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Climate Change Effects on Temperate Forests

(On the Example of the Czech Republic and Georgia)

Master´s thesis

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Declaration

I hereby declare that I have authored this master's thesis carrying the name „Climate Change Effects on Temperate Forests (On the Example of the Czech Republic and Georgia)" independently under the guidance of my supervisor. Furthermore, I confirm that I have used only professional literature and other information sources that have been indicated in the thesis and listed in the bibliography at the end of the thesis. As the author of the master's thesis, I further state that I have not infringed the copyrights of third parties in connection with its creation.

In Prague on date _____13.04.2023_____

Acknowledgment

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Summary

The main goal of the thesis is to determine the climate change effects on temperate forests using different professional literature research, satellite images comparison, and field trips. Climate change is one of the large-scale problems in the modern world with different circumstances. It is affecting many different fields such as science, economics, politics, health, and forest loss. As forest loss is one of the biggest environmental problems, it is crucial to learn about the connections of climate change and deforestation. Due to the importance of the climate change problems and the importance of the forests as one of the most valuable natural resources on the earth, the thesis aims to find, present, and underline specific threats caused by climate change, as well as the anthropogenic effects. Climate changes are likely to affect important ecological processes and forest parameters around the world. The thesis work aims to find connections between climate change and forest conditions in two different countries, Georgia, and the Czech Republic; different scientific data is used for better determination and understanding of the problem. Using the different research and field findings, the thesis aims to determine connections between global warming, rising temperatures, and the loss or degradation of the forest. There are clear prints of bark eater beetle negative effects in the forests of both the countries Georgia and the Czech Republic, according to our study within the field observations bark beetle is strongly promoted by climate change.

Different methods were used for completing different objectives of the thesis work. One of the main methods was using remote observation of the forest conditions using satellite images in Georgia and the Czech Republic. The time of the images taken varies between the years of the last two decades according to the forest condition changes in specific areas. The most visible examples in the study were caused by forest fires or anthropogenic negative activities. Field trips were an important method to study the conditions of the forests in both countries. The most common effects determined by the field trip method were caused by the bark beetles, forest fires and drought activities.

The questionnaire was created to determine awareness of the society in both countries. It was done to determine general awareness and doesn't aim to collect or aim to collect or sort any personal information or data. The proper research in both countries could be suggested work for the future.

Keywords: Climate change, Global warming, Wildfires, Forest fires, Forests, FDI, Insect outbreak

Contents

1. Introduction

The main goal of this work is to determine the main effects of climate change in temperate forests in the Czech Republic and Georgia, at the same time to compare awareness of society in both countries about the climate change and its effects on the forests. Climate change is one of the most pressing problems of our society, climate change threatens our environment and people around the earth. Disasters promoted by climate change, degradation of our natural resources and extreme weather patterns damaging harvests, exhaust fisheries, and spread infectious diseases. Climate influences our living environment and our health. Each species of living organisms has adapted to live within a specific climatic and geographical niche (Jezkova and Wiens, 2016). Due to global warming the average earth surface temperature increased by 0.7 °C in the 20th century, according to the 2007 IPCC report. According to Fagan (2008) climate change will cause mass migration of different species of animals from one place to another, including that of humans.

In recent years concentrations of the three main greenhouse gases (carbon dioxide, methane, and nitrous oxide) are increasing significantly. The annual increase of methane concentration in the atmosphere was the highest on record in 2022. (WMO Report, 2022).

Torchinava[1] (2015) in the Case Study about Georgia Prepared for FAO as part of the State of the World's Forests 2016 (SOFO) describes the location of Georgia to prove the diversity of its climate and challenges connected to deforestation. Territory of Georgia is located on the border of subtropical and moderate climate zones. The country belongs to the Mediterranean climate region, through mountainous landscape changes its typical climate characteristics substantially, the country is characterized by various climate types. The territory of Georgia contains 11 out of 14 existing climate zones due to very complicated merging of climate factors and vast scale circulation processes.

According to Olagunju[2] (2015) forests are not only the material wealth and natural resources but they perform socio-cultural and economic functions as it includes food security, source of employment, generation of income and economic profit, providing of raw materials for various industries. Forests are important buffers against climate change.

[1] *Torchinava, 2015. Georgia Case Study Prepared for FAO as part of the State of the World's Forests 2016 (SOFO)* https://www.fao.org/3/C0181e/C0181e.pdf

[2] *Olagunju, 2015. Impacts of Human-induced Deforestation, Forest Degradation and Fragmentation on Food Security* https://www.researchgate.net/publication/336232078_Impacts_of_Human-induced_Deforestation_Forest_Degradation_and_Fragmentation_on_Food_Security

Global climate change has specific indicators which provide an overview of changes in the climate system at a wide scale. Various interconnected physical indicators coupling the changing composition of the atmosphere and the response of forests. The indicators are based on a wide range of data sets which are, in turn, based on multiple observing systems including both satellite and in situ data sources described within the work.

Main challenge of the study is to connect different issues connected to climate change and human influence on the forests in the Czech Republic and Georgia. It is necessary to take into consideration the fact that the problems in any habitat in the modern world can't be independent from each other. In forests at the same time is possible to see negative effects of direct and indirect climate change issues or anthropogenic pressure.

2. Review of Literature

2.1. Droughts and Insect outbreaks

Natural disturbances, such as fires, insect outbreaks and wind throw, are an integral part of ecosystem dynamics in forests around the globe. They more often occur as relatively disconnected events, and are forming different disturbance frequencies of characteristic regimes, sizes, and intensities over extended spatial or temporal scales. Disturbances alter the function, configuration and structure of an ecosystem, or population. They also change resource availability and physical environment. They form diversity of the landscapes of forests, wide range of orders and species and promote ecosystem renewal or reorganization (Seidl et al., 2017).

Climate change could change the intensity of forest destruction. It can affect the frequency of wildfires, windstorms, forest pest outbreaks and distribution of invasive species. These distractions can reduce forest productivity and change the density of tree species (Dale et.al., 2001). Usually, it is a big challenge to determine the direct climate change effect on different areas because climate fluctuations are not unusual, and it always happened before. Climate changes which are caused by human activities (anthropogenic) also developed over the course of several decades. This makes it difficult to assess the impact of humans on climate with certainty but the speed of it this time makes it very clear, modern climate change is happening within a very short range of time and causes important damage on different areas, for example on the forests (Sterling et.al., 2008).

Relations between wildfires and other disturbances, such as drought and insect outbreaks, are likely to be the main drivers of ecosystem degradation in a warming climate. Repeated wildfires are likely to happen more often, it can have potential influence on the regeneration of forests and species composition (Peterson et.al., 2020) [1]. Reburning example of the forests was clearly visible in the south of the Georgian example on Figure 12. Deforested area near Tsagveri village.

The forests we have today were developed significantly by the warming of the temperatures at the end of the last ice age. But climate change is happening very fast in modern times. Since the record of the climate data began in the 1880s the global average temperatures have increased by 2 degrees (Celsius). Earth typically experiences changes of climate on the scale of hundreds of thousands of years (Ruiz, 2020).

[1] *Peterson et.al, 2020. Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA"* https://fireecology.springeropen.com/articles/10.1186/s42408-019-0062-8

Temperatures have a strong role in population growth of bark beetles, at the same time reduced precipitation can cause the stress of the host tree, this means that climate change-associated shifts in temperature with precipitation will affect bark beetle populations in future. Global warming affects the populations of bark beetles differently, according to the specific species and geographic location. In some cases, it can promote an increase in population, while in other cases it can decrease it or alter the growth. Adaptation to local environmental conditions has significant influence on the successful distribution. Species that infest and reproduce in trees in warm habitats (e.g., some southern pine beetle populations and (Ips) have evolved physiological mechanisms that allow for multiple generations in a single year. Species of the bark beetles in colder climates have developed to thrive during cold winters and emerge as adults to attack trees during warm months. Recent temperature increases have had a huge influence on bark beetle population increase in slightly cool habitats, allowing population levels to increase significantly. (Bentz, 2008).

Climate change is rising temperatures on earth, creating deeper droughts and drier vegetation periods, according to Scheller (2021). These conditions will continue in the coming years or decades and will lead to an increase in intensity and frequency of wildfires.

In the period of 2013-2022 global average temperature rose 1.14°C, if we compare it with the period of 2011-2020 when temperature rise was 1.09°C we can see the trend which shows the global average temperatures fast increase. Those estimates are done by the Intergovernmental Panel on Climate Change (IPCC) in the Sixth Assessment report (2022). According to the same report 6% of the glacier ice was lost between the years of 2021 and 2022 in Switzerland. In this mountainous country for the first time in recorded history, snow melted in the summer season even at the very high elevation sites and no accumulation of fresh ice was observed. Between 2001 and 2022 the size of glacier ice in Switzerland decreased from 77 km3 to 49 km3. This means that more than a third of glaciers were lost in the country. (WMO, 2022).

According to the NASA report 2022[1], air temperatures on Earth have been rising since the Industrial Revolution. Natural climate change events are playing an important role, but much evidence indicates that human activities—particularly emissions of greenhouse gasses—are mostly responsible for global warming speed. According to the same report the year 2022 was the fifth warmest year on record. The last nine years have been the warmest years since the 1880s when recordkeeping of the climate data started.

[1] *NASA Report, 2022*

https://earthobservatory.nasa.gov/world-of-change/global-temperatures

On Figure 1 global climate anomalies are shown for the period of 1880s-2022.

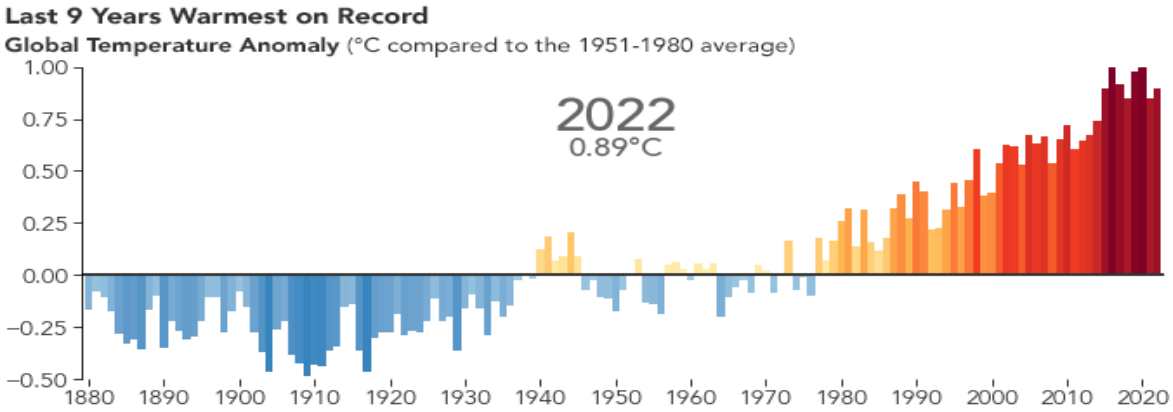

Figure 1: Global Temperatures Anomaly according NASA report, 2022

According to the same report of NASA 2022, as the map below shows, global warming does not mean temperatures rise everywhere at every time at the same rate.

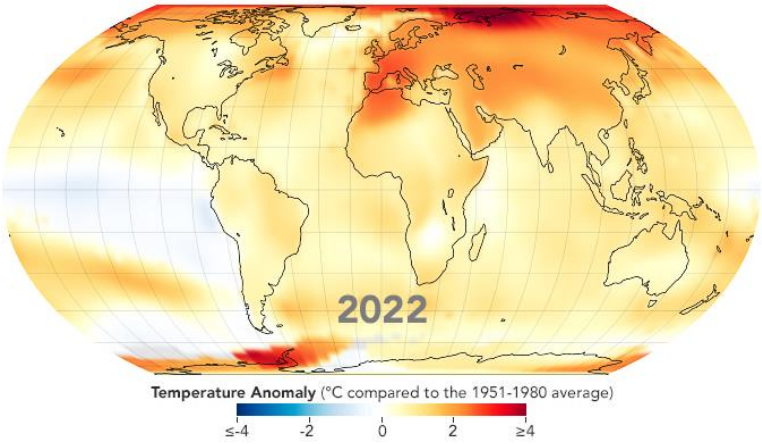

Figure 2: Global Temperatures Anomaly by areas according NASA Report, 2022

The temperature rise is different in different regions of the world. If it can rise 5 degrees in one region at the same time it might drop 2 degrees in another. For example, exceptionally cold winters in one place can be balanced by extremely warm winter seasons in another part of the world. Due to slower absorbance and releasing heat (thermal inertia) global warming is slower and less harsh over the oceans compared to the earth surface. Warming may also be different in different landmasses or different ocean basins. (NASA report, 2022).

Fagan[1] (2008) writes that “Even without greenhouse gasses, the effects of prolonged droughts would be far more catastrophic today than they were even a century ago.” Highlighting the severe consequences of global warming, he has further said that climate change will induce mass migration of different species of animals from one place to another, including that of humans. Thus, such migration will be responsible for the extinction of some species and clashes of civilization will take place resulting in the rise and fall of civilizations.

In the research work "Forest Disturbances Under Climate Change '' by Seidl[2] (2017) we can see discussion how forest disturbances are sensitive to climate and how modern society's understanding of climate change is incomplete, especially regarding large-scale patterns. Seidl (2017) in the same study provides a combination of climate change effects with global scale. Study describes important abiotic (wildfire, droughts, winds, snow, and ice) and biotic (insect outbreaks and plant pathogens) disturbance agents. Most of the abiotic and biotic factors were observed during the study in both countries, like on the satellite images as well as during the field trips.

The article “Georgian Climate Change under Global Warming Conditions” is a very important source to discuss Georgian climate patterns and its modern characteristics with climate change conditions. It is written by Elizbarashvili et al., (2013) to determine temperature patterns and different types of extremes in Eastern Georgia and Western Georgian coastline areas.

Maanen et.al., (2021) in the research “Climate Impacts in the Czech Republic” is describing how average temperature has been rising at a faster rate than the world average in the past two decades in the country. According to this research the frequency and duration of droughts are also expected to increase and so are the damages.

Elizbarashvili et al., (2017) is explaining how the degradations of forests in Georgia are promoted by the climate change in their research „Georgian climate change under global warming conditions we can find the information about southern part of the Georgia, which has usually highest risk of the forest fires and is the main target area of our research.

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[1] *Fagan, 2008. “The Great Warming: Climate Change and the Rise and Fall of Civilizations”*

https://ethz.ch/content/dam/ethz/special-interest/usys/ites/ecosystem-management-dam/documents/EducationDOC/Readings_DOC/The%20Great%20Warming.pdf

[2] *Seidl et al., 2017. “Forest disturbances under climate change”*

https://www.researchgate.net/publication/317248864_Forest_disturbances_under_climate_change

MacCarthy[1] (2022) in his article „Forest Fires Are Getting Worse “, which is published on the page of World Resources Institute, describes heat waves which are already happening 5 times more today than they were happening 150 years ago and this natural phenomenon are expected to become even more frequent as the earth continues to warm. These extreme events are described as one of the dangers of having more risks of forest fires.

The research of Martin and Haggith (2018) is one of the important literatures to determine climate change events which are caused by human activities. It explains how anthropogenic factors are changing the chemical composition of the atmosphere, such that it translates into changes in the climate then. The work describes the heavy effects on ecosystems that are not able to adapt themselves to these climate condition changes. In the research the examples are pulp mills that contribute big emissions of carbon dioxide that covers the earth, traps the heat, and raises the global temperature. It reviews the global awareness of climate change which is connected to one of the methods of our research as well. According to the article majorities in many countries say global climate change is a major threat to their nation.

Mullan and Cimato[2] (2010) in the research article „Adapting to Climate Change: Analyzing the Role of Government“ describes how there are two components to our response to the issues caused by climate change: addressing the causes of climate change by reducing greenhouse gasses emissions in the atmosphere and preparing for the expected consequences for adaptation. Restoration of woodlands and prevention of forest fires will aid adaptation to varying and harsher environmental conditions. Study suggests that governments should take more frequent and efficient actions to stop the main causes of global warming, accordingly climate change.

Cermák et.al., (2020)[3] are researching the forests in the Czech Republic, it is an important source to our findings on the satellite images. According to the study droughts increasingly threaten the Moravian forests, it promotes pathogens and pests which are massively killing mostly coniferous trees. This condition was clearly visible during the site visits as well in the surrounding areas of Vsetin district.

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[1] *MacCarthy (2022) in his article „Forest Fires Are Getting Worse“*

https://www.wri.org/insights/global-trends-forest-fires

[2] *Mullan and Cimato F, 2010. „Adapting to Climate Change: Analysing the Role of Government“.*

https://www.researchgate.net/publication/238706180_Adapting_to_Climate_Change_Analysing_the_Role_of_Government

[3] *Cermák et.al.,2020 „Long-term course of transpiration in a floodplain forest in southern Moravia associated with changes of underground water table“*

https://www.researchgate.net/publication/289392425_Long-term_course_of_transpiration_in_a_floodplain_forest_in_southern_Moravia_associated_with_changes_of_underground_water_table

2.2. Wildfires

Wildfires are not new for our planet, they have been an important process affecting the Earth for over 350 million years and humans have adapted with wildfires since their emergence on the planet. Nowadays many consider wildfire as one of the important problems, with widely held discussions both in the media and scientific papers about increasing wildfire numbers, their severity or resulting losses. There are some important exceptions which show that the quantitative evidences available about wildfires do not support these perceived overall trends (Doerr and Santín., 2016) [1]. These exceptions in quantities are possible to see in FDI data analyses done within our study.

Wildfires occur frequently in periods of drought, high temperatures, low humidity, and windy weather. The risk of such wildfires is significantly affected by the type of plants and conditions for their ignition, for example conifers and deciduous trees can have different ignition levels. Climatic condition has been the most important cause and strongest driver of regional burned areas (Možný et.al., 2021).

Peterson et.al. (2020) in their research called "Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA" – are describing how warmer and drier conditions will drive lower moisture levels and longer wildfire seasons in the future, likely increasing the frequency and extent of fires in our century compared to the twentieth century.

According to UN Environment Program (UNEP) new report (2022) climate change with large scale land-use change are projected to make wildfires more frequent and intensive, it is projected that global increase of extreme wildfires will be about 14% by 2030, it will increase to 30% by the end of 2050 and still will increase to 50% by the end of the century. The report is addressing different governments in the world to adopt a new 'Fire Ready Formula', with two-thirds of spending allocated to planning, prevention, preparedness, and recovery of damaged areas, with one third left for response. Direct responses to localize or liquidate wildfires usually receive over half of related expenditures, while planning and preparation receives less than 1%, which is not the right way. To prevent fires, authors of the report call for a combination of data and science-based monitoring systems development with indigenous knowledge of local communities for a stronger regional and international cooperation.

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[1] *Doerr and Santín., 2016. Global trends in wildfire and its impacts: Perceptions versus realities in a changing world.* *https://www.researchgate.net/publication/303504221_Global_trends_in_wildfire_and_its_impacts_Perceptions_versus_realities_in_a_changing_world*

Ruiz (2020) in her report for Global Forest Watch reviews climate change from a historical perspective. The UN Environment Program (UNEP) report (2022) is an important source to understand climate change and land-use change in one perspective, how wildfires are more frequent and intense. The report gives specific statistical data on how wildfires' numbers increased significantly in this century.

Forest fires significantly affect the amount of global greenhouse gas emissions and can damage public health, same time it can damage economics, and can alter providing of ecosystem services. However, global trends which would connect wildfire-related forest loss to climate change events are still uncertain due to the lack of proper methodologies applied to high spatial resolution data. Within the study of Tyukavina et al., (2022) the first global 30-m resolution satellite-based map was created of annual forest loss due to wildfires. When producing this map, they match the mapped area of forest loss due to wildfires to the reference areas which were obtained using a sample-based unbiased estimator, which enabled the research team to determine map-based area reporting and trend analysis. They found an increasing global trend in forest loss due to wildfires from 2001 to 2019. The result of the study shows quantity of the increasing threats of wildfires to remaining forests globally and may improve modeling of future forest fire loss rates under various climate change or global warming scenarios (Tyukavina et al., 2022).[1]

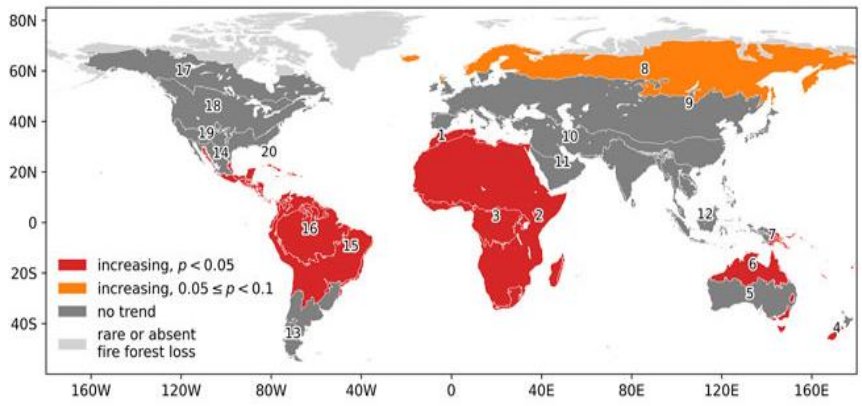

Figure 3. Forest loss due to fire between 2000 and 2019 by Tyukavina et al., 2022.

Figure 3. illustrates the detailed information about the forests lost because of the forest fires, in the research it is possible to find data of all types of the forests and global loss of the forests. However, territories of Georgia and Czech Republic are not showing a trend of increase in this specific study, which shows tropical and boreal areas with the trends.

[1] *Tyukavina et al., 2022. Global Trends of Forest Loss Due to Fire From 2001 to 2019*
https://www.frontiersin.org/articles/10.3389/frsen.2022.825190/full

On the figure 4 we can see the trends of the lost forest within the period of 2001-2019. It shows that record areas burnt in the world was earlier in 2012 but in the case of temperate forests of North America sharp increasing trend has started later in 2015-2016. It should be mentioned that temperate forests are burning at much bigger scales in North America than in Eurasia or on any other continent.

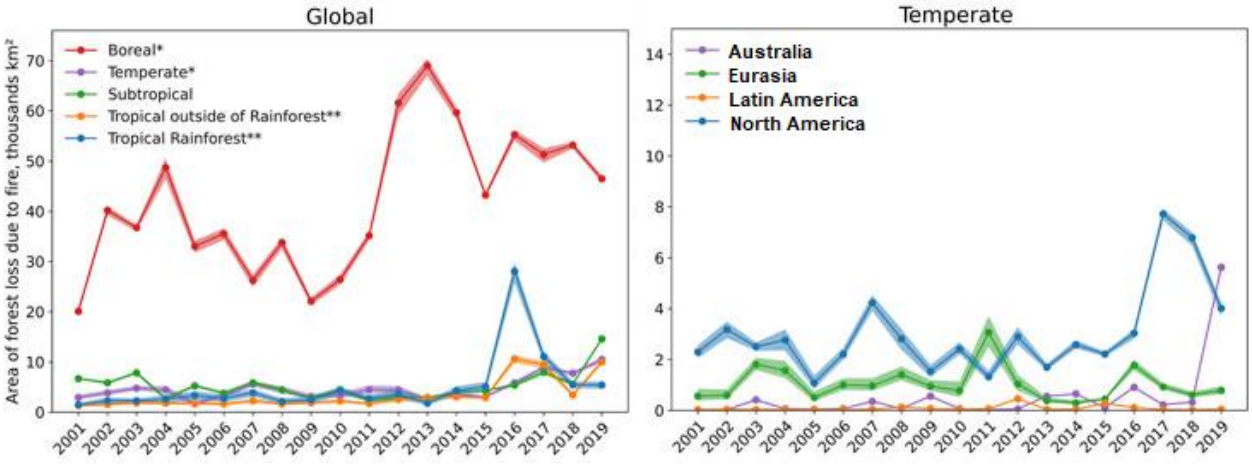

Figure 4. Forest loss trends due to fire between 2000 and 2019 by Tyukavina et al., 2022.

2.3. Anthropogenic effect

The changing of the human activities on the earth changes the composition of the atmosphere, at the end it causes global scale climate change. Some ecosystems are not able to adapt to the continuous change of the climate which has heavy effects on them. In fact, paper and pulp mills contribute big emissions of carbon dioxide that covers the earth, traps the heat, and raises the global temperature. Majorities in different countries say that global climate change is an important threat to their nation (Martin and Haggith, 2018)[1].

In recent years temperate forests significantly have been accumulating carbon. In an article about evolution of European forest sector by Nabuurs et al., (2008)[2] is reviewing that from 1950 until 1999 European forests have been accumulating carbon both in tree biomass and the soil compartment. Ciais et al., (2008) found that this accumulation process has been compatible with timber extraction over these five decades. This fact has been due to the substantial increase in net primary production, led by the increase in atmospheric CO2 concentrations and nitrogen deposition.

[1] *Martin and Haggith, 2018. "The state of global paper market industry"*

https://environmentalpaper.org/wp-content/uploads/2018/04/StateOfTheGlobalPaperIndustry2018_FullReport-Final-1.pdf

[2] *Nabuurs et al., 2008. "Temporal evolution of the European forest sector carbon sink from 1950 to 1999"*

https://onlinelibrary.wiley.com/doi/abs/10.1046/j.1365-2486.2003.00570.x

According to the Landmark Report (2021) released by the United Nations, climate change is expected to worsen over the next century as greenhouse gas emissions continue to increase, this is a trend that according to some experts will have important consequences for the health of forests worldwide. According to the report at North Carolina State's College of Natural Resources Scheller (2021) is examining the impacts of climate change and human activities on long-term landscape health and developing models to predict landscape changes to inform policy and management decision makers.

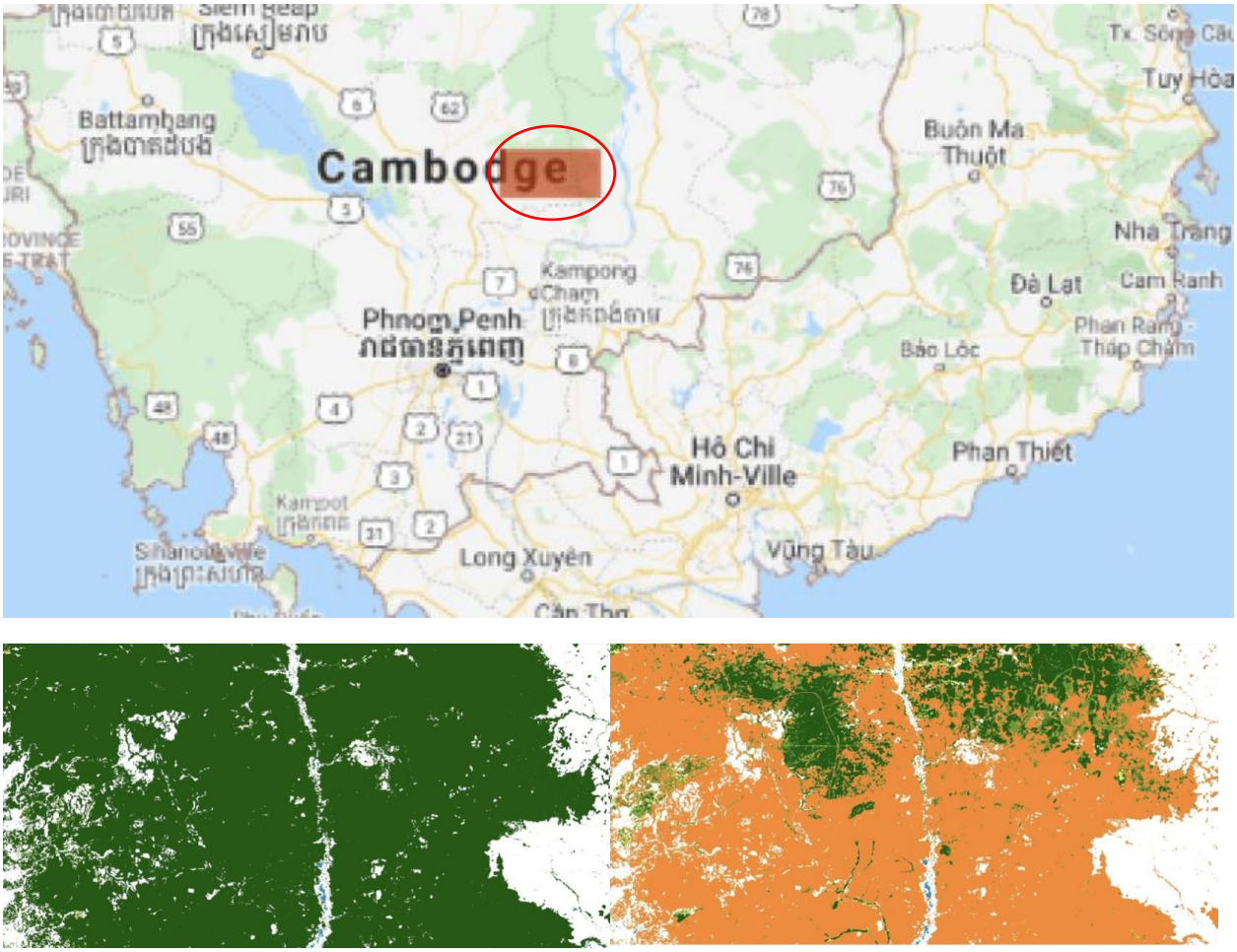

Figure 5: Images (L-R) show selected 65 km wide area in Cambodia, satellite images from 1990, and satellite images from 2019, the orange areas reflecting the change over time in deforestation mostly due to conversion to rubber plantations By Vancutsem et.al., 2021.

Methodology of satellite images comparison was used in the study of Long-term (1990–2019) monitoring of forest cover changes in the humid tropics by Vancutsem et al., (2021)[1].

[1] *Vancutsem et.al., 2021. Long-term (1990–2019) monitoring of forest cover changes in the humid tropics* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7935368/

This study suggests that fast and decisive actions are needed to prevent the initial degradation that leads to forest loss in 45% of the cases. One of the very visible examples in the study is the Cambodian deforestation scale since 1990.

In their research Vancutsem et.al., (2021) are using satellite images to determine climate change effects on the humid tropical forests. They document different scales of changes (degradation, deforestation, and recovery) of humid tropical forests over the past three decades. They estimated that 17% of tropical moist forests have disappeared since 1990 with a remaining area of 1071 million hectares in 2019, from which 10% are degraded. This study shows the importance of the degradation process in these ecosystems as a predecessor of deforestation, and in the recent increase of tropical moist forest disturbances (natural and anthropogenic degradation or deforestation).

2.4. New EU Forest strategy for 2030

The new EU forest strategy for 2030 is one of the important and interesting initiatives of the European Green Deal and is built on the EU biodiversity strategy for 2030. The strategy will contribute to achieving the EU's biodiversity objectives as well as greenhouse gas emission reduction target of at least 55% by 2030 and climate neutrality by 2050. (Tamma et al., 2019). In 2020 the European Parliament supported the deal as well, with requests for higher ambitions with environmental measures. The Green Deal has measures to help non-developed nations to not stay behind in the transition to renewable energy.

The European Green is the document which promotes the use of energy efficient technologies and moving to a cleaner and sustainable economy which will help stopping climate change, the aims of the document are recovering biodiversity and decreasing environmental pollution as well. It outlines different investments which are needed as financing tools, which will ensure a comprehensive transition. The European Green Deal covers all sectors of the economy, especially energy, agriculture, transport, construction, and industries such as steel, cement, ICT, textiles, and chemicals (Tamma et al., 2019).

The smooth and successful transition to renewable energy is one of the main priorities for the European Union. The EU Member States are trying to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels. And in an ideal situation to become climate neutral by 2050 (Jaeger et al., 2021).

The Proposal for a new Regulation to control EU-driven deforestation and forest degradation sets strong mandatory due diligence rules for companies that want to place relevant products on the EU market or export them. Importers and traders will have to have special proof that the products are deforestation-free (produced after 31 December 2020) and legal as well. Companies will also be required to collect precise geographical information on the farmland where the commodities that they source have been grown, so that these commodities can be checked for compliance (European Commission, 2022). Within the many strengths there is one important point from an economic standpoint, many critics say that the money guaranteed for the green transition is not enough. According to the European Commission information the whole of Europe needs an investment of €260 billion annually to achieve its 2030 energy targets, which is more than double the current €100 billion investment per year (De Sousa, 2022).

2.5. Forestation and habitat change

Within the climate change patterns some plant species are changing their habitats and are migrating to the areas where they don't typically grow. This phenomenon is clearly visible on the satellite images researched within the work below.

Climate change can create different habitats for tree species and make their existing habitats unsuitable for their growth. Like all other living things, trees seek suitable environments for their survival. Some tree species are moving on the upper elevations and northward as temperatures increase every year, while some other species of the trees are changing their habitat to lower elevations, they move westward as well because of the precipitation difference. (Seppälä and Panel, 2009).

In their research "Forest productivity under climate change" (2011) Medlyn and Duursma are discussing and defining climate change effects on plants and on the different crucial processes, such as photosynthesis. In this study a special checklist is provided by using them it is possible to evaluate and model climate changes regarding forest productivity.

As a conclusion of this study climate change is highly likely to impact on forest productivity over the next century. Warmer temperatures increase the time for photosynthesizes and this can lead to enhanced forest growth with increased forest productivity and carbon sequestration (Medlyn and Duursma, 2011).

3. Climate Change overview in Georgia and in the Czech Republic

3.1. Climate change in Georgia

Georgia is located at the crossroad of the Mediterranean from south-west, arid Aral-Caspian depression, and Forward Asia highlands from east and south with continental climate. This special location, various topography and elevation differences, landscape and flora created a big diversity of climate patterns. The territory of Georgia is mountainous in the north and south, it has steep terrain and lowlands. Part of the lowlands is at sea level in the west of the country, and some of the peaks of mountain ridges reach over 5000 meters above sea level. The Great Caucasus ridge stretches from north-west to south-east. In the southern part of Georgia is located South Georgian Highlands. (Part of the Lesser Caucasus) (Elizbarashvili et.al., 2017).

The orographic diversity of Georgian territory, along with other physical-geographical factors, mineral types and geology are creating a wide variety of climate types and landscapes. There are almost all types of climates in Georgia, from the climate of permanent snows of high mountains with glaciers to the steppe continental climate of eastern Georgia and in the west of the country it is possible to find humid subtropical climate close to Black Sea coastline (Climate and climatic resources of Georgia, 1971).

Georgian Climate change has been the subject of comprehensive studies in this century, the country has a big climatic diversity which makes this field of study more interesting. Within the study done by Elizbarashvili et.al. (2017) special geo-information maps were created showing mean temperature and precipitation decadal patterns for the 1936-2012 years period and Georgian territory was distributed into different zones. For each zone climate indicating main trends have been studied. For example, hot days, cold days, tropical nights, precipitation intensity simple index, precipitation days, rainy or rainless periods that best characterize climate change. (Elizbarashvili et.al., 2017) [1].

According to the study, if we consider Georgian climate change current trends, precipitation amounts on the Black Sea coastline as well as some parts of western Georgia will increase by 50% and will reach 6,000mm respectively, this will strengthen humidity of those areas. Besides, increasing the rainy period duration may constitute the risk for more frequent flooding and high-water levels. According to the study, if the climatic patterns continue to change in the eastern part of Georgia, especially in Kvemo Kartli region, annual precipitation amounts will decrease by 50% or even more, and will be only 150 to 200 mm. This will increase the intensity of issues created by climate change, including desertification of steppe and semi-desert landscapes of Georgia.

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[1] *Elizbarashvili et.al., 2017. "Georgian Climate Change under Global Warming Conditions"*

https://www.researchgate.net/publication/313580659_Georgian_Climate_Change_under_Global_Warming_Conditions

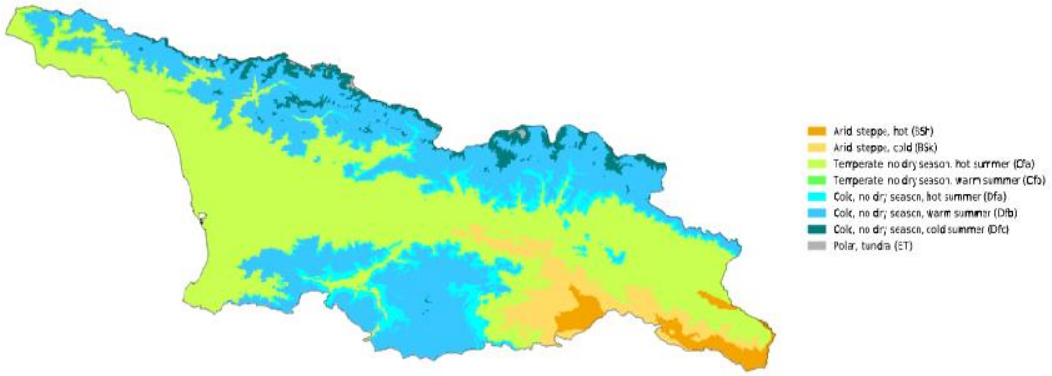

Figure 6: Köppen Geiger climate classification map of Georgia by Beck,2018.

Figure 6 shows Köppen Geiger climate classification map of Georgia (Beck., 2018.) Main results of global warming in Georgia can be a significant rise of air temperature in the eastern continental part of Georgia. Changing of the patterns in east and west of Georgia can cause various problems for forests in both areas. (Elizbarashvili et al., 2017).

On most of the territory of eastern Georgia annual precipitations have decreased per decade with a rate of 1-3%. The largest decrease is observed in the Kvemo Kartli region, south of Tbilisi city, the decrease in the region is more than 5%. In the extreme edge of the eastern part of Georgia, terrain is characterized by steppe and semi-desert landscapes, at the same time it needs to be mentioned that in most parts of western Georgia, a significant change in precipitation averages hasn't been observed.

The annual precipitation sum increasing is observed in only some parts of Western Georgia- especially in the central part of Colchis lowland, the eastern part of Adjara region, as well as in the central part of the Iori Plateau in Eastern Georgia, where the ten-day trend of annual precipitation was 1-3%. In the mountainous Adjara and in some areas of the Black Sea coastline precipitation increase rate is quite significant with around 5%. (Elizbarashvili et al., 2017).

This temperature and precipitation patterns in both part of Georgia (West & East) shows the trends which can cause significant problems for the forests and agriculture especially in the Eastern part of the country. Lower precipitation and higher temperatures can make wildfires more intensive and make significant changes in forest productivity, less precipitation automatically can cause less productivity of the forest and with more frequent wildfires it can cause forest loss. Agriculture is a vulnerable field even now since most of the Eastern or South Georgian lands need irrigation for growing crops and with a 50% decrease of precipitation it will make agriculture more difficult. (Megrelidze., 2021) [1].

[1] *Megrelidze et.al., 2021. "Impact of Climate Change on Some Agricultural Crops Distribution and Productivity in Georgia"*

https://www.researchgate.net/publication/351788873_Impact_of_Climate_Change_on_Some_Agricultural_Crops_Distribution_and_Productivity_in_Georgia

3.2. Climate change in the Czech Republic

There is a temperate climate in the Czech Republic, the country is situated in the bordering zone between the oceanic and continental climate types, with warm summers and cold, mostly cloudy and snowy winters. The Czech Republic's landlocked geographical position is creating the high temperature differences between summer and winter seasons. Temperatures vary depending on the elevation as well. In general, at higher altitudes of the Czech Republic, the temperatures decrease, and precipitation patterns increase. The wettest area in the Czech Republic is located around Bílý Potok in Jizera Mountains, these mountains are in the Western Sudetes on the border between the Czech Republic and Poland, and the driest region of the country is the Louny District to the northwest of Prague. Another climate-creating factor is the distribution of the mountains. (Tolasz, 2007) [1].

The coldest month is usually January in the country, followed by February and December months. During these months, there is mostly snow in the mountains and sometimes in the cities and lowlands, more rarely in Prague. During the Spring months the temperature usually increases, especially during April, when the temperature and weather tends to vary during the day and is characterized by fast changes. In Spring there is usually higher water levels in the Czech Republic rivers, because of melting snow in mountains within the rising temperatures, this often causes occasional flooding. The largest flood in the recent history of the country happened in 2002. The warmest month of the year in the country is July, followed by the second warmest month in August and June. On average, summer temperatures are about 20–30 °C higher than during winter months. Rain and storms are usual in the Summer.

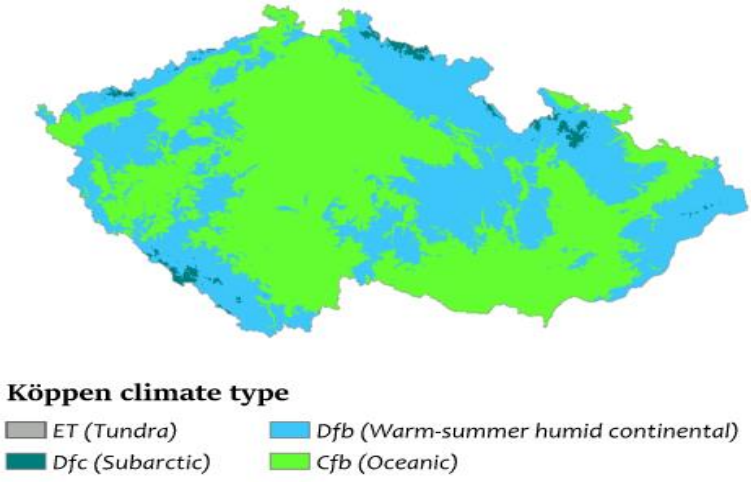

Figure 7: Köppen Geiger climate classification map of Czech Republic by Beck, 2018.

[1] *Tolasz, 2007. "Climate Atlas of the Czech Republic"*

https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/wea.126

Most rain falls during the summer. Irregular rainfall is throughout the year (for example in Prague, the average number of days per month experiencing at least 0.1 mm of rain varies from 12 in September and October to 16 in November) but concentrated rainfall (days with more than 10 mm per day) is more frequent in the months of May to August (average around two such days per month). (Tolasz, 2007).

The Czech Republic is vulnerable to the negative impacts of climate change from increase in temperature, decrease in precipitation, and at same time increase in the risk of frequent occurrence of extreme weather events. These will impact the country's agriculture and forestry sectors and partly also affect the state of health of the population. Average temperatures in the Czech Republic have been rising at a faster rate than the world averages in this century. According to the studies, warming will continue until the end of the 21st century, causing summer temperatures to rise more quickly and intensively than winter temperatures. (Maanen et.al., 2021) [1].

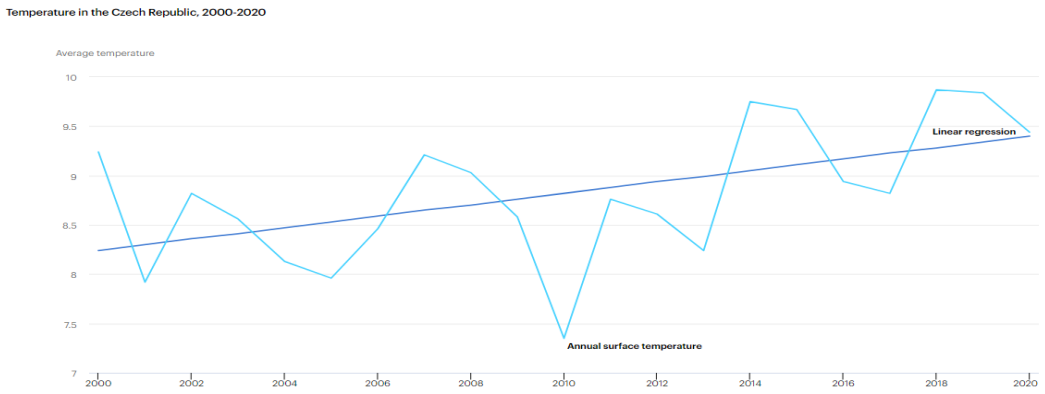

Figure 8: Average temperature increase of Czech Republic in 2000-2020 by Maanen et.al.,2021

Changes in temperature and precipitation patterns are significantly affecting the occurrence and frequency of droughts. The increase of the number of drought events is expected to be most visible and intensive in areas where a higher number of droughts occur already, such as the South Moravian region and the north-western part of the Central Bohemian region.

Potopová et al.,[2] 2012. suggested that a shortage of rainfall is the primary reason for drought development during the autumn seasons in the Czech Republic. Drought can have huge impacts on population, including impacts on economics, agriculture or forests. Another important feature of droughts is their time scales and frequency, usually they vary substantially.

[1] *Maanen et al., 2021. "Climate Impacts in the Czech Republic"* https://www.klimazaloba.cz/wp-content/uploads/2021/03/FINAL_impact-profile-Czech-Republic.pdf

[2] *Potopová et al., 2012. Drought at various time scales in the lowland regions and their impact on vegetable crops in the Czech Republic* (1) (PDF) Drought at various time scales in the lowland regions and their impact on vegetable crops in the Czech Republic (researchgate.net)

According to the study of (Potopová et al., 2012), the role of temperature was clear in summer drought episodes that depend on temperature anomalies and droughts, this is usually contributing to a higher water demand.

There are different types of floods in the Czech Republic annually. Winter and spring floods are caused mainly by snowmelt in the mountains and at the same time precipitation, while summer floods are caused by long regional rainfalls or intensive short-term precipitation. The negative impacts of floods on local communities, agriculture and energy infrastructure were demonstrated in August 2010, when flash floods struck central Europe and left thousands of people in the northern Czech Republic without electricity or gas. (Disaster Risk Management Summary Report, 2020) [1].

[3] *Disaster Risk Management Summary Report – Czech Republic, 2020*
file:///C:/Users/user/Downloads/DisasterRiskManagement_SummaryReport_2020-12-11_FINAL%20(1).pdf

4. Methodology

Different quantitative and qualitative methods were used during the research for better understanding of the problems in temperate forests connected to climate change and finding solutions.

Measuring and mapping of forest degradation have become important tasks for determination and prevention of the deforestation and degradation process.

4.1. Satellite images

One of the methods to determine different patterns of changing climate in the forests was to visualize satellite images and compare them in different times within the last 20 years. Only free, publicly available data was used from Google Earth satellite images. Google Earth is a useful computer program with various functions. It can render a 3D representation of Earth which is mostly based on satellite images. The program can map the Earth by overlaying satellite images, as well as with different aerial photography, this allows users to see forests, urban areas, and landscapes from various angles. By this way we could compare the condition and amount of the forests in the Czech Republic and Georgia. From the satellite images it is possible to determine deforestation and newly forested areas on different locations. Google Earth software gave us the possibility to travel in time to the specific location and compare the frequency of the forest cover and clearly see wildfire event results. During the work some layers were removed from the imagery, for example borders, settlement names or other possible disturbances to visualize forest conditions. Image resolution usually ranges from 15 meters to 15 centimeters of resolution. In most cases Google Earth uses digital elevation model data which is collected by NASA's Shuttle Radar Topography Mission.

We should mention that Google Earth is not a just tool for observing physical conditions of the earth terrain, but it can find climate change patterns as well, same time it is one of the important tools online the world to help society for better understanding the problems caused by the changing our planet's climatic conditions. To contribute to our planet's sustainability Google Earth has created Google Earth Outreach, which is an important charity program. With this program Google promotes and donates to various non-profit organizations for various projects. (Plotkin, 2011) [2].

[1] *Kilday, 2018. "Never Lost Again: The Google Mapping Revolution"* https://www.perlego.com/book/660272/never-lost-again-pdf

[2] *Plotkin, 2011. "Amazon Conservation Team Project with Surui Indians and Google Earth"* https://www.comminit.com/global/content/amazon-conservation-team-project-surui-indians-and-google-earth

One of the important offerings of Google Earth Outreach is online training on how to use Google Earth and Google Maps for public education on different issues which are affecting local communities in the entire globe. In June 2008, training was given to 20 indigenous tribesmen in the Amazon rainforest, named Suruí, to help them preserve their culture and raise awareness about modern problems of deforestation. (Plotkin, 2011).

For the satellite images method Google article "Exploring Global Awareness Layers in Google Earth" (2022) by the online platform breakoutofthebox.com was used, it describes Google Earth program possibilities and advantages regarding the collecting data for different types of research. It mentions similar methodology to determine deforestation problems to help 20 indigenous tribes in the Amazon rainforest to help them preserve their culture and raise awareness for the problem of deforestation.

Within our study we've chosen a few areas in Georgia and the Czech Republic to compare the condition of forests from 2000 until 2022. Areas are chosen to cover different elevations, geography, and climatic conditions to have the possibility of analyzing them and comparing them to each other. Since on every individual geography the changes are observed within different time ranges there is not universal time chosen for comparison, for some of them short time range is enough for determination significant changes, when in other areas the changes took decades.

4.2. Field trips

Field trips were conducted visits was held for determination and observation of forest fires and bark eater beetle *(Scolytinae)* activities in both of countries different times. In the Czech Republic Bohemian Switzerland National Park was visited in the northwest part of the country, as well as Moravian Forests in the East of the country. Different observations were made, and digital materials were collected. Digital material consists of pictures which were taken to collect the data of the damaged trees, burned areas and logged trees.

In Georgia south part of the country was visited which is most vulnerable with climate change problems according to different studies. During the field trips in Georgia the important source of the information was local authorities in Borjomi-Kharagauli National Park. They provide detailed information about the current conditions of the forests and described methodology for how determination and monitoring of the forests is conducted within the administration management plan. Different digital materials were collected.

4.3. Fire danger index calculation

In the thesis to determine fire danger classification methodology of Možný and Bares (2013) was used from their original study. Možný and Bares (2013), created the Fire Danger Index for the whole Czech Republic.

In the original study of Možný and Bares (2013) the Fire Danger Index (FDI) was calculated for the whole country. For the calculation special formula was used:

$$\mathrm{FDI} = (-0.4\,W + 1.15)\,F,$$

In this formula *F* is the simple fire danger index (Sharples et al. 2009) and *W* is the model soil moisture percentage (% of available water capacity) in the soil layer 0–10 cm (Možný and Bares 2013). According to this method the simple fire danger index F is calculated using:

$$F = U/(10-0.25\,(T-H)),$$

where T represents the daily maximum air temperature (°C), H is the daily minimum of relative humidity (%), and U stands for the daily maximum of wind speed (km h−1).

Region (code)	Mean annual temperature (°C)	Mean annual precipitation (mm)	Altitudinal interval (m asl)	Area (km^2)	Population density (people per km^2)
20	8.6	587	153–865	11,016	120
31	7.4	687	350–1378	10,058	63
32	7.6	684	250–1370	7561	76
41	6.8	747	320–1244	3314	90
42	8.2	636	113–1225	5335	154
51	7.4	893	208–1435	3163	139
52	7.8	760	202–1602	4759	116
53	7.9	702	201–1424	4519	114
63	7.4	673	239–837	6796	75
64	8.9	559	150–819	7195	163
71	7.8	708	190–1491	5267	121
72	8.2	775	173–1205	3963	148
80	7.7	802	195–1491	5428	224

Figure 9: Mean annual air temperatures and precipitation totals for the 1981–2010 period with the altitudinal range, area and population density of the individual Czech regions (Možný et.al., 2021)

The FDI divides danger levels into a different five-part scale, as shown in Figure 10. For each day, the fire danger class was calculated.

Within the thesis using the same method Fire Danger Index for the two different regions of the Czech Republic were calculated and analyzed in the 1991–2022 period. Specially vulnerable months with wildfire danger April to September were studied.

Fire danger class	FDI
1 – Very low	< 1.0
2 – Low	1.0-1.7
3 – Moderate	1.7-3.0
4 – High	3.1-6.0
5 – Very high	> 6.0

Figure 10. Fire Danger classification thresholds for FDI values (Možný and Bares 2013)

Data for the FDI of Ústí nad Labem and Holešov regions was provide by the thesis supervisor Doc. Dr. Mgr. Vera Potopová for the 1991–2022 period.

This method, which is provided by Možný et.al. (2021) was helpful source for understanding the increasing wildfire intensity and its connection with different climate changing patterns.

4.4. Determination of the awareness by questionnaire

One goal of the work was to determine awareness of society about climate change and its effects on the forests, its conditions and amount. The purpose of this work is not to determine target groups of the answer authors, their origin, or any personal data. This work aims to just collect very general data about very tiny parts of societies and the results can't be generalized on a larger scale. For better understanding of society awareness, a bigger scale survey with a larger number of respondents is needed. The survey contains 14 different questions, and they are seeking to determine awareness of people about the existence of climate change, its negative effects. Questions are connected to how much climate change threatens people's personal health and safety, same time how the conditions and development of forests are connected to climate change events or global warming. By using questionnaire different questions work is aiming to have better conclusion about the problem solving. It can help the environmentalists to plan their prevention activities and awareness rising activities better if the level of awareness is known. The questionnaire aims to determine if individuals ever participate in any action against climate change. Main target of audience was the society with any ties to the topic of climate change or forests conservation. The goal of the questionnaire was not to aggregate, describe and analyze response authors themselves but to get the information about the general awareness about the climate change, its importance and social awareness about the connections of two main topics of the thesis work – the climate change and its effect on the forests. Questionnaire was sent using email to people from both of countries the Czech Republic and Georgia. A total number of 50 people were interviewed.

5. Results

5.1. Satellite images comparison results

5.1.1. Satellite images comparison - Georgia

For understanding Climate change and improving the situation satellite measurements of Earth's temperature, measuring greenhouse gas emissions and sea levels are crucial. Precise data and other inputs provided by satellites are crucial for environmentalists and scientists to understand, determine, analyze, and predict the impact of climate change, while at the same time policymakers won't be able to create effective strategies. There are 162 "climate satellites" that are pulling data together from the World Meteorological Organization, NASA, NOAA, and other operators (Purwar, 2022) [1].

In each area chosen within our study a different kind of effect is visible from deforestation to wildfire caused forest type change or to the growing new forests on the high elevation subalpine meadows where there were not forests before.

Foresting of the highland meadows is not only visible from the satellite but by the bare eyes, during the discussion with the biodiversity expert Levan Tabunidze from the Biodiversity Monitoring Center NACRES of Georgia he describes his experience working in Borjomi-Kharagauli National Park during 2004-2018 years, that surrounding area of Lomismta Mountain (2,198m) has forested in last 15 years and during his early years most of this mountain was subalpine and alpine meadows.

At this place shown on Figure 11 changing habitat is even visible in the last 3 years. If we take a 400 square meters study area the increase of trees and bushes are visible on the meadow, if we put white dot next to the tree kind of plant, we will see that it has increased from 9 to 13 units.

Figure 11. Lomismta mountain surrounding meadow (1,985m above the sea level) (X 41.871280°; Y 43.255507°)

[1] *Purwar, 2022. "Role of Satellite Data in Monitoring Climate Change"*

https://blueskyhq.io/blog/assessing-satellite-data-and-its-role-in-monitoring-climate-change#close-cookie

Another study area is shown on Figure 12 in South Georgia, close to village Tsagveri where different wildfires have happened in the last 20 years. The first big fire in the forest had occurred in 2008 during the war between Georgia and Russia, since then territory still reforested with different types of trees. Before the first fire it was mostly forested by the coniferous species Caucasian spruce *(Latin: Picea orientalis)* and local species of pine tree *(Latin: Pinus sosnowskyi),* after it was burnt deciduous trees European hornbeam *(Latin: Carpinus betulus)* and oriental beech *(Latin: Fagus orientalis)* became dominant, but during the dry summer of 2017 there was wildfire, and this forest has burnt again. Now in the picture it is clear how much area of natural forest was burnt.

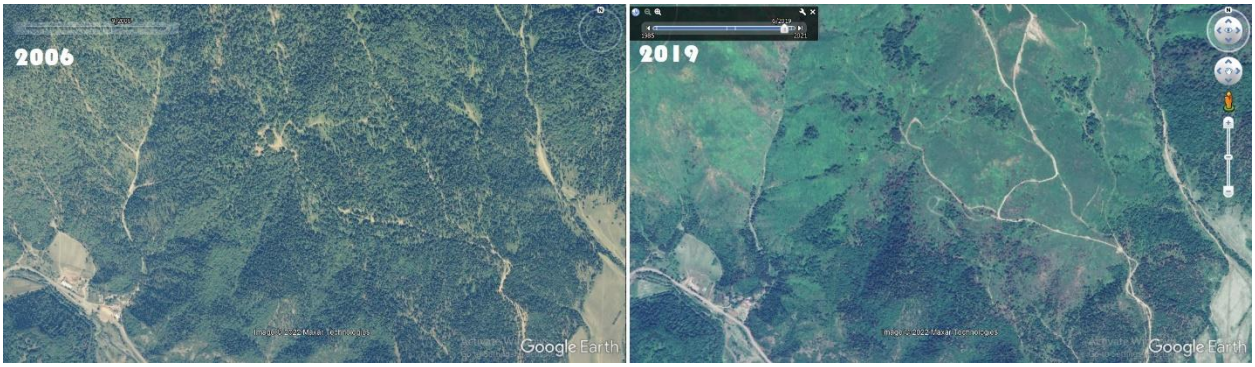

Figure 12: Deforested area near Tsagveri village, South Georgia (X 41.812605°; Y 43.480233°)

Forest fires are one of the most visible and probable effects of climate change on the forests in our geography. Thousands of hectares of forests are lost in Georgia. One of the last important wildfire events happened in August 2022 where the author of the research himself witnessed the devastating effects of the wildfire around his community, where more than 500 hectares of the forest was burnt in 5 days. According to NASA satellite data the fire was covering the areas marked in white on Figure 13.

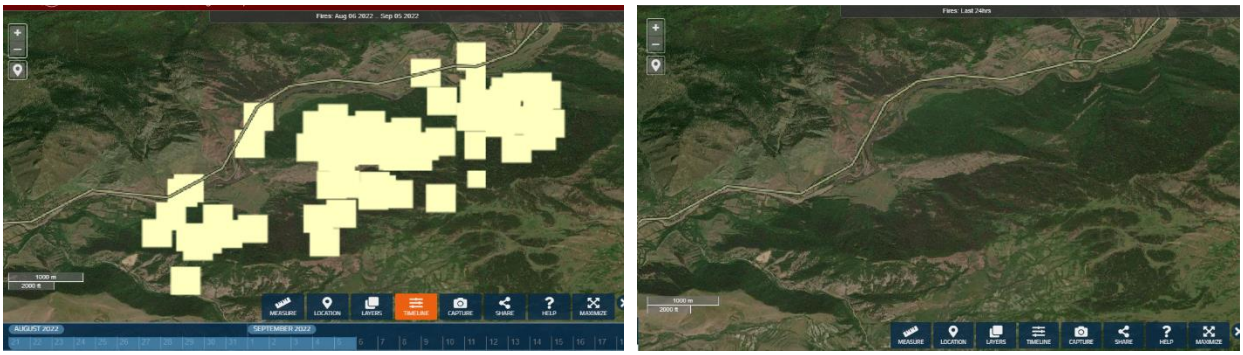

Figure 13: Latest wildfire pictures according NASA images near Kvabiskhevi village, South Georgia (X 41.752517°; 43.222881°)

Usually in Georgia there is the problem of big size air tactical or air attack planes which are coordinating aerial firefighting aircraft over wildland fires. Usually, Turkey and Ukraine are the countries that help the country when there are large forest fires, but usually it takes time.

One of the major forest fires in Georgia happened in 2010 near the village Atskuri at the border of Borjomi-Kharagauli National Park. The results clearly can be seen in Figure 14. It started in August as most of the country's wildfires were due to high temperatures and little amount of precipitation. On the satellite images we can clearly see how the forest condition differs before fire and after fire. In the white circle on the picture on the right we can clearly see survived forest conditions which is in the national park, at this time firefighters service, part of army and volunteers have managed to don't spread the forest fire on the territories of Borjomi-Kharagauli National Park which has largest untouched wild forest areas in the region. The current condition of the forest is getting better, but the species are lost and only a few species of deciduous trees (Latin: Carpinus betulus, Fagus orientalis) have survived.

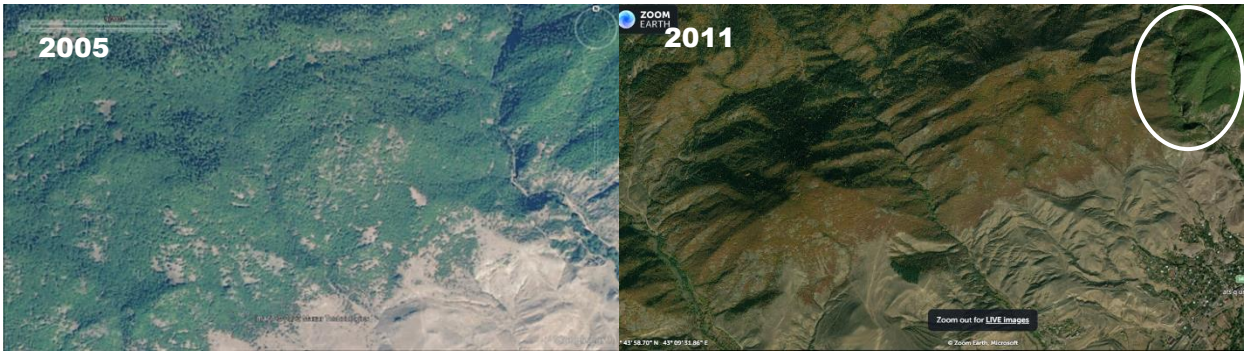

Figure 14. Atskuri forest fire results (X41.746270°; Y43.142616°)

Excellent example of the new forest at subalpine meadows can be seen on Figure 15 at the study area near Abastumani town, Georgia. On the slopes between elevations 1800 and 2000 above sea level the area has significant increase of forest cover between the years July 2006 and September 2021.

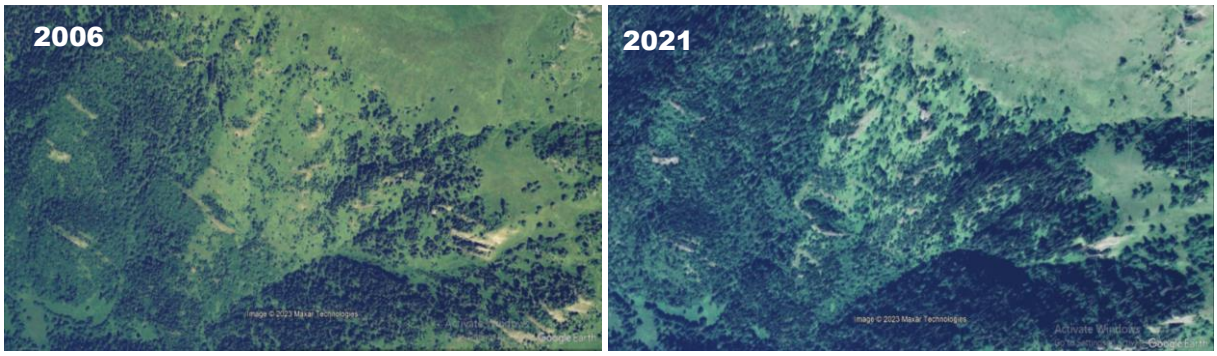

Figure 15. Forested subalpine meadows due to global warming near Abastumani resort, Georgia (X41.842221°; Y42.767706°)

5.1.2. Satellite images comparison – Czech Republic

Many comprehensive studies have been done about forests in the Czech Republic within the framework of social sciences, especially in relation to environmental problems with one of the most important global climate changes. Bark beetles that infest and reproduce in live trees can cause landscape-wide tree mortality with large scales. Larval development and cold hardening of bark beetles significantly is affected by temperature, including other physiological processes. Because of this fact temperatures and population growth of beetles are strongly connected. Usually, higher temperatures mean higher survival rates and faster development, but there are certain warmer temperature limits when the development and survival rates go down.

The North-West part of Czech Republic, where Bohemian-Switzerland National Park is located, is a very clear example of climate warming's negative effect on the forests. According to Hlásny et al., (2021) only in the 5 years period from 2016 to 2021 thousands of hectares of forest were killed by bark beetles. Study done by Hlásny et. al., (2021) found that bark beetles were damaging 0.2 -- 1.4% of Norway spruce *(Latin: Picea abies)* growing stock annually across the Czech Republic in the period 2003–2016. This level of the killing trees has increased to 3.1–5.4% in 2017–2019, causing the total loss of spruce in some regions. Figure 16 shows a large scale of deforestation near the Svor municipality area. Even on satellite remote observation it is clear to see deforested areas from 2016 to 2021. On different areas deforestation takes different time, at this location it is quite fast and happened with short range of 5 years period. According to Czech Forest Owners' Association (SVOL) in 2019 the record levels of draught have put more than one million hectares of forests under the risk of deforestation in the Czech Republic.

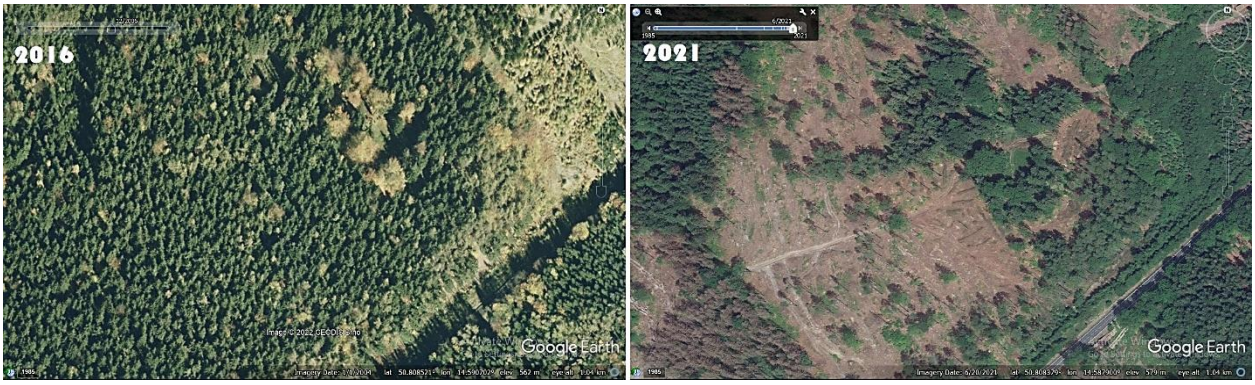

Figure 16. Satellite image of the study area near Svor Municipality (X 50.807841°; Y14.587173°)

Bohemian Switzerland National Park forests were not damaged only by the bark eater beetle activity but by the devastating forest fires in different times. The 2022 forest fire was one of the strongest and wild scale forest fires in the Czech Republic's history, and the Czech authorities requested help from different European countries. For the rescue operation Sweden, Italy and Slovakia sent different types of planes, helicopters, and various numbers of personnel. (Tait, 2022).

Figure 17. Forest fire actual picture from satellite by "Planet"

During these extreme fire events in the Bohemian Switzerland National Park more than 1,400ha of forest was lost (Milanovič et.al.,2022)[1]. Observed territory of 1,500 square meters was intensively forested before 2016 and in a 5-year period most of the forest is lost. Trees were killed by the European spruce bark beetle *(Latin: Ips typographus)* which is the most aggressive bark beetle in Eurasia (Hlásny et al., 2021)[2].

Tree logging effect is clearly visible in the satellite images of Czech Forests. According to state-owned company Lesy ČR, which owns nearly a half of all woodland in the Czech Republic, a record number of 35.8 million cubic meters of wood was cut in the Czech Republic in 2020, according to their data the amount of wood being cut down annually has been growing every and is strongly connected to the bark beetle infestation which is ravaging Czech forests. This is not only an environmental problem for the country but economic damage as well for the financial market. Prices of the firewood is dropping with fast speed in the Czech Republic according to the Czech Statistics Agency, for example from 2019 to 2020, the price of firewood from conifers dropped from CZK 722 per cubic meter to just CZK 423.

[1] *Milanovič et.al.,2022. "Modeling and Mapping of Forest Fire Occurrence in the Lower Silesian Voivodeship of Poland Based on Machine Learning Methods"* https://www.mdpi.com/1999-4907/14/1/46/pdf

[2] *Hlásny et al., (2021). Devastating outbreak of bark beetles in the Czech Republic: Drivers, impacts, and management implications*

https://www.researchgate.net/publication/350089271_Devastating_outbreak_of_bark_beetles_in_the_Czech_Republic_Drivers_impacts_and_management_implications

Next remote study site is in the Plzeň Region, near the municipality of Chotěšov. Figure 18 shows satellite images where it is clear how completely cut down territories are added on the landscape from 2008 till 2021 when a second satellite image is taken for comparison. Still, it is a non-direct effect of climate change but according to Hlásny et al. (2021) bark beetles *(Latin: Ips typographus)* which is promoted by global warming is the most aggressive bark beetle in Eurasia and damaging Czech forests with enormous scale. Bark beetle number dynamics (2003-2019) was caused by the combination of two main reasons: the combination of wind disturbance and climatic patterns. In the 2017-2019 period the effect of wind was changed by the effects of droughts as a main reason for the wildfires. Možný et.al. (2021) concluded that population growth in the wildland-urban areas is strongly connected to the frequency of vegetation fires. However, the main reason for the statistically significant increase in the frequency of wildfires is the ongoing climate change patterns, which is presented by an increase in values of the Fire Danger Index and heat wave occurrence.

Figure 18. Forested area near Chotěšov with the disappeared areas (X49.250006° Y 13.342924°)

Forests are stressed significantly in the Kolin District area. According to Figure 19. We can see how much of the forest was lost from 2006 to 2021 in the areas between two municipalities: Nučice is a municipality and Barchovice municipality.

Figure 19. Deforestation example from the Kolin district of Czech Republic (X 49.952043°; 14.948513°)

Droughts increasingly threaten the Moravian forests, it promotes pathogens and pests which are massively killing mostly coniferous trees in the region (Bednárová et al., 2020)[1]. This condition was clearly visible during the site visits as well in the surrounding areas of Vsetin district and Holešov. After searching the satellite images for comparing data of last decade it is even clearer to see the devastating effects of climate change on the forests, even in the case that these effects can be not direct. According to the FAO recommendations, forest managers should assess the costs, benefits, trade-offs and practicality of climate change adaptation and mitigation actions. The possible positive or negative results achieved by the forest management should be under consideration.

[1] *Bednárová et al., 2020. „Consequences of Bark Beetle Calamity for the Future of Forestry in Central Europe"* *https://www.vulhm.cz/files/uploads/2021/04/FORESTS%C2%B4-FUTURE-2021-Minutes-2.pdf*

5.2. Fire danger for the forests

Forest fires statistics have increased significantly in the last decade. If we compare the 12 year time period from 2009 to the year of 2020 forest fires number increased 16 times. These statistics show how important the issue can be in upcoming years. Climate change is most probable the most important driver in increasing wildfire activity. Strong heat waves are happening around five times more today than they were happening 150 years ago and it is expected that they will become even more frequent as the planet continues to warm every year (MacCarthy, 2022). From 2013 to 2017 the number of the wildfires per year was more less stable and was ranging from 35 to 55. In 2018 the number of fires dropped significantly.

According to the expertise of Biodiversity Research Organization NACRES, the amount of forest fires was ranging from 10 to 15 in the first decade of XXI century, but now we can see the numbers which is giving us the reason for alarm. The degradation of forests can be connected to the climate change that promotes forest fires. Most of the wildfires are usually happening in the southern part of the country and it can be connected to the increase of temperatures and decrease of precipitation. This trend is visible on the Figure 20.

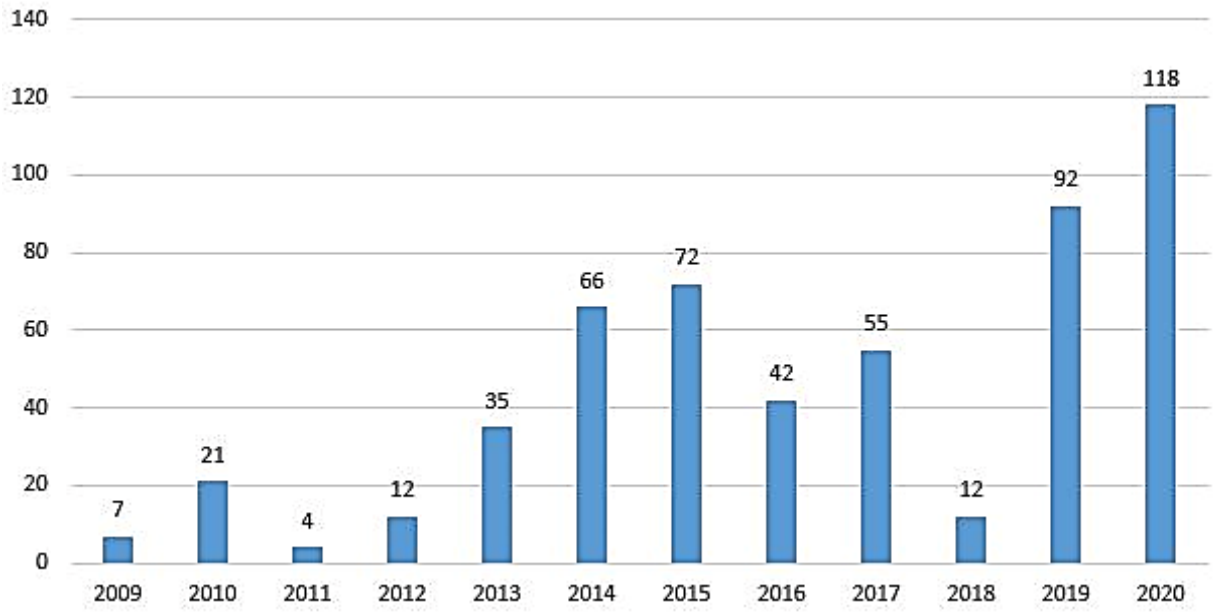

Figure 20. Forest fires statistics of Georgia in 2009-2020 years according NACRES data

Možný et.al. (2021)[1] illustrates the wildfire changes over the territory of the Czech Republic for 1971–2015 period. According to their study the frequency of wildfires depends on the weather patterns. The study shows that the frequency of wildfires has increased mostly in the warmest and driest regions of the Czech Republic. The period between 1991 and 2015 had 70% more wildfires than the period between 1971 and 1990. Similar trend is visible in all administrative regions of the country, according to study the wildfire statistics and weather conditions are directly connected. To make a seasonal forecast of wildfire danger it is possible to use the relationship between heat waves and frequency of wildfires. Statistically the frequency of wildfires is increasing in all regions of the Czech Republic. The combination of drought and heat waves (which are lasting more than 6 days continuously) is the most evident cause of wildfires which occurred for example in 1992, 2003, 2012, and 2015..

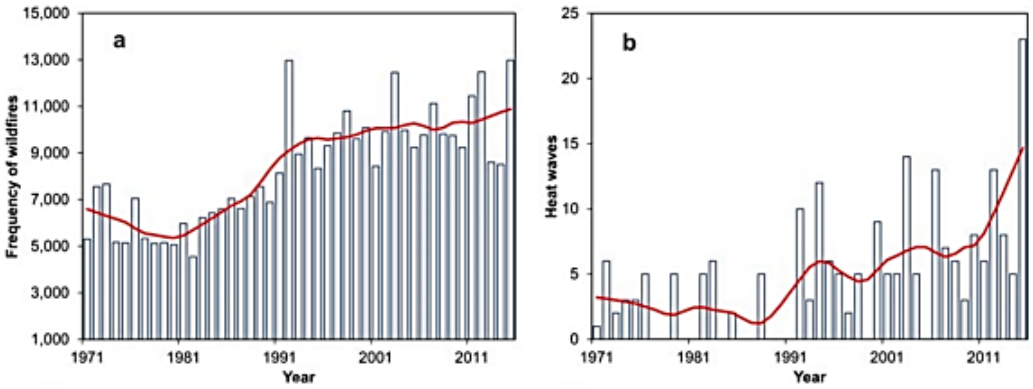

Figure 21. Fluctuations in the frequency of wildfires (a) and heat wave days (b). Figure by Možný et.al.,2021.

[1] *Možný et.al., 2021. „Climate change driven changes of vegetation fires in the Czech Republic".*

https://www.researchgate.net/publication/346490222_Climate_change_driven_changes_of_vegetation_fires_in_the_Czech_Republic

5.2.1. Fire danger index calculation results (FDI)

The fire danger index was determined for two different regions visited during the study according to Možný et al. (2021). The first region is Ústí nad Labem Region in the northern Czech Republic and the second region where FDI was calculated is in Holešov town in Kroměříž District in the Zlín Region.

Fire danger class	FDI
1 – Very low	< 1.0
2 – Low	1.0-1.7
3 – Moderate	1.7-3.0
4 – High	3.1-6.0
5 – Very high	> 6.0

Figure 32. Fire Danger classification thresholds for FDI values (Možný and Bares 2013)

According to classification given by Možný and Bares (2013), in the both of the regions there are mostly moderate or high average FDI for the period between the years of 1991-2022. In Ústí nad Labem region, most of the days of the studied period of 1991-2022 belongs to the Moderate FDI (1.7-3.0). The number of Moderate FDI (1.7-3.0) days is 4,485 (76.6%) and it is followed by High FDI (3.1-6.0) with the number of 1,157 (19,8%) days. Low FDI (1.0-1.7) was only 214 (3,6%) days out of total 5,856. Like in Ústí nad Labem in Holešov most of the days of the studied period of 1991-2022 belong to the Moderate FDI (1.7-3.0). The number of Moderate FDI (1.7-3.0) days is the same 4,485 (76.6%) and it is followed by High FDI (3.1-6.0) with the number of 1,007 (17,19%) days. This region has 150 days less with High FDI class compared to Ústí nad Labem in the period of 1991-2022. Low FDI (1.0-1.7) was only 364 (6,2%) days out of total 5,856 and there was not very low or very high class of FDI days determined in any of the region.

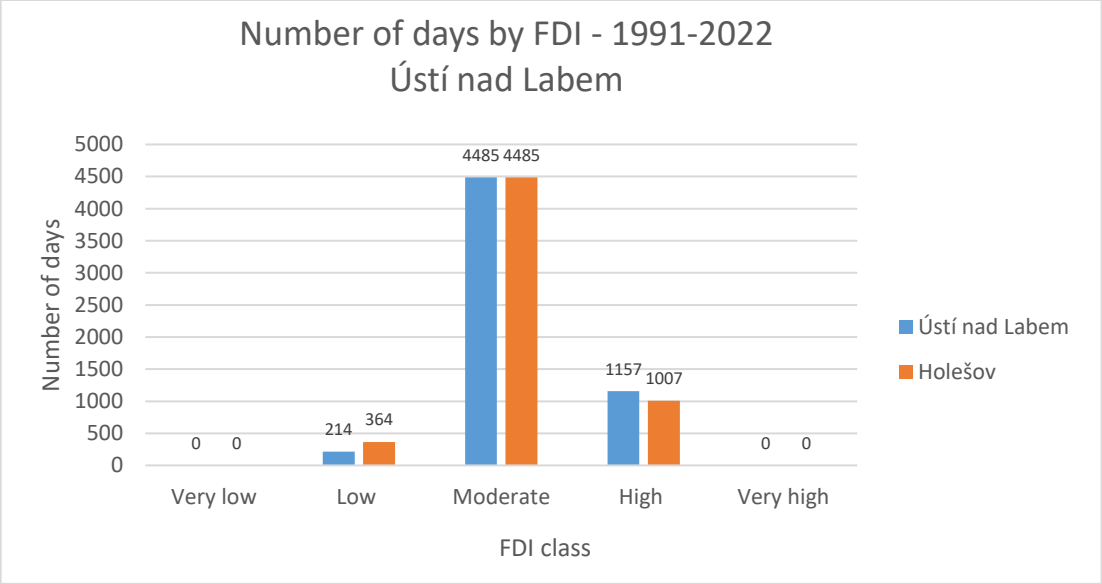

Figure 33. Comparison of number of days by the class of FDI in Ústí nad Labem and in Holešov (1991-2022)

Even in the case that Ústí nad Labem has 150 more days with high FDI (3.1-6.0) than Holešov last decade trend shows that in this Moravian town the High FDI days number is increasing more significantly compared to the data from the beginning of 1990s. This trend is clearly visible in Figure 34. since 2014 for 9 years period Holešov had a higher number of the days with high FDI for 7 years and Ústí nad Labem just two (2014, 2020).

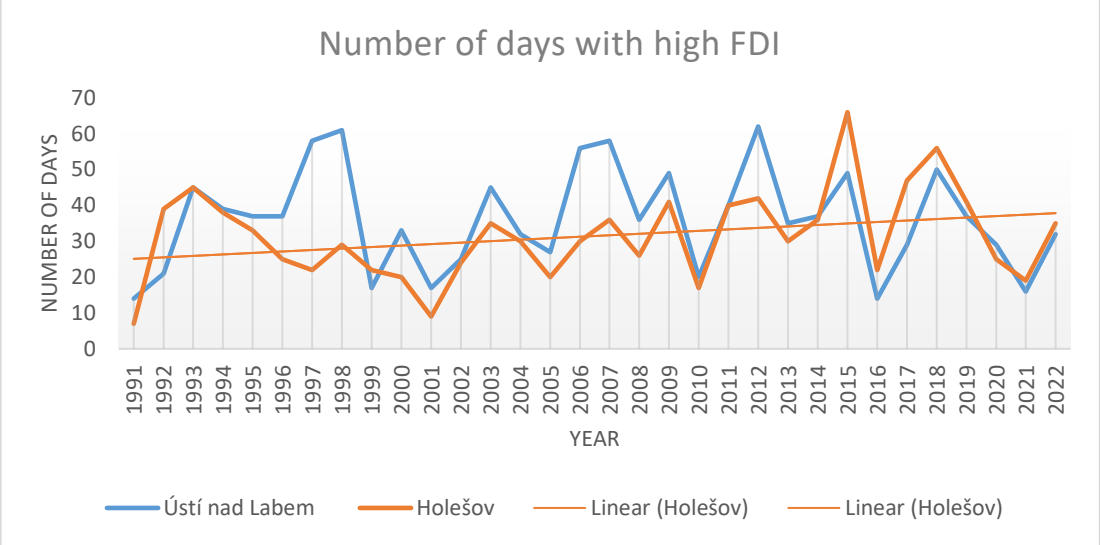

Figure 34. Trendline of the number of days by with High FDI in Ústí nad Labem and in Holešov (1991-2022)

If we compare the climate of both locations, we can see that temperature and precipitation patterns are in correlation with the trend of High FDI increase in last decade. According to climate-data.org the Köppen-Geiger climate classification in Ústí nad Labem is Cfb (subtropical highland climate). The average temperature in Ústí nad Labem is 8.2 °C. In a year, the rainfall is 798 mm. The average temperature in the warmest month July 18.1 °C in Ústí nad Labem. According to Köppen and Geiger, Holešov climate is classified as Cfb. The average annual temperature is 9.4 °C in Holešov. Annual rainfall is 689 mm, it shows that the territory is drier than Ústí nad Labem (798mm). Holešov has a yearly average temperature of 9.4°C, which is 1.2°C higher than Ústí nad Labem. Same time it is drier territory with 109mm less rainfal during the year. Those two important parameters can be the reason of the higher FDI values within the last years. In Ústí nad Labem 2012 had most of the high FDI days of 62 between the years of 1991-2022. Holešov had most of the high FDI days of 66 in 2015.

In all months instead of April Ústí nad Labem has higher averages of FDI than Holešov. On both of the locations the highest risk of the FDI is in the month of July, it has most of the FDI high class days in Ústí nad Labem and as well as in Holešov. As it was determined that Ústí nad Labem has higher risks of FDI in July with number of high FDI days of 241 than Holešov, which has same level risk days of 225 for the years 1991-2022.

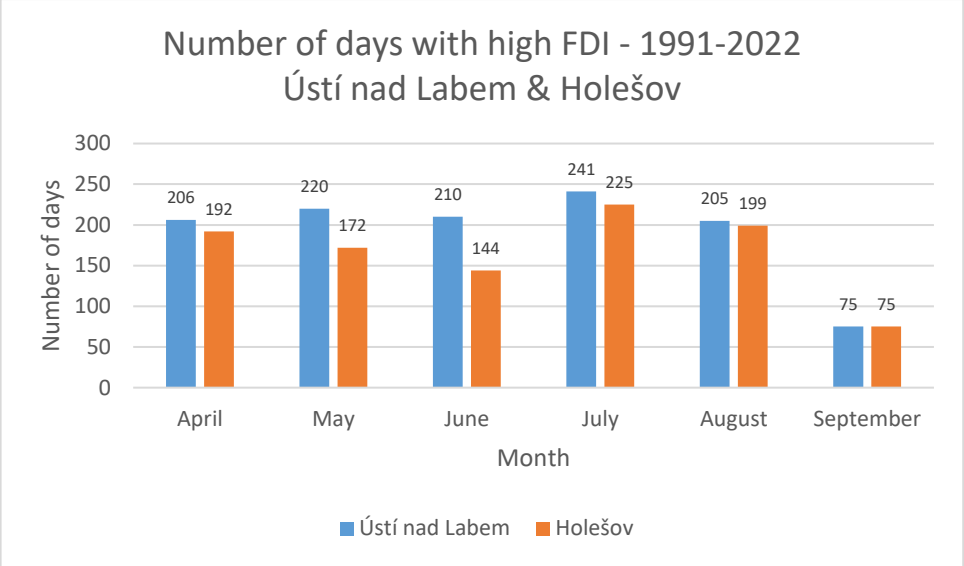

Figure 46. Number of days with high FDI for each month and total in Ústí nad Labem & Holešov (1991-2022)

On Figure 46 there is comparison of the number of days per month in both of regions. Within the work with FDI we can conclude that both regions have increasing trend of FDI and Ústí nad Labem was leading most of years before 2014 but since this year Holešov has higher amount of the days with High FDI class.

5.3. Field trips

During the research important field visits were organized for better understanding of the forest conditions and finding different climate change, or human activities effects. Field visits were planned and implemented in Georgia and the Czech Republic. In Georgia, visited areas were in the south of the country, where the most satellite images are collected. These areas have intensive climate change and human stress due to its location, climatic conditions and economical value of the forest. With the experience of 10 years working with locals in the region of Borjomi-Kharagauli National Park, it was clear how highly important the forest is for the local community as an economic value.

5.3.1. Field trips in Georgia

The anthropogenic stress on the forests is especially stronger in developing countries such as Georgia. Georgian forests are affected by climate changed patterns significantly, it includes large forest fires and massively killed trees by the six toothed bark beetle *(Latin: Ips sexdentatus)*. During the field visit, use of pheromone-baited traps for monitoring *Ips sexdentatus* was observed.

Figure 22. Pheromone-baited traps for monitoring Ips sexdentatus (2022)

The practice of illegal logging results in noticeable disturbances to forest biodiversity and soil, can damage the residual trees and reduces carbon storage. The necessary infrastructure (e.g., roads and decks) opens canopy gaps and the resulting forest edges are more susceptible to fire, droughts, and other disturbances, besides use for agricultural activities.

Local nature resources specialist of Borjomi-Kharagauli National Park, Demur Latsabidze had shared the images of illegal tree loggers who were captured and then arrested by local rangers. Wood was confiscated and according to the Georgian law of protected areas the local court will discuss the possible penalties. Law is a crucial tool to manage different forest management issues in every country, but in some cases, it is complicated and has some gaps. In Georgia by law the rangers are not allowed to directly make penalties for breaking the law of protected areas of

Georgia. They can only write reports to the local courts and judges can decide whether to use penalties or lighter “verbal reports”.

Figure 23. Illegal tree loggers in the village of Georgia (photo by local authorities). (2022)

To determine wildlife habitat, different species of mammals and forest conditions Georgian rangers are using Camera traps, which they usually are hiding in the forest to sometimes capture illegal activities as well. According to Borjomi-Kharagauli National Park report for the major donor Global Conservation we can find information about camera traps in National Park, by 2020 more than 50% of active camera traps in the National Park were purchased by Global Conservation and hundreds of photo and video data is processed by rangers. All camera traps are mapped and monitored on a daily basis.

Figure 24. Camera traps for determination and monitoring of forest conditions, pictures taken in Borjomi-Kharagauli National Park, Georgia (2022)

Using the camera traps, it is possible to compare conditions of the forest and its changes within a long range of time. For the camera installation foresters need experience and knowledge to hide it well from the possible law breakers in the forest. Camera traps were invented long before they were massively produced and used in biodiversity monitoring. Camera traps have a long and rich history. George Shiras III, an American congressman, is widely credited as being the first ‘camera trapper’, way back in the 1890s. It was a very simple idea – a tripwire would trigger a camera and flash units. This tripwire could have bait attached or simply be low along the ground (Shiras, 1906). Camera traps, also known as trail cameras, are used to capture images of wildlife with as little human intervention as possible. Since the introduction of commercial infrared

cameras in the early 1990s, their use has increased significantly, and their purpose has become wider. With advancements in the quality of camera equipment, this method of field observation has become more popular among researchers and foresters (Meek et al., 2014).


Figure 25. Camera traps installation process, pictures taken in Borjomi-Kharagauli National Park, Georgia (2022)

Field trips in Georgian forests are a useful way to visually determine conditions of the forests in the country which has mostly wild, natural forests unlike most of the European countries. The conditions of the forests are mostly affected by illegal tree logging and six toothed bark eater beetles but during the trip in August 2022, the big wildfire event was happened near Kvabiskhevi village in the south of Georgia, it is discussed in the research part as satellite images, but it was clear to see how high temperatures and continuous droughts can trigger large scale forest fires. According to the National Agency of Environment of Georgia there was no precipitation in the south part of Georgia for more than three weeks which caused a large area of mixed forest. During the fire local firefighters, volunteers and helicopters were trying to localize and liquidate the fire spots but it was not possible for more than a week due to strong daily winds, which is typical for this area. According to the Ministry of Interior Affairs of Georgia, Turkish firefighting aircraft have joined efforts to extinguish the forest fire in central-western Georgia's Borjomi municipality. According to the ministry official statement, the aircraft was equipped with an eight-ton tank for fire extinguishing material and was being utilized by its crew on sectors of the fire in the municipality.


Figure 26. Forest fire near Kvabiskhevi village, Borjomi municipality, Georgia. Photos taken during the field trip on August 25, 2022

5.3.2. Field trips in the Czech Republic

The Bohemian Switzerland National Park is one of the most beautiful corners of the Czech Republic. In the summer, 2022 it was ravaged by a devastating wildfire. Within a broad debate on restoring the region, there is controversy about whether people should let nature take its course or if they should help by replanting as many trees as possible (Pohanka, 2023). National Park botanist Ivana Marková is one of the people who are against direct and massive reforestation. She argues that if people leave the forest alone, it will regenerate itself without a problem and natural forests will cover the territory (Pohanka 2023). In fact, the new growth would be better suited to the given climate, and the new forest will be more adapted. Marková says: "The first trees that will start growing here spontaneously will be birches, poplars, aspens, willow, and rowan trees. We call them pioneer species since they are normally the first to start growing in our temperate climate. It will take some time before the seedlings of the next generation of trees will start catching up in the ground under the canopy of the pioneer group. There will be beech, oaks, and pines. A lot will depend on the location but also the climate. Frankly, we cannot predict what kind of climate our descendants will have in one hundred years. So, I think it is irresponsible to plant anything as it may be a waste of money." Because of this existing discussion in the Czech Republic there is one of the questions in our questionnaire regarding the ways of reforestation. (Pohanka, 2023).

Figure 27. Forest of Bohemian Switzerland National Park after the fires in the Sumeer of 2022 (Photos by Pohanka)

During the visit to Bohemian-Switzerland National Park it is clearly visible that huge territories of forests are killed. On some territories specific beetle catcher pheromones were observed which are usually good, ecological ways of solving the problem but not with this big scale, without some special intervention this method will be not effective.

Figure 28. Forest after the damage by bark eater beetle (Scolytinae) in Bohemian Switzerland National Park. Photos are taken during the field visit.

Massive tree logging was clearly visible during the field visit in Moravian Forests in the Zlín Region. As we already have mentioned, according to state-owned company Lesy ČR, which owns nearly a half of all woodland in the Czech Republic, a record 35.8 million cubic meters of wood will be mined in the Czech Republic in 2020 and numbers are growing every year. According to the research of Klimo et al.,[1] (2013) the forests in Moravia have been strongly affected by changes in the forest environment caused by natural and anthropogenic impacts. The dominant change factors encompassed changes in the 12–14th centuries resulting in the formation of a flooded alluvium and a significant transition of hardwood floodplain to softwood floodplain. The primary impact in the 20th century was stream regulation and the construction of three water reservoirs, which resulted predominantly in changes in the groundwater table.

Figure 29. Massively logged coniferous trees in the Zlín region, near the village Liptal. Photos are taken during the field trip in 2022.

[1] *Klimo et al., 2013. "Functioning of South Moravian Floodplain Forests (Czech Republic) in Forest Environment Subject to Natural and Anthropogenic Change"* https://downloads.hindawi.com/journals/ijfr/2013/248749.pdf

According to different studies bark beetle outbreaks significantly influence forest ecosystem dynamics and carbon cycles. Warming summer and winter temperatures are major drivers of beetle population outbreaks In the World. Populations of the beetle exist at low levels for many years until triggered by factors such as drought, windfall, and pathogens that stress trees. Temperature drives bark beetle physiological processes such as larval development and cold hardening, thereby directly tying temperature to population growth. In general, warmer temperatures result in higher survival and faster development, although there are temperatures above which survival and development go down.


Figure 30. Tree killed by parasite insects in the Zlín region, near the village Liptal. Photos are taken during the field trip in 2022.

Bark beetles usually attack the trees massively and kill them. The synchronized adult emergence is essential for this process. Emergence synchrony Temperature-driven thresholds in development and diapause causes synchronal in occurrence. During the field trip in the Zlín region climate change insect activities were significant and clearly visible.

Monoculture plantations is a big challenge in the Czech Republic, most of the existing forests in the country don't have natural diversity and include just massively planted trees. Monocultures may exhaust soil, causing soil erosion and degradation. They often worsen the water balance, causing desertification and climate related problems. Sometimes they are referred to as “green deserts” due to their little diversity. Plantation forests are expanding rapidly all over the world. Monocultures have been dominated in practice and well documented in forest research, but in the period of fast increasing climate change and resource scarcity, there is a growing interest in mixed-species plantation systems which can be more natural (Liu et al., 2018)[1].

[1] *Liu et al., 2018. “Mixed species versus monocultures in plantation forestry: Development, benefits, ecosystem services and perspectives for the future”*

https://www.researchgate.net/publication/326677444_Mixed-species_versus_monocultures_in_plantation_forestry_Development_benefits_ecosystem_services_and_perspectives_for_the_future

Despite these facts reforestation activities still contain mostly monocultures in Europe, most of the new plantations on the visited areas within the study includes two main species Norway spruce or European spruce *(Latin: Picea abies)* and Scots pine *(Latin: Pinus sylvestris)*.

Figure 31. Tree killed by parasite insects in the Zlín region, near the village Liptal. Photos are taken during the field trip in 2022.

6. Questionnaire and awareness results:

1.If you think that Climate Change exists as one of the problems of the modern time?

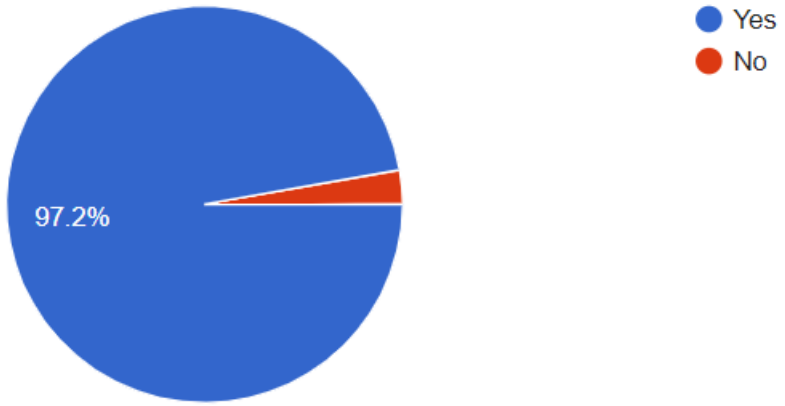

Figure 42. Climate change as one of the main problems of modern times.

As we can see on Figure 42 most of the people who were asked the question are agreeing that climate change exists as one of the problems of modern times.

2.On a scale of 1 to 10, how much do you think climate change threatens your personal health and safety?

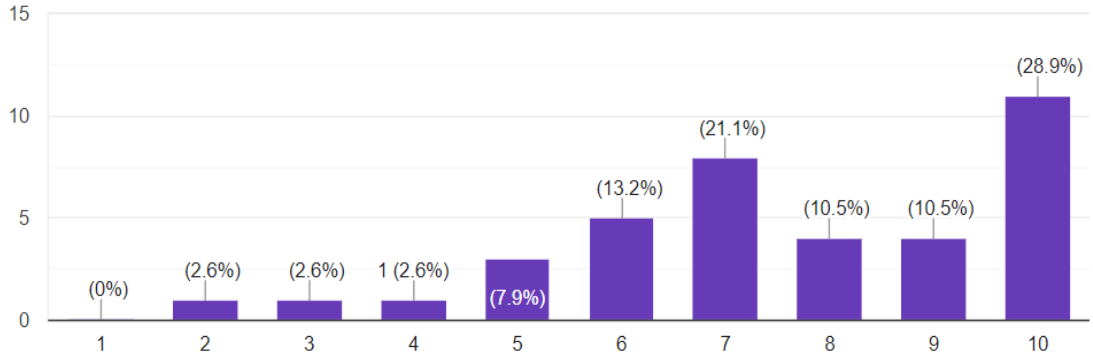

Figure 43. Climate change as a threat for the health and safety.

On Figure 43 respondents answered how the climate change threatens the health and safety of them, as we can see most of the respondents are thinking that this treat is significant.

3.On a scale of 1 to 10, how much do you think that conditions and development of forests are connected to climate change?

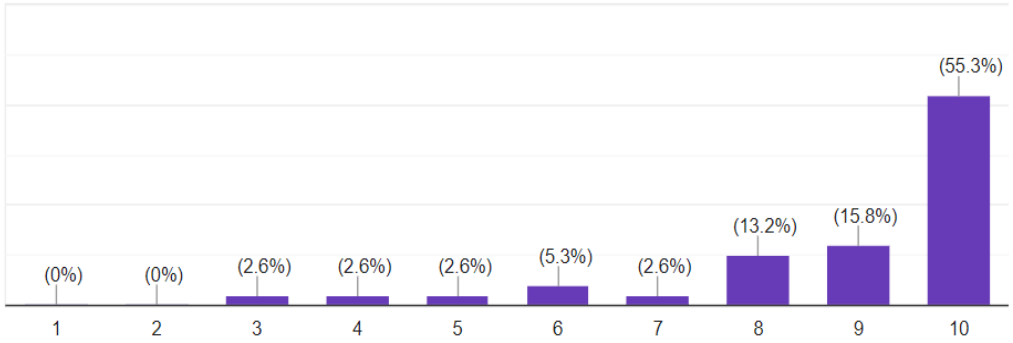

Figure 44. Climate change connection to the development and conditions of the forests

About the question, how much conditions and development of forests are connected to climate change, 55% gives 10 out of 10.

4.Have the conditions of the forests in your surrounding changed in the last decade?

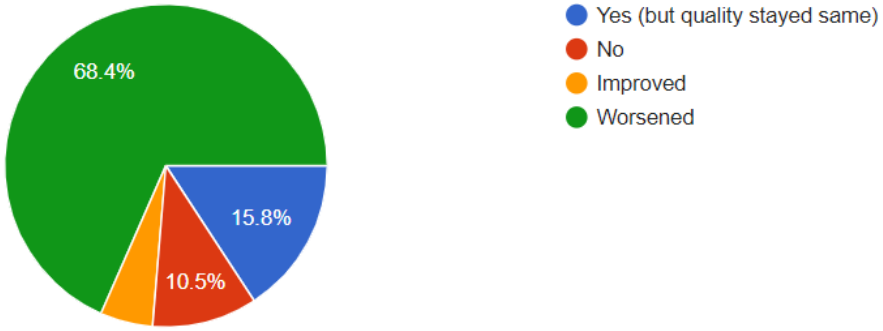

Figure 45. Conditions of the forests in last decade

68.4% of respondents think that conditions of the forests have changed in their surrounding areas in the last decade.

5.In your opinion will global warming change the condition of the forests in the temperate climate territories?

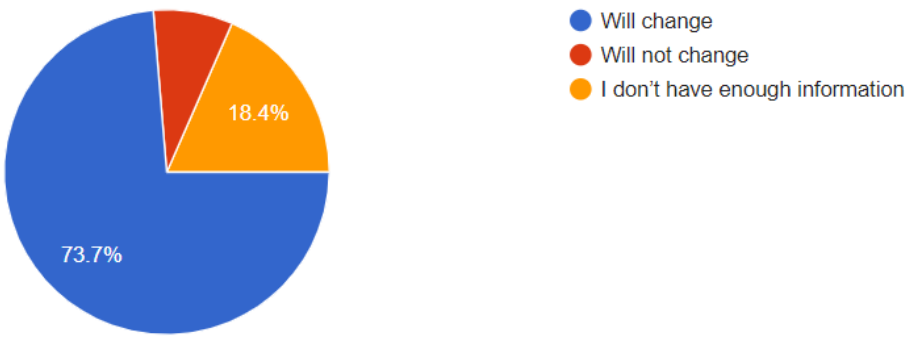

Figure 46. Global warming and the conditions of the forests in last decade

Most of the respondents (73,7%) think that climate change will change the conditions of the forest in the temperate climate territories. This opinion matches many scientists' opinions we've mentioned in our study.

6.In your opinion, do you think the temperatures on earth have been rising over the past decade?

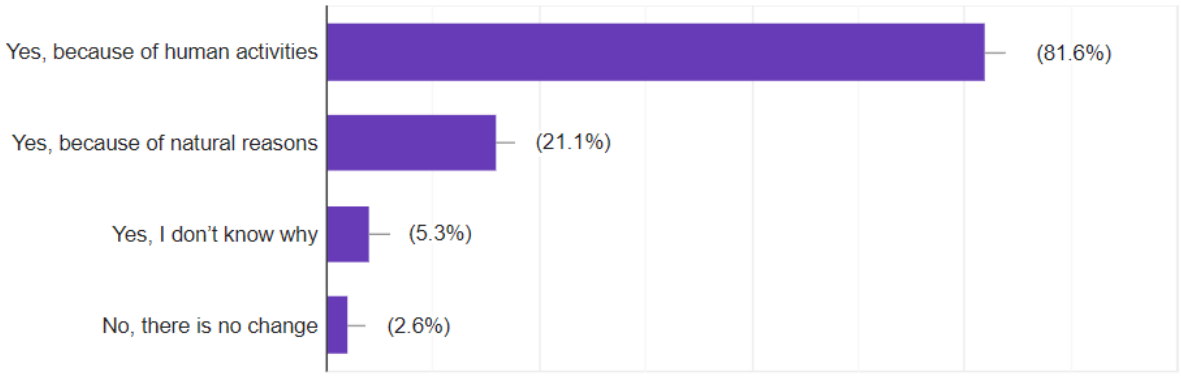

Figure 47. Temperature raises on the earth.

About the temperature rise respondents are more certain, 81,6% of them already have observed that temperatures have been rising over past decade.

7.In your opinion what is the biggest threat from climate change for the upcoming 20 years regarding forests?

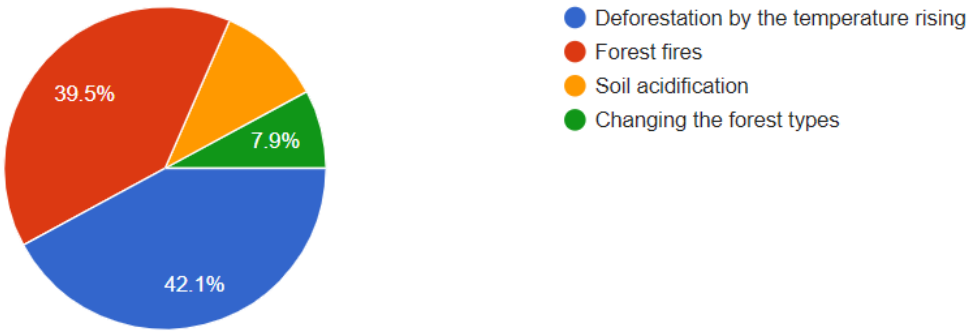

Figure 48. Biggest threats caused by the climate change.

Deforestation and forest fires are leading among 4 main problems suggested as the biggest threats that climate change can cause for the upcoming 20 years period. Soil acidification and changing the forest types are following threats.

8.In your opinion, happened forest fires are connected to climate change?

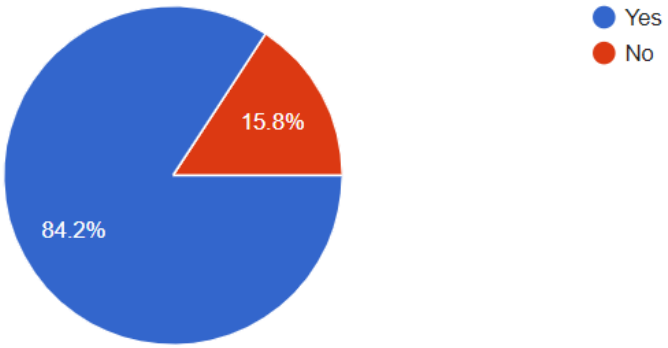

Figure 49. Forest fires frequency connected to the climate change.

A significant part (84,2%) of respondents think that frequency of the forest fires is connected to the climate change.

9.How much do you agree the statement that current climate change is caused mainly by human activities?

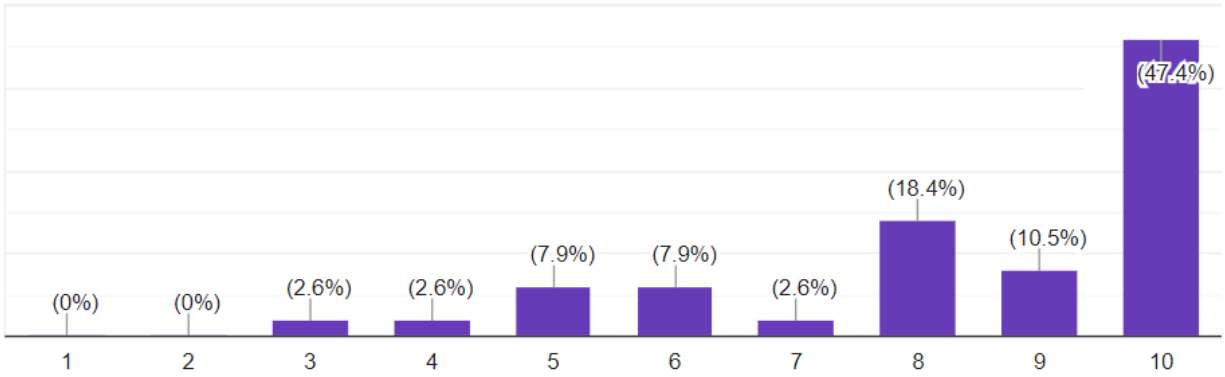

Figure 50. Climate change caused by human activities.

Most of the respondents think that the current climate change is caused mainly by anthropogenic factors. 47,4% of the respondents are giving 10 out of 10.

10.How much are you aware of the environmental policies connected to climate change in your country?

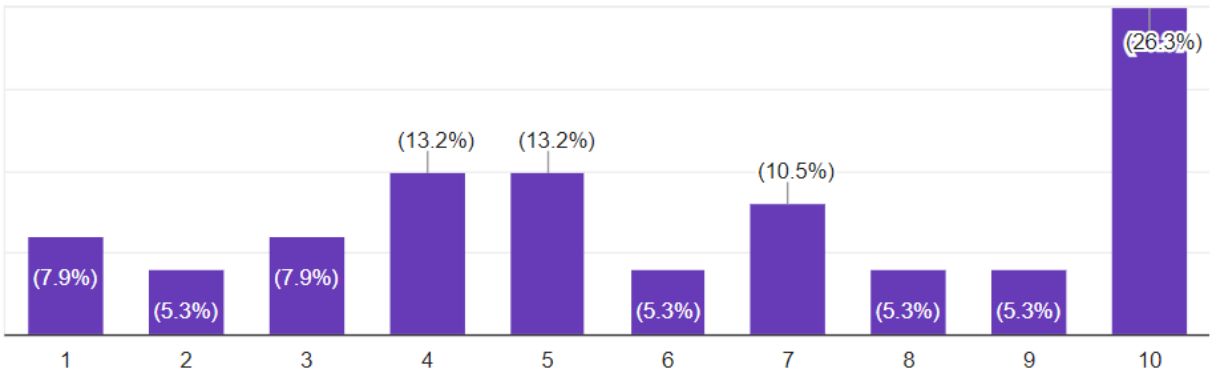

Figure 51. Environmental policies connected to climate change.

The answers about the awareness of respondents vary significantly, the results show that awareness about environmental policies is not high comparable to other question results.

11.On a scale of 1 to 10, how important do you think deforestation is for your country?

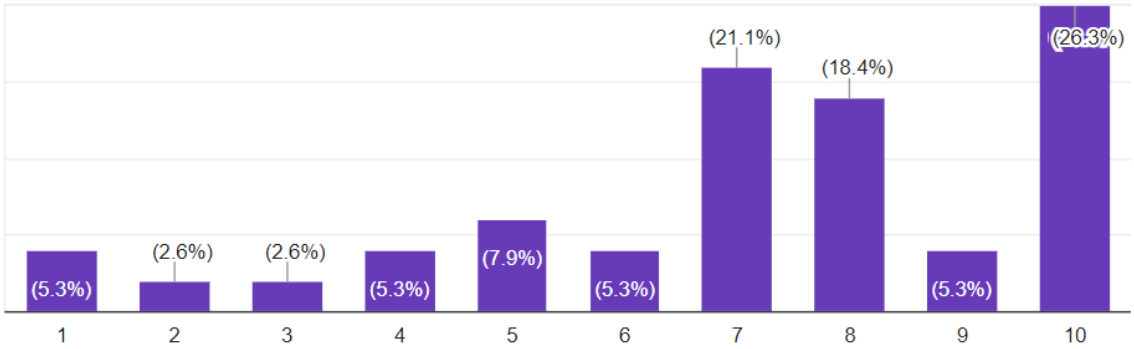

Figure 52. Importance of deforestation.

Results are distributed in the case of deforestation importance as well, but most of the respondents give high values to the importance.

12.If you have ever made or participated in any action against climate change?

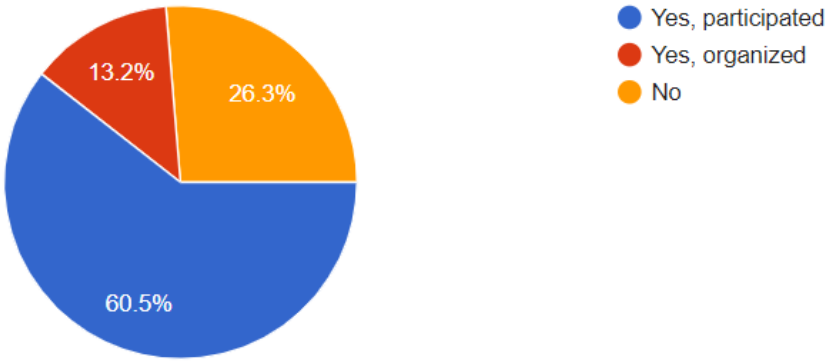

Figure 53. Participation in the actions against climate change.

Most of the respondents have participated (60,5%) in the actions addressing climate change, same time 13,2% themselves have organized such a kind of actions. These results show the significance of climate change for the respondents.

13.On a scale 1 to 10, how likely would you recommend a friend or a colleague to promote activities that will help reduce global warming?

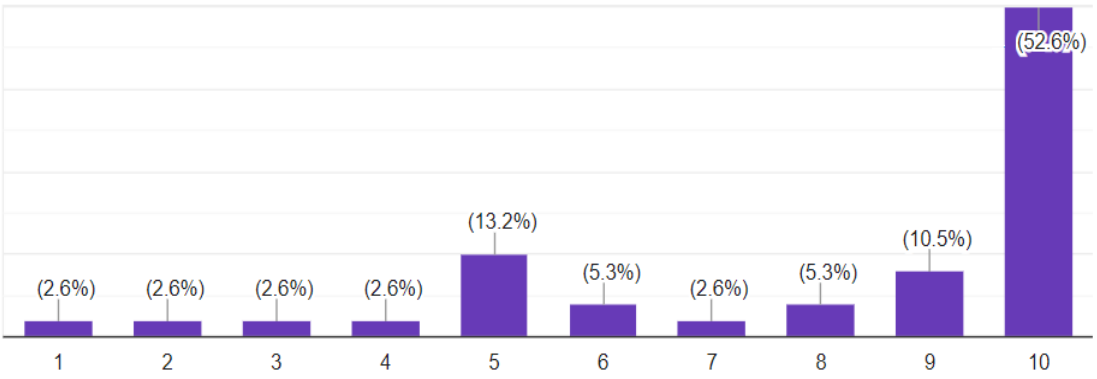

Figure 54. Recommendations to the society to take part in the activities against climate change.

Most of the respondents are willing to promote participation in the activities against global warming for their friends or colleagues.

14.If you agree existed discussion by some specialists that climate change caused deforestation is good for Czech Republic forests, because after decades monocultures will be exchanged by the natural forests?

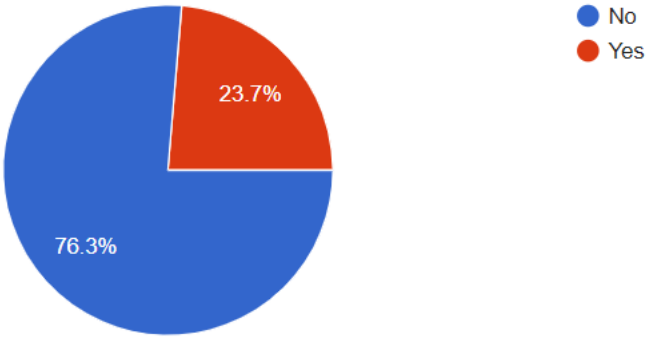

Figure 55. Opinion about the Czech forests' recovery after the wildfire

7. Discussion

It is important for the UN to promote governance structures to implement and develop sustainable forest management practices, this includes the United Nations Forest Instrument, which has the 2030 Agenda for forest sustainable development. (UN Report., 2021). Average temperature rise on our planet makes forests more vulnerable, according to the Global Forest Watch data global temperature has already risen 2 degrees since record keeping began in the 1880s.

Earth typically experiences an important scale of climate change every hundreds of thousands of years. In this situation when anthropogenic climate change is happening at fast speed forests are having much more stress and higher risk of deforestation, species change, or habitat change.

The need to protect the planet's forests is not only expressed by individual scientists around the world, but the United Nations has also specified 6 different goals in their agenda to preserve forests. This includes stopping the loss of forest cover worldwide through sustainable forest management, including protection, conservation, active restoration, afforestation, and reforestation, and increasing efforts among society to prevent or slow down fast forest loss and contribute to the effort of environmentalists to address climate change. It is an important goal of the modern world to strengthen forest-based economy, increase social and environmental benefits from the forested areas, including by improving the livelihoods of forest-dependent people and make their lives sustainable around the globe.

Wildfires are one of the main dangers of our forests in modern days. Using the method provided by Možný and Bares (2013), daily maximum air temperatures, minimum of relative humidity and the daily maximum of wind speed create the different levels of the fire danger on different territories.

Results of many different studies show that different changes in climate are likely to affect forest distribution, growth, and productivity. Increasing average temperatures increase the length of the vegetation season in the forest and shift the geographic ranges of some tree species distribution to another geography. Habitats of some types of trees are likely to move north or to higher altitudes, this phenomenon is clear in the Georgian' case on satellite imagery examples, where trees are covering subalpine meadows intensively.

During the field trips it was clear that insect outbreaks often damage, weaken, and kill trees, so more intensive and better forest management methods are needed at the areas where insect activity is clear. As Bentz (2008) has studied temperatures and precipitation parameters together and assumed that they can increase bark beetle populations, according to this study, species which are distributed in colder climates (e.g mountain pine beetle and spruce beetle) have developed to survive during cold winters and emerge as adults to attack trees during warm

summer months. This study result shows that we need to learn about the results of insect outbreaks or occurrence of them in specific areas, but their behavioral tactics as well.

The climate change-associated rise in temperature and changing precipitation will influence bark beetle populations in future forests. The role of decreased precipitation can play a strong role in population growth, and these two patterns together can cause host tree stress, suggest that this could lead to increase in bark beetle populations, or in some cases decrease as well, depending on the species and geographic location.

Bark beetles usually adapt to the local climatic conditions to be successful and survive. Species that occupy and reproduce in trees in warm habitats (e.g. some southern pine beetle populations and (Ips) have evolved physiological mechanisms that allow for multiple generations in a single year which is causing significant population growth. Temperature increases in this century have had the greatest influence on bark beetle population increase in slightly cold habitats, allowing population levels to increase (Bentz, 2008).

We can conclude that forest loss in the country is a very fast process in both countries. For example, as the official forest company provided the stats discussed in previous chapters of our study, the numbers of the cubic meters of the trees logged are increasing every year, for example according to their data 35.8 million cubic meters of wood has been mined in the Czech Republic in 2020.

According to Olagunju E., 2015. Forests perform socio-cultural and economic functions as they include food security, source of employment, income and revenue generation, provision of raw materials for industries and place of religious worship among others.

On the Google satellite images it's easy to observe the stark contrast in deforestation between these protected areas and their surroundings, while logging events differ in Georgia and in the Czech Republic. In Georgia there are no massive agricultural logging spots and forest is kept less in natural conditions. But Georgia has a similar high risk of wildfires as the Czech Republic. According to the statistics of the Biodiversity Research Organization NACRES, forest fires statistics have increased significantly in the last decade. If we compare the 12-year period from 2009 to the year of 2020 forest fires number increased 16 times. These statistics show how important the issue can be in upcoming years. Climate change is likely a major driver in increasing wildfire activity in the world. Extreme heat waves are happening much more often today than they were in the last century and it is expected that they will become even more frequent as the planet continues to warm (MacCarthy, 2022).

It is possible to conclude that approaches and methods in both of the countries differ because of different types of forests and its degradation, for example according Pohanka (2023) there is an intensive debate on restoring the Czech forests, there is controversy about whether people

should let nature take its development itself or people should help by replanting as many trees as soon as possible, other hand in Georgia there is not a large areas of artificial monoculture plantations and most of the forest loss happens on the natural areas. According to the Bohemian-Switzerland National Park botanist Ivana Marková we can conclude that there is an alternative way of planting and reforestation. In her opinion, if people leave the forest alone, it will regenerate without a problem. In fact, the new growth would be better suited to the given warmer climate (Pohanka 2023).

Georgia is located on the border of subtropical and moderate climate zones and belongs to the climate region of the Mediterranean, though its typical characteristics are substantially changed by mountainous landscape and is characterized by a variety of climate. The territory of Georgia has 11 climate zones which is quite a high number for a small country like it, there are 14 existing climate zones due to very complicated merging of climate factors and huge scale circulation processes (Torchinava, 2015). Because of this diversity the response of the country is very different in different areas, within the thesis research the more vulnerable South Georgia was chosen, where the natural and anthropogenic factors are causing forest degradation intensively.

According to the data analyzed within the study, warmer and drier conditions will create lower moisture conditions and longer fire seasons in the future, likely increasing the frequency and extent of fires compared to the twentieth century. According to Peterson (2020) interactions between wildfire and other forest disturbances, such as drought or insect outbreaks, are likely to be the main drivers of ecosystem change in a warming climate. Because of more frequent heat waves, droughts, and rising temperatures, returns of the forests are more likely to occur, with potential effects on tree regeneration and species composition on specific habitats. More hot and drier sites may be especially at high risk for regeneration failures with some species.

If we put together researched facts that mean temperatures warming permanently every year (NASA report 2022), insect outbreaks are more frequent and tree logging as an anthropogenic factor stressing forests regularly (Dale et al., 2001). It can be concluded that more effective and faster majors are needed to be done to protect natural or artificial forests of Georgia and of the Czech Republic. As we can see there is not one way of approach in both countries and even in one country particularly, if the Northwest part of Czech Republic suffers more with forest fires and insect outbreaks in the South-East of the country, in the region of Moravia, the biggest problems are insect outbreaks and massive tree logging (Bednárová et al. 2020).

There are two components to our response to the challenge posed by climate change: addressing the causes of climate change by reducing concentrations of greenhouse gases in the atmosphere as one component – mitigation and preparing for the consequences – adaptation.

Restoration of woodlands and prevention of forest fires will aid adaptation to varying and harsher environmental conditions is another component (Mullan and Cimato, 2010).

Questionnaire results showed that Climate Change exists as one of the problems of the modern time for the most of the interviewed people. Most of them agree that current climate change is caused mainly by human activities. Absolute majority of 97.2% of 50 people interviewed agrees that climate change exists. Same time, most people think that the frequency of forest fires is connected to climate change. Same time, the majority of the interviewed people think that global warming will change the condition of the forests in temperate climate territories. According to the answers 68.4% of them already see the change in their surrounding forests. Deforestation by the temperature rising and frequent forest fires are mentioned as main threats caused by climate change followed by soil acidification and forest type change. 47.4% believe that modern climate change is caused mainly by human activities. 60.5% of them have participated in the actions organized against climate change, most of them recommend for their friends to do so. 76.3% agrees with the opinion of some specialists that climate change caused deforestation is good for burnt forests, because after decades monocultures will be exchanged by the natural forests.

8. Conclusion:

Within the work various climate change effects on the forests were determined. The main effects are connected to the forest degradation which was clearly found on the satellite images and as well as during the field trips in both countries. Forest degradation was visible at the clearly cut areas found on the satellite images of the last 20 years, according to the various literature used for the research. Usually, the large-scale forest loss is connected to the two different major factors anthropogenic and the climatic. Climate change causes a big threat for forests as permanently increasing wildfires in this century. The burnt areas were visited in the north Czech Republic and South Georgia.

The strong role of the average temperature increase in population growth of bark beetle populations was found during the field trips in Moravia. Same time Moravian forests around Holešov town in Kroměříž District in the Zlín Region have had higher FDI in recent years, than Ústí nad Labem which is in the northwest of Czech Republic. Average temperatures in Holešov are higher with lower rainfall throughout the year, which can explain its higher average FDI during the last decade.

According to a questionnaire of the awareness filled by 50 people climate change is a big threat to every person on the planet, it is a fast process and the decision making and actions against it are urgent to be done effectively.

According to satellite research and field trip visits, we can conclude that the northwest part of the Czech Republic, where Bohemian-Switzerland National Park is located, is a very clear example of climate warming promoting bark beetle outbreaks and forest fires (Ústí nad Labem). The study area located in Moravia (Holešov) has large-scale tree logging activities and higher FDI due to climate conditions.

According to the study done about visited sites of the Czech Republic Ústí nad Labem has higher averages of FDI than Holešov. On both locations the highest risk of the FDI is in the month of July.

In all months instead of April Ústí nad Labem has higher averages of FDI than Holešov. On both of the locations the highest risk of the FDI is in the month of July, it has most of the FDI high class days in Ústí nad Labem and as well as in Holešov. As it was determined that Ústí nad Labem has higher risks of FDI in July with number of high FDI days of 241 than Holešov, which has same level risk days of 225 for the years 1991-2022.

We can conclude that climate change has various effects on the forests. It can alter the frequency of the plantation and it can intensify forest disturbances, including wildfires, heat waves, insect outbreaks, and the occurrence of invasive species in different habitats.

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10. List of Abbreviations

Cfb - Temperate oceanic climate or subtropical highland climate in Köppen climate classification.

EU – European Union

FAO - Food and Agriculture Organization

FDI – Fire danger index

NACRES - Centre for Biodiversity Conservation & Research

NASA – The National Aeronautics and Space Administration

NOAA – National Oceanic and Atmospheric Administration

UN - United Nations

UNEP - United Nations Environment Program

SPEI - Standardized Precipitation Evapotranspiration Index

SVOL - Czech Forest Owners' Association

WMO – World Meteorological Organization