Nature Protection and Tourism

A challenge of human-nature relationships in mountain national parks

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"I will do my endeavor.
I try all things;
I achieve what I can."

Herman Melville, Moby-Dick; or, The Whale

Statutory Declaration

I, Simon Landauer, hereby declare that this diploma thesis has been written independently and without assistance from third parties. Furthermore, I confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself.

Date: ______________________ Signature: ______________________

Preface and Acknowledgements

Throughout my entire life I have been drawn between various subjects of interest, which appear to have come together in the research on protected areas. My personal enthusiasm for national parks has accompanied me for a certain time now. Starting of with a field trip to Yosemite National Park, in the context of a recreational geography class at SDSU, the concept of preserving natural beauty alongside recreational, educational and scientific activities has continued to fascinate me. Be it along coastal water, tropic woods or high altitudes; it is the necessity of integrative work which I got so interested in. During my studies, I tried to look at national parks from various possible angles including philosophical, socio-economic, ecological but also artistic and literary perspectives. Here, my passion for travelling has allowed me to foster an understanding for the diversity of national parks; in terms of topography, tourism and management. This, together with my personal affection for mountains, may have eventually brought me to write this thesis. Yet, the development of this thesis would not have been possible without the help of extraordinary people.

First of all, I want to thank my parents for their dedicated support, which led me to become the person I am today. Furthermore I would like to thank my beloved sister, who kept lending me a sympathetic ear. Together, they have continuously pushed me to personal greatness and accompanied me equally in good as well as bad times. They are the pillars of my life.

Special thanks goes to my supervisor Ao.Univ.-Prof. Mag. Dr. Gehrard Karl Lieb, whose constant feedback and critical contributions helped me develop this thesis. The repeated discussions with him have brought forward new ideas and questions, making the work on this thesis an enormous joy. Here, I also want to thank Assoz. Prof. Mag. Dr. Susanne Zimmermann-Janschitz for her dedicated support on my interest in GIS.

Last but not least, I want to thank all of my friends and relatives who accompanied me throughout the years of my study and beyond. The shared moments with them are what made these years so special.

Abstract

National parks take on a crucial role within the realms of protected areas as they aim among others for both: nature protection and human recreation. The connection of those seemingly dichotomous objectives results in complex human-nature relationships, posing a constant challenge for park authorities. This is especially true for mountain regions, which have become central to the national park idea due to their biological and cultural relevance. The present thesis investigates the difference of human-nature relationships within three mountain national parks by providing an analysis of hiking trails, which function as the most essential meeting points for those two entities. With the use of geographic information systems (GIS) and remote sensing, general characteristics and ecological sensitivity of trails as well as intensity of use could be quantified and rendered visible for Yosemite, Torres del Paine and Hohe Tauern National Park. The results have confirmed that individual sites take different approaches on the spatial bringing together of humans and nature. On the one hand, trail design may promote visitation of potentially higher biodiverse forest areas while limiting overall accessibility. On the other hand, trails may lead through an entire park with no special distinction. Additionally, high intensity of trail use tends to concentrate on a few hot spots, which are also often areas of high ecological sensitivity. The standardization of methods and general use of open data within this study resulted in the development of a transferable model, which can be applied to other study areas.

Zusammenfassung

Naturschutz und Tourismus
eine Herausforderung von Mensch-Umwelt Beziehungen in Gebirgs-Nationalparks

Im Gefüge der Naturschutzgebiete nehmen Nationalparke eine wesentliche Rolle ein, da sie unter anderem sowohl den Naturschutz als auch die Erholung zum Ziel haben. Die Verknüpfung dieser scheinbar gegensätzlichen Zielsetzung führt zu komplexen Mensch-Umwelt Beziehungen, welche eine ständige Herausforderung für Parkverwaltungen darstellen. Dies trifft vor allem auf Gebirgsregionen zu, die auf Grund ihrer biologischen und kulturellen Bedeutung zentral für die Nationalparkidee geworden sind. Die vorliegende Arbeit untersucht die Unterschiede von Mensch-Umwelt Beziehungen in drei Gebirgsnationalparks anhand einer Analyse von Wanderwegen, welche als essenzielle Treffpunkte dieser beiden Entitäten fungieren. Unter der Verwendung von geographischer Informationssysteme (GIS) und Fernerkundung konnten allgemeine Charakteristika der Wege und die ökologische Sensibilität sowie die Intensität der Nutzung für Yosemite, Torres del Paine und Nationalpark Hohe Tauern quantifiziert und sichtbar gemacht werden. Die Ergebnisse bestätigten, dass einzelne Gebiete unterschiedliche Ansätze für das räumliche Zusammentreffen von Mensch und Natur wählen. Einerseits kann die Wegplanung den Besuch Gebiete potentiell höherer Biodiversität fördern, während die allgemeine Zugänglichkeit limitiert wird. Andererseits können Wege ohne spezielle Differenzierung durch einen gesamten Park verlaufen. Die Standardisierung der Methoden und die generelle Verwendung von Open Data in dieser Untersuchung führten zur Entwicklung eines übertragbaren Modells, welches auf weitere Untersuchungsgebiete angewandt werden kann.

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List of Abbreviations

Topographic

HTNP	Hohe Tauern National Park
TdPNP	Torres del Paine National Park
YNP	Yosemite National Park

Contentual

ALOS	Advanced Land Observing Satellite
API	Application programming interface
DEM	Digital elevation model
ES	Ecological sensitivity
GIS	Geographic information system
GPS	Global Positioning System
LiDAR	Light detection and ranging
NDVI	Normalized difference vegetation index
NIR	Near-infrared
OGD	Open government data

Institutional

ASF	Alaska Satellite Facility
CONAF	Corporación Nacional Forestal
ESA	European Space Agency
ISRIC	International Soil Reference and Information Centre
IUCN	International Union for Conservation of Nature and Natural Resources
JAXA	Japan Aerospace Exploration Agency
NPS	National Park Service
OSM	Open Street Map
SAGIS	Salzburger Geographisches Informationssystem

1 Introduction

Within the last century, protected areas have continuously gained in importance, as general awareness of ecosystem protection and sustainability have been increasing. Today, despite numerous kinds of protected areas exist, there is one type which has become especially famous: national parks. For the reason that those areas do not focus on complete human exclusion but rather promote recreational use, they constitute a connecting link between people and nature. Consequently, these two entities form a unique relationship within the boundaries of this dedicated land. Here, mountain regions in particular have constantly played a central role, as they represent centers of biological diversity and cultural heritage (Price, 2015, p. 79). However, as interest and visitation in national parks started to rise, so did the pressure on ecosystems within those areas.

Today, tourism is both, a driving force for the further establishment of national parks as well as a potential threat to its protective goals (Hall & Frost, 2009a, p. 303). Hence, the tie between conservation and human recreation represents a constant challenge for park management authorities. Yet, though increasing effort is put into the establishment of unified frameworks and definitions for protected areas, in order to secure sustainable development, individual parks differ strongly in their way of dealing with the afore noted human-nature relationships. One manifestation of such relations can be found in hiking trails, forming corridors where people and nature influence one another. This is particularly relevant, as the use of trails has by far become the most prominent recreational activity in protected areas, with a strong ecological impact (Geneletti & Dawa, 2009, p. 230).

Recently, numerous studies have investigated the environmental influence of tourism in mountain areas, with a specific focus on hiking trails. While some tried to model and assess potential impacts for entire regions (Geneletti and Dawa, 2009; Ólafsdóttir and Runnström, 2009; Tomczyk, 2011), others concentrated on specific aspects of intensive trail use (D'Antonio, et al. 2013; Kolasinska et al. 2015; Lynn and Brown, 2003; Monz et al., 2010). Still, most of the existing research focuses on a single protected area, making it hard to compare the results to other protected areas, in order to get a better understanding of different national park practices. Though there are exceptions which draw on the matter of individuality and contrast, such as Schaller (2014), the intensity of use is hardly implemented. Eventually, trails in national parks need to be assessed based on both, individual factors and general impact to understand underlying human-nature relationships.

Therefore, the objective of this paper is to investigate the relationship between humans and nature in mountain national parks by analysing trail systems in selected study areas. To be more precise, the present study should develop a model to examine characteristics of trails and connected ecological sensitivity in different national parks. For such an analysis, the use of geographic information systems (GIS) in combination with remote sensing is perceived to be of great advantage in terms of workflow standardization and comparability of results.

Consequently, deriving from those considerations, the central three hypotheses which need to be tested within this study are:

(a) There is a difference in the way human-nature relationships are realized in individual mountain national parks.

(b) An analysis of trail systems can help to identify, evaluate and explain challenges of human-nature relationships in mountain national parks.

(c) A GIS can be used to determine, analyse and assess human-nature relationships in the context of trail systems.

In order to address those hypotheses, the thesis first clarifies the general unit of investigation, by elaborating on the national park concept and development. Subsequently, the second chapter deals with human-nature relationships in mountain areas in a broader sense. In more detail, effects of mountain tourism, representing the anthropogenic sphere, as well as subjects of protection, the natural sphere, are examined. Furthermore, this section finally discusses some influences of hiking as a coming together of the two spheres. This is followed by an introduction of the selected study areas, found within the third chapter. Next, the fourth part outlines the methods used for the GIS analysis; including general considerations, selection of data and workflow. Afterwards, the received results are presented in chapter five. The latter are discussed together with the overall advantages and limitation of the model in the ensuing section. Finally, a brief conclusion wraps the study up by putting forward future perspective.

2 | The National Park Idea

Before going into any detail on nature protection or tourism, it is necessary to shed light on the conceptual and spatial framework those topics will be discussed in, namely national parks. As the realm of those specific protected area type forms the basis for all ideas presented in this paper, one needs to consider the historical emergence as well as the clear differentiation of national parks, in order to grasp their unique position. Therefore, this chapter will first elaborate on the origins and spread of national parks, shifting from a national to a global concept. Furthermore, a presentation of the contemporary framework on protected areas, provided by the International Union on the Conservation of Nature and Natural Resources (IUCN), will guide towards a better understanding of the difficulties of uniformity when it comes to nature protection. Finally, the third section will outline major aspects and developments of national parks in mountainous regions.

2.1 Historic Approach

The concept of national parks has been around for more than 100 years now, spreading from its claimed origin in North America all over the world. Nevertheless, this does not imply that the national park idea has stayed a static construct since then. If anything, it rather evolved over the course of time, as it got passed on from region to region, where its implementation led to a constant shift of principles. “Accordingly, as circumstances varied, so too did the application of the national park concept. Different countries adapted the concept to suit their needs” (Frost & Hall, 2009, p. 32). Throughout the years, national parks, and notions on nature protection in general, grew enormously due to various driving forces. In order to understand the contemporary system of national parks, however, one needs to reflect on its development and the original rational behind the desire to set aside land for the benefits of humans and nature.

2.1.1 The National Park Creation Myth

Just like numerous other modern day concepts, national parks offer a romanticized story on their origin. According to a widespread myth, the fate of Yellowstone, the world’s first national park, was decided by a few explorers sitting at a campfire, who agreed to preserve the beauty of those unique natural wonders for generations to come. Despite certain well known activists, such as John Muir, played a critical role in the legislative process, they are by no means the only reason for the establishment of national parks. In fact, the idea was actually legally pushed and partly funded by the Northern Pacific Railroad Company in prospect of future touristic activity and economic benefits, which could be gained through the marketing of such areas of value and interest. (Mark, 2009, p. 81)

Initially, the idea of protecting landscape, not talking about a modern awareness of nature protection here, derived from a cultural perception of nature as ’the sublime’; an inspiring artistic, metaphysical and spiritual synthesis of higher order and greatness. This, almost sacred and superior entity was both, feared and worshipped by humans. Consequently, starting of with landscape gardens in the seventeenth century, natural areas have continuously played an important role for people living in cities and urban areas. During the nineteenth century, public parks became increasingly popular, as industrialization moved forward and planners wanted to transfer nature to the city. Eventually, the final urge for rural recreation was brought forward by the breakdown of the wilderness frontier in combination with the idea of experiencing nature outside city limits. In other words, physical as well as psychological accessibility to wilderness increased the curiosity and desire for the latter. (Mark, 2009, pp. 81–82)

One major step towards the historic establishment of national parks was the acquisition of lands close to, and beyond the 'frontier'. As this zone marked the boundaries of Western American settlement in the nineteenth century, the initial interest in lands beyond this barrier had been relatively small. Only due to the rising concern of bringing agricultural products and other commodities from the Midwest to international markets did those areas gain in importance. Consequently, with the help of governmental subsidies, a railroad network had been set in place to make the American West more accessible. This again fuelled the interest of investors, as the extraction of natural resources became more cost efficient. Additionally, the West saw a population growth along its railway tracks. Despite all that, nature tourism has not been of significant importance until the use of the automobiles became feasible for visiting national parks in the West. Before that, only affluent people could afford a trip to such natural sanctuaries. (Mark, 2009, p. 84)

Those points raised illustrate that it was not a mere act of individuals, but rather a composition of cultural, economical, social and spiritual change which brought forward the idea of bringing nature and perceived wilderness closer to the general public. Additionally, the technical innovations reduced the distance to remote areas and increased the accessibility of the latter. However, the question remaining is, why all of this happened in North America rather than any other place during that time.

There are a few factors why the national park idea could initially develop in the United States at that point in history. First, in contrast to various other countries, the U.S. developed a strong sense for public domain during the nineteenth century. Strong democratic ideals and the protest against monopolistic feudalism were potential driving forces, leading to an increasing demand for public ownership of land, as a counterpart to private possession. Second, wilderness was still largely existing in the country when the need for it arose. In other words, had the continent been colonized earlier, large areas of untouched nature, which could be set aside, might have been scarce or possibly not available at all. Third, the one-directional progress of settlement in North America supported the afore-mentioned point. If the United States had been settled equally from the Pacific as well as the Atlantic, wilderness would have likely disappeared even faster. Finally, the United States was affluent enough to afford setting aside land for recreational purposes. Had the U.S. depended on these areas for agricultural or other economic reasons, national parks could probably not have been established. (Nash, 1970, pp. 731–734)

Despite Yellowstone being the world's first actual national park, established in 1872, the fate of Yosemite is often considered being the first large step towards organized nature protection.

In 1864, the Yosemite Valley and the adjacent Mariposa grove, home to the giant sequoia trees, had been handed over to the state of California by the U.S. government; which should eventually prevent private ownership and keep the landscape open to the general public (Keiter, 2013, pp. 41–42). The dedicated land should neither be settled nor used for commercial activity; though former settlers still stayed in the valley until 1874. (Price, 2015, p. 80)

Considering the institutionalization of national parks, this did not happen until 1916, when the United States Congress passed the National Park Service Organic Act, putting the equally named institution into place. With this law, the National Park Service (NPS), being part of the Bureau of the Interior, was given the task of managing and protecting nature within the designated lands, while also making them accessible to visitors of present and future generations; all of which was outlined in the legal act of 1916 (Keiter, 2013, p. 8)

> The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations ... which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations (National Park Service Organic Act of 1916, 1916).

This provided the newly established NPS with a somewhat contradictory mission of leaving designated lands unimpaired, but yet allowing for recreational use. Today, this task appears to be even more difficult, as processes of globalization and global warming are putting evermore pressure on the national parks (Keiter, 2013, p. 9). Still, so far we have solely been talking about the situation in the United States, noted as the country of origin. Therefore, we may now turn to a spatially more diverse perspective on national parks.

2.1.2 The Spread of an Idea

National parks can be thought of as an American invention; a brand or product which has been spreading globally. Frost and Hall (2009, pp. 30–32) point out that, just like Coca-Cola or McDonalds, the national park concept may be perceived as a standard brand, though it is actually locally adapted to consumers' needs. When exported, national parks evolved, which can be measured or characterized by various variables, including size, protection focus, ecosystems, land ownership, administration, infrastructure and visitor focus. The US may have been the first country using the term 'national park', but other countries applied it to protected areas and even had an administrative system in place before 1916. On an international, transcontinental level, the World Conservation Union (later IUCN) was only set in place after numerous countries had already laid out their interpretations of a national park.

In terms of their historical development, parks are often categorized in four regional groups: the new world, developing countries of Africa and Asia, the old world (Europe) and totalitarian states (Frost & Hall, 2009, pp. 32). This historical-spatial spread, originating from the U.S., can be divided into three main phases. First, the concept was adopted by other English speaking nations on the rise, such as Canada, New Zealand and Australia. Second, smaller European powers including Sweden and Switzerland set aside land, whereas leading empires such as Britain and France mostly established parks in their African and Asian colonies. Third, after 1945, the idea spread to the rest of the world, where parks became an essential part of national identity. (Hall & Frost, 2009b, p. 7)

As a detailed elaboration on the individual phases of the historical development would go beyond the scope of this paper, the presentation of the general concept appears to be sufficient. What should be considered important though is the observed strong connection between space and politics. When thinking about the afore-mentioned new world countries, we might observe a similar pattern as outlined in the section on the United States. Countries such as Australia and Canada not only had a large amount of 'unsettled' land under their control, but might have also striven towards a strong feeling of national identity and independence. Of course, the term 'unsettled' should be used with caution here, as native cultures have inhabited those lands for centuries.

When considering the second phase, we might deduce that countries which were holding large amounts of low densely populated areas, were first to establish national parks. Here, Sweden, with a high proportion of woodlands, and Switzerland, where a substantial part of the country's total area is found at high elevation levels, form good examples. Imperial powers, on the other hand, might have outsourced nature protection due to numerous reasons. One might be that protected areas in colonies might have functioned as manifestations of greatness. In other words, unique natural scenery found in Africa or Asia could eventually be considered part of imperial identity. Another reason could be the actual protection of natural resources for later use. Germany and Britain, for instance, established game reserves in Africa during the late nineteenth century, which form the foundation for contemporary national parks in those areas (Frost & Hall, 2009, pp. 38–39). Whether this transition would have happened under imperial authority, or is a product of modern sovereignty is open for discussion.

Over the course of time, national parks were finding themselves with different focuses ranging from protection over tourism to national identity. Those values were manifested in the planning and upholding of the protected areas. Though some of those principles could possibly conflict, there was also a potential for combining them with one another. Still, many of today's conflicts on what a national park is (nature protection, tourism or something else) date back to the creation of the national park. While certain countries borrowed ideas and believes from the U.S. approach, others defined this concept independent of any presumptions; setting their own definition of a national park. (Hall & Frost, 2009b, pp. 9–10)

This brief historic synopsis demonstrates the strong divergence we find in national parks today. Just like humans experience a strong cognitive evolution of thought patterns, so do the physical and metaphysical manifestations of their believes and values, resulting in a constant flux of human-nature relations. The only thing that is for certain, is the constant underlying change that national parks experienced in the past and will have to deal with in the future (Hall & Frost, 2009b, p. 15). Therefore, the approach towards nature protection always needs to be discussed under the caveat of a certain zeitgeist. Today, this can be somewhat represented by the IUCN guidelines.

2.2 IUCN and Protected Areas

First efforts of defining a set of international categories for protected areas were already made during the 1930s, at the International Conference for the Protection of Fauna and Flora in London. However, it took another 30 years until the First World Conference on National Parks in 1962 produced an initial list of parks. This United Nations List included 9.214 protected areas with a total spatial extent of 2.4 million km^2 (Hall & Frost, 2009b, p. 14). Shortly afterwards, the first concrete definitions for protected area categories were formed and have ever since been continually revised by the World Commission on Protected Areas (WCPA), which, today is part of the IUCN. (Krueger, 2016, pp. 14–15)

Although national parks were first included into the IUCN's six categories of protected areas in 1969, the allotment of individual parks was based on the information given by the park holding authorities. To be more precise, no additional proof on meeting criteria was needed when ascribing allegedly protected areas to categories. This distinguishes the IUCN's accreditation from other processes, such as the declaration of a World Heritage, which uses stricter terms for assignation. To put it another way, in order to call an area 'national park', no permission is needed, which, on the contrary, is impossible for World Heritage Sites. (Hall & Frost, 2009b, pp. 8–9)

As a means of depicting this issue, the following sections will introduce the contemporary IUCN classifications and its criteria concerning protected areas. In order to understand the place of national parks within this framework, it is important to clarify general definitions before dealing with the specific field of interest. The reason for briefly introducing all categories, not limiting it to category II, is the implied understanding of the special position national parks find themselves in.

2.2.1 Definitions and Typologies

In general, the IUCN denotes a protected area as "A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2013, p. 8). Nevertheless, this is not the initial definition put forward by the IUCN, but rather a 2007 revised version of the formerly in 1994 agreed on phrase, stating that a protected area is "An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (Dudley, 2013, p. 4).

Despite the fact that the recent definition completely replaced its predecessor, it is important to have a short glimpse at the major differences between those two in order to understand the perception of modern day protection of nature. First, by using a broader spatial terminology, bodies of fresh water, such as rivers or lakes, are now more explicitly included in the protected area definition (Dudley, 2013, p. 60). Although those bodies of water might have already been implicitly thought of as part of land, this inclusion is now beyond discussion. Additionally, a geographical space can be considered a multi level area, not merely limited to the surface. The second noteworthy adaptation of the former definition brought in the abiotic environment, by shifting the focus from the sole protection of biological diversity to the much broader term of nature conservation (Dudley & Stolton, 2016, p. 35). By this rather holistic understanding, nature is comprised of all living creatures and plants as well as the underlying geology.

Based on the afore-discussed definitions, the IUCN created two major typologies in order to define different subtypes of protected areas. Those include six management categories as well as four major governance types, whereas each category of the former can go along with each type of the latter (Dudley & Stolton, 2016, p. 35–36). For the reason that this paper specifically deals with national parks, only category II will be of explicit interest and therefore discussed in more detail. However, as mentioned before the other categories are also briefly introduced, for reasons of clarity.

2.2.1.1 Management Categories

Despite each management category features its own individual aims, there are also certain objectives which apply to all protected areas equally (Dudley, 2013, p. 12). In other words, those overall goals have to be met by any potential area to fall into one of the six underlying categories. According to the *Guidelines for Applying Protected Area Management Categories*, those general aims include:

- “Conserve the composition, structure, function and evolutionary potential of biodiversity;
- Contribute to regional conservation strategies (as core reserves, buffer zones, corridors, stepping-stones for migratory species etc.);
- Maintain diversity of landscape or habitat and of associated species and ecosystems;
- Be of sufficient size to ensure the integrity and long-term maintenance of the specified conservation targets or be capable of being increased to achieve this end;
- Maintain the values for which it was assigned in perpetuity;
- Be operating under the guidance of a management plan, and a monitoring and evaluation programme that supports adaptive management;
- Possess a clear and equitable governance system” (Dudley, 2013, p. 12).

While some of the above mentioned objectives appear rather specific, others seem comparatively vague. This may again be due to the fact that protected areas all around the world face increasingly different challenges, making it hard to define globally applicable narrow objectives. Additionally, the measurability of some aims could be questioned, especially when it comes to terms such as diversity, leaving space for interpretation. Despite being scientifically graspable, diversity and its role in ecosystems sometimes appears to be hard to identify, as outlined in Chapter 3. Still, the difficulties of an internationally valid concept needs to be acknowledged.

Such as mentioned before, there are six different management categories; with the first one being subdivided into two separate categories. The categories themselves are labelled by Roman numerals and lowercase letters, and they are sorted in ascending order, representing their restrictive level of human intervention.

Ia - Strict nature reserve: the ultimate goal of those areas is to conserve ecosystems in their unimpaired state and protect biodiversity and geodiversity, while keeping visitation of humans to an absolute minimum. They are heavily controlled and are solely to be entered by researchers and monitoring staff. (Dudley, 2013, p. 13)

Ib - Wilderness area: these areas try to preserve their natural condition and character by steering clear of significant, but not all, human activities. (Dudley, 2013, p. 14)

II - National parks: those will be discussed in more detail in Section 2.2.2.

III - Natural monument or feature: these are usually relatively small areas, focusing on the protection of one specific natural element, which may or may not be anthropologically influenced. Monuments can reach from geomorphological interesting landforms, over biotic features, such as groves, to cultural influenced sites, e.g. ancient tracks. (Dudley, 2013, pp. 17–18)

IV - Habitat/species management area:: such areas attempt to protect certain flora or/ and fauna species as well as habitats. Those areas may be in need of a constant active management, in order to fulfil their objectives. (Dudley, 2013, p. 19)

V - Protected landscape/seascape: here, protection is focusing on areas shaped by interactions between nature and culture. Those land- and seascapes hold unique values due to those interrelations. (Dudley, 2013, p. 20)

VI - Protected area with sustainable use of natural resources: the goal of those, mostly large areas, is to combine the sustainability with ecosystem conservation. While certain parts of the area feature moderate, sustainable use of natural resources, other parts remain in almost untouched condition. (Dudley, 2013, p. 22)

This short overview demonstrates the relatively broad span and variation in management of protected areas. While some promote human activity, others try to steer completely clear of any anthropogenic interference. Nevertheless, all of these given definitions are rather descriptive than prescriptive. As there is no binding law for the achievement of the categories' objectives or compliance with the framework, it all comes down to the position of each and every individual entity in charge of the protected area. This leads us directly to the question of who, or what, is the responsible authority for administrating and managing those areas.

2.2.1.2 Governance Types

Just as with the different kinds of management areas, the IUCN defines a clear set of governance types for protected areas. In juxtaposition to the management categories, those are codified by upper case letters, whereas the letter ascribed to them has no evaluative meaning of any sort.

A - Governance by government: the administration and management is conducted by an institution of the public sector, which defines objectives and executes management plans. The possible authorial level holding those functions reaches from national or federal bodies all the way to municipal institutions. In some places, the enforcement of plans may be delegated to non-governmental organizations, acting within a binding framework. Participation of the general public is strongly encouraged as a mode of decision making. (Dudley, 2013, p. 26)

B - Shared governance: tasks and responsibilities are shared between a set of several institutions, of governmental or non-governmental nature. Often this is executed in the form of a co-management, where one actor holds the responsibility and authority but has to discuss all plans and decisions with various stakeholders. Another form would be the joint management. Here, the decision making process, and the accompanying responsibility, rests with all participating actors equally, whereas the execution of those acts is passed on to other institutions. A special kind of shared governance, called transboundary management, is required when protected areas stretch across political borders. (Dudley, 2013, p. 26)

C - Private governance: with this type of governance, protected areas are owned and managed by individuals, organizations or cooperations for either non-profit or profit reasons. Schemes in privately governed areas may often include hunting, ecotourism or other forms of recreation. Frequently NGOs purchase land for protective means, who are then in charge of defining objectives and creating management plans. Sometimes those privately owned protected areas may be off limits to the general public. (Dudley, 2013, p. 26)

D - Governance by indigenous peoples and local communities: in this special case, the decision making authority as well as responsibility is ascribed to indigenous people or local communities within or close to the protected area. For their management, formal or informal institutions have to be established and legislative frameworks need to be defined. Sometimes, different parts of those areas and the connected resources may be owned by unique tribes/groups within a larger community, while others may be collectively managed. (Dudley, 2013, pp. 26–27)

From this short overview we might already deduce that each type of governance comes with various different interests of administrative stakeholder groups, which will again be manifested in the management plans of those protected areas. To be more precise, privately owned national parks, for example, might pursue goals highly contradicting government owned interests. Nevertheless, this does not always imply that private organizations follow capitalistic ideals. In Tanzania, for instance, state owned national parks are mostly designed for loosely regulated mass tourism, being one of the largest sources of national income, while privatively run hunting grounds, keep defined strong sustainable regulations, leading to an often better protection of fauna compared to the national parks (Dudley & Stolton, 2016, p. 39).

Considering the combination of management categories and governance types, there are no limitations (Dudley & Stolton, 2016, p. 35). This results in a matrix, providing a better overview of the interplay between categories and types, by showing every possible combination of the two typologies (see Figure 1). The presented table also shows subdivisions of governance types, which can vary strongly across nations and regions. In general, it is important to acknowledge,

Governance types / Protected area categories	A. Governance by government			B. Shared governance			C. Private governance			D. Governance by indigenous peoples and local communities	
	Federal or national ministry or agency in charge	Sub-national ministry or agency in charge	Government-delegated management (e.g., to an NGO)	Transboundary management	Collaborative management (various forms of pluralist influence)	Joint management (pluralist management board)	Declared and run by individual land-owners	… by non-profit organizations (e.g., NGOs, universities)	… by for-profit organizations (e.g., corporate owners, cooperatives)	Indigenous peoples' protected areas and territories – established and run by indigenous peoples	Community conserved areas – declared and run by local communities
Ia. Strict Nature Reserve											
Ib. Wilderness Area											
II. National Park											
III. Natural Monument											
IV. Habitat/ Species Management											
V. Protected Landscape/ Seascape											
VI. Protected Area with Sustainable Use of Natural Resources											

Figure 1: The IUCN protected area matrix (Dudley, 2013, p. 27).

that even within countries, various philosophies of nature protection can coexist (Dudley & Stolton, 2016, p. 41). Once again, it is important to understand the larger framework in order to make a strong distinction between the different categories.

2.2.2 Category II - National Parks

For the fact that the label 'national park' already existed long before the IUCN categorization, contemporary national parks may assign themselves to other categories than their label might suggest, depending on their aims (Dudley, 2013, p. 11). While some parks list themselves under 'strict nature reserve' (category Ia) others meet the description of 'protected landscapes' (category V). Nevertheless, those out-of-category parks bear the term 'national park' for historical reasons, having nothing to do with the category II label. However, as this is an issue which would have to be discussed for each national park individually, we may now return to standardized definitions of the IUCN. In their guidelines from 2013, they define national parks as follows:

> Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities (Dudley, 2013, p. 16).

One of the biggest distinguishing features of this category is the spatial scale at which protection takes place. According to the IUCN, national parks should aim to conserve whole ecosystems and protect native flora and fauna as well as physiographic features, while at the same time provide space for tourism, education and science. In comparison to other categories, national parks allow for a slightly looser conservation approach than category Ia and Ib and provide a consecutively maintained visitor infrastructure. Unlike categories III and IV, national parks strive to protect whole ecosystems instead of individual features or species. However, they are not cultural systems, as in category V, but natural areas. Consequently, they only allow for an extremely limited use of natural resources. (Dudley, 2013, pp. 16–17)

Thinking back to the National Park Service Organic Act of 1916 and the early history of national parks, the definition of those protected areas has slightly changed. Although one always needs to be mindful of the difference between IUCN 'national park' and the historical term 'national park', it can still be acknowledged that there has been a certain shift towards ecology and sustainability. When considering the U.S. legal act, as a first attempt of constructing a framework, it centered on the conservation of scenery and wildlife to provide for intergenerational human pleasure, without any explicit formulation of the latter. In contrast, the IUCN definition of 2013 notes that special human activities within those areas need to be justifiable on an ecological basis. This can be seen as the result of an ongoing revision of definitions, since 1969, based on empirical values and experience.

However, the increasing restriction also forces existing national parks to constantly adapt their management priorities, in order to meet the criteria for category II. The IUCN guidelines acknowledge this by saying that the definitions of naturalness are subject to constant change, forcing protected areas to reevaluate their category and alter their management (Dudley, 2013, p. 17). This leads us back to the previously introduced consistency of change; especially, when considering the increasingly fast gained knowledge on the effects of climate change and natural degradation.

2.3 Protection of Mountain Areas

Numerous of the worlds first national parks can be found in mountain areas. The first European parks, for example, were established in the mountains of Sweden (1909), Switzerland (1914) and Spain (1918). Other continents followed soon after, with Belgian Congo (1925), today Democratic Republic of the Congo, and India (1936). In 2015, roughly 17 % of the world's mountain areas were situated within the borders of protected areas, including national parks, national reserves and others. The international protection of lowland areas, on the other hand, only reached a share of around 12 %. Nevertheless, these shares underlie a strong regional variation. (Price, 2015, p. 79–81)

Especially in mountain areas, the idea of national parks dates further back than the North American preservation of scenery. For millennia, human beings have valued mountains and adjacent forests as sacred places. This can be considered one reason why numerous areas have remained relatively untouched for such a long time, making them highly biological diverse places. The idea of spiritual connectivity, however, is not a local phenomena but spreads across continents, cultures and ages. Another principle, why several mountain areas have been conserved so well over the course of time is the preservation of forests for royal hunting. Specifically the continuous strict control of game since medieval times in Europe and the beginning of the late modern era in Central Asia has kept animal populations high for centuries. (Price, 2015, pp. 81–82)

One significant event in the history of mountain protection has been the designation of Sagarmatha National Park in Nepal. Starting in the 1950s, the Himalayan mountains became of increasing interest to mountaineers from all over the world. Especially areas close to peaks such as Everest, K2 or Annapurna, sacred to local people, started to experience problems by the rising international visitation. As a response, in 1976 the Nepalese government, together with Himalayan Trust and New Zealand, eventually designated Mount Everest (Sagarmatha) and the land around it as a national park. Studies had later shown, that the protected area helped conserve plants, protect endangered species and produce economic benefits for local communities. Over time, the area under protection was further expanded through the establishment of new parks close by. (Parish, 2002, pp. 244–245)

For the creation of Sagarmatha National Park, interests and needs of local people have been included throughout the whole establishment process (Parish, 2002, p. 244). This can be viewed as a positive integrative approach, as people have been inhabiting those lands long before they were of international interest. Therefore it is extremely important to provide for the adequate use of those mountain areas, including farming opportunities as well as sacred rituals. Protected areas need to incorporate those needs into their management, while constantly being aware of the rising numbers of international tourists, putting alpine areas under increasing pressure.

As mentioned before, while the number of mountain protected areas is relatively high, their distribution is rather irregular. In fact, most protected mountain regions are found in places where population density is relatively low, such as the Americas, Australia and Arctic regions, while Europe and parts of Asia find themselves under much higher pressure. Protected areas within the 'Old World' often find themselves adjacent to areas with intensive use, e.g. large-scale farming. This again has an impact on species habitat and migration as well as plant diversity, by creating some kind of endemic island. Keiter acknowledges this by saying that "today, national parks can no longer be viewed as isolated islands. Rather, they are part of larger ecosystems subject to ongoing human development pressures" (Keiter, 2013, p. 5). Therefore, the concept of buffer zones, enabling species movement across borders, is becoming increasingly important in order to overcome this, often called, doughnut issue. (Parish, 2002, pp. 249–251)

With those ideas at hand, we may now turn to a theoretical approach on the spheres within those mountain national parks, and the interplay between mankind and nature.

3 | Human-Nature Relationships in Mountain National Parks

In mountain regions, connections between humans and nature can be found on multiple levels. For humanity, mountain areas are extremely valuable when it comes to fresh water supply, as around half of the global population depends on water derived from alpine streams, be it for domestic, agricultural or industrial use (Price, 2007, p. 10). Additionally, mountains hold a significant amount of natural resources, accessible through mining and forestry, as well as provide for various agricultural practices and products derived from high elevation farming (Godde et al., 2000, p. 3). Furthermore, mountain areas represent spaces of strong diversity. On the one hand, they are home to numerous endemic species of flora and fauna, making them strongly biodiverse hotspots; on the other hand they are spaces of unique cultural practices reaching from spiritual to recreational activities (Price, 2007, pp. 10–11). This twofold diversity already gives a hint on the ongoing need for protection of, and awareness raising for mountain areas.

However, to understand mountain areas and tackle issues of protecting those environments, an integrative approach is needed, bringing together the anthropogenic and natural sphere. In order to provide for a sufficient coverage of both areas, we will first draw on the idea and necessity of integrative thinking before talking about some individual aspects of the human and natural sphere within alpine national parks. Finally, those ideas will come together in a synopsis on the activity and impact of hiking within mountain protected areas, as a specific type of human-nature relationship.

3.1 An Integrative Approach

As mentioned above, conservation in mountain areas needs to be viewed from a broader perspective, not reducing it to the mere protection of one element, but rather focusing on the idea of integrative ecosystems. The constant tie between human and natural activities calls for the need of integration. By definition, the integrative approach within the field of geography suggests the striving for an understanding of the complete landscape as a complex composition of all its individual parts, whereas the term integration itself reflects the interlinking and feedback of elements within the geoecosystem (Leser, 2010, pp. 386–387). This requires the consideration and thus integration of sustainable human activity and local people's needs (Parish, 2002, p. 243).

The necessity of interdisciplinarity and transdisciplinarity within mountain research has already been acknowledged by Alexander von Humboldt in the nineteenth century. According to him, nature could only be studied as a combination of its individual elements. This idea however did not come of age, but was even refined over the course of time. When it comes to mountain regions, the Man and Biosphere Programme (MAB) has helped to initially understand the complex interplay between humans and their environment. An examination of multiple test sites in the Swiss Alps during the 1970s and 80s resulted in the definition of models, showing the relationships within a socio-economic-ecological system. Such an open system approach, including the influence of external factors as well as the responsiveness of internal aspects was a major step towards the final deduction of long term goals and strategies for mountain protection. (Messerli & Messerli, 2007, pp. 24–30)

Nevertheless, one of the main requirements, which was hardly met in the past decades, is the actual cooperation between researchers from social sciences and natural sciences; being vital to a complex understanding of mountain regions (Messerli & Messerli, 2007, pp. 45–46). Especially in geography there has been a long lasting divide between physical geography, studying biophysical phenomena, and human geography, strongly focusing on the social sphere. As both fields are extremely important and provide methods and specific knowledge, the investigation of protected areas calls for a combination of both fields. This can be found in human-environment geography, focusing on the impact and influence of humans on the natural environment and vice versa (Moseley, 2014, pp. 9–10). Consequently, this study tries to bring in knowledge and findings from a broad scale of scientific research in order to provide for a sufficient argumentation on the investigated matter.

3.1.1 The Question of Epistemology

On a fundamental level, working integratively conveys bringing in ways of thinking from different scientific fields. In general, any research and reasonable argumentation whatsoever is based on fundamental assumptions deriving from various philosophical approaches to the idea of knowledge. For centuries, epistemology, the study of knowledge, has been focusing on the questions of what we may know, and how we may acquire this knowledge (Craig, 2002, p. 66). Over the course of time, various movements have developed, taking different stances based on diverse ontological principles, which again shape the approaches on our acquisition of knowledge. Consequentially, epistemological approaches define the specific methods used for conducting research and drawing conclusions, in order to find 'truth' (Moseley, 2014, p. 346). Whereas the word truth is intentionally put in quotation marks, as the idea of truth itself can set off a discussion of its own.

In geography, positivism and humanism (also constructivism) have become the most dominant schools of thought. Positivism, on the one hand, is based on the ontological assumption that reality exists outside of human cognition and can therefore be objectively observed; whereas humanists, on the other hand, believe the world to be a construct of peoples individual perceptions, making knowledge a subjective complex (Moseley, 2014, p. 346). This dichotomy mostly reflects the addressed contemporary divide between physical and human geography, also resulting in a divergence of used methods. A significant development can be found in the 1970s, when human geographers wanted to set themselves apart from the concept of objective science, by using interviews and participant observations in order to accredit for subjective, irrational human behavior as a world-shaping element (Clifford & Valentine, 2003, pp. 3–4).

However, this dichotomy is less extreme than it might appear from theoretical considerations, as both specialist disciplines mostly agree on the impossibility of complete objectivity and the limitations of hypotheses' representative ability. Today, the most prominent approaches appear to be social constructivism and critical rationalism; with both believing in the existence of a certain objective reality, which cannot be completely perceived. Social constructivism, not primarily interested in objectivity, draws on qualitative methods, such as the interpretation of texts, in order to investigate the constructive role of society. On the contrary, critical rationalism, reasoned by Karl Popper, tries to approach the inexplicable objective reality through a process of continuing hypothesis testing and falsification based on quantitative methods. (Gebhardt et al., 2011, pp. 94–96)

Although we need to acknowledge both epistemological positions to understand human-nature relationships, this study will lean more towards a critical rationalist thinking, with a strong focus on quantitative methods. Particularly the use of geospatial technologies makes geographic features quantifiable and measurable by reducing real-world complexity. This suggests a somewhat objective knowledge acquisition, though the generalization process is guided by subjective principles. Never, however, should the use of numeric values postulate complete objectivity, and much less if 'truth'. As mentioned, it is a means of simplifying complexion in order to make it easier comprehensible.

3.1.2 Concepts of Human-Nature Relations

Throughout history, numerous theories developed on how the natural environment and humans are related to each other. In academic research, various scholars of distinct fields tried to evaluate and model the interplay between those to entities on a theoretical level. Today, however, according to Moseley (2014) three concepts appear to be the predominant perspectives on this matter: the ecocentric approach, the socionature approach and the human-environment approach. Those will be shortly introduced in the following lines.

First, the ecocentric approach, which is also often referred to as non-human perspective. This rather constructivist idea views flora, fauna, invertebrates and microbes, due to their impact on everything else, as equally important as humans, when it comes to modifications in the system. In other words, those beings might even evoke a stronger change in their surrounding around them than human beings do. Therefore this perspective tries to find answers to the suggested rights of those beings within the global system by questioning our own ethical values and the idea of anthropogenic dominance. Additionally, because of the acknowledged capability of all beings to elicit change, econcentrists try to investigate every potential influence on the studied elements. One example of this would be the question of animal rights within society. (Moseley, 2014, pp. 33–34)

Second, the socionature perspective completely integrates the natural environment and human society into one indivisible unit; resulting in a unity. Despite it is not separable, the supposed nature is somewhat a mental idea constructed by human concepts. To put it another way, within this concept, social constructivists view environment as part of an ensemble, which is again shaped by cultural, political and temporal elements rooted in human activity. Consequentially, such a holistic approach is often argued to be hard to disentangle from socio-cultural elements. A good example for this could be a societal experience of natural variability, such as an annual draught. While one community might perceive it as a normal phase of agriculture, another, rather economically driven society may have to fight for survival due to inappropriate preparation. (Moseley, 2014, pp. 32–34)

The last concept being introduced here is the human-environment approach. Briefly, this concept puts forward a synergistic relationship in which humans are the main modifiers of the natural environment, whereas the latter also has an influence on the former, though nature does not completely determine anthropogenic acting (Moseley, 2014, p. 32). At first glance, this perspective might appear somewhat unilateral; however an integrative approach does not automatically imply an equal weighting of all elements, but rather the consideration of all necessary factors. For this matter, this concept appears to be the best fitting idea when it comes to protected areas.

When thinking about national parks in particular, it is important to keep in mind that the relation between humans and nature within those areas is somewhat special. No matter which philosophical approach one is taking, whether one perceives humans as part of or superior to nature, it is essential to recall that this designated area (national park) is set aside for protection. This fact again implies, that there is an adversary at hand from which the protected element needs to be guarded. Ironically, the potential antagonist (mankind) is the actual entity putting the protective act in place and overseeing it. Hence, humans are undeniably the major driving force when it comes to the management of national parks. As a result, the mentioned human-environment approach appears to be the best concept for this issue. This is also confirmed by Moseley (2014), who states that “it is clearly a human construct to designate one area as a ’hotspot’ even if there are clear criteria and reasons for doing so” (p. 288). Therefore, it would be unfitting to take an ecocentric approach, as the human activity appears to be more central to the protected area than the one by other natural stakeholders. However, the natural voice or vote, as we might call it, can be indicated through the measurement of physical indicators, with biodiversity being one of them.

3.2 Human Sphere - Mountain Tourism

The following section will deal with the human sphere of activities in protected mountain regions. Within national parks, this is mostly limited to tourism and the management of the afore. Despite acknowledging the fact that there have historically been, and partly still are uses such as hunting, forestry and agriculture present within protected areas, they are not part of this analysis. Just as the contemporary IUCN definition suggests, solely recreational, scientific and educational activities are consistent with the guidelines.

Parish (2002, pp. 266–268) points out that the origins of modern mountain tourism can be connected to the increasing activity of alpine explorers in the nineteenth century. During that time, a complex image of mountains evolved through the rising activity in those areas. While the numerous ascents and the increase in infrastructural accessibility have led to a feeling of human superiority over nature, the cultural depiction of mountain wilderness in arts and literature has created a mystical view on those areas. Today, one of the most attractive attributes for visitors of those areas are the relative remoteness and perceived unimpaired state as well as their aesthetic value of scenery; eventually leading to a broad span of tourist use reaching from adventurous hiking to high-class skiing.

Though this paper solely deals with hiking in protected areas, the complexity of all touristic mountain uses needs to be acknowledged for a holistic understanding of alpine perception. Just like the mentioned approaches of the past shape our contemporary attitudes and interests in mountains, so do modern practices define future uses. Concerning our postmodern society, Luger (1995, p. 38) talks about hybrid tourism as a mix of adventure and recreation, in which landscape and culture act as consumer goods helping to shape people. In other words, the participation in touristic action may even function as a process of self-identification and social belonging, bringing in a socio-psychological dimension. Consequently, there is more to hiking a well-known trail than the mere physical action; it is a statement. Parish (2002) confirms this by pointing out that in global mountain regions, "fashions dictate the types of holiday and destination" (p. 268), making some activities more attractive than others. As an anthropogenic product, recreation is within a constant flux based on social values.

Already in the second half of the twentieth century, tourism was found to be one of the fastest growing and strongest spatially spreading activities of all, leading to numerous ecological and economical debates, especially when it comes to recreation in areas of conservation (Godde et al., 2000, pp. 1–2). In the United States for example, the total number of recreational visits in all of its National Parks rose from 50.418.120 in 1979 to 85.451.798 in 2017 (National Park Service, 2019a). Certainly, the number of parks has also changed over the course of time, with the NPS today listing 61 National Parks (National Park Service, 2019b). Nevertheless, the afore shown numbers represent a visitation increase of almost 70 % within the last 40 years. Such a rising pressure on protected areas has also led to an increase in research on the impacts of tourist activity in popular destinations. Still, impact should not automatically be considered as a synonym for negative effects; in fact, touristic activities in mountain regions can eventually hold significant benefits. As a consequence of all this, institutional frameworks, such as those proposed by the IUCN (see Chapter 2), have been the result of an increasing awareness of those impacts.

3.2.1 Economic Impacts

Thinking back to the early beginnings of national parks and their connection to the railway system in North America, one can already derive a certain economic driving force and consequential benefit from tourism in those areas. The Scottish national parks, for example, even define the "sustainable economic and social development of the area's communities" (National Parks UK, 2018) as one of four central aims. This appears to be somewhat contradictory to the ideas postulated by the IUCN, which neither verbatim mentions economic goals in the general aims nor in the category II specifics. Still, for the reason that economic interest has become so central in every sphere of human life, we also need to elaborate on this in connection to protected areas.

3.2.1.1 Benefits

One argument which is continually made is the beneficial effect of tourism on local job markets. Continuously, tourism industry is described as a strongly labour-intensive branch, providing for jobs in numerous field, including lodging, catering, maintenance or entertainment, to name but a few. Another positive aspect, on a national level, might be the economic stabilization through diversification of income sources. This can be traced back to the fact that tourism can provide a relatively constant flux of income for private and state run businesses, while other industries in the primary or secondary sector might experience stronger ups and downs based on market developments. This again may also influence governments' tax income. Additionally, the created welfare may lead to an enhancement of infrastructure, which may had initially been intended for tourists, but eventually benefits local communities in the long run. To draw a coherent argument, it needs to be acknowledged of course, that tourism revenues may also underlie drastic uncertainties due to political issues, climate change and a variation of cultural values and public interest. (Hall & Lew, 2009, pp. 109–110)

Transferring this to protected areas, and national parks in particular, we might see major differences in economic benefits from tourism depending on the way parks are managed. This is again highly dependent on the attitude towards recreation in protected areas and the implementation or avoidance of IUCN guidelines. While some national parks may strictly limit the type and extent of touristic activity, others may provide for a large variety of resorts and entertainment within their boundaries. Nevertheless, the positive economic impact of a protected area can be shown through another example from the United States. In 2017 the gateway region of the Great Smoky Mountains National Park in the Appalachian Mountains received a visitor spending (including admission fees, transportation costs, spending on food an lodging as well as souvenirs) of $ 922.947.100, which supported around 14.000 jobs within a 60 mile radius around the park (Cullinane Thomas et al., 2018, p. 23). Despite one always has to be critical about labor statistics, as they might include seasonal and part-time workers, this immense number shows what an important direct, and indirect employer the local national park is. Considering the fact that there are also expenses, one has to take a look at the value added, as the actual contribution to the regional economy. For the Great Smoky Mountain National Park area, the value added was around $ 695.842.300 in 2017 (Cullinane Thomas et al., 2018, p. 23). This example demonstrates why tourism, and especially nature tourism in recent years, is considered such an important industry for national income and regional development. All this, however, ignores the environmental impacts of such an increasing number of tourists and the use of resources, which will be discussed in Section 3.2.3.

3.2.1.2 Costs

Despite its benefits, the expansion of tourism can also come at a high monetary cost, resulting in various negative effects; again not talking about quantified ecological impacts. Here Hall and Lew (2009, pp. 110–112) refer to three major aspects. First, providing sufficient infrastructure for tourist destinations can be very cost intensive for the public sector. Especially as those upgrades might be necessary to uphold touristic activity and maintain a flux of income, whereas authorities may lack the funds to meet those urgent needs. This can result in a somewhat downward spiral, where private institutions and investors have to jump in. Second, while tourism may create a vast number of job positions, the salary for those occupations is often very low and can be close to minimum wage. Of course, this does not take management positions into account. Additionally, a high share of seasonal works confronts governments with the task of occupying those people somewhere else during less work-intensive seasons. Third, an increase in affluent tourism might force prices of goods and services, and even cost of land, to rise, which may eventually force local residents to leave the area. Especially, an increasing demand for secondary residences in tourist regions can lead to such developments. The latter goes strongly in hand with the second aspect of wages and job opportunities, making it hard for locals to afford a living.

Though specific data on costs is hard to obtain, it becomes clear that rising numbers of national parks visitors result in an increasing demand for infrastructure maintenance. Depending on the park, this may feature roads and trails as well as camping sites and lodging. However, the funding of those renovations can in many cases hardly be covered by the government or park authorities, which can eventually lead to rising admission fees, as had repeatedly been the case in the United States (Colley Clarke, 2017). For parks which haven't had fees so far, this may result in the introduction of the latter, which can bring about a social segregation when it comes to recreation. Skipping the discussion whether admission fees should generally be charged for the recreation in national parks, high entrance fees might indeed limit accessibility of national parks. As a result, only affluent citizens and tourists could afford visits, which would again lead to specialized high-class tourism, drastically changing the local job situation; as a smaller, but higher qualified number of personal might be needed in catering and hosting. In other words, in case the demand for high class lodging and accessibility could rise, park authorities are forced to either close areas further off, or provide for this new touristic demand.

3.2.2 Cultural Impacts

Although the aspect of culture has a limited significance for this study on national parks, one should still consider the potential influences of tourism on local cultures for the sake of completeness. Historically, ancient human settlement was perceived as an intruder to scenic beauty and the protection of nature. When initially creating national parks in North America, Native Americans had been explicitly excluded from those sites, forcing them to leave their native land (Keiter, 2013, p. 122). Today, this is strongly different, with Sherpa people, for example, living in Nepal's Sagarmatha National Park and natives from the Tlingit culture keeping a connection to Alaskan national parks (Sillitoe, 2015, p. 311). Though this approach has changed towards a more reciprocal understanding, it has definitely changed the perception of national parks forever. For the reason that some category II protected areas feature indigenous communities while other do not, the following lines should be considered a rather holistic approach to impacts on cultures within and around park areas.

Generally, one needs to differentiate between the socio-cultural impacts of tourism on hosts and those on guests, whereas an impact itself can be described as a change in quality of life for the former and the latter (Hall & Lew, 2009, p. 143). While guests are clearly defined as the incoming visitors, hosts of touristic actives can be of two origins. On the one hand, they might be local people who have been living within mountain areas for ages and shaped the historical landscape. On the other hand, hosts could also be communities who moved to those areas in search of economic prospects. Here, however, we will mostly refer to the historic communities mentioned first, as they appear to be closer connected to the origins and initial development of a local protected area.

Rest (1995, pp. 83–84) already acknowledged in the 90s that in the Austrian mountain regions, for instance, a general shift from traditional Alpine agriculture and subsistence farming to a predominate service economy focusing on tourism could be observed. Of course, this change cannot only be traced back to tourism, but also to the advance of large-scale farming, making Alpine agriculture less profitable. However, the incoming visitors provided for a promising, probably economically more stable alternative to insecure income. As a consequence, the adaptation of cultural practices toward a service industry also changes the appearance of the cultural landscape, including the large spread of touristic infrastructure such as hotels, parking spaces, sport facilities and road networks (Rest, 1995, pp. 89–90). However, the remaining of old chalets or barns can be seen as cultural persistences in the landscape, which might again foster tourist interest and value.

One very often discussed aspect in this regard is the question of authenticity. No matter where, tourism definitely results in a certain shift of cultural practices. One example is the revival of local traditions and their manifestation in souvenirs as a means of displaying authentic host culture. Here one needs to differentiate between objective and subjective, or experienced authenticity. While the former may be manifested in a scientifically defined historical object or site, the latter may be a personal feeling emerging from a tourists' experience. Though diverse, the interplay of both concepts forges the bridge between place and people. Additionally, it is important to note that cultural representation is also guided by socio-political interest and therefore a dynamic concept often adapted to fit touristic demand. (Hall & Lew, 2009, pp. 149–151)

Over the course of time, tourism has left its mark when it comes to native communities in protected mountain regions. In South America, for instance, descendants of ancient Andean civilizations, such as the Inca or Tiawanaku, have experienced changes in their way of life. While some peasant communities were overran by urban tourism agencies, others managed to keep control over local resources by the independent provision of transport and accommodation. The fact that some families within local groups managed to gain more monetary wealth out of tourism than others divided some communities and created a previously non-existent social gap. As a result, the influx of tourism resulted in a process of transformation for all affected natives; be it positive or negative. (Regalsky, 1995, pp. 267–269)

Another idea pointed out by Hall and Lew (2009, pp. 153–154) is the concept of acculturation, defining the blend of cultures through constant exchange of goods and ideas, whereas one participating culture is usually dominant. On a global scale the term glocalization describes this mashup between local and global values and perspectives, often determined by western culture, leading to a certain homogenization of cultures (Hall & Lew, 2009, p. 147). However, this process is not only caused by global tourism but also by other elements of globalization, including the interconnectedness through technological advance and political dependencies. To round this off, one always needs to remember that culture is not a static concept, but underlies a constant transformation due to external and internal factors (Parish, 2002, p. 95). It is safe to say that tourism has an impact on destination cultures, though we might not think of it as a threat to local cultures, but rather as an aspect of change, being one of many in a complex dynamic system.

3.2.3 Physical Environmental Impacts

Defining the natural environment can be difficult as there are numerous definitions for the term, focusing on different aspects. Considering the fact that this section deals with human activity, we might choose a relational definition instead of a merely natural scientific one. One approach to environment can be found in its relation to human presence. Hall and Lew (2009, p. 188) argue that there are multiple forms of environment, which can be defined by their naturalness and remoteness; while the first variable describes the degree of human interventions and the second one the distance from permanent influence by settlements. Based on this, it is possible to make a classification reaching from natural to cultural environments, spanning all the way from wilderness to urban areas. Figure 2 illustrates this idea of continuity between the individual categories .

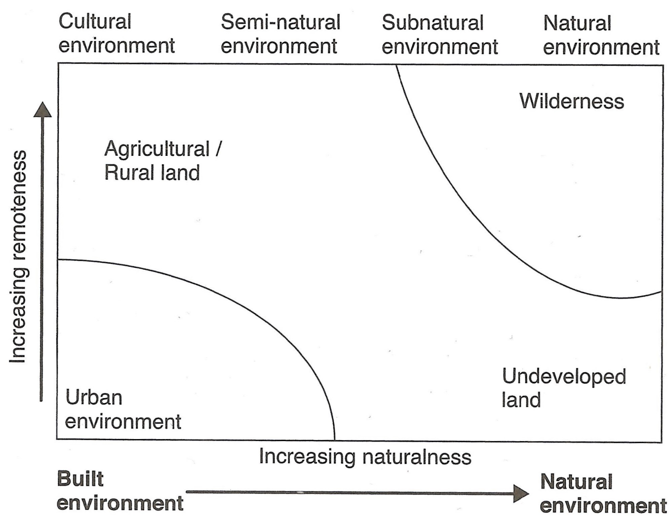


Figure 2: The continuum of environmental categorization (Hall & Lew, 2009, p. 188).

This graphic shows that there are areas of strong human impact as well as relatively unimpaired places. Thinking back to the classification of national parks, some protected areas might find themselves in a relatively close-to-wilderness state, while others might be described with medium remoteness and naturalness. Of course, this categorization appears to be somewhat subjective and would need a definition of quantitative indicators for an actual comparative analysis. However, this arrangement is mostly based on the idea that environments are the result of local or regional interactions, ignoring a global systems approach. Despite the fact that this study is not specifically focusing on the contribution of recreational tourism to climate change or other global issues, we might still need to touch on some of those impacts for the sake of a more complex understanding of the physical environment.

Within the IUCN report, human impacts in protected areas are considered in three dimensions including the subterranean and underwater space, the surface as well as the airspace above an area (Dudley, 2013, p. 9). Here, the focus often lies on local biodiversity and species living in those spaces. Despite it is hard to really segregate those two from each other, the following lines might take this idea one step further, transferring the scope of observation to regional and global scales of impacts. What should always be kept in mind though is the difficulty of directly ascribing certain changes to touristic activities, while ignoring other causes (Hall, 2006, p. 166). In other words, without sufficient evidence it is impossible to be certain that shifts in biodiversity, for example, may only be caused by human interference. Eventually, some species may be extremely sensitive to human action, while others might not be affected at all (Lévêque & Mounolou, 2003, p. 148). This however does not mean that we should discard the idea of tourism impacts, but rather foster investigation into this matter.

3.2.3.1 Land Alteration

The influence of tourism on local and regional land use as well as biota of those areas is probably the most investigated field. Gössling (2002, p. 287) tried to quantify those impacts, concluding that worldwide around 515.000 km^2 (0,34 % of terrestrial surface) can be directly ascribed to touristic land use, comprised of accommodation, infrastructure and golf courses. This result however should only be seen as a rough estimation, as the quality of the data used appeared to be somewhat poor in certain fields. Additionally, the quantification does not include the land needed to produce various products made available within these areas (e.g. agricultural products) as well as urban and communal developments resulting from job opportunities. Finally, one must remember that change of land cover within national parks is very limited to certain areas, though there might still be a concentrated conversion for tourism close to park borders.

The question remaining is what those changes in land use might evoke on a regional scale. Despite there might be numerous potential effects, I want to draw on two specific aspects which are strongly affecting protected areas. The first aspect is the impact on the freshwater system, caused by the increasing direct and indirect consumption of water resources and the rising volumes of wastewater involved in tourist activities. Gössling (2002, p. 297) notes that water consumption of tourists can range from 100 up to 2000 l per bed night, depending on the region. This can be a big issue for national parks situated in relatively arid areas or mountain regions where streams and springs might only be seasonally aquiferous. The second, and today most strongly researched aspect is the impact of tourism on biota and species. According to Hall and Lew, a change of land use towards tourism has often gone hand in hand with a repression of native species, making way for the invasion of non-native flora and fauna. Sometimes this is also triggered by the introduction of diseases by international tourists. Consequently, this can be a threat to local, regional and eventually global biodiversity. On the local scale, biodiversity can be described as a balance between invasion and extinction rates. (Hall & Lew, 2009, pp. 201–202)

However, there might also be a positive effect of tourism on biodiversity; as "tourism provides an economic justification for biodiversity conservation, including the establishment of national parks" (Hall & Lew, 2009, p. 208). Furthermore, "tourism provides an economic alternative to other forms of development that negatively impact biodiversity and [...] a mechanism for educating people about the benefits of biodiversity conservation" (Hall & Lew, 2009, p. 208). The suggested positive effect however is highly dependent on the implementation of those ideas by individual national parks. Additionally, this can be argued to be somewhat contradictory as tourism can be seen as both; the reason for and the cause of nature protection.

3.2.3.2 Global Environmental Change

When thinking one step further, all of the before discussed aspects are integrated into a complex supraregional system, where local actions lead to global effects; resulting in intergenerational challenges for humanity. Today, the use of resources and its impact on climate can be identified as such a, if not the most central challenge. With respect to tourism, energy use is related to transport, accommodation and entertainment; being measured in energy consumption and CO_2 emissions, whereas the latter not only has a strong impact on global warming but may also directly affect species (Gössling, 2002, p. 287). In 2008, the United Nations World Tourism Organization (UNWTO) and United Nations Environment Programme (UNEP) estimated that around 4.9 % of global CO_2 emissions (equalling 1.302 Mt) are caused by the tourism sector, whereas 40 % of those emissions come from aviation followed by 32 % from car transport (UNWTO et al., 2008, pp. 33–34). This, however, is not estimated to decrease in the upcoming decades. Following a 'business-as-usual' scenario, the UNWTO and UNEP estimated that by 2035 the annual emission of CO_2 caused by tourism could reach 3.000 Mt (UNWTO et al., 2008, p. 36).

Getting back one more time to the Great Smoky Mountain National Park example mentioned before, the 2017 report by the NPS state that 98,3 % of the visitor spendings were made by visitors living outside the 60 mile gateway region (Cullinane Thomas et al., 2018, p. 35). This again demonstrates what role CO_2 emissions and energy consumption play, as almost all of the parks visitors journey at least 120 miles there and back again, in case they are not flying in to an airport in closer proximity to the park. For the reason that around 12 % of the total visitor spending in the National Park System can be ascribed to gas and oil, we might deduce that a high percentage of tourists visit the park by car (Cullinane Thomas et al., 2018, p. 12). Besides the impacts global warming has on the ecosystems within national parks, we may also see that a certain fraction of this change is caused by the increase in visitation of those protected areas.

3.2.3.3 Relationships

Resulting from those impacts, Budowski (1976, p. 27) describes three different relationships which can exist between tourism and nature conservation in protected areas. First, they can be in *conflict*, where recreational activity is largely harmful to the natural environment. Second, a state of *coexistence*, which can only exist temporarily, might induce a relationship of little to no contact, whereas there is neither a strong positive nor negative effect for each entity. Finally, a *symbiosis* suggests that nature conservation and tourism development go hand in hand with each other, for the benefit of both. In more detail, this would mean that environments remain in a relatively natural, unimpaired state while people might get recreational, educational, cultural an physical benefits from this symbiosis.

In relation to Budowski's idea, Hall (2006) states that "tourism in a rural context displays many of the features of the symbiotic relationship that exists between tourism and the environment and is a key component of this very attraction to tourists" (p. 244).. His words mark the thought that it is not necessarily the actual naturalness drawing people to protected areas, but very often the accessibility of this naturalness which makes those areas so attractive. To phrase it another way, looking back at Figure 2 we might deduce that wilderness is most attractive when it is less remote but feels most natural. Eventually, despite partly touched in the next section, the question what 'natural' signifies in this sense will be left open for discussion.

3.3 Natural Sphere - Ecosystem Protection

The question of what comprises nature can be a hard one to answer. Because of its wide use, the term nature is extremely difficult to delimit. Setting the boundaries on what is, and what is not part of nature depends strongly on the field of interest as well as the philosophical approach one has toward the term nature. In one of his most famous works *Nature* (1836), Ralph Waldo Emerson noted that "Nature, in the common sense, refers to essences unchanged by man; space, the air, the river, the leaf" (2003, p. 487). This would infer that nature is somehow equivalent with the absence of humans, which can again be linked to Hall and Lew's concept (see Figure 2). Today, this idea is something which a majority of scientists would describe as wilderness, as there are hardly places completely unimpaired, or at least without occasional impact.

While originally nature was defined as the compound of all things the world is composed of, today, the term is more diverse and can refer to rather specific concepts, such as landscape or environment for instance (Leser, 2010, p. 594). Again, however, those terms can be relatively vague, as landscape may not only represent the composition of solely physiographic factors, but can also, when talking about cultural landscape, imply human impact. As we have already dealt with human influences in the previous section, this part should form some sort of juxtaposition. Therefore, a linguistic definition, as a manifestation of popular communicative use, appears to be best fitting; where nature is described as "the phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, as opposed to humans or human creations" (Stevenson, 2010, p. 1183). Here society can be seen as the counterpart to nature, acting within its own realms; a somewhat binary division, which is also manifested in scientific research.

This idea of a certain dichotomy started back in the modern era, when an understanding of nature became equivalent with a reality unchanged by man, deriving from an increasing interest in objectivity and rational scientific thinking. Such an approach omits the historically believed dominance of mankind over nature. Consequently, nature is found to be a self-organized entity which humans are exposed to and passively experience. However, one needs to differentiate between *natura naturans*, referring to natural laws, and *natura naturata*, all elements originating from these laws, including animals, plants and landscape, which are of particular interest for protective acts. (Gebhardt et al., 2011, p. 1080-1082)

These separating thoughts on nature should not shake the fundamental idea of integration, but rather highlight the importance of spherical thinking. In order to get a better understanding of the natural sphere, it is important to clarify certain terms and concepts which are often used when referring to nature in protected areas; including biodiversity and ecosystems. As a final critical remark it needs to be mentioned that from a constructivist approach one needs to keep in mind that the definition and limitation of nature itself is done by humans, as is the decision on what to protect.

3.3.1 Ecosystems

Leading back to the IUCN guidelines, given in Chapter 2, the conservation of ecosystem services is specifically mentioned within the general definition of protected areas. Stated in article 2, the Convention on Biological Diversity defines an ecosystem as “a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit” (United Nations Convention on Biological Diversity, 1992, p. 3). To put it another way, it is the interplay between all biotic and abiotic features and processes which eventually comprises an ecosystem. Another word of importance in this matter is the term community, which refers to the interaction of a heterogeneous group of different living organisms within a defined area, including plants, animals and microbes (Cox et al., 2016, p. 89).

Ecosystems are studied on different scales ranging from tiny ponds to the entire globe, whereas the concept of those systems is based on the flow of energy as well as the nutrient cycle. In more detail, after solar energy is absorbed by the primary producers, plants, it gets passed on to herbivores, carnivores and later destruents, with each of them bringing parts of energy directly back to the initial producers. For the sake of simplification, such systems are then often represented by feeding webs, showing various layers of consumption and production, trophic levels. Due to the consumption and transformation of energy within each stage, the number of organisms at higher trophic levels decreases along with the total amount of energy available. It is important to keep in mind, that there is not only a flow of energy but also a flux of nutrients deriving from inorganic materials. The latter are additionally transported by abiotic elements, with the hydrological cycle playing a central role in this process. (Cox et al., 2016, pp. 92–94)

When talking about ecosystems there is another aspects we need to elaborate, namely its services and functions. First of, ecosystems provide us, humanity, with services essential to our health, including fresh water, clean air, food and medicine (World Health Organization & Secretariat of the Convention on Biological Diversity, 2015, p. 1). While some of those may be defined as goods often monetary valued by humans, such as raw materials (e.g. timber) or food production (e.g. fish), Lévêque and Mounolou (2003, pp. 208–209) point out that there are also services from ecosystems, which are difficult to evaluate, including climate and gas regulation, water purification, soil formation, biological control and others. Additionally, ecosystems hold functions of psychological importance to human well-being, such as spirituality and recreation (World Health Organization & Secretariat of the Convention on Biological Diversity, 2015, p. 35).

3.3.2 The Matter of Diversity

As mentioned in the beginning of this chapter, mountain areas all over the world appear to be hotspots of biodiversity due to their topography, unique bio- and geophysical aspects as well as isolation. For a variety of plants and animals, mountains provide some sort of sanctuaries, away from constant human landscape transformation. In Europe, for instance, around one third of the continent's total number of plant species can be found in the Alps (Byers, Price, & Price, 2013, p. 346). But diversity is not only found in flora and fauna, as there is also a great variety in abiotic elements. Therefore, the following two sections will introduce the concepts of biodiversity as well as geodiversity, and clarify their connection and relevance for mountain protection.

3.3.2.1 Biodiversity

Widely used in public media, the term biodiversity appears to have become a buzzword when talking about sustainability, conservation and, in particular, nature protection. Especially in mountain regions, the preservation of biodiversity has been the number one argument for the establishment of protected areas within the last 40 years (Kollmair et al., 2005, p. 184). Therefore it is important to clarify this term before actually thinking about its evaluation and importance for mountain areas. The following lines will present three different definitions for biodiversity, which will help to foster an understanding of the overall concept.

According to Lévêque and Mounolou (2003), the study on biological diversity, or biodiversity, encompasses "the whole range of activities traditionally connected with inventorying and studying living resources" (p. 8). This methodological definition highlights the strong focus on scientific taxonomy and quantification. When trying to find a rather standardized description, however, one has to turn to the internationally agreed description from the 1992 Convention on Biological Diversity in Rio de Janeiro, giving the following wording for the term biodiversity.

> 'Biological diversity' means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems (United Nations Convention on Biological Diversity, 1992, p. 3)

Although slightly vague formulated, these lines show biodiversity in connection with a spatial focus, whereas in this sense ecosystems are only understood as groups of biotic elements rather than a complex of processes. To round this off, we might turn to one last definition given by Mayhew (2009), which seems to build on the afore mentioned ideas, but gives a more explicit phrasing.

> The number and variety of living organisms, from individual parts of communities

> to ecosystems, regions and the entire biosphere, including: the genetic diversity of an individual species; the subpopulations of an individual species; the total number of species in a region; the number of endemic species in an area; and the distribution of different ecosystems (Mayhew, 2009, p. 47).

This somewhat hierarchical definition brings up the idea of diversity as a dependent factor of scale, but also shows the difficulty of strictly delimitating the term. In other words, while a set of living organisms is comprised of flora and fauna within a defined space, the scope of diversity observation within those sets can reach from a microbiological DNA-analysis, to a subcontinental evaluation of species. In this regard, Mayhew's phrasing also brings in the term communities, which has been introduced previously. It is also noteworthy that the definitions shows a strong quantitative approach, measuring diversity by the total number of organisms. However, numbers are of course not interspecifically comparable due to various reasons, one being their trophic level.

Thinking back to alpine areas it is important to remember that mountain ranges not only show a wide horizontal extension, but also a high vertical variation. Concerning the relation between altitude and biodiversity, there seems to be a pattern that in numerous mountain areas the number of plant species often appear to be richest around 1500-2000 m, before experiencing a more or less rapid decline. This pattern can mostly be traced back to changing physical conditions, caused by temperature and rainfall (Lévêque & Mounolou, 2003, p. 32). Though this can of course be immensely different depending on local conditions and should, though empirically validated, be rather considered as a rule of thumb. However, it may be true that biodiversity in less high regions might be lower due to permanent anthropogenic modifications of land. Concerning animal species diversity, the observation of a distribution pattern appears to be much more difficult as they are not as rigid as flora. (Cox et al., 2016, pp. 134–136)

Over the years, protected areas have become the number one element for fighting biodiversity loss, though they are only partly driven by scientific reasons, as socio-political factors much more influence the establishment and management of such areas (Cox et al., 2016, pp. 443–444). Still, research on biodiversity has an impact on the initial designation of, and continuous planning within protected areas. One major reason for the importance of biodiversity protection is probably its linkage to human health. In 2015, the World Health Organization (WHO) and Secretariat of the Convention on Biological Diversity (CBD) released a review, outlining that biodiversity provides essential psychological and physiological benefits for individual people, communities and the entire biosphere, while a loss of biodiversity can have direct impacts on human health (e.g. diseases, air and water quality, nutrition) (World Health Organization & Secretariat of the Convention on Biological Diversity, 2015, pp. 30–31). In general, biodiversity is considered to be directly and indirectly relateable to a healthy fauna (Parish, 2002, p. 262). This, however, will be discussed in Chapter 5.

3.3.2.2 Geodiversity

Though not explicitly mentioned in the IUCN guidelines, the abiotic part of nature should still be considered part of protected natural sphere within a national park. Broadly speaking, geodiversity can be considered the abiotic pendent to biodiversity. Despite there are numerous definitions for the term, wording by Gray (2004) appears to be the most precise on this matter.

> Geodiversity: the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (land form, processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems (Gray, 2004, p. 8).

In other words, Gray is talking about the set of elements which form the physical basis of landscapes, with flora and fauna only constituting the cover on top of those foundations. Here, the active process of protection is referred to as geoconservation, whereas diversity is hard to define and mostly based on values ranging from functional and scientific, to economic and aesthetic qualities (Seijmonsbergen et at., 2018, p. 156). Therefore, when investigating geodiversity it mostly comes down to the underlying interests and aims, with a study on mining requiring different criteria than research on the aesthetic appeal of graded bedding. Sometimes, geodiversity may also hold a cultural value manifested in folklore, appropriately called geomythology; one example being Devil's Tower in Wyoming, believed to have been shaped by the claws of a giant grizzly bear (Gray, 2004, p. 70).

Though still limited in number, one active initiative for geoconservation is the establishment of geoparks to protect geological sites holding significant scientific, cultural and ecological value (Gray, 2004, pp. 193–194). In national park research, however, one might think of geodiversity as a functional element within the complexity of an ecosystem. Various studies have consequently tried to systematically bring abiotic and biotic elements together; often with the help of geographic information systems. Seijmonsbergen et al. (2018, pp. 156–159), for example, used various indicators, including land surface parameters (slope, aspect, elevation and solar radiation), geology and hydrology, to developed a geodiversity index which could be interlinked with biodiversity.

3.3.3 Species Diversity and Ecosystem Functioning

Based on all of these aspects, and the concept that species are interlinked within an ecosystem, one may deduce a certain relationship between biodiversity and ecosystems. In fact, numerous theories exist on how a decrease in species diversity might influence the functioning of an ecosystem. Hypotheses on this matter range from the believe that certain species are more important than others and consequently show a larger impact in case of loss (redundant species hypothesis), over the idea of equal significance resulting in a static impact on functioning (linear relationship model), to the concept of keystone species, whose removal would be crucial (rivet hypothesis) (Cox et al., 2016, p. 95). Despite this study cannot investigate those relationships on a micro level, as it focuses on a certain generalization, it is still important to understand the basic concepts on how those two elements might be intertwined.

Though it does not hold truth in every situation, there seems to be a general connection between primary productivity and species diversity within an ecosystem (Lévêque & Mounolou, 2003, p. 113). On first sight, this appears to be logical as plants form a fundamental trophic level for the energy flow within the feeding web. For instance, Currie and Paquin (1987, pp. 326–327) found a strong positive correlation between primary production and tree species richness at different North American sites. Yet it needs to be noted, that such correlations constantly have to be treated with reservation as they are the result of a limited investigation, where general validity can only be assumed.

While the intervention of human activity is often found to be of destructive nature, it can also foster mountain biodiversity. Price (2015, pp. 69–70) notes that the survival of certain endemic plant species and invertebrates in temperate mountain areas relies on recurrent trampling and grazing, which, if practised on a moderate basis, can lead to a stability in plant diversity.

The final question is whether a diverse ecosystem does also happen to be more stable. To answer this issue, we will go with Cox et al. (2016) who state that "although species richness in an ecosystem does not guarantee the success, or even survival, of individual species, it does provide that ecosystem with a greater capacity to cope with disasters" (p. 96). In other words, such systems might be more stable in reaction to external influences, which may be caused by anthropogenic actions. Experiments have shown that more complex ecosystems generally show a higher resilience, meaning they can more easily recover from external disturbances (Lévêque & Mounolou, 2003, p. 115). In terms of protected areas in mountains, Parish (2002, p. 251) notes that there has been a shift towards an approach focusing on integrated ecosystems, rather than single species protection.

3.4 Hiking: Humans Walking Through/On Nature

Within national parks, hiking is widely allowed as it is considered a non-consumptive use of natural resources and therefore perceived to be reconcilable with the preservation of landscape and biodiversity (Moseley, 2014, pp. 12–13). Though there are other forms of recreational use in mountain areas that gain increasing popularity within national parks around the world (e.g. rock climbing, kayaking, mountain biking and ski tours), hiking may still be the number one activity deriving from its long tradition as well as easy practicability. In fact, some of the before mentioned activities might not even be allowed within park borders, depending on the individual park policies. As recreational trail use in mountain areas is the most rapidly growing activity, it is also considered to have the strongest influence on local ecosystems (Geneletti & Dawa, 2009, p. 230).

Generally, trails are, and have always been, a means of directing tourist flux in protected areas. They are providing access, but also limit people to certain areas within a national park. From a certain perspective, they constitute the most prominent gateways of human-environment relationships in such areas. This makes them extremely important for planning and management decisions as they define where the two entities are to meet, and where nature should roam without any disturbance.

3.4.1 Influences of Trails on Ecosystems

As already mentioned in Section 3.2, human recreation can have a broad impact on the natural environment. Concerning hiking, this includes biological impacts (wildlife disturbance, vegetation trampling, loss of biodiversity, introduction of exotic species etc.) and physical impacts (soil erosion, trail widening and off trail walking as well as littering, which may result in ground pollution) (Geneletti & Dawa, 2009, p. 230). Of course, those are mostly directly relateable impacts, excluding large scale effects resulting from tourism infrastructure, as the latter are often not only hard to measure but also difficult to differentiate. Therefore, we may now turn towards some considerations on biological impacts.

Besides hiking and the enjoyment of scenery, wildlife watching has become another important factor drawing people on trails (Farrell & Marion, 2001, p. 32). Geneletti and Dawa (2009, p. 229) note that recreation in mountain regions is highly concentrated within the short summer season, which simultaneously is the time for a majority of biological activities, including vegetation growth, mating and spawning as well as migration. Therefore, summer appears to be the most intense temporal phase of collision between human and environmental activities, with hiking trails as the most important space of potential interaction. Despite we might not automatically assume a negative relationship here, a certain degree of disturbance by human presence needs to be acknowledged, though this depends on the proximity of trails to areas of high biological productivity and wildlife habitats.

Nevertheless, though trails guide visitor use, they do not resemble rails, as people might not precisely stick to the indicated tracks. In a study carried out for the Pieniny Mountains National Park in Poland, Kolasinska et al. (2015, pp. 29–32) found a significant correlation between the touristic traffic of a trail and the trampled areas next to it; with the total percentage of people walking off trail being around 30 %, though this number differed slightly between age groups and study areas. In other words, popular pathways are also subject to high frequency vegetation trampling. However, it is important to point out that it is not the total number of hikers, but rather the share of off-trail walkers causing those effects. This can be traced back to technical reasons, due to difficult sections involving steep terrain, as well as volitional off-trail walking, in order to take pictures or watch wildlife.

Furthermore, large scale off-trail walking in sensitive areas may also have an effect on plant cover, diversity and species richness. In alpine heathlands, trampling decreases deciduous shrubs and understory plant cover; while proximity to trails also reduces species richness of non-vascular plants, such as lichens, which carry a significant role in alpine ecosystems (Jägerbrand & Alatalo, 2015, pp. 4–6). Again, emphasis needs to be put on the intensity of use, rather than the use itself. Furthermore, vigorous vegetation, such as forest herbs for example, might show a higher resistance to mechanic impacts than dry grasslands; while recovery periods of plants also depend on general resilience and length of growing season (Farrell & Marion, 2001, p. 36).

Another impact, often related to the decrease in vegetation cover, is the loss and compaction of soil. Especially in alpine and subalpine areas, impacts on soil are critical as they might limit plant growth due to the low soil development rates (Monz et al., 2010, p. 339). Within harsh areas of high elevation, flora is highly dependent on the availability of fertile soils. However, soil erosion on trails is not merely traced back to hiking frequency, but highly dependent on local conditions including erodibility of soil and slope (Farrell & Marion, 2001, p. 49). Consequently, topographic factors play an important role when it comes to the evaluation of ecological impacts.

However, the design of trail systems in national parks does not always consider potential zones sensitive to impacts. In Gorce National Park, Poland, for example pathways were found to mainly lead through vulnerable areas, despite the majority of the region was identified to show low to mean sensitivity (Tomczyk, 2011, p. 347). However, existing trails are not always the result of mere management planing, but can also be relics of long term practices.

3.4.2 Impacts on Experience by Hikers

Hiking on trails does not only have an influence on the environment, but can also have an effect on nature-based tourism itself. Lynn and Brown (2003, pp. 81–86) investigated the way in which impacts of recreational trail-use in natural areas affect the perception and experience of hikers in Starkey Hill, Canada. By measuring the perception of naturalness, remoteness, artifactualism (absence of anthropogenic impact) and solitude, the scholars concluded that especially damaged vegetation and litter had extremely large impacts on experience levels. Additionally, trail widening, through off-trail walking, showed a strong impact, though only a small amount of hikers confirmed their contribution.

From this we can deduce that intensive use of ecologically sensitive areas does not only influence the natural sphere, but additionally reflects on the human sphere. When researching nature-based tourism in the Rocky Mountain National Park, D'Antonio et al. (2013) discovered that "in all study areas, the extent of informal trails equals or exceeds that of the system (designated) trails in that area" (p. 75). This highlights that no matter the trail, off-trail hiking appears to be present in all sections of the park. However, when asking about the acceptability of vegetation loss caused by informal trails, visitors responded to find any vegetation cover lower than 42 % of the original unacceptable, where the percentage values resulted from simulations (D'Antonio et al., 2013, pp. 75–76). In other words, despite the omnipresent practice of off-trail walking, the acceptability of its influences is comparatively low.

One reason for this might also be that intensive use decreases the perceived sensation of naturalness. More precise, one might say that national parks convey a certain expectation of solitude and wilderness, though this often conflicts with the idea of wilderness as remote spaces, therefore far off from anthropogenic actions. Mostly, wilderness areas are defined by their proximity to human disturbance elements such as trails, roads, settlements or resource extraction practices, which, nowadays, can be easily evaluated by spatial GIS analyses allowing for a better designation of those areas (Pulsford & Ferrier, 1994, p. 224). The reason for mentioning this is the fact that remoteness and wilderness have increasingly become elements of desire in nature-based tourism, though vast remote areas are becoming evermore rare (Boller et at., 2010, p. 320). Consequently, tourism demands the expansion of trail systems to remote spaces. Yet by doing so, (perceived) wilderness is lost, which besides diminishing visitor experience can have a strong impact on local ecosystems.

4 | Study Areas

This study investigates three specific mountain national parks, of which two are situated in the northern and one in the southern hemisphere. In particular, the selected sites are Yosemite National Park in the United States, Torres del Paine National Park in southern Chile, and Hohe Tauern National Park in the central part of Austria. Those areas were chosen due to various reasons.

First of, all mentioned national parks feature international popularity and reputation, drawing in a vast number of local as well as international visitors every year. This aspect was considered important, as a strong touristic flux plays a central role for all of those parks. Second, all three areas are declared Category II protected areas according to the IUCN protected area categorization, making them national parks on a conventional and terminological level. Third, the three areas mentioned are all situated in democratic and developed countries. Within the report on the global Human Development Index (HDI) of 2017, all three countries are listed under 'very high human development'; with the United States showing a HDI of 0,924, Austria 0,908 and Chile 0,843 (UNDP & HDRO, 2018, p. 22). The rational behind this criteria was a potentially higher awareness for the protection of nature within those countries as well as the economic possibility to establish vast protected areas while still providing primary care for its citizens. Additionally, a democratic government should in theory provide a higher potential for participation in decisions on land use and protective acts.

Despite their similarities, there are of course certain differences between the study areas, ranging from physical factors to regional social and political frameworks. The following three short sections should briefly introduce the individual national parks by giving necessary information on each site. A general overview on the study areas can be found in Table 1.

Table 1: Overview of the selected study areas

Category	**Yosemite**	**Torres del Paine**	**Hohe Tauern**
Area (km^2)	3006	2053	1856
Year established	1890	1959	1984
IUCN Category	II	II	II
Governance type	Collaborative governance	Federal or national ministry or agency	Federal or national ministry or agency
Management authority	National Park Service (NPS)	Corporación Nacional Forestal (CONAF)	Nationalpark-verwaltungen Kärnten, Salzburg, Tirol

This data, except for the area of HTNP, was retrieved from Protected Planet holding the most up to date information on protected areas (UNEP-WCMC & IUCN, 2019). The platform is managed by the United Nations Environment World Conservation Monitoring Centre and supported by the IUCN and WCPA. The area for HTNP was taken from *Tätigkeitsbericht 2018 Nationalpark Hohe Tauern* (Rupitsch et al., 2019).

4.1 Yosemtie National Park

Located in the Sierra Nevada of central California, Yosemite National Park (YNP) has carried the label national park since 1890, prior being a state park governed by the state of California. Since the Organic Act, the park is managed by the National Park Service, just as all other national parks within the United States.

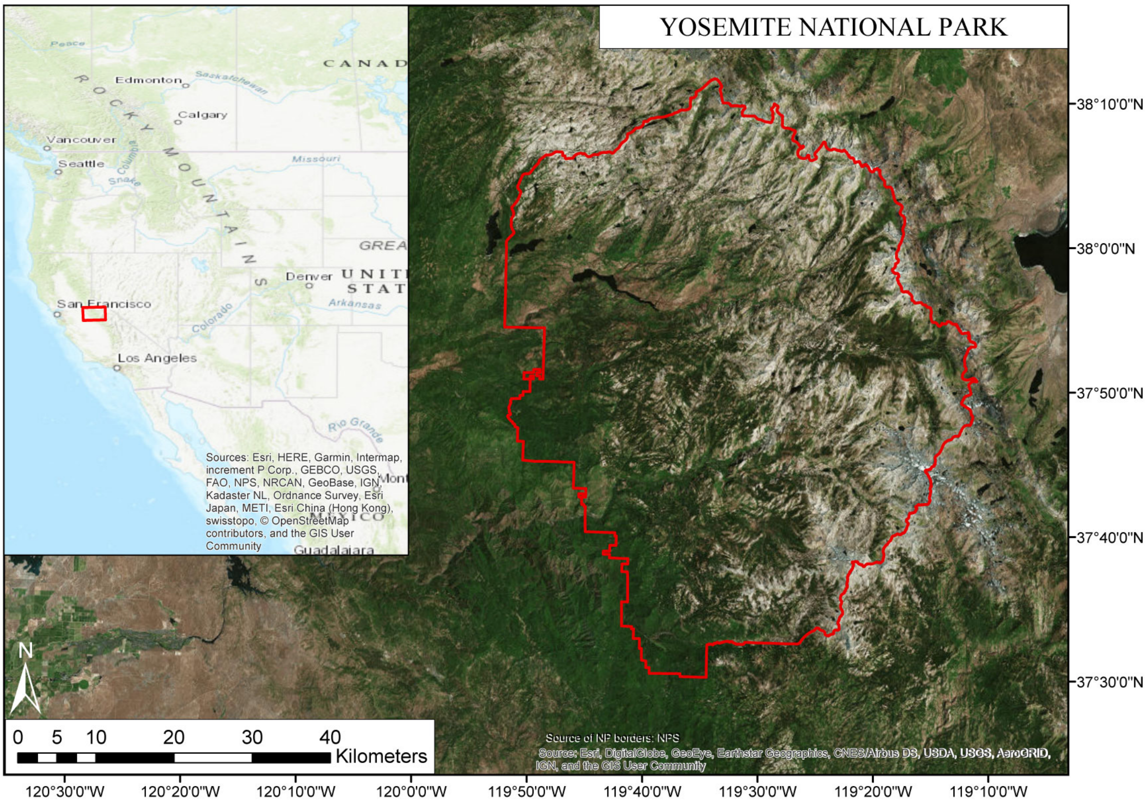


Figure 3: Yosemite National Park in California, United States

Topography, Vegetation and Wildlife

Generally, landscape in YNP has been formed by ancient glacial activity, carving deep valleys and abraded domes, such as Yosemite Valley (a U-shaped valley) and Half Dome, which have become iconic landmarks of this national park. Today, the only two small glaciers remaining are Lyell and Maclure in the eastern part of the park. Here, in close proximity to the ice, Mount Lyell (3.997 m), the highest point within park boundaries can be found. In terms of geology, the park is mostly dominated by massive granite, which, in steep areas, has been subject to repeated rockfall due to fracturing and weathering. Besides, famous vertical rock formations such as El Capitan, YNP feature a vast number of waterfalls including the 739 m tall Yosemite Falls. Furthermore, Merced River and Tuolumne River have their origin within park boundaries, the former flowing through Yosemite Valley and the latter continuing through the Hetch Hetchy Reservoir. (National Park Service, 2019f)

Concerning the climatic aspect, Yosemite can be said to have a Mediterranean climate, based on the Köppen-Geiger climate classification system, with a wet and dry season (Wuerthner, 1994, p. 8). Additionally, of course, the differences in elevation has a strong impact on local climate, with low valleys experiencing an average daily temperatures of 23°C in summer and getting as low as 5°C in winter, whereas higher plateaus may only reach a daily average of 12°C in summer, but drop all the way to -3°C in winter. In terms of precipitation, rainfall ranges between 5 mm to almost 170 mm per month. (National Park Service, 2019h)

YNP is home to more than 400 different species of animals. Mammals such as black bears, mountain lions, bighorn sheep, foxes and deer roam the area together with lizards, turtles, snakes as well as a high number of different bird species (National Park Service, 2019c). Concerning vegetation, the protected area features shrub communties, montane forests including giant sequoia groves and California black oaks, subalpine forests and meadows as well as alpine zones with increasing sparse vegetation (National Park Service, 2019g). Due to the strong droughts in summer, 'cool' natural forest fires have been a shaping force in YNP providing for ecosystem stability; however the long practice of fire suppression policies has led to the repeated occurrence of large scale high-intensity fires (Wuerthner, 1994, pp. 83–85).

(a) Yosemite Valley with El Capitan and Bridalway Fall (22.04.2016, personal archive).

(b) View from Yosemite Point, with Half Dome, Mount Starr King and the Clark Range (25.04.2016, personal archive).

Figure 4: Iconic landscape aspects of YNP

Visitation and Hiking

Over the course of time YNP has become a somewhat iconic entity in the realm of protected areas, leading to a constant increase in visitor numbers. In 2017, the park recorded a total of 4.336.890 visitors from January till December, whereas the ultimate high so far was reached in 2016 with 5.028.868 visits and since 1956 never dropped below 1 million visits per year (National Park Service, 2019i). On average, the summer months from June till September are by far the busiest, experiencing around 58 % of annual visits (National Park Service, 2017). For a seven-day pass, YNP charges an entrance fee of 20 $ per person for adults entering the park via non-commercial buses or on foot, and 35 $ per private vehicle (National Park Service, 2019d).

In general, hiking mostly centers around the Yosemite Valley area, including the trail up to Yosemite Falls. One of the most prominent hikes, however, is probably the cable secured path up to the top of Half Dome. Besides those, the Hetch Hetchy area, Glacier Point, Wawona and many other regions feature a variety of trail systems. (National Park Service, 2019e)

4.2 Torres del Paine National Park

Torres del Paine National Park (TdPNP), or Parque Nacional Torres del Paine, was established in 1959 and is situated within the Patagonia region in southern Chile. Politically, the protected area is located within the Magallanes and Chilean Antarctica Region, being one of Chile's administrative divisions. The park itself is managed by the National Forestry Corporation (Corperacion Nacional Forestal - CONAF) and has additionally been a UNESCO Biosphere Reserve since 1978 (Parque Nacional Torres del Paine, 2019a).

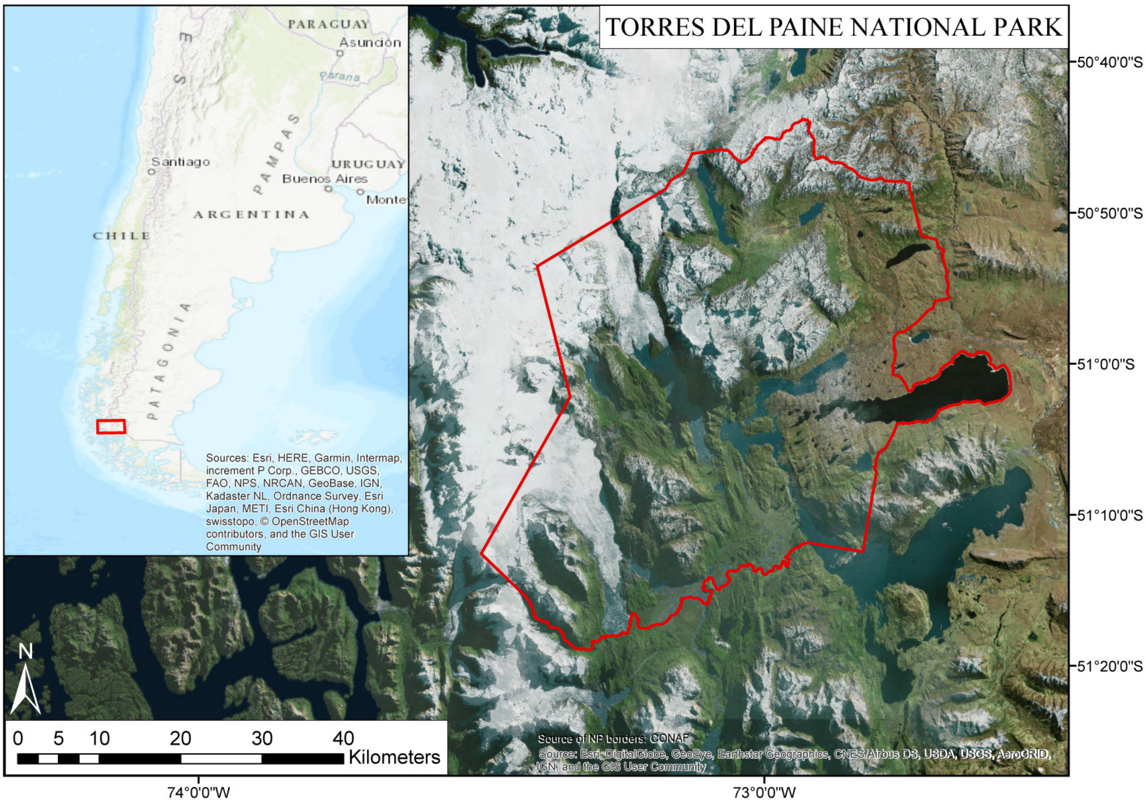


Figure 5: Torres del Paine National Park in the Magallanes Region, Chile

Topography, Vegetation and Wildlife

TdPNP is within a transitional zone between the Patagonian steppe to the east and the Southern Patagonian Ice field to the west, with numerous glaciers stretching into the park. The largest of those are Dickson Glacier, Grey Glacier and Tyndall Glacier, all of which have been receding in the last decades (Chinni, 2006, pp. 97–102). Additionally, the park holds a vast amount of lakes, though not all are completely within park boundaries, including Grey Lake, Sarmiento Lake, Del Toro Lake, Nordenskjöld Lake and Pehoé Lake. The most prominent attractions in the park are the Torres (towers) and Cuernos (horns), which are part of Cordillera Paine (Ruiz et at., 2019, p. 2). Those formations consist of granite and black shale, and were morphologically carved by glacial processes and weathering. The highest peak in TdPNP is Paine Grande, with an elevation of 2.884 m. In terms of climate, the park is situated within the temperate zone, being subject to rapidly changing local weather conditions, featuring strong winds and monthly precipitation ranging between 200-300 mm. Over the year, temperatures vary strongly ranging from a daily average of 16°C in summer to an average of 2°C in winter. (Farrell & Marion, 2001, pp. 37–38)

Within the protected area different plant communities can be observed, including steppe and thicket, home to shrubs and grasses, forest with coniferous and deciduous trees as well as sparely vegetated areas in higher altitudes (Vela-Ruiz Figueroa & Repetto-Giavelli, 2017, pp. 62–67). In terms of fauna, TdPNP features a variety of regional wildlife such as guanacos, pumas and foxes, as well as the endangered huemul (Vela-Ruiz Figueroa & Repetto-Giavelli, 2017, p. 99). Additionally, fish such as trout, to name but one, can be found within TdPNP. Furthermore, the park is also home to a large variety of birds, with presumably more than fifteen different raptor species including the Andean condor (Jaksic et at., 2002, p. 450).

(a) Torres del Paine (Torre Sur, Torre Central, Torre Norte)(22.02.2017, personal archive).

(b) View to the southwest, from the entrance of the Ascensio Valley (22.02.2017, personal archive).

Figure 6: Iconic landscape aspects of TdPNP

Visitation and Hiking

Within the year of 2017, Torres del Paine had a total number of 264.800 visitors (113.978 Chilean nationals and 150.822 foreigners), making it the most visited national park in Chile (Corporación Nacional Forestal, 2018, p. 3). Ten years earlier, in 2007, the park experienced half as many visitors (128.396) than it has today, though almost three quarters, 95.260 visitors, came from outside the country (Corporación Nacional Forestal, 2008, p. 3). However, as those numbers show, the share of Chilean citizens has strongly increased in the recent decade. In general, TdPNP charges entrance fees for visitation of the protected area. Yet, prices differ for local and foreign tourists, with Chilean adults paying 6.000 CH $, and international visitors being charged 21.000 CH $ for a multi-day pass in the high season (Parque Nacional Torres del Paine, 2019b).

TdPNP allows hiking besides other tourist activities within its park boundaries. Most prominent and frequently hiked is the Circuit Trail, also called 'O' Circuit, encircling the Cordillera Paine, on a 86 km footpath (Farrell & Marion, 2001, p. 38). However, this is probably more true for multi-day visitors. The second, very popular trail is the 'W' Circuit, leading into the valley of the Paine massif as well as to Grey Lake (Ruiz et al., 2019, p. 8). Both circuits are named after the letter they depict from a birds eye perspective.

4.3 Hohe Tauern National Park

The third study area, Hohe Tauern National Park (HTNP), is found in the central part of Austria, stretching over the states of Carinthia (Kärnten), Salzburg and Tyrol (Tirol). Due to the Austrian federal constitution, the responsibility of nature protection lies with the individual states. Whenever there is a large project in cooperation with the federal government, such as the designation of a national park, a contract between states and federation needs to be made based on the article 15a of the Bundesverfassungsgesetz (B-VG); determining the framework for the desired protected area. This was also done for the HTNP, resulting in an agreement between the three states, where specifications can be found in the Federal Law Gazette: BGBl. Nr. 570/1994. (Nationalparks Austria, 2019b)

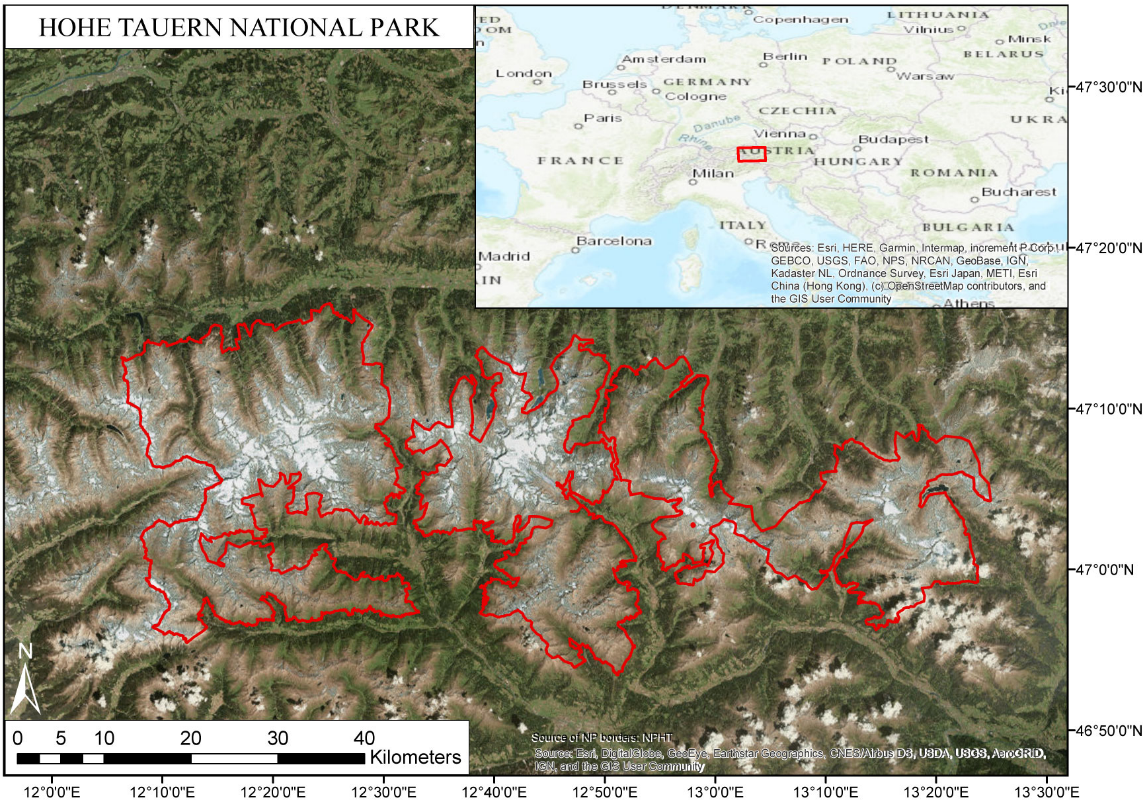


Figure 7: Hohe Tauern National Park in Carinthia, Salzburg and Tyrol, Austria

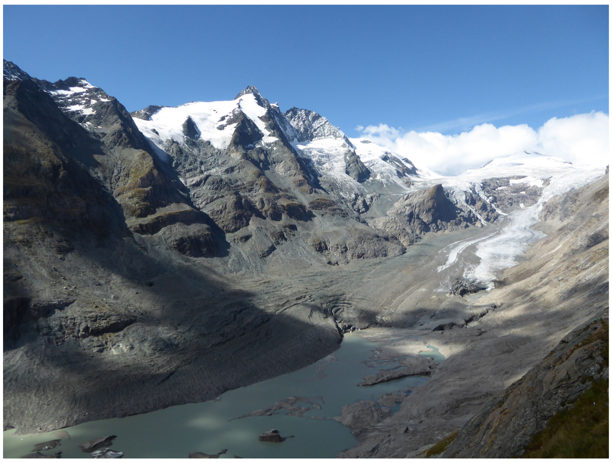
However, what is important mentioning here is the fact that the entire HTNP is divided into two zones; a core zone and an outer zone. Whereas the first zone, with a few exceptions, strictly prohibits any intrusion into natural environment, the outer zone constitutes a transitional sphere to areas of permanent settlement, protecting historically shaped cultural landscape. Yet, also within the exterior zone the construction of technical infrastructure, such as cable cars or hydroelectric plants, is forbidden. Each state has a share on both zones. (Rupitsch et al., 2019, pp. 6–7)

Topography, Vegetation and Wildlife

HTNP is the largest national park within the Alps, holding more than 300 peaks with an elevation above 3.000 m; including Austria's highest mountain: Großglockner (3.798 m). Furthermore, there are around 340 glaciers spreading over an area of 170 km^2. The most important, and historically best documented glacier is by far Pasterze (16 km^2), being also a major attraction for national and international visitors (Nationalpark Hohe Tauern, 2019b). Generally, the last glaciation and consequential glacial and periglacial processes can be defined as the main shaping forces responsible for the contemporary morphology of the Hohe Tauern region (Lichtenberger, 2002, p. 102). Partly resulting from the runoff of persistent glaciers, numerous streams, lakes and waterfalls can be found in HTNP; here the Krimmler Waterfalls, with a hight of 380 m should be pointed out as another popular site (Nationalpark Hohe Tauern, 2019b). (Nationalpark Hohe Tauern, 2019a)

Generally, HTNP can be said to be in a continental climate without a dry season, in terms of the Köppen-Geiger classification. This so called alpine climate is characterized by a monthly precipitation ranging from 50 mm to 200 mm, with a higher rainfall on the northern slopes. Annual temperatures are again highly dependent on altitude, where areas close to peaks, for example Sonnblick, reach an annual maximum of around 3°C and a winter low of -12°C while relatively lower areas tend to be slightly warmer in both seasons. (Lichtenberger, 2002, pp. 109–112)

In terms of flora and fauna, the official website mentions around 15.000 distinctive animal species and 3.500 different plants, found within park boundaries (Nationalpark Hohe Tauern, 2019a). The most prominent, and largest animals in HTNP are ibex, chamois, marmot, golden eagle, bearded vulture, despite numerous other, smaller vertebrates and invertebrates roam the area (Nationalpark Hohe Tauern, 2019e). In terms of vegetation, plant communities can be strongly connected to attitudinal belts. While the montane zone features mixed and forest, the subalpine level shows arolla pines, larches and shrubs before giving way to meadows and grassland in the alpine zone, with the final, nival level showing almost no vegetation except for lichens and few endemic herbs (Nationalpark Hohe Tauern, 2019c).



(a) View from the Kaiser-Franz-Josefs-Höhe towards Großglockner and Pasterze (10.09.2018, Gerhard Lieb).

(b) Dorfer valley with Muntanitz mountain (13.07.2017, Gerhard Lieb).

Figure 8: Iconic landscape aspects of HTNP

Visitation and Hiking

Compared to the other protected areas introduced, HTNP does not charge any entrance fee for a visit of the park, making it also hard to present a concrete statistic on visitors. Nevertheless, in 2018 the annual review of the national park mentions that 418.021 people have made use of visitor centers (Rupitsch et al., 2019, p. 37). In total, the number of annual visitors in all three sections of the park is estimated to be around 5.000.000 people (Nationalparks Austria, 2019a).

HTNP features a high number of themed and educational hikes, including signposted paths in close proximity to glaciers, waterfalls and streams, animal habitats, sites of historical relevance and others (Nationalpark Hohe Tauern, 2019d). The alpine infrastructure including hiking trails, however, is maintained by various organizations including the Austrian Alpine Association (ÖAV - Österreichischer Alpenverein), Naturfreunde, German Alpine Association (DAV - Deutscher Alpenverein) and others (Rupitsch et al., 2019, p. 48). This represents an execution of management tasks by non-governmental institutions, mentioned under governance types in Chapter 2, which, in this case, have been taking care of hiking trail construction and maintenance long before the establishment of the park.

5 | Methods

Resulting from the complexity and multidimensionality of human-nature relations in mountain national parks, it is almost impossible to consider all potential variables for an analysis on multiple areas of interest. Consequently, it was deemed important to focus on specific aspects within those protected areas, which can also be expressed through standardized parameters, allowing for a transregional comparison of study sites. For the reason that this investigation strongly focuses on the national park idea of protecting nature while providing for tourism, the analysis will focus on one particular manifestation of such a recreational purpose: hiking; constituting the number one recreational activity in mountain regions (Section 3.4).

For this matter, the use of GIS (geographic information systems) appeared to be most fitting in this context as it would allow for a spatial, multi-level analysis of hiking trails in connection with environmental features such as vegetation and landscape. In general, GIS and remote sensing have become widely used techniques when it comes to the analysis and representation of human-environmental relationships (Moseley, 2014, p. 10). As acknowledged by Gebhardt et al. (2011, p. 209), the use of GIS should produce relatively objective and reproducible results based on mathematical methods, which can later also be brought together with qualitative data in a comprehensive synthesis. Furthermore, GIS approaches have proven to be especially promising when it comes to large scale evaluations of recreational trails and areas, where a consecutive direct assessment appears to be infeasible; eventually supporting planning and management of trails (Hammitt et al., 2015, p. 147).

This chapter will deal with the specifics of the GIS approach used for the intended analysis. The first part will outline the overall rational, before talking about the actual sources and acquisition of data for sequential processing steps. Concerning the data itself, one central aspect of great significance was the availability of open data, as there was no financial budget available for this research. This, however, should not be perceived as a limitation, but rather as an aspect of high reproducibility and validity of results, as will become clear in the subsequent sections.

5.1 Considerations and Workflow

Before starting with actually obtaining datasets and working on an analysis, considerations had to be made in order to clarify opportunities and limitations in terms of data, software and workflow. Due to the focus on a spatial and quantitative comparison of hiking trails as well as an evaluation of potential sensitivity, two overall output categories were aimed to be generated for this study:

- First, the relative distribution of hiking trails based on natural geographic features and factors, in comparison to the share of the factor-specific area within each national park. This includes topographic, biological and pedological aspects.
- Second, a multi-criteria map showing the degree of potential ecological sensitivity of hiking within each national park, with an additional distribution of hiking trails on these areas.

Those analyses should not only provide information on the individual touristic hiking layout, but also shed light on the differences between all three sites. In order to attain this knowledge, three things needed to be considered: the choice of specific environmental factors which should be taken into consideration for the analyses, the choice of data which could best represent those factors across study areas and the choice of processing steps available to compute meaningful results. Of course, all three aspects are strongly intertwined with one another, as the choice of features, for instance, relies on the availability and processability of data. For the reason that field measurements were not an option due to the global spread and size of study areas, the research had to rely on existing primary datasets. Therefore, evaluating and obtaining data played a crucial role in the overall process, in order to guarantee comparability. This, however, will be discussed in more detail in Section 5.2. Hence, we will now turn to the issue of choosing the natural geographic features for this study.

As already mentioned in Chapter 4, regardless of its definition, nature is an extremely copious compound of individual elements, and therefore difficult to represent within a generalized model. However, there are a number of natural geographic factors which appear to be more directly relateable to hiking than others, including topographic, biological and pedological aspects. Here, slope, vegetation and soil can be considered particularly important, as they can indicate both, the hikability of an area but also the potential impact caused by hikers (Ólafsdóttir & Runnström, 2009, p. 30). To put it another way, steepness, soil composition, land cover and biological factors along trails are effecting erosion, sensitivity to trampling and habitat disturbance, while also indicating potential accessibility of an area. Concerning the characterization of ecosystems, Petorelli et at. (2016, p. 244) note, that a variety of parameters can be derived from satellite data including information on topographic features, vegetation indices and land cover data. While it is possible to directly derive topographic features from terrestrial laser scanning (TLS) data, information on flora and fauna appears to be less explicit and needs to be represented in other ways.

Despite a theoretical approach would imply the first-hand evaluation of all system relevant biological features, such a research seems to be virtually impossible, especially due to the large scope and distribution of investigated areas. As a matter of fact, estimates on diversity, made through the interpretation of indicators, have to be deemed as sufficient, where the categorization of ecosystem entities based on landscape features appears to be a good alternative for large scale evaluations (Lévêque & Mounolou, 2003, pp. 26–27). One approach for the observation of diversity can be found in the measurement of abundances, with numbers of individuals being the most explicit method, while data of land cover or biomass also appear suitable (Tuomisto, 2018, p. 296). In other words, indicators such as a vegetation index and land cover data gained from satellite images are a good means to evaluate ecological aspects. Additionally, abiotic variables derived from topographic data, such as slope, aspect and elevation, can be of great interest when trying to model species distributions in alpine regions with spatial data (Raes & Aguirre-Gutiérrez, 2018, p. 311). Though habitat modelling is not a goal for this research, those indicators might give an insight on hikers proximity to potential habitats.

Another aspect difficult to evaluate, due to the lack of standardized comprehensive field measurements in all areas, is the potential erosion of soil. Yet, once more, data produced from

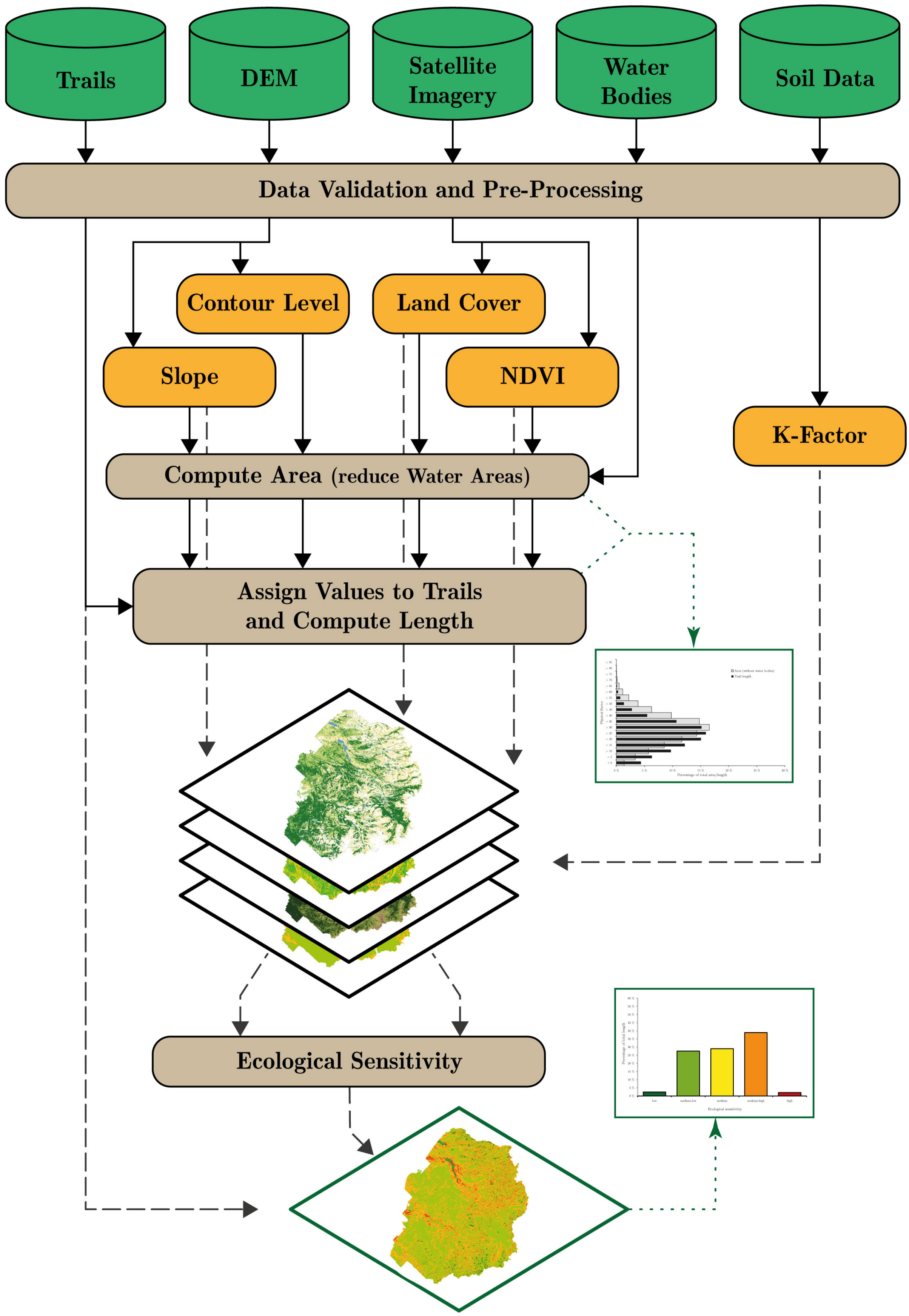


Figure 9: General overview on the overall workflow (own design).

remote sensing imagery can provide a good opportunity to integrate pedological features into the analysis, which will eventually support a more holistic understanding of the regional ecology. Ultimately, the present research makes use of the following parameters derived from different datasets: slope, elevation, NDVI, land cover and soil erodibility (K-factor). Details on the generation and usability of those features can be found in the subsequent sections. Figure 9 presents an overview on the overall workflow. This again highlights the potential for using GIS in this matter, as it gives the opportunity to systematically generate and process information for multiple areas of interest.

The GIS software used for all consequential processing steps outlined in this study were ArcGIS Desktop 10.5.1 (ESRI, 2017) and ERDAS IMAGINE 2018 (ERDAS, 2018). The main reason for choosing those products was their large set of processing, analysis and mapping tools as well as their compatibility with various data formats. Additionally, the use of compact geodatabases and feature classes in ESRI software was considered a better option compared to working with individual shapefiles. Furthermore, ArcGIS allowed for the use of Python scripts in order to improve processing and standardize procedures. This was important as initially produced scripts could be used for all study sites, reducing the chance of manual step-by-step caused errors. When working with GIS, it is always important to consider an appropriate projection for dealing with the spatial data at hand. For this purpose, I decided on using individual site appropriate zones of the WGS 1984 UTM conformal projection. In more detail, the zones 11N, 18S and 33N were used for Yosemite, Torres del Paine and Hohe Tauern. The main reason for choosing UTM over local projections was the equal geodetic datum in all regions allowing direct comparison.

5.2 Obtaining and Preparing Data

As stated above, the data acquisition was limited to globally available open data, being also free for further processing and adaptation. While open government data (OGD) might suggest the highest reliability in terms of accuracy and standardization, other sources should not be neglected, as publicly acquired data might sometimes even be more comprehensive and detailed. For the reason that it was not possible to validate attributes in the field, the selection of data needed to meet a balance between global standardization and areal coverage. Nevertheless, experiences gained from past visits to the study sites as well as the use of aerial photographs helped to check for data validity and choose the most representative datasets. Overall, it was considered very important for this research to use similar datasets for all investigated areas, as much as possible, since this would guarantee comparability and consequential significance of the results. Table 2 shows an overview of the used data as well as their origin.

5.2.1 Trails and Hiking Paths

For the matter of comparability between the different study sites, a globally available and standardized dataset on hiking trails was needed. As there is no free OGD available for all researched areas at this point there were three options left for acquiring the necessary data. The

Table 2: Metadata on the obtained input datasets

Dataset name	Description	Data type	Resolution	Data source
Trails	Hiking trails	Vector	-	NPS, CONAF, NPHT, SAGIS, OSM
ALOS	DEM	Raster	12,5 x 12,5 m	ASF
LiDAR	DEM	Raster	10 x 10 m	Open Data Österreich
Sentinel	Multispectral satellite images	Raster	10 x 10 m	ESA
SoilGrids	Clay, silt and sand fractions	Raster	250 x 250 m	ISRIC
Water bodies	Larger bodies of water (e.g. lakes, reservoirs)	Vector	-	OSM
NP boundaries	Official national park borders	Vector	-	NPS, CONAF, HTNP

first option, and also the most favourable one, was to obtain an official hiking trail geodataset from each individual national park authority. A second possibility was the manual digitalisation of trails, in the form of polyline features in a GIS, with the help of georeferenced, study site specific hiking maps in combination with aerial imagery data. Finally, another option was to acquire the data from a globally available network, such as Open Street Map (OSM), by extracting reduced datasets from their publicly accessible download servers.

Though all three options seemed feasible, inquiring official data was considered most appropriate. For YNP and TdPNP, it was possible to obtain trail networks from management authorities. Whereas the former was available through the open data portal of the NPS (https://public-nps.opendata.arcgis.com/), the latter could be acquired from CONAF for academic purposes via an official request. Both datasets were reviewed and reduced to contain hiking trails only, based on the attributes given for the individual pathways. To be more precise, restricted administrative trails, roads, biking tracks, specific bridlepaths and others were excluded from the data.

Concerning HTNP, on the other hand, it was impossible to obtain a complete trail dataset for the entire protected area from one source. Regarding the Tyrolean section of the park, an official hiking trail GeoPackage was acquired from the responsible department. Additionally, an agreement with the SAGIS (Salzburger Geographisches Informationssystem) department of the Land Salzburg could be reached, in order to use available data on rural pathways and long-distance hiking trails for scientific purposes. Finally, another set of long-distance trails stretching over the entire park was given by the Carinthian administration. Despite having those datasets at hand, numerous areas in the Salzburg and Carinthia part of the park where still missing any data. Accordingly, this data needed to be acquired otherwise.

The first alternative would be the digitalization of an official hiking map published by the National Park Hohe Tauern. However, when georeferencing scanned hiking maps or digital available image-files, it can be hard to achieve the desired accuracy. First, scanning documents is always connected with a reduction in quality and potential distortion of an image. Second, the accuracy of the digitalization does highly depend on the scale and format of the trail map and resulting raster image, limiting them to a certain level of spatial detail. Finally, maps are always subject to generalization, resulting in an omission of data. All those aspects would influence further processing, which would ultimately have an effect on the final results.

Therefore, the use of OSM data, which would have to be examined and corrected with the help of official Austrian topographic maps, was considered the best option to fill the gaps. Today, OSM data is available for almost all regions of the world, with an increasing tendency in detail and coverage. So called 'Contributors', members of the OSM community, edit, adapt and verify data by drawing on GPS devices, field maps, aerial imagery and local knowledge, in order to keep the dataset as accurate as possible (OpenStreetMap, 2019). Therefore, OSM can be seen as a self-sustaining system of geographical data for the public, operated by the public. To a certain extent, users and creators are the same people, giving additional reason for keeping the accuracy level high.

Despite the fact that there are numerous ways to obtain data from OSM, they are mostly available based on their sheer spatial extent, including all different geoobjects and features within the defined area. Therefore, extracted datasets often contain a bulk of elements which appear to be unnecessary for the users interest. In order to avoid this for the acquisition of relevant data, a Python script for ArcGIS was written in order to download and process data from OSM restricted to the polylines of interest. This was accomplished with the help of the Overpass API, allowing to extract individual sets of features from the OSM dataset by sending specifically designed queries to the server. To be more precise the tags 'highway=path', 'highway=footway', and 'highway=track' were used to acquire the desired data. These tags were selected based on the standards and descriptions defined for those features by the OSM community. In order to reduce the bulk of information within OSM data, the Python script included a processing of fields and attributes to secure a less dense data output.

At this point all data for HTNP were reviewed and brought together in one dataset, with OSM data helping to fill the blank spots. For the reason that certain trails were overlapping, a high-resolution imagery basemap and official topographic map was used to select the most appropriate feature. It is noteworthy though, that, when comparing official trails with OSM paths, the latter appeared to largely match the official pathways, leading to the conclusion that OSM data on trails should not be underestimated in this context. Nevertheless, whenever at hand, official data should be given priority. Figure 10 shows the different sources for the constructed trail network of HTNP.

Last it is important to point out that trails within a study area did not necessarily have to be connected or joined, as this research did not draw on a network analysis, but rather on the distribution of hiking trails in general. Consequently, it might be the case that certain trails are found to be loose, detached polylines as they might normally be connected to a road or close to the park border. For the reason that road networks or bikeways are not subject of this investigation, they are intentionally excluded.

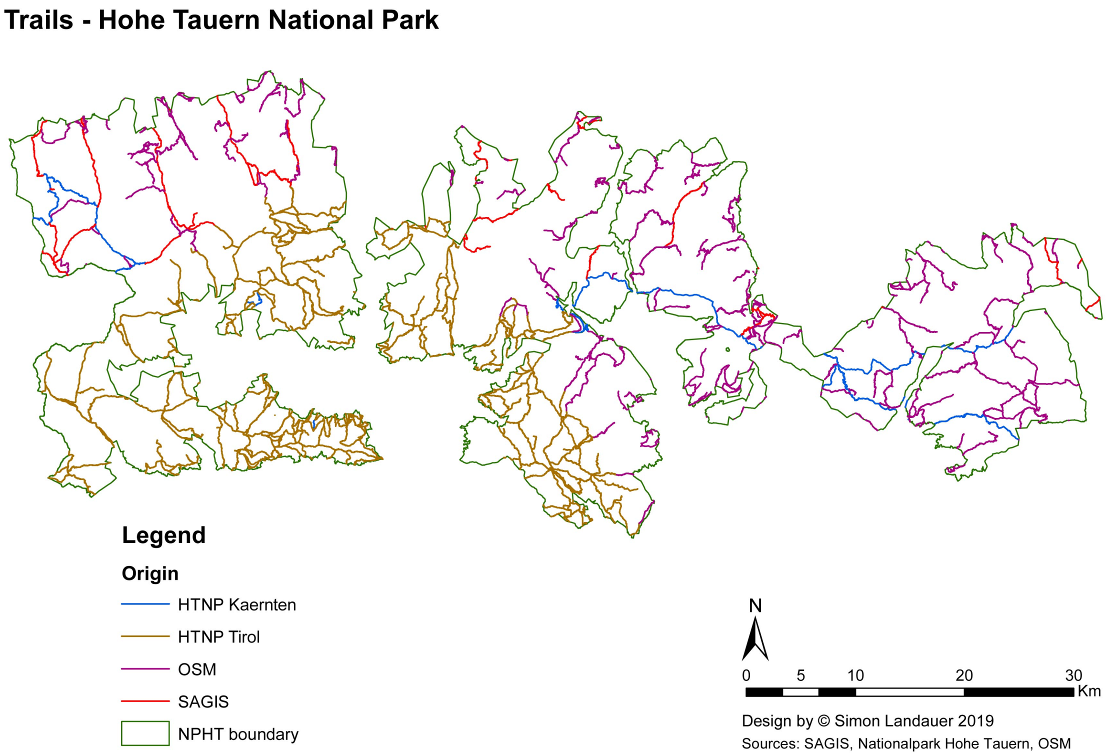


Figure 10: Origin of trail data for the National Park Hohe Tauern

5.2.2 Digital Elevation Model (DEM)

In the first phase of research, when searching for an appropriate globally available digital elevation model (DEM), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and SRTM (Shuttle Radar Topography Mission) datasets, available through the USGS Earth Explorer, where considered to be the most promising DEMs; providing a geometric resolution of 30 m. However, when first reviewing the datasets, both appeared to show inaccuracies in high elevation areas in the study regions of TdPNP as well as HTNP. Therefore, another publicly available DEM needed to be taken into account.

Within a second phase of research, data from ALOS (Advanced Land Observing Satellite) appeared to be very promising in terms of higher spatial resolution as well as global coverage. Operated by the Japan Aerospace Exploration Agency (JAXA) from 2006 until 2011, the Advanced Land Observing Satellite (ALOS), also refereed to as DAICHI, was a mapping and land cover observation satellite which was equipped with tree sensors (PRISM for measuring land elevation, AVNIR-2 for visible and near infrared and PALSAR for all-weather, day and night land observation), all able to map on a scale of 1:25.000 (JAXA, 2019a). This scale equals a potential spatial resolution of around 12,5 meters, when using the cartographic rule defined by Tobler (1987, pp. 13–14), defining the relationship between scale and resolution, where the spatial resolution of the raster equals the denominator of the map scale divided by 2.000.

In order to handle and distribute the immense data volume of global ALOS data, JAXA established the ALOS Data Node (ADN) concept where the management of data is outsourced to archives of other agencies including ESA, ASF, NOAA and Geoscience Australia (JAXA, 2019b). For the reason that ASF (Alaska Satellite Facility) is responsible for ALOS products on the Americas, site specific DEM for Torres del Paine and Yosemite needed to be retrieved from their data portal Vertex at https://vertex.daac.asf.alaska.edu/. Within their range of products, ASF provides a high-resolution, radiometrically terrain-corrected (RTC) GeoTIFF with a 12,5 m spatial resolution, derived from ALOS PALSAR data (ASF, 2019). Those DEM not only appeared to be gapless, but would also improve the quality of final output products due to their spatial resolution.

Unfortunately, those processed DEM are not available for the Hohe Tauern region. After contacting ESA, as the local Data Node for Europe, and getting permission to ALOS datasets for Austria, I had to realize that all retrievable data were raw, unprocessed images. As it would have been too inefficient to develop a model for the processing of a DEM, a different solution for the Hohe Tauern area had to be found. In order to compensate for the missing data, a LiDAR dataset from 2015 with a spatial resolution of 10 m covering all of Austria was retrieved from Open Data Österreich (data.gv.at), with geoland.at being the official publisher. In order to provide for comparability between all study areas, the LiDAR data from Austria was downscaled, by resampling the 10 m raster to a 12,5 m raster file using the Resample function in ArcGIS, based on the technique of cubic convolution.

5.2.3 Satellite Imagery

For the derivation of satellite imagery products, including the NDVI index, Sentinel-2 data from the European Space Agency (ESA) Copernicus Program were obtained. The Sentinel-2 mission uses two, 180° phased, polar-orbiting satellites (S2A and S2B) to reach a temporal resolution in cloud-free conditions of 5 days at the equator (ESA, 2019a). The major reasons for choosing this datasets were its spatial and spectral resolution as well as the global coverage. In contrast to Landsat 8, Sentinel-2 has a spatial resolution of 10 m within the range of the visible light (VL: bands 2,3 and 4) as well as the near infrared (NIR: band 8) (ESA, 2019b). The data itself was retrieved, free of charge, from the Copernicus Open Access Hub, which can be found at https://scihub.copernicus.eu/dhus/#/home.

During the initial acquisition phase, acquiring a relatively cloud-free image for the Patagonian region turned out to be extremely difficult; probably because of the unique regional climatic conditions along the ice field. Despite checking with other sensors or trying to find an appropriate method for cloud removal, this issue appeared to be omnipresent. As a consequence, it became clear that it would be impossible to calculate a mean annual NDVI for this area. Therefore, the best solution was to take one scene from the summertime in which park visitation as well as vegetation cover are likely at their maximum. As already mentioned in Chapter 3), this was also acknowledged by Geneletti and Dawa (2009, p. 229), stating that summer time constitutes not only the peak season for human, but also natural activity in mountain regions. Additionally, snow cover usually appears to reach its minimum in (late) summer, providing the best time for vegetation studies and land cover classification (Paracchini & Folving, 1994, p. 65). This became obvious when comparing images for the European Alps from May/June and August/September;

with the latter containing less areas of snow while still showing fertile vegetation.

Table 3: Metadata on used Sentinel-2 scenes

Study area	Title Number	Sensing date	Cloud Cover (in %)	Satellite	Relative Orbit
Hohe Tauern	T32TQT	2018-09-26	5,41	S2A	22
Hohe Tauern	T33TUN	2018-09-26	1,37	S2A	22
Torres del Paine	T18FXJ	2017-02-22	12,47	S2A	10
Yosemite	T11SKB	2018-08-20	0,20	S2A	70
Yosemite	T11SKC	2018-08-20	1,64	S2A	70

In order to secure comparability, and for the reason that the other selected mountain areas were also facing some troubles with cloud cover, the decision was made to take only one representative sensing date for each study region. This, of course, needs to be taken into consideration for the later interpretation of the results. Details on the exact images chosen for the study areas can be found in Table 3. From those images, subsets were generated and all scenes were preprocessed in ERDAS Imagine 2018. When creating mosaics from the acquired images, the Feather function was used for dealing with overlay sections.

5.2.4 Soil Data

The desired calculation of potential soil erodibility for the individual study sites required data on soil properties. In this regard, the SoilGrids system, providing automatically generated soil maps of the world based on machine learning appeared to be the best option. This dataset, operated by ISRIC (International Soil Reference and Information Centre) World Soil Information, offers raster layers of 250 m geometric resolution on various soil properties, for example soil pH and cation-exchange capacity, at seven different depths ranging from 0 cm to 200 cm (Hengl et al., 2017, pp. 1–3). For this research, only the data on clay, silt and sand content (in %) at 0 cm, 5 cm and 15 cm was being requested, whereas the three depths were used to later calculate mean values for each raster cell. The data was retrieved in GeoTiff format from the database http://soilgrids.org, generally available under the Open DataBase License (ISRIC - World Soil Information, 2019).

Besides its wide scientific use, further information on the assessment of accuracy and validity of the SoilGrids250m can be found in a detailed study proposed by Hengl et al. (2017). In this regard, there are two things which need to be acknowledged. First, the model used for the computation of this global dataset is based on soil profile data from over 150.000 sites and soil covariates derived from remote sensing data (Hengl et al., 2017, pp. 6–8). While allowing for global coverage, a certain standardization and generalization was necessary in order to improve predictability by overcoming gaps in the soil profile data. This leads to the second noteworthy aspect, namely the small number of samples in certain areas. Aside from arid to semi-arid regions, this also includes strongly inaccessible areas such as mountain tops and extremely steep slopes (Hengl et al., 2017, p. 7). However, at present, this is still the most promising dataset available in terms of coverage and accuracy.

5.2.5 Water Bodies

Last but not least, areal bodies of water, including lakes, ponds and reservoirs, had to be acquired for the later quantification of area. For the reason that such bodies of water are insignificant for an analysis on hiking trails, as they are neither walkable nor crossable, they have to be reduced from the potentially accessible area. For this purpose, the OSM data on those features appeared to be sufficient, especially as those polygons would only be used as subtraction features for the total area computation of the protected areas, where small inconsistencies in accuracy would be insignificant. Therefore, another Python script was created in order to specifically request data on water bodies from the OSM server and pre-process them, before implementing those datasets in later calculation processes.

5.3 Analyses

With the necessary preprocessed data at hand it was possible to conduct further analyses for the generation of the desired output. While providing an overview on the individual procedures, this section should also point out why certain processing methods and indices were chosen over others, and what opportunities or limitations might be induced by their use. In order to limit the extent of research, all data were of course clipped to the areas of interest. The results of the processing steps for each individual natural geographic feature, except for soil erodibility, were eventually represented in a bar chart contrasting overall area and trail length within each park.

5.3.1 Slope

Being well aware of the fact that there is a difference between terrain slope and slope of a trail, there is a reason for choosing one over the other. Petrášová et al. (2018, pp. 135–136) acknowledge this by saying that planners and ecologists might focus on the slope of the terrain, while hikers show a stronger interest in the actual steepness in trail direction. Within this study, the steepness of terrain was chosen over the directional slope for two major reason. First, when thinking about aspects of environmental degradation such as erosion, for example, the steepest slope appears to be of great importance. Additionally, while many trails might show serpentine paths within steep sections, the gradient of the terrain still has to be overcome in the long run. Furthermore, major erosive processes are more likely to take place in the direction of the steepest slope. Second, the distribution of trail steepness might only be comparable to the overall classified slope area within a region in case terrain is used as the basis for computation. In other words, choosing two different approaches would not allow to plot area and pathways against each other.

The slope angles, or gradient, of the terrain within the study areas were calculated in ArcGIS based on the obtained DEM. In terms of measurement units for the resulting slope

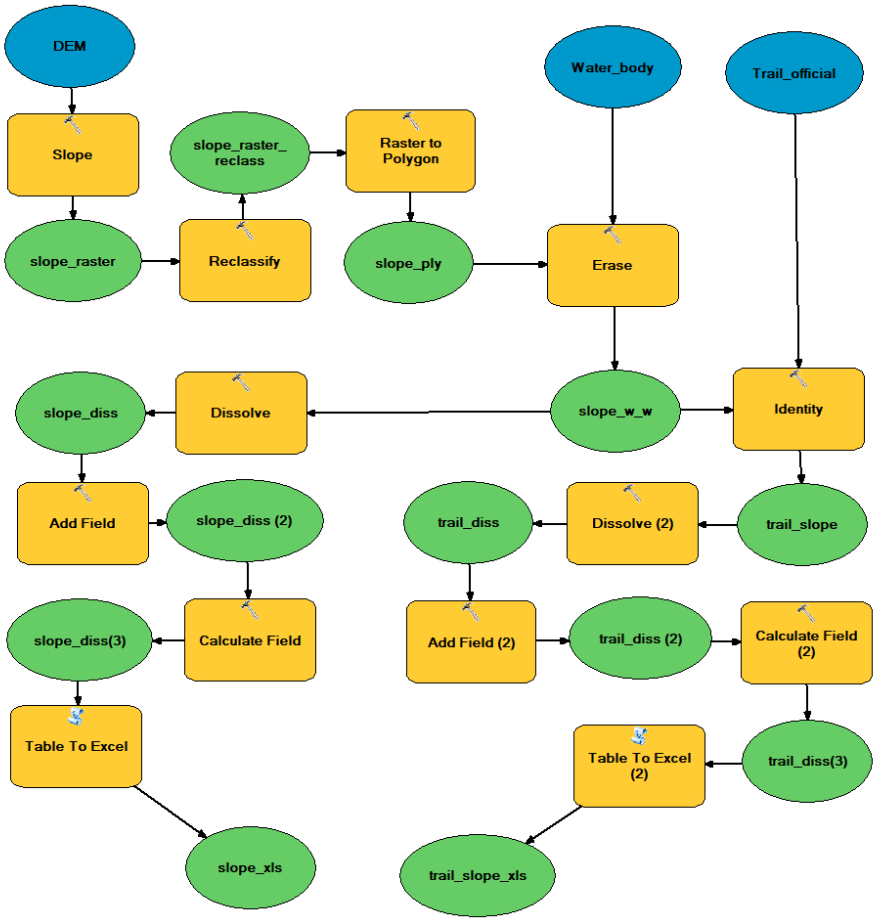


Figure 11: Spatial model of used Python script for slope analysis.

raster, degrees were chosen over percentage due to their more frequent use in scientific contexts. This data was later reclassified, vectorized, reduced by water bodies, calculated in terms of area and eventually transferred to hiking trail segments with the help of an identity tool. This procedure was written in a Python script, which could be used for all three study sites. For illustrative purposes the steps were graphically put into a spatial model which can be seen in Figure 11. For the classification of the slope data, equal intervals of 5 degrees were considered appropriate in terms of comparability and overview.

5.3.2 Elevation

Despite altitude differs strongly inbetween all study areas and can therefore not compared directly, the interregional distribution in contrast to hiking trails was still considered an interesting aspect. Especially as this might give insight into tourists peak accessibility in the investigated mountain national parks. Consequently, the relative height within the protected areas should be the focus when interpreting the results, rather than the effective elevation above sea level.

In order to transfer the information from the DEM to the hiking trails and calculate the area, the classification of the height information into contour levels was necessary. First of, contour lines with an equidistance of 100 meters were generated from the DEM. Based on those closed lines, polygons could be generated, which cover the area between two consecutive isohypses. On the one hand, this vectorization was necessary to ascribe values to trail segments; on the other hand, division into 100 m steps allows for a better classification and visualization of altitude distribution. Finally, area and length of trails could be calculated after dissolving individual segments into compounds of equal value. Again, the sequence of all processes had been automated through the use of a Python script drawing on various tools for spatial analysis.

5.3.3 NDVI

Over the course of time, the NDVI (normalized difference vegetation index) has become a very popular, and easily applicable remote sensing index for environmental modeling. The rational behind the NDVI is that green leaves of plants strongly reflect incoming solar radiation in the near-infrared range (NIR) of the electromagnetic spectrum (around 0.7 µm to 1.1 µm), while highly absorbing visible light in the red range (RED). Those reflectance characteristics can be related to the chlorophyll concentration in leaves, giving information on plants' photosynthetic capacity, which is often related to health condition. Consequently, the NDVI expresses a ratio, being calculated by using the equation Eq. 1, where NIR and RED represent the reflectance in the respective ranges sensed by the corresponding bands of a multispectral sensor. Following, the range of possible values reaches from -1 to 1, with negative values representing unvegetated areas. (Yengoh et al., 2015, pp. 10–11)

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

This multispectral imagery based vegetation index is considered an indirect approach on environmental assessment, in contrast to direct detection of individual species via high spatial resolution images (Turner et al., 2003, pp. 309–311). In recent years, numerous studies have shown that NDVI can not only be an important index when it comes to vegetation, but can also help predicting wildlife. This derives from the idea, that primary production of plants not only effects herbivores but consequently the whole food web, including non-herbivore species, making NDVI a strong tool for the prediction of species richness and distribution (Pettorelli et al., 2011, p. 19). Basille et al. (2009, p. 687), for example, showed that areas with high plant productivity, measured by NDVI, constitute a preferable habitat for lynx populations in southern Norway. Furthermore, another study found a strong relationship between NDVI, in terms of ecosystem functioning, and brown bear habitat quality in the Cantabrian Mountains, Spain (Wiegand et al., 2008, pp. 100–101). This, however, does not only relate to mammals but also other animal species. Koh et al. (2006, pp. 549–550) discovered that NDVI appears to be the best predictor in terms of bird species richness, as those two variables showed a strong positive correlation.

Additionally, when researching the relationship between plant richness and satellite-derived indices in mountain areas, Levin et al. found a strong positive correlation between NDVI and the variation in plant species, which had been sampled during field trips. This result was found to be true for all tested sensors (Landsat, Aster and QuickBird), spatial resolutions and dates of sensing. Overall, up to 87 % of the species richness could be explained by NDVI, making this index an extremely promising tool for evaluating ecosystem productivity. The main reason for this relationship can be found in primary productivity, leading to a positive correlation between richness of species and energy. (Levin et al., 2007, pp. 697–699)

A Study on alpine environment in Glacier National Park showed that plant productivity, measured by NDVI, highly depends on local topography, mainly slope and elevation, with different degrees of explanation depending on the spatial scale of the data. When using geometric resolutions around 30 m, lower NDVI values can be expected at an increasing degree of slope. Such a lower plant productivity can be the result of disturbances such as debris flows or avalanches, occurring at a higher rate along steeper slopes. This again can be related to land cover, with barren ground, in juxtaposition to meadows and forests, being mostly found in steep areas. In terms of elevation, the use of higher spatial resolutions around 300 m appeared to have a stronger explanatory value when it comes to plant productivity. (Walsh et al., 1997, pp. 49–51)

For protected areas in mountain regions, satellite imagery based environmental analyses make it possible to research large and often inaccessible areas with a relatively easy short-term repeatability (Levin et al., 2007, pp. 700–701). The characterization and monitoring of ecosystem functioning, through NDVI trends and dynamics, can then be used to deduce management measures within national parks; helping to implement non-static policies and actions (Alcaraz-Segura et al., 2009, pp. 42–45). Despite the fact that NDVI can provide significant information for the assessment of biodiversity, it is again important to acknowledge certain limitations depending on spatial and temporal resolutions as well as its application in extremely arid areas (Pettorelli et al., 2011, p. 23).

The NDVI for this study was calculated from the respective satellite images in ERDAS IMAGINE, before the data was further processed in ArcGIS Desktop. Similar to the slope analysis, an equivalent workflow was used for processing and calculating classified NDVI areas and trail lengths. Again a Python script was used, following similar steps as displayed in Figure 11. In terms of reclassification of the original data, equidistant classes, with a span of 0,1 were chosen for all values above 0. As all values smaller or equal to 0 represent completely unvegetated areas, those values were grouped within one class ranging from 0 to -1. Again, larger water bodies are not included in the output, and were therefore erased from the derived polygons before transferring the attributes to the hiking trails.

5.3.4 Land Cover

In order to gain information on the land cover within the investigated national parks, a classification of the selected satellite imagery needed to be conducted. As it allows for more control, a pixel based, supervised classification was chosen. This approach demands the initial definition of training sites, providing the spectral signatures by which all cells within the image can later be classified based on statistical algorithms (Woodcock et al., 2003, p. 99). Those testing sites should be internally homogeneous and representative for a specific land cover type, while simultaneously showing heterogeneity towards other classes (Lange, 2006, p. 416).

Before elaborating on the supervised classification used for this study, it needs to be clarified that, though other methods for land cover classification were considered and examined, they have proven to be inappropriate. This included unsupervised classification, image segmentation and knowledge-based image classification. When testing unsupervised classification on the study sites, the process resulted in inappropriately clustered groups, where classes in itself showed very heterogeneous land cover types due to reflective properties. Same holds truth for the segmentation of the images, as, despite altering the parameters for several iterations, the grouping of pixels appeared to be inaccurate in complex regions, such as large areas of shadows for example. For the reason that both of those methods allowed for limited invention and control of the classification process, the supervised or knowledge-based classifications seemed to be more promising. However, the reason for eventually not using the latter was the lack of profound on-site knowledge on the spatial growth patterns of different vegetation types, which restricts the implementation of elevation data, derived from DEM, and NDVI values for a rule based classification. Finally, supervised classification was chosen as the preferred method.

As this study is not focusing on one area, but rather three mountain regions far apart from each other, it was important to clearly define land cover classes before anything else. Deciding on those classes depended on three factors: the purpose and intended goal of the classification itself, the spectrum of possible land cover types existing within each investigated region, and the geometric resolution of the satellite imagery, determining the possibility of identifying individual objects versus having to deal with mixed pixels. For the reason that this constitutes a transregional comparison of areas which, on a large scale, are home to different vegetation species, a certain level of generalization was necessary. Consequently, the classification should not be based on individual trees, for example, but rather on compounds of the same vegetation type. Here, the 10x10 m resolution of the Sentinel scenes appeared to fit in terms of distinguishability and degree of complexity. In other words, as the investigated area of each national park stretched over hundreds of square kilometers a very high resolution image could result in a high degree of misinterpreted pixels, as testing sites would need to be extremely specific. In order to achieve a representative output, the number of different classes was kept as low as possible to avoid a high degree of misclassification.

After conducting some test runs and reviewing the available information, the following classes were considered appropriate for all study areas. In order to get a better understanding of the selected classes, Figure 12 displays examples of land cover types for each study area. The presented images were directly taken from the used satellite imagery.

- **Water**: larger water areas such as lakes, reservoirs or ponds, but also larger rivers. (No distinction between flowing streams and bodies of standing water has been made.)
- **Snow**: surfaces covered with snow at the time of sensing.
- **Glacier**: areas of visible glacier ice.
- **Rock and debris**: areas of bare rock, piles of debris and generally non-vegetated areas.
- **Forest**: densely vegetated areas of coniferous and deciduous trees.
- **Grassland**: areas dominated by mostly lush grasses.
- **Alpine meadow and shrubland**: areas of thin vegetation not containing trees. Besides low-growing grasses this class features areas covered by different shrubs varying in size.

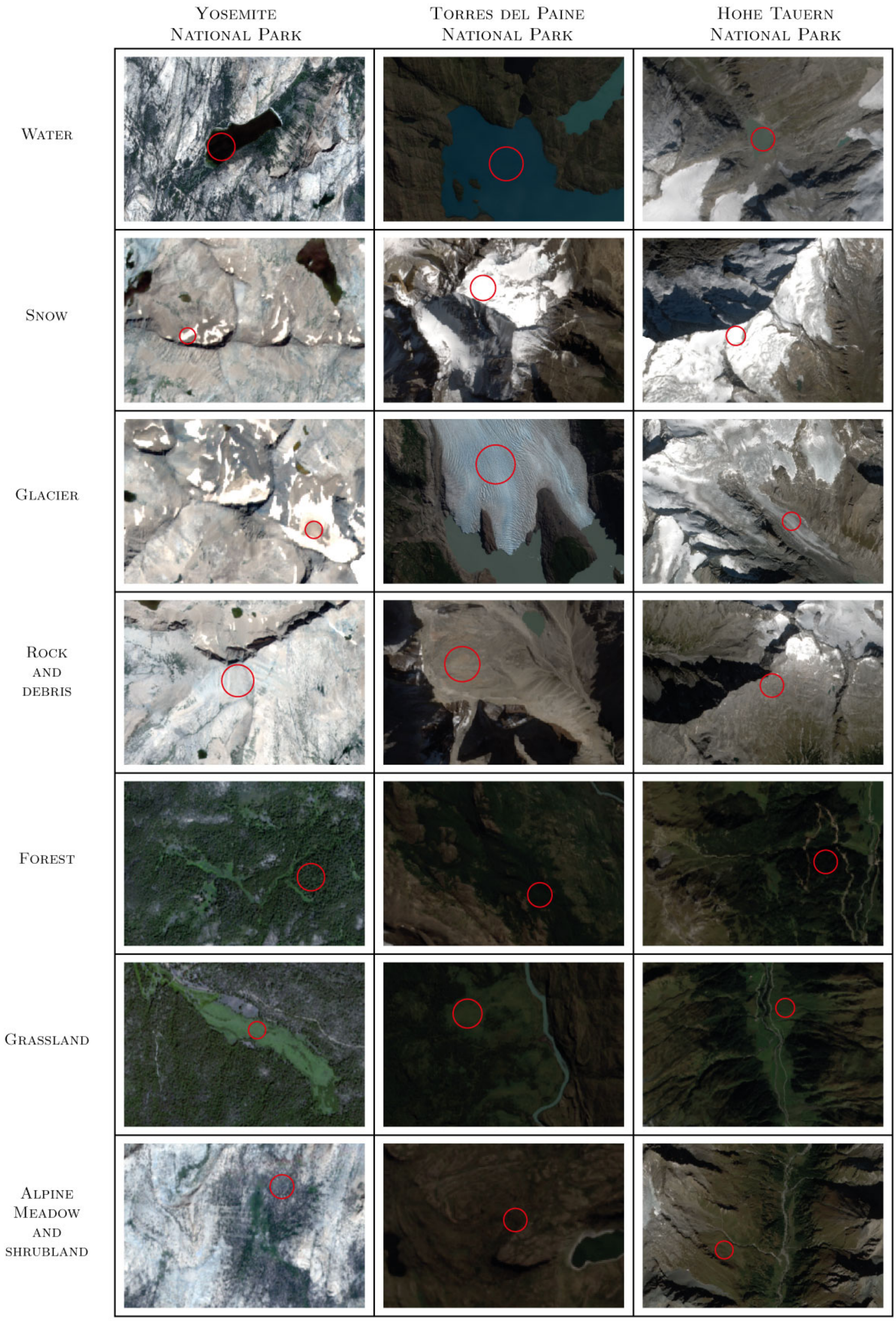


Figure 12: Selected examples of land cover types for all study areas.

One aspect which causes particular classification problems in mountainous regions is the issue of cast shadow. Particularly in regions with high relief energy, shadows can cover large areas, making a classification of those pixels extremely hard due to the distortion of class specific spectral values. Still, this issue could be partially overcome by dividing classes into subcategories, which also improved the quality of the overall classification. As recommended by Woodcock et al. (2003, p. 100) numerous training sites were used for the same types of land cover as well as multiple classes for similar elements which were eventually merged for the final output map. For example, multiple training sites (polygons) were defined to gather spectral information for the class 'Forest', while additionally more than one class for forest areas existed (e.g. 'Forest2', 'Forest-shadow') which were later combined.

Once all testing sites had been defined within the signature file, all pixels within the image could be assigned to different classes based on the spectral information from those testing sites. The chosen method for this process was the maximum likelihood classification. This approach, deriving from cluster analysis, uses the probabilities of each pixel for being assigned to a certain class, while assuming that reflexive values of each class and spectral channel are roughly normally distributed (Lange, 2006, pp. 417–418). The software used for those steps was again ERDAS IMAGINE.

Finally, the produced images needed to undergo some post-classification processing in order to produce a more proper output. Here a majority filter was considered appropriate in order to reduce the amount of noise, by decreasing the number of isolated pixels. This was done with the help of the Majority Filter tool in ArcMap, using the four orthogonal neighbours as the kernel. Additionally, a boundary clean was performed in order to further minimize issues of misclassification by smoothing zones.

5.3.5 Soil Erodibility

Finally, soil erodiblity constitues the last natural geographic feature for this study. The calculation for soil erodibility is derived from the Revised Universal Soil Loss Equation (RUSLE) by Renard et al. (1997, pp. 14–16), being a revision of the Universal Soil Loss Equation (USLE). The equation tries to estimate the long-term average soil loss of an area based on various factors. Within RUSLE those variables include rainfall-runoff erosivitiy factor, soil erodibility factor, slope length and steepness factor, cover-management factor and support practice factor. The soil erodibility is here represented as K, therefore mostly refereed to as the K-factor. For the reason that this research does not try to evaluate the average annual soil loss, but rather the assumed susceptibility of erosion, the K-factor appears to be the only value of interest.

In more detail, "soil erodibility should be viewed as the change in the soil per unit of applied external force or energy" (Renard et al., 1997, p. 68). While this concept is usually thought within the context of physical impact by raindrops or runoff, it is here thought of as soil resistance to detachment and transport by human treading. Despite the RUSLE has been around for some time, numerous equations have been developed for the soil erodiblitiy factor (K). The most widely used is probably still a nomograph which draws on five parameters: fraction of silt, sand and organic matter as well as soil structure and permeability (Renard et al., 1997,

p. 74). However, due to the lack of sufficient (open) data on some parameters, this equation could not be used. Despite SoilGrids holds data on soil organic carbon content, for example, which could be roughly converted to soil organic matter (OM), those computed fractions are still strongly overestimated (Hengl et al., 2017, p. 20).

Still, within their publication Renard et al. (1997, p. 76) propose another equation, in which soil erodibility is related to the mean geometric particle diameter. This relationship, which is expressed in Eq. 2, was based on an analysis of 225 global soils. Within this formula, D_g represents the mean particle size (mm) which is calculated by using 3. Here, f_i is the individual particle size fraction (clay, silt and sand) in percent, while m_i refers to the arithmetic mean of particle size limits (in mm).

$$K = 0,0034 + 0,0405 \cdot exp\left[-0,5\left(\frac{\log D_g + 1,659}{0,7101}\right)^2\right] \tag{2}$$

$$D_g = exp(0,01 \cdot \sum_{i=1}^{n} f_i \ln(m_i)) \tag{3}$$

The original equation included a multiplying factor of 7,594 in the Eq.2, which yields values in U.S. customary units t·acre·h/hundreds of acre·ft·t·in (Renard et al., 1997, p. 74). By omitting this factor, the result will be in metric units t·ha·h·/ha·MJ·mm or t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}, which can be considered more appropriate for international comparison.

Though this model generally appeared to be fitting for the present purpose, it was important to investigate its actual degree of applicability. Though implicated in various studies on soil loss, there was hardly any evaluation of its level of accuracy. However, Wang et al. (2013, pp. 74–75) compared four of the most popular K-factor models, coming to the conclusion that the above presented equation, refereed to as Dg model, best estimates K-values, with the smallest overestimation. As this model outperformed others despite its limited number of input data, it was deemed most appropriate when considering the available open data.

As mentioned in the section on data acquisition, soil property datasets for three depths (0 cm, 5 cm and 15 cm) were obtained. This was done in order to overcome certain irregularities by calculating mean values for each cell. First, for each depth, K-values were calculated based on the presented equations by using map algebra in ArcGIS. The particle size ranges for the data retrieved from SoilGrids are 0 µm-2 µm for clay, 2 µm-50 µm for silt and 50 µm-2000 µm for sand. Consequently, the arithmetic means (m_i) for each physical property are 0,001 mm (clay), 0,026 mm and 1,025 mm (sand). Once all K-values were computed, the arithmetic mean of all three depths could be calculated.

Ultimately, the raster was resampled to a geometric resolution of 10 m, which could later be used in the subsequent analysis on ecological sensitivity. However, no separate output was generated in terms of trails and area comparison as the original resolution of 250 m was considered insufficient for such a direct comparison. Therefore, the soil erodibility was solely relevant for the subsequent multilevel analysis.

5.4 Multilevel Analysis

Finally, based on the discussed individual features, a multicriteria analysis was developed to model the potential ecological sensitivity of hiking in the study areas. This approach was partly based on the research presented by Schaller (2014) as well as Ólafsdóttir and Runnström (2009), who focused on mountain protected areas in Japan and Iceland. The general rational was to classify the individual factors accordingly, and combine the results in order to create a conclusive map for each region, showing the potential sensitivity. Those results can then be transferred to existing hiking trails to identify sections of assumed low, moderate or high impact. With these sets at hand, the introduced protected areas for this research could then be confronted with one another.

Assessing ecological sensitivity depends on the combination of numerous ecological parameters, usually derived from existing data. Here, Schaller (2014, pp. 11–12) notes that there is a difference between ecological and environmental sensitivity, with the first including topographic, pedological and ecologcial factors, whereas the second additionally integrates climatic and hydrological parameters. However, the latter often appear to be hard to model and difficult to incorporate into a hiking trail assessment. For the reason that this study investigates the direct, physical impact of touristic hiking, the use of biological, topographic and pedological factors appears to be sufficient. To be more precise, those aspects will be represented by data on slope, land cover, vegetation (NDVI) and soil erodibility.

Due to the fact that not all datasets introduced follow a rational scale of measurement, a classification is inevitable for the purpose of combining individual factors to a multilayer output. Additionally, there are certain 'natural' breaks within the datasets which have been identified in various studies. However, it needs to be acknowledged that the process of classification is constantly accompanied with a degree of generalization. Especially, as this research investigates and contrasts entire national parks instead of small subregions within protected areas.

Table 4: Sensitivity categories

Sensitivity category	Slope	Land Cover	NDVI	K-values
very low sensitivity (1)	00,000° - 10°	Water	-1,00 - 0,01	0,0000 - 0,01
low sensitivity (2)	10,001° - 20°	Rock and debris, Glacier	0,001 - 0,2; 0,551 - 1,0	0,0101 - 0,02
medium sensitivity (3)	20,001° - 30°	Grassland, Forest, Alpine Meadow	0,351 - 0,55	0,0201 - 0,03
high sensitivity (4)	30,001° - 90°	Snow	0,201 - 0,35	> 0,03

Following the idea of Ólafsdóttir and Runnström (2009, p. 32), all factors were classified into four categories of different sensitivity levels, each being represented by an individual integer. Despite mainly following their model, the category of 'no sensitivity' was perceived to be inappropriate and therefore replaced with 'very low sensitivity'. Consequently, the final sensitivity categories for this analysis range from very low to high sensitivity, where the numbers in brackets represent the assigned integer values. An overview of the different classes can be found in Table 4. In order to understand the rational behind the classification presented above, it is significant to elaborate on the individual class limits for the used datasets. Hence, the following paragraphs explain the origin and thoughts which led to the mentioned classification.

Slope

The classification of slope gradients strongly follows the one suggested by Ólafsdóttir and Runnström (2009, p. 31), assuming that a higher degree in slope results in a higher degree of gravitational erosion. Here, any area above 30° can be perceived to have a high sensitivity, while any slope gradient lower than or equal to 10° results in very low sensitivity. Except for the last class, all classes follow an equidistance of 10 degrees.

Land Cover

The ecological sensitivity of land cover is largely based on the study by Schaller (2014), who used his classification for an interregional comparison between mountain protected areas in Iceland and Japan. Hence, those relatively broad classes also appeared to be appropriate for this comparative study. As the land cover dataset of this research only holds seven different classes, the according land cover types were assigned to sensitivity levels where they were found to be most appropriate. Despite mostly following Schaller's classification, two things need to be mentioned.

First, while in his research glaciers appear to show no sensitivity to hiking, my analysis placed this land cover type within the class of low sensitivity, as only water was perceived to have very little to no sensitivity. This is confirmed by Ólafsdóttir and Runnström (2009, p. 32), who also considered proximity to glaciers to have a slight impact. Again, it needs to be mentioned that this refers to direct sensitivity to hiking and not extended impacts through global warming for instance. Second, Schaller (2014, p. 18) notes that, besides moss heaths, snow patch community plants are most sensitive to physical impact. Due to the spatial resolution of the satellite images used in this research, it was not possible to identify such plant communities in the supervised classification process. Still, as the images used had been sensed in summer, the snow patches appearing can be considered potential habitats for such plant communities. In order to account for that, snow was considered strongly sensitive in terms of land cover, which would only result in an overall high sensitivity in case other values appeared to show equal sensitivity.

NDVI

Though vegetation is already to some part incorporated in the previous parameter, it appeared to be necessary to include the state and potential productivity of vegetation into this ecological evaluation. Especially, as this cannot only be an indicator for plant health, but also a help to deduce potential habitats for animal species, as elaborated in Section 5.3.3. Additionally, the state of plants is assumed to form the basis of a functioning ecosystem (see Section 3.3). Hence, in this context, the NDVI should be considered as an indicator of assumed ecosystem stability derived from the potential primary production of vegetation.

As mentioned before, negative NDVI values can be considered to represent completely non-vegetated areas such as water, snow and ice. Positive values up to around 0,2, on the other hand, are generally estimated to represent bare soil. Eventually, high green-leaf-biomass is found above 0,5, whereas values around 0,35 are indicators for a low biomass. Those ranges should be considered guidelines and are subject to slight changes due to atmospheric influences (aerosols). However, the stratification of those cover-types is maintained despite the condition. (Holben, 1986, pp. 1419–1422)

Tang et al. (2015, pp. 4867–4869), beside others, confirm that NDVI values below 0,2 are bare soil, while anything above 0,5 is considered fully vegetated. Consequently, we might consider anything between those two values as gradations of plant biomass and further plant health. Here, Gross (2005, p. 3) presents a threshold of 0,3 as the dividing value between plants of lower and higher vigour, with anything above 0,6 representing dense healthy forests and anything below 0,1 bare rock. Though not exactly similar, these assumptions strongly align with the ones mentioned afore. Therefore, the classification presented in Table 4 can be seen as a middle course, after repeatedly revieweing all study areas. This can be traced back to the idea introduced in Section 3.3, stating that healthier and rather diverse ecosystems are more resilient.

Soil erodiblity

In terms of the classification of K-values, there appear to be no standardized class limits or thresholds which one can refer to. The classes used in most studies appear to follow site specific patterns. Therefore, an equal interval based on the overall range of values in all three study sites appeared to be the best option. As the maximum was found to be around 0,04 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$ and the minimum beneath 0,01 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$, an equidistance of 0,01 $t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$ was found to be suitable. The resulting classification can once more be seen in Table 4. Due to the fact that some values were already missing in the original SoilGrids dataset, their value had to be assumed in order to overcome gaps in the final overlay. Therefore, a value indicating medium sensitivity was taken due to its dominance in all datasets.

Overlay

Once each mentioned natural geographic feature had been classified, an overlay of all layers could be performed, resulting in the final ecological sensitive layer. For this process, all datasets had to be in raster format in order to reclassify pixels and later calculate each pixel value with map algebra. Due to the fact that the data on soil retrieved from SoilGrids shows a much lower resolution, it was percieved to be less representative. Therefore, the soil erodibility was classified accordingly, but only weighted with a factor of 0,5 for the final ecologial sensitivity. Ultimately, computing the final ecological sensitivity (ES) layer was the result of the combination of all classified rasters (Eq. 4). The results were then again regrouped into five classes of sensitivity (Table 5), which, in contrast to other options, have proven to best represent the output. Last, the classes were transferred to the hiking trails, which have been segmented and later dissolved in order to calculate overall length of trails found within each sensitivity category.

$$ES = \frac{Slope_{(ES)} + Land\,Cover_{(ES)} + NDVI_{(ES)} + 0,5 \cdot Soil\,Erodibility_{(ES)}}{3,5} \tag{4}$$

Table 5: Classes of ecological sensitivity

Sensitivity category	**Range of accumulated values**
very low sensitivity	1,00 - 1,99
low sensitivity	2,00 - 2,49
medium sensitivity	2,50 - 2,99
high sensitivity	3,00 - 3,49
very high sensitivity	3,50 - 4,00

5.5 Strava Heatmap

Besides analysing natural geographic factors and the ecological sensitivity, considerations were made on incorporating the intensity of use for the studied hiking trails. However, this had proven to be very difficult. On the one hand, no first-hand measurements could be taken due to reasons already mentioned, including the global spread of the study sites and vast extent of the individual hiking trails within the protected areas. On the other hand, no open data, which would be accessible for further processing, exists on this matter. In fact, there is no standardized publicly official product showing the spatial distribution of visitor intensity within all park borders. Consequently, despite many national parks keep track of overall numbers of visitors entering the protected area, only few management authorities keep track on where those visitors roam.

Nevertheless, the ongoing technological progress and the increasing coverage and use of technical devices with GPS (Global Positioning System) functionality in combination with the ability to process big data provide possibilities to render spatial patterns of use visible. In other words, by collecting multiple GPS-tracks of hiking activities, it would be possible to allegedly deduce the intensity of trail use. However, it needs to be noted that such collections of information always raise the question of data privacy and security. As already mentioned, no governmental or official dataset exists on this matter. Yet, when extending the research scope to the private sector, one can find a product which may be of significant interest for this research; namely the Strava Global Heatmap accesible at https://www.strava.com/heatmap (see Figure 13).

The Global Heatmap is a project by Strava Labs, which, though working as an independent entity, develops products based on the data collected by Strava (Strava, 2019b). Briefly, Strava is an application and a social fitness network, which lets users track (GPS) their sport activities and share them with other community members; while offering free service but also paid subscriptions (Strava, 2019a). In general, the Strava Global Heatmap introduced in 2017 is an online accessible heatmap based on all spatially recorded sportive activities of Strava users, which have been marked as public by the latter. Those activities are separated into four categories: cycling, walking/running, water and winter activities. Within this map, areas featuring a high frequency of activity are colored brighter due to the underlying amount of GPS-tracks.

The map provides a global coverage based on data collected within the preceding two years. According to Strava, the heatmap is updated monthly following a strict privacy policy, giving members the possibility to prevent the use of their data for the project. (Strava, 2018)

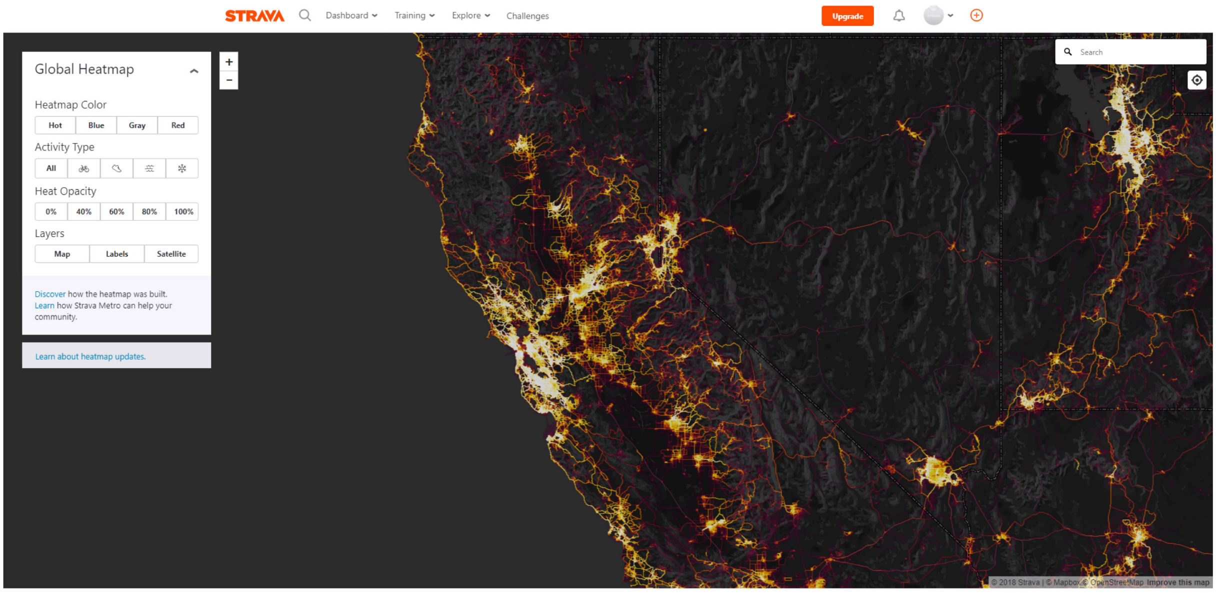


Figure 13: Strava Global Heatmap webpage (screenshot 22.06.2019).

Apart from the heatmap, the collected data is also processed by Strava Metro, which anonymizes and merges individual datasets for GIS use before providing them to partnering cities and metropolitan planing departments (Strava, 2019c). Institutions can then use this information to develop local infrastructure plans based on pedestrian and cyclist activities. Generally, those datasets have to be ordered and are priced according to extent and size. Though inquiring anonymized GIS data for the present research, Strava was not able to provide datasets free of charge for the study sites. Hence, no analysis could be conducted based on actual values for intensity of use. However, the Strava Global Heatmap was still considered a valuable complement to the conducted ecological analysis, partially representing the human sphere in the national parks. Therefore, the following procedure was chosen to incorporate images from the heatmap into a visual evaluation of intensity of trail use. Yet, the limitations and origins of the data have to be taken into account when interpreting the images.

First, small scale raster images (screenshots) were taken from the above mentioned website, georeferenced and stretched in ArcGIS. In order to solely include hiking, the online heatmap was filtered to display walking/running activities. For the final output, the background was set transparent displaying only the relevant data. It needs to be mentioned that, due to the difference in GPS devices and reception obstruction deriving from their use in mountainous and forested areas, including effects of shading and lack of satellite suffiecient signals, the heatmap includes distortions (Figure 14). Those positioning errors may be recognizable as single, perfectly linear, thin polylines surrounding the trails, often in an angle of 90 degree to alleged pathways. Within the chosen color scheme they appear purple, as they represent single lines, sometimes isolated. Specific cases, however, will be outlined, where necessary in the subsequent chapters.

Before moving on to the final results, there are some limitations in terms of the heatmap

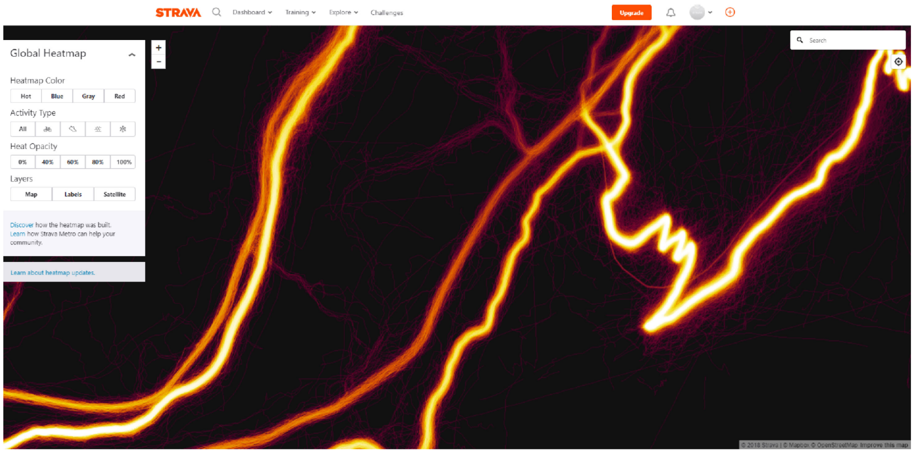


Figure 14: Large scale image of Strava Global Heatmap with visible GPS positioning errors in Yosemite Valley (screenshot 22.06.2019).

which have to be pointed out. First and foremost, this dataset is the result of activities by members of the Strava social network only. In other words, as only a certain part of national park visitors make use of this application, the heatmap can not be seen as a comprehensive portrayal of all activities in a region. Therefore, the interpretation of those images needs to be treated with caution. Nevertheless, it can express spatial patterns as well as local differences. Additionally, due to the vast amount of data stretching over a two year period, those patterns might be more reliable than initially thought as single uses or disturbances are of little to no consequence. Second, there is a limitation in the interpretability of the images themselves. For the reason that we are dealing with raster images taken from a tiled web map, pixel values differ depending on the scale the screenshot was taken. Same holds truth for the hue of the individual areas. Consequently, it was not possible to reclassify those rasters in any way. Ultimately, a visual interpretation of the heatmap in comparison to other results appeared to be the best option, where limitations have to be acknowledge while the significance of the images should not be underestimated.

6 Results

This chapter will present the results from the geospatial analyses on hiking trails in the selected national parks. The subsequent pages are divided into two main parts, displaying the outcomes from the analyses on the individual physical parameters and the ecological sensitivity. Before getting into detail on the individual results, however, it was considered necessary to give an overview of some overall numbers gained from the analyses. Those are presented in Table 6 and were retrieved from the corresponding geoobjects in GIS. Though the spatial extent was already shown in Chapter 4, the presented (km^2) were the ones used for the analyses, calculated within the introduced reference system WGS 1984 UTM.

Table 6: Geographic dimensions of study areas

Category	**Yosemite**	**Torres del Paine**	**Hohe Tauern**
Total area (km^2)	3019,92	2334,3	1856,81
Water area (km^2)	29,29	263,25	5,28
Perimeter (km)	299,78	262,74	887,20
Length of Trails (km)	1263,95	229,16	1589,13
Density - trail length/area without water (km/km^2)	0,422	0,077	0,858

The list highlights the strong difference when it comes to the length of trails and size of area, being of course also the major reason for choosing proportions as the best measure of contrast for subsequently presented results. Especially, TdPNP has a relatively small amount of hiking trails compared to its size. This can also be seen in the density of trails within the potential accessible area, which is close to 0 in the Chilean park, while being near to 1 km of trail per km^2 in HTNP. Here, it is also worth mentioning that almost a tenth of TdPNP is permanently covered by water. Despite, being the largest park, YNP also features a high total length of trails within its boundaries, while holding only a small portion of water area. Those differences will also become evident when having a look at the maps presented in this chapter.

6.1 Natural Geographic Factors - Area and Trails

The figures in this section show the relative distribution of hiking trails and area within each study site, based on slope, elevation, NDVI and land cover. As all charts follow a similar pattern, it appears to be necessary to give a short introduction on their depiction. While the gray bars represent the relative share of total area within national park boundaries, the black bars show the proportion of trail length on individual characteristics. Once again, due to its inaccessibility to hikers, any surface permanently holding water was excluded from the computation of the total area and is therefore not found in the relative distribution. Except for the charts on land cover, the abscissa shows the percentage of total area or length, whereas the ordinate holds the classes representing the values for each parameter. The following sections also feature factor-specific maps, showing the classified results for area, water bodies and hiking trails.

6.1.1 Steepness

First of, Figures 15 to 17 show the relative distribution of slope in degrees. At first sight, one might observe a certain difference in the overall morphology of the individual parks. Whilst in Yosemite and Torres del Paine more than half of the area is found to be lower than 20° slope, Hohe Tauern shows a high proportion of steep terrain above this value. To be more precise, almost four fifths of the park's area is found between 20° and 70°. Despite no study site holds a relevant proportion of area above this limit, the relief of HTNP appears to strongly deviate from the other sites (see Figure 18). However, there is also a slight difference in the share of thoroughly flat areas within the American parks. In TdPNP, one fifth appears to be equal to or below 5° slope, whereas YNP only shows half the proportion. Again, no water bodies are included in these shares.

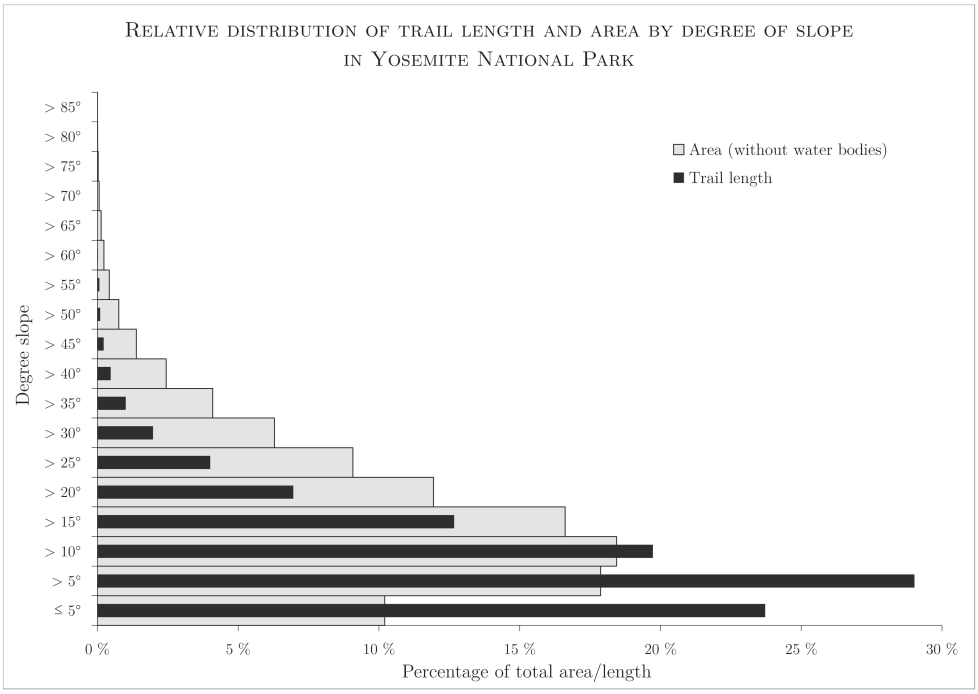


Figure 15: Relative distribution of trail length and area by slope in YNP.

In terms of trail, the distribution roughly follows the shares of the overall surface within all parks, slightly shifted towards less steep areas. Note, that the class of slope does not tell the exact degrees of the trail, but rather the terrain it is found in. In YNP (Figure 15), over half of the trails are found beneath 10° slope, while only a quarter of the parks area is found within this incline. TdPNP (Figure 16), shows a similar pattern as YNP, with a higher proportion of trails in very flat areas. More than a quarter of all paths in this protected area do not exceed 5°, which is very close to the corresponding share of total area. Again, HTNP (Figure 17) presents

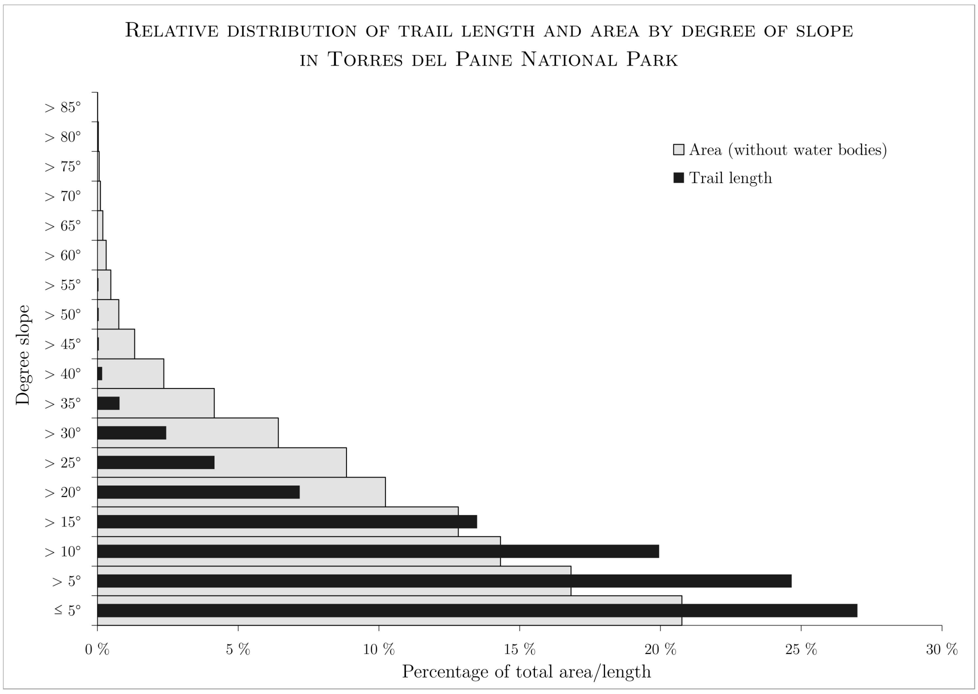


Figure 16: Relative distribution of trail length and area by slope in TdPNP.

a different picture, where trails are largely distributed over all gradients below 60°, with no slope level showing a higher proportion than 16 %. However, most hiking paths are found between terrain of 15° and 40°. What needs to be mentioned though is the relatively high share of trails in flat areas, despite the small proportion of overall surface equal to or beneath 5° slope.

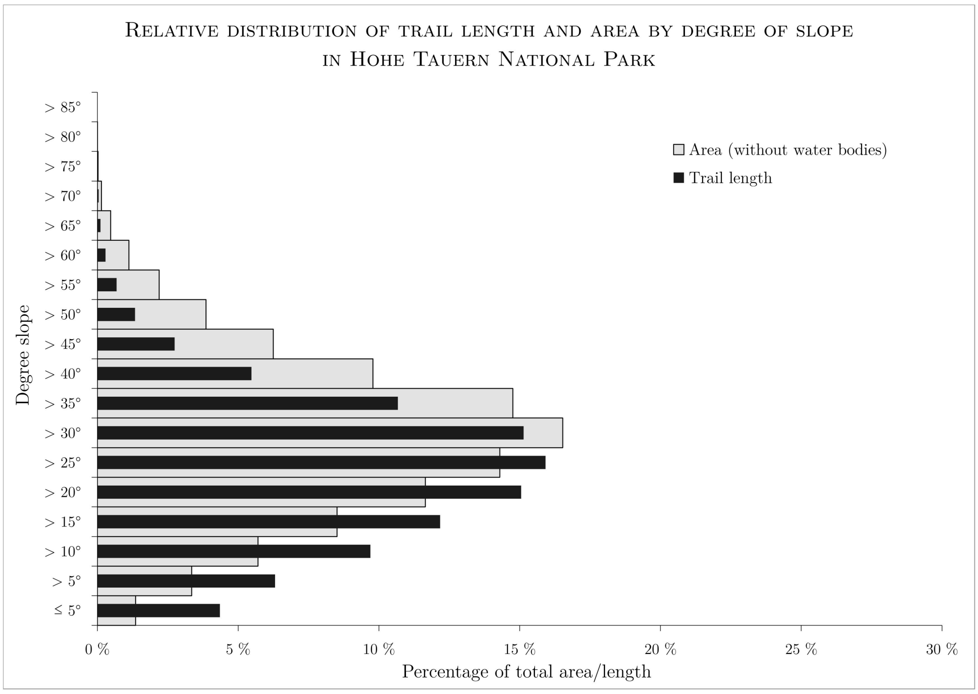


Figure 17: Relative distribution of trail length and area by slope in HTNP.

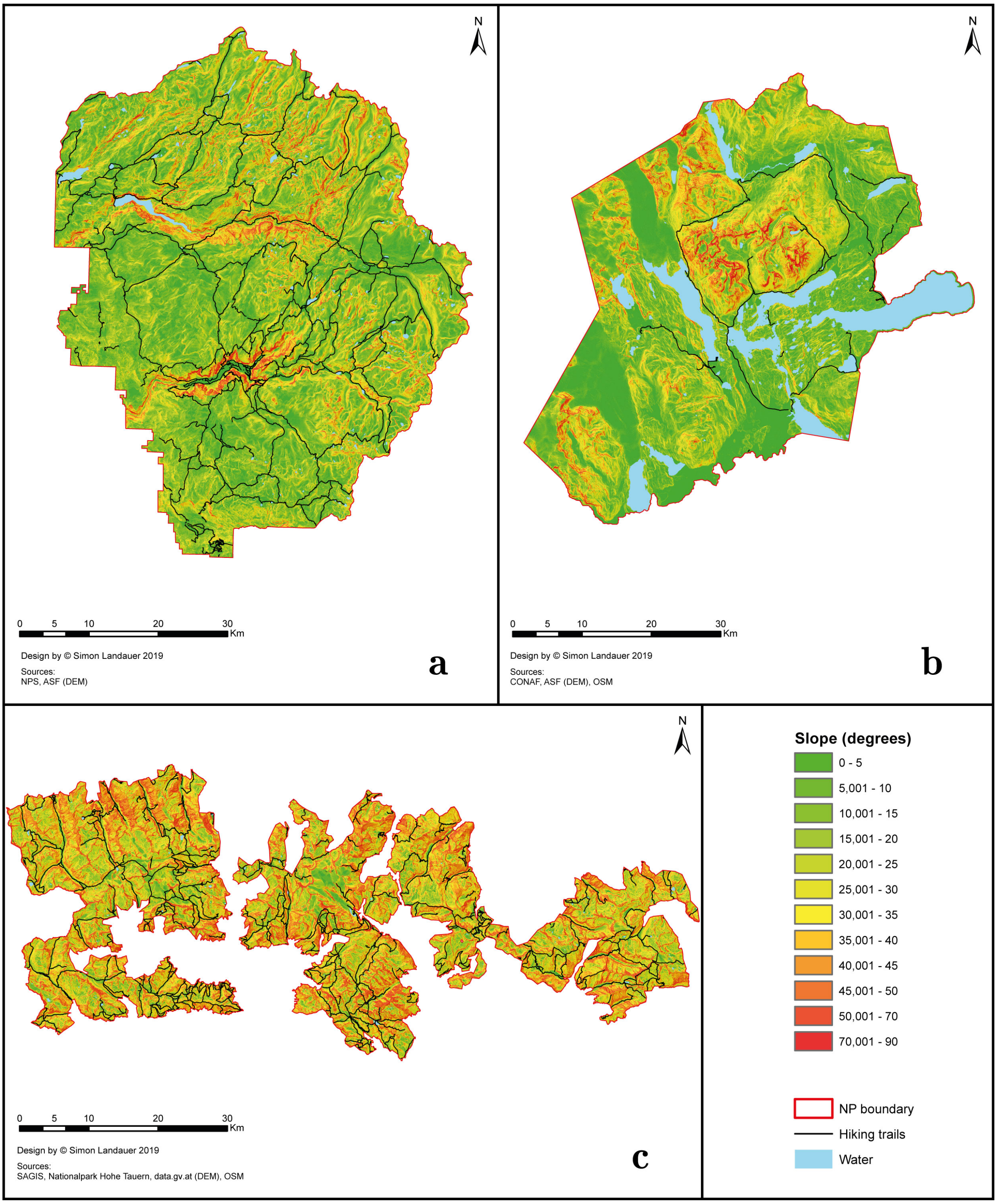


Figure 18: Slope and hiking trails in YNP(a), TdPNP(b) and HTNP(c).

6.1.2 Altitude

The next charts display the distribution of elevation within the protected areas. Despite the absolute altitude has a limited explanatory value when contrasting parks of different topography, it is the relative height and span of elevation levels which is interesting. In other words, though all study areas surpass a maximum elevation of 2500 m above sea level, some might feature a broader range in higher elevations than others. To be more precise, YNP shows a vertical extent of nearly 3300 m; TdNP and HTNP of about 2800 m. This can also be observed in the spatial representations visible in Figure 22. While Yosemite and Hohe Tauern follow a closely similar distribution, with the majority of area found in-between 1800 m and 3000 m, the shares within Torres del Paine are almost consistently shrinking with increasing elevation. It is important to point out here that the x-axis within Figure 20 has a different scale than the other two charts in order to guarantee readability.

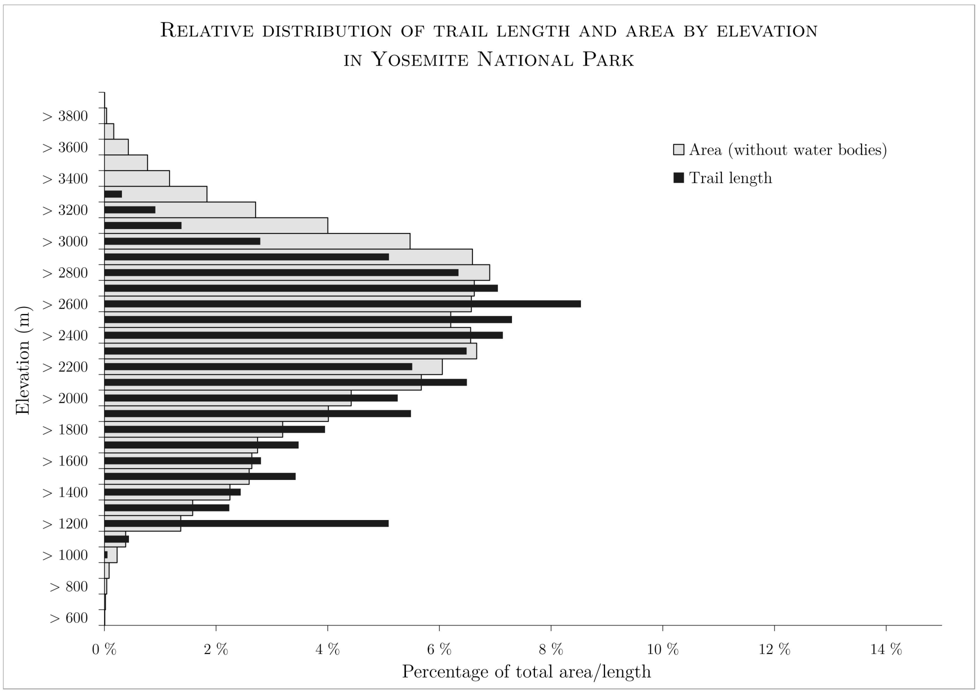


Figure 19: Relative distribution of trail length and area by elevation in YNP.

Concerning the distribution of trails within the parks, there is again a strong divergence in-between parks, and within the protected areas themselves. Starting off with YNP, it can be observed that the highest as well as lowest areas are inaccessible by hiking trails. However, the latter, in juxtaposition to the highest areas, might be accessible by roads, for example, which were not included in this examination. Despite the distribution of hiking paths mostly follows the areal shares, there are some exceptions. The most dominant is found between 1200 m and 1300 m, where only 1,37 % of area, but more than 5 % of kilometers of trail are found. Until 2800 m altitude, share of trail length almost constantly exceeds the proportion of area, before rapidly decreasing with every 100 m gain in elevation. Turning to TdPNP, around 90 % of the overall trail length is found within the lowest 500 m, whereas only 45 % of the area is situated within those heights. Just as in Yosemite, the highest peaks are not accessible by hikers, with the remaining tenth of hiking paths between 500 m to 1200 m. Only in HTNP hiking paths are to be found in every height, meaning that also high peaks within the protected area are accessible. It needs to be mentioned that this only concerns official hiking trails, not including routes for climbing or guided tours on restricted terrain.

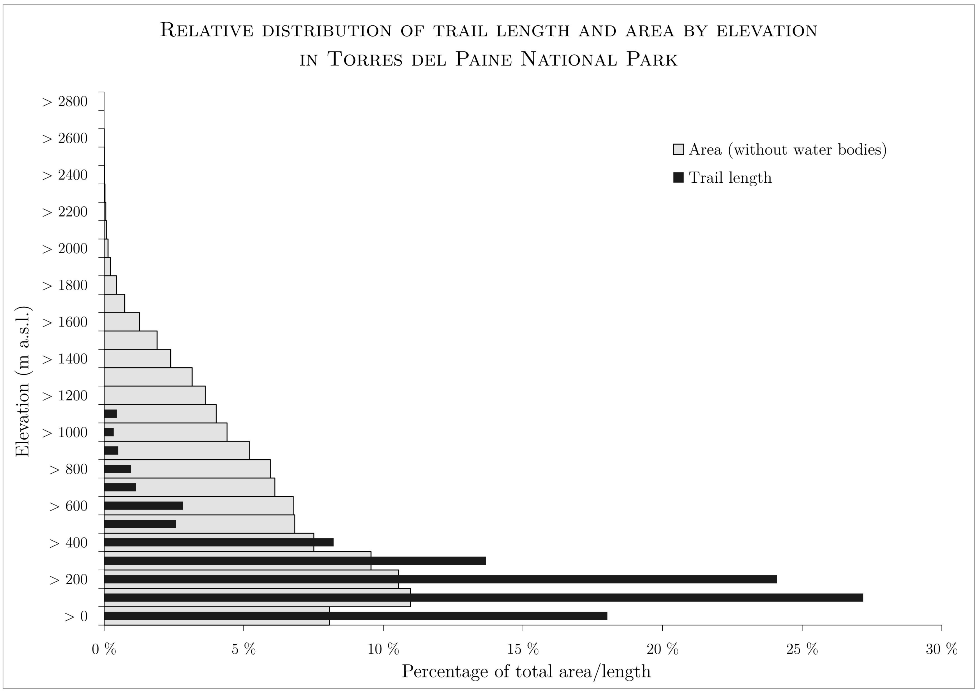


Figure 20: Relative distribution of trail length and area by elevation in TdPNP.

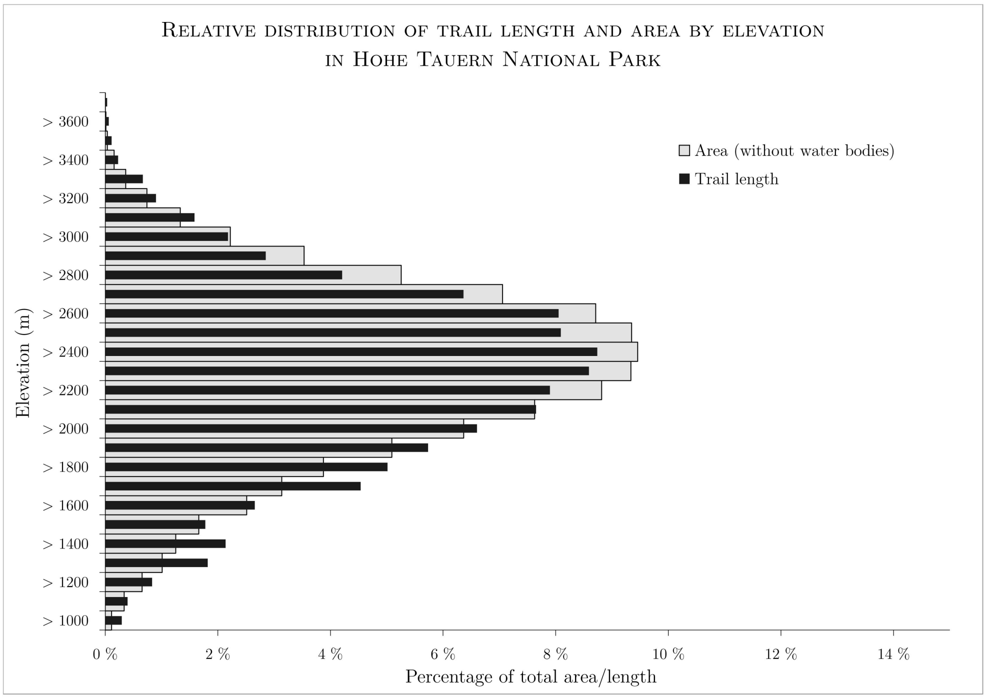


Figure 21: Relative distribution of trail length and area by elevation in HTNP.

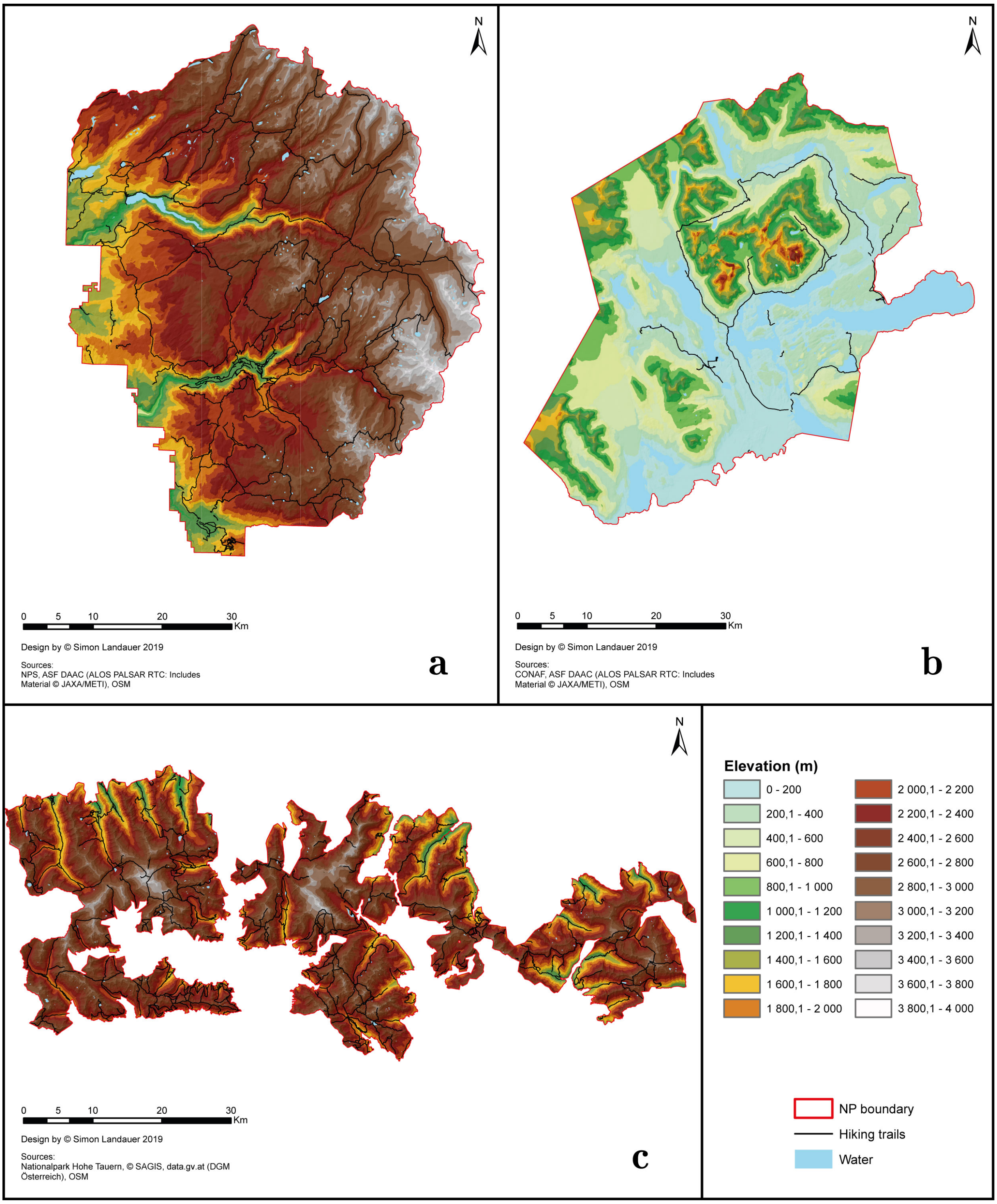


Figure 22: Elevation and hiking trails in YNP(a), TdPNP(b) and HTNP(c).

6.1.3 Primary Production and Biodiversity

Yet already introduced in Chapter 5, it is again worth mentioning that all NDVI values below zero represent completely unvegetated surfaces such as water, snow and ice, whereas values up until around 0,2 are considered to represent bare soil or rock; anything above can be interpreted as biomass, with the vigour and/or density of plants being expressed by the values proximity to 1. Additionally, it is important mentioning that certain rock surfaces may also show negative NDVI values due to their reflectance characteristics. For the reason that water bodies were once more subtracted, no water areas are incorporated in the class holding the lowest values.

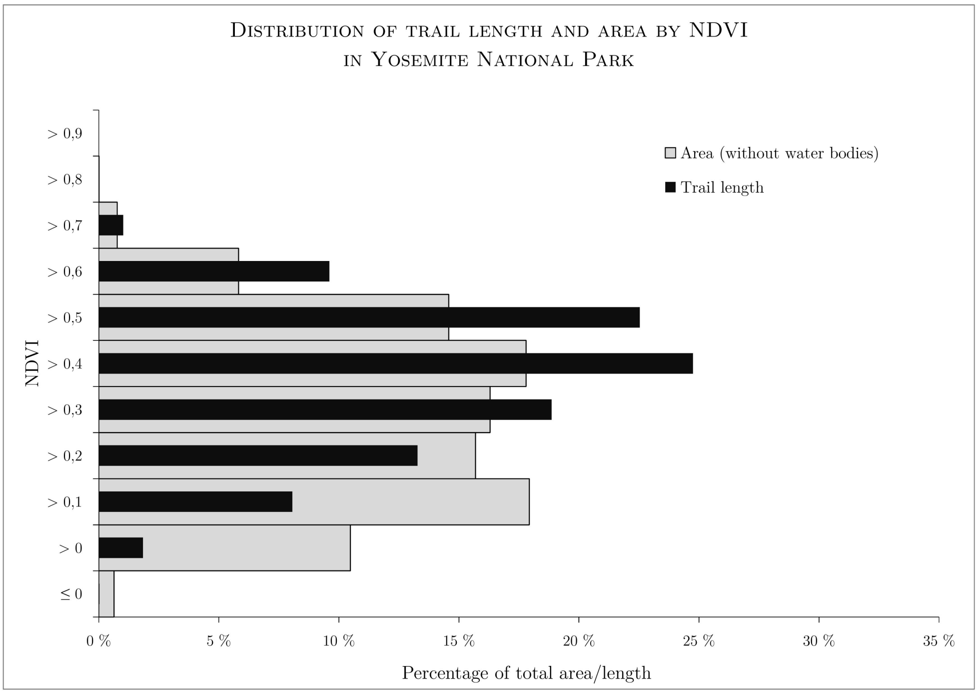


Figure 23: Relative distribution of trail length and area by NDVI in YNP.

Within all three protected sites, no area exceeds a NDVI of 0,9, which in general is usually rather found in tropical areas. However, each national park holds relatively healthy, dense vegetated areas, indicated by values around 0,5 to 0,9. In YNP (Figure 23), more than a quarter of the area is covered by quite vigorous plants, with another great proportion found in areas of bare soil and rock. The distribution of trail lengths, however, does not very much align with those proportions as the majority of trails are found in areas of rather healthy vegetation and comparatively higher primary production. Interestingly, despite there is a small proportion of area covered by snow or ice in YNP, no trails are to be found on those surfaces.

Moving to TdPNP (Figure 24), almost half of the area can be said to hold very limited to no vegetation. The high proportion of nil and negative values might be explained by the vast amount of glaciers within the national park. However, less than 15 % of trail length is situated within these areas, whereas three quarters are found in places with a NDVI above 0,4. In contrast to Yosemite, TdPNP features trails on ice and snow. Still, the highest proportion of trails on those surfaces is found in HTNP (Figure 24). Generally, around 46 % of the area in the Austrian protected area can be said to feature no vegetation, with one third of total trail length

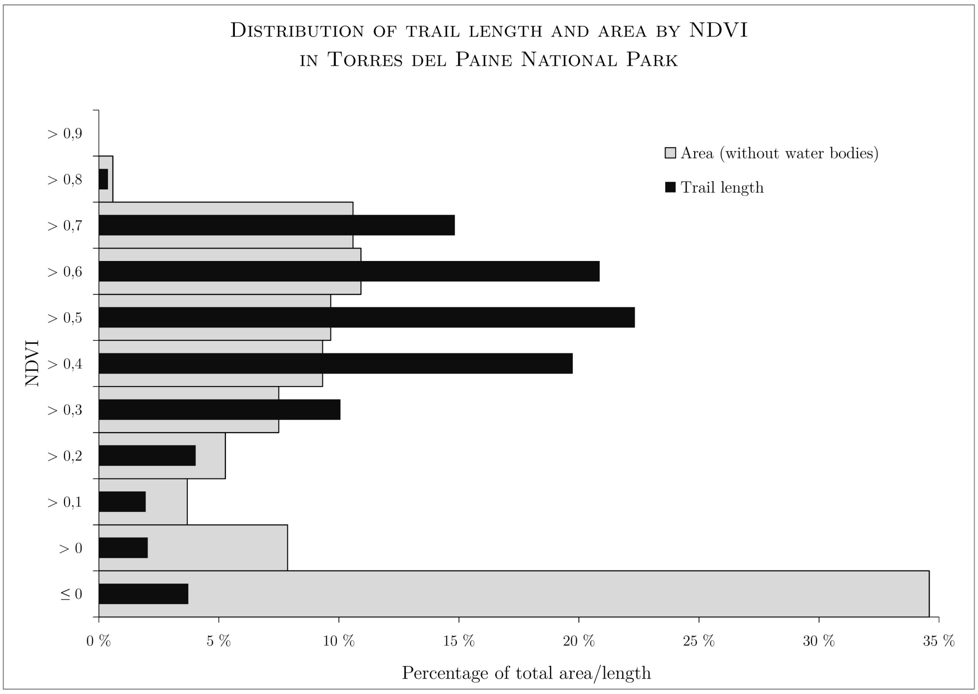


Figure 24: Relative distribution of trail length and area by NDVI in TdPNP.

within those areas. Nevertheless, the highest share of trails is once more found in spaces with a relatively vigour vegetation. Though not exactly as much as in Yosemite (53 %), 58 % of total trail length are to be found in areas showing a NDVI higher than 0,4, with the corresponding shares of total area being noticeably lower.

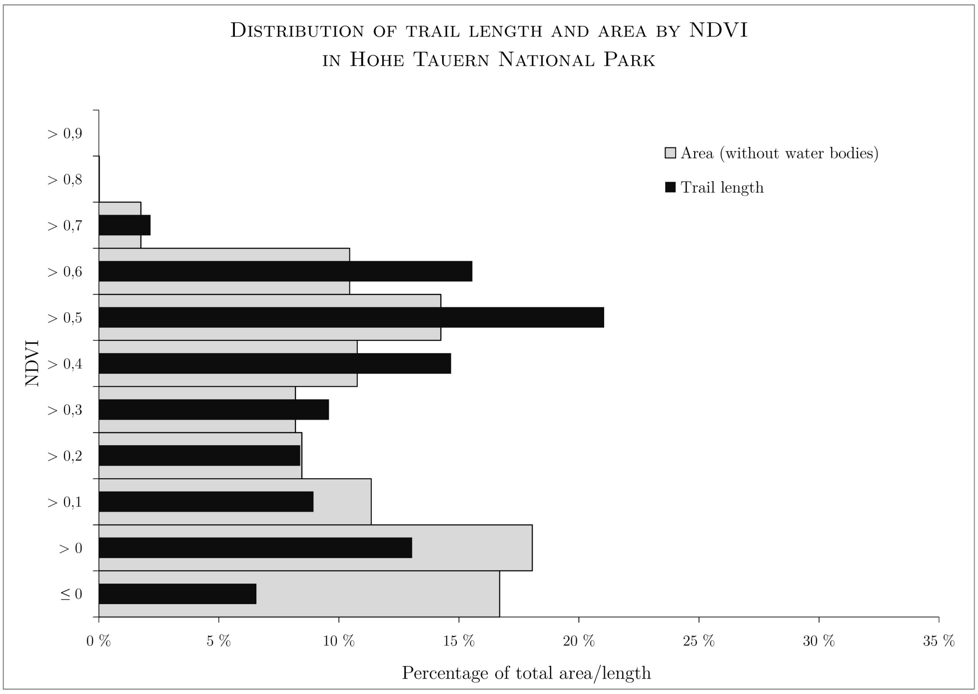


Figure 25: Relative distribution of trail length and area by NDVI in HTNP.

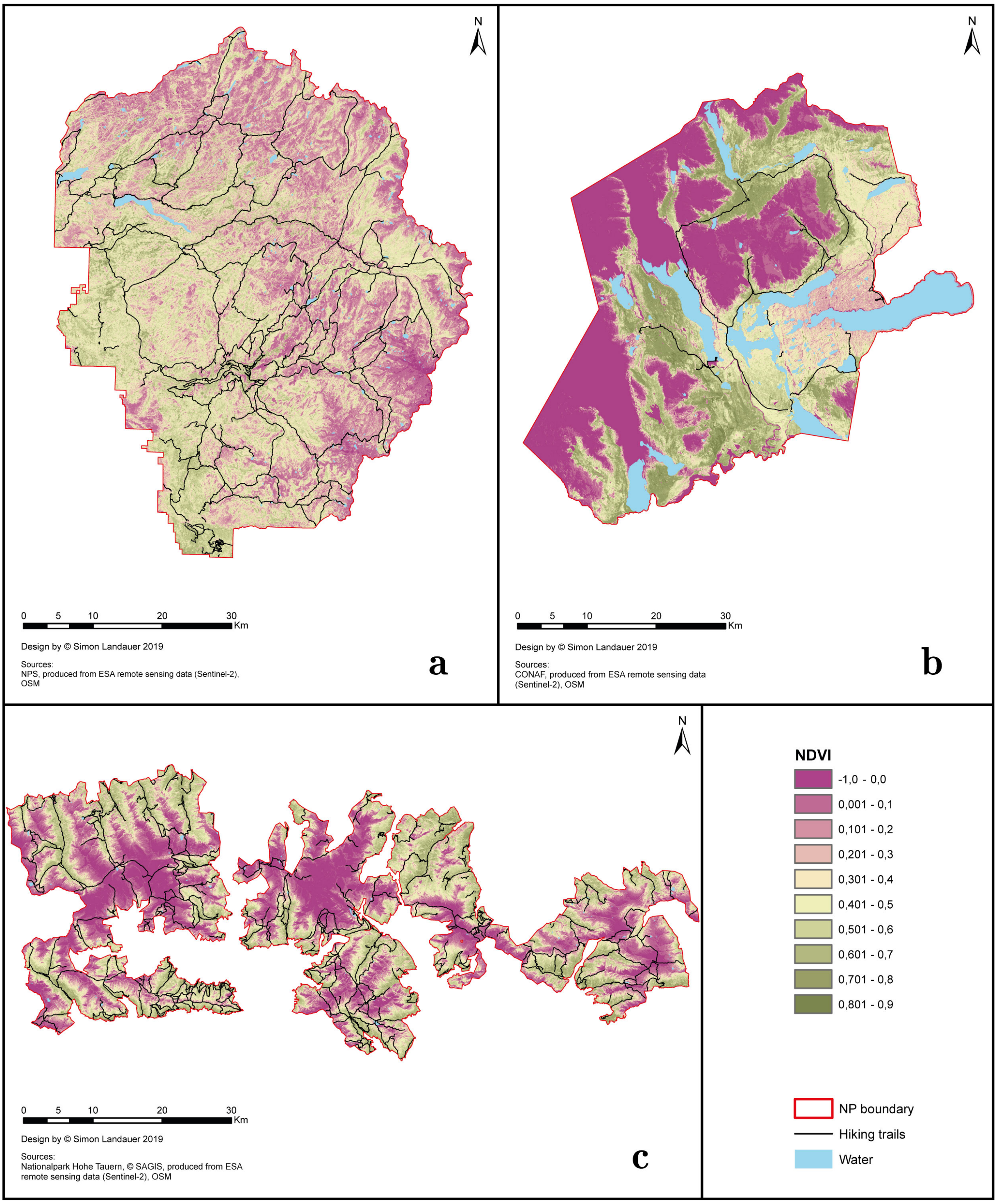


Figure 26: NDVI and hiking trails in YNP(a), TdPNP(b) and HTNP(c).

6.1.4 Land Cover

One more time, all three sites of interest show a different pattern in terms of total area as well as trail length. Despite some results align with the ones shown in the figures on NDVI, these charts present a stronger differentiation when it comes to the actual type of vegetation. Yet, the area shares on snow and glacier should not be perceived equivalent with the previous ones found in the NDVI class containing negative values, as rocks and debris might also fall within this category, as has been mentioned before.

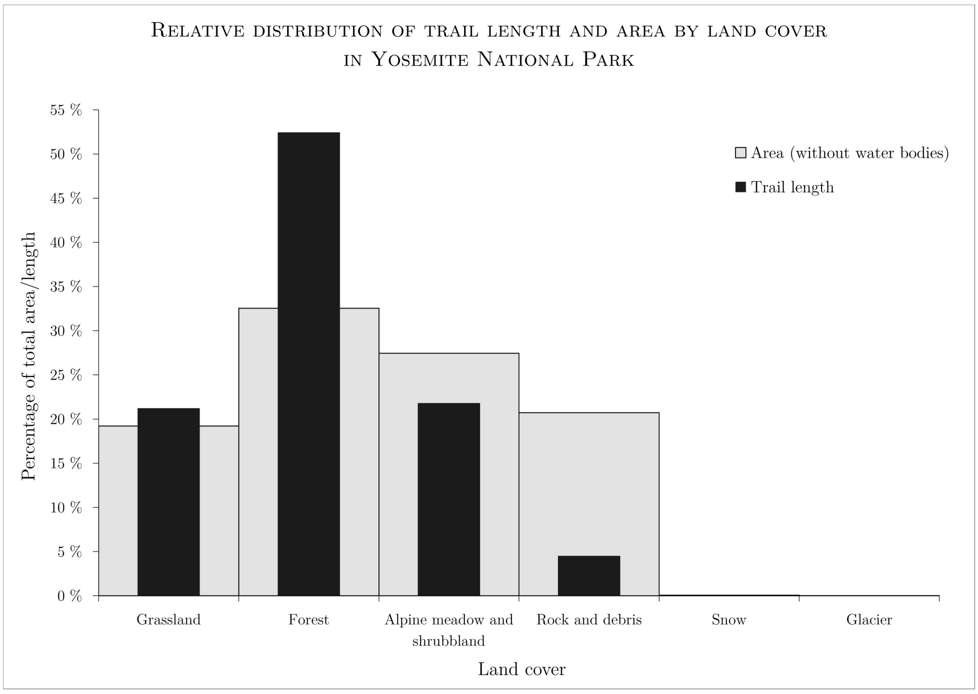


Figure 27: Relative distribution of trail length and area by land cover in YNP.

Though not visible in the chart due to its extremely small proportion, less than 1 % of YNP (Figure 27) are covered by snow and glacier. Continuing with non-vegetated areas, it can be observed that a very small share of trail length is found on rock surface. Consequently, more than 90 % of the total trail length is situated in vegetated areas, with more than half of it found in forests. Turning towards TdPNP (Figure 28), a much larger proportion of snow and glacier surface is found in this protected area, though again no trail is situated within those areas. Yet, once more, around nine tenths of the total trail length is in forests, grassland as well as alpine meadows and shrubland. The highest percentage of all area, however, is found to be rock and debris. On the contrary, HTNP (Figure 29) has more than one third in this land cover type and is the only study site to have trails in snow and glacier areas. Besides rock and debris, alpine meadow and shrubland are the most dominant land cover type. Still, HTNP shows the lowest proportion of forest and grassland, where the same holds truth for the share of trail length.

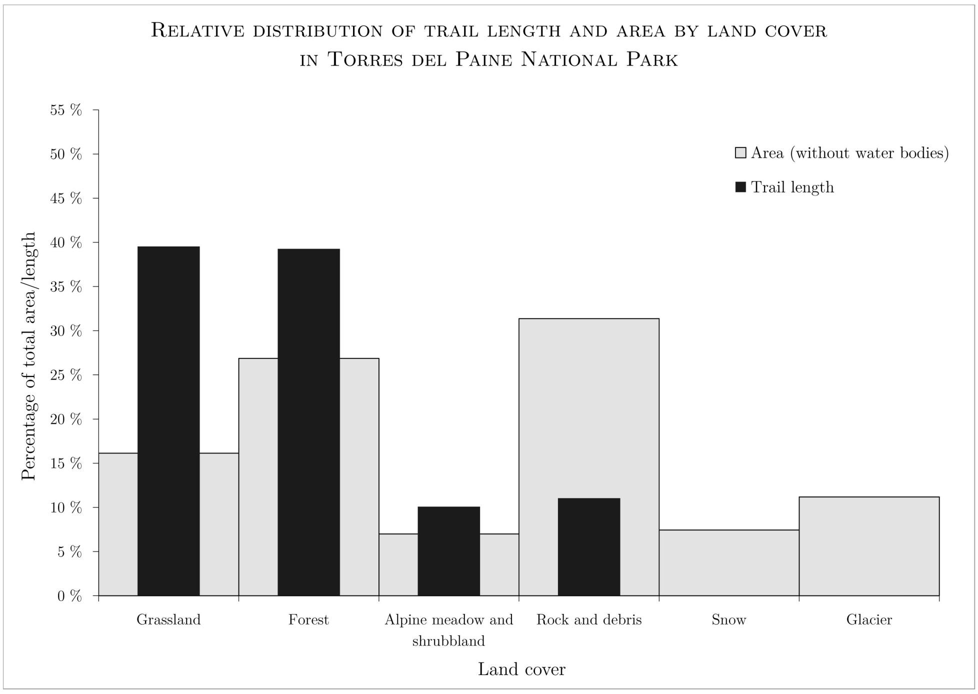


Figure 28: Relative distribution of trail length and area by land cover in TdPNP.

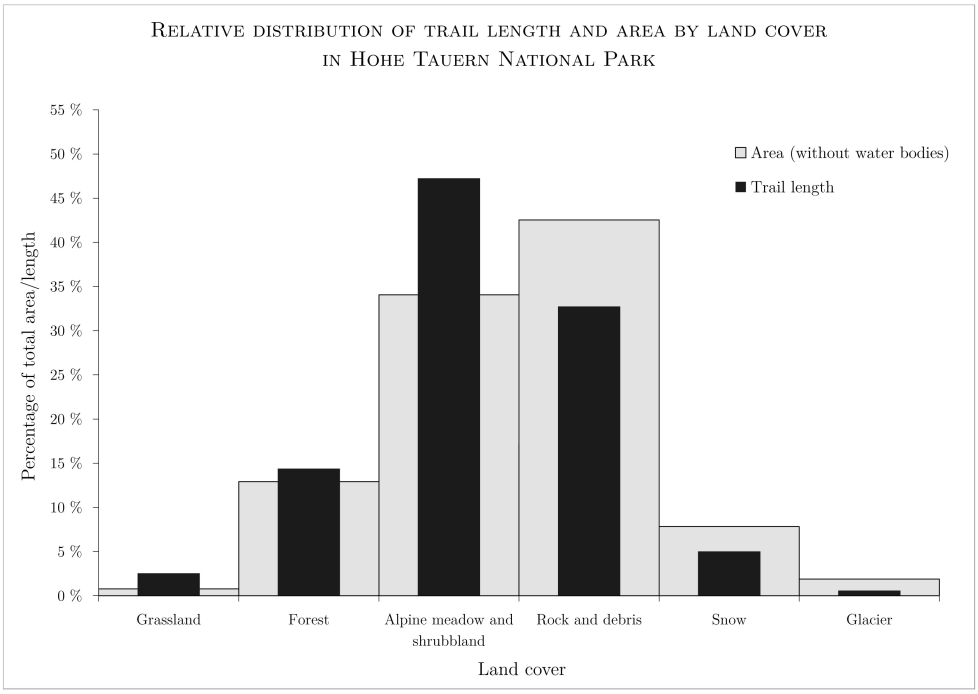


Figure 29: Relative distribution of trail length and area by land cover in HTNP.

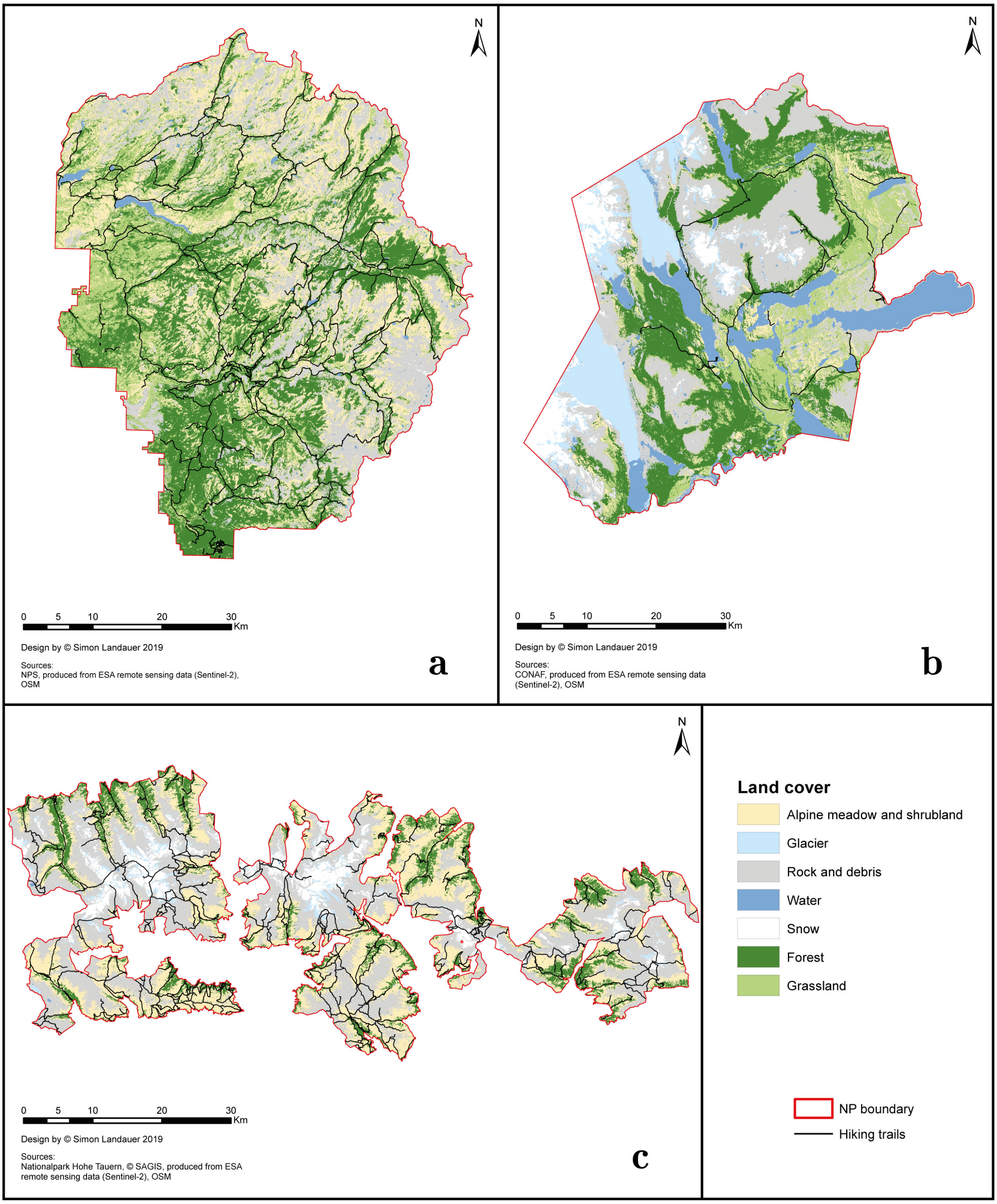


Figure 30: Land cover and hiking trails in YNP(a), TdPNP(b) and HTNP(c).

6.1.5 Soil Erodibility

Though soil erodibility was not evaluated as an individual natural geographic factor and is only included in the final ecolgocial sensitvity, due to reasons expressed in Section 5.3.5, the spatial results from the calculation of the K-factor are only represented for the sake of completeness (Figure 31). Generally, a strong difference in soil erodibility can be observed in-between parks, with values ranging from 0,0005 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1} to 0,04 t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}. White areas represent lack of data for this factor.

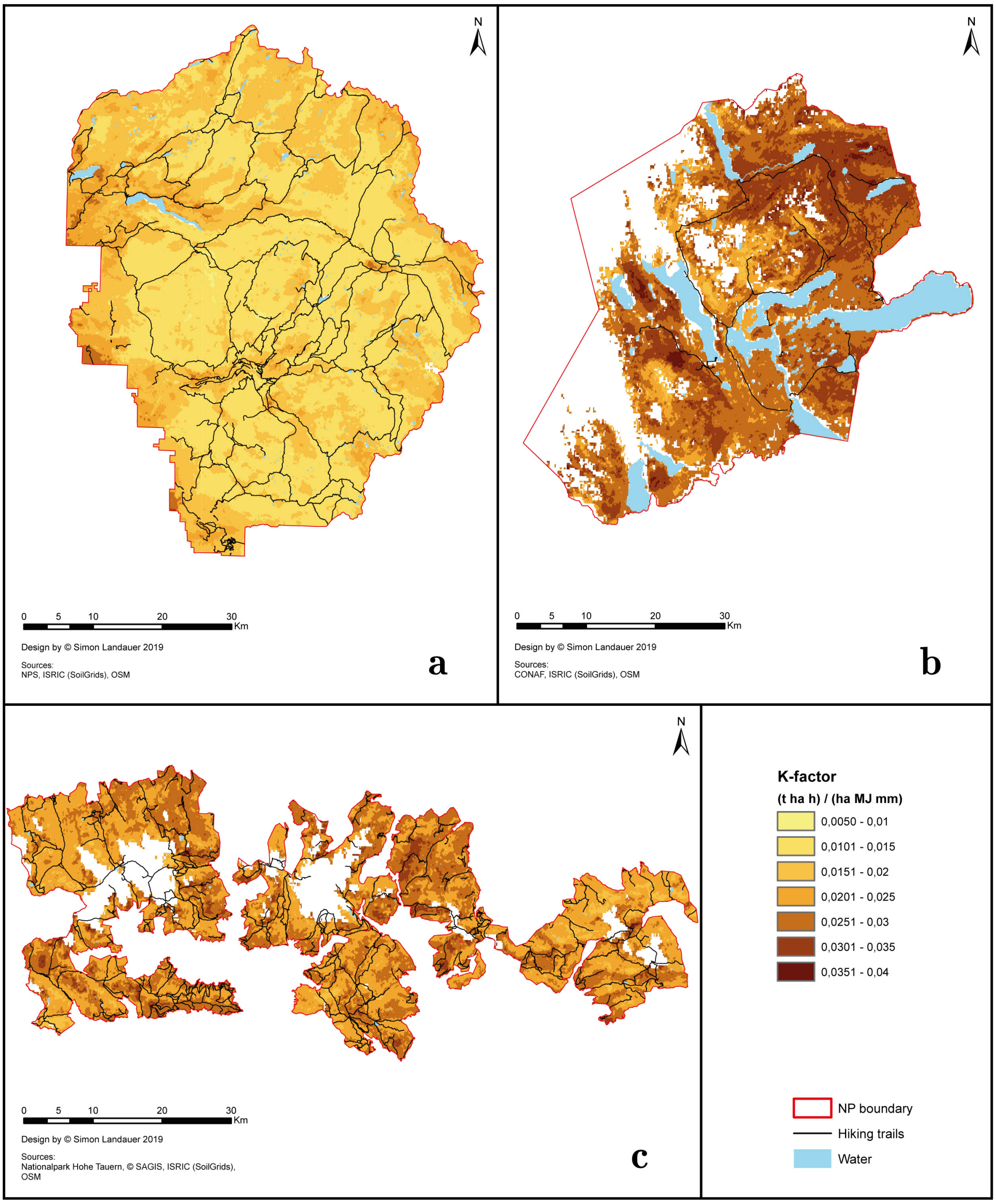


Figure 31: Soil erodibility (K-factor) and hiking trails in YNP(a), TdPNP(b) and HTNP(c).

6.2 Ecological Sensitivity

After elaborating on the individual natural geographic factors and deducing characteristics of the overall trails within the study areas, we may now turn to the outcomes of the analysis on ecological sensitivity within the investigated sites. Aside from the overall results for trails within each national park, the following pages additionally present more detailed images for popular touristic areas within the protected areas. Additionally, the intensitiy of use is displayed by the afore introduced Strava heatmaps.

6.2.1 Yosemite

The majority of trails within this U.S. national park are found in areas of medium and low ecological sensitivity, together making up more than 90 % of all pathways (see Figure 32). According to this analysis, only around 7 % of the total trail length is found on segments of high sensitivity. The remaining two categories, representing maximum and minimum sensitivity each make up less then 1 % of the total length.

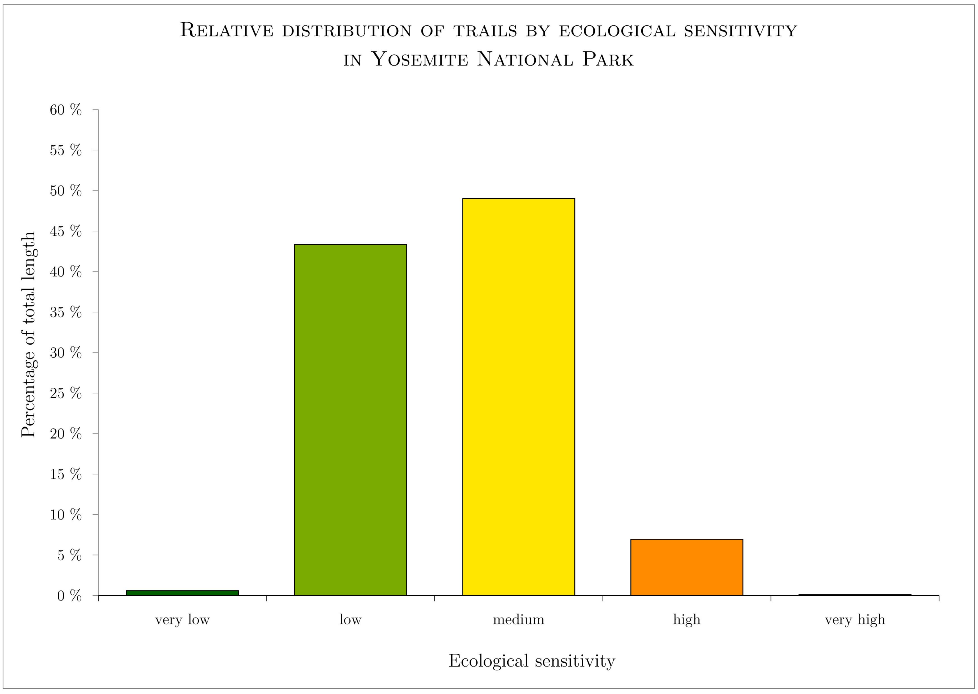


Figure 32: Relative distribution of trail length by ecological sensitivity in YNP.

Looking at the general spatial distribution of ecological sensitivity within the area (Figure 33), larger zones of high sensitivity can predominantly be found in the northern and central sections of the park. To be more precise, this includes regions around the biggest water body within the park, Hetch Hetchy Reservoir, as well as areas stretching east along the canyon of the Tuolumne River, including numerous valleys to the northeast. Furthermore, Yosemite Valley, in the center of the park, shows spots of high sensitivity. Based on the criteria chosen, the region in close proximity to the Tuolumne Meadows, on the central-eastern border, mainly displays low sensitivity. Additionally, areas around Mount Lyell, in the southeast, fall within this category,

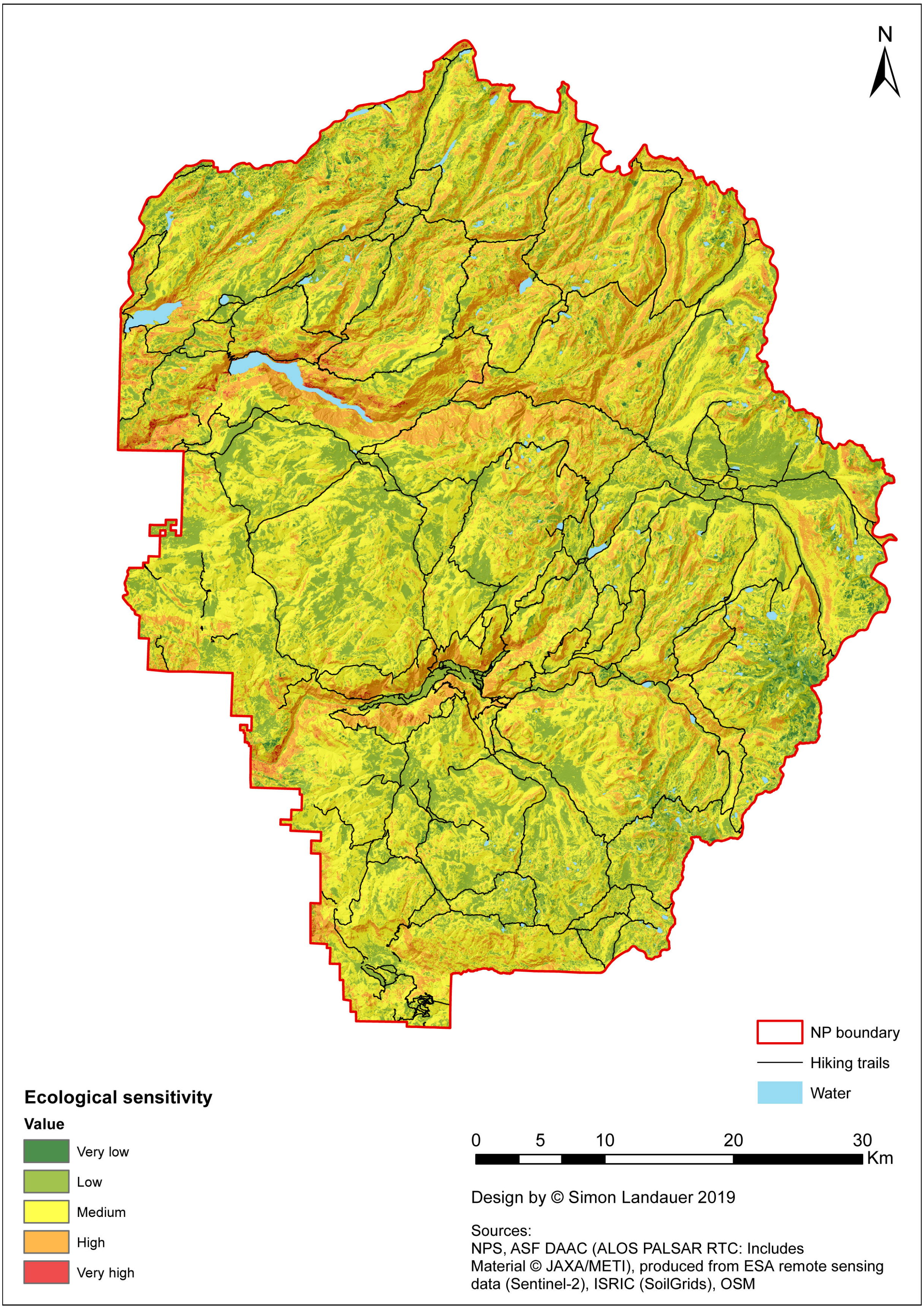


Figure 33: Ecological sensitivity and hiking trails in YNP.

as glaciers were generally considered less sensitive to hiking than other surfaces.

Concerning the intensity of use, it can be observed in Figure 34, that the Yosemite Valley represents the center of hiking activity within YNP. Additionally, the region to the northeast of the famous center can be said to receive a relatively higher visitation than the northern and western sections, which also corresponds to the density of hiking trails. Furthermore, there is another small trail usage hotspot in the very south of the protected area. In general, pathway data from the heatmap covers most, but not all official trails. Reasons for this are explained in Section 5.5.

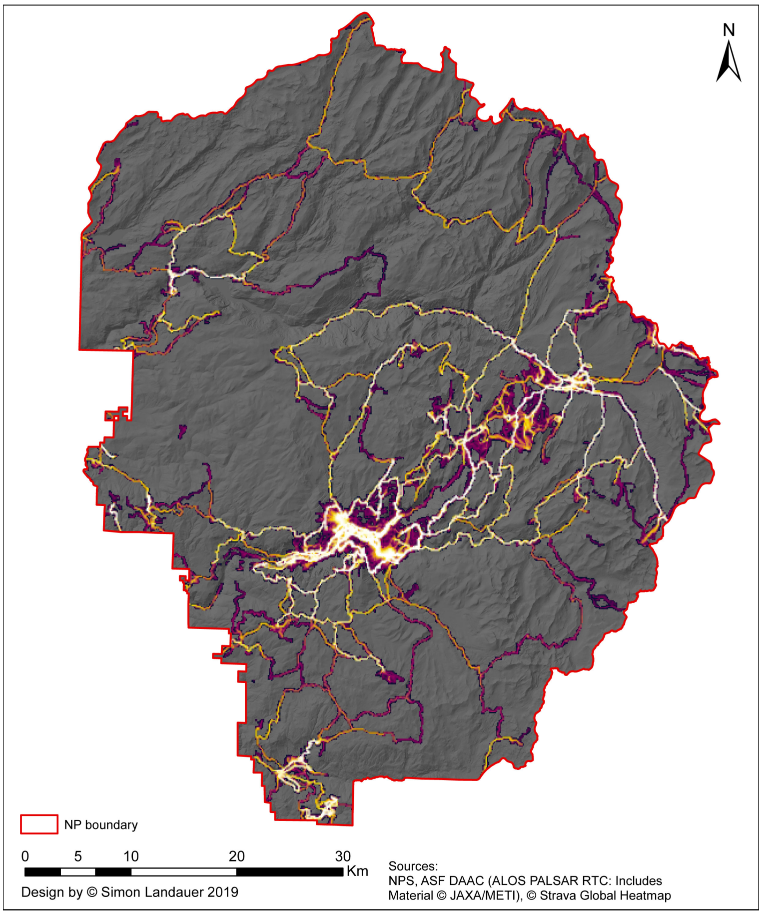
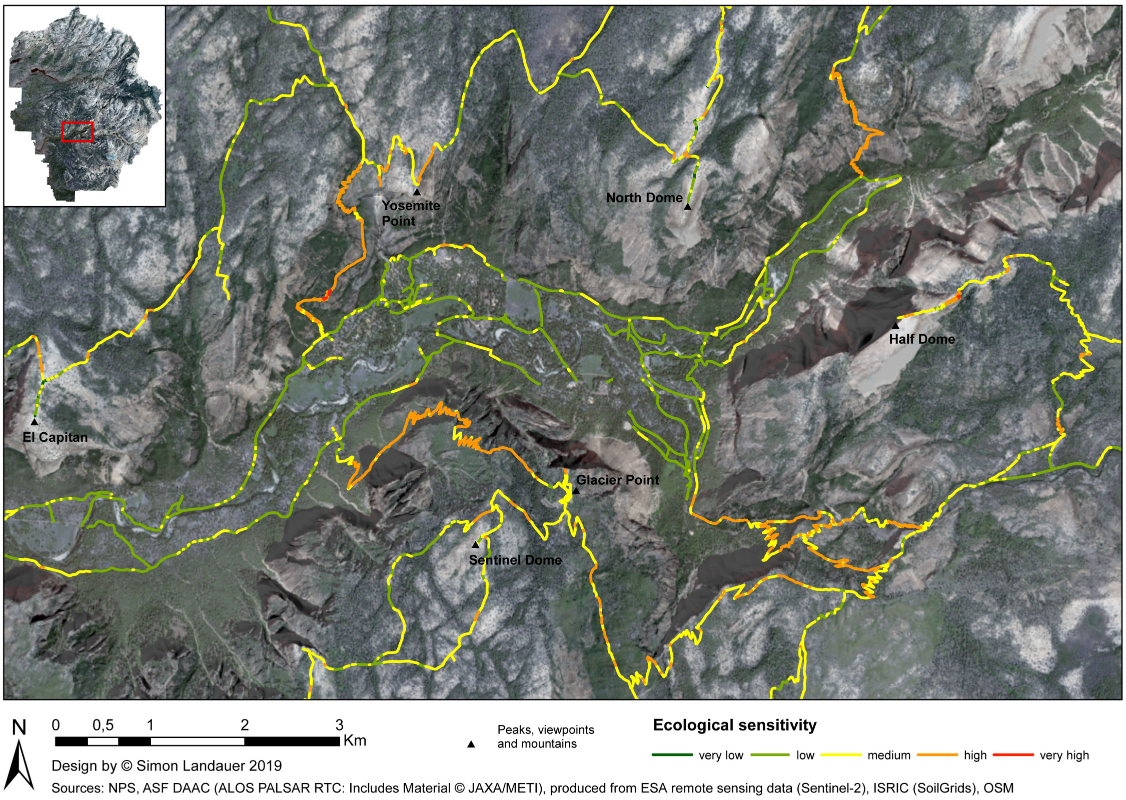
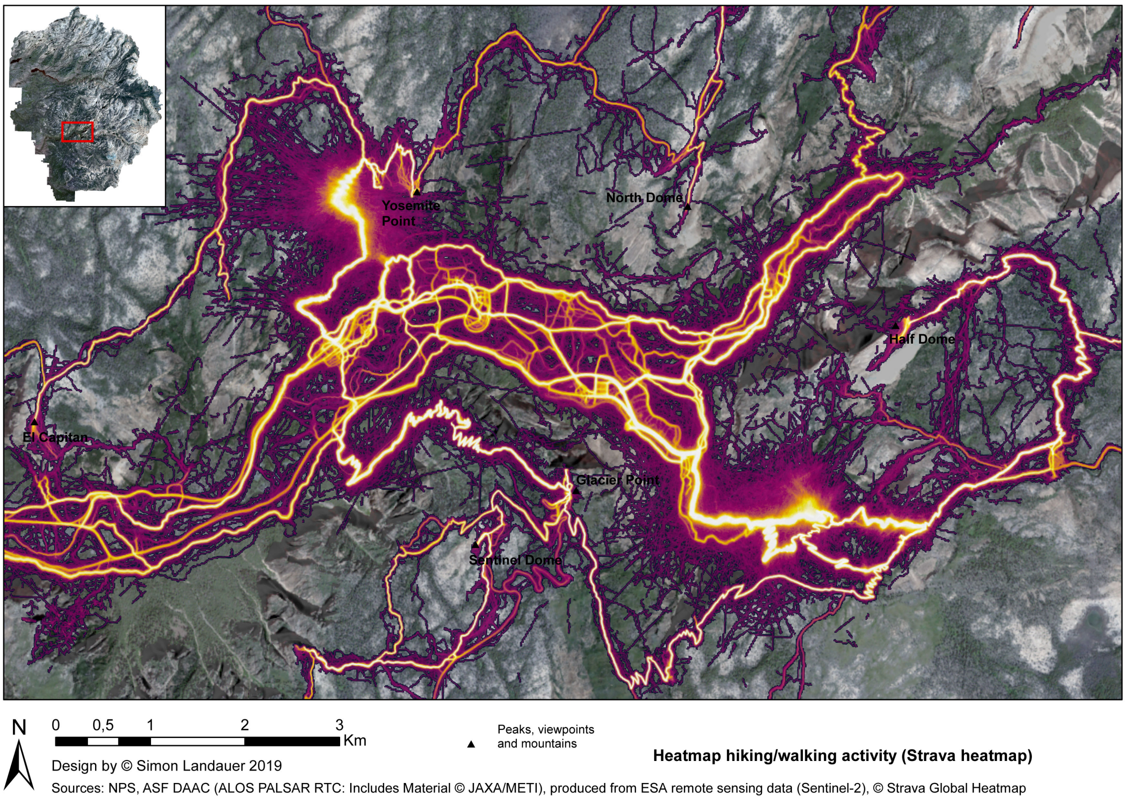


Figure 34: Strava heatmap of YNP.

In Yosemite Valley (Figure 35), the ecological sensitivity ascribed to trails differs strongly based on the trail section. While most trails in the widely vegetated flatter area, the valley bottom, show an overall lower sensitivity, trails leading up steep terrain display a higher ecological sensitivity. Especially, the pathways up to Yosemite Point and Glacier Point as well as parts of the track to Half Dome stand out in this matter. When having a look at the hiking/walking activity heatmap for this region, it can be said that the entire valley experiences a high use; though some sections again stand out, including the ones mentioned before. Once more, it needs to be pointed out that the heatmap also includes activities on roads or bridleways which are not part of the analysis. Additionally, a vast amount of GPS positioning errors can be observed due to the strong effects of shading and reflectance within the valley. Yet, to some extent, the bulk of



(a)



(b)

Figure 35: Yosemite Valley area: (a) showing the ecological sensitivity of trails and (b) depicting the intensity of use based on the Strava heatmap.

signal errors around the trail to Yosemite Falls, Glacier Point and Half Dome is also an indicator for the high amount of people hiking those pathways. In contrast, the trail, also categorized with high ecological sensitivity, leaving the valley to the northeast, experiences way less tourist flux. Same can be said for the pathways leading to peaks of North Dome and Sentinel Dome.

6.2.2 Torres del Paine

Moving on to the Chilean national park, hiking paths can predominately be found in zones of low ecological sensitivity (Figure 36). In TdPNP, around 57 % of the trails are within this category. Furthermore, one third is on surfaces of medium ecological sensitivity, with another 7 % found in areas of high sensitivity. Again, the remaining two categories only feature shares lower than 3 %.

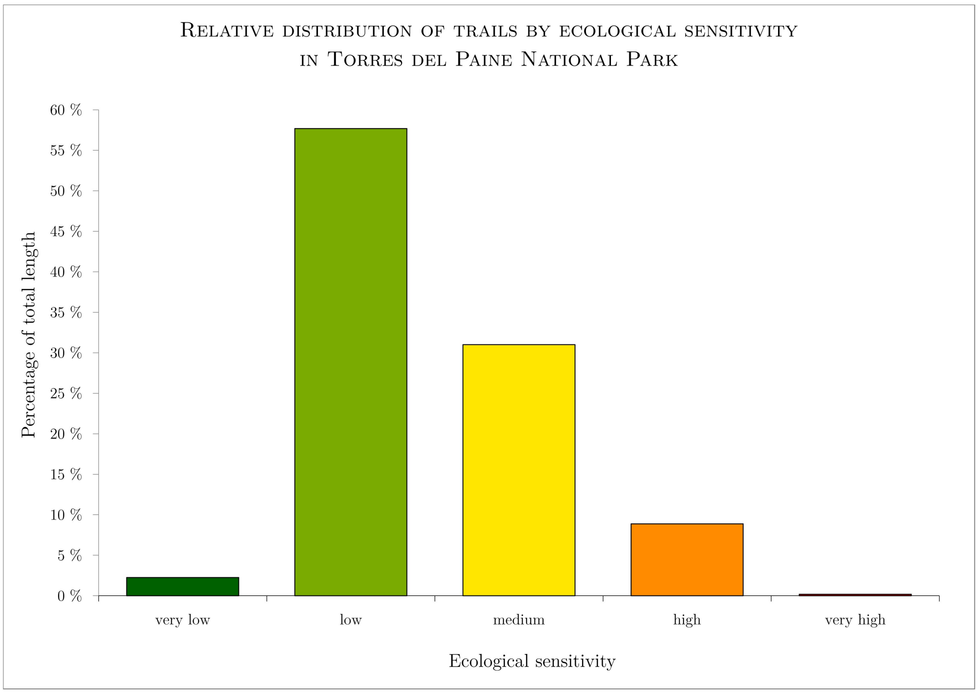


Figure 36: Relative distribution of trail length by ecological sensitivity in TdPNP.

When inspecting the spatial distribution of areas based on their sensitivity level, a few characteristics stand out. First, similar to YNP, glaciers and larger rivers are categorized as having a very low sensitivity to hiking due to reasons mentioned in Section 5.4. Yet, as outlined in the previous section, no official hiking trails (accessible without guidance) run on glaciers. Second, zones of high ecological sensitivity can mostly be found in the center, around the Cordillera Paine in proximity to the W Circuit, close to Dickson Lake and Paine Lake in the north as well as soutwest of Tyndall Glacier in the very south-western corner of the park. However, the latter area does not feature hiking trails. Finally, the predominately flat area in the southern part of the park shows low sensitivity, while the rather rugged area between Pehoé Lake and Sarmient Lake in the east features all levels of sensitivity.

In terms of use it is clearly visible, that the O Circuit and W Circuit experience most

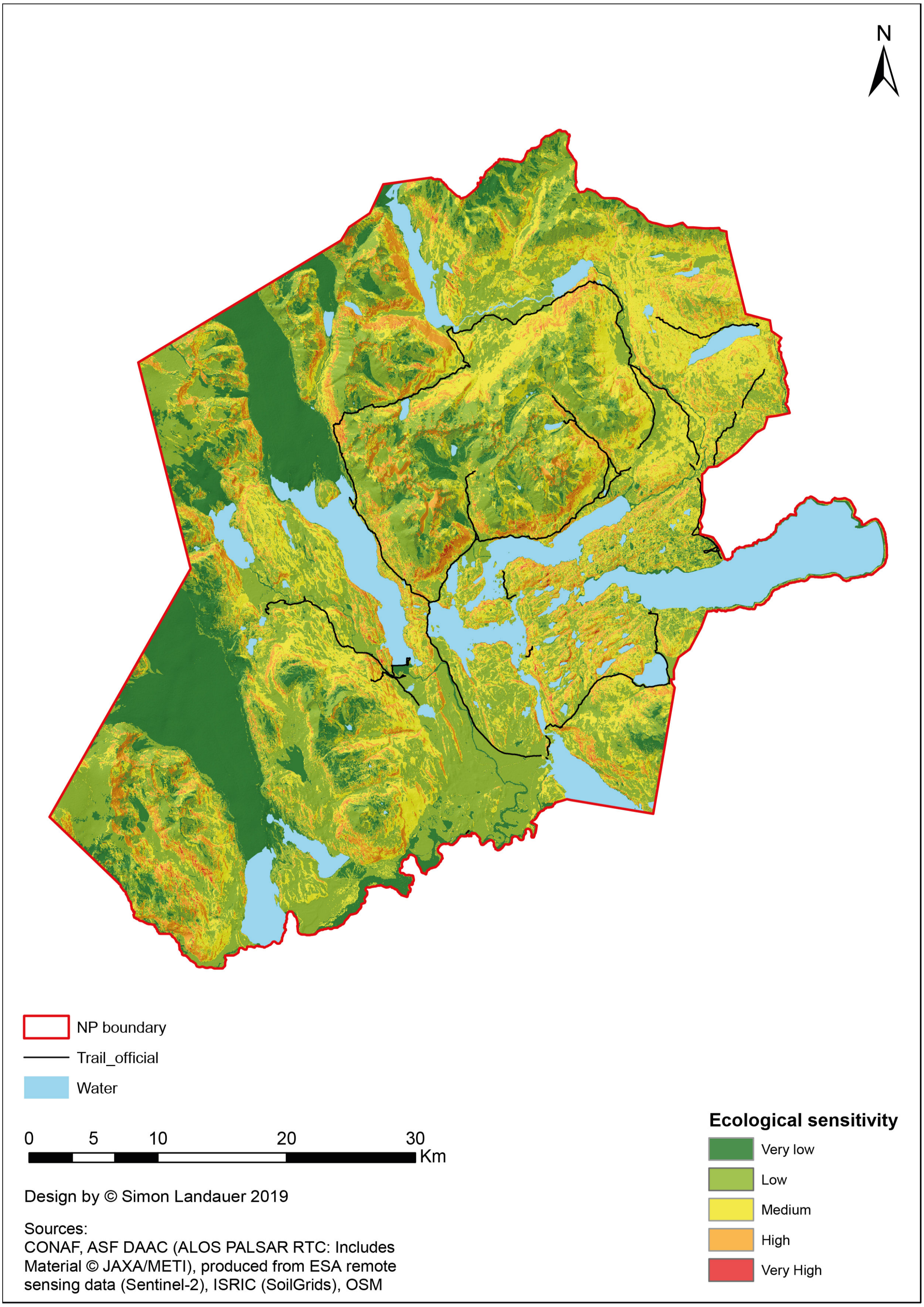


Figure 37: Ecological sensitivity and hiking trails in TdPNP.

hiking activity (Figure 38). Still there are two more intensive areas of hiking to the south of the central mountain range. Interestingly, there are few trails with very limited activity. One aspect which needs to be pointed out is the fuzzy section west of the O Circuit, where the trail actually leads on a glacier. This, and certain other pathways do not appear on the offical trail system (Figure 37), as they may represent guided tours.

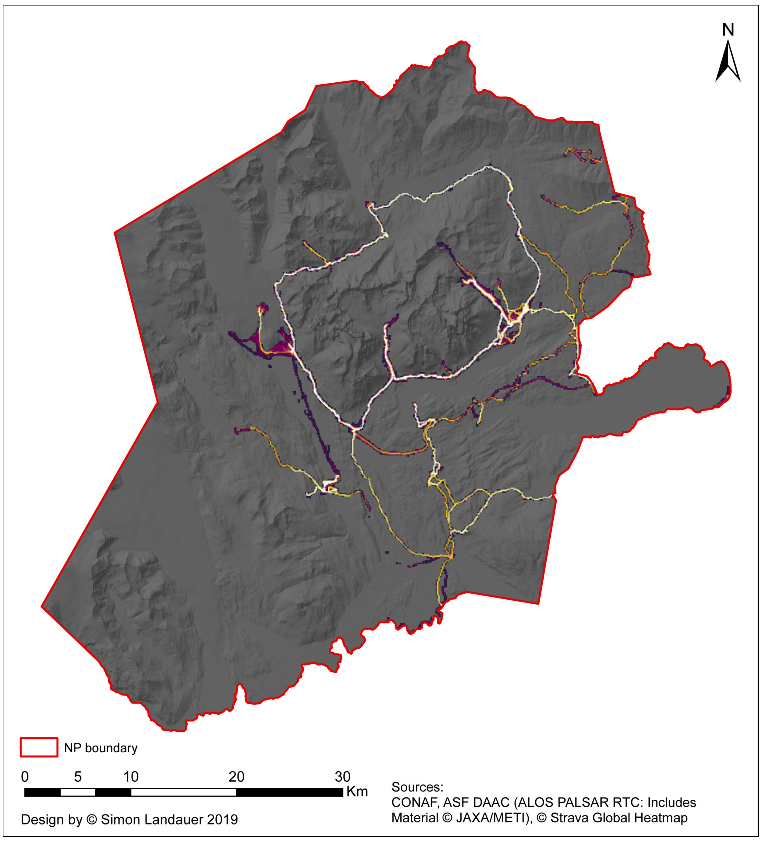
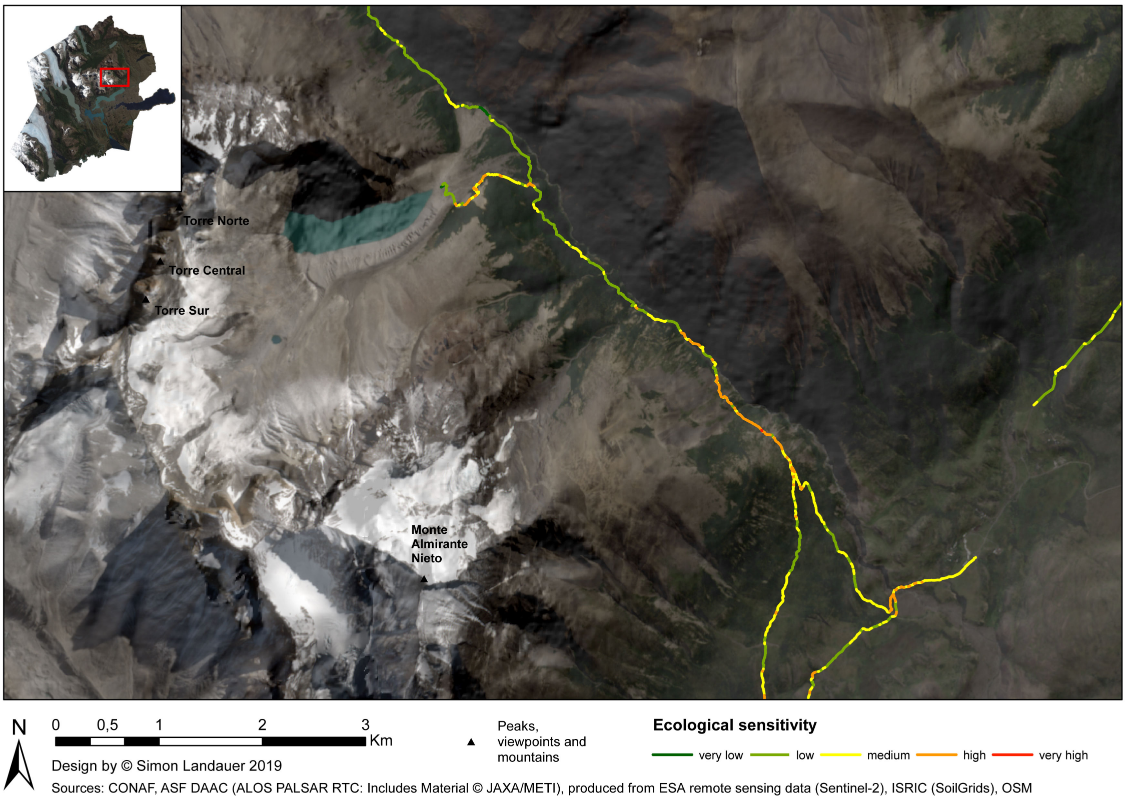
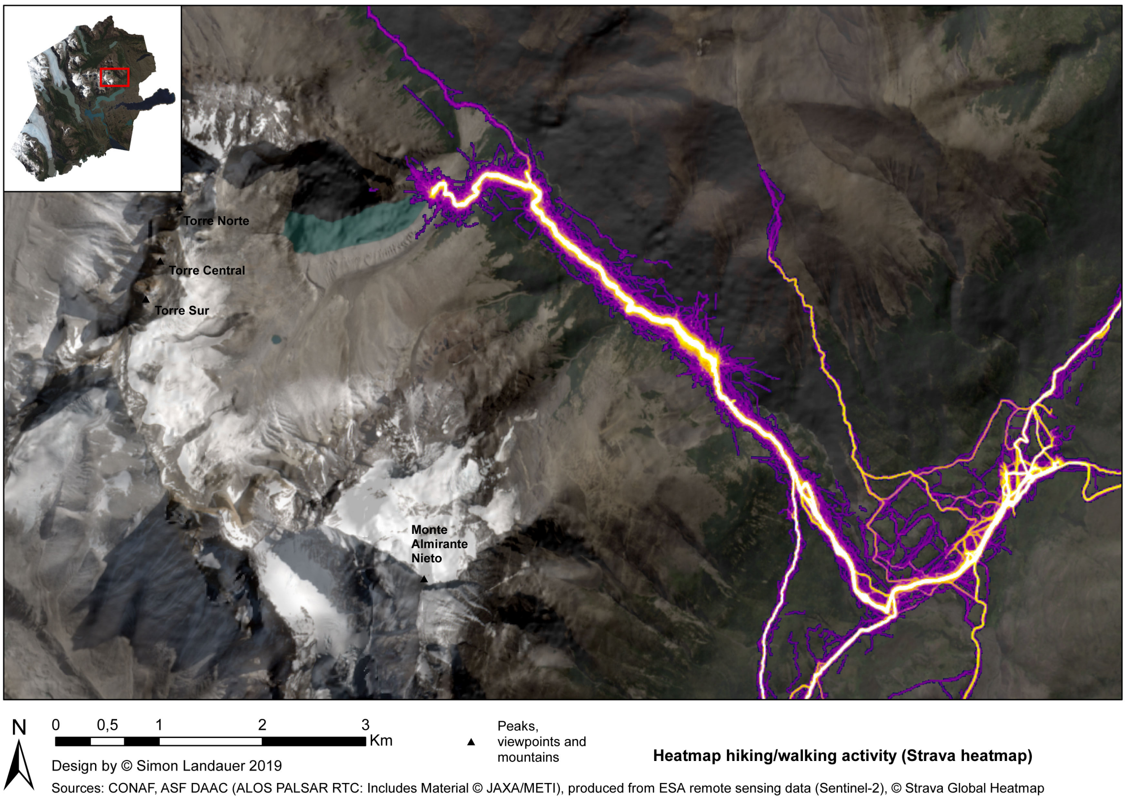


Figure 38: Strava heatmap of TdPNP.

As the three towers, Torre Norte, Torre Central and Torre Sur, are the most prominent features within the national park, extracts on the pathways to the viewpoint Mirador Base Las Torres through the Ascencio Valley are presented in Figure 39. Despite the main part of trail segments feature low to medium ecological sensitivity, there are parts in which high sensitivity is at hand; especially the sections at the southeastern end of the Ascencio Valley as well as the final ascent to the lagoon. The gap between trails in the eastern part of the map can be explained by the fact that they are connected by a bridleway/road rather than a specific hiking path. In the heatmap, the entire pathway leading from outside the valley to the Mirador experiences a high level of use. In comparison, other trails in that region receive somewhat less visitation though being still strongly hiked. Additionally, there are tracks within the heatmap which are not part of the official trail system. Those could either be informal trails or the result of guided tours.



(a)



(b)

Figure 39: Trails to the Mirador Base Las Torres: (a) showing the ecological sensitivity of trails and (b) depicting the intensity of use based on the Strava heatmap.

6.2.3 Hohe Tauern

HTNP shows a broader distribution of trail shares across levels of ecological sensitivity. Within the largest Austrian national park, around one third of the overall hiking path length can be considered to be in areas of low sensitivity; with the medium category showing the almost same proportion. In terms of high sensitivity, though, this park shows the highest share so far, ranging up to around 40 %. Furthermore, the trail segments situated in areas of very low and very high ecological sensitivity each take up around 2,5 % of the total length.

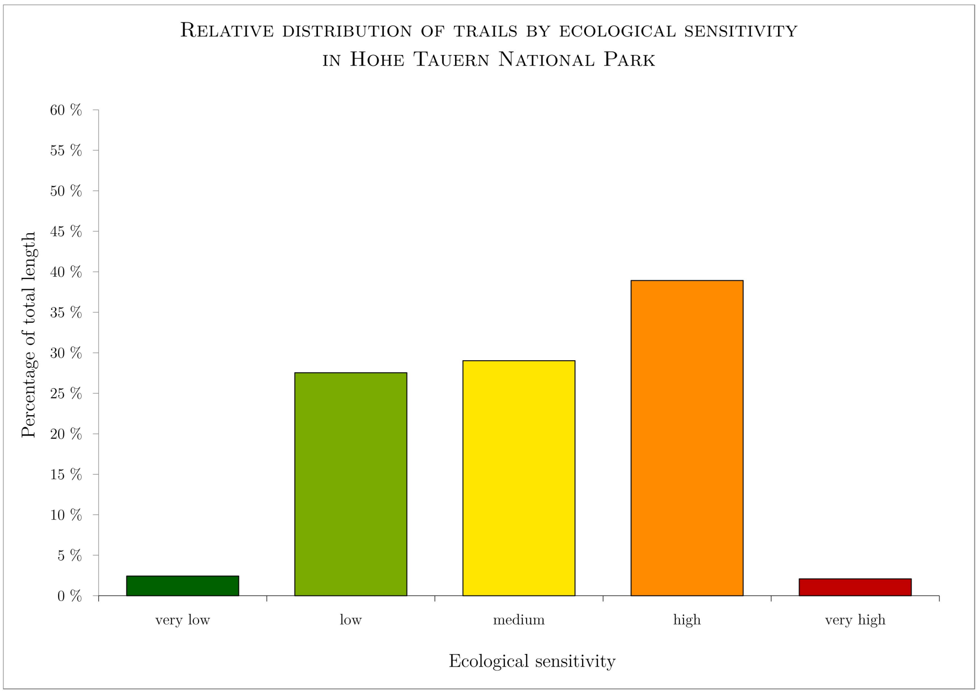


Figure 40: Relative distribution of trail length by ecological sensitivity in HTNP.

Concerning the spatial distribution of ecologically sensitive areas, a vast amount of the park's extent is categorized as highly sensitive based on the chosen parameters (Figure 41). Generally, valley sides within HTNP appear to show a specifically high sensitivity, while valley bottoms display lower sensitivity. This includes almost all larger mountainsides within each of the three separated park sections. Only in the higher regions, rather low ecological sensitivity can be observed, including areas around the Venediger Group in the west, the Großglockner Group and Schober Group in the center, as well as Ankogel Group in the east. Once more it needs to be pointed out, that glaciers resulted in very low sensitivity.

Turning towards the heatmap of hiking activity for HTNP, a different pattern can be observed compared to the other two study areas. Here, though a vast amount of the park experiences use by hikers, there appear to be little to no sections of extremely high usage, as visible in YNP. Only some trails show higher use, often in valleys, recognizable by the yellow colour. Additionally, around Großglockner, in the center, Großvenediger in the west and Hoher Sonnblick in the east, tracks seem to be fuzzy. This may be the result of non strict trail use, where hikers tend to chose their own pathway. Nevertheless, some of those fuzzy representation could also result from the technical limitation discussed in Chapter 5.

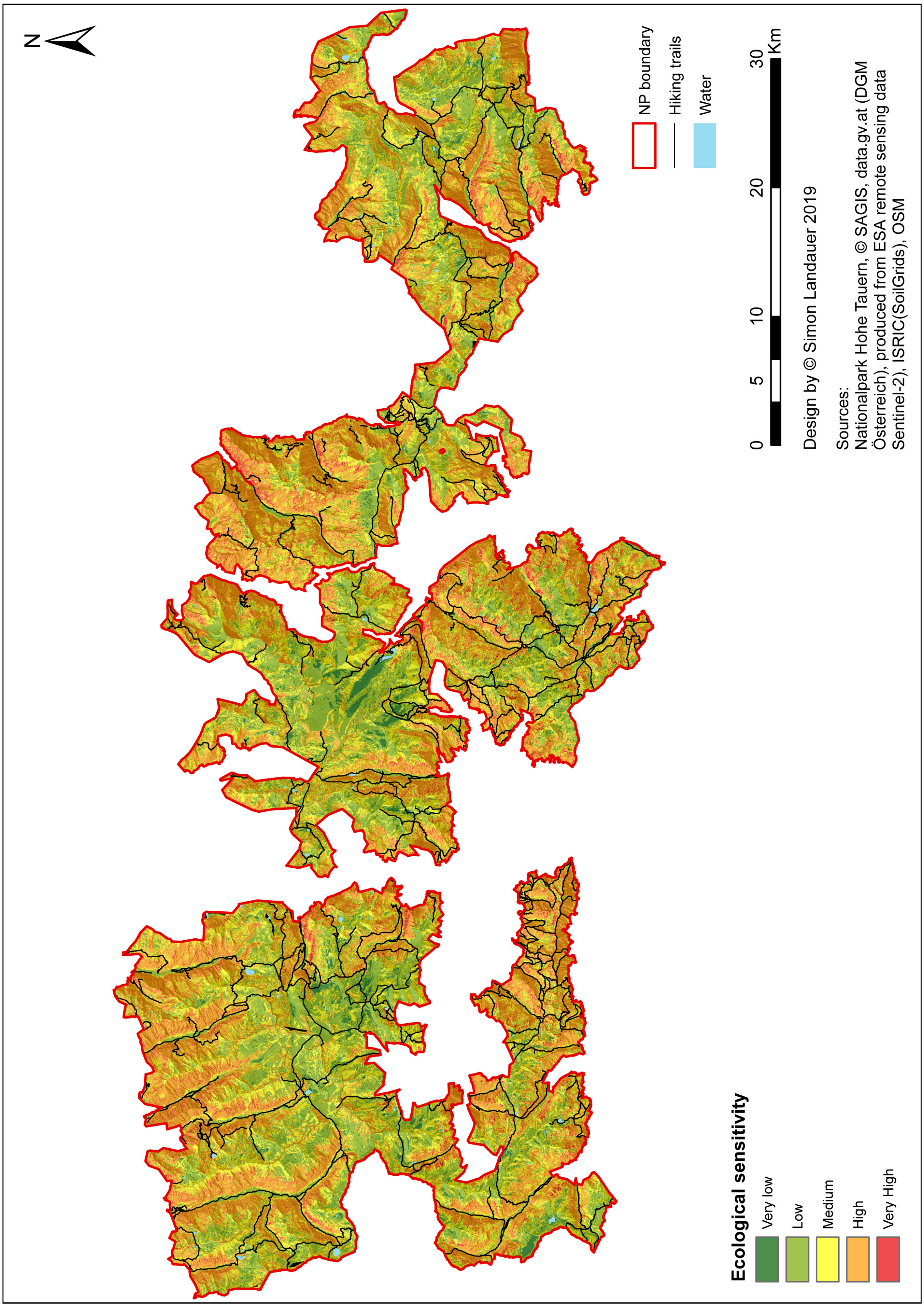


Figure 41: Ecological sensitivity and hiking trails in HTNP.

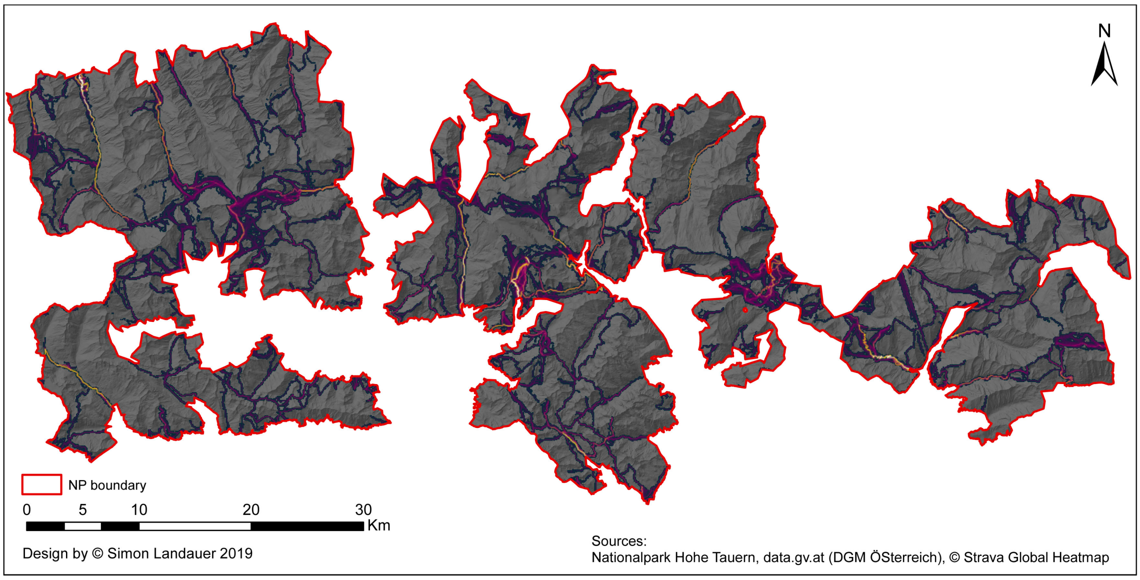
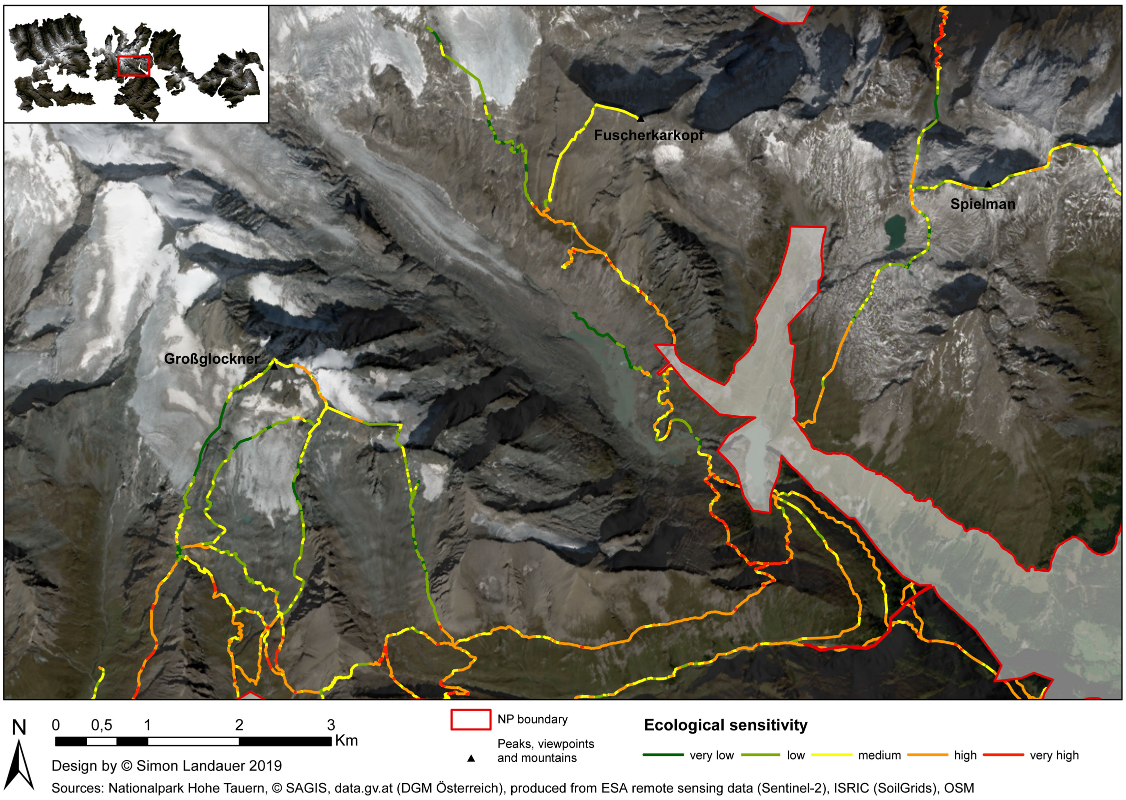
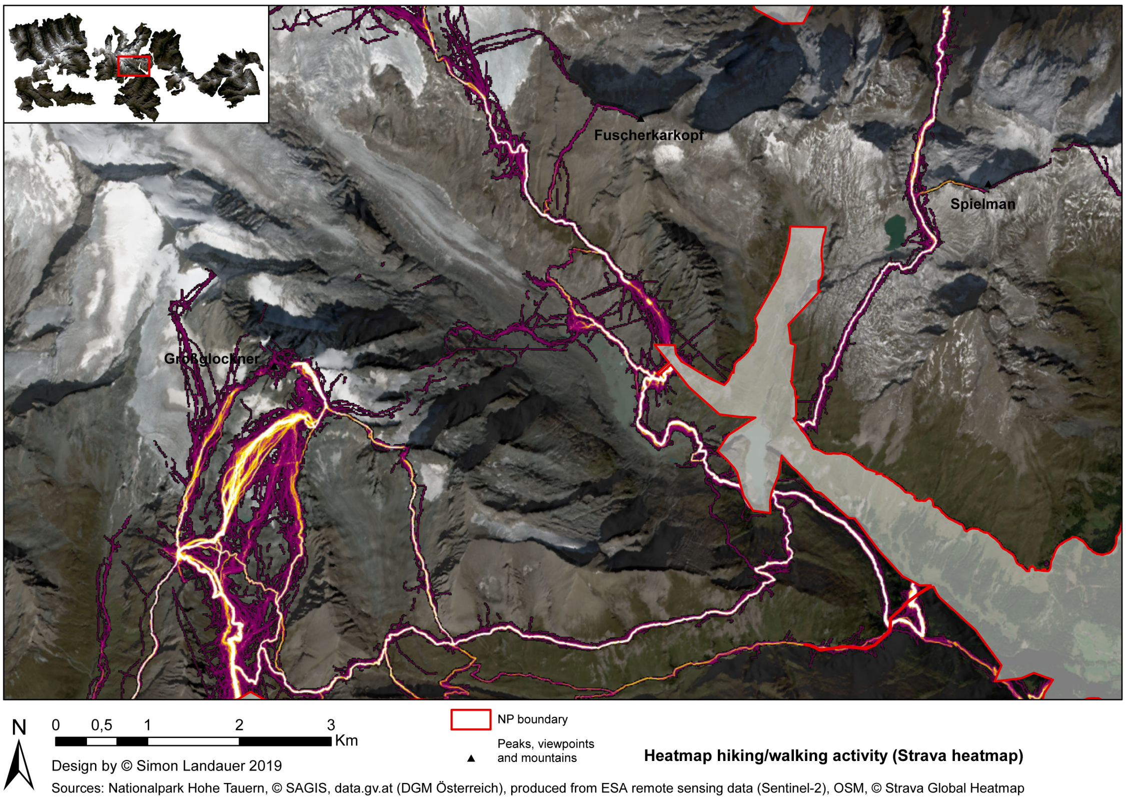


Figure 42: Strava heatmap of HTNP.

Within the area around Großglockner and Pasterze, a high variation of ecological sensitivity can be observed along trails (Figure 43). Pathways leading up to the peak of Großglockner show medium to high sensitivity in lower areas before becoming less sensitive by increasing altitude. Additionally, the hiking paths running along the southern and south-eastern mountainside are characterized by high sensitivity. Same holds truth for the trail leading northwest from the Kaiser-Franz-Josefs-Höhe. Yet, here, similar to the Spielman, pathways are dominated by medium to low sensitivity as elevation increases. The heatmap shows a relatively high usage of almost all trails, though paths to Großglockner stand out. Another area of intense visitation can be found south of Kaiser-Franz-Josefs-Höhe, close to the Sander Lake.



(a)



(b)

Figure 43: Area around Großglockner and Pasterze: (a) showing the ecological sensitivity of trails and (b) depicting the intensity of use based on the Strava heatmap.

6.3 Synopsis

Within the subsequent lines, tendencies and patterns within the afore presented results should be brought together to gain a better understanding of the individual study areas.

Yosemite

Within YNP, most trails are situated in relatively flat, or less steep areas, though being distributed over a large span of heights. Most hiking paths are found in forests. In terms of primary productivity and plant vigour, trails can be said to be mostly situated within areas of rather healthy vegetation. Despite the whole park experiences a rather high usage compared to other study areas, most hiking activity is strongly concentrated around one hotspot, Yosemite Valley, which additionally appears to show areas of high ecological sensitivity. Overall, however, most trails in YNP are situated in areas of low and medium sensitivity.

Torres del Paine

Concerning TdPNP, the majority of pathways for hiking are to be found in rather plane regions. However, most hiking paths are within the lowest part of the park, with only a few in higher elevations, but none close to the highest peaks of the area. The biggest share of the trails is found in forests and grasslands as well as on areas of high primary production and plant vigour. Generally, the total length of trails is very small compared to YNP and HTNP, with the highest proportion of pathways to be found in low ecologically sensitive areas. Though all trails experience a rather high usage by hikers, the highest activity is to be found on the most famous paths around the Cordillera Paine.

Hohe Tauern

Trails in HTNP are found on various degrees of slope, with a higher proportion in relatively steep terrain. Here, hiking paths reach all levels of elevation, including the highest peak. In terms of land cover, the majority of trails are in areas of alpine meadow and shrubland as well as rock and debris. Consequently, a large part of pathways is situated in non-vegetated areas, though the majority of trails is found close to healthy vegetation. In juxtaposition to the other parks, HTNP shows a higher proportion of trails in high ecologically sensitive areas. Generally, however, the intensity of hiking appears to be lower, with only some sections displaying concentrated activity; one being the area around Großglockner and Pasterze.

7 | Discussion

This study provided numerous insights into the issue of human touristic activity and its connection to nature protection in mountain national parks by bringing together general theories and specific analyses. Though definitions and conceptual frameworks exist on the combination of environmental protection and recreation in IUCN category II protected areas, the results have shown that human-nature relationships vary in different parks. The characterization of trails supported an understanding of how sites and park managements approach this relationship.

Within YNP and TdPNP, the dominance of trails in relatively flat areas shows the potentially broad accessibility to non-experienced hikers, where HTNP obviously draws on a broader, more experienced audience of hiking visitors. Usually, higher accessibility may lead to an increase in popularity, which often results in rising tourism impact (Ólafsdóttir & Runnström, 2009, p. 34–35). Furthermore, analysing trails by elevation gave insight into the intended reachability of higher altitudes and peaks by park managements. Here, TdPN keeps visitors at lower heights by not providing public access to major mountain tops, which may require advanced climbing skills. This is additionally important, as areas around summits tend to be subject to increased informal trail creation (Monz et al., 2010, p. 339). Additionally, a general difference in the spatial distribution of pathways could be observed. While the trail systems in YNP and HTNP spread across the entire park area, TdPNP limits visitation to a relatively small corridor of pathways centering around the major attractions.

Though vast amounts of non-vegetated areas exist, the design of trails in YNP and TdPNP appears to mainly lead visitors through forests, grasslands, alpine meadows and shrublands; mostly showing a high primary production. This could be connected to the increasing interest in wildlife watching (Farrell & Marion, 2001, p. 32). Despite not empirically confirmed in this specific study, the generally observed link between biodiversity and primary production should be acknowledged in this matter (Pettorelli et al., 2011, p. 19). Further, however, as vegetation trampling tends to be highest in forests, those areas need special attention (Kolasinska et al., 2015, pp. 31). In HTNP trails rather align with the predominant land cover, also providing for hiking on rock surfaces as well as snow and glaciers.

Yet all study areas have been designated as national parks for at least more than 30 years, the practice of hiking within those parks may date back further. Therefore, the presented characteristics of trails can not be seen as a mere result of management planning activity, but rather constitute a contemporary shot of a historical processes. For instance, though YNP may be the oldest national park of the investigated areas, HTNP may represent the region where hiking activities date back the farthest, due to the long colonization of the Old World, Europe. Here, hiking can be understood as a long existing cultural practice, making limitation of accessibility harder for managements.

Eventually, topography and cultural tradition need to be considered as central factors for the design of trail systems. Just as relief determines reachability, so does a long history of alpinism, such as in the Alps, impact trail layout and legal frameworks. Hence trails in HTNP, for instance, are the manifestation of long term traditions in accordance with natural limitations. In TdPNP, on the other hand, pathways are mainly the result of park planning.

Talking about the presented results on ecological sensitivity, most areas of high sensitivity are generally to be found in sections of steep terrain. The strong influence of topographic factors on sensitivity was also found by Tomczyk (2011, p. 347), mentioning that slope appeared to be one of the most determining aspects for environmental resilience. This might also explain why HTNP shows a larger proportion of high sensitive trail sections, being the only study are which features high mountain relief throughout the whole national park. Additionally, there were barely pathways with very low or very high sensitivity, raising the question of the necessity of those categories. Generally, though sensitivity appeared to be highest in HTNP, a sufficient statement can only be made through the consideration of actual human presence; as trails showed a lower flow of tourists than YNP and TdPNP.

In terms of usage intensity within the investigated areas of this study, it could be observed that despite the vast spread of trail systems within parks, high flux of visitors mainly concentrates on a few sections. This aligns with the findings by Geneletti and Dawa (2009, p. 240), stating that even in large areas, tourism tends to intensify on a few pathways. Within this study, Yosemite Valley and the hike to the Torres del Paine in particular constitute such centers of intensity, whereas HTNP generally features less intense usage. The spatial concentration of tourism not only puts pressure on sensitive natural areas, but may also diminish the quality of recreational visit experience (Lynn & Brown, 2003, pp. 83). Overall, we might assume that this corresponds to international popularity of natural sites. However, in order to assess the potential human impact on the environment, the multilevel analysis helped to identify ecologically sensitive trail sections.

Advantages of the model

The presented GIS analysis provides a simple and cost efficient way of investigating various natural geographic factors and spatial patters of ecological sensitivity, related to recreational tourism in protected mountain areas. So far the quantitative evaluation of trails based on individual factors has barely been implemented, but has proven to contain a high explanatory value. By contrasting shares of overall area and trail length, possible intentions behind trail layout may be deduced and help to understand the relationship between humans and nature within national parks. While this approach is rather an evaluation of the current situation, the analysis of ecological sensitivity can help support future decisions on trail construction. Here, GIS proves to be a well suited tool for planing touristic activity in protected areas (Ólafsdóttir & Runnström, 2009, p. 36).

Given that data is available, the used approach could be repeated for any protected area, due to the standardized procedure. This may be used in order to compare numerous parks of interest, or to conduct an in-depth analysis of an individual park. Additionally, as many processes have been scripted and partly automatized, the computation for other study areas can be relatively fast. Furthermore, in case resources are available, the model can be adapted to provide even more information by bringing in specific knowledge and higher resolution data. This can help management authorities to plan for human recreation while focusing on nature protection within national parks, by spatially identifying areas of high sensitivity. However, the choice and classifciation of parameter for the multilevel analysis continue to be a central subject of debate (Schaller, 2014, pp. 36). With the general increase in the availability of open data, also national parks with limited budget can make use of this model.

Another important aspect is the applicability of the model to large areas. Though there are certain studies focusing on sections within national parks, only limited research was done on entire trail systems. This is of significance, as usually neither recreational use, nor ecological sensitivity tend to be spatially equally distributed (Tomczyk, 2011, p. 347). Consequently, this model provides a way to make those patterns visible for entire protected areas in mountain regions.

Limitations of the model

Though various benefits of the presented study have been pointed out, there are also limitations which need to be acknowledged. First of, the use of GIS in general induces a certain simplification of reality. However, the degree of this reduction is often strongly correlated to the used geodata; an issue also put forward by Schaller (2014) as well as Geneletti and Dawa (2009). Though the most promising freely available data was obtained, higher resolution could potentially improve the significance of the study. Still, this does not only apply to the raster datasets, but also to the hiking trails, where a heterogeneity in sources could result in a more accurate representation.

Furthermore, the quality of some computed datasets, including soil erodibility and NDVI, would need to be confirmed through field measurements in all investigated national parks. Though the chosen equation for the K-factor was found to be the most promising, the input dataset itself needs to be questioned. Here, in situ measurements could help to confirm validity and improve the prediction of erodibility. In this regard, a field survey could also help to evaluate the degree of potential correlations in-between factors. This appears to be an ongoing concern which was also identified by Tomczyk (2011). For example, as acknowledged in the methods, NDVI not only contains information on plant vigour, but also on land cover, which could again be related to potential soil erosion.

Another element which needs to be addressed is the models limitation to the trails themselves, without any incorporation of pathway adjacent areas. Though this was not part of the investigation, hiking activities may also lead to impacts on wildlife and vegetation in close-by areas. This appears to be of importance as off-trail hiking is a pattern generally occurring in all sections of protected areas (D'Antonio et al., 2013, p. 75). In order to estimate such influences, however, precise data on the intensity of trail use would be needed, leading to the last aspect which has to be addressed: the use of the Strava heatmap.

Though providing a good overview on spatial usage patterns within the study areas, the validity of the hiking activity heatmap needs to be questioned. For the reason that no actual values could be obtained on the trail sections, a comparison should be treated with care. Nevertheless, in case those limitations could be overcome, the implementation of such a dataset would lead to an immense potential in an improved analysis of human-nature relations.

8 | Conclusion

The objective of this study was to identify and investigate human-nature relationships in mountain national parks, with a focus on trails and hiking activity as a manifestation of such relations. Further, a model should be developed for analysing and evaluating spatial properties of trail systems as well as ecological sensitivity connected to pathway use in individual protected areas.

Concerning the initially raised hypotheses it can be said that individual mountain national parks show different approaches on the implementation of human-nature relationships based on their accessibility and sensitivity. With the theoretical considerations at hand, trail systems helped to foster an understanding on how park design represents various focuses on the connection of humans and nature, which confirms the first hypothesis. Additionally, as the analysis of trails has proven to hold an important explanatory value when it comes to the spatial identification of human-nature relationships, the second hypothesis was partly verified. Yet, an empirical field survey would be needed to fully confirm this. In terms of the third hypothesis, this paper has shown, that GIS represents a helpful tool when it comes to the spatial identification of aspects and potential challenges related to tourism and nature protection; though general limitations of such reduced representations of reality always need to be acknowledged. By using free open data only, a comparable and easily reproducible method could be developed, which can be used by park authorities as well as other organizations working on protected areas. The IUCN, for instance, could apply the analysis on multiple sites, which could help to understand how different parks approach trail use. Due to the clear and standardized structure of the developed model, the process can be adapted in order to suit specific needs.

Nevertheless, this study has also raised questions which could be discussed in future research. What appears to be of special interest is the consideration of further recreational needs and preferences. For instance, attractiveness of trails would be one element which could help to understand the spatial concentration of visits. In case implemented in a model, this information could help future parks predict potential areas of highly intensive use within the initial planning phase. Furthermore, by using a larger number of factors for the multilevel analysis, including climatic and hydrological elements, one could achieve an even more comprehensive understanding of the investigated areas. Additionally, a temporal comparison of individual parks could provide further information. However, there is one aspect which plays a key role in all decisions, but has only slightly been touched within this research: governance. Without debate, the interplay between humans and nature in national parks has always depended on the prevalent attitude of people in power. Consequently, nature protection and tourism will presumably continue to hold a challenge of human-nature relationships, as needs and wants of both entities are factors variable in time and space.

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