoportal - Metadata. Online:https://geoportal.cuzk.cz/(S(k0wimlxydeyuwgf0cu1yige5))/Default.aspx?mode=TextMeta&metadataID=CZ-CUZK-ORTOFOTO-R&metadataXSL=Full&side=ortofoto. Accessed 03.04.2021.

EEA (2010). 10 messages for 2010: Mountain ecosystems. EEA, Copenhagen. Online: (www.eea.europa.eu) accessed 01.27.2021

Engel, Z., Nývlt, D., Křížek, M., Treml, V., Jankovská, V., & Lisa, L. (2010). Sedimentary evidence of landscape and climate history since the end of MIS 3 in the Krkonoše Mountains, Czech Republic. Quaternary Science Reviews, 29(7-8), 913-927.

EU.CZ Czech Presidency of the European Union (2009) Regions of the Czech Republic. Online:http://www.eu2009.cz/en/czech-republic/regions/regions-of-the-czech-republic-329/index.htm accessed on 01.23.2021.

GLORIA (2021) Global Observation Research Initiative in Alpine Environments. History. Aims. Online: https://gloria.ac.at/scope/aims accessed 01.26.2021.

Gergel, S. E., & Turner, M. G. (Eds.). (2017). *Learning landscape ecology: a practical guide to concepts and techniques*. Springer, 3-41.

Gray, M. (2019). Geodiversity, geoheritage, and geoconservation for society. International Journal of Geoheritage and Parks, 7(4), 226-236.

Gutierrez, B., & Pena, C. (Eds.). (2010). The Reciprocal Relationships between High Latitude Climate Changes and the Ecology of Terrestrial Microbiota: Emerging Theories, Models, and Empirical Evidence, Especially Related to Global Warming in Tundras: Vegetation, Wildlife and Climate Trends. Nova Science Pub Incorporated.

Halounova, L. (2004). The automatic classification of B&W aerial photos. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *34*

Harcarik, J. (2002). Microclimatic Relationships of The Arctic-alpine Tundra/Mikroklimatické poměry arkto-alpínské tundry. *Opera Corcontica*, (39), 45.

HK Region (2015) MINING IN KRKONOŠE MOUNTAINS, Published in the framework of the project „Support for Tourism Development In The Hradec Králové Region ". Online: https://www.hkregion.cz/filemanager/files/154634.pdf accessed 01.05.2021.

Hominick, W. M. (2002). Biogeography. Entomopathogenic nematology, 1, 115-143.

Hussain, M., Chen, D., Cheng, A., Wei, H., & Stanley, D. (2013). Change detection from remotely sensed images: From pixel-based to object-based approaches. ISPRS Journal of photogrammetry and remote sensing, 80, 91-106.

Jones, K. R., Venter, O., Fuller, R. A., Allan, J. R., Maxwell, S. L., Negret, P. J., & Watson, J. E. (2018). One-third of global protected land is under intense human pressure. *Science*, *360*(6390), 788-791.

Kašák, J., Mazalová, M., Šipoš, J., & Kuras, T. (2015). Dwarf pine: invasive plant threatens biodiversity of alpine beetles. *Biodiversity and Conservation*, *24*(10), 2399-2415.

Körner, C. (2004). Mountain biodiversity, its causes, and function. AMBIO: A Journal of the Human Environment, 33(sp13), 11-17.

Körner, C., Jetz, W., Paulsen, J., Payne, D., Rudmann-Maurer, K., & Spehn, E. M. (2017). A global inventory of mountains for bio-geographical applications. Alpine Botany, 127(1), 1-15.

Knowles L, Massatti R. 2017. Distributional shifts—not geographic isolation—as a probable driver of montane species divergence. Ecography OnlineEarly.

KRNAP (2010)., Official website: Downloads: Treasures of the Krkonose Tundra and Making Love in Krkonose; Nature in the Krkonose Mountains: the current conditions. Online: https://www.krnap.cz/en/download/ accessed in 02.18.2021 and 03.01.2021.

KRNAP (2020)., TZ: Nová zonace KRNAP začne platit 1. července *in* “At the end of last week, the Minister of the Environment Richard Brabec signed a new decree on the delimitation of nature protection zones in the Krkonoše National Park”. Online: https://www.krnap.cz/aktuality/tz-nova-zonace-krnap-zacne-platit-1-cervence/ accessed in 02.04.2021.

Křížek, M., Krause, D., Uxa, T., Engel, Z., Treml, V., & Traczyk, A. (2019). Patterned ground above the alpine timberline in the High Sudetes, Central Europe. *Journal of Maps*, *15*(2), 563-569.

Li, X., & Shao, G. (2013). Object-based urban vegetation mapping with high-resolution aerial photography as a single data source. International journal of remote sensing, 34(3), 771-789.

Lillesand, T., Kiefer, R. W., & Chipman, J. (2000). *Remote sensing and image interpretation*. John Wiley & Sons.

Lokvenc, T. (2001). History of Giant Mts.’dwarf pine (Pinus mugo Turra ssp. pumilio Franco). *Opera Corcontica*, *38,* 21-42.

Lu, D., & Weng, Q. (2007). A survey of image classification methods and techniques for improving classification performance. International journal of Remote sensing, 28(5), 823-870.

Malá Upa (2020) Municipal Authority. History. Online: https://malaupa.cz/historie/. Accessed in 03.08.2021

Mauer, O., & Palátová, E. (2010). Decline of Norway spruce in the Krkonoše Mts. *Journal of Forest Science*, *56*(8), 361-372.

Manuelli, S., Hofer, T., & Springgay, E. (2017). FAO's work in sustainable mountain development and watershed management—A 2017 update. Mountain Research and Development, 37(2), 224-227.

Marcucci, D. J. (2000). Landscape history as a planning tool. *Landscape and urban planning*, *49*(1-2), 67-81.

Messerli, B. (2012). Global change and the world's mountains. Mountain Research and Development, 32(S1).

Millennium Ecosystem Assessment (MEA) (2005). Ecosystems and human well-being: A framework for assessment. Washington D.C.: Island Press

MIREN (2021) Mountain Invasion Research Network. Online: https://www.mountaininvasions.org/ accessed 01.26.2021.

Moore, Peter D. (2006) Geography of the tundra & Geology of the tundra in Tundra. Chelsea House Publishers, New York.

MP., 2015 - *Mountain Partnership. Working together for the mountain people environment.* FAO Food, Agriculture Organization (2015) online: http://www.fao.org/mountain-partnership/about/our-vision-and-mission/en/ accessed in 12.29.2020

MRI (2020) Mountain Research Initiative. Who we are Online: https://www.mountainresearchinitiative.org/who-we-are accessed 01.26.2021

Müllerová, J. (2005). Use of digital aerial photography for sub-alpine vegetation mapping: A case study from the Krkonoše Mts., Czech Republic. *Plant Ecology, 175*(2), 259-272.

Müllerová, J., Vítková, M., & Vítek, O. (2011). The impacts of road and walking trails upon adjacent vegetation: Effects of road building materials on species composition in a nutrient poor environment. Science of the total environment, 409(19), 3839-3849.

Müllerová J., Pergl J. & Pyšek P. (2013). Remote sensing as a tool for monitoring plant invasions: testing the effects of data resolution and image classification approach on the detection of a model plant species Heracleum mantegazzianum (giant hogweed). International Journal of Applied Earth Observation and Geoinformation 25: 55–65.

Munroe, D. K., Nagendra, H., & Southworth, J. (2007). Monitoring landscape fragmentation in an inaccessible mountain area: Celaque National Park, Western Honduras. *Landscape and urban planning*, *83*(2-3), 154-167.

Nagy, L., & Grabherr, G. (2009). The alpine environment: energy and climate in. The biology of alpine habitats. Oxford University Press on Demand.

Nagy, L., Grabherr, G., Körner, C., & Thompson, D. B. (Eds.). (2012). *Alpine biodiversity in Europe* (Vol. 167). Springer Science & Business Media

Nilsson, C., & Grelsson, G. (1995). The fragility of ecosystems: a review. Journal of Applied Ecology, 677-692.

Olson, C.E., Jr., (1960) Elements of Photographic Interpretation Common to Several Sensors, *Photogrammetric Engineering*, vol.26, no.4, pp.651-656.

Pasek, L; Hudecek, V., (2015) Analysis of Radiation Risks Of Remaining Dumps After Uranium Mining In Krkonoše-jizera Crystalline Complex In Czech Republic. Proceedings of the International Multidisciplinary Scientific GeoConference SGEM, 41-48 [cit. 2021-01-06]. ISSN 13142704.

Payne, D., Spehn, E. M., Snethlage, M., & Fischer, M. (2017). Opportunities for research on mountain biodiversity under global change. *Current opinion in environmental sustainability*, *29*, 40-47.

Pec pod Sněžkou (2021) hory v pohyby. Municipal Authority. Basic Information. History. Online: https://www.pecpodsnezkou.cz/en/contact/ accessed on: 03.02.2021.

Plesnik, P. (1978). Man's Influence on the Timberline in the West Carpathian Mountains, Czechoslovakia∗. Arctic and Alpine Research, 10(2), 491-504.

Portal Geo. Czech National Geoportal (2010-2019). Historical orthophoto map (1950s). Online:http://geoportal.gov.cz/php/catalogue/libs/cswclient/cswClientRun.php?template=iso2htmlFull.xsl&metadataURL=http%3A//micka.cenia.cz/record/xml/50210752-9d9c-4f47-956b-1951c0a80137. Accessed in 03.04.2021

Rien, A. (2009). Nitrogen supply effects on leaf dynamics and nutrient input into the soil of plant species in sub-arctic tundra ecosystems. Polar Biology, 32, 207-214.

Sayre, R., Frye, C., Karagulle, D., Krauer, J., Breyer, S., Aniello, P., ... & VanSistine, D. P. (2018). A new high-resolution map of world mountains and an online tool for visualizing and comparing characterizations of global mountain distributions. Mountain Research and Development, 38(3), 240-249.

Štursa, J. (1998). Research and management of the Giant Mountains' arctic-alpine tundra (Czech Republic). Ambio (Sweden).

Štursa, J., (2013) Krkonose Mountain National Park In: Bašta, J., Štursa, J., eds. 50 years of the Krkonose Mountains National Park. Published by Krkonoše National Park Administration in Vrchlabí in 2013, 62- 180.

Střeleček, F., Zdeněk, R., & Lososová, J. (2009). Comparison of agricultural subsidies in the Czech Republic and in the selected states of the European Union. Agricultural economics, 55(11), 519-533.

Soukupová, L., Kociánová, M., Jeník, J., & Sekyra, J. (1995). Arctic-alpine tundra in the Krkonoše, the Sudetes. Opera corcontica, 32, 5-88.

Soukupová, L., Jeník, J., & Frantík, T., (2001). Edge effect of krummholz in Giant Mts. tundra, the Sudetes. Opera Corcontica, 38, 77-87.

Soukupová, L., Frantík, T., & Jeník, J. (2001). Grasslands versus krummholz in arctic-alpine tundra of the Giant Mountains. Opera Corcontica, 38, 63-76.

Špindlerův Mlýn (2020). Oficial Municipality Website. City. History and Photogallery. Online: https://www.mestospindleruvmlyn.cz/en/historie#popup-chb-content549. Accessed in 03.08.2021

Strahler AH, Woodcock CE, Smith JA (1986) On the nature of models in remote sensing. Remote Sens Environ 20:121–139

Svoboda, M., (2001). The effects of Pinus mugo (Turra) plantations on alpine-tundra microclimate, vegetation distribution, and soils in Krkonoše National Park, Czech Republic. Opera Corcontica, 38, 189-206.

Theurillat, J. P., & Guisan, A. (2001). Potential impact of climate change on vegetation in the European Alps: a review. *Climatic change*, *50*(1), 77-109.

Treml, V., Wild, J., Chuman, T. and Potůčková, M., 2010. Assessing the change in cover of non-indigenous dwarf-pine using aerial photographs, a case study from the Hrubý Jeseník Mts., the Sudetes. Journal of Landscape Ecology, 3(2), pp.90-104.

Treml, V., Šenfeldr, M., Chuman, T., Ponocná, T., & Demková, K. (2016). Twentieth century treeline ecotone advance in the Sudetes Mountains (Central Europe) was induced by agricultural land abandonment rather than climate change. Journal of Vegetation Science, 27(6), 1209-1221.

Trimble (2017). Trimble documentation eCognition Developer 9.3. User guide, Trimble eCognition Developer for Windows operating system. Munich, Germany.

UNEP (United Nations Environment Programme), (2007). In the 3rd international expert meeting on a 10-Year framework of programs on sustainable consumption and production (Marrakech Process). Meeting report and co-chairs summary.

UNESCO (2016) Natural Science, Environmental, Ecological Science, Biosphere Reserves, Krkonoše/Karkonosze in Ecological Science for Sustainable Development. Online: http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/europe-north-america/czech-reppoland/krkonosekarkonosze/ accessed in 01.19.2021.

Young, J., Richards, C., Fischer, A., Halada, L., Kull, T., Kuzniar, A., ... & Watt, A. (2007). Conflicts between biodiversity conservation and human activities in the central and eastern European countries. AMBIO: A Journal of the Human Environment, 36(7), 545-550.

Vacek, S., Bastl, M., & Lepš, J. (1999). Vegetation changes in forests of the Krkonoše Mts. over a period of air pollution stress (1980–1995). *Plant Ecology*, *143*(1), 1-11.

Vacek, S., & Matějka, K. (2010). Health status of forest stands on permanent research plots in the Krkonoše Mts. *Journal of Forest Science*, *56*(11), 555-569.

Yu, M., Huang, Y., Cheng, X., & Tian, J. (2019). An ArcMap plug-in for calculating landscape metrics of vector data. *Ecological Informatics*, *50*, 207-219.

Walker, M.D., Gould, W.A. & Chapin III, F.S. (2001) Scenarios of biodiversity changes in arctic and alpine tundra. Global Biodiversity in a Changing Environment (eds F.S. Chapin III, O.E. Sala & E. Huber-Sannwald), pp. 83–100. Springer, Heidelberg, Berlin, New York.

8. LIST OF FIGURES

9. APPENDICES

A1. MAP OF TUNDRA