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Impact from Tourism on Vegetation Greenness in Yellowstone National Park

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Bachelor thesis, 15 credits, in Physical Geography and Ecosystem Analysis

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Abstract

Tourism has increased drastically during the last decades in Yellowstone National Park, from nearly 20 000 visitors in 1910 to almost five million visitors in 2021. Yellowstone is an important ecosystem with unique wildlife, and geological and cultural history. It has a high variety of plants and serves as the home for many different animal species. Previously, tourism has been found to have an impact on vegetation. Trampling reduces vegetation and tourists scare away animals and pollute the waters. The aim of this thesis is to study the effects of tourism on vegetation greenness with the use of remote sensing and the normalised difference vegetation index (NDVI; a proxy for vegetation greenness) in Yellowstone National Park, USA. To study the impact of tourism, the area in the park was divided into different zones depending on their distance to roads and trails being the source of influence from tourism. The NDVI values are being compared between years from 1991-2013, with a lower tourist rate, and the years 2015-2022 with a higher tourist rate. Vegetation close to roads seem to be more impacted by the increased amount of tourism than areas close to trails. However, the results cannot prove that there is any statistically significant impact from tourism on any areas.

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1 Introduction and Aim

1.1 Introduction

Tourism has increased rapidly during the last century (statista, 2023). One of the travelling activities that has grown rapidly in the USA and around the world is hiking and ecotourism (Cole, 2004; NPS, 2023f; Statista, 2022; Wang & Miko, 1997). In 2021 the global ecotourism market size was valued at 185.87 billion USD (GVR, 2020) and it is expected to grow even further. There are many different activities related to tourism but most people taking part in ecotourism are doing shorter hikes no longer than one day (Cole, 2004).

Being in nature and hiking has many positive effects on people such as presenting people with an affordable way of getting exercise and time in nature which will in turn decrease health issues and mortality rates (Mitten et al., 2018). Hiking is also shown to lead to a number of benefits for mental health (Nordbø & Prebensen, 2015) such as reduced stress, increased mindfulness, and well-being (Mutz & Müller, 2016). This highly popular recreational activity has a big impact on the local economy as it is an important source of income for many areas and people, and is essential to maintain global trade (Geneletti & Dawa, 2009; Stubbles, 2001). Today hiking is so deeply rooted in many economies that a disruption of it would have serious consequences (Stubbles, 2001). Stubbles (2001) states that developed countries benefit the most economically from tourism.

However, tourism is also found to have a visible negative impact on the environment (Boori & Vozenilek, 2014; Leung & Marion, 2000) and it is impossible for recreational activities in nature to not have an impact on wilderness (Leung & Marion, 2000). Recreational use has the most intense impact on parks and wilderness (Cole & Landres, 1996). The impact is inevitable and rapid whereas the recovery is slow (Cole, 2004). Boori and Vozenilek (2014) found that tourism has an effect on landcover, and that forest cover decreases closer towards cities. The closer to destination areas and travel corridors, the more intense the impact on vegetation becomes (Kim et al., 2014). Tourism in national parks in the USA is found to lead to reduced water and air quality as well as vegetation and wildlife problems (Wang & Miko, 1997). Geneletti and Dawa (2009) also report that waste from tourists contributes to the pollution of the local waters. The negative effect from hiking on the landscape is also negatively impacting the visitors' experience (Lynn & Brown, 2003). Lynn and Brown (2003) found that the visitors' experience is being affected negatively by litter, fire rings as well as trail widening and vegetation trampling.

There is clear evidence for the direct impacts from tourism on the environment (Boori & Vozenilek, 2014; Cole, 2004; Kim et al., 2014; Leung & Marion, 2000) but it is harder to know how it will affect the whole system with food chains, energy flows and nutrient cycles (Kim et al., 2014). Vegetation serves as an important carbon sink contributing to a reduced effect of global warming which further strengthens the importance of its existence (Stuart Chapin et al., 2012). One of the most threatened habitats on the planet are the North American grasslands (Bolt, 2022) which make up a big part of Yellowstone National Park (NPS, 2023c).

Remote sensing and Normalized Difference Vegetation Index (NDVI) are widely used to investigate land use and vegetation changes (Bhandari et al., 2012; Gandhi et al., 2015) as well as the effects from tourism on the landscape (Boori & Vozenilek, 2014; Geneletti & Dawa, 2009; Kim et al., 2014). The strength of remote sensing is its ability to, in a simple and effective way, investigate the overall trend and patterns of a change in a larger area (Bhandari et al., 2012). NDVI is shortly described as the degree of greenness in plants which equals to the chlorophyll concentration (Gandhi et al., 2015). It is found to be an accurate measurement of vegetation and other features and it is one of the best techniques for detecting varying densities and scattered vegetation (Bhandari et al., 2012).

1.2 Aim

Hiking has always been an important part of the American lifestyle (Stubbles, 2001) and today many national parks in the USA receives a high amount of tourism (NPS, 2023f). In the field it is clear that tourism has an effect on vegetation however the extent that it can be observed on a larger landscape scale is unclear (Boori & Vozenilek, 2014; Cole, 2004; Kim et al., 2014; Leung & Marion, 2000). Hence, the aim of this thesis is to study if the effects from tourism on vegetation greenness can be found with the use of remote sensing and NDVI and to what extent vegetation is affected by tourism in Yellowstone National Park, USA. My hypothesis is that vegetation greenness will be most affected close to the roads within the park but that no major change will be found in areas close to trails. Vegetation is further expected to be more affected in the areas close to roads after 2013 after which the visitors per year increased drastically (nationalparked, 2022).

2 Background

2.1 Geography and Ecology of Yellowstone

Yellowstone's inception as a national park began in 1872 and it is the first national park in the USA to protect the ecological and geological systems, wildlife, and cultural heritage (Park, 2022). It is located in western USA with 97 % of the area in Wyoming state (Figure 1). The park is 8991 km^2 one of the largest temperate zone ecosystems in the world with a unique geological history (NPS, 2023c; Service, 2020). Yellowstone's highest elevation point is at 3462m and the lowest at 1610m (Figure 2) (NPS, 2023c). Forest covers 80 % of the area, grasslands account for 15 % and water 5 % (Figure 2) (NPS, 2023c). The summer daytime temperatures in general range from 21º to 27 ° C and in the winter the temperatures fall between -7° and -18° C (NPS, 2023g). The annual precipitation varies greatly in the park from 26 cm in the north to 205 cm in the southwestern corner. For both temperature and precipitation, the general trend is that they are increasing (Figure 3 and 4). In the park there is hydrothermal activity, and a high variability of flora and fauna as well as a variety of cultural resources making the area attractive for tourists (NPS, 2023c; Service, 2020). The park sits on an active volcano and experiences 1000-3000 earthquakes annually, and it has more than 1000 hydrothermal features and more than 500 active geysers (NPS, 2023c). In Yellowstone you can find 67 species of mammals, out of which two are threatened: Grizzly bears and Canadian lynx. Furthermore, there are 285 species of birds, 16 species of fish as well as a number of amphibians and reptiles (NPS, 2023c). The flora is also highly biodiverse with nine species of conifers, over 1000 species of flowers, 186 species of lichens as well as 225 species of invasive plants (NPS, 2023c).

The park is consistently being disturbed by wildfires with larger fires happening every 200-300 years (Hansen et al., 1998). The latest big fire was in 1988, where more than four thousand km^2 of the area (36 %) were burned, and a slightly smaller one again in 2016, where almost three hundred km^2 got burned down (NPS, 2021a, 2021c). The fires are an important part of the dynamics of the ecosystem and many plants and birds depend on them for their growth and nesting (Hansen et al., 1998).

Figure 1: Geographical position of Yellowstone National Park (USGS).

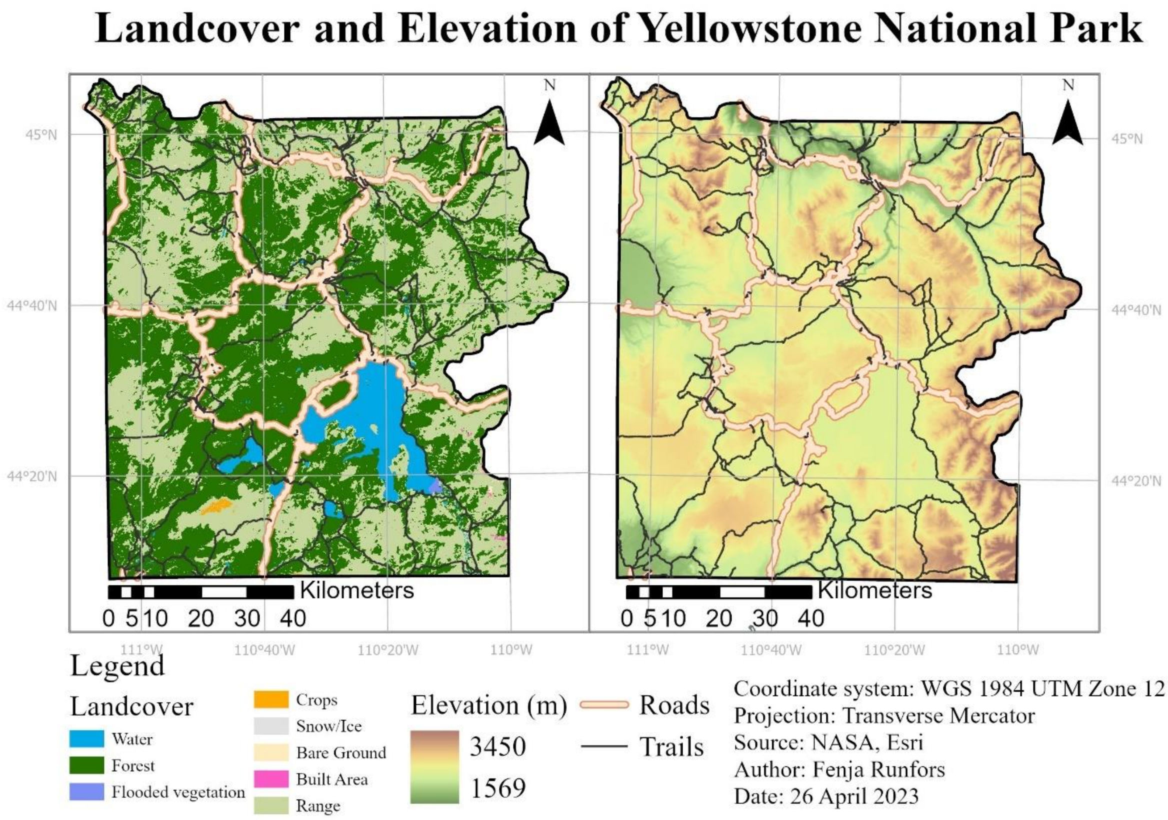

Figure 2: Landcover and Elevation of Yellowstone National Park as well as Roads and Trails.

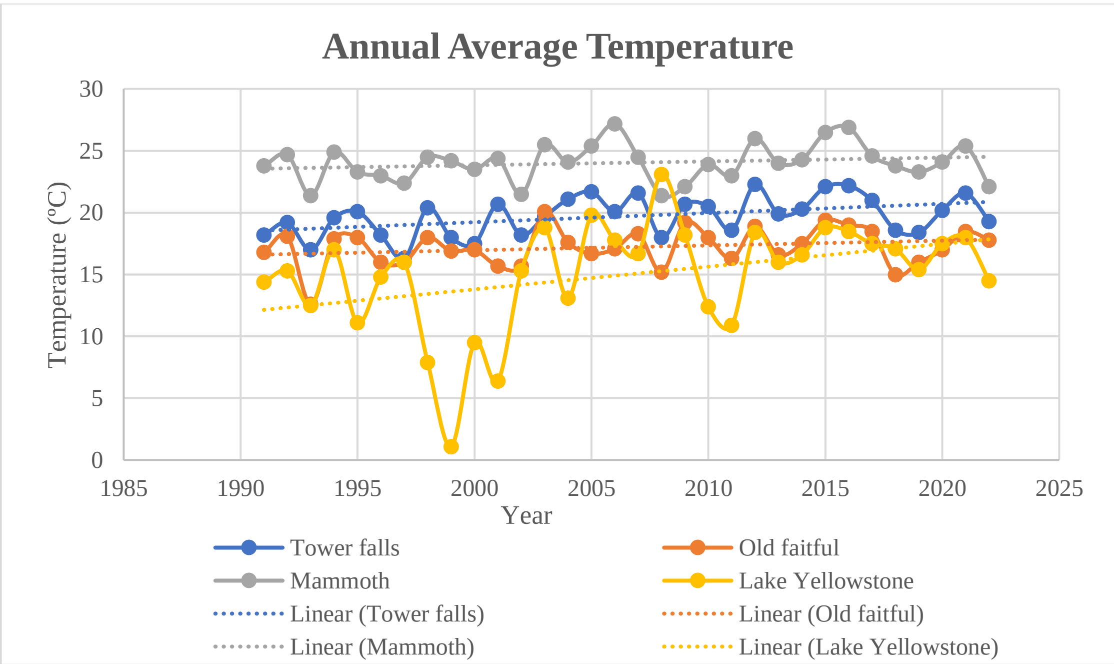

Figure 3: Annual average temperature from 1991-2022 with trendlines for four different stations in Yellowstone National Park: Tower falls, Mammoth, Old Faithful and Lake Yellowstone. Source: (NOAA, 2023).

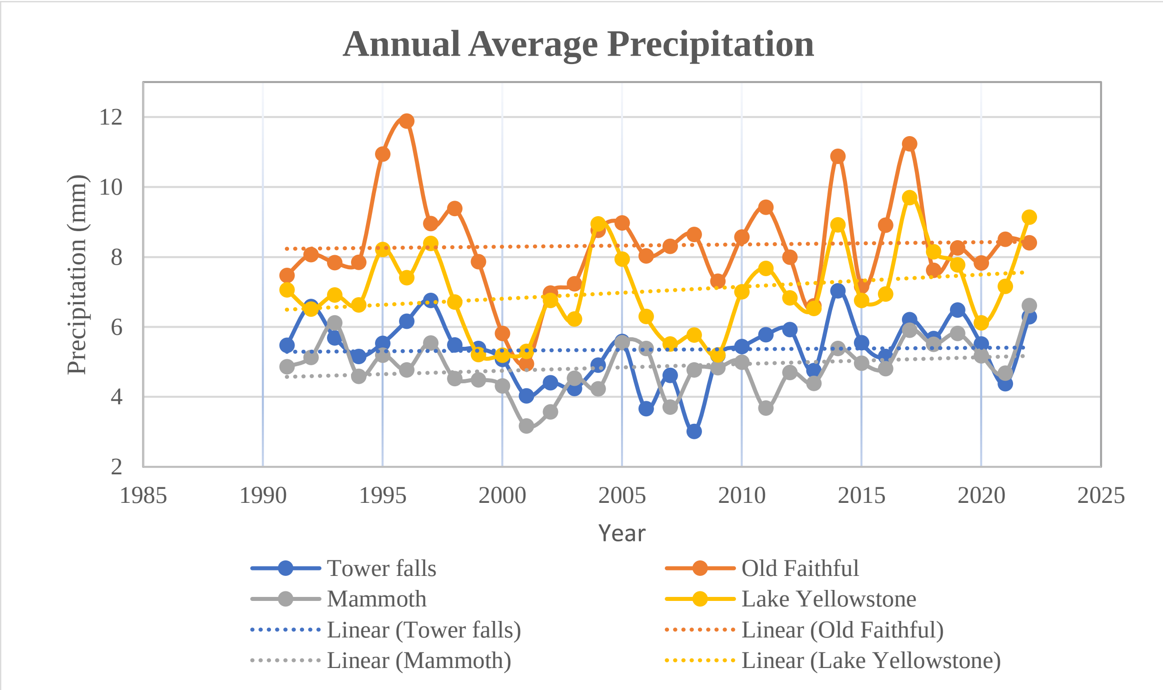

Figure 4: Annual average precipitation from 1991-2022 with trendlines for four different stations in Yellowstone National Park: Tower falls, Mammoth, Old Faithful and Lake Yellowstone. Trace amounts of precipitation, snowfall, as well as snow depth are regarded as zero in the data. Source: (NOAA, 2023).

2.2 Tourism in Yellowstone

Tourism in Yellowstone National Park has increased rapidly during the last century. From nearly 20 000 visitors in 1910 to almost five million visitors in 2021 (nationalparked, 2022). The years between 1991 and 2013 showed a relatively stable amount of tourism each year with a rapid increase after 2013 (Figure 5). Half of the annual visitors occur in June, July and august (NPS, 2023e). Tourists like to engage in various different activities while visiting the park such as hiking, visiting geysers, nature viewing, eating at restaurants, lodging or camping and rock climbing (Benson et al., 2013). The park also offers activities such as boating, horseback riding and fishing. Built environment features and cultural amenities are also important for the majority of visitors (Benson et al., 2013). Most visitors stay within a 30 minute walk from their car (NPS, 2022a).

The park has 11 visitor centres, over 700km of roads and 1600 km of hiking trails (NPS, 2023c). Within the park you can also find 12 campgrounds with over 2000 established campsites, mostly located above the 2000m elevation mark (NPS, 2023b). Furthermore, there are 9 lodges for overnight stay with more than 2000 rooms. For dining there are a big variety of restaurants and picnic areas throughout the park (NPS, 2022b). Several restrictions are applied within the park for the safety of the visitors and conservation of the nature. In thermal areas it is prohibited to leave the boardwalks. In the whole park you are not allowed to take anything from the ground such as rocks and plants or camp outside designated areas (NPS, 2021d, 2023b).

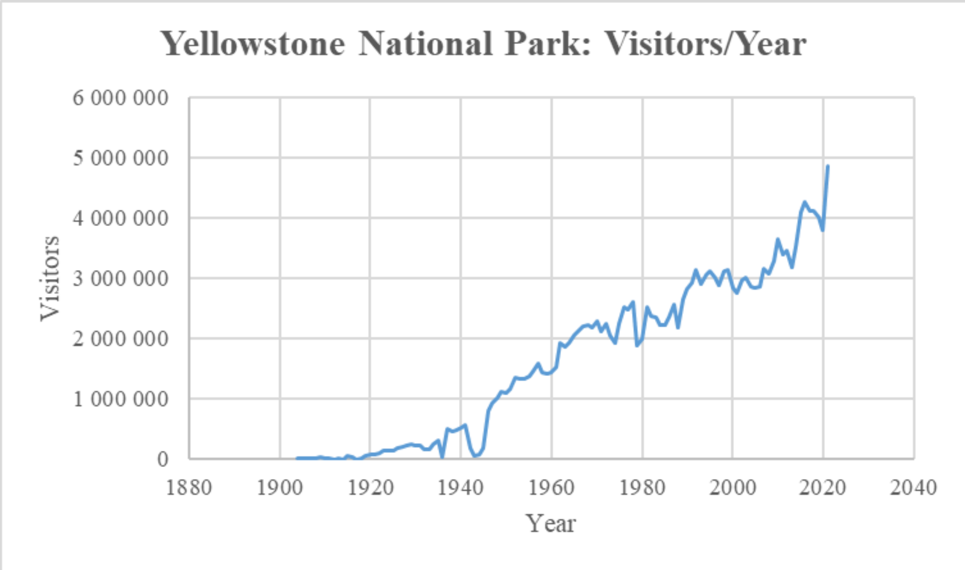

Figure 5: Visitation statistics for Yellowstone National Park 1904-2021. Source: (nationalparked, 2022)

2.3 Importance of Vegetation and Potential Impacts

Plants are an important part of the ecosystem as well as important for the fight against climate change through their ability to capture carbon dioxide (CO_2) from the atmosphere (Stuart Chapin et al., 2012). Forests are essential for many species' survival and for humans they have important individual, social and economic benefits; they purify the air, prevent erosion, filter drinking water, and serve as an important carbon capturer (Lopes et al., 2019; Patel et al., 1999; WWF, n.d.). Grasslands also serve as an important buffer against climate change, in addition to acting as a water filter and serving as an important wildlife habitat (Bolt, 2022). Plants and ecosystems are complex systems that are impacted by many different factors (Stuart Chapin et al., 2012). The most important factors that influence plants are light, water, temperature and nutrients, their abundancy, and their cohesiveness (Darrel Hess, 2016; Stuart Chapin et al., 2012). Light together with CO_2 are the driving factors for photosynthesis which provides the plants with its energy (Darrel Hess, 2016). The timing of precipitation strongly impacts plant productivity and when water is the main limiting factor plants often focus on a higher root ratio compared to shoots (Izaurralde et al., 2011). The optimal temperature differs a lot between plants and the growth rate increases until the optimal temperature, and decreases when the temperature exceeds those values (Hatfield & Prueger, 2015; Izaurralde et al., 2011). The CO_2 concentrations in the atmosphere also affects plant growth with higher concentrations resulting in better growth (Reiny, 2016). As temperature decreases with altitude, elevation also has an impact on plant growth with higher elevation generally resulting in less vegetation (Darrel Hess, 2016). The main nutrients plants need are nitrogen, which is found in all plant cells, phosphorous which helps transfer energy from sunlight to plants, and potassium which helps form and move starches, oils and sugars in plants, increases disease resistance and vigour and it can improve the fruit quality (Darrel Hess, 2016; NSW, 1992). Disturbances such as fire or treefall also alter the plant communities (Stuart Chapin et al., 2012).

2.4 Hiking and Camping Impact on Flora and Fauna

2.4.1 Hiking and Camping Impact on Flora

Recreational activities affect soil, vegetation, wildlife, and water (Leung & Marion, 2000). In remote areas trekking by tourists is furthermore affecting soil erosion and degradation (Geneletti & Dawa, 2009). Vegetation damage is also common due to campsites and off road driving (Geneletti & Dawa, 2009). Trampling is one of the main factors of vegetation damage as it disturbs and alters the local flora (Cole, 2004; Cole & Landres, 1996). Cole (2004) found that a high amount of trampling generally results in a low plant cover and biomass, a reduced species richness and shorter plants. Furthermore, trampling also affect the water holding capacity of the soil due to reduced soil porosity (Cole, 2004). Kycko et al. (2018) found that trampling leads to a reduced and shattered plant canopy resulting in a higher transmission of solar radiation to the soil which led to increased soil temperature and transpiration. Camping and burning wood in campfires and harvesting of plants leads to a direct removal and distribution of vegetation (Cole & Landres, 1996). A study conducted by Stevens (2003) in the Himalayas found that the biggest impact of tourism on the vegetation is forest thinning in some areas and loss of alpine shrub.

A study conducted in Grampians National Park found that most trails are located in low altitude regions on susceptible soils and that the impact on the ground decreased in a higher elevation (Arrowsmith & Inbakaran, 2002). The low altitude areas consist of more coarse soil material whereas higher elevations have more rocky outcrops and resilient surfaces (Arrowsmith & Inbakaran, 2002). High elevation areas are, on the other hand, in general less resilient for stress (Cole & Landres, 1996). To minimise the risk Arrowsmith and Inbakaran (2002) suggests to dissipate the tourists over a greater area and to use logs and fences to keep hikers on the path. However, development of infrastructure to support tourism has a great effect on the environment as well (Cole, 2004). Still, Cole (2004) states that the impact of hiking and tourism can be limited through use of well-established trails and campgrounds.

2.4.2 Hiking and Camping Impact on Fauna

Multiple papers found that tourism has an effect on fauna as well (Cassirer et al., 1992; Thomsen et al., 2022). Cole and Landres (1996) states that the disturbance of animals is one of the biggest ecological impacts of recreation. Hiking through habitats and wildlife photography is shown to cause disturbances on animals which can lead to changes in food habits, behaviours, and increased mortality (Knight & Cole, 1995). Thomsen et al. (2022) found that grizzly bears avoid humans as well as roads and developments which has affected the population negatively. Cassirer et al. (1992) found similar results for elk in Yellowstone

National Park and that they got disturbed and displaced to higher elevation by skiers. Knight and Cole (1995) that bird may alter their nest placements to be further away from humans. These changes can be either short or long term (Knight & Cole, 1995). Vegetation damage due to overgrazing of animals is another effect of tourism (Geneletti & Dawa, 2009).

2.5 NDVI and Remote Sensing for Detecting Vegetation Changes

Normalized Difference Vegetation Index (NDVI) is used to detect vegetation density and changes in plant health as well as quantifying vegetation greenness (Landsat Missions, n.d.b). In addition it is also commonly used to examine the relationship between vegetation vigour or growth rate and spectral variability, the production of green vegetation and vegetation changes (Bhandari et al., 2012). NDVI is also a useful tool for investigating vegetation stress through remote sensing (Huang et al., 2021). It was developed as one of the first remote sensing analytical products to simplify the complexities of multi-spectral imagery. Today it is still the most popular index used for vegetation assessment due to its long history, easy access to multispectral bands and simplicity (Huang et al., 2021). From a multispectral remote sensing image NDVI is found to give the best and most accurate results for scattered vegetation and vegetation with varying densities (Bhandari et al., 2012; Gandhi et al., 2015).

NDVI shows the degree of greenness in plants which is equal to the chlorophyll concentration (Gandhi et al., 2015). The values vary with the reflection of infrared radiation by water-filled leaf cells and the absorption of red light by plant chlorophyll; when the green vegetation decreases the NDVI values decreases as well (Gandhi et al., 2015). The values range from minus one (-1) to one (1) with one being the strongest/greenest vegetation and zero no vegetation. Very low values (0.1 and below) represent barren areas of snow, sand, or rock. Moderate values (0.2-0.3) correspond to grassland and shrub and high values (0.6 to 0.8) temperate and tropical rain forest (Herring, 2000).

NDVI is not perfect and scattering and absorption of atmospheric compositions such as clouds, atmospheric molecules, solar altitude, and aerosols all impact the results (Hu et al., 2008; Xie et al., 2010). The sensor used for obtaining the satellite image also influences the final NDVI values due to differences in spatial resolution, data processing and band widths (Huang et al., 2021). It is therefore important to use data with reliable sensors and use the right data processing methods (Huang et al., 2021). One way of improving the NDVI values is through atmospheric correction (Xie et al., 2010). Atmospheric correction ultimately eliminates the effects of atmospheric interference on the satellite data, whereas data that is not atmospherically corrected have smaller NDVI values than the true values (Hu et al., 2008; Xie et al., 2010). However, the values still follow the same seasonal change and trend when compared (Xie et al., 2010). NASAs Landsat images are commonly used for NDVI calculations (Bhandari et al., 2012; Boori & Vozenilek, 2014; Gandhi et al., 2015). The level-2 Landsat images are atmospherically corrected (Landsat Missions, n.d.a).

3 Materials and Method

3.1 Materials

Landsat images 4-5 TM C2 L2 for the year 1991-2011 and Landsat 8-9 OLI/TIRS C2 L2 from U.S. Geological Survey for 2013-2022 were used in this study: It was chosen as it provides a free source of data frequently updated and available during the full study period with relatively high resolution. The cloud cover was always set to under 10 % and the resolution was 30 by 30 m. Images were taken during the months of June, July, and August, with most of the images being taken in mid-July to minimise changes due to seasonal differences. No data was found for the years 1994, 2001, 2004, 2009, 2012 and 2014, due to too many cloud issues. Data for the waterbodies was taken from USGS (2012). Trail data was collected from ArcGIS (2014) and the road data from NPS (2018).

3.2 Method

Normalized difference vegetation index (NDVI) was calculated with equation 1 for each image. All spatial analysis and mapping were conducted with ArcGIS pro 2.7.0 (2020).

$$\frac{(NIR-R)}{(NIR+R)} \qquad \text{(Eq. 1)}$$

where:

NIR= Near infrared reflectance, and

R= red reflectance.

For Landsat 4-5, NIR corresponded to band 4 and R to band 3, and for Landsat 8-9, NIR corresponded to band 5 and R to band 4. From the NDVI images all water bodies were removed. The NDVI images were divided into seven impact area zones in relation to distance to roads and trails in Yellowstone as following: R1: 0 to 250m, R2: 250 to 500m, and R3: 500 to 3000m from roads as well as T1: 0 to 250m, T2: 250 to 500m, and T3: 500 to 3000m from trails. The last control zone, Z4, consists of all areas further than 3000m from roads and trails and is assumed to have very low impact from tourism (Figure 6). From each zone the average NDVI was taken for each year. The years 2010 and 2011 were discarded due to being extreme outliers with way higher and lower values than any of the other years.

The NDVI trend was analysed as the slope of an ordinary lease square linear regression 1991-2022. In order to see if the change differed between the years with lower tourist rate (1991-2013) and the years with a higher tourist rate (2015-2022) the trend was analysed for all impact zones and for both year intervals. In order to see if the slopes were statistically significant from each other, the standard deviation of slope was calculated for all zones for both year intervals. To test the impact of tourism, the significance of the difference between the slopes and Z4 (being the zone with low tourism impact) was calculated with a significant level of P=0.05 with an online calculator (Soper, 2023). The slope of R1, R2 and R3 was compared to Z4 for 1991-2013 and 2015-2022, the same procedure was done for the slopes.

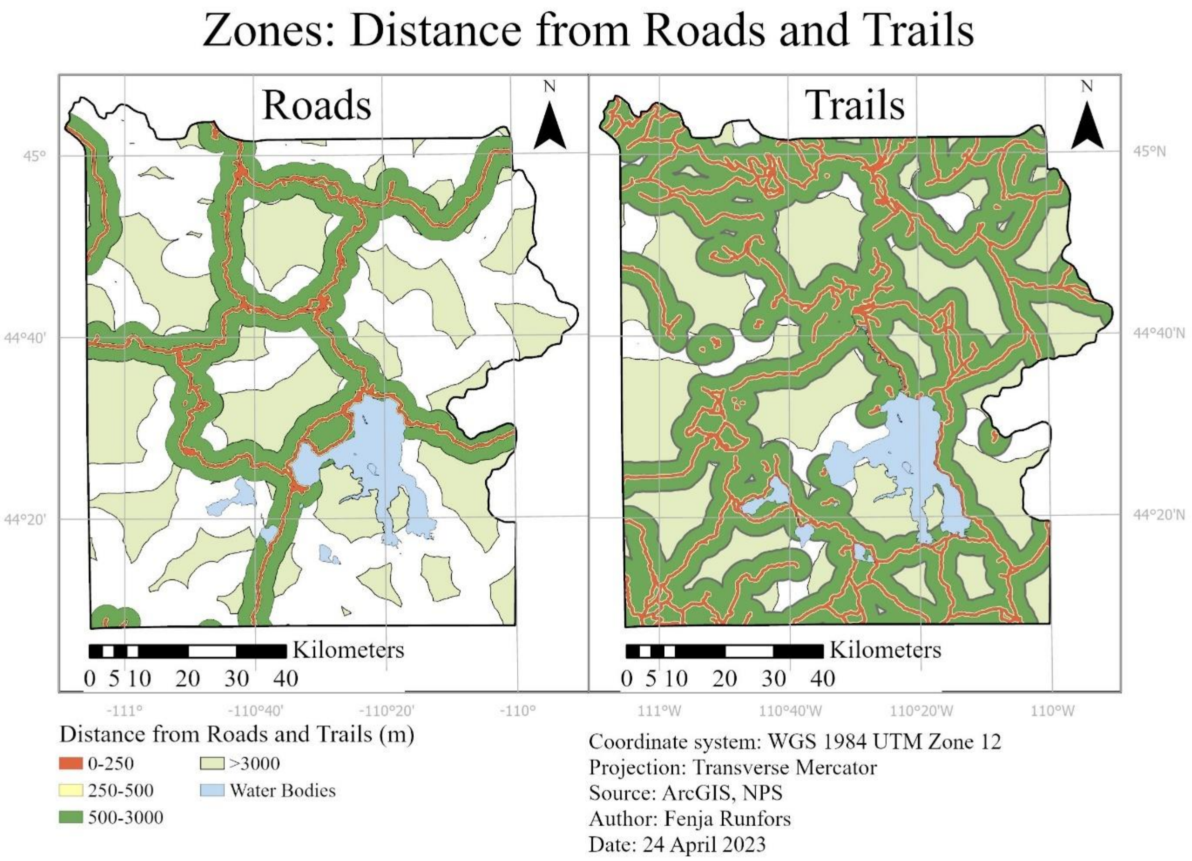

Figure 6: The different impact area zones used in the analysis. The zones are based on the distance to the centre of roads and trails.

4 Result

4.1 General NDVI Trend for Roads and Trails 1991-2022

The general trend is that the NDVI value for all zones increases from 1991 to 2022 (Figure 7 and Figure 8). For areas close to roads zone R3 does almost always have the highest NDVI followed by zone R2 and thereafter zone R3. Zone Z4 does frequently have the lowest NDVI. All values can be seen in appendix (Table A1 and Table A2). For the areas close to trails zone T1 mostly has the highest NDVI followed by T3 and thereafter T2. Z4 frequently has the lowest NDVI (Figure 8).

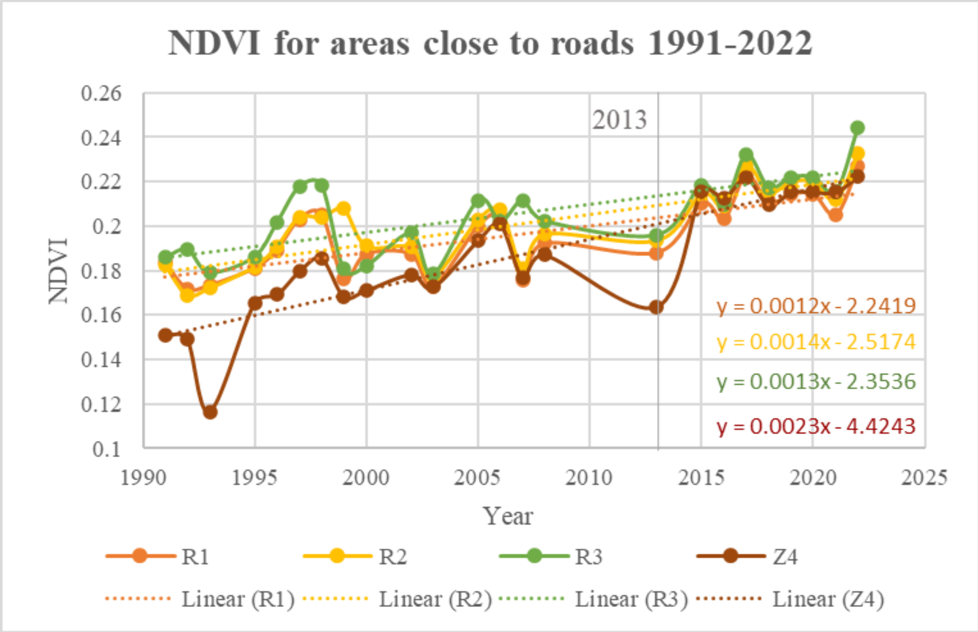

Figure 7: NDVI for the three zones, R1, R2, and R3 close to roads as well as the control zone Z4 from 1991-2022 with trendlines. The general trend is that NDVI is getting stronger for each year. The trend differs slightly for each year.

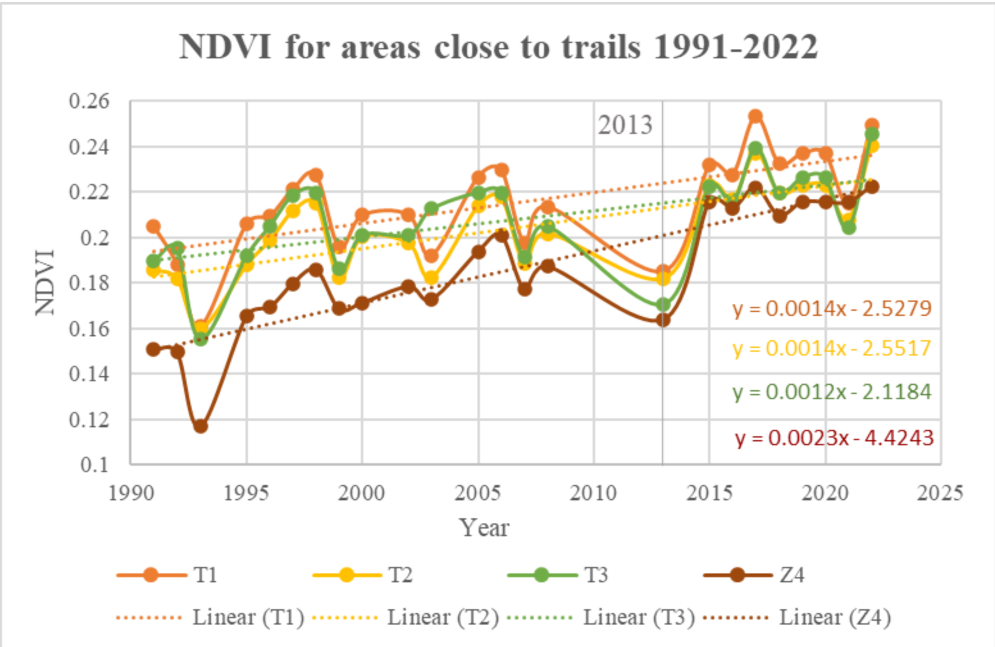

Figure 8: NDVI for the three zones close to trails, T1, T2, and T3 as well as the control zone Z4 from 1991-2022 with trendlines. The general trend is that NDVI is getting stronger for each year. The trend differs slightly for the zone 500-3000 compared to the other zones.

4.2 NDVI Trend in Relation to Tourism for Roads 1991-2013 & 2015-2022

In the first period (1991-2014) NDVI in Z4 is generally the lowest followed by R1, R2 and R3 (Figure 9a). Excluding Z4 the NDVI is higher further away from roads. During the second period R1 is mostly the lowest followed by Z4, R2 and R3 (figure 9b). Looking at the road zones NDVI gets higher the further away from roads one gets.

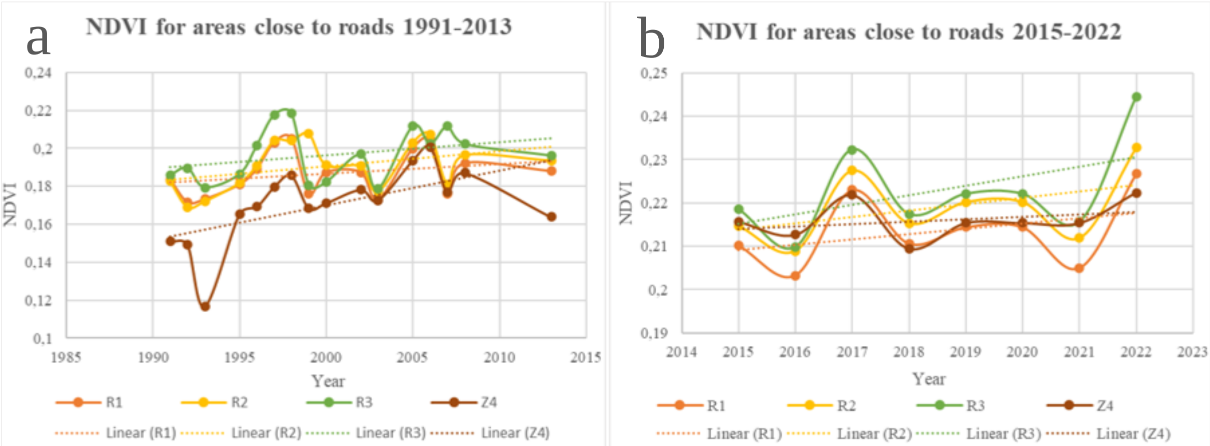

Figure 9: The NDVI for the zones close to roads, R1, R2, and R3, as well as the control zone Z4, and the trendline. To the left (a) from 1991 to 2013 and to the right (b) from 2015-2022.

The NDVI trend differed in all zones between the two time intervals (Table 1). During 1991-2013 zone Z4s NDVI increased the most with 0.0018 units/year and zone R2 the second most with 0.0008 units/year. During the second period zone R3s NDVI increased the most with 0.0022 units/year and Z4s the least with 0.0006 units/year. Excluding Z4 the NDVI increased less, closer to roads than further away in both time intervals. The NDVI increased more during the second time interval than the first in all zones except Z4. As the probability always is greater than P=0.05 the trendlines are not statistically significantly different from Z4 (Table 1).

Table 1: The trend and standard deviation (NDVI unit per year) of slope for all road zones and Z4 as well as the probability of significance difference between the R zones and Z4 for both periods.

	1991-2013			
	R1	**R2**	**R3**	**Z4**
TREND ± STD	0.0005 ± 0.0743	0.0008 ± 0.0250	0.0007 ± 0.0218	0.0018 ± 0.0940
	R1 & Z4	**R2 & Z4**	**R3 & Z4**	
PROBABILITY	0.9901	0.9897	0.9886	
	2015-2022			
	R1	**R2**	**R3**	**Z4**
TREND ± STD	0.0012 ± 0.0272	0.0015 ± 0.0418	0.0022 ± 0.3975	0.0006 ± 0.0049
	R1 & Z4	**R2 & Z4**	**R3 & Z4**	
PROBABILITY	0.9948	0.9863	0.9969	

4.3 NDVI Trend in Relation to Tourism for Trails 1991-2013 & 2015-2022

NDVI in Z4s is the lowest in both periods except for in the year 2021. 1991-2013 Z4 is followed by T2, T3 and T1 (Figure 10a) and 2015-2022 T2 and T3 interchangeable (Figure 10b) with T1 having the highest NDVI during both time intervals. The NDVI is mostly following the trend that it is highest closer to trails than further apart.

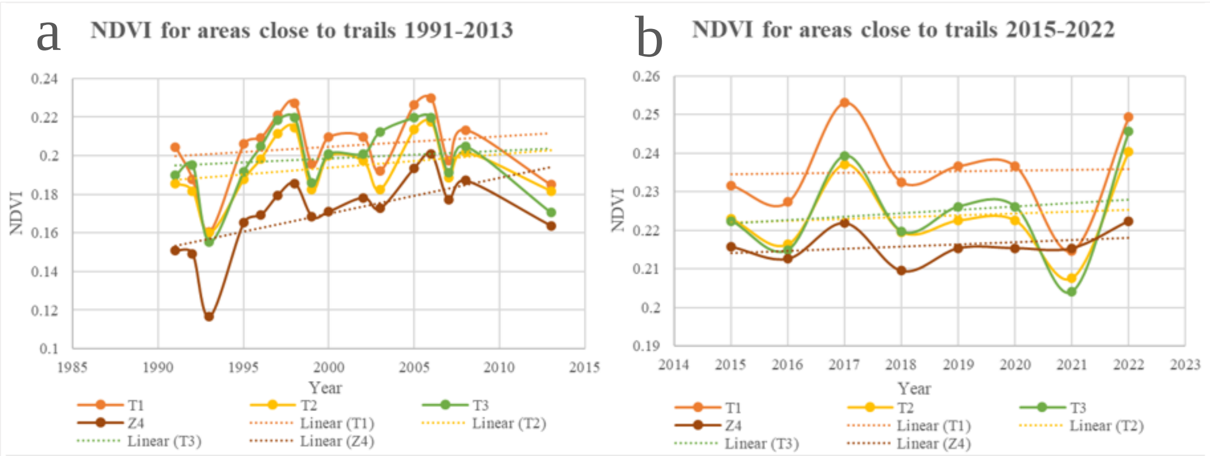

Figure 10: The NDVI for the zones close to trails and the trendline. To the left (a) from 1991 to 2013 and to the right (b) from 2015-2022.

The NDVI trend differs in all zones for both periods, although they are not shown to be statistically significantly different from Z4 as the P value is always greater than 0.05 (table 2). For 1991-2013 T3 has the smallest increase with 0.0004 units/year and T2 the biggest with 0.0007 units/year out of the trail zones. With zone Z4 included it had the highest increase with 0.0018 units/year. For 2015-2022 zone T1s NDVI increased the least followed by T2 and T3 out of the road zones.

The trend differs less between period one and two compared to the trend of the road areas.

Table 2: The trend and standard deviation of slope for all trail zones and Z4 as well as the probability of significance difference between the R zones and Z4 for both periods.

	1991-2013			
	T1	**T2**	**T2**	**Z4**
TREND ± STD	0.0005 ± 0.0859	0.0007 ± 0.0150	0.0004 ± 0.0143	0.0018 ± 0.0940
	T1 & Z4	**T2 & Z4**	**T3 & Z4**	
PROBABILITY	0.9908	0.9983	0.985	
	2015-2022			
	T1	**T2**	**T2**	**Z4**
TREND ± STD	0.0002 ± 0290	0.0005 ± 0.0055	0.0009 ± 0.0861	0.0006 ± 0.0049
	T1 & Z4	**T2 & Z4**	**T3 & Z4**	
PROBABILITY	0.9966	0.9991	0.9973	

5 Discussion

5.1 General NDVI Trend for Yellowstone National Park 1991-2022

NDVI has in general increased in Yellowstone National Park from 1991-2022. Ichii et al. (2002) found that the NDVI is increasing in the northern mid- to high latitudes and that a strong correlation can be found between NDVI, temperature and precipitation. Yang et al. (2019) also found global trends in increased NDVI with precipitation being the most important factor followed by temperature, land cover change, population, and elevation. In the norther hemispheres mid and high latitude areas, rising temperature was also found to be the most important factor for the increased NDVI (Ichii et al., 2002). Both the precipitation and temperature has increased in Yellowstone from 1991-2022 (NOAA, 2023). Growth rate is shown to increase with temperature until it reaches its tipping point (Hatfield & Prueger, 2015; Izaurralde et al., 2011) and it is therefore likely that the increased temperature is closer to the vegetation's optimal point. When water is not a limiting factor, plants produce more leaves and above ground vegetation, which would also lead to increased NDVI (Darrel Hess, 2016; Izaurralde et al., 2011; Stuart Chapin et al., 2012). On rangelands, which is common in Yellowstone, reduced rainfall has a strong effect on reduced net primary production (NPP) (Izaurralde et al., 2011). NPP and NDVI are shown to be correlated and have consistent ratios and trends, and both be highly influenced by precipitation (Rafique et al., 2016; Schloss et al., 1999). A decrease in NPP would therefore likely lead to lower NDVI values. Gandhi et al. (2015) found that a high availability of water in the soil lead to high NDVI values. The CO_2 in the atmosphere has also increased from 1991-2022 (Buis, 2019). Izaurralde et al. (2011) found that rangeland is experiencing advanced development and accelerated metabolism with increasing CO_2 which leads to longer growing seasons. Increased carbon is also shown to increase forest production when temperature and precipitation are not limiting (Kirilenko & Sedjo, 2007). Pastor and Post (1988) found that climate change might enhance vegetation growth in forests if water is not a limiting factor. It is therefore likely that the increase in NDVI seen in the park is due to climate change and increased temperature, precipitation, and CO_2.

Another reason for the increase of NDVI over time could be because the forest was recovering from large wildfires in both 1988 and 2016 where many lodgepole pines were burned down. This specific species covers 80% of the forest (NPS, 2021a, 2021b). In Yellowstone National Park 30% of abrupt negative shifts in NDVI could be linked to recent wildfires (Potter, 2019). However, fire also helps new pine seedlings to grow due to more favourable conditions being created (NPS, 2021b). The roots of plants were mostly unharmed by the fires and regrowth was seen already after 3 days (NPS, 2021a). For a few years after a fire many grasses and forbs have increased productivity due to all the nutrients released into the soil by the fire (NPS, 2021b). Potter (2019) states that fires have many different impacts on NDVI values, and that a positive NDVI trend could be found in young forests and regrowing forest cover after wildfires in Yellowstone National Park and that areas burned during both 1988 and 2016 had a higher positive NDVI trend than areas only affected by the 2016 fire. The 1988 fire transformed old dense forest to NDVI values of nearly 0 that then regrew slowly until the beginning of the 2000's when it burned again, resetting the cycle (Potter, 2019). Furthermore, recovery is less likely on steep slopes, high elevations and areas further from seed sources (Kiel & Turner, 2022). Kiel and Turner (2022) found that 30 years after the 1988 fire around 16% of the forest still had not recovered to the same density as before the fire. It is possible that one or multiple zones investigated in this study have a higher impact from fires than others and that that could impact the overall results. This study cannot show how big of an effect the wildfires have on the NDVI trends in the different zones and how it impacts the results. However, as fires are frequent and distributed throughout the park (NPS, 2021a, 2021c), it is assumed that the scale of this investigation will outweigh the effects from fire as all impact area zones will be affected.

5.2 NDVI Trends for Roads and Trails 1991-2013 and 2015-2022

5.2.1 Roads

Focusing on only the road zones, R1, R2, and R3, the second period shows a greater increase in NDVI in all zones compared to the first period, which at first glance looks like increased tourism has a positive effect on vegetation. However, R1 always has the lowest NDVI followed by R2 and lastly R3. R1 also increased less than both R2 and R3 in both periods. In the first period R2 increased more than R3 and in the second period R3 increased more than R2. This show that the increased tourism rate might have a bigger impact on vegetation than the lower tourism rate and that tourism close to roads most likely has an impact on vegetation in all the years investigated. This study cannot prove statistically that tourism has an effect on vegetation. However, the results would line up with similar studies conducted elsewhere where tourism was found to have an effect on vegetation (Cole, 2004; Cole & Landres, 1996; Rodway-Dyer & Ellis, 2018).

5.2.2 Trails

For the trails it is harder to find a pattern linked to tourism. Looking at only the NDVI values it looks like tourism has a positive effect on vegetation as NDVI is highest closer to trails. It is possible that plants with higher NDVI, but lower biodiversity are growing closer to touristed areas and that the impact from tourism on vegetation therefore is more complex than this study can show. Rodway-Dyer and Ellis (2018) found that grass expanded into heather vegetation close to trails, in a case study conducted in the UK. Fieldwork would be needed in future studies to investigate if this is the case in Yellowstone as well. It is also possible that it is due to the change in elevation. NDVI is highly linked to precipitation and temperature (Izaurralde et al., 2011; Yang et al., 2019; Yuhas & Scuderi, 2009). Which are both affected by elevation (C. Donald Ahrens, 2017). Aboveground net primary productivity (ANPP) is found to decrease with increasing elevation and suspected to be due to decreased temperature (Hansen et al., 2000). The areas further away from trails are located at higher elevations (Figure 2) and the NDVI would therefore be lower. During the second period we can see that the NDVI is increasing at a slower rate closer to the trails than further away which would support the fact that when the visitors' numbers increased, tourism on trails also has an influence on vegetation that can be seen at the scale used in this investigation. However, none of the results can be found to be statistically significant.

5.2.3 Sources of Error

As some of the trail zones overlap with the road zones it is also possible that the results from the trails are influenced by the results of the roads and that a different result would have been found if those areas were excluded. In this study years with zero impact are not being tested, and zone Z4 (furthest away from touristed sites) is being used as the control zone. Z4 often had a much lower NDVI value than the other zones, even though it was furthest away from trails and roads and therefore was expected to have the least impact from tourism and therefore a higher NDVI. The trend also differed the most from the other trends, as it had the highest increase out of all road zones 1991-2013 and the lowest increase 2015-2022. Z4 is mainly located on higher elevations than the other zones. As previously discussed, the elevation is therefore likely to be the reason for the lower NDVI values. Roads in general are found on the lowest elevation, whereas the trails are more varied and found at different elevations throughout the park (Figure 2). The further away from roads, the higher the elevation gets. R1-R3 are all relatively close in elevation and the difference in NDVI is therefore likely to be due to the impact of tourism rather than a difference in elevation. As vegetation generally decreases with elevation, R3 should have a lower NDVI than R1 if it was impacted by an elevation change. Since the different NDVI and trend of zone Z4 is most likely due to the difference in elevation, the focus in this analysis is to compare the difference between R1-R3 and T1-T3.

The NDVI values varied a lot between the years. Some years were more impacted by clouds which would have lowered the NDVI values for those years (Ali et al., 2013; Jing et al., 2022). However, as most years were cloud free the general trend should not be impacted by it. This study uses two different sensors, NASAs Landsat images 4-5 TM C2 L2 for the year 1991-2011 and 8-9 OLI/TIRS C2 L2 for 2013-2022. This was necessary as no sensor was available for the entire period. NDVI is found to differ between sensors, however the trend is always the same (Huang et al., 2021; Xie et al., 2010). Jarchow et al. (2018) compared Landsat 5 TM, Landsat 8 OLI with Modis data and found that on large areas with homogenic vegetation Landsat 5 TM, Landsat 8 OLI and Modis data was highly similar. This indicates that there should be no significant difference between the sensors of Landsat 5 TM and Landsat 8 OLI. The results of this study therefore should not be affected by the change of sensors.

5.3 Comparison of NDVI Results for Roads and Trails

The NDVI values increased more in the road zones than in the trail zones. All zones exist in both forest and rangeland which are the most common land classes in the park (NPS, 2023c) which would suggest that the landcover does not play a role in the different trends. Arrowsmith and Inbakaran (2002) found that tourism has a bigger impact on vegetation on lower elevations. NPS (2022a) state that most tourists stay within a 30 min walk from their car. Hence the majority of tourists would not walk on most of the trails in the park. Impact from trampling therefore has the biggest effect on areas closer to the roads than on the trails. Lodges and camping sites are also located next to roads which attract a lot of visitors (NPS, 2022b; Park, 2023). This supports the hypothesis that areas close to roads would experience a bigger impact from tourists than areas close to trails. However, comparing the two it is hard to draw that conclusion based on the NDVI trends.

Yellowstone National Park was already very influenced by tourism 1991 with around 3 million annual visitors and most of the big lodges and roads were already built by that time (NPS, 2020). Yellowstone National Park has a lot of tourism infrastructure in the form of roads and pathways in highly visited areas, and has strong conservation and management programs (NPS, 2021d, 2023a, 2023h). Good infrastructure minimises the impact from tourists on vegetation (Cole, 2004; Geneletti & Dawa, 2009). It is therefore a possibility that the high increase in NDVI is due to the conservation and management efforts for the park are paying off and the vegetation is recovering from previous years of less managed grounds. However, the high number of visitors during recent years has led to an increase in roadside parking (Susan Sidder & Ashley D'Antonio, 2019). People have also been observed walking off path and littering which are both found to impact vegetation (Cole, 2004; Cole & Landres, 1996; Kycko et al., 2018; Susan Sidder & Ashley D'Antonio, 2019). Still the park has experienced limited impact from visitors in 2023 (NPS, 2023h). This would show that the impact from tourism can be limited with good planning, management, and infrastructure. On the other hand, it is not possible to see what caused the high increase in NDVI in the road zones during the second period.

NDVI values do not tell us anything about biodiversity, since a forest and a golf course can have the same values (Huang et al., 2021). In areas close to roads, lawn grass is often seen which would have a high NDVI value (NPS, 2020, 2023d). It is therefore also a possibility that trampling and tourism have shifted the vegetation from species with lower NDVI to higher ones and that the impact on vegetation is greater than can be seen in this study and with NDVI. However, this doesn't explain why the NDVI is increasing less in zone R1 than R2. Blanco et al. (2008) found that grazing has an impact on NDVI. Tourism is found to displace animals (Cassirer et al., 1992; Thomsen et al., 2022) and it is therefore a possibility that areas close to roads are less trafficked by animals and that the areas are experiencing less grazing than others, hence resulting in a higher increase in NDVI. Another possible explanation is that the areas close to roads are affected by pollution from cars. Cars release a variety of pollutants such as carbon and nitrogen (Bhandarkar, 2013). Kenkel et al. (2013) found that cars and other vehicles were the main source of nitrogen near roadways in Grand Canyon national park. Globally carbon dioxide accounts for 70% of the greening effect, with nitrogen as its second strongest driver (Reiny, 2016). Cobley and Pataki (2019) and Honour et al. (2009) found that cars have an effect on urban vegetation. It is therefore very likely that cars have an effect on the vegetation in Yellowstone and that the increased number of visitors and cars might have contributed to the increase in NDVI.

6 Conclusion

Overall vegetation has increased in Yellowstone national park from 1991 to 2022 which most likely is due to increased temperature, precipitation, and CO_2. It seems that vegetation is most affected by tourism close to roads rather than trails as the NDVI values are lower closer to roads, and secondly, the trend is increasing more drastically in the road zones during 2015-2022 than any other zone. However no statistical significance can be found proving that tourism has an impact on the area. There are many different possible factors influencing vegetation around roads and trails, such as trampling, infrastructure, pollution, and grazing. Because fieldwork could not be conducted in this study it is not possible to state why the NDVI is shifting differently close to roads contra close trails. Using solely NDVI for testing the effects from tourism on vegetation is limiting, as it not possible to see why and how the vegetation is shifting except for the greenness. Fieldwork, in form of comparing species composition in the different road and trail zones, is therefore recommended for future studies to further investigate how tourism effects the vegetation in Yellowstone National Park. It is possible that a greater effect would have been found with the use of smaller zones which is recommended to be investigated in future studies.

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Appendix

Table A1: Average NDVI value for all road zones for all years.

	R1	*R2*	*R3*	*Z4*
1991	0.183576	0.182628	0.185893	0.150948
1992	0.171663	0.169044	0.189655	0.149314
1993	0.173221	0.172093	0.179382	0.116658
1995	0.180954	0.181761	0.186383	0.165431
1996	0.189223	0.190893	0.201573	0.169170
1997	0.203023	0.204038	0.217740	0.179600
1998	0.205299	0.204038	0.218650	0.185713
1999	0.176144	0.207730	0.180660	0.168516
2000	0.187289	0.191126	0.182166	0.171154
2002	0.187401	0.190658	0.196831	0.178298
2003	0.173136	0.177332	0.178620	0.172700
2005	0.199925	0.203042	0.211678	0.193596
2006	0.204741	0.207532	0.202379	0.200803
2007	0.175927	0.181145	0.211678	0.177079
2008	0.192183	0.196475	0.202379	0.187109
2013	0.188008	0.193595	0.196171	0.163815
2015	0.210288	0.214709	0.218583	0.215704
2016	0.203306	0.208885	0.209810	0.212676
2017	0.223019	0.227500	0.232321	0.221811
2018	0.210674	0.215299	0.217418	0.209529
2019	0.214250	0.220004	0.222290	0.215188
2020	0.214450	0.220204	0.222090	0.215388
2021	0.205000	0.211882	0.215621	0.215388
2022	0.226773	0.232747	0.244512	0.222370

Table A2: Average NDVI value for all trail zones for all years.

	T1	*T2*	*T3*	*Z4*
1991	0.204582	0.185735	0.189791	0.150948
1992	0.187952	0.181697	0.195267	0.149314
1993	0.160761	0.159928	0.155207	0.116658
1995	0.205969	0.187753	0.191806	0.165431
1996	0.209242	0.198440	0.204875	0.169170
1997	0.221010	0.211440	0.218448	0.179600
1998	0.227297	0.214700	0.219679	0.185713
1999	0.195599	0.182356	0.186161	0.168516
2000	0.209678	0.200038	0.201104	0.171154
2002	0.209772	0.197318	0.201104	0.178298
2003	0.192085	0.182473	0.212474	0.172700
2005	0.226448	0.213634	0.219735	0.193596
2006	0.229693	0.217739	0.219586	0.200803
2007	0.197558	0.188441	0.191252	0.177079
2008	0.213410	0.201692	0.205005	0.187109
2013	0.185018	0.181814	0.170649	0.163815
2015	0.231639	0.222986	0.222433	0.215704
2016	0.227376	0.216454	0.214960	0.212676
2017	0.253068	0.237079	0.239367	0.221811
2018	0.232469	0.219600	0.219697	0.209529
2019	0.236459	0.222381	0.225963	0.215188
2020	0.236659	0.222581	0.226163	0.215388
2021	0.214749	0.207723	0.204044	0.215388
2022	0.249404	0.240413	0.245566	0.222370