A Geospatial Analysis and Comparison of Snow Leopard and Mountain Lion Habitat: Implications for Conservations and Research

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April 8th, 2022

A GEOSPATIAL ANALYSIS AND COMPARISON OF SNOW LEOPARD AND MOUNTAIN LION HABITAT: IMPLICATIONS FOR CONSERVATIONS AND RESEARCH

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Honours Bachelor of Environmental Management

Faculty of Natural Resources Management

Lakehead University

Thunder Bay, Ontario

April 8th, 2022

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Thesis Supervisor Second Reader

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ABSTRACT

Berry. M. B. 2021. A geospatial analysis and comparison of snow leopard and mountain lion habitat; implications for conservation and research. 56 pp.

Keywords: climate change, ecology global change, habitat loss, landscape classification, mountain lion (*Puma concolor* L.), remote sensing, snow leopard (*Panthera uncia* S.)

Big cats form an integral part of landscape ecosystem management and are vital to the persistence of natural habitats. Global change, alongside human interactions has severely harmed populations of these predators, often to the point where many species are at risk of being, or already are, extinct. Two examples of big cats affected by human development are the snow leopard and the mountain lion, which each have their respective difficulties adapting to an anthropogenic world. Examples of factors that have affected these species include habitat loss and fragmentation, prosecution and poaching, and increased disturbance. The purpose of this report is to employ GIS and remote sensing techniques to analyze sample habitat of these animals and to determine how to best conserve the future of these big cats. The results of this paper showed that mountain lion habitat was more stochastic than that of snow leopards, however, both are changing. Future management projects directed towards these species will need to consider how these species' habitat is being affected, moving forward.

CONTENTS

ACKNOWLEDGEMENTS

This thesis is the product of a great deal of collaboration between students, supervisors, and faculty and this section will hopefully reflect that. I would like to acknowledge the countless contributions from my original supervisor Dr. William Wilson who suggested both the topic of big cat ecology and the Terrset application to explore it through. With these, the basis for this thesis was developed. Tomislav Sapic was kind enough to provide his GIS knowledge and expertise as my second reader. Dr. Brian McLaren also volunteered to contribute his time when Dr. Wilson was unable to review my final drafts. I also need to thank Jennifer Johnson, my fellow peer who provided program advice and edits for my thesis.

INTRODUCTION

Human activities have created severe restrictions on big cat populations on a global scale (Morrison et al. 2007). The ranges of these large predators have been reduced, in part, by habitat removal, alteration, and fragmentation (Jiang et al. 2017). Traditionally, big cats have occupied most of the earth's surface excluding Antarctica, Oceania, and parts of Europe. (Zanin and dos Santos Neves 2019). This makes conservation efforts complex since maintaining large, un-fragmented areas across multiple political boundaries is a difficult task (Jiang et al. 2017). Humans also exert additional pressures on big cats through direct harvesting or poaching, along with multi-scale persecution (Maheshwari and Meibom 2016, Mishra et al. 2016). The need to prevent and reverse these effects is of great importance since big cats serve important roles in ecosystems as predators at the top of food webs (Ripple et al. 2014). Top-down control exerted by big cats controls the shape and composition of their ecosystems (Ripple et al. 2014). Additionally, apex predators serve as umbrella species for conservation helping other native species in their ecosystem when protected. Big cats are also known for serving as the faces of global conservation programs (Morrison et al. 2007, Ripple et al. 2014).

Panthera uncia, or the snow leopard, is such a species and is both the dominant big cat and top predator in its ecosystem (Fox and Chundawat 2016). Historically snow leopards have avoided human interaction due to the remote nature of their habitat (McCarthy et al. 2017). Recently however, human population growth, climate change, and resource exploitation have led to increased confrontations between man and cat. Population estimates put the total number of snow leopards at around 7500 individuals in the wild (McCarthy et al. 2016). These are only rough estimates owing to the secretive nature of the animal, combined with the remote habitat they inhabit. Despite this, we know that the snow leopard population is declining overall and currently the animal is listed as vulnerable (McCarthy et al. 2017). There are several reasons for this such as habitat loss, a decline in prey species, and human-wildlife conflicts (HWC) (Rashid et al. 2020). While there are many possibilities for future snow leopards' conservation, there are also many dangers that could easily push the species closer to extinction. Across the globe, this is often the case, with declining populations in often-fragmented habitats, with little opportunities for population and range expansion (Morrison et al. 2007).

The exception to this, is *Puma concolor*, the mountain lion, also known as the cougar or puma, which despite facing similar pressures through European settlement of the Americas, is managing to re-settle its lost habitat (Morrison et al. 2014). While populations are still vulnerable, current and improved management practices there is a very real possibility to see mountain lions return across North and South America. This report will seek to explore the differences in how these two, similar felid species are experiencing and adapting to a modern, human-dominated world.

It is important to understand that while these two animals are similar, there are many differences within the big cats' habitat, life history, and prey. Snow leopard's habitat is limited, mostly to rocky terrain in the high mountains of Central Asia, where there is little tree cover (Fox and Chundawat 2016). In contrast, the mountain lion is widely distributed across the Americas and its habitat is therefore determined on where it is geographically located (Murphy and Ruth 2010). For example, these predators could be observed in open steppe, mountain, forest, desert, and swamp habitats (Murphy and Ruth 2010). Prey is also determined by the habitat in which these big cats live. For the snow leopard, most of the animal's diet is made up of large wild ungulates and domesticated animals (Aryal et al. 2016). Mountain lions' prey are much more varied and would depend on where the animal is located. Where these animals are most similar is in terms of morphology and life history. Both are solitary animals, with an exception during breeding season or with young, that operate over massive home ranges (Fox and Chundawat 2016, Quigley and Hornocker 2010). Cougars in particular are notorious dispersers with cats travelling hundreds of kilometers to find suitable territory (Choate et al. 2018, Karelus et al. 2021).

The objective of this study is to use GIS and remote sensing tools to examine the habitat of these big cats. Snow leopards and mountain lions occupy huge home ranges and are sensitive to human activities that occur within the same area. Therefore, this study will examine and compare the selected habitats for the two species and changes that have occurred within them and to suggest conservation measures for both species. The geospatial part of the analysis will be done through GIS applications QGIS and TerrSet, using Landsat 5 and 8satellite data. The goal is the establish if there is any kind of significance between the habitats that might lead to either prosperity or decline of either species.

It can be hypothesized that due to the current re-colonization success of mountain lions their habitat has more suitable characteristics for big cat population success (Davenport et al. 2010). This would include habitat quality, connectivity, less disturbances, etc., but would also be affected by sociopolitical changes such as protected areas, conservation initiatives, and reduced HWC. Therefore, it can be determined that mountain lion habitat is experiencing less overall negative factors in their selected habitat, than that of the snow leopard, which is allowing the species to be more successful. If this is determined than we need consider how the success of the mountain lion can be replicated with the snow leopards, and with other big cat species.

LITERATURE REVIEW

Snow Leopard Ecology

Snow leopards are a top predator within the central Asian mountainous regions where they reside (Chetri 2018. Juan et al 2019) This includes habitat within 12 different countries including Afghanistan, Bhutan, China, India, Kazakhstan, Kyrgyzstan, Mongolia, Nepal, Pakistan, Russia, Tajikistan, and Uzbekistan (McCarthy et al. 2016). The actual range of snow leopards remains a discussed topic, but recent estimates by McCarthy et al. (2017) put their distribution at between 1,776,000 km^2 and 3,300,000 km^2. These numbers can be misleading since snow leopards exist at extremely low population densities with reasonable estimates placing the wild population at 7446 – 7996 animals (McCarthy et al. 2016, McCarthy et al. 2017). Moreover, since so few of these animals exist inside their vast range, it is functionally impossible to determine exactly where snow leopards live. Furthermore, the prey of snow leopards also exist at low densities, forcing these few snow leopards to cover huge land areas in search of prey (Di Minin et al. 2016, Fox and Chundawat 2016, Juan et al. 2019). Male snow leopards can have home ranges of over 207 km^2 while females have a comparatively low 124 km^2 home range (Fox and Chundawat 2016, Johansson et al. 2015).

The environments through which these animals' traverse are amongst the most remote and inhospitable places on earth. The northern extents of their range passes through the Tianshan Mountains (China) and Altai Mountain chain (Mongolia and Russia), where snow leopards live in high, dry climates of 600 m – 4000 m above sea level (Fox and Chundawat 2016, McCarthy et al. 2016). This environment mostly consists of treeless mountain slopes, but snow leopards can be found traversing the open forests and scrubland that separate mountains in search of prey (Fox and Chundawat 2016). The southern range of snow leopard habitat is even more inhospitable with habitats ranging from 1800 m – 5800 m above sea level in many of the highest mountain ranges in the world (Fox and Chundawat 2016). These include the Hindu Kush Mountains (Afghanistan and Pakistan), Pamir Knot (Afghanistan, Tajikistan, Uzbekistan), Karakorum Mountains (China, India, Pakistan) and the Himalayas (Bhutan, China, India, Nepal, Pakistan) (Chetri 2018, Fox and Chundawat 2016, McCarthy et al. 2016). Here, snow leopards are found hunting at the edges of high alpine forests and in grass or scrub land where prey is available (Fox and Chundawat 2016). The remote nature of this habitat, along with the sparse population of snow leopards creates many challenges for conservation applications.

Historically snow leopards have been saved from human interactions due to the many difficulties present when living at high altitudes Indeed, it was not until the second half of the twentieth century that a basic range map for the feline had been produced (McCarthy et al. 2016). Since that time however, human populations have grown and the demand for more space and resources has skyrocketed which has put even the most remote regions of the Earth at risk (Balatsky et al. 2015, Morrison et al. 2007). In turn what was once a protective element, the impossibility of encountering the reclusive animal at the top of the world, has now become a danger to it as many details of snow leopard's ecology and thus habitat, remain unknown (Maheshwari and Niraj 2018, McCarthy et al. 2016).

While the integrity of their habitat remains, the biggest obstacle to snow leopard persistence is the direct killing of individuals through poaching and retaliatory killings (Maheshwari and Niraj 2018). Snow leopard products are highly valuable on the illegal market, despite strong regulations against the trade of animal products (Maheshwari and Meibom 2016). A study by Nowell et al (2016) determined that over the course of an 8-year study from 2008 to 2016, at least 450 snow leopards were found within illegal markets. Considering what the global population of snow leopards is estimated at, this is a sobering discovery. More than this, many snow leopards are killed as result of HWC over the predation of livestock (Juan et al. 2020, Maheshwari and Niraj 2018). With the depletion of natural prey, livestock are becoming an increasingly important part of snow leopards' diets (Lovari and Mishra 2016, Mishra et al. 2016). This then creates conflict since livestock animals are a significant economic investment from local herders (Pokahrel and Chetri 2006).

When considering HWC it is important to understand that these relationships are not new and have existed for a long time (Mishra et al. 2016). In short, the root cause of these conflicts lies with human anthropogenic values and public perception of big cats. Until this changes on a local and global level, there is little room for improvement. To do this it is important to encourage cooperation between all range countries to properly facilitate the growth of the species (Juan et al. 2020). This is especially true when considering trans-border issues and how low-density animals are best managed at a range-wide conservation level. Involving local governments and peoples in conservation efforts has already proven to increase protection and planning efforts for at risk cat species (Juan et al. 2020, Nowell et al. 2016).

Mountain Lion Ecology

Mountain lions are one of two big cat species found in the Americas, the other being the jaguar, and have the greatest distribution of any mammal species on the continents (Dellinger et al. 2019, Murphy and Roth 2010). Historically the range of mountain lions extended east to west across both North and South America and the majority of areas in between (LaRue et al. 2012). However, persecution from humans as well as removal of habitat has pushed cougars into more remote pockets, mostly in the mountainous western portions of both continents (Beschta et al. 2009, LaRue et al. 2012). Today, except for the Floridian panther population, the furthest confirmed populations of pumas in North America are found off the edges of Rocky Mountain terrain in the American Midwest (LaRue et al. 2012).

Owing to them once near cosmopolitan distribution, mountain lions can be found in a wide range of habitats. As habitat generalists, mountain lions are able to live most environments but are commonly found in rugged terrain with some form of tree cover (Morrison et al. 2014, Murphy and Roth 2010). This is only a generalisation since cougars in Florida live in low elevation swamps or pumas in South America that live in the jungle. Mountain lions are incredible dispersers, able to travel well more than 1000 km in search or habitat or mates (Morrison et al. 2014). Currently this has allowed mountain lions to start to re-colonize their former range. While cougar dispersal has facilitated the recolonization of past habitat, it has also brought increases in HWC. This is especially the case for areas of eastern expansion, where people who have not had to coexist with the animal for many decades now are (Morrison et al. 2014).

Legal protection of mountain lions varies with location and can hinder the progress of the animal's recovery. In many states across the USA, mountain lions are considered a game animal and are allowed to be hunted (Dellinger et al. 2019). Whereas in California mountain lions are protected and are only allowed to be removed if a specific animal is causing issues (Dellinger et al. 2019). This problem with cougar exists across their range with some advocating for the protection of the species, while others insist that cougar cause significant negative effects to game and livestock species. Still, despite both current and historic persecution, mountain lions are making a remarkable comeback across the continent (Beschta et al. 2009, Dellinger et al. 2019, Morrison et al. 2014).

As mentioned above, cougars are habitat generalists and great dispersers, but their main advantage is that they also have shown great adaptation to living in a human modified landscape (Knopff et al. 2014, Morrison et al. 2014). While large scale infrastructure does inhibit mountain lion movement, animals frequently make use of roads and other transport lines to facilitate movement (Knopff et al. 2013, Morrison et al. 2014). The rise of ungulate populations in North America from increased protection has also benefited cougars (Knopff et al. 2014). A study by Morrison et al. (2014) found that white tailed deer congregated in areas, near humans where the animals are protected and often feed. Mountain lions then follow these deer to hunt them and can establish populations. Both deer and cougars are also well adapted to landscape fragmentation and often forage at the edge of habitats (Morrison et al. 2014). Other behavioral adaptations such as avoiding areas based on peak human activity are allowing cougars to live and possibly benefit from human development (Knopff et al. 2014, Morrison et al. 2014). With strong evidence supporting a successful recolonization for former habitat, what remains to be seen is whether humans can tolerate a coexistence with these animals (Knopff et al. 2014).

Landscape Mapping

The workshop for Remote Sensing and GIS for Monitoring Habitat Quality was held on September 24-25 in Vienna, Austria (Zlinszky et al 2015). Its goal was to look at the challenges involved with monitoring habitat quality at three levels. The first level was identifying and mapping the locations of habitats. The second level was in the mapping of environmental features of a habitat that contribute to habitat quality. The third level of the workshop was to combine the various models and data into an observable medium for conservation purposes. Traditionally these landscapes have not been explored with remote sensing due to inability for the technology to separate similar spectral responses and produce at high spatial resolutions.

However, with improvements in technology, researchers at the conference produced various analysis of grassland habitat with the use of GIS and remote sensing. Further improvements in sensors and processing allowed for multi-scale analysis in the second level. Levick et al. (2015) were able to map the dynamics of invasive grasses in a savanna ecosystem at multiple regional scales by using LIDAR technology. Similar methods were applied in the third step to create a comprehensive habitat map that met international standards. Through various research projects a conservation status map was created that met the standards of Europe's most extensive monitoring scheme: Natura 2000 (Trochet and Schmeller 2013).

The evolution of GIS and Remote sensing has allowed these varied levels of habitat quality to be assessed with greater levels of optimization and accuracy. End-users have also become more experienced with these applications resulting in greater efforts to standardize information mediums and to promote different scale applications of these tools. Technology has improved the spatial and temporal resolution of related imagery which has allowed for accurate habitat quality assessments. Additionally, the high-quality images needed for analysis have become ever available with global imaging collections such as those from the Sentinel-2 and Landsat-8 satellites. These and many other image databases are free, allowing for the greater ease of access. As GIS and remote sensing are increasingly used in conservation applications, their support within various governance bodies needs to increase. Zlinszky et al. (2015) demonstrate that as our understanding of GIS technologies increase, so too do the conservation issues they can be applied to. Therefore, there is a need for continued research that can further prove the accuracy and usefulness of these technologies as we work towards preserving the world habitats and biodiversity.

Land Change Modeler of TerrSet

The Land Change Modeler (LCM) is a component of the TerrSet Geospatial Monitoring and Modeling Software which can be used for a variety of GIS and remote sensing applications (Armenteras et al. 2019). LCM is based on the Markov chain and cellular automata dynamic model that is designed to predict the spatial and temporal differences within land use/land cover scenarios (LULC) (Gidey et al. 2017). The purpose of the LCM is to interpret data from LULC cases, which are human caused alterations of the surface of the earth (Hamad et al. 2018). The TerrSet modeler is then able to perform a variety of functions such as land cover change analysis and identification of trends with multiple class transitions (Armenteras et al. 2019). The result of this analysis is the ability to assess different LULC categories and how they have changed over the course of time (Hamad et al. 2018). Modeling LULC has many implicated benefits to understanding historic habitat change and predicting future land conversions, both of which are critical for conservation understanding (Armenteras et al. 2019, Hamad et al. 2018)

Importance of Big Cats and Decline

Despite existing at relatively low abundances, large predators play a crucial role in ecosystem management (Morrison et al. 2007, Ripple et al. 2014). This is known as top-down control, where animals at the top of food chains shape population dynamics (Mallory et al. 2019). Top-down control affects environments across all trophic levels through either direct or indirect effects (Mallory et al. 2019, Ripple et al. 2014). Directly, predators exert control over the population sizes of prey species in their respective food webs (Ripple et al. 2014) This then indirectly affects habitat structure depending on which species are preyed upon (Morrison et al 2007). Due to this significance, large predators are often designated as umbrella species by conservationists since the protection of an animal at the top of the food chain has a blanketing effect of protecting many animals in the ecosystem (Maheshwari and Niraj 2018, Ripple et al. 2014). Despite their importance, populations of large mammalian predators such as big cats, have been declining due to human influences (Beschta et al. 2009).

Human activities have caused a global reduction in the number of large carnivores (Beschta et al. 2009). There is no single reason behind this collapse; instead, a multitude of human practices including habitat alteration, resource extraction, and direct confrontation have resulted in large predators becoming among the most globally endangered mammals (Ceballos and Ehrlich 2002, Morrison et al. 2007, Ripple et al. 2014). Habitat loss and alteration generally have a disproportionate effect on large carnivores since these animals have large habitats, disperse over great areas, and have large energy requirements (Juan et al. 2019, Mitchell et al. 2018). Along with this, large predators also have slow life histories and exist at low population densities making it harder for these animals to recover after experiencing reductions (Ripple et al. 2014). These traits also increase the chances that big cats come into conflict with people and development, over their vast territories (Ripple et al. 2014). Conflict between humans and big cats, such as poaching or retaliatory killings are both a historic and current threat to the persistence of big cat species. Cougars were nearly brought to extinction across the Americas when European settlers expanded across the continent (Beschta et al. 2009). More recently, snow leopards have been persecuted for their valuable hides and in response to predation on livestock (Maheshwari and Meibom 2016). This places huge importance on the conservation of large carnivores as they are both very vulnerable to human-induced extinction but are also a key part to controlling ecosystem services (Ripple et al. 2014).

Effects of Global Change

Global temperatures have continued to rise at an increasingly alarming rates through the twenty and twenty-first century (Farrington and Li 2016). In a period between 1952 and 2012 mean annual temperatures increased 0.72 °C with temperatures expected to continue to rise, as high as by an additional 4.8 °C by 2100 (Farrington and Li 2016). Already this has caused major shifts in habitat, animal range, and resource availability, among other effects (Farrington and Li 2016, Trouwhorst 2020). The most immediate of which is the global loss of species diversity due to the aforementioned factors. Climate change has also already begun to shift the range of species habitats, which is especially evident in colder, high elevation or high latitude ecosystems (Farrington and Li 2016, Mallory et al. 2019).

Mountain lions in North America are expected to experience a northward shift of habitats with tundra and boreal forests ecosystems experiencing higher temperatures (Mallory et al. 2019). This could put southern range cougars at risk as extreme heat and drought could prevent animals from existing within the desert regions of the United States or Mexico (Trouwhorst 2020). While animals in the northern Canada may benefit, increasing in natural disturbances will likely shift the successional stages of boreal forests, which could help or harm mountain lions (Mallory et al. 2019). Snow leopards, who already exist within a restricted habitat will be forced to move further up mountains as climate change pushes tree lines higher (Farrington and Li 2016, Trouwhorst 2020). While climate predictions do show the potential for range increase in the northern parts of snow leopard habitat, the animals are also expected to lose much of their southern range (Farrington and Li 2016). Furthermore, these predictions only include effects from climate, not the many other human activities that threaten big cat species globally.

In order for healthy populations of animals to persist in the wild there needs to be enough connected habitat for the survival of multiple, exchanging populations (Riordan et al. 2016). This is to prevent the negative effects associated with small, isolated populations such as inbreeding depression, bottleneck effects, and overall species extinction (Riordan et al. 2016). There are two things to consider when examining the effects of habitat fragmentation on big cat populations. First is that the relevant habitat scale depends on an animals' life history (Collinge 2009). To a mouse, a fragmented field presents a full ecosystem that can support the animal's needs. In contrast a whale may require entire oceans to search for food or mates. In simple terms, fragmentation disproportionately affects animals based on their necessary habitat size (Collinge 2009). Second is the need to recognize that species react differently to fragmented landscapes (Fahrig et al. 2019, Riordan et al. 2016). Large carnivores have huge distributions and therefore are typically vulnerable to increased fragmentation and human activities within their range (Riordan et al. 2016). However, studies like those by Morrison et al. (2014) showed how the mountain lion benefits from the presence of edge habitat and close human proximity. Therefore, it is imperative in conservation management that when considering habitat fragmentation to also consider how the species of interest is affected (Fahrig et al. 2019). While any species will suffer if its habitat is simply removed, there can be both benefits and costs associated with habitat fragmentation.

METHODS AND METHODS

Study Area

The study area selected for sample snow leopard habitat is the 7,629 km^2 large Annapurna Conservation Area (ACA) (N28-29°, E83-85°), which is situated amongst the Trans Himalayan Mountains, bordered in the north by the endless Tibetan Plateau (Chetri et al. 2017) (Figure 1).

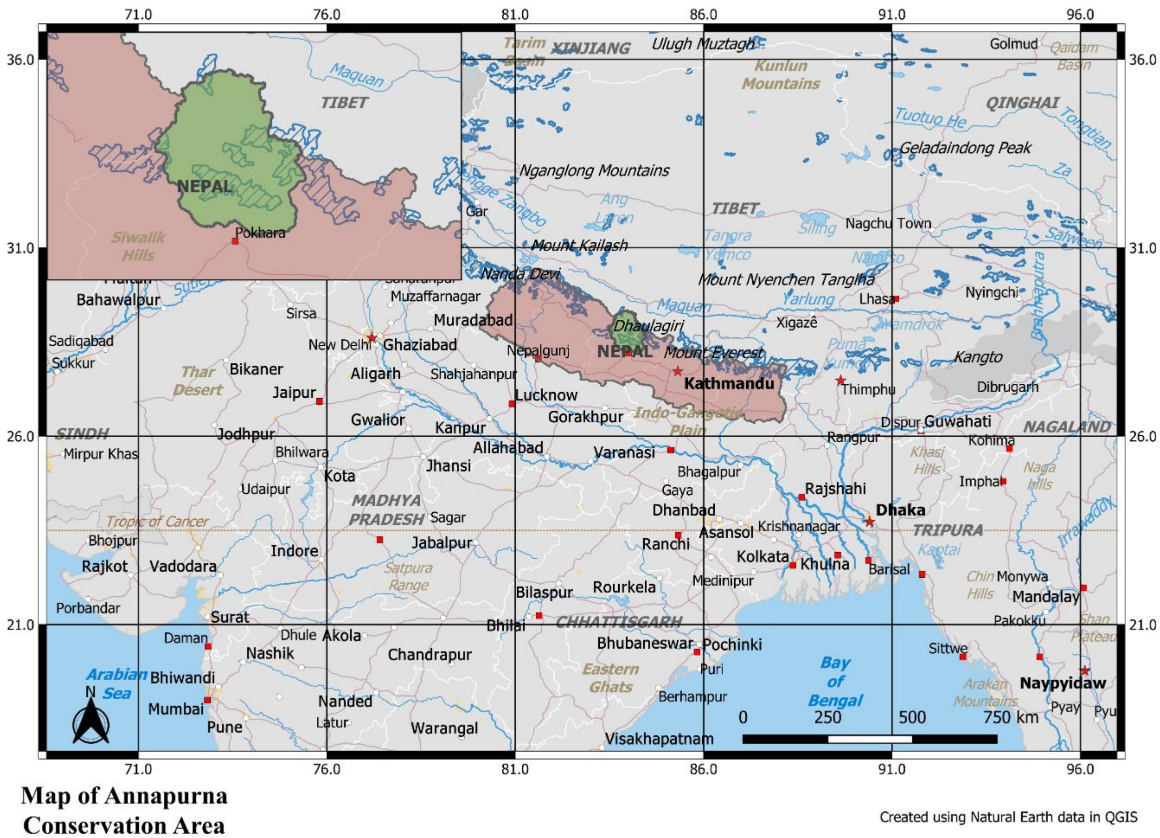

Figure 1: A map of Annapurna Conservation Area showing its reference position in Asia

Since 1995 this area has been protected by the National Trust for Nature Conservation and is now the largest area of protected space in Nepal. The topography of the land varies greatly, ranging from high mountain peaks to deep valleys and glaciers, and all area in between (Shrestha and Wegge 2008). Vegetation in ACA is then accordingly diverse, owing to the range of altitudes present (Chetri 2018). Grass- or scrublands, which are staple habitat of snow leopards, are abundant in the dry valleys and slopes formed between the Himalayan peaks. At lower elevations dense, deciduous forests cover the southern portion of ACA (Shrestha and Wegge 2008). ACA is home to a large diversity of mammal species including many ungulate species that serve as snow leopard's primary prey (Chetri 2018). Human development in the area has brought large quantities of domesticated to the area, as communities' main economy is based around pasture herding (Chetri 2018, Pokharel and Chetri 2006).

Mountain lion habitat was selected in 8991 km^2 large Yellowstone National Park (YNP) (N 44-45°, W110-111°) which falls within the Greater Yellowstone ecosystem. YNP is the oldest National Park in the lower 48 and was established in 1872 (Meyer and Youngs 2017). (Figure 2).

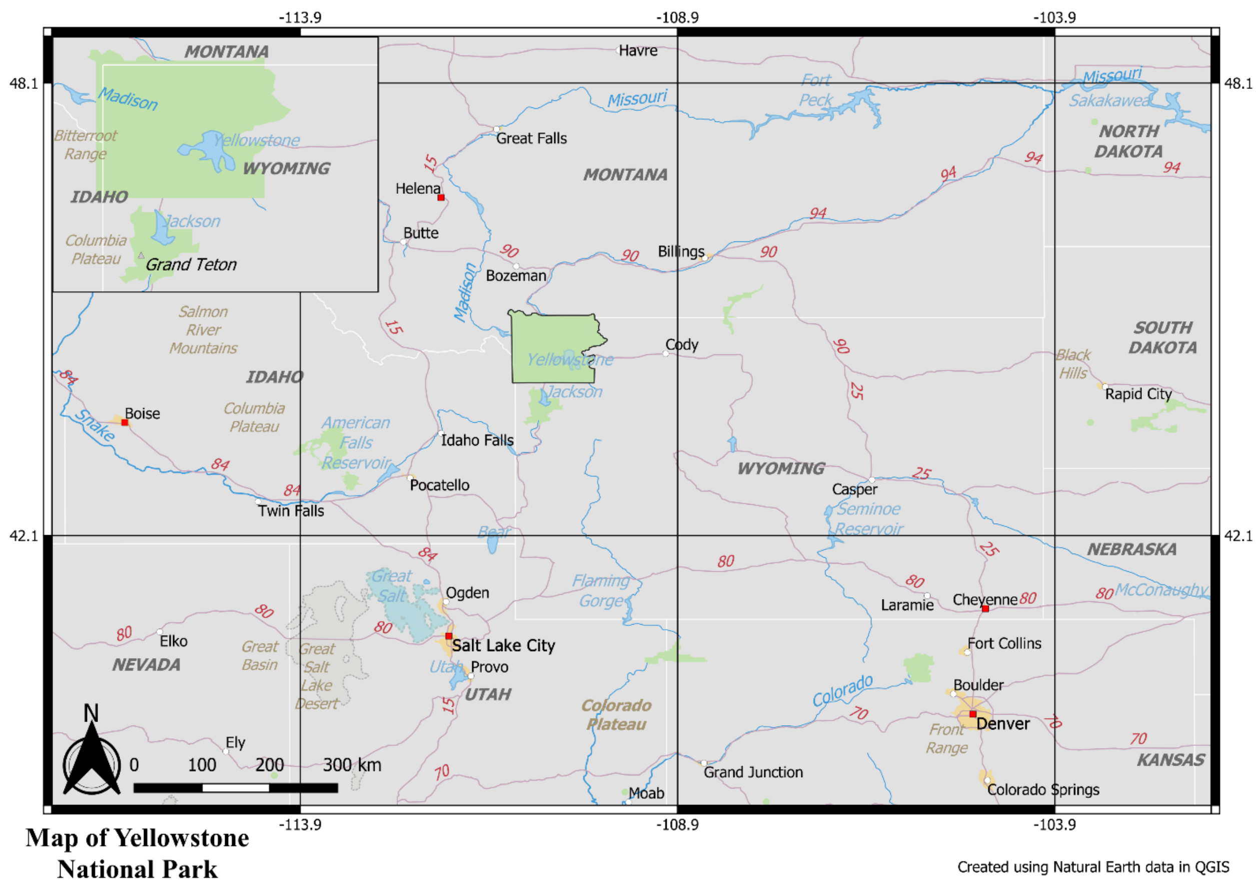

Figure 2: A map of Yellowstone National Park with reference to its surrounding area

The Yellowstone area is situated between mountain slopes in a forested plateau in northwestern Wyoming (Turner et al. 2004). The majority of the vegetated area in the park is dense forest, with lodgepole pine being the dominant species. Other softwoods are also present, but at lower abundances. Yellowstone is also rife with geothermal activity and much of the landscape is covered with geysers and acidic pools (Meyer and Youngs 2017). The climate in YNP is cool and dry with low precipitation throughout the year (McMenamin et al. 2008). The park is large, and covers nearly 9,000 km^2, which in combination with its long standing protection has allowed many animals to thrive in the Yellowstone ecosystem (Turner et al. 2004). This includes many iconic species such as the wolf, bison, and the mountain lion (Garrot et al. 2009). Human presence in the park has been consistent since its opening and even before, however as a protected area, influence has been minimal (Meyer and Youngs 2017).

Data Collection

Data for these sample habitat areas was obtained from the United States Geological Surveys (USGS) EarthExplorer Web Application, which provides users with access to a catalogue of imaging from many different satellites (Housaka 2012). Thanks to its long running service, the Landsat program's satellites were chosen as the sensors for data on both animal's sample habitat. Images of the sample habitats were taken from both Landsat 8 and 5 satellites across a four-decade period (Tables 1, 2). Emphasis was placed on collecting data from similar dates throughout the year as to reduce potential variation between seasonal vegetation (Schmidt and Karnieli 2000, Yang et al. 2017). At the same time images were only selected if the scene was free of clouds or other atmospheric interference. Therefore, the scenes acquired from the Landsat 8 and 5 satellites were not spaced by equal time intervals but were taken around similar seasonal periods and were relatively free of blemishes. These Landsat images then formed the basis of the classification and land change detection going forward.

Table 1: Landsat 8 and 5 sensor information for sample snow leopard habitat

Date of Acquisition	Landsat Sensor	Path/Row	Image Resolution
10-Oct-89	TM	142/40	30 m
11-Nov-95	TM	142/40	30 m
29-Oct-09	OLI_TIRS	142/40	30 m
14-Oct-21	OLI_TIRS	142/40	30 m

Table 2: Landsat sensor information for sample mountain lion habitat

Date of Acquisition	Landsat Sensor	Path/Row	Image Resolution
02-Aug-89	TM	38/29	30 m
14-Aug-02	TM	38/29	30 m
29-Jul-08	TM	38/29	30 m
15-Aug-20	OLI_TIRS	38/29	30 m

Study Design

When completing an image classification there are two general methods employed: supervised and unsupervised classifications. Supervised classifications are better suited for applications where sufficient information of ground conditions are known (Hasmadi et al. 2009). Unsupervised classifications were then selected since they can be configured to use the same input parameters for all scenes across both sample habitats. Classifications were completed using the Semi-Automatic Classification Plugin (SCP), as a part of the QGIS software. Before the images could be classified, they were first put into the Normalized Difference Vegetation Index (NDVI). This index is commonly used to determine drought conditions but is also applicable for general vegetation surveys (Drisya et al. 2018). The NDVI was selected for the study area since the three major habitat types of desired (grasslands, forests, barren area) all have significantly different spectral signatures within the index. The total coverage of the NDVI index ranges from -1.0 to +1.0 (Drisya et al. 2018). Barren area was represented by values of approximately -1.0 to 0.1, while grassland covered values of 0.2 to 0.7, with forests at values of 0.8 to 1.0. Equation 1 explains the raster band math needed to calculate the index.

$$NDVI = (NIR - Red) / (NIR + Red) \tag{1}$$

Once a new image in the NDVI had been created for each Landsat scene, each image was classified through the SCP. This was done for easier integration into the IDRISI application. A summary of the input parameters for the unsupervised classification for each image can be found in the Appendices. Image classifications were condensed to only represent 3 different classes within the landscape to simplify analysis in the LCM. The next step was to process the images for use within the TerrSet application. The LCM was then run to create change scenarios from each period for both snow leopard and mountain lion sample habitat.

RESULTS

Snow Leopard

Results from the first period (1989-1995) show that both the forest (6,792 ha) and barren area (22,122 ha) experienced a positive net growth in their area from cell gains and losses (Figures 3, 6). The grassland class experienced a large net loss of area (-28,903 ha), with nearly triple the area lost than gained. Through the second period (1995-2009) grassland habitat grew with a positive net growth (12,144 ha) with both large gains and losses (Figures 4, 6). Forested area continued to grow (21,867 ha) and experienced a high ratio of gained area to lost. Barren area alternatively declined with a negative net area (-33,651 ha) and had little gains in the period. In the final period (2009-2021), we observed a change in land change turnover as areas in each class only experienced either a loss or a gain (Figures 5, 6). Grassland habitat was the only class to have a positive growth (21,591 ha) while the other class both declined. The forest class only decreased slightly (-6575 ha) whereas the barren area lost significant area (-15,016 ha). The total cumulative gains and losses of these landscape classes show that, through the study period, grassland habitat saw a small growth of 4,832 ha (Figure 7). Forested area also grew, with a larger cumulative growth of 22,084 ha. The barren area then lost area through all periods with a total of 26,555 ha.

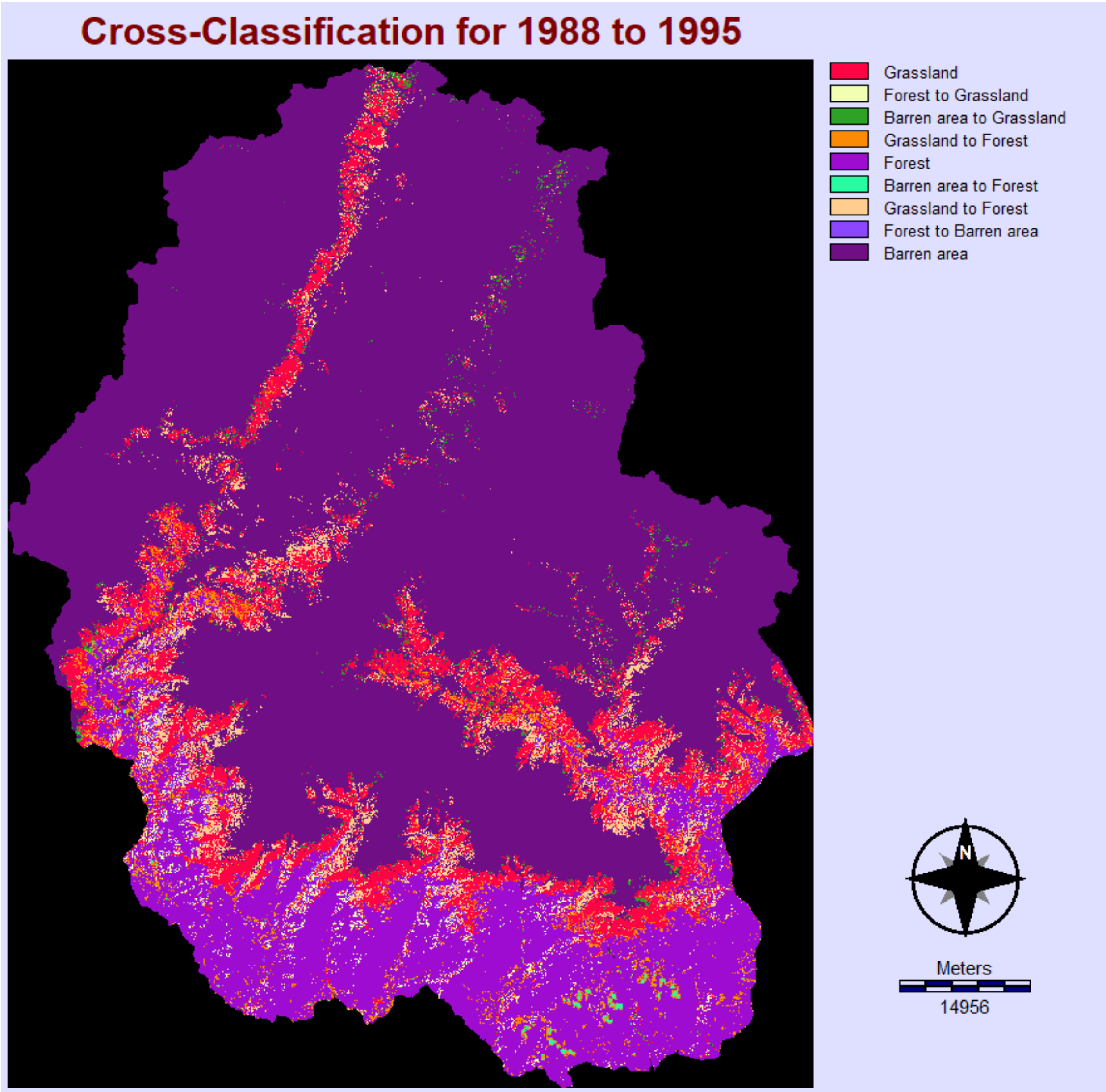

Figure 3: A map of the landscape classification matrix for Annapurna Conservation Area from 1988 to 1995

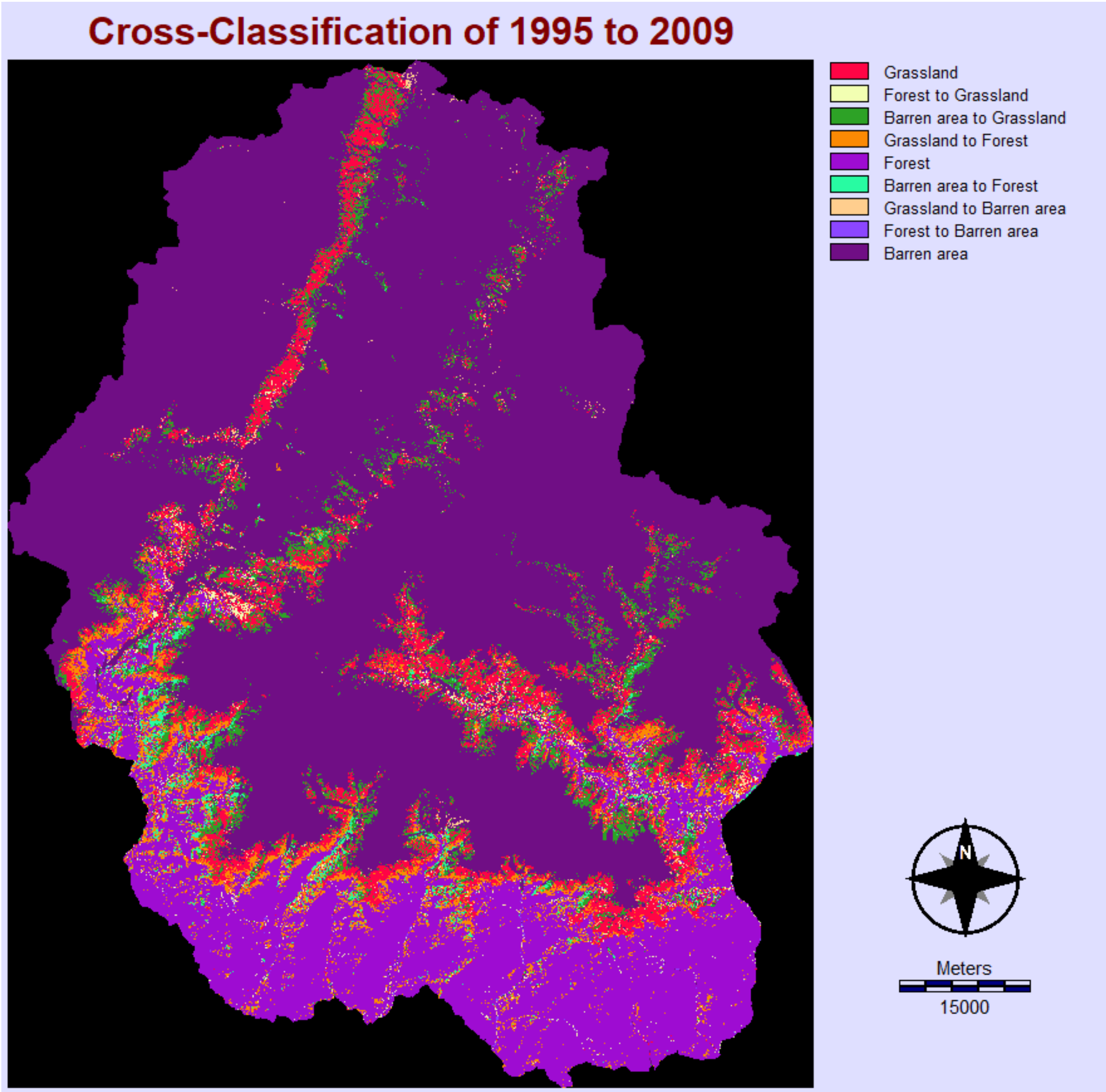

Figure 4: A map of the landscape classification matrix for Annapurna Conservation Area from 1995 to 2009

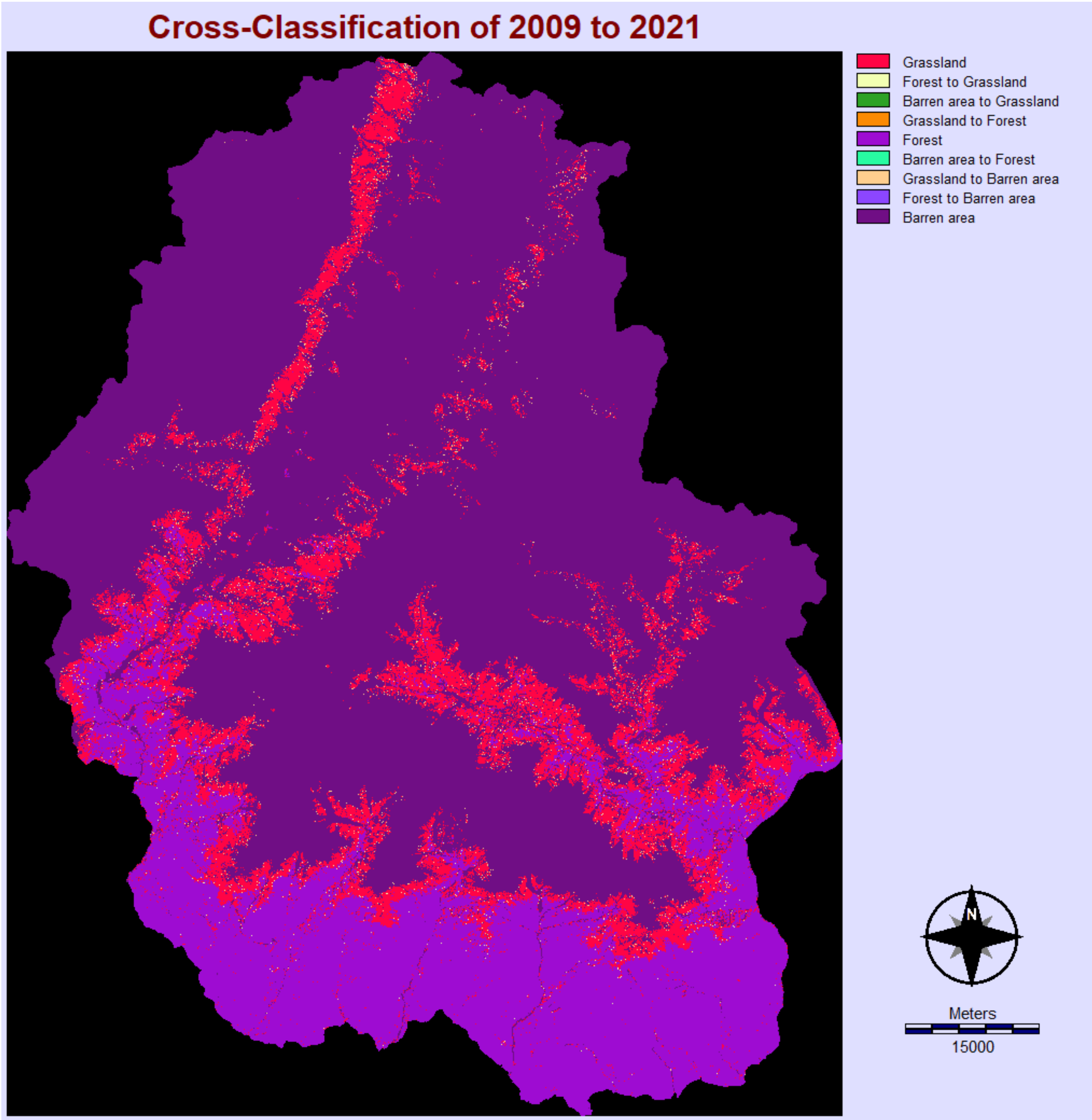

Figure 5: A map of the landscape classification matrix for Annapurna Conservation Area from 2009 to 2021

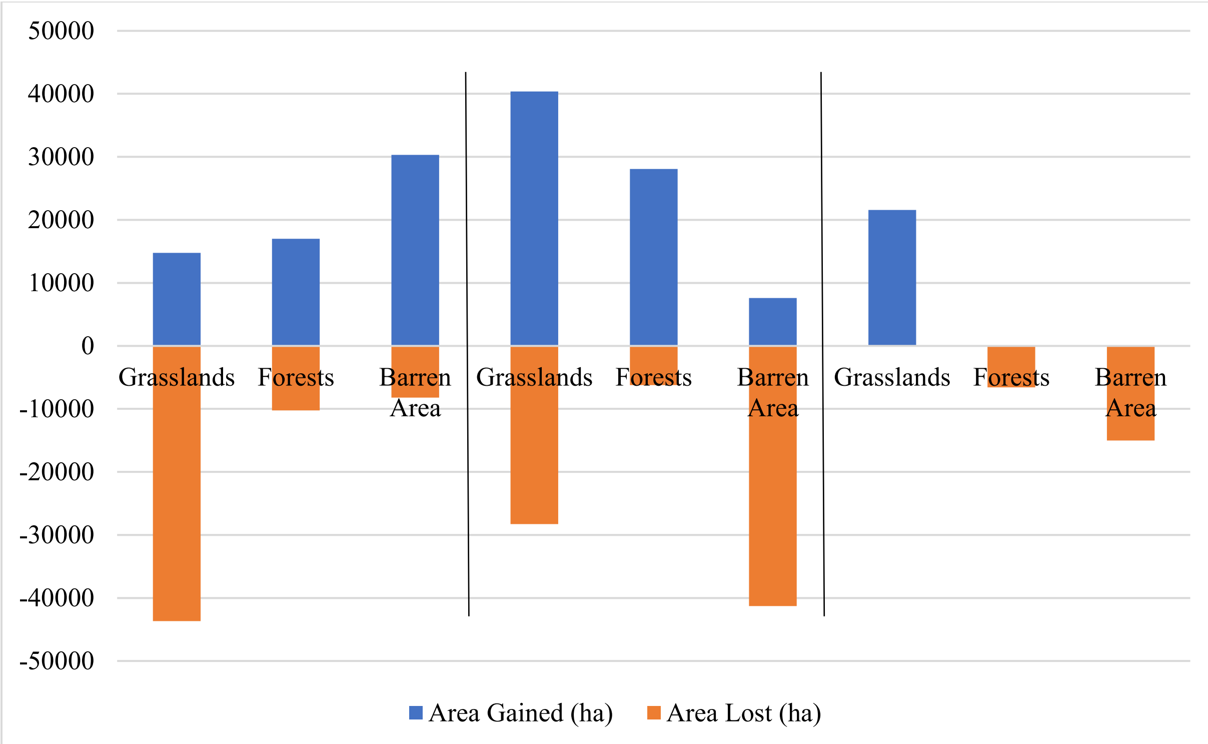

Figure 6: Gains and losses in ACA within each of the three periods

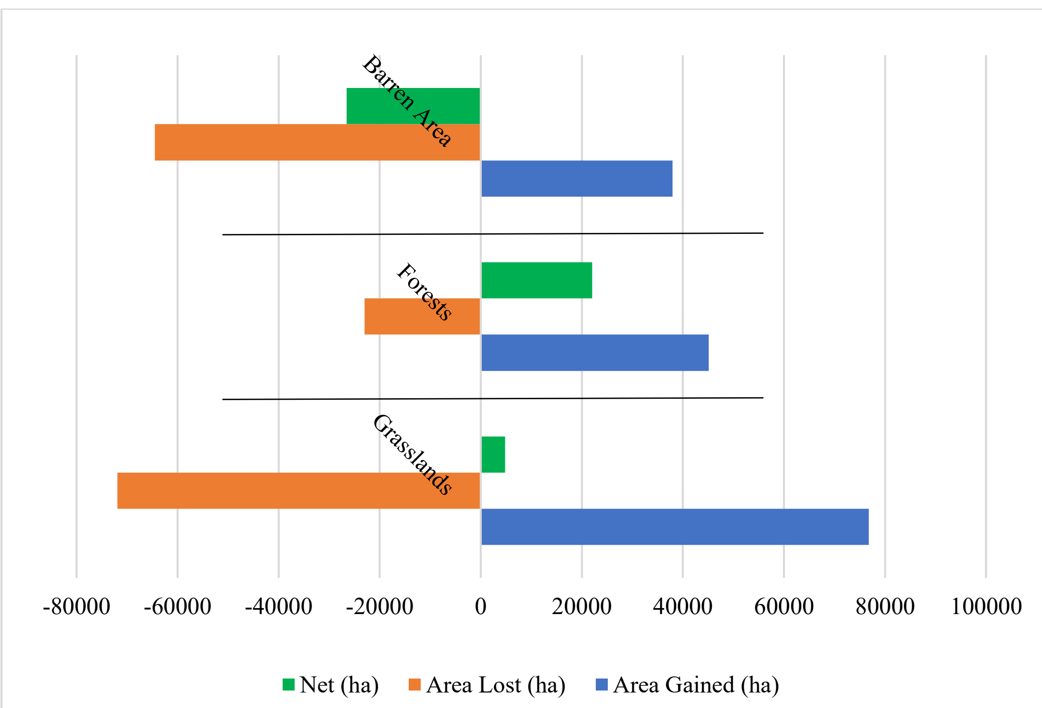

Figure 7: Cumulative gains and losses in ACA across all periods

Mountain lion

We observed that changes in landscape class in sample mountain lion habitat followed a pattern: within a period one of the classes would experience significant gains with the other class mirror in lost area. This pattern alternated between each of the three study periods. In the first period (1989-2002) the forest class gained area (130,621 ha) and had an overall net positive growth of 95,926 ha (Figures 8, 11). The barren area class then lost and gained the opposite amount of area resulting in a net negative growth of -95,926 ha. The second period (2002-2008) saw the decline of forested area and an increase of barren area, although these changes were less extreme than observed in the previous period (Figures 9, 11). Forested areas lost a total of 90,559 ha and had a negative growth area of -49,694 ha. The barren area class then saw opposite change (90,559 ha) with a positive growth, the same value as the lost area in forests. The third and final period (2008-2020) saw the largest increase, and by extension decrease, in class area throughout the Yellowstone study area (Figures 10, 11). The forest class once again saw large gains in area (133,338 ha) and had a net growth of 92,423 ha, which was slightly smaller than the net growth seen in the first period. Barren area accordingly lost the same amount of area (-133,338 ha) and saw net declines of the same area as well. Analysis of our results show that overall, the forest class experienced a net cumulative growth of 138,655 ha across the three periods (Figure 12). The barren area class therefore saw cumulative losses of the same net area (-138,655 ha).

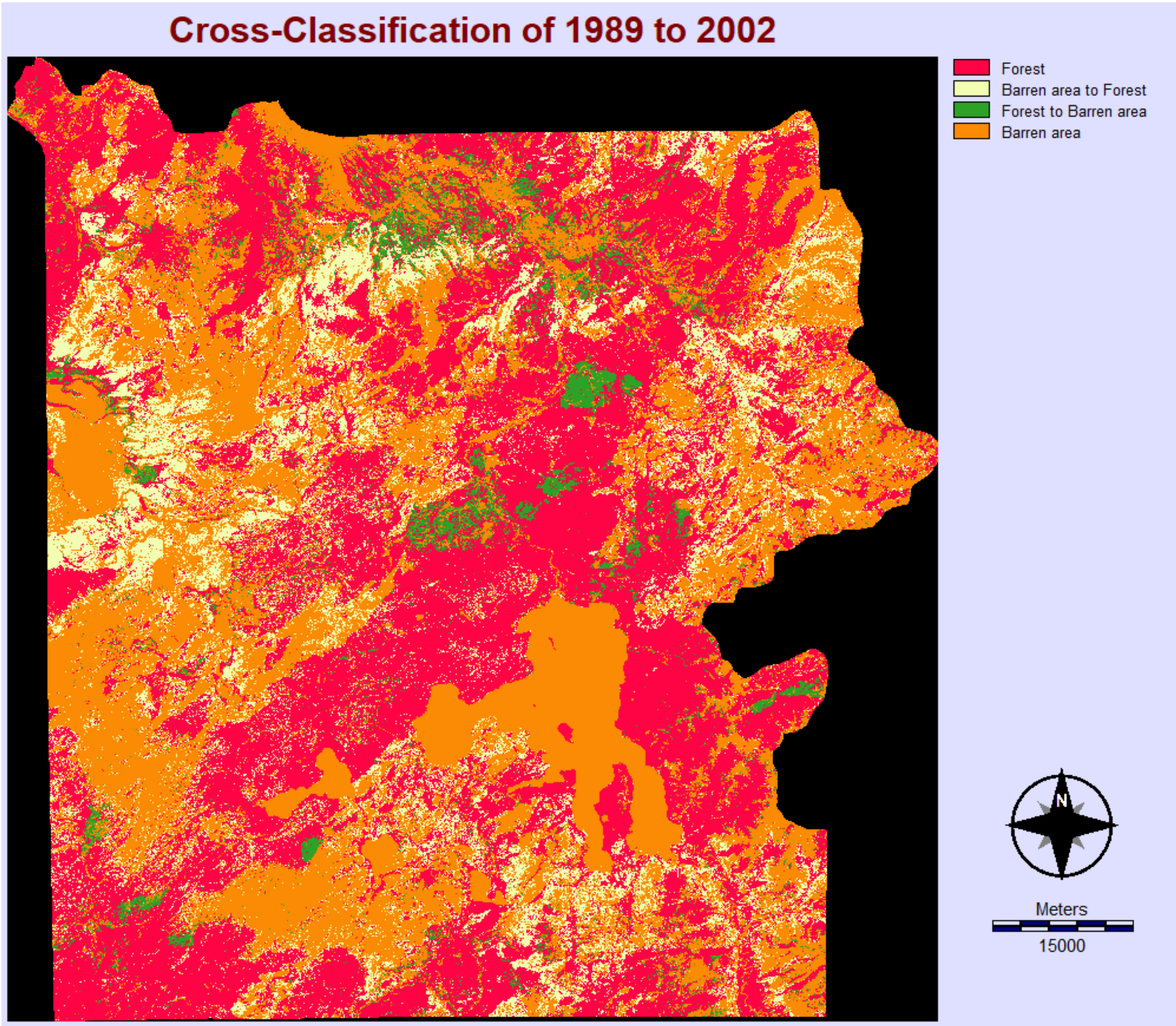

Figure 8: A map of the landscape classification matrix for Yellowstone National Park from 1989 to 2002

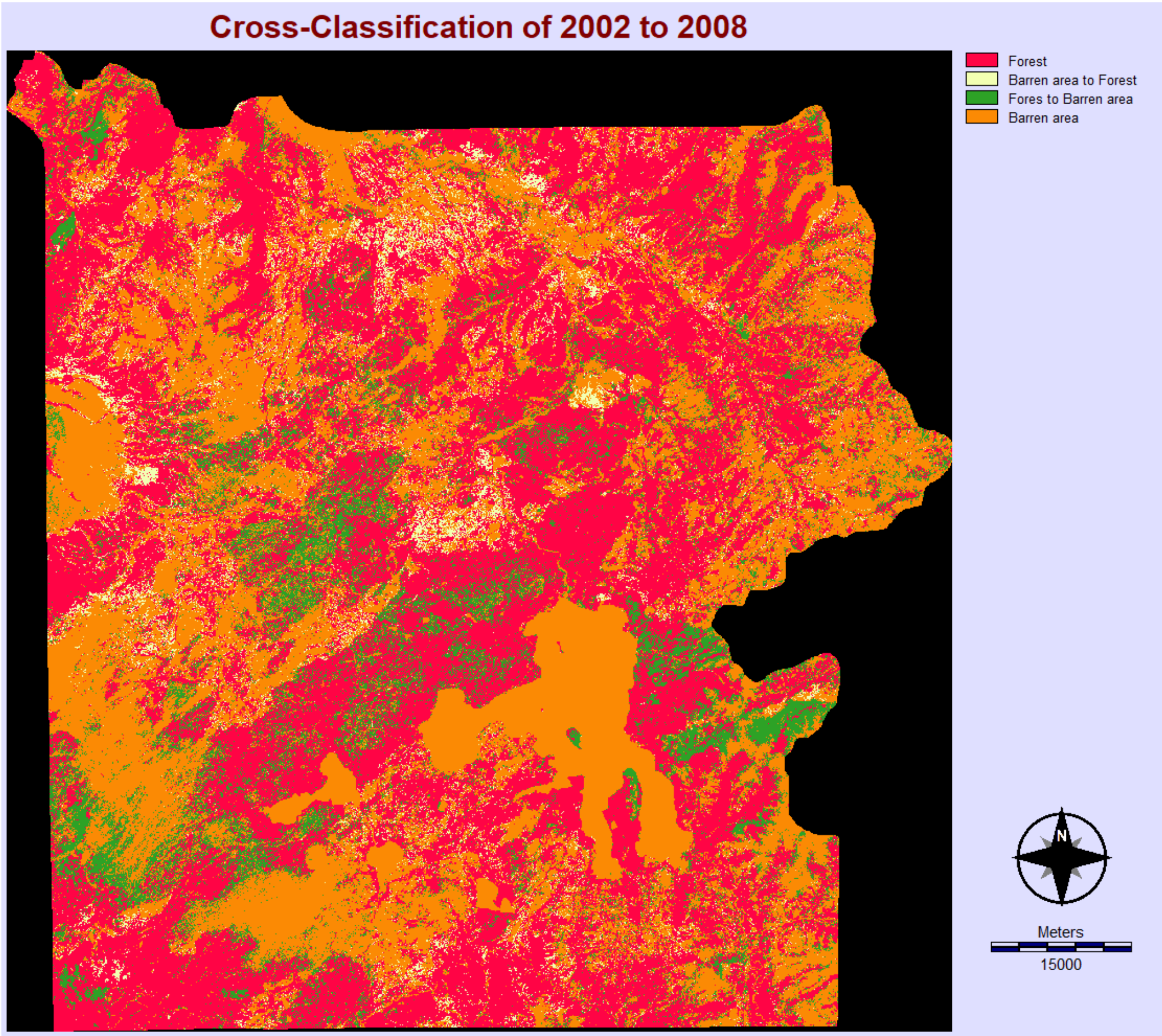

Figure 9: A map of the landscape classification matrix for Yellowstone National Park from 2002 to 2008

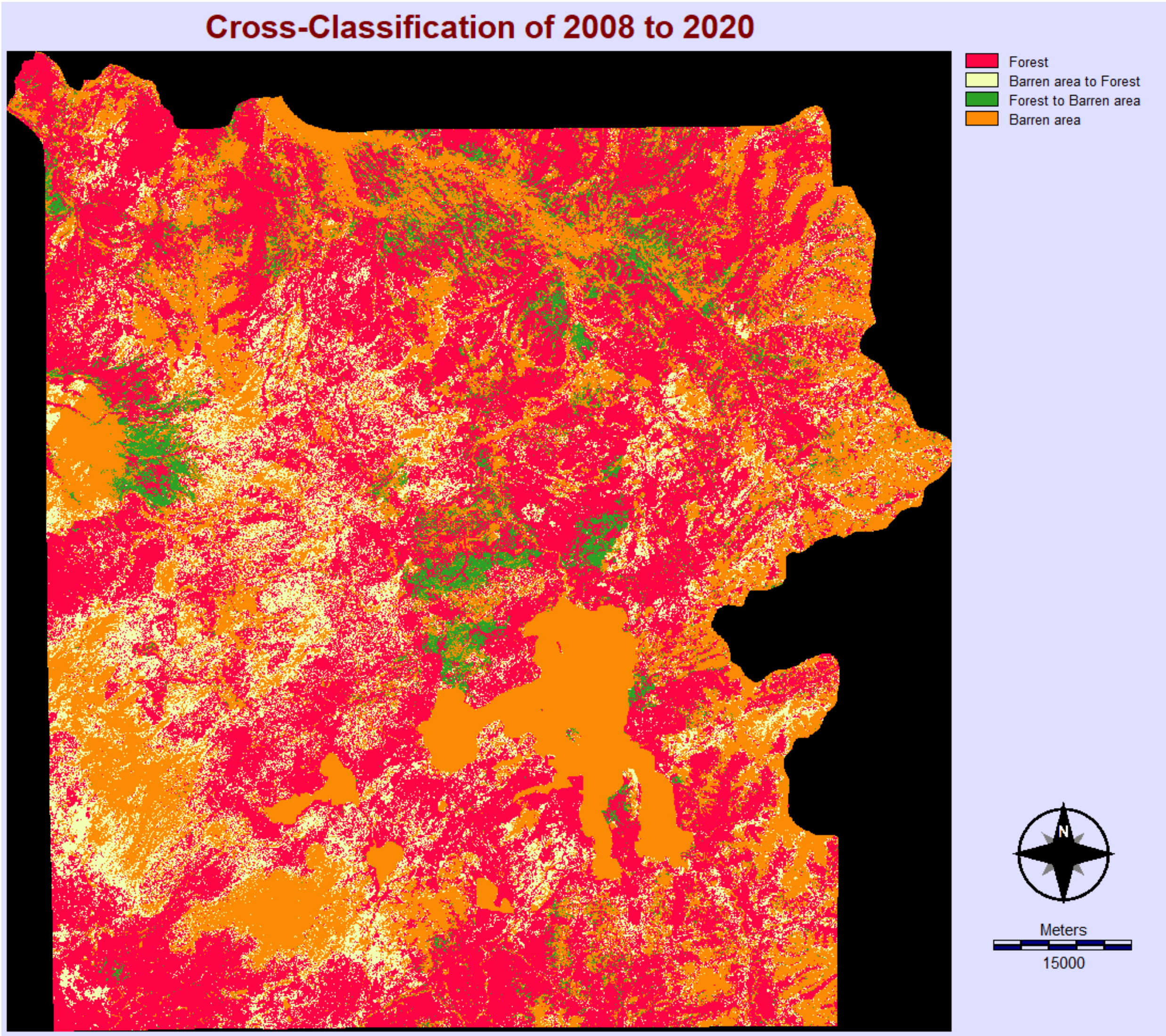

Figure 10: A map of the landscape classification matrix for Yellowstone National Park from 2008 to 2020

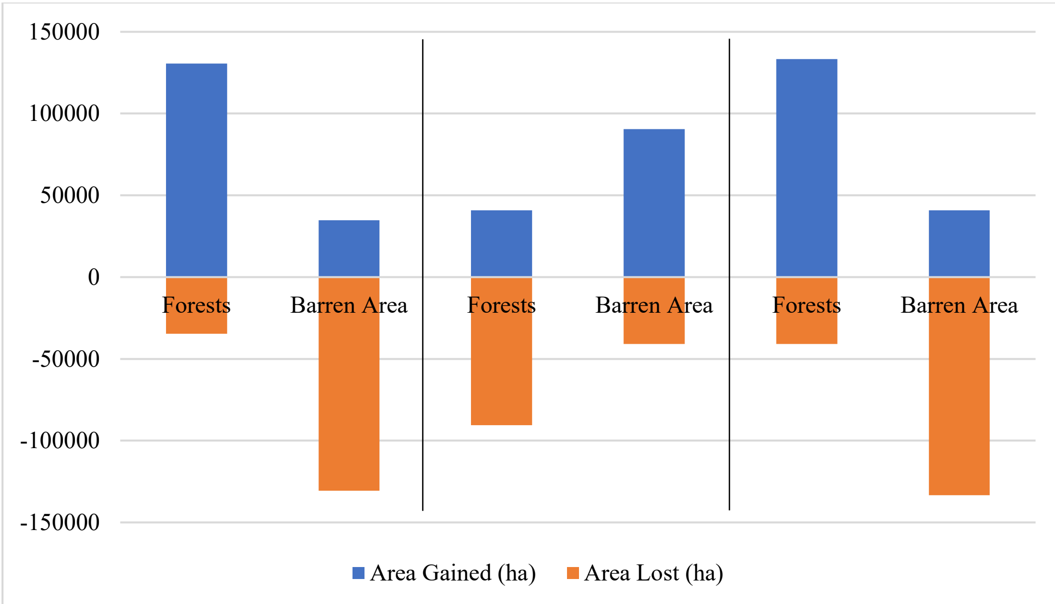

Figure 11: Gains and losses in YNP within each of the three periods

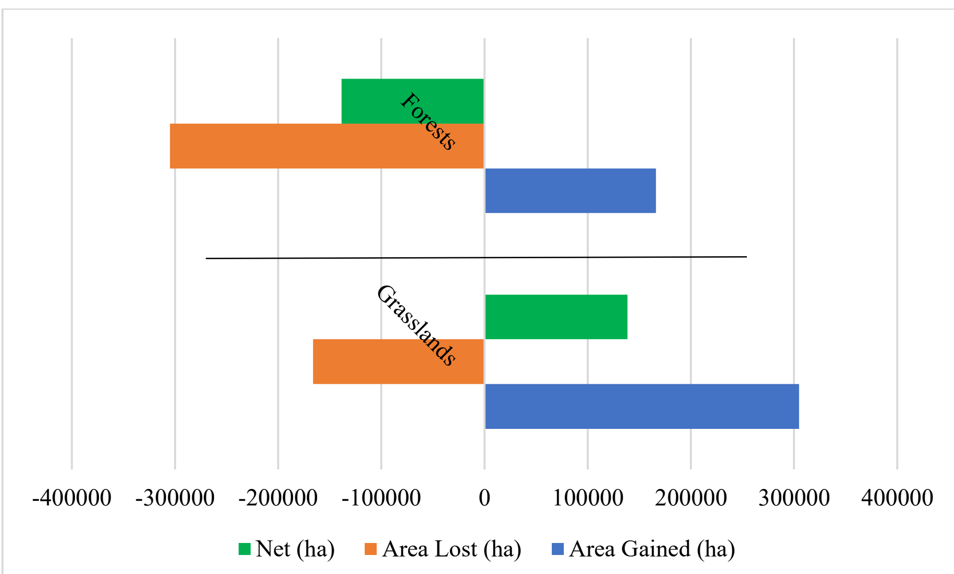

Figure 12: Cumulative gains and losses in YNP across all periods

DISCUSSION

From our results we observed changes in both sample habitats that were not in line with predictions and the hypothesis. Based on the historic and current status of these species it was expected that mountain lion habitat would have been of higher quality when compared to snow leopard habitat (McCarthy et al. 2016, Neilson et al. 2015). However, it was found that snow leopard sample habitat experienced moderate variation between landscape classes during the initial period of study. This then balanced to smaller changes in later periods, which suggests that little variation has occurred within the ACA environment in the last decade. The total net change of grassland, which is designated as core snow leopard habitat, over this period was 48.3 km^2 (2.83% of total area) and represents only a small area within the ACA (Figure 7). Oppositely, we saw that sample mountain lion habitat changed dramatically between each period with large gains and losses between both landscape classes (Figure 12). In the final period of study, the net change of forested habitat was 924.2 km^2 and represented a much larger change in total landscape area (10.3% of total area). These results suggest that opposite to our hypothesis, mountain lion habitat is far more variable and of potentially lower quality than the snow leopard habitat. It should be noted that the Landsat scenes for the species' habitat was selected for high visibility and peak vegetation occurrence to ensure the best performance within the SCP landscape classification (Hasmadi et al. 2009). This resulted in large gaps between period, which may have exaggerated or underestimated changes in land change in the two study areas (Land and Wilkerson 2008). More scenes, at more equal intervals could have been preferred, which may have provided more accurate year-to-year analysis of the landscape. The potential downside of this would have been worse image quality and coverage, since areas with abnormalities would need to be classified out of the image. While not supporting the hypothesis, the results given insight into the future of these species and how conservation may need to change to suit each animal.

Overall, changes in area gained and lost within the ACA habitat suggests that snow leopard habitat size has remained stable, although the exact composition and quality of that habitat remains unknown. Grassland habitat saw a small increase in total area, with the majority of its total gain occurring between the last 2 periods of study. Most of the lost habitat from the first and second periods occurred in areas where grassland habitat was overturned into the forest class. In contrast, the majority of gains in the grassland class across all periods occurred where barren area was converted to grasslands. This suggests a pattern where barren area is slowly being converted to grass or shrubland, which is then transitioning into a more forested environment. These results match the findings of several studies that suggest that snow leopard habitat in the species' southern range is being constricted due to climate warming (Aryal et al. 2016, Farrington and Li 2016, Trouwhorst 2020). Climate studies have demonstrated that the effect of global warming will be more pronounced in high altitude ecosystems, such as those found in the ACA (Telwa et al. 2013). As our data shows there is currently a greater rate of forest area gain than in the grassland class. Therefore, it could be expected that over the next century we would expect the observed pattern to continue with a positive rate of barren area-to-grassland conversion and a larger, also positive rate for grassland-to-forest conversion. This would result in overall lower levels of snow leopard habitat in the long-term, likely following the predicted declines in the species population over the next century (Aryal et al. 2016).

Results of analysis on mountain lion sample habitat show that the landscape of these animals is far more stochastic than predicted and ecosystem conditions vary greatly over short periods of time. The forest class, which was used to represent cougar habitat, did demonstrate cumulative growth through the three periods of study, however our results suggest that this not a trend but rather a cyclic pattern in landscape vegetation (Romme and Knight 1982). If we were to trend these patterns observed through the data, it would be predicted that the next period would show a decrease in forest area and an increase in barren area. The cause for this is likely that each period studied experienced alternating gains or losses depending on the occurrence of a disturbance, such as fire, that resulted in an increase in barren area.

For example, the gain in forest cover within period one is the result of regeneration following a historically devastating fire season in 1988 which burned much of the area within YNP (Turner et al. 2004). There is evidence of some other fires that occurred after that period, that exist in the 2002 data, but much of the previously affected area had since also regrown. There again appears to be an overall decline in vegetation coverage in 2008 which resulted in the increase in barren area seen in period two. There is less evidence for what might have caused this, since much of the damage does not appear to be fire damage. There is some evidence of droughts across the US during that period, however these were located more in eastern states, which would not explain why vegetation appears to have declined during this time (McMenamin et al. 2008). Forests amount then increase through the last period, although there again is evidence of new fire damage that had occurred within the period. What was not observed within these datasets was a period-to-period shift where either disturbance was consistent throughout, resulting in low forest area across the period, or where there was a lack of disturbance and the amount of forested area remained high. Over time we should expect that in less developed, fire prone areas such as Yellowstone that cougar habitat will continue to shift with disturbance cycles (Romme and Knight 1982). These cycles may be expected to increase in frequency and severity as some climate research has shown, but further research into the specific ecosystem is required.

There are several procedural limitations with completing a land change study purely on the quality of big cat habitat. Firstly, is that the scope of this project focused only on the presence of potential habitat; meaning that many other important environmental factors were left out from the analysis. This analysis was not able to quantify the changes in fragmentation or edge habitats, which are spatial habitat characteristics that affect both species. Our results reveal potential evidence of the effects of climate on different aspects of big cat habitat however, Landsat data does not include any information about the climactic factors that could create these observed changes. Data on historic temperatures for the same dates could be used to complement Landsat image analysis when assessing the effects of climate change (Jones et al. 1997, Vila-Vicosa et al. 2020). This would allow for direct relations of climate data to changes in big cat sample habitat. Other important information that could be incorporated into such studies is record data for cat species along with similar data for prey populations. With this data, these points could be plotted alongside shifting habitat and climate lines to derive further relation between them (Jones et al. 1997). Furthermore, this form of study is unable to considered other conservation concerns such as poaching and retaliatory killings that could affect the populations snow leopards (Maheshwari and Meibom 2016). There already is evidence that snow leopard decline is related to the decline of their focal prey species, with the opposite being true for the puma.

Landscape scene classifications through QGIS and TerrSet are also poorly suited to accurate, intensive analysis of large habitats. Large sample habitat areas were chosen since each big cat species have extremely large dispersal ranges and live in remote areas (Aryal, et al 2016, Di Minin et al. 2016, Jaun et al 2019). This made supervised classification impractical since there was not enough information of areas to create training sites that could classify different landscape uses, without significant bias (Hasmadi et al. 2009). Unsupervised classifications were also unable to differentiate between small-scale differences in landscapes, however the software was consistent classifying different land types. Detailed analysis of habitat may be better applied on a different level, within smaller sample areas where finer details in the landscape can be derived from local maps and sources. To compensate for a smaller area of focus, more sample areas could be used per species to cover the same overall area. (Fahrig et al. 2022).

CONCLUSIONS

In conclusion this paper demonstrates the potential use of modeling big cat habitat in determining conservation considerations for the species. It was predicted that following the current status of the focal species, that mountain lion habitat would be higher quality than that seen in snow leopard habitat (McCarthy et al. 2016, Neilson et al. 2015). However, the results were polar to our hypothesis, and data showed opposite changes in each species habitat then was predicted. Importantly however, these findings did show potential struggles that snow leopard and cougar habitat might face in the near future. Moreover, we show the accessibility and ease of use of modern satellite imagery and GIS applications. As technology continues to progress, users will be able to apply these tools to a greater range of applications and further scientific knowledge (Levick et al. 2015). Overall, the insights gained from this paper implicate the need for future conservation efforts for these species to be geared towards preserving and growing their habitat needs. Further studies using a more refined method of classification and incorporating more environmental will be needed to determine the exact nature of these species' needs.

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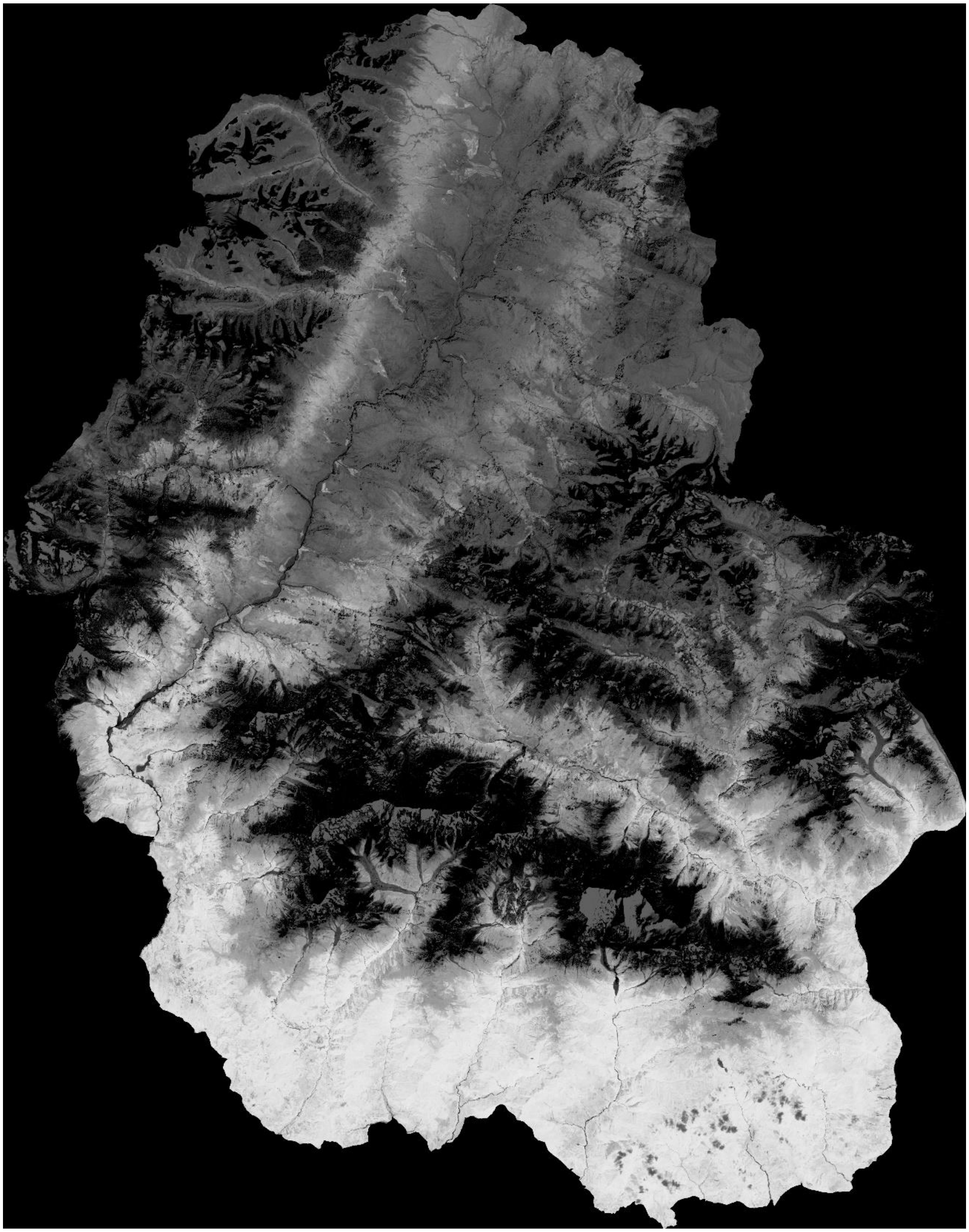
APPENDICIES

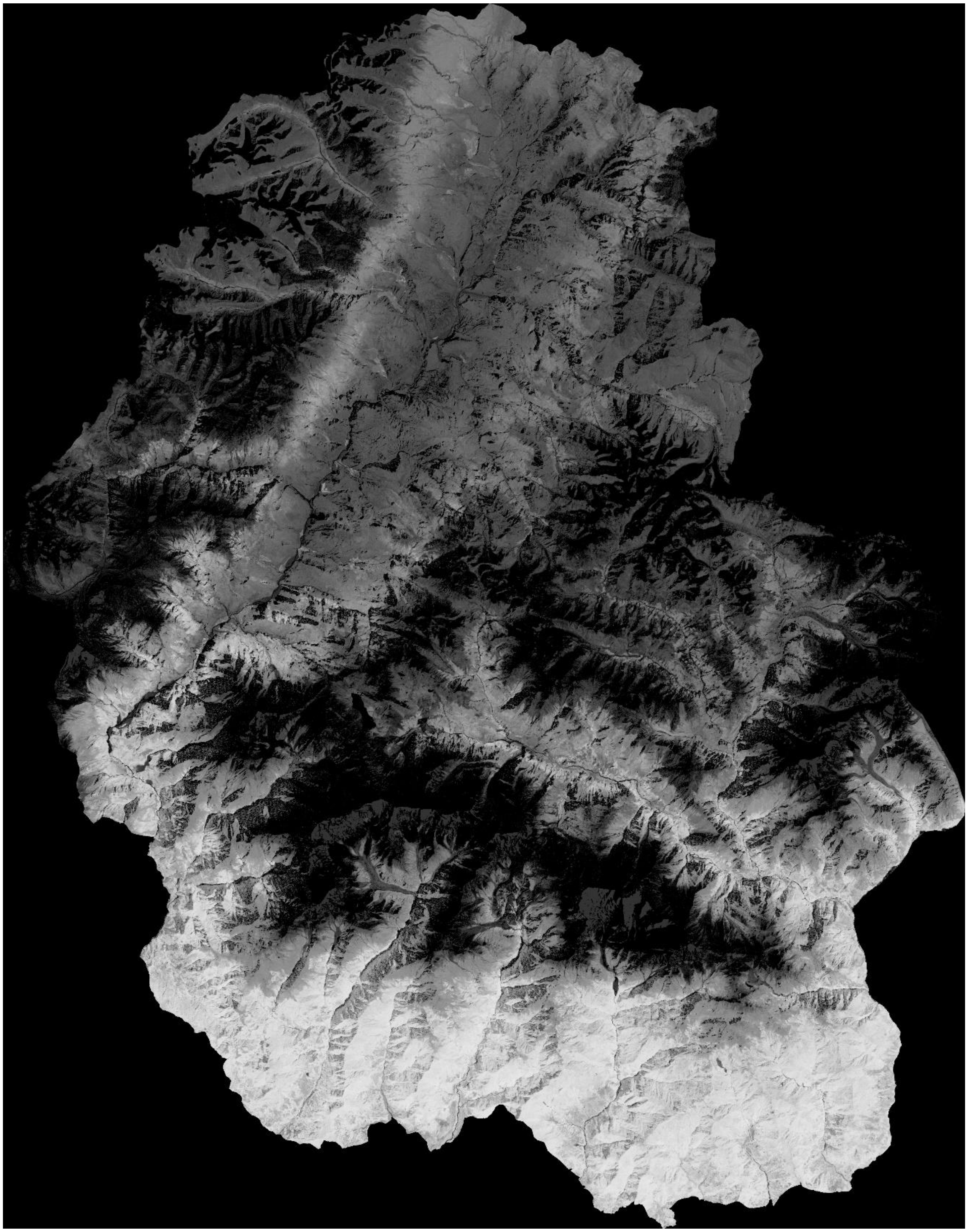
Appendix I

NDVI image of the 1988 data from Annapurna Conservation Area



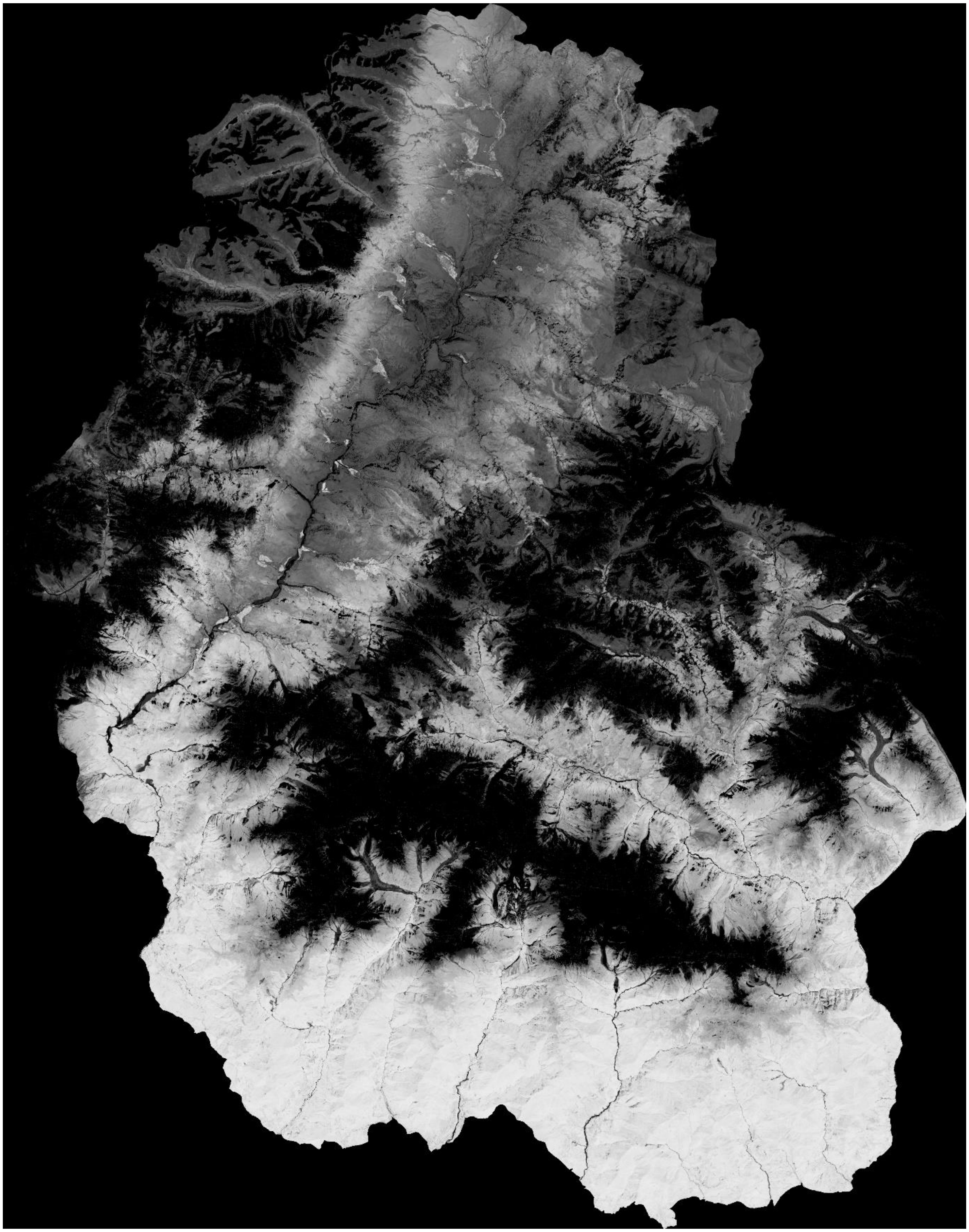
Appendix II

NDVI image of the 1995 data from Annapurna Conservation Area



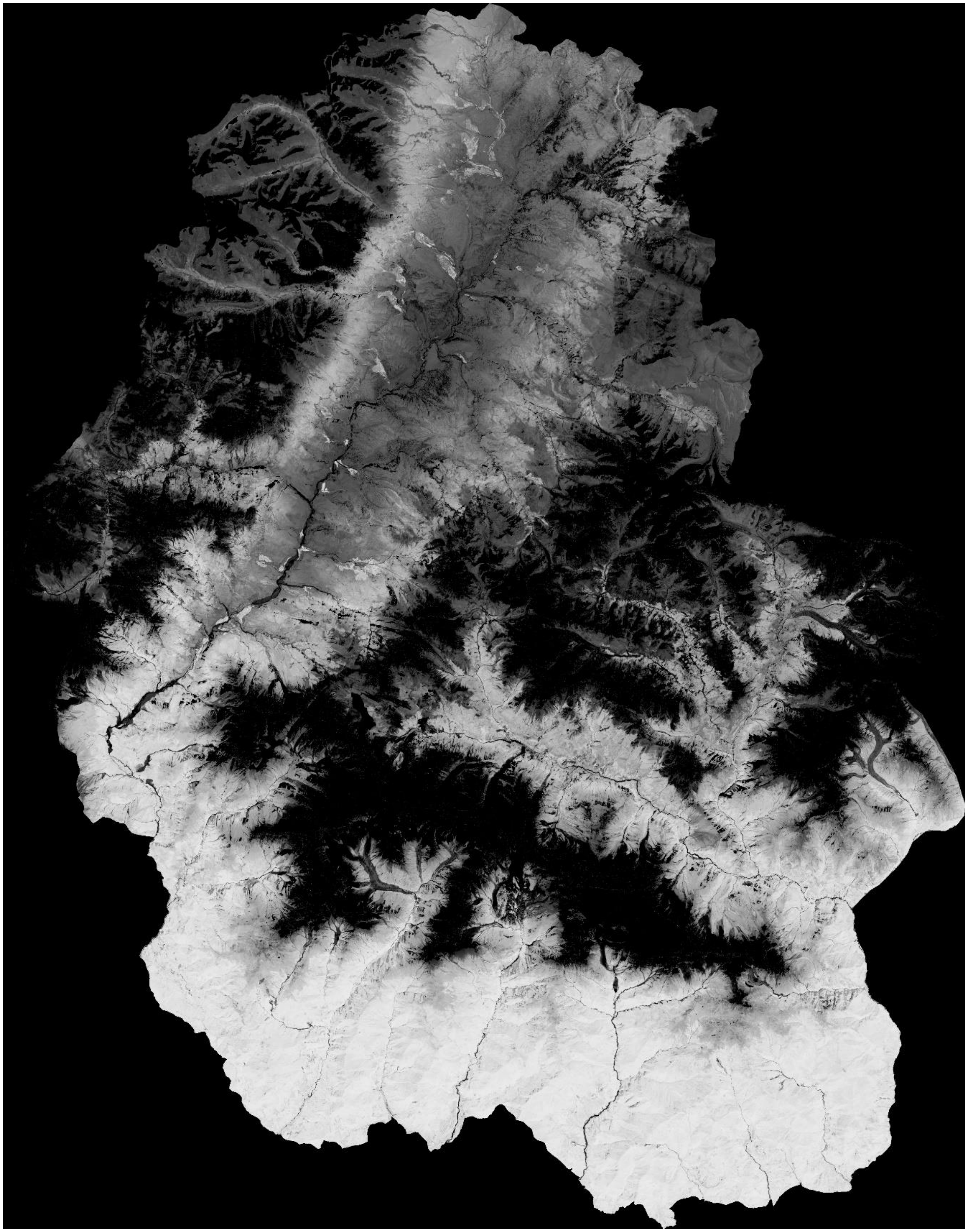
Appendix III

NDVI image of the 2009 data from Annapurna Conservation Area



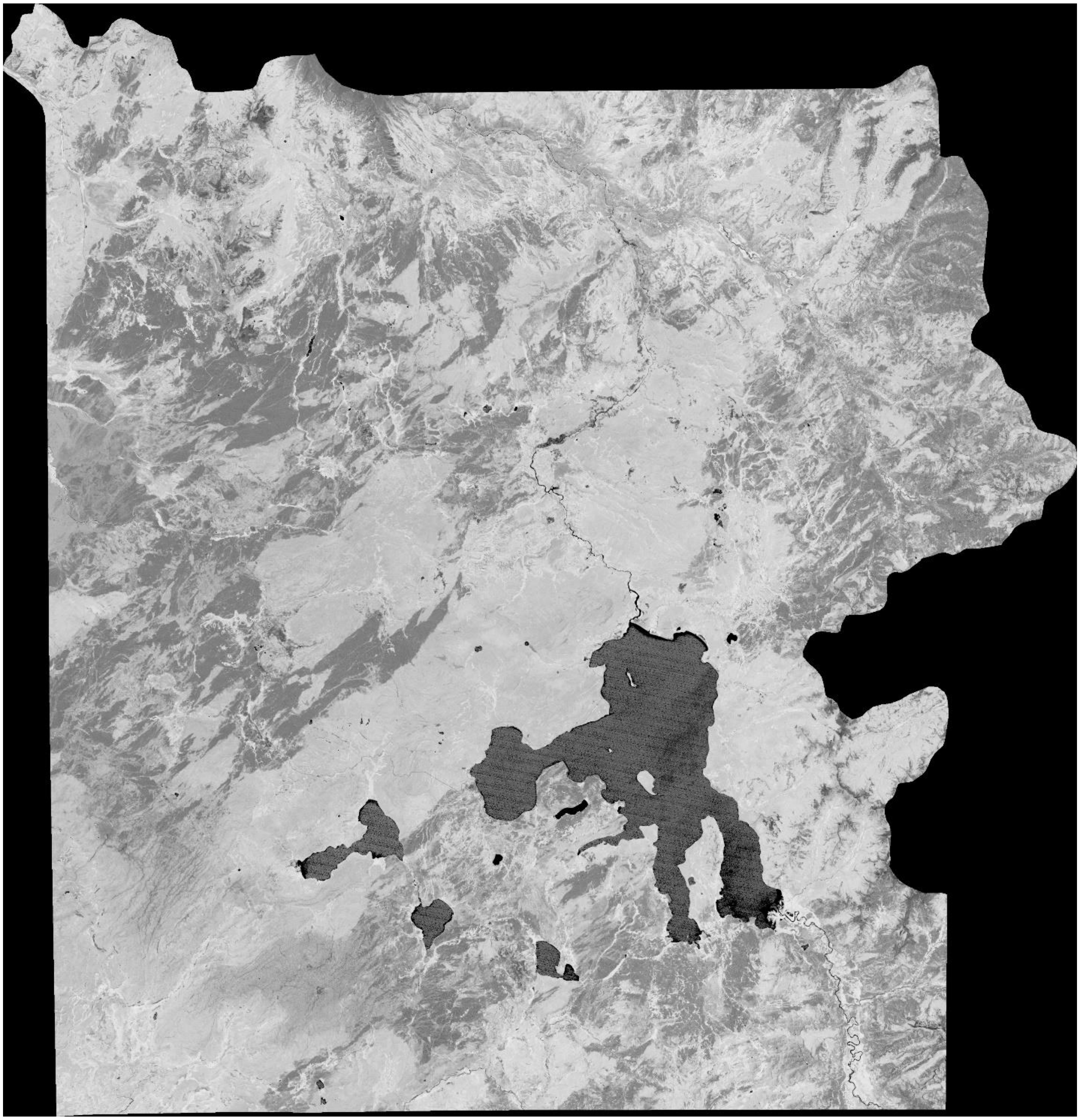
Appendix IV

NDVI image of the 2021 data from Annapurna Conservation Area



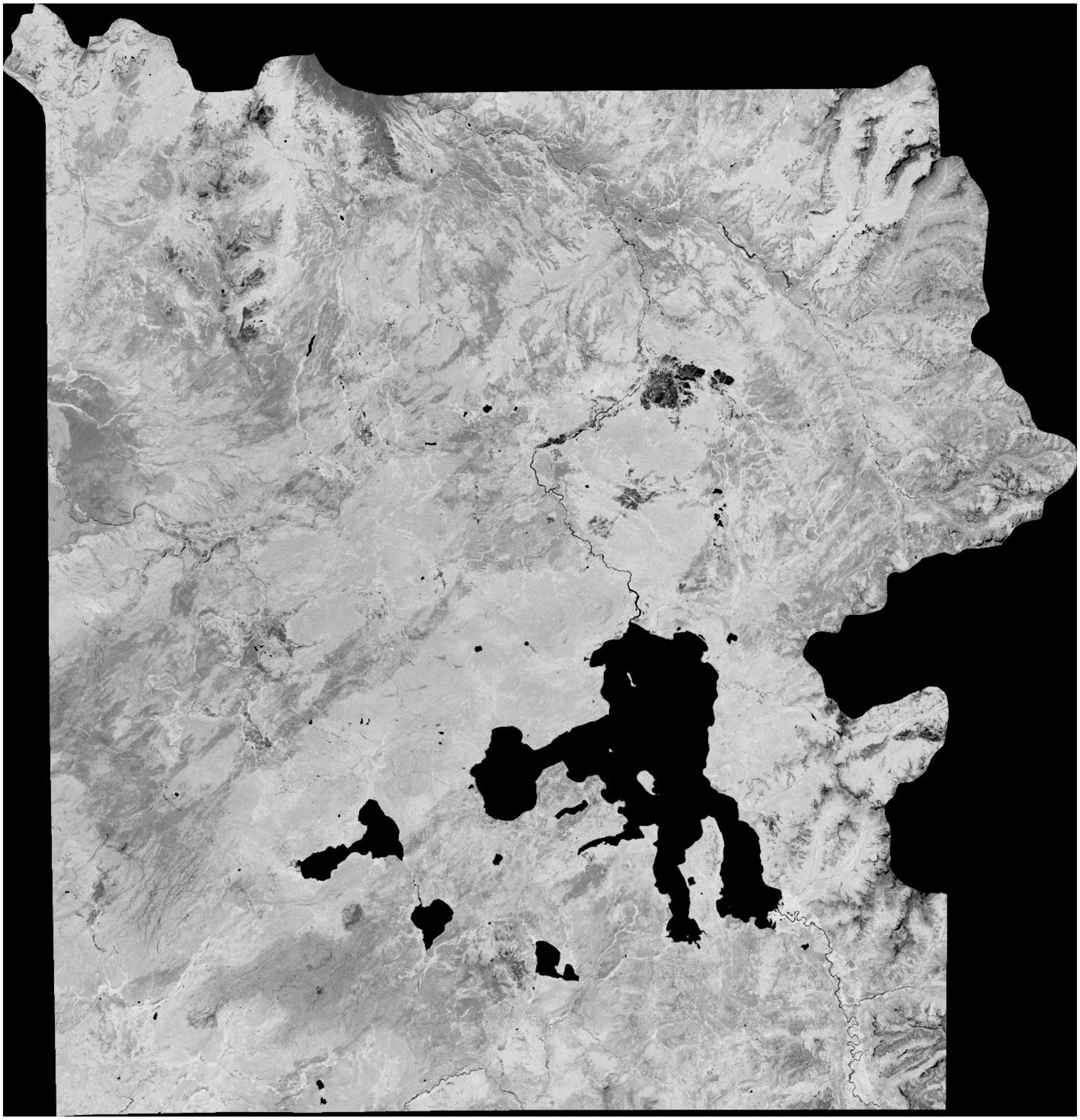
Appendix V

NDVI image of the 1989 data from Yellowstone National Park



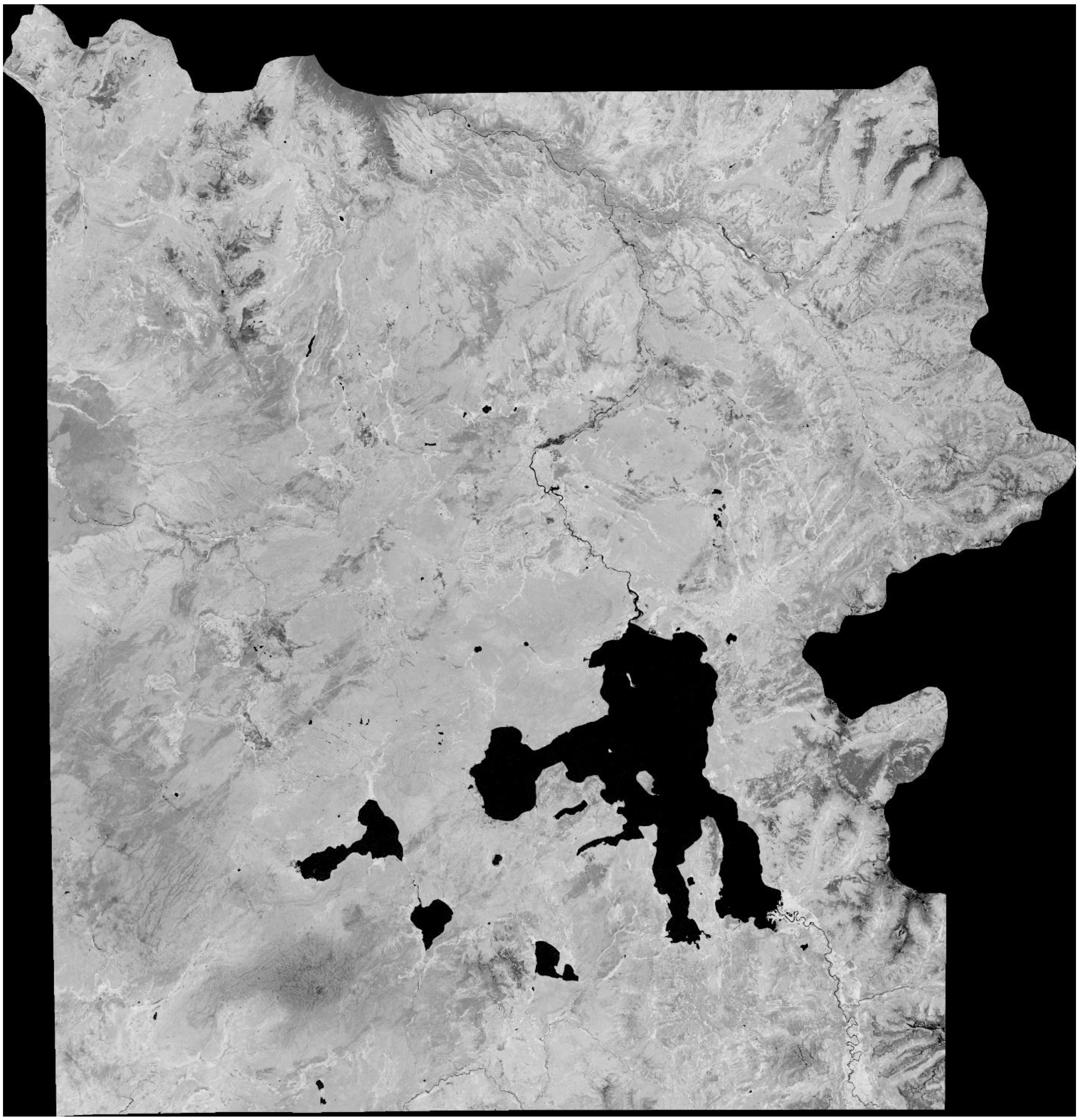
Appendix VI

NDVI image of the 2002 data from Yellowstone National Park



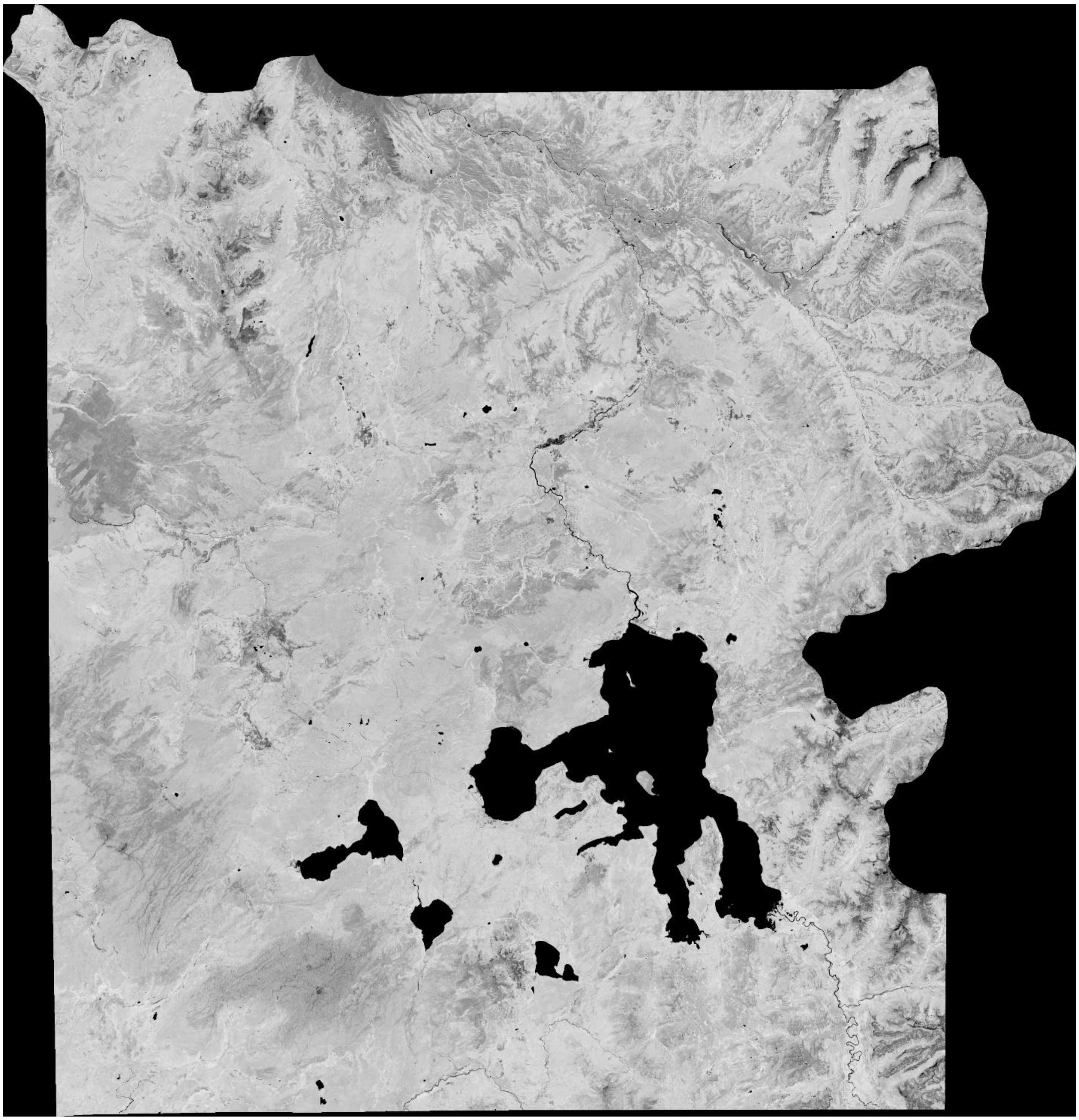
Appendix VII

NDVI image of the 2008 data from Yellowstone National Park



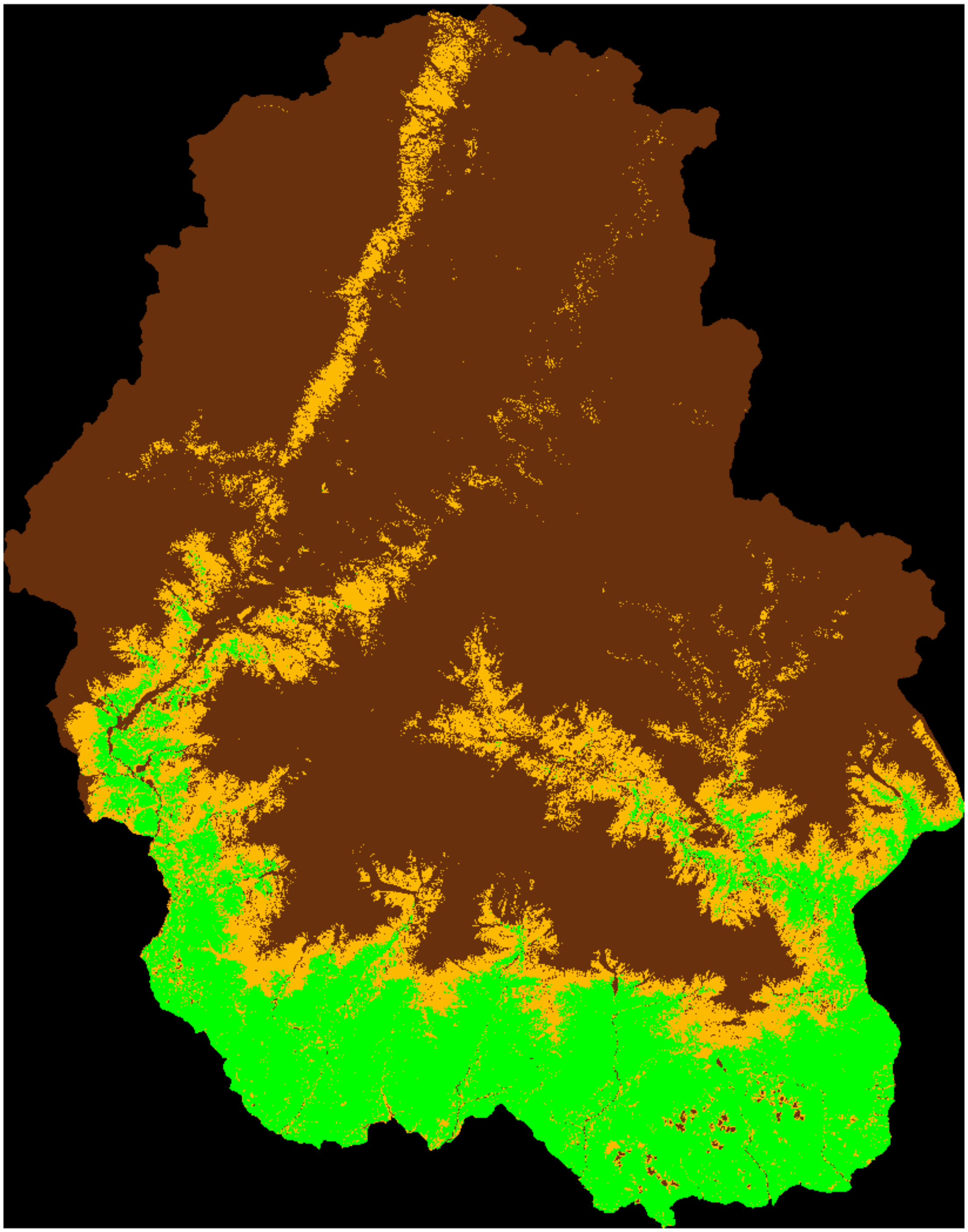
Appendix VIII

NDVI image of the 2020 data from Yellowstone National Park



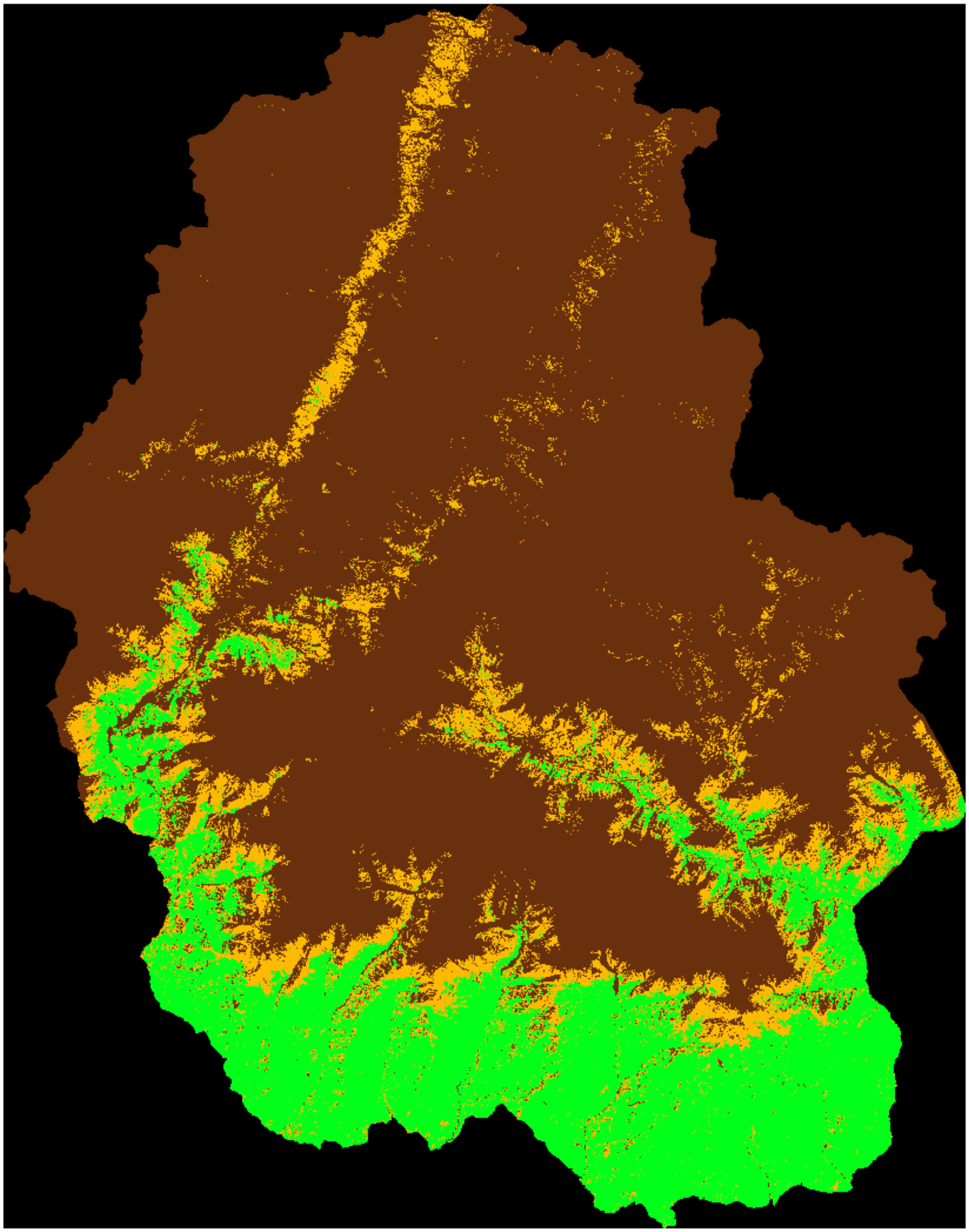
Appendix IX

Landscape classification of the 1989 NDVI capture from Annapurna Conservation Area



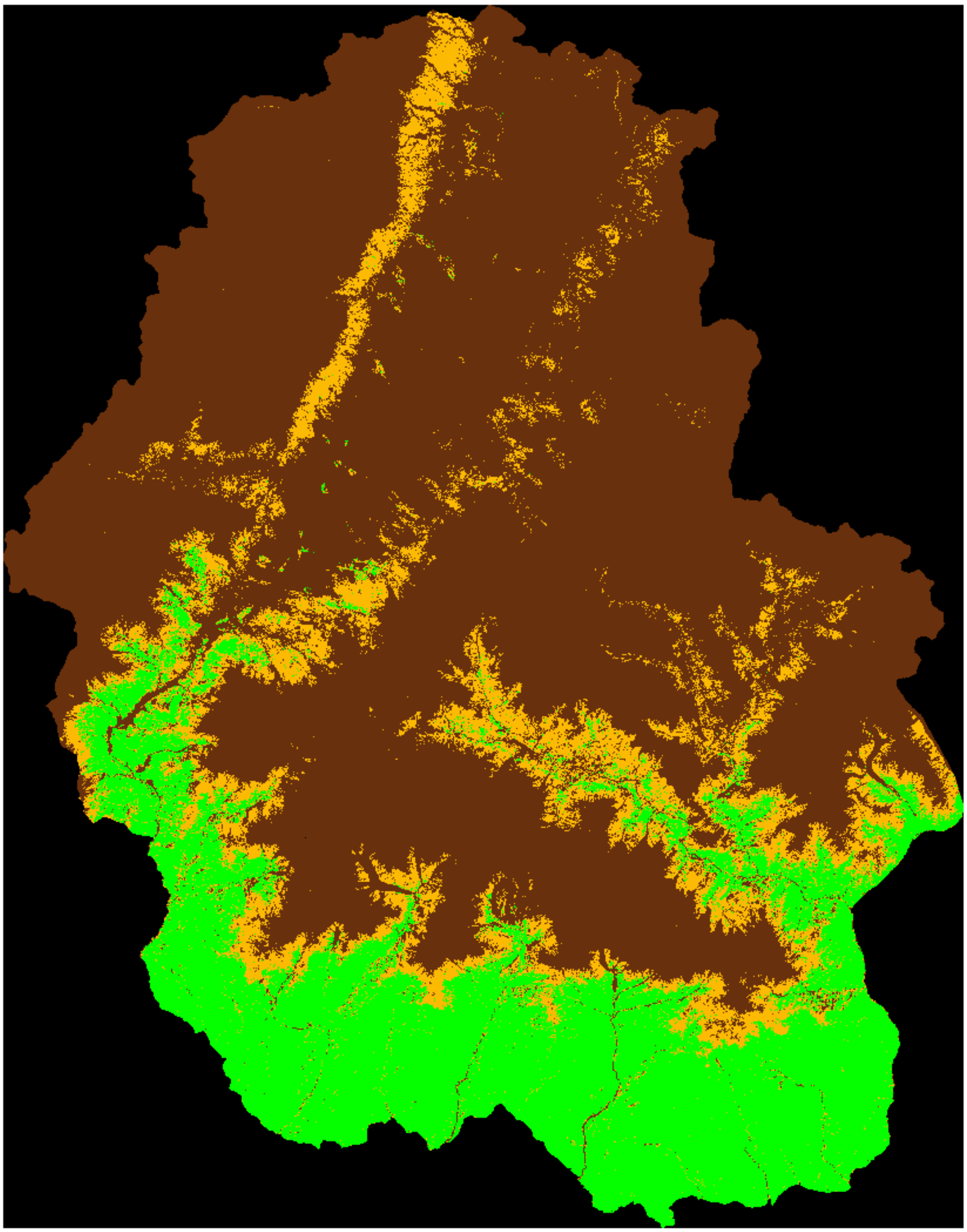
Appendix X

Landscape classification of the 1995 NDVI capture from Annapurna Conservation Area



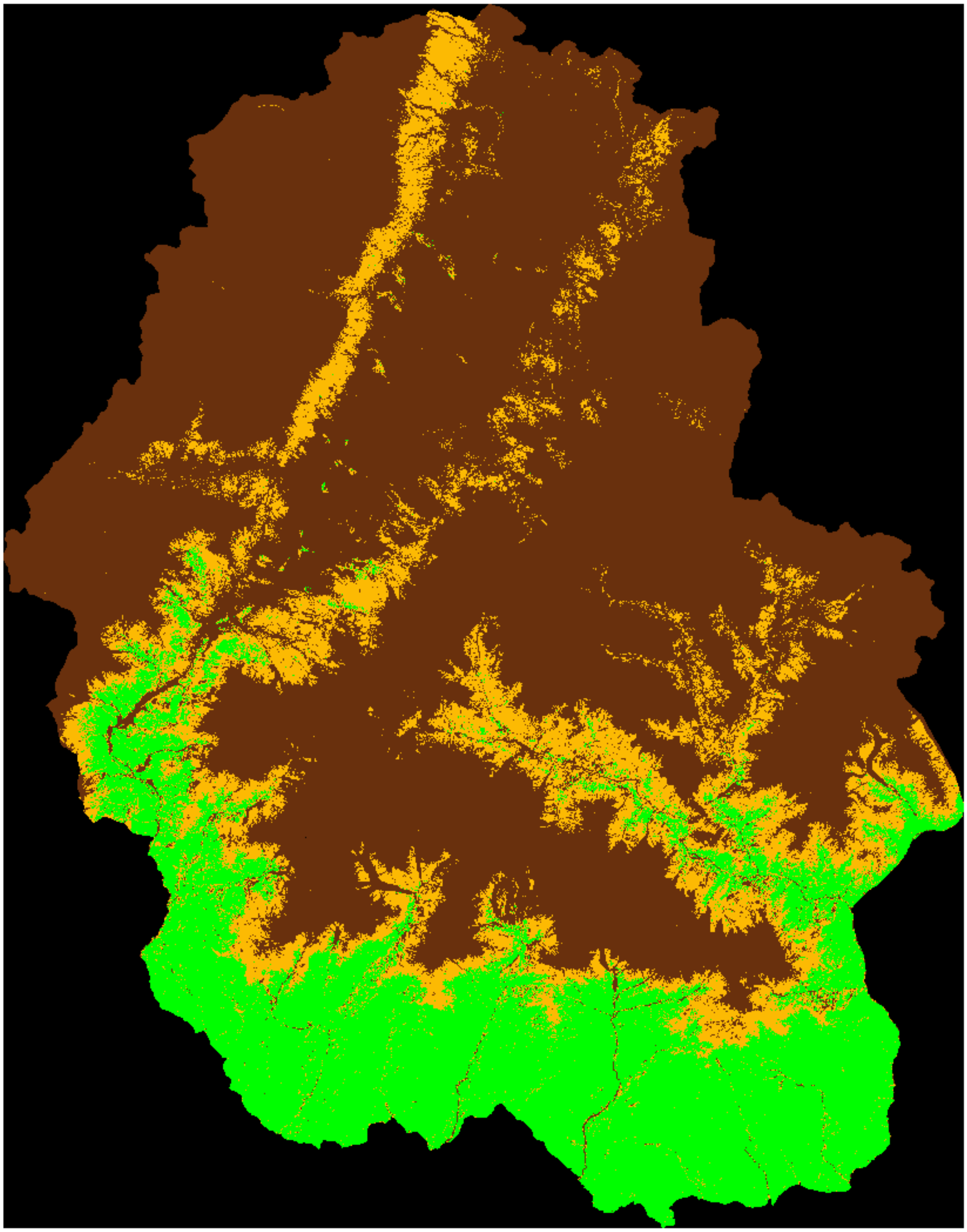
Appendix XI

Landscape classification of the 2009 NDVI capture from Annapurna Conservation Area



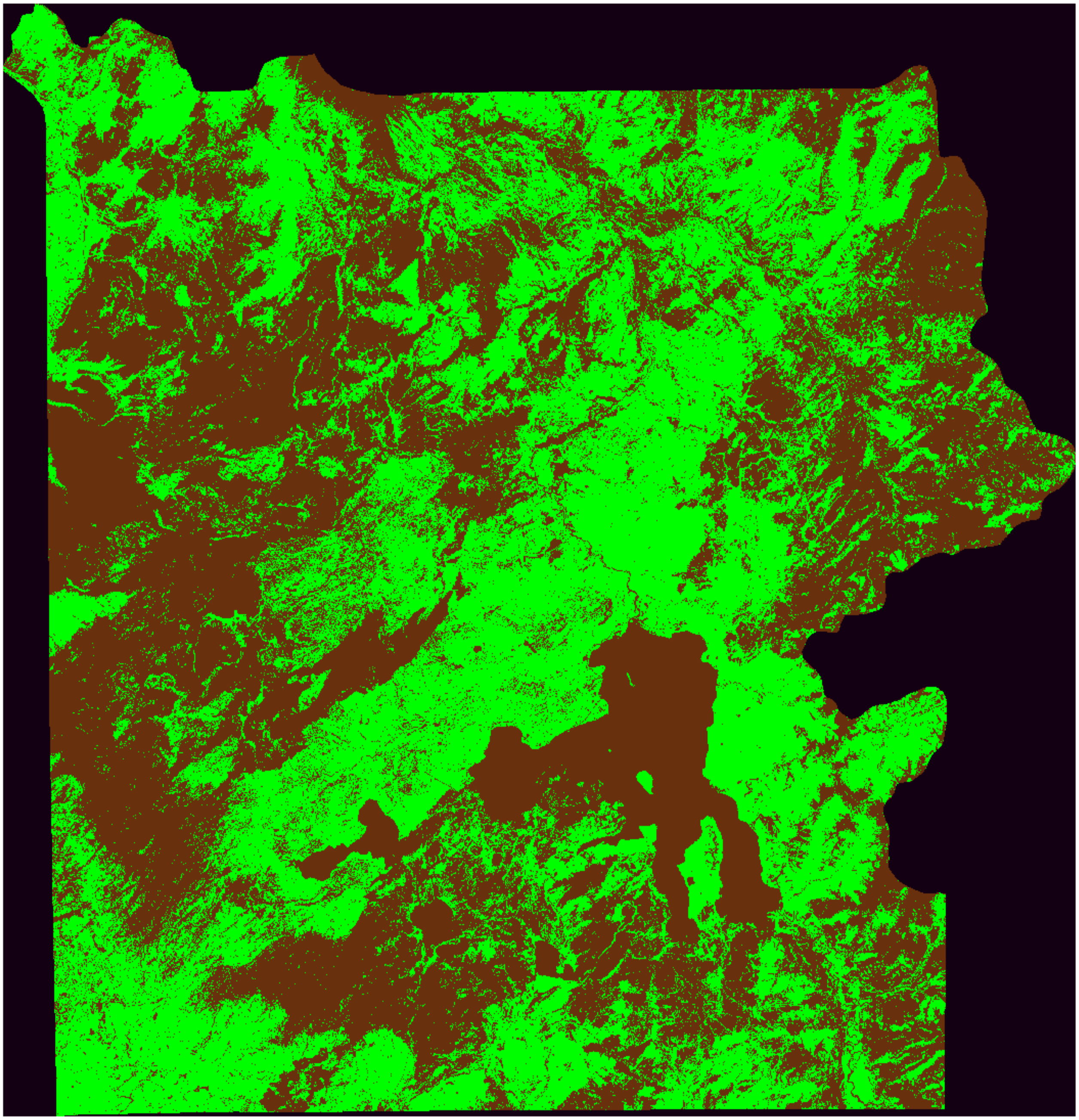
Appendix XII

Landscape classification of the 2021 NDVI capture from Annapurna Conservation Area



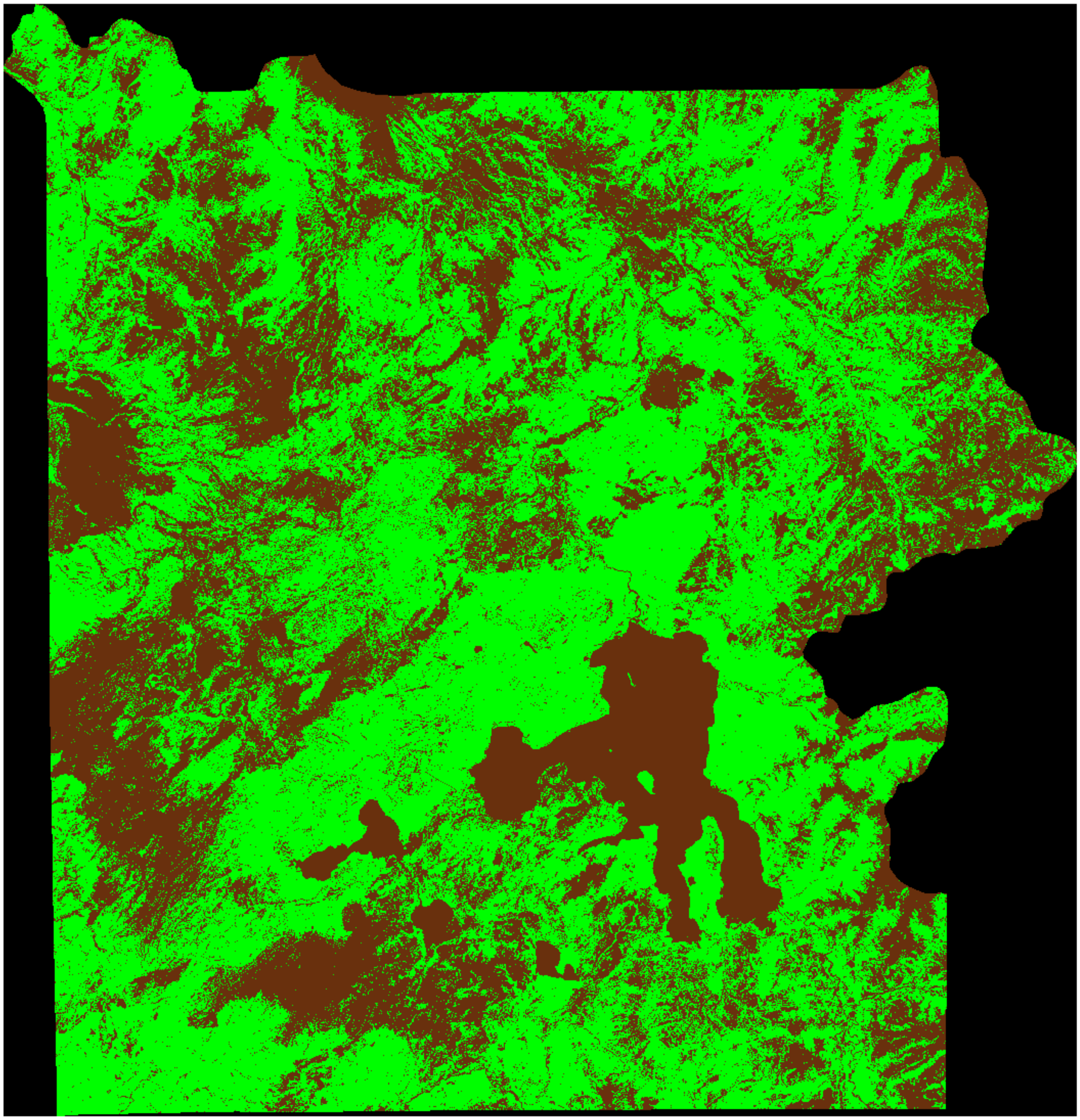
Appendix XIII

Landscape classification of the 1989 NDVI capture from Yellowstone National Park



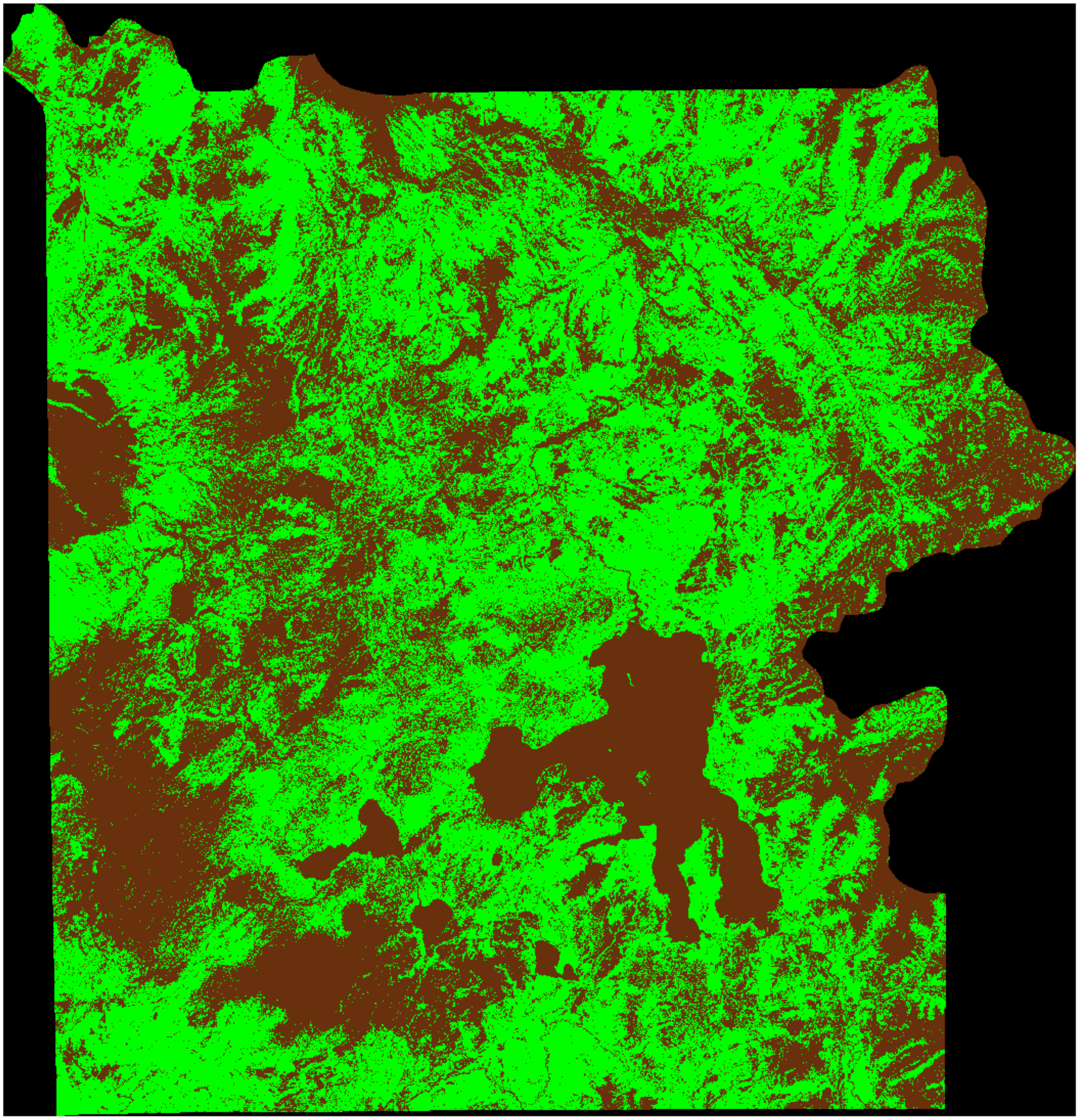
Appendix XIV

Landscape classification of the 2002 NDVI capture from Yellowstone National Park



Appendix XV

Landscape classification of the 2008 NDVI capture from Yellowstone National Park



Appendix XVI

Landscape classification of the 2020 NDVI capture from Yellowstone National Park