Emiliano Tolusso

CHARTING THE UNCHARTED

Making space for climate change science in Alpine protected areas

FrancoAngeli
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In copertina: Jens Johnsson, *Brown Wooden Arrow Signed*

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Introduction

1. Honor the Promise

How can one define what a protected area is?

She should probably start with searching the meaning of a protected area, finding the goals that this land unit is called to chase, or the natural or cultural objects it stands for.

Over the course of human history, the pulsion of preserving a piece of land from the transformations of anthropic land-use created a plethora of very diverse reserves. However, the mission of every protected area could potentially be different. Protecting a valued game species has been historically one of the main drivers in the creation of some of the eldest protected areas in Europe, as in the case of Gran Paradiso. Or lately, even species we used to consider harmful became the target of legal initiatives that took the form of land protection, like wolves or bears, or lynxes. In some regions, we created protected areas for preserving wildlife from the threat of poaching, as in the Stelvio region, or in some African National Parks. In some country, we created protected areas to conserve even entire landscapes from the perils that the transformative forces of modernity entail, like in Japan. We instituted protected areas because we wanted to freeze in time ecosystems, as the entire US park system was meant to do, but at the same time, we created protected areas because we wanted to lose control of ecosystem processes and see how nature can develop without human intervention, as happened with the first and only National Park in Switzerland. Lately, the science of ecology thought us that what we believed to be an equilibrium was just one moment of transition in an infinite continuum. We decided that nature should be left alone to develop in its own terms, but we also founded new protected areas where paleo-ecological conditions could be recreated in order to test scientific hypotheses, as in the case of the Oostvaardersplassen in the Netherlands.

Protected areas are geographical riddles. They are land unit we are setting aside because we want them to stand in protection of our values, of something we deem worthy of being spared from progress and development. These values took many forms: gene pools, species, ecosystems, landscapes. Values have a history, and they have a geography as well. For this reason, protected areas have been defined with many names: "heterotopic spaces" (Vilsmaier, 2016), "beautiful promises for the future" (Kupper, 2014), "spaces of nature" (Lorimer, 2015). Protected areas are, under a certain light, acts of resistance.

Global change, the large umbrella term used to point at many different processes taking place in large regions of the world, is threatening today the integrity and effectiveness of protected areas in honoring their promises. Of the many wide phenomena that are constituting global change, climate change is one of the most discussed, reported, narrated, and analysed. Climate change is a global threat for protected areas, since there are no walls, fences, or legal shields that can hide anyone from its effects. As a result, some of the values we want to protect, no matter if in the form of iconic species, regional biodiversity or landscapes, are already being compromised. Global warming is teaching us that no ecosystem or landscape can be frozen in time. The same has to be acknowledged for the values we used to associate with protected areas and the natural objects they are protecting. Some of those values are fit to survive the new climate-altered reality, some of those are not.

Regardless the task of the protected area, climate change can transform, sometimes dramatically, protected areas as we know them today. If the task of answering these challenges rests primarily upon policy, park managers and policymakers are helpless without a solid, encompassing contribution coming from science. Building adaptive processes and new management paradigms is impossible without the guidance of science.

Exactly at this point, the geographical inquiry can be developed. Science has been a protagonist in the history of protected areas, and it will be even more a focal point in the future if we are to adapt and keep conserving wildlife, landscapes, ecosystems and the values they embody. However, science, despite being one of the most universal social endeavours of mankind, is not equally practiced everywhere in the world. Science maintain different roles in different protected areas. As a result, there are regions where scientific information is created more frequently. At the same time, different places are following different scientific paths. It is no surprise that Yellowstone National Park is involved in the creation and circulation of studies on wildlife and the effects of climate change and produce scientific research more than any other protected area in the world. Conversely, it is highly surprising that climate change science can be completely excluded by the research activities carried in some protected areas in the Alps. International monitoring initiatives, in the meantime, are promoting the circulation of science beyond borders, and providing us with data and powerful images of the effects of climate change from all parts of the world. It is normal, in our everyday scientific landscape, to see proofs of new pioneer species settling in mountaintops in the Tien Shan Range, while living at the foothills of the Alps. We are accustomed to seeing pictures of glacier melting in National Parks in the Andean Cordillera while we spend time monitoring the upward and northward distributional shift of butterflies' species in the Rocky Mountains. However, we seldom inquire in the precise geography of the distribution of scientific research. Which protected areas in which regions are producing more research? What are the factors that influence distribution? This work aims at filling exactly this gap, with a particular focus on the Alpine range.

2. The geography of climate science in protected areas. From a world-wide perspective to the Alpine range

In a comprehensive paper published in 2017, Bennett et al. delineated the role, scope and aims of what they called "conservation social sciences". In their efforts to promote social sciences as a mean "to understand, improve conservation policies, practices and outcomes" (p. 94), they identified a set of disciplines that can actively contribute to the task. Among them, environmental geography was addressed as the only one focused in particular with on the spatial dynamics that shape conservation. This work intends to find its place in this recent current, as we try to understand how spatial processes and features impact the construction, conduct and circulation of environmental sciences in protected areas. Chasing this goal, we will rely on the epistemological instruments of the geography of science, while inquiring in classical environmental geography field, as conservation.

In the first chapter, we will address the development of the Alps as a scientific region. Starting with the analysis of the main paradigmatic positions assumed by science while studying Alpine environments, we will reconstruct some of the principal defining moments that shaped the path of science in this region, focusing in particular on the role of climate and climate research played in the story. After this initial historical focus, our attention will shift to contemporary research on climate change in the Alps, considering the volumes and the contents of scientific literature indexed in one of the main scientific databases in the world.

In the second chapter, we define the theoretical framework in which the study will take place, namely, the geography of science. This current is rather small in the broad fields of human and environmental geography, but encountered a growing interest lately, thanks especially to recent works addressing the problem of climate change. Having defined the theoretical tools we need to search for the answers we are chasing, we turn our attention towards one of the main methodological tools we need to develop the research, as network analysis will be a fundamental help in gathering the descriptive statistics we will need to understand trends and geographical hotspot in contemporary climate change research in PAs. After defining a large-scale geography of climate change research, we focus on the most significative and productive research region as defined by the data. The United States is playing a leading role in climate change research in the context of PAs, and we will try to gain a better understanding of the drivers and constraints, scopes and aims of research developed in this country. However, the methodological tools are going to change, from a preliminary geo-statistical analysis to a more in-depth qualitative approach, looking for, in Foucauldian terms, the general traits of the institutional and public discourse that is developing around research on climate change un PAs.

The third chapter will be completely devoted to a detailed analysis of the geography of climate change science in Alpine PAs. We will once again turn our attention to the insights that network analysis and science mapping can provide in order to shed light on issues as research composition and distribution. Additionally, we will try to overcome the limits of the scientometrics and metadata-based science mapping, looking for scientific programmes and projects focused on climate change in Alpine PAs. While chasing these very pragmatical tasks, we will test the validity of some theories and ideas coming from the traditional geography of science literature, as questions of "scientific cultures" and "circulation of science" will be addressed.

In the last chapter, we will turn our attention towards a subregion of the wider Alpine macroregion, namely Switzerland, in order to touch with our hands, and beyond the scope and capability of the previous analyses, what are the factors that limits or promote climate change research in PAs, what are the main features of climate change literature produced there, who is conducting research and where. This approach is aiming at a different goal than the previous chapter, since we look for the processes that govern the making of climate science, rather than the tangible products of science. In order to achieve these goals, we will employ a different methodology. The chapter will be based on experts' interviews, conducted by the author during the last year, and will cover a wide range of topics arising from the results of the previous analyses.

It is easy to note that the research will employ a wide array of methodologies, ranging from quantitative to qualitative, from descriptive to critical approach, from data-driven to question-driven. In their work, Bennet et al.

highlighted the broad range of scales and instruments in which conservation social sciences might make their contribution. We firmly believe that a contemporary geography of science – and more broadly speaking, environmental geography – could benefit from the integration of diverse epistemological perspectives and methodologies, that can help in making sense of complex patterns. The adoption of mixed methodologies, however, has a cost. As the reader will certainly note, the chapters differ from one another: sometimes slightly, sometimes heavily. As the tools applied to the research questions change, even the tone and style of the narration change. Chapter 1 will provide a narrative account, while chapter two is based on a geographical characterization of research distribution, and coherently – at least in our view – takes advantage of a descriptive and critical approach. Chapter 3, being totally focused on analysis of the networks of data, employs an IMRAD approach – Introduction, Methodology, Results and Discussion – that is most common in the domain of natural sciences, while the final chapter will employ again the form of a narrative journey through different perspectives provided by diverse forms of expertise.

Our hope is that the diversity of methodologies and styles can benefit the inquiry, without damaging the clarity of the arguments discussed. As Lucio Gambi, an influent Italian geographer used to say "disciplines, defined by more or less precise and encompassing formulations, do not exist. Problems, that are to be addressed with every piece of science available, exist" (Bonardi, 2004). We also hope this research can stay true to this principle.

3. Geography and climate change across the academic space: from the Brit-wave to the Italian case

The relationship between climate as an object of scientific enquiry and human geography is complex and challenging to model. In recent years, climate change studies have multiplied in political, economic, and environmental geography. The recent spike in productivity follows a long period of uncertainty about the necessity of a scientific contribution by the human geographers' community in the broad climate talks. By the time climate change emerged as an environmental, socio-political issue, human geography, alongside a great part of the social sciences, had long withdrawn from climate studies. The British geographer Mike Hulme labelled the phenomenon as "Climate reductionism", which involves:

> isolating climate as the (primary) determinant of past, present, and future system behaviour and response. If crop yield, economic performance, or violent conflict

> can be related to some combination of climate variables, then knowing the future behaviour of these variables offers a way of knowing how future crop yield, economic performance, or violent conflict will unfold. Other factors that influence these future environmental, economic, or social variables – factors that may be more important than climate or perhaps just less predictable – are ignored or marginalized in the analysis (Hulme, 2011, p. 253).

As a result, climate and climatic changes became exclusive domains of the natural sciences, contributing to creating a rift between physical and human geography. The author, profoundly dissatisfied by the outcome of such a fracture, calls for a re-examination of the phenomenon of climate change, the starting point of which is not the natural sciences but the social sciences and humanities "married to a critical reading of the natural sciences, and informed by a spatially contingent view of knowledge" (Hulme, 2008). Hulme's vision became popular among human geographers, and especially in Anglo-Saxon environments, the reworking of climate change as a social, cultural, and political object allowed the social sciences and the humanities to set the basis of a prolific scientific program. Climate change became "one of the inescapable themes of current times" (Aspinall, 2010). In virtue of their peculiar epistemological stance, geographers are very well positioned to contribute to this new, and profoundly interdisciplinary, strand of research.

The new wave of research travelled across the space virtually, as non-Anglo-Saxon departments and researchers embraced the challenge of a profound reworking of the conception of the climate-society relationship. Nevertheless, travelling space takes different times for different spaces and distances. The case of Italian geography, the "academic soil" from which this work stems, is compelling. The scientific community of Italian geography start cultivating a promising interest in climate dynamics and its consequences at the beginning of the new millennium, with geo-spatial (Coronato, 2010; Salvati et al., 2011; Salvati, Perini, 2011), geo-historical, (Bonardi, 2008, Scaramellini, 2010) and political (among others, Leone, 2002; Tinacci, 2006; Canigiani, 2007; Grasso, 2012, 2014, 2016) perspectives. This literary production is capped by the most recent publication of a dense and compelling review of climate change as an object of geographic interest by Bagliani et al., who effectively dissect climate change as (I) a complex dynamic taking place into a structured system, an agent of change for our geographical reality, and (II) an object of strong political interest on the international level.

The Italian geographical community's acceptance of climate change as a substantial object of interest is absolute at this point. Surprisingly, only with the recent work proposed by Bagliani and Pietta (2019) we witness the start of a new reflection on the implications of climate change for the formulation of the scientific concept of "Anthropocene": an encouraging stepping stone toward bridging Italian geography with the ongoing critical discussions about the spatiality and mobilisation of knowledge entailed by the study of climate change. After engaging initially into the underlying scientific discussion on climate change and systematizing climate change as a multi-layered, feedback-charged object of prioritised interest, social sciences, and geography amongst them, should questions the origin of the very knowledge employed in a field that brings together scientists and policymaker at the same table.

This work aims at moving in this last direction. Following the cultural turn in the Eighties, geography should uncover how ideas, knowledge, and social practices are produced, maintained, and circulated, especially in everyday life. Science, like any other human endeavour, can be read under these lenses. What we know about climate change is mediated by science, and by the everyday work of academics, researchers, and scientists. Knowledge is not formed in a void but is the result of constant interaction between social forces and actors, and the environment they live and work in. Our hope is that this work can represent a first step toward establishing a critical reading of the knowledge cumulated and prioritised by the international discourse on climate change.

4. The Epistemological Monster

The Intergovernmental Panel on Climate Change (IPCC) plays a central role in our story. Founded in 1988 within the United Nations Environment Programme (UNEP), an evident example of Boundary Institutions as it works in the intersections of two heterogeneous domains, has a key role in the collection, review and evaluation of research on climate change, without, however, undertaking it directly, a prerogative that remains independent of the central institution (Bonardi, Tolusso, 2017). The IPCC relies (almost) entirely on the instrument of peer-review evaluation as a compass to locate and assess relevant science in a growing body of information. Since its foundation, the organization took a leading role in the research ecosystem, both in affirming epistemic relevance and directing information flows from the scientific domain to the political one. However, working such a key role in bridging two worlds has proven to be non-neutral, as, in the words of Bruno Latour (2001), the institution of the IPCC summoned an "epistemological monster" in the transdisciplinary realm of climate science.

The two systems interact and co-evolve (Vasileiadou et al., 2011), exercising pressure on each other. Policy faces the need to create a selection mechanism for navigating the growing body of climate literature through science programming and funding, while science needs to direct attention and funding towards specific scientific programs.

Noticed the mechanism set in place, scientific communities have been notably proficient in critical analyses. In a comprehensive review of such criticisms, Mahony and Hulme (2010) grouped some categories: critiques of the origins and mandate of the IPCC (I), of the selection of expertise and participation (II), of the governance (III), of scientific consensus and uncertainties (IV), of the impact and influence of the knowledge produced (V). Assessing the first point (I), social scientists questioned the origin and task of the IPCC, as the close encounter of science and policy in a politically charged environment posed threats to the very own integrity of science and science-making, according to some accounts (Boehmer-Christiansen 1994). In a slightly less grave account, Miller (2004, 2007) offered a historical reconstruction of the converging factors that allowed the carving of the space needed for an institution like the IPCC to emerge. Among those, the loss of a socio-cultural discourse entailed by the "globalization" of climate promoted by the earth-system paradigm, alongside with the rise of environmentalism into policy. Accordingly, Shackley (1997) wondered about the IPCC's capacity to define a clear role for itself in a distinct niche outside of the policy process itself. A lively discussion emerged around selecting the expertise (II) needed for the particular knowledge constructed by the IPCC, like many authors (Shackley, Skodvin, 1995; Malone, Reiner, 2001; Hiramatsu et al., 2008; Mahony, Hulme, 2010), as natural scientists – and earth scientists among those – emerged as the vast majority of experts involved in the construction of the reports, overlooking the potential contribution of the social sciences. Disciplinary flags are not the lone bias of the selection process, as the geographical distribution has proven to be sensibly skewed towards developed countries. This geography of scientific knowledge comes with plenty of consequences over the framing and shaping of climate change as a global issue, causing some disregard for the work of the IPCC in developing countries (Bolin, 1991). It is worth noting that in a quantitative study, Vasileiadou et al. (2011) demonstrated that, while IPCC is – citations wise – indeed an epistemological juggernaut, the efforts towards a sensible reduction of its representational, geographical and ideological biases is detectable in a comparative analysis of the different editions of the Assessment Reports.

On the governance side of the issue (III), sociological literature highlights how the organization has been well governed, leading to a decrease of the influence exerted by national governments on climate negotiation and an affirmation of the role of the IPCC; still, this accomplishment came at the price of a gargantuan amount of procedural bureaucracy, with the risk of losing transparency and accountability (Siebenhüner, 2003).

The creation of consensus among scientists (IV) is a delicate process susceptible to different forms of critiques. Scientific literature already remarked that the depiction of the process as a "creation of truth" that marginalizes dissenting voices (Edwards, 2010) does not serve justice to the complexity of the problem. Building consensus is both a truth-making and a community-building process. When the IPCC claims that thousands of scientists reached consensus over a specific topic, such as the anthropic origin of the current changes in the climatic system, is simplifying the issue: specialization prevents such kind of plebiscitary outcome. Expertise is varied and asked to contribute to their very own subject of specialization. In recent history, this kind of communication gave a pretentious occasion to introduce into the public discourse position of open denialism about the IPCC work, and about the reality of human-made climate change. Notably, the creation of the mirror institution NIPCC (Non-governmental International Panel on Climate Change) marked a crucial moment in a collective (and now organized) effort to undermine the legitimacy of the consensus claimed by the IPCC.

Despite the limitations and latent bias of its work, the IPCC changed the structure of climate change research completely and remains at the centre of the scientific landscape for its enormous work. The process and procedures upon which the entire organization is built are perfectible, but none of the critiques could diminish the role and the scope of the assessment provided. Additionally, the Assessment Reports showed a gradual betterment of their shortcomings, as well as the IPCC itself engaged in many public discussions over the issue anticipated in this paragraph. Embarking on any reconstruction of the scientific knowledge available around questions on climate change unavoidably leads to confronting the titan that inhabits the land. Given the task of this work, namely, the reconstruction of a geography of scientific knowledge around the issues brought to the table by climate change for protected areas in the Alps, some of the fundamental assumptions undertaken by the organization are to be adopted, starting from a strict consideration of the peer-review process.

5. Pre-methodological Remarks: the legacy of the IPCC and working on the limits of the research framework

Peer-reviewed literature is assumed to hold the highest scientific reliability amongst informative documentation over complex systemic issues, as in the case of climate change. Despite the many shortcomings of the peer-review procedures, this principle is assumed to be a constant from the IPCC, which seldomly recurred to non-peer-reviewed documents in its assessments.

When it comes down to protected areas, however, the influence of the IPCC is rather undirect. The IPCC itself never conducted a metastudy on the available literature, nor produced any technical guideline. Coherently with the Alpine ecological, biogeographical and morphological features of the region, related reports of interest for our case study regard the forests (AR4, Working group 3, Chapter 9) and the linkages between climate change and biodiversity (Technical Paper 5, 2002). The influence of the IPCC, the knowledge produced and mobilised, and its modus operandi are nonetheless apparent in the guidelines for adaptation produced by the International Union for the Conservation of Nature (IUCN, 2016), that often refers directly to work produced by the IPCC. The two organizations are working on a global perspective, applying the universal principles of science to inform decision making on a broad spectrum of climate-related issues. Nonetheless, both downscaled their effort to produce regionalised reviews and guidelines, even if never on a fine grain. It is of primary interest for a geographic eye to understand the spatial constant and variables of this far-reaching environmental discourse, especially on a regional level, where policies can be downscaled and organised, according to the concept of multilevel governance promoted at the 2015 Conference of the Parties in Paris.

Precisely in this void lies our interest. This work aims at aggregating the relevant scientific literature on climate change in Alpine Protected Areas while analysing the geographic and sociological conditions that mould the shape of this form of knowledge. In doing so, a reasonable (and coherent with the way scientific research is mobilised to produce relevant information) starting point is represented by the analysis of peer-reviewed literature. Such a review can benefit from applying a distant reading perspective, with the help of scientometrics and science mapping.

Scientometrics is the study of measuring scientific research. In practice, it employs bibliometrics, which is a measurement of the impact of publications. Modern scientometrics is mostly based on the work of Derek J. de Solla Price and Eugene Garfield. Methods of research include qualitative, quantitative, and computational approaches (Petrovich, Tolusso, 2019).

Science mapping is a flourishing research topic at the crossroad of scientometrics, information visualization, network analysis, and sociology of science (Börner, Chen, Boyack, 2005; Börner, Theriault, Boyack, 2015; Chen, 2013). It aims to display the structure and dynamics of scientific knowledge by using 2- or 3-d visualizations, known as "science maps" (Chen, 2017).

The approach to science mapping employed in this work is based on the analysis of the links between scientific publications, i.e., on the analysis of citation networks. Citation networks are a useful tool to evaluate the size of a research field, together with the relational properties of the objects (the research articles) that compose it. Another type of science map employed uses the textual meta-data of scientific publications, namely their titles, abstracts, and keywords. These textual properties of scientific publications are a very rich source of information about their content. Thus, they can be used to obtain fine-grained pictures of the structure and dynamics of scientific knowledge (Callon et al., 1983).

These instruments are proven to be very powerful in retrieving, analysing, and representing precise information regarding a research field, but they suffer from some epistemological and procedural limitations that we must take into account. Some of these limitations descend directly from the structure of the publishing system and must be carefully considered: most of the literature indexed in the international scientific databases is written in English, excluding contributions arising from regional and national debates. This implicit operation of linguistic conformation narrows the possible basin of information available, segregating local epistemologies and hiding the fruits of local scientific activities. By the same token, the horizon in the available literature is set by the boundaries of the databases, reflecting the editors' assumptions, epistemic commitments, and policies. The very own boundaries are, to some extent, an artificial border. Therefore, the researcher's central question is how to overcome such limitations and how to interpret the available peer-reviewed data.

A potential answer stems from the field of Science and Technology Studies (STS). STS look at the sociological, epistemological, and political contexts where science is practiced and can provide valuable insights into the interpretation and contextualisation of scientific products. Therefore, scientometrics data are to be considered a key element upon which build a broader conversation with scientists, project managers, and practitioners in the field of conservation. Considering scientometrics as a starting point enable the researcher to scan different channels of research, to measure its results against an always mutating sociological context, and to grasp part of the inner complexity of every science-making process. Reconstructing the (regional) geography of scientific questions requires consideration for different epistemologies, methodological frameworks, and heterogeneous data. Making of these different sounds a coherent language is the main task of this book.

1. From Terra Incognita to a Scientific Region

1.1. Of Dragons and Laboratories. A brief history of scientific interest in the Alpine Region

The unfolding of the relationship between the Alps and Man is a fascinating subject of vast complexity, the analysis of which requires the use of diverse sources. If then the researcher's interests turn specifically to reconstructing the relationship between Man's search for knowledge and the Alpine region, he will be following a thread that unwinds back over the centuries. He must combine the hazardous ventures of seventeenth-century explorers and mountaineers with the great modern centres of research. He must range widely, from the pioneering scientific enquiry of a University of Zurich physics professor, Johann Scheuchzer – who returned from his Alpine exploration with a great many botanical and mineralogical observations, mingled with ethnozoological notes on the taxonomy of the dragons native to the region (Fleming, 2001, p. 21) – up to the construction of forecast models of the distribution of the flora and fauna populations. Science has found in the Alps material that tests its boundaries, drawing it closer to the mysteries that nature presents from the first random observations, the result of exploration in regions no better known than the Arctic or the Amazon, to the organization of systematic projects, and finally to true and active testing, conscious manipulation of the environment in order to explain nature's behaviour by scientific means.

The question of the birth and development of scientific interest in Alpine, and in general mountainous, environments, is engrossing, not only for what we learn of the relationship between mountain and man over the centuries, but also, and perhaps above all, for the light it sheds on the epistemological foundations of science and scientific research. The mountain not only assumes the role of a field of strict application of the scientific method, of a passive setting for testing a method of acquiring information but has also made an active contribution to defining the actual processes by which scientific knowledge is produced.

Although a true definition of 'mountain' remains more or less impossible on the basis of specifying the necessary and satisfactory conditions, the attempt to learn about and describe scientifically the phenomena that characterise mountainous environments has produced various paradigms, influenced by diverse scientific positions, already described elsewhere (Debarbieux, 2001; Brun, Perrin, 2001; Dobremez, 2001). It will, all the same, be useful here to recall what Bernard Debarbieux wrote of the stances assumed by different scientific schools of thought in relation to mountains. Debarbieux recognised four main paradigms in scientific interest in specific topics of mountainous environments. The paradigm of verticality brings together all those research studies on the consequences of altitudinal development in mountain surveys as the structuring principles of the mountains' morphology and processes. Studies linked to the gravitational processes of the slopes, morphogenetic dynamics, the effects of atmospheric stratification, and variations in solar radiation in relation to the altitude, are all covered by this paradigm. By contrast, the paradigm of the spatial system concentrates on the intervening relationships between different phenomena of the mountain environment and hence on their reciprocal influences, searching for evidence capable of justifying a system-wide perspective. Research in ecological and geographical fields belongs to this thinking, in their enquiries into the influences between the components of a single ecosystem and between ecosystems and forms of human use of the environment. While more recent in its development, the paradigm of the mountain as an indicator of global change represents another perspective of fundamental observation. Research here is interested in the mountain as an ideal theatre in which to observe the unfolding of more extensive phenomena, due to growing evidence for the phenomenon studied in the particular geographical context and the more marked instability of mountain equilibrium. Research on climate change fits perfectly into this paradigm. Finally, the paradigm of the cultural construct looks at mountain phenomena under the lens of understanding the mountain as a collective representation. This paradigm, found only in human and social sciences, covers a range of research, from analysis of pictorial art and artefacts as tools for interpreting the representation mechanisms of the community to the adoption of public policies for self-representation in mountain contexts (Debarbieux, 2001, pp. 101-121).

The Alps are an exemplary case of Debarbieux's wider thinking: the Alpine range, in a pre-global age, was the preferred area for the scientific work of European academia, whose research activities, for obvious reasons, did not enjoy the mobility and circulation from which they benefit today. Scientific positions and paradigms that developed in Europe on the study of mountain phenomena were necessarily directed to the most widely known mountain range of the continent. The geographical restrictions thus add up to the symbolic value of the region: the Alps represent one of the most iconic geographical areas of the world, with many examples in European literary tradition of the influence they exerted upon intellectuals from the 17th to 19th centuries. By the mid-seventeenth century, 'the Alps are no longer an unknown and hostile environment, but gradually [have become] a place of travel and an object of interest and veneration, and eventually almost a cult' (Scaramellini, 1995, p. 52), so becoming the object of scientific accounts, such as those of Saussure or Wyttembach, but also the preferred setting for narrative, through the descriptions of, among others, Goethe, Chateaubriand, and Percy and Mary Shelley. European literary culture is steeped in Alpine iconography, in its huge frozen surfaces, its rocky bastions and deep valleys. Perhaps it is also thanks to the difficulty of distinguishing between the intellectual and the scientist that interest in the Alps leads to the supremacy of science, in particular due to the 'discovery' of the glaciers, of which there are vivid literary accounts, such as Mary Shelley's famous diary, written during an excursion to the Sea of Ice Mer de Glace in 1816. Both glaciology and climatology remain fundamental themes in the growth of scientific interest in the Alpine range. On that subject it is possible to retrace – without any claim to completeness – a number of the stages that mark the process of growth and differentiation in scientific work directed at the Alps.

Some of the first evidence of research themes focused on the study of the region can be traced back to 1807, with a scientific contest launched by the Société Helvétique des Sciences Naturelles (Bonardi, 2004), which was concerned about obvious glacial advance and the risks it posed. Really from this moment in time research concentrated upon the formation of a 'glacial theory' in order to give a sense of the morphology of the glaciated areas: moraines, erratic masses, and rounded rocks became objects of scientific observation and fundamental evidence through which the theory of the ice ages took form, thanks to the works of Ignaz Venetz and Louis Agassiz. The Alps thus first became a place of scientific enquiry and – in time – a centre from which the ideas tested here were spread throughout the world. The Alpine region is an open book on the geological history of the planet, gathered in the heart of, from the viewpoint of scientific activity, its most energetic continent.

If the formation of glacial theory remains the first fruit of a scientific programme born and developed in the Alps, it is certainly not an isolated case limited to two of the great figures of the history of science but was quickly interwoven with other disciplines and other scholars. Eduard Richter's studies on the glaciology and morphology of the High Alps are in this sense a perfect example of the growth of the relationship between scientists and the Alpine environment. Richter worked on analysing the forms of the high-altitude landscape in order to reconstruct a 'morpho-history' of the Alps, revealing the coeval evidence of the effects of much more ancient glacial processes. In particular, Richter's studies on the formation, erosion and conservation of cirque glaciers was widely received among the intellectual circles of the early twentieth century, just as a fundamental interest in constructing a systematic knowledge-base of the Alps' high environments can be inferred from his wider studies – linked to a succession of different geomorphological and environmental features rising up the Alpine slopes. From a published report at the start of the 20th century by the geographer Olinto Marinelli we can see how Debarbieux's 'paradigm of verticality' was already evident in Richter's research.

The height at which one can begin to speak of a high mountain varies from region to region and is closely linked to meteoric erosion action (parietal erosion) which can only happen on bare rock; that is, rock that is not covered by a layer of vegetation. A middle-sized mountain is therefore one covered by vegetation (particularly arboreal), whereas the high mountain is uncovered, of bare rock. The boundary between the two mountain regions varies with the latitudes and the different meteoric conditions of the individual mountain systems (Marinelli, 1901, p. 12).

Richter's studies and interpretations were therefore aimed not only at searching for the typical forms of landscapes of different altitudes, but also at tracing their limits, at breaking down the complexity of the mountain environment into subsets with consistent characteristics, while also indicating their possible variations. It is interesting to note how Marinelli himself, at the beginning of his own commentary on the work of Austrian glaciology, made clear the necessity for a fresh approach to this work for the benefit of the mountaineering community (Marinelli, 1901, p. 3), indirectly showing the community scale of the Alps' fact-finding mission, which involved not only academics but also practising amateurs in a scientific dialogue not dissimilar to the formative one at the same period in Germany around the botanical exploration of the Hercynia. With this in mind, through further reports the existence of an established scientific community is clear, interested in explaining the effects of altitude on the natural environment in all its facets. Arrigo Lorenzi had already shown, two years before Marinelli, how the same paradigm of a study linked to verticality was not only glaciological and geomorphological but was made up of other sciences. He provided examples of various research studies, including his own, that proved there were definite limits of altitudinal distribution of living organisms and how such limits – although subject to a general law – always tended to show a certain level of variability. Lorenzi – and the scientists cited by him – was actually stating a law already formulated by Richter in a geomorphological field on a different testing ground, that of biology:

The altitudinal, physical and biological boundaries in the Alps are in general highest in the central regions, higher than in the peripheral regions, which are lower (Lorenzi, 1899, p. 3).

Among the examples given by Lorenzi, the studies carried out in the field of vegetation by the Swiss botanists Heer, Stebler and Schröter stand out, as do the observations on fauna by the zoologist Friedrich Zschokke, also Swiss, all eminent personalities in the scientific panorama of the early 20th century who are an integral part of a trans-national community formed around the study of the characteristics of verticality as a founding principle.

If the dominant scientific position seems clear from the accounts given here, having developed independently through the course of scientific enquiry into Alpine conditions, a further step towards understanding the growth of scientific knowledge in all its complexity can be made simply by widening our observation to regions outside the Alps and showing how paradigms, scientific methods, and practices were already able to circulate in different geographical situations. The Alpine community is one of several active scientific communities committed to developing explanatory theories on the complexity of the natural environment. Since the Alpine scientific community belongs to a wider circle that is already to some extent interconnected, it receives information emanating from outside which is then adapted to its own context. Research studies on the boundaries of species' spatial distribution are certainly not new in the scientific panorama, which back to the time of Humboldt's explorations have shown consistent threads of interest in the subject. The study of plant and animal distribution became a central element in the new science of ecology and developed into a fundamental subject in American ecology following Clinton Hart Merriam's research on Life zone theory, further developed by Joseph Grinnell. The influences of the new discipline on the Alpine region were not however limited to basing it simply on the paradigm of verticality, but encouraged a push towards new subjects of research. The theory formulated by the Darwinist Ernst Haeckel directed the scientific community's attention for the first time towards the study of the relationships between living organisms and their environments (Keller and Golley, 2000). In his inaugural lecture at the University of Jena he defined with the term 'ecology':

the body of knowledge concerning the economy of nature – the investigation of the total relations of the animal both to its inorganic and to its organic environment; including, above all, its friendly and inimical relations with those animals and plants with which it comes directly or indirectly into contact – in a word, ecology is the study of all those complex relations referred to by Darwin as the conditions of the struggle for existence (Stauffer, 1957, p. 141).

Haeckel's paradigm met with considerable academic success, leading to the spread of the science of ecology into all the major European and North American universities. The figure of Karl Möbius appears as a central element in the development of ecological enquiries, thanks to his formulation of the concept of biocoenosis. Mobius' observations, directed to the study of banks of oysters in different geographical contexts, – from the seabed of Schleswig-Holstein to the estuaries of English rivers – drew attention to the idea of 'community ecology', based upon the co-presence in the same environment of more populations belonging to different species, linked to each other by functional relationships. Ecology still lacked a definition, and so of scientific attention structured for a programme of research towards such a community (Möbius, 1881, p. 723). The concepts of biocoenosis and interspecific relationships between different populations became central to ecological research, providing a pattern for interpreting the complexity of the environment and at the same time an interpretative paradigm. At this moment in history, ecology adopted the aim of describing living communities and their relationships, a mission which would be followed, with several variations in its formulation, up until the paradigmatic revolution of Arthur Tansley and the introduction of the idea of ecosystems.

Against the background of Möbius' theory, the Swiss botanist Carl Schröter, whom we mentioned above, was carrying out his own research in the Alps. Continuing the theory of biocoenosis, in 1902 he introduced into the literature the term synecology to identify that thread of study which was not only concerned with examining the relationships between organisms and environment – the field of autoecology derived from Haeckel – but with the relationships between different communities of organisms and their environment. Schröter therefore concentrated upon the systematic classification of the Alpine flora and paid particular attention to the description of the phenomenon of ecological succession, consisting of the gradual transformations that occur within biocoenosis themselves, which – according to the interpretation of the botanist Frederic Clements – tended towards a state of optimum ecology termed climax (Kupper, 2014). From an epistemological viewpoint, the study of spatial variability of the Alpine environments was thus enriched on the temporal level, while the attention of Alpine research was centred for the first time upon the functional relationships between different elements, accomplishing a fundamental step towards the affirmation of Debarbieux's second paradigm, that of the mountain as a spatial system. Schröter's studies found practical expression in the newly born interests in the conservation of the natural environment, with the founding in 1916 of the Swiss National Park, which represented a unique case in the world panorama at the time of its foundation, in contrast to Yellowstone Park for the central importance of scientific knowledge in the conservation aims adopted. Carl Schröter was entrusted here, together with Friedrich Zschokke, with the task of drawing up assessments of the ecological needs of the area to be protected, at that time identified between Val Cluozza and Val S-Charl in Engadina. Once the area for protection had been established, the fundamental influence in constructing a research agenda remained in the hands of Swiss botanists. Schröter applied his own research perspective to the park, seeking, paradoxically, to show that without human intervention the succession would basically be 'evolved in reverse', restoring pre-anthropic biocoenosis. The park was a site of observation for him to prove his own hypotheses, an experiment in rewilding ante litteram in which to verify several conjectures that remained too dependent on theory rather than long-term empirical evidence (Kupper, 2014). For the first time, the Alps were home to an open-air laboratory in which to test ecological theories, whose value could be a resource for observing Nature's behaviour in a space segregated from human influence. The park formalized the natural sciences' need for a physical space in which they might justify their own work by guaranteeing the integrity and consistency of their observations, in imitation of laboratory sciences and the scientific and experimental paradigms that the latter had constructed in the 19th century (Livingstone, 2003; Kupper, 2014).

In this way, as the Swiss National Park took on the role of a laboratory for the study of the Alpine environment, the whole region gradually assumed a similar role for the study of natural, and to a lesser extent socio-anthropological, phenomena in mountain contexts throughout the world from the 1970s. The history of science in the Alps is not just a history of ideas, but also a history of the birth and development of the institutions concerned with science in the 20th and 21st centuries. In this sense the foundation in 1912 of the Institut de Géographie Alpine at Grenoble represents an important step in the institutionalization of research. In 1925 the Institute's scientific work was already branching out in a variety of different research interests, which embraced physical and human geography, confined on the whole to the national boundaries. Historical accounts tell of an authoritative institution, at once constituting a model for the scientific exploration of the Alpine situation:

> Much still remains for the French to do before they can complete a picture that summarizes the natural and human conditions in their Alps: but the great love that they sustain for their mountains, the tenacity with which the relevant studies are begun and conducted to the end allow us to hope that in the not so distant future the Alps will have given up even their most recondite secrets to the eyes of these passionate enquirers. The Government, administrations, citizens, all are working with faith and enthusiasm on the Alpine problem and numerous journals (….) are competing to publish articles and findings, while the Revue de Géographie Alpine publishes every year a complete bibliographical review on the Alps (Landi, 1925, pp. 8-9).

Among the many scientific activities promoted by the new research institutions in the 1920s and 1930s is included the project of surveying the glaciological data. The link between glacial spread and climatic variations was certainly not unknown, but now for the first time the idea was voiced of monitoring the variations in the ice-fronts not only on the wide climatic scale – in order to explain the main causes of high altitude morphology – but on the annual meteorological scale, with the aim of observing close up the short-term behaviour of the glacial systems. In this context are seen the many regular Italian accounts published by Umberto Monterin in the Bollettino Glaciologico Italiano (Monterin, 1925-1935). Further, in a special publication, Monterin tackled the subject of the historical fluctuations of the treeline, on the basis of a spruce trunk recovered after the retreat of the Verra glacier in Val d'Ayas. Monterin not only resumed contact with the wide temporal scales of the scientific community's first contacts with glaciology, but also part of the paradigm of verticality, which became associated with the study of natural climatic variations. In the publication he speculated on the origin of the find, hypothesizing that it was part of a forest that could be localized at least three hundred metres higher than the site of the find. This therefore was evidence of a warmer past in which the arboreal line was much higher, allowing with a fine margin of confidence the dating of the growth of the tree, ascribed to the 17th century. This agreed with observations made by Venetz in Vallese on the altitudinal limit of the cherry tree more than a century earlier (Monterin, 1936, p. 23). In the systematic nature of Monterin's observations, notes and study methods we can today trace the precursors of the advent of modern climate sciences, which were also to be applied to the study of situations geographically far from the Alps.

The metaphor of the Alps-laboratory was consolidated in the following years and gained full recognition in the 1950s and 60s with the development of different scientific traditions in European universities (Scheurer, Sgard, 2008, p. 29). They saw in the Alps a concrete possibility of observing different environments on a scale that was spatially limited and clearly definable, and this led to a proliferation of studies in the fields of botany, geomorphology and soil science. The Alps became a model for scientific research in the world's mountain contexts, used both as a source of terminology in comparative research and as a database of evidence for the development of study methodology. The increase in the volumes of scientific work on themes linked to the Alps was to be one of the greatest growth phenomena in the scientific communities of Europe and North America, which in the years after the Second World War saw constant growth and at the same time increasing specialization of disciplines; this gradual transition led – in the words of the scientist Derek de Solla Price – from a situation of little science to one of big science (De Solla Price, 1963), and in this the Alpine region was no exception. In the Alps the transition not only consisted of an increase in the number of scientists involved in the processes of increasing scientific knowledge but also of the beginning of thematic convergence with other regions. This was actually a regional phenomenon endowed with connections to the wider international context, and the birth of 'Alpine research' accompanied the rise of environmental problems, cutting across every attempt at regionalization, that characterized the 20th century. With the 1960s research was systematized around common focal points, starting with crystallised in the Unesco programme Man and the Bioshphere, launched in 1971. The programme set out to provide a common scientific approach to environmental problems, including in the Alps (Scheurer, Sgard, 2008, p. 30), and to spread themes of an environmental nature beyond the scientific context, moving into a political sphere. The internationalization of research in an environmental field followed the adoption of the ecological paradigm and sustainable development, which became imperative after the Rio de Janiero Earth Summit of 1992, which was to act as a benchmark in the years following for the explosion of interest in the relationship between the human community and the environment, influenced both by science and environmental policies. In the Alps as well, Rio – particularly with the formulation of the Mountain Agenda – had an effect, together with the newly formed Convention of the Alps, underwritten by the member states in 1991. In 1999 the creation of the International Scientific Committee on Research in the Alps (ISCAR) sanctioned the definitive creation of a permanent network of scientific partners working in the Alps, under the aegis of the Committee, with the aim of carrying out interdisciplinary research work in a transalpine framework, so actually completing the process of institutionalization of scientific practice at a regional level.

In this context of strong structuring of research, the Alps – and more widely, the mountain – gave yet more force to its role of the 'region-laboratory', directed to the study of the processes of socio-economic development in their relationship with the erosion of natural capital and to the definition of both trans- and inter-disciplinary approaches (Brun, Perrin, 2002, p. 32). In tandem with the growth of participation and the creation of different institutions of scientific coordination, from the 1960s interest in environmental transformations gained prominence inside the scientific community, not only from the perspective of a regional study but, in agreement with that theorized by Debarbieux, also from the perspective of the construction of a scientific paradigm which studied the Alps as an indicator of global change. Topics linked to the limits of development were already central to the scientific agenda from both the publication of The Club of Rome's *The limits of growth* and debates linked to the accidental products of such growth, a course of enquiry that was to be gradually strengthened as the century advanced. The Alps, in response to the global crisis, assumed the dimension of a place for protecting the natural heritage of Europe, a situation recognized by the adoption in communications of general public interest by the different European bodies of the metaphor of the water tower of Europe – a reference to the Alps' capacity to 'produce' drinking water – and of the hotspot (CIPRA) – a reference in this case to the region's high levels of biodiversity. Linked to these salient characteristics of the Alpine region, a thread of specific research grew in importance from the mid-1980s to the first decade of the 21st century, connected to a crisis situation perceived on a global scale: climate change.

1.2. Climate Change in the Alps and Scientific Research

From the emergence of scientific interest in the Alpine ranges, and certainly not just in the last thirty years, climate and its changes have assumed a central role in the unfolding of scientific research in the region. From Venetz' first hypotheses in his study of the glaciers, climate research in the Alpine region has known various levels of interest and has changed the position taken for reading changes in the climate – from the paradigm of verticality to that of the region uncovering a global change – gradually structured around central institutions whose interest from a geographical viewpoint transcends the Alpine region.

The Alps are, for students of climate and its dependent phenomena, one of the most interesting regions on the planet. From a purely climatological viewpoint, the incidence of climate change in the region is more intense and more easily identifiable: the average increase in temperature here is almost double the global average (European Environment Agency 2010, p. 7). The Alps are not only characterized by a strong climatic-environmental gradient, origin of the vast specific biodiversity and ecosystem, but are also host to a variety of cultures and production systems. They are therefore a region of special interest for the study of the impact of climate on the biomass and on hydrological and glaciological dynamics, and indeed on the possibilities of adaptation for the human communities settled in lands that are ecologically fragile. Interest in the influence of climate in the Alps is not restricted to purely scientific fields but has carved itself a space in the institutional discourse of the larger NGOs working in the Alpine region[1]. In fact the converging interests of science and politics in the region on the one hand lead to a new dialectics between the Alps and central localities of continental Europe, and on the other cause an increase

[1] Note the important volume of documents produced by CIPRA and the WWF intended for public communication and widely based upon a metaphoric representation of the environmental characteristics of the Alpine region.

in scientific interest in this most iconic European range of mountains. The study of climate has seen a gradual growth of interest from the 1990s and in particular in the first years of the 21st century. The course of scientific production can be monitored today by analysis of the major research databases. By considering the number of articles published annually and shown in the Web of Science database[2] (figure 1.1), the temporal development of data indicates a small increase, which reflects the growth of the topic's prominence within the wider public discussion[3].

Interest in the climate grew gradually from the end of the 1990s until 2006, then rapidly to become central to discussion in the scientific community studying the Alps, with 2007 seeing a striking increase in productivity. From 2012 the number of publications 60 three times, only in 2015 dipping below 50, and with the highest number, of 78, in 2013 and 2018. In the same way the data on citations found in the literature show similar behaviour on an annual scale, indicating a growing scientific community and sustained advance in their research programmes.

From a spatial perspective, it is interesting to note how the Alpine region is today one of the more studied – in relation to the state of the climate and its consequences – among the major mountain ranges in the world (figure 1.2).

[2] The choice of the Web of Science database rather than other potential research digital archives is dictated by the greater number of titles shown – in the full database and in the specific case dealt with in the present study – and by the possibility of, with relative ease, using the metadata interface with specific software developed for handling vast volumes of data. By combining the needs of analysis of a wide spectrum with the need to process the data with third party analysis tools, the Web of Science shows itself to be the choice of best performance.

[3] The search string used was shown to be the most reliable from the perspective of representation of the field. The acronym TS (*topic subject*) is a metadata generic selection command, with which the algorithm will search through any article indicating an equivalent value (TS=X) among the fields of title, abstract, keywords, author. The acronym TI (*title*) represents on the other hand the title and so is targeted at a single field, equated to an explicit value ("TI"=X). The choice of the string "TS"="*climate change*" AND "TI"="*Alps*" underlies the necessity of explaining the setting of the research in the title. A string with broader conditions of validity (i.e. TS= "*Climate Change*" AND TS= "*Alps*") will return misleading indications around the central nature of the Alpine area in its treatment, including also publications in which the word 'Alps' appears only in the abstract because of tangential references. Moreover, a result characterized by the use of the adjective 'Alpine' rather than the noun 'Alps' would considerably alter the field's representative sampling by including publications using the adjective not in a strictly topographical way, but nominating all those phenomena in the eponymous climatic-vegetation zones, so including all the mountain ranges on the planet. Even although the solution found here could impose strict restrictions on the criteria of selection, it remains, in the opinion of the author, the most appropriate for using a technological tool devised and constructed for handling vast amounts of data. The exclusion of a number of publications that would be legitimately included according to different and more searching criteria is a workable compromise, given the risk of including in the field a significant number of records not pertaining to the scope of the research.

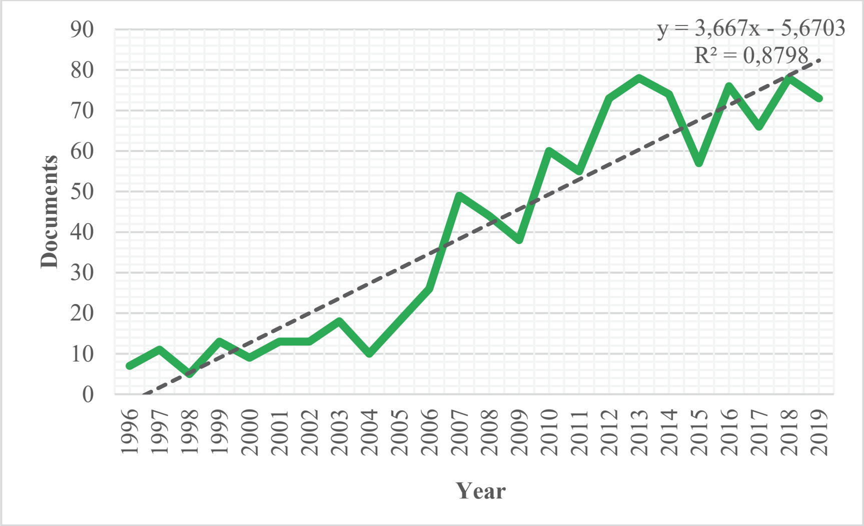

Figure 1.1 - Research on climate change in the Alps. The number of articles published by year. Derived by the author from Web of Science data. Search terms: TS=(climate change) AND TI=(Alps)[1].

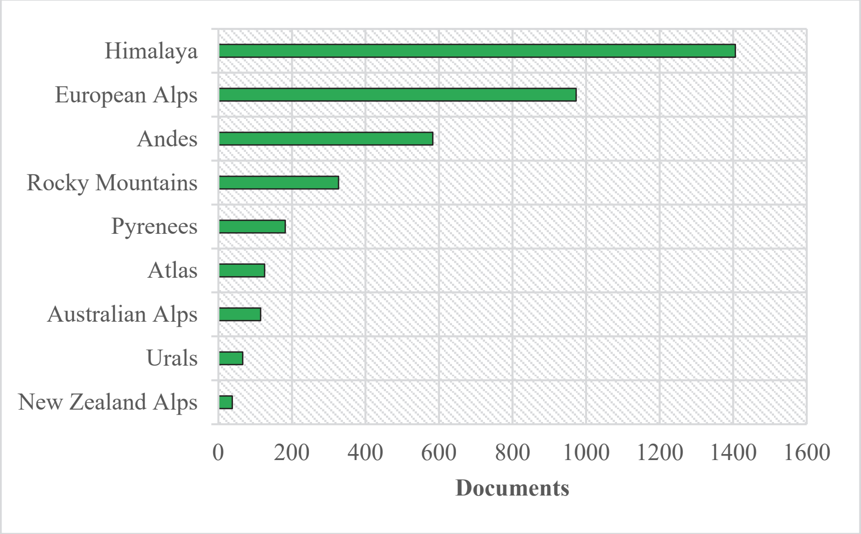

Figure 1.2 - Number of scientific articles on climate change by geographical area. Web of Science data. Search terms

It is not difficult to read in the data historical continuity of the role of the region-laboratory, which still today represents one of the preferred settings for scientific research in mountain contexts, which, however, to be fully understood need to be regarded as relative within the context of the database being examined. Considering the size of the entire database the number of publications produced in Europe are greater than in any other macro-region, including other large geographical areas with a long scientific tradition or comparable investment in academic programmes, such as China and USA-Canada. The majority of titles centred on the principal mountain range of the European continent is also linked to the geographical sources of research production in mountain contexts, assuming that research conducted in European universities still maintains their preference for the Alps – purely through scientific interest or because of the cost in approaching more distant mountain ranges.

Moving our attention to the analysis of data on the growth of annual citations in the scientific literature (fig. 1.3) a comparable picture is found, with values of constant increase since 2004 and a marked more than linear trend than the publications.

Climatic research in an Alpine environment is accumulating and becoming a real research programme; the number of citations is growing hand in hand with the publications and exhibiting an increasingly marked positive trend.

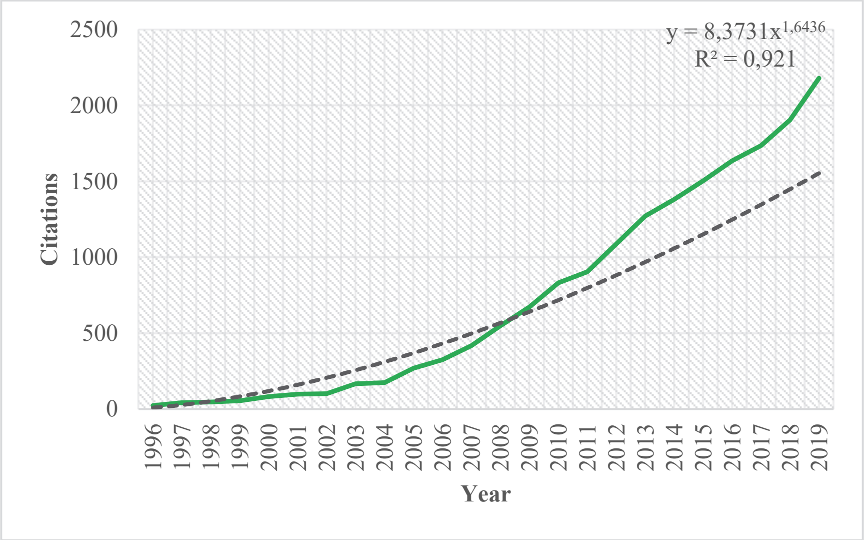

Figure 1.3 - Research on climate change in the Alps. Number of articles cited by year. Drawn by the author from Web of Science data.

The analysis of citations adds a new dimension to the qualitative data since it brings together the different publications, by describing not only how much scientific discourse has grown in raw terms but also how much individual articles are linked to form a discussion within the community. In this sense, the parallel growth of the two parameters can be considered a strong indicator of the state of health of climate research in the Alps, which is constantly gaining in importance in the wider scientific panorama. Even though the raw quantitative data illustrated already to some extent explains the subject's ability to assert itself in the panorama of Alpine research, the scientific production considered here cannot be thought of as homogeneous: climate change constitutes a theme of convergent interest for a plurality of disciplines and institutional subjects, with their own objects of research, methods and tools of enquiry. A further step, needed to understand the subject's development dynamics, should necessarily break down the data into different categories, widening the quantitative analysis and incorporating a qualitative dimension. Enquiry into what the research community into Alpine climate change consists of and what is specifically studied are two necessary stages for entering this path. For this purpose, a useful tool is once again provided by the Web of Science database, this time through a deeper – and in a certain sense cartographic – analysis. Beginning with the quantitative data illustrated and already analysed, it is then possible to draw maps that trace the functional relationships between the data, called *network maps*, in order to extract information given through algorithms of *text mining*[4]. From the epistemological perspective network maps are constructed around two fundamentals: nodes and connections. One entity corresponds to each node; the entity can be the name of an author, a term frequently used in the literature, a research institution, or a nation state. The size of the nodes is directly proportional to the number of occurrences of the term, or entity, associated with them: intuitively the larger nodes correspond to the terms more frequently found in the corpus under examination. The connections, on the other hand, determine the co-occurence of two terms, linked by a line; in this case there is a direct relationship to the actual number of co-occurrences of the connecting terms, indicated by the width of the link line. Apart from these basics, the maps allow information to be organized on a further level, by the division of terms into specific *clusters*, which group together families of closely linked terms, since they tend to co-occur more often. By thus summarising briefly the rules for a correct interpretation of the network maps, we can attempt to answer the first question: who works on climatic research in the Alps?

[4] The term indicates the application of techniques of *data mining* (extraction of data) to a corpus of literature not necessarily structured. The aim of the application of these algorithms is the identification of pattern relationships, either temporal or spatial, which are difficult to identify through direct reading of the documents processed.

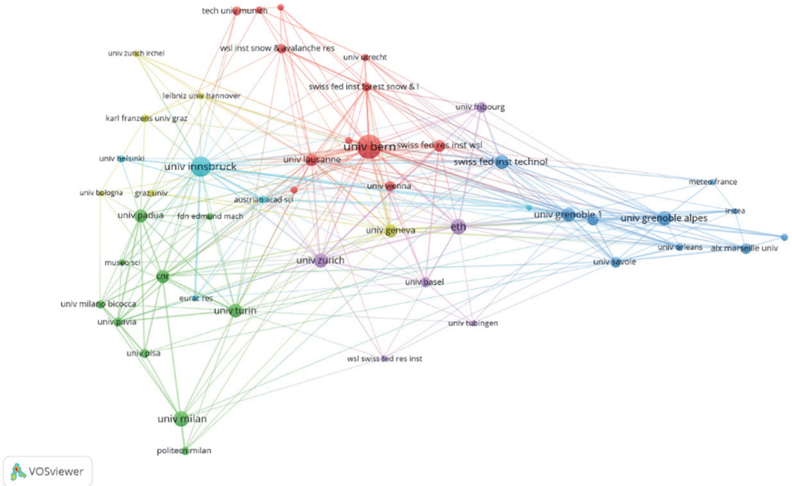

Figure 1.4 - Network map of the research institutions involved in the reference dataset (minimum 6 publications, 1 citation), connected by co-authorship relations. Visualization through a network map. Developed by the author from Web of Science data (07-2020), visualization in VOS viewer.

From the visualization given in Figure 1.4 a number of interesting descriptors on the panorama of research emerge. The network of connections is dense and highlights how the construction of scientific knowledge is a process shared among different research institutions. We can therefore identify determinate spatial characteristics of the scientific network:

1) *(Macro)regional interest*: the research organizations mapped here, in the majority of cases, are established in the Alpine region or its immediate surroundings. There is a smaller cluster countering the norm which groups together a number of institutions from outside the Alpine region who have built study inter-relationships with the region. In the same way, isolated non-European institutions are distributed inside other clusters, although the relative weight of literature produced by these organizations remains small compared to the total volume of the dataset.
2) *Production-connection relationship*: in general, the relationship between the number of scientific articles produced and the number of connections that the institutions have with other institutions tends to be positive. From this it can be assumed that the larger and more productive research institutions are also the most connected. In spite of this basic assumption, there are obviously individual cases which run counter to the overwhelming trend. The behaviour of the two variables is best described by Figure 1.5.

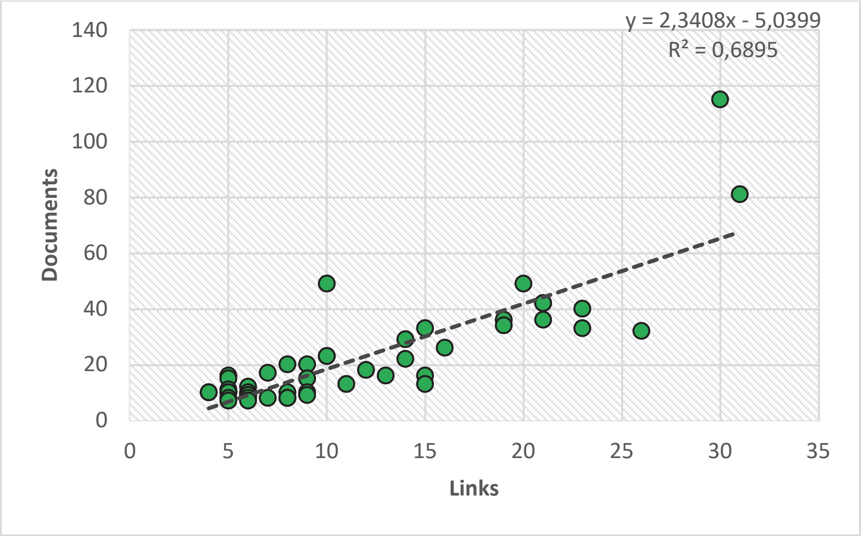

Figure 1.5 - Number of documents associated with each research institution compared to the number of scientific interconnections. Developed by the author from Web of Science data network VOSviewer.

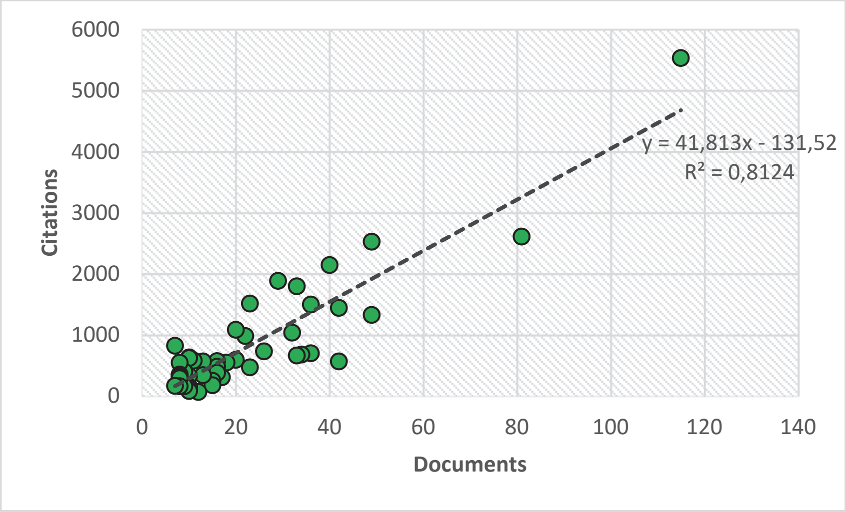

Figure 1.6 - Number of documents authored compared to the number of citations received. Drawn by the author from Web of Science data.

3) *Production-citation relationship*: similarly, citation values for the single institutions exhibit a strong correlation with the number of its publications. In a simple formulation, the cumulative number of citation varies directly with the number of documents produced by an institution. The linear trend is nonetheless challenged by outlier values, as in the case of the University of Bern, whose citations are disproportionally higher than the expected output in a linear model (5533 citations of 115 documents). Conversely, another great producer of scientific literature as the University of Innsbruck (2610 citations of 81 documents) underperforms in terms of cumulated citation in respect to the expected values (fig. 1.6).
4) *Pseudo-national cluster*: although the clusters identified can be superimposed on the national scientific production of the different Alpine countries, a closer look shows how the subdivision is not rigorous and inside pseudo-national clusters there are sometimes hidden institutions belonging to other countries. The case of Austria is the most obvious in this sense since the cluster that contains the most national institutions (light blue) also includes the University of Helsinki, but excludes the Universities of Vienna and Graz, breaking up the national unity of the part of the dataset under consideration. The case of the WSL Institute is also interesting since it has interconnections beyond Switzerland. No less worthy of attention is the concentration of connections between Swiss universities and research centres and German speaking and Francophone institutions. Huggins and Thompson (2017) have highlighted how the connections of geographical proximity contribute to the spread of knowledge between the nodes of a network and also through channels that cannot be measured by this type of analysis – face to face discussions and local channels for the spreading of knowledge – and therefore cannot be codified (Huggins, Thompson, 2017, p. 528); in the case of the Alpine region, the relatively restricted geographical extent of which is codified in a small network, linguistic affinity can in the same way play a key role in constructing channels of regional (or sub-regional) channels of information.
5) *Non-linear internationalization*: it is not necessarily true that the national connections are more numerous than international ones for every institution. Looking at the major centres (in terms of documents produced: Bern, Innsbruck, Milan, Grenoble, Zurich, WSL), it is easy to see how they frequently strike up international relationships, but a deeper examination of the social behaviour of the "secondary" institutions highlights very conflicting trends among them, which range from exclusive collaboration with their co-nationals (University of Basel) to the absence of any scientific relationships on research topics within national boundaries (University of Vienna).

By increasing the scale of observation and moving to terms of individual institutions, figure 1.7 illustrates the data of the first twenty research institutions shown in the Web of Science.

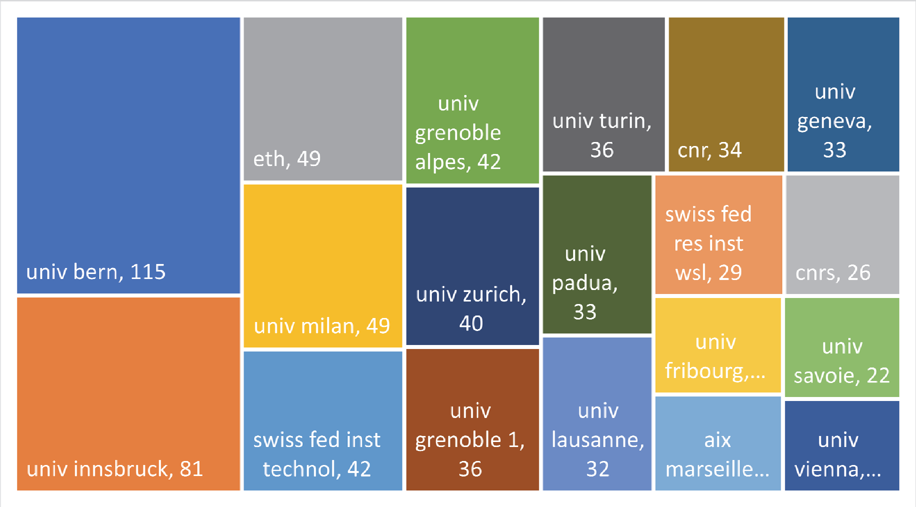

Figure 1.7 - Tree diagram of the first 20 research institutions included in the dataset. Search terms: TS=(climate change) AND TI=(Alps). Developed by the author from WOS data

Switzerland has the largest number of research institutes and a majority percentage share of the volume of literature produced, showing a greater average activity among their researchers in the field. This also confirms a trend already highlighted in analysis of the network map, in not showing in the table any localized institution in national contexts other than the Alpine states.

A reply to the second question – what is specifically studied in research into climate change in the Alps – requires a different type of network map, generally known as a *term map*, the merit of which lies in allowing a complete view of the corpus of literature in a facilitated identification of the main research arguments and the citation relationship between the different research trends in the field of study. As far as the nodes go, they represent a single recurrent term from within the volume of literature under examination. The semantic analysis of the lexemes allows a rough identification of the disciplines involved, thereby actually providing a thematic picture of the field examined. The connections, yet again, represent the co-occurrence of the two linked terms.

The map reproduced in Figure 1.8 considers the literature produced from 1985 to 2017 on the subject of climate change in the Alps.

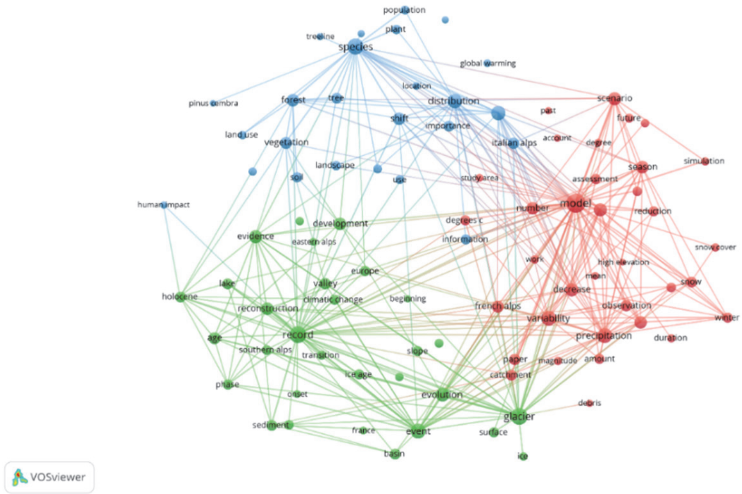

Figure 1.8 - Thematic distribution of research on climate change in the Alps. Visualization by a network map. Developed by the author from Web of Science data 1985-2019, visualization VOS viewer. WoS search terms TS=(climate change) AND TI=(Alps). VOS filter: 30 items.

It results in a clear tripartite division, with one cluster linked to ecological-biogeographical terms (blue), one focused on climatological and paleo-climatological analyses (green), and finally a large cluster around the subjects of glaciology and measurements of snow and rainfall. The division into these three clusters does not suggest that the disciplines involved in the research have been unequivocally identified, but has the aim of understanding which themes the scientific community is turning their attention to in relation to the study of climate change. The thematic sub-division is therefore useful for organising a more detailed review of the existing literature, no longer with a kind of *distant reading*[5] approach, but by directly analysing the publications most cited among those identified in the Web of science database (*close reading*), in such a way as to define what the state of the art is in the different thinkings on research on climate change. By following the schema given by the network map shown in figure 1.8, the climatological characteristics of global warming in an Alpine context can be analysed, so as then to allow attention to concentrate on the consequences for the biotic (green) and abiotic (red) environment.

[5] By the term *distant reading* is meant the particular approach of literary analysis which is based upon statistics – tests of hypotheses, computer modelling and quantitative analyses – and not on the traditional approach based on direct reading of the texts that are part of the specific literature on an argument.

1.3. How is the Alpine climate changing?

1.3.1. A necessary premise: the spatial variability

Variability is one of the main characteristics of the climatic system, on both the spatial and temporal levels. Although it constituted a central topic of research in the past, the synchronic study of the Alpine climate's spatial characteristics has given way to the study of temporal evolution, which has become a priority due to emergence of the phenomenon of global warming[6]. Yet the spatial dimension of climatic variability has a fundamental role in best understanding the reason for the emergence of climatic research in the Alps.

In all mountainous regions, climatic variability within the area is intuitively influenced by the altitudinal gradient between the valley bottoms and the mountain peaks, but this can only offer an approximate interpretation of what is in reality a much more complex system. It is possible to identify four principal factors that regulate the climate: the continental nature, latitude, altitude, and topography (Beniston, 2006, pp. 4-5). Continental nature refers to the proximity of a given region to the ocean, which regulates its daily and annual temperature range, much more stable in oceanic climes due to the warming capacity of the sea, which also acts as a source of humidity and hence of rainfall. The continental mountain ranges enjoy greater exposure to sunlight, less precipitation, and more marked ranges of temperature. To a large extent latitude determines the extent of the annual temperature cycle and – to a lesser extent – of precipitation, while altitude plays a fundamental role in mountain climates, since atmospheric density, pressure, and temperature fall with the rise in elevation. Temperatures reach lower temperatures in response to the decrease in the atmosphere's thermal capacity as height increases, so exerting a strong influence on the ecosystem distributions.

In the specific case of the Alps, Bätzing identified four fundamental patterns for climate variations in the area, linked to the hypsometric variation, variation between margins and central Alpine areas, and latitudinal and longitudinal variation (Bätzing, 2003, pp. 52-55). As in every other mountain context, temperatures tend to drop with the increase in height, in parallel with the thinning of the atmospheric stratum and so heightened radiation. The hypsometric variation is the only constant in the spatial variability of the Alpine climate and only meets with exceptions in the phenomenon of temperature inversion found in certain valley bottoms or basins embedded in longitudinal valleys, where masses of cold air are unable to rise up the slopes,

[6] If the temporal dimension has become a cornerstone of research in the Alpine context, the spatial dimension is by contrast linked to an ancillary role, normally of the creation of future forecast models through statistical techniques.

trapped by masses of much lighter warm air, leading to the formation of a thin cloud layer. The variations between areas on the Alpine margins and those in the central Alpine region is linked to the position of Atlantic or Mediterranean influxes, which tend to rise and download their accumulated humidity once they meet mountainous obstacles. Because of this the pre-Alpine regions tend to be wetter and colder than the internal areas, which exhibit continental traits, with low precipitation and strong sunshine, leading to wide daily and annual temperature ranges. In parallel to the two patterns identified, latitudinal variation influences the distribution of microclimates. The Alps act as a barrier between a Mediterranean climate to the south and a temperate-cold climate to the north, resulting in a notable difference in temperature – with the southern slopes decidedly warmer and with higher rainfall levels. The phenomenon is also found on a local scale, with higher temperatures recorded on slopes exposed to the south compared to those otherwise oriented. Finally, longitudinal variation determines the gradual transition between an oceanic climate to the west and a more continental one in the eastern sectors of the Alpine ranges. The greater humidity of the western Alps compared to the eastern results from this difference, even if the effect is mitigated by the influence of the Mediterranean, which channels humid air across the Carnic and Julian Alps, reaching the high and low *Tauern* in Austria.

The crossing of all the spatial patterns described is the origin of the wide range of microclimates that characterize the Alpine region. In Bätzing's words:

> […] in describing the climatic condition of the Alps the problem lies in the fact that the regular elements, clearly identifiable, are on their own insignificant: the conditions are so complex and change so gradually inside the vast Alpine region that in the final analysis we can say that each valley has its own climate[7] (2003, p. 52).

It is no surprise, therefore, that the study and systematic description of the Alpine climate's spatial variations captured the attention of scientists well before the appearance of the phenomena of global climate change. The spatial diversity of the Alpine climate is, in any case, one of the main factors in the development of its specific biodiversity and the richness of its ecosystems; the climate, therefore, is a subject of interest that transcends the field of climatology, and is not even confined to the realms of ecological and biogeographical sciences.

[7] "[…] *nel descrivere la condizione climatica delle Alpi il problema consiste nel fatto che gli elementi di regolarità, chiaramente individuabili, sono di per sé poco significativi: le condizioni sono così complesse e si modificano così gradualmente all'interno della vasta regione alpina, che in ultima istanza si può affermare che ogni valle ha un proprio clima*" (original version in Italian).

1.3.2. Temporal variations in the Alpine climate

Climate variability over time is widely studied today, over both the short and long term. The term *reconstruction* has assumed a fundamental role in research on climate in the past, where the behaviour of the variables over time is defined in accordance with the behaviour of climate dependent variables. Historical series of dendrochronological, glaciological and palynological data are common tools of retrospective enquiry, which allow the production of data that precedes the beginning of instrumental observation. The history of climate has therefore been the subject of minute reconstruction and enquiry, which have received both widespread interest and notoriety with the advent of the IPCC and Mann's famous, or notorious, diagram, the best known and most discussed representation of long-term climate variability. In the same way, the emergence of *global warming* – which has also driven the need for studies on a geological scale – is the direct cause of the proliferation of publications on the subject of recent climate change and of increased scientific interest in the subject.

As far as the specific case of the Alps is concerned, studies of climate variations on different time scales are extremely widespread. The reconstructions of long periods highlight how the region has gone through different climatic phases over the last millennium, attributable to the variable nature of the climatic system. Through reconstruction studies based on documentary sources, the history of the climate shows the principal climatic variations that have marked the phases of the Mediaeval Warm Period (MWP) and the following Little Ice Age (LIA), which, for all that they were characterized by definite trends towards warming and cooling respectively, were made up of shorter and uncertain phases which sometime ran counter to their prevailing trend (Bonardi, 2004, p. 127). The climatic system is characterized by identifiable macro-trends but underlies a short-term variability decidedly more complex than an analysis on a wider time scale can show, unless it focuses on very minute observation.

By analysing the main publications in the specific cluster, Casty, in one of the larger climatic reconstructions in an Alpine context (Casty et al., 2005) – stretching over 500 years and based upon annual data – highlighted on the one hand a distribution of cold phases in the decades around 1590, 1690, 1730 and 1890, while on the other a strong concentration of warmer phases between 1994 and 2003. The same author emphasized how the pre-1900 temperatures were on average lower, with negative records around the last decades of the 17th century, consistent with the record of the minimum temperature on the European scale in the same period. In particular the winters show the greatest distance from the average, with values of 1.6°C below the average of the period 1901-2000 (p. 1859). A strong transition towards milder winters on the other hand is recorded between 1890 and 1915. The variability in summer temperatures is less than the winter one, with a positive extreme recorded around 1550, and periodic phases in the 17th century and the second half of the 18th. From 1946 to 1950 a warm phase was recorded preceding the constant warming from 1970 to today, with the summer of 2003 showing a deviation of 4.4°C from the 1901-2000 average, confirmed to be around 16.1°C. From the perspective of precipitation, the same study shows how the annual amount before 1800 was less than the average of the 1901-2000 period, then to increase strongly around the 1840s and correspondingly fall in the 1860s. The negative extreme is recorded in 1540, by far the driest year. There was a sudden transition from dry periods to wet phases around 1830, 1920, and 1945. At a seasonal level, dry winters are recorded around the second half of the 19th century and were much drier from 1990 to 1994. Wet winters on the other hand mark the decades around 1670, 1720, and 1910 and those from 1950 to 1990. The year 1915 had the wettest month of the series, with one anomalous measurement of 140 mm compared to the average (245 mm). In the case of the summers three dry phases are identified: around 1540, after 1770, and 1860. That of 1540 was the driest summer with -164 mm compared to the norm (352 mm), while 1663 was the wettest (+148 mm).

It is thus clear how from the 1990s episodes of thermal anomaly are more widespread, with four year of anomalous heat recorded, in a total of six throughout the period under consideration, compared to the 1901–2000 average. Episodes of precipitation anomaly – much sparser than thermal anomalies in the period considered – do not indicate an important change in the most recent period.

Focusing on shorter periods, Beniston (2006) concentrates on the main climatic trends recorded in the 20th century. His article is one of the most cited in the dataset and provides a good guideline for the study of contemporary state of the art Alpine climatology, for the geographical widening of the analyses, and cover of different climatic parameters. Beniston highlights how the increase in the minimum temperatures recorded in the Swiss Alps during the period of reference is almost double the global trend, with an increase of around 2°C compared to the average and a slightly more restricted increase of maximum temperatures, whereas the analysis of precipitation shows trends of little importance. By examining the ten-year variations in temperature, the 1940s were among the warmest, followed by a cold phase in the 1950s. The 1990s show the strongest trend of temperature increase in the whole series, probably because of the persistent positive values recorded by the NAP indices[8]. Figure 1.9 shows the author's thermometric reconstruction for three Swiss climatological stations, contrasted to the deviation from the average on a global scale.

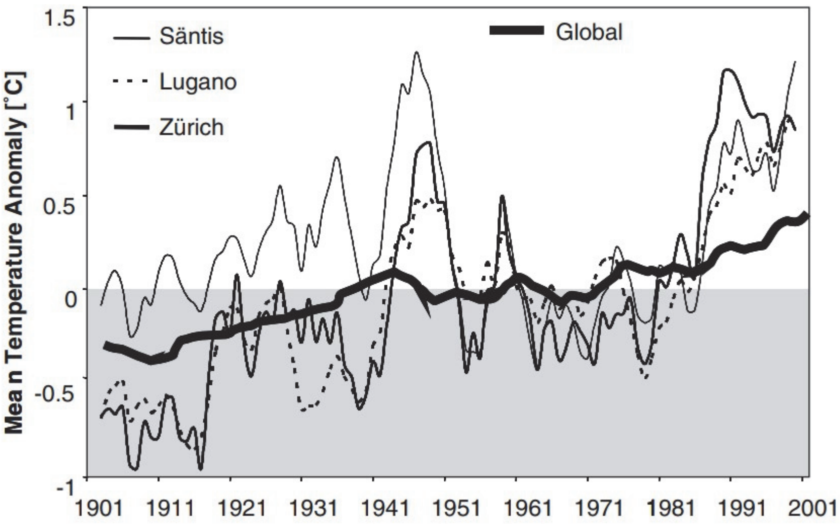

Figure 1.9 - Thermal anomalies of three Alpine stations compared to the average 1961-1990, contrasted to global thermal anomalies. Source: Beniston, 2006.

In line with Beniston, Acquaotta, Fratianni and Garzena (2014) considered the development of temperatures between 1961 and 2010 in sixteen climatological stations at different altitudes in the north-western sector of the Italian Alps. The results show a trend of agreement in almost all the stations towards warming, with evidence of an increase in intensity with the growth in height. Above 1600 metres a.s.l. there is a marked increase in temperature and a drop in cold periods. Once again, the authors identify a clearer trend among minimum temperatures, confirming Beniston's data and – on a global scale – also that provided by the IPCC (2013). Above 1600 m, the greatest increase is recorded in spring, while maximum temperatures show similar behaviour in the different altitudinal ranges studied by the authors.

For snowfall, reconstruction of variables over the centuries, whether of episodes of snowfall or depth of snowdrifts on the ground are rare, and hence large-scale studies on the entire area are not found in the dataset. Studies

[8] According to Beniston, positive values in the indices are associated to higher temperatures and lower rainfall compared to the Alpine region average. More precisely, the author estimates an average increase of around 1°C during periods marked by high values of Atlantic oscillation in the indices.

exist, however, that concentrate on more limited sub-areas and shorter time periods, covering approximately the period from the 1960s to today. Beniston highlights how a quantification of snow phenomena – and of those of the disappearance of accumulated snow – are essential for evaluating the effects of climate changes on the availability of water in the Alps in terms of run-off, also in his study using the metaphor of *water towers*. In one study of historical reconstruction, Latersner and Scheebeli (2003) work on tracing the development of parameters of snow in the Swiss Alps (the mean depth of snow, duration of continuous snow coverage, number of days of snowfall) in the period 1931-1999, and highlight gradual trends with increasing figures until the 1980s, followed by a statistically significant decrease towards the end of the century (Latersner, Schneebeli, 2003, p. 745). Considerable spatial differences are, however, noticeable in the data: the slopes of the southern Alps differ from those of the north in having a shorter average duration of the snow cover, caused by earlier melting in spring rather than later autumn snowfall. Similarly, the authors point out differences in altitude, with a more marked trend in the lower areas of the mountain relief compared to stations at a higher altitude. Moving deeper into specifics, the series of data moves from beginning in a period of winters with low snowfall to then showing a return to average values immediately after the 1930s. The 1960s and 1980s stand out for their high snowfall even compared to the average of the more snowy periods, whereas the 1990s touch negative spikes for the whole series. As regards the extreme snowfall events, the authors do not identify any significant trend. In general the long-term trends have strong variations between years, which makes their reading more difficult, although this does not prevent the recording of a number of anomalies without precedence, such as the already cited winters of the 1990s and the negative record of snow accumulation in the decade 1988-1997. In agreement with the evidence provided by Latersner and Schneebeli, Durand (2009) undertook a retrospective study on snowfall parameters in the French Alps, using for the objectives of the study three numerical models normally used for the daily avalanche forecast, joining the results with past meteorological observations. These results also showed decreasing trends in snow cover depth, its duration on the ground[9], and days of snowfall. In both the studies cited, the importance of the spatial dimension of the change was not neglected, which, combined with the great temporal variability, makes the study of Alpine snow a complex undertaking. Durand in particular highlights how the French region is characterized by a falling gradient

[9] The decrease in accumulated snow on the ground in the period under study could, according to the authors, be explained by a strong variation at the end of the 1980s, which triggered a *step effect* in the series of data, rather than an actual negative trend in the longer term.

crossing it from the north west to the south east, leading to clear altitudinal variations in the behaviour of the variables; the variations linked to the altitude, moreover, are not disconnected to factors of latitude and do not exhibit the same characteristics if measured at different levels of latitude.

Briefly, and simply to gather the specific data into a homogenous argument, from the analysis of the main documents in the literature a picture is formed of a climate characterized by long-term fluctuations as far as temperature is concerned, with stages of contrasting evidence consisting of annual or inter-annual variability that is not necessarily in agreement with the dominant trend over a number of decades. By focusing on the second half of the 20th century – a period in which the phenomenon of global warming originated and developed – a trend towards increased temperatures becomes even more evident, and in the case of minimum temperatures shows a growth trend of double the global average, although tracing the maximum rainfall trends remains difficult. The parameters for snowfall on the other hand point to a decrease, even if long-term trends are difficult to extract clearly from the spatial and temporal variability of shorter periods.

Climate science in the Alps has given much thought to reconstructions of the past, but the retrospective view does not represent the only method of climate study; at a regional scale as well specific climatological sciences literature provides future projections based on statistical models. Gobiet, in an influential study of 2014, reviewed the climatic projections available today at an Alpine level for the 21st century, gathering the results of different research studies. The Alpine climate will be strongly influenced by the phenomenon of global warming, with important consequences for its thermal and rainfall systems and on the frequency of extreme events. Under the IPCC A1B scenario[10], temperatures are destined to grow at a rate of 0.25°C per decade until the mid-century, then to accelerate to a rate of 0.36°C per decade, actually slowing down the rate recorded in the last decades (0.5°C), probably due to the intervention of factors of natural variability. The datum should be interpreted with a cautious margin of uncertainty, not so much on the dominant evidence of climatic variation – the process of warming is not in doubt – as on the effective intensity of the phenomenon, which is subject to inherent imprecisions in the forecasting models or the techniques of statistical downscaling, uncertainties about the future emissions of GHG, and natural variables (Gobiet et al., 2014, p. 1149). From the spatial viewpoint, the clearer increases are recorded at greater altitudes, above all through the

[10] The IPCC A1B scenario is normally defined as 'moderate' in its forecasts for temperature increase. It is based upon a hypothetical situation in which energy supply is guaranteed by equal share from among the possible sources, without excessive dependence on any one of them, whether fossil or not.

reduction of the albedo effect with the melting of the snow and ice, but noticeable thermal increases are also foreseen at lower altitudes, above all in summer. The extreme summer temperatures will be subject to increases in frequency and intensity compared to the norm of 19611990, without, however, exceeding the absolute extreme of the summer of 2003. Precipitation will undergo substantial change in the annual cycle, with a fall in average volumes in summer and a rise in winter. From the perspective of extreme phenomena as well, flooding and drought will see substantially shorter periods between their occurrences. Extreme rainfall events will be particularly severe in autumn and in northern Alpine regions, where increases of up to 30% could be recorded by the end of the 21st century. In the same way, the frequency of droughts is destined to grow as a consequence of the alteration of seasonal distribution of rainfall, the increase in temperature, and correlated rate of evapotranspiration. Finally, for snow the projections generally foresee a raising of the snow line of 150 m for every °C of temperature rise. Gobiet, basing himself on the RCM forecasts, which see a rise in average temperatures of between 2 and 4°C by the end of the 21st century, foresees a snowline rise of between 300 and 600 m[11]. Finally, the future frequency of particularly snowy winters has been calculated by Beniston in a study of 2011, in which the author pointed out a strong reduction of their probability by the end of the 21st century, passing from one in eight winters to one in thirty (Beniston, 2011).

1.4. Climate and the Alpine biomes

A region's climate has a profound influence on its biological characteristics: the temperature, in particular, is responsible to a large extent for the distribution of organisms in the region; not only its average values but also its oscillations play a fundamental role in defining the distribution areas of both plant and animal species (Zunino, Zullini, 2008, p. 60). It is not surprising, therefore, that the appearance of global warming has drawn the attention of the scientific community to its effects on biological communities, leading to the multiplication of research studies and articles produced. In analysing the literary corpus, it is striking how the number of publications in the field of botany – or at least linked to the ecology, distribution and migration of plant species – represents the great majority of these studies and

[11] Even if this figure may be considered as an approximation erring on the high side, because it does not include phenomena of cooling and temperature inversion linked to precipitation, these will not compensate in any way for the rise in temperatures, which remain the most important factor of control on the fall, persistence and melting of the snow.

publications[12], whereas the scientific proportion of studies on the animal species has not increased in proportion to the cluster's general trend.

The Alps are a context of uncertainty in possible scenarios of change, through its mesoclimatic richness, already analysed here; moreover, they have been subject to pressure from anthropic activity for centuries, which has profoundly influenced species distribution. In one comprehensive panorama of Alpine flora's answers to global warming, Theurillat and Guisan (2001) identified a number of possible responses to change by plants faced with a climate in a phase of change: persistence, migration towards areas with more favourable climates, extinction. The persistence of plants in adverse climatic conditions is only possible through gradual genetic adaptation, increased phenotype plasticity, or a phenomenon of ecological buffering, in which the final results of the plant's survival is controlled by edaphic and not climatic factors[13]. From this assumption, the authors develop a review of the consequences of climate change on the level of species, population, vegetation, phenology, and the landscape.

On the level of plant species, paleo-ecological evidence shows how the preferred response to climatic fluctuations is migration, not without certain exceptions, such as Tertiary orophytes that survived *in situ*. The same paleoclimatic and paleoecological evidence suggests that during the warmer interglacial periods the forests climbed to higher altitudes, reducing the orophyte population at these heights. Today a significant proportion of the orophytes established in *refugia* – areas of an isolated population or the remains of a previously more extensively populated area – such as mountain peaks of limited altitude, are subject to a strong risk of extinction, due to the impossibility of migrating to greater heights. Theurillat and Guisan point out how the greater part of nival and alpine species can tolerate an increase of 1-2°C, but would have difficulty in supporting greater increases. In general, evaluating the response of a species to climate change depends on a series of factors which include the altitudinal range, the ecology, the size of the population, the genotypic and phenotypic diversity, and the area of distribution. In general the species with greater potential for adaptation, given all the characteristics listed above, are less subject to the risks of climate change (Theurillat, Guisan, 2001, p. 81). Climate change does not therefore represent a risk for all the Alpine plant species and can even mean an opportunity for some of them. In the same way, the Alpine animal species have different reactions to

[12] Among the 853 publications identified, only 25 are characterized under the labels of 'zoology', 'entomology', 'ornithology', and 'veterinary science', which represent the only ones explicitly directed towards the study of Alpine fauna.

[13] Obviously, for these conditions to succeed other determining influences must be added, such as fragmentation of the habitat or plant-animal interaction.

the change in climatic parameters, although the volume of literature dedicated to them is more sparse. In one study of 2012, Ravermann identified how the increase in temperature could lead to a reduction of up to two-thirds in the habitat of the Alpine rock ptarmigan (*Lagopus muta helvetica*) by 2070, pointing out, however, that climate is a dominant factor in future predictions only at a macroscale and mesoscale, while on higher scales the availability of habitat and the local topography retain greater explanatory powers of the output produced by the forecast model used (Ravermann et al., 2012, p. 898). In agreement with Ravermann's results, a recent study has modelled the future dynamic of the distribution area of two species of owl – the Eurasian pygmy owl and the boreal owl – highlighting how distribution in the Alpine region is experiencing a contraction, above all in the case of the boreal owl (Brambilla et al., 2015). In contrast, studies on the pine processionary moth (*Thaumetopoea pityocampa*) show that the increase in winter temperatures is lowering the larvae's mortality rate, so increasing the parasite's population (Dobbertin et al., 2007, pp. 237-238).

Concentrating on studies of the individual populations, Theurillat and Guisan arrange the influences of climate change on plants into separate categories: genetic diversity, persistence, dispersal, fragmentation, and plant-animal interaction. Looking at genetic diversity, present climate change creates situations of population isolation at high altitudes, indirectly encouraging impoverishment of the genetic patrimony of the isolated population where it is cut off from dispersal by physical barriers and so from potential hybridization. Where, by contrast, hybridization is in some way made possible by the absence of geographical barriers, climate change can encourage mechanisms of speciation, removing the new hybrids from competition by means of genetic and geographical isolation compared to the parent population, avoiding competition and *back-crossing.* Phenomena of persistence exist above all in the presence of cryogenic processes, permafrost, and upward slopes (Theurillat, Guisan, 2001, p. 82), while with dispersal, climate change should allow new areas of colonization to be reached in the nival and Alpine zones by populations whose dispersal is ruled by the wind. Studies on dispersal at lower heights remain much more difficult because of human use of the soil, the forests, and changes in the practices and extent of agricultural surfaces.

The prevalent role of the Alpine snow zone in the study of climate change is also confirmed in the case of the phenomenon of fragmentation of the population, which plays a particularly important role for orophytes and endemic species. Endemisms in the Alpine snow zone are subject to high risk of fragmentation due to the reduction of the areas on which they can become established. Although the populations more widely distributed in the Alps do not face any immediate risk of extinction, a number of isolated Arctic populations could disappear and this could also be true for the endemic populations established on the peaks of the lower mountains in the Alpine region. To this can finally be added the interaction between plants and animals, which influences the phenomena of dispersal, primarily through the activity of herbivores, parasites, and pollinators. The herbivores exercise a selective control of the populations through grazing and their own food preferences. The increase of atmospheric CO_2 can lead to a 'dilution of nitrogen' effect in the plant tissue, causing the herbivores to graze more intensely in order to maintain constant levels of nitrogen, so applying selective pressures on some populations and thus altering the composition of the species. There is no lack of examples of selective pressure by red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) to the damage of populations of European silver fir (*Abies alba*) and the advantage of competitive populations, such as the Norwegian spruce (*Picea abies*) (Motta, Nola, 1996, pp. 81-85).

In the case of parasites, rising temperatures, joined to more marked conditions of aridity, could cause a rise in sugar levels accumulated in the needles of the dominant tree species, increasing the availability and quality of nutrients. The same climatic conditions could cause a fall in the parasites' mortality levels, at the same time accelerating their growth. Cases in line with this theoretical development have been recorded in the Italian Prealps with invasions of *pamphiliidae*, to the damage of the Norwegian spruce (*Picea abies*) populations (Marchisio et al., 1994), or the attacks by the common pine shoot beetle (*Tomicus piniperda*) on populations of the Scots pine (*Pinus sylvestris*) in the Vallese (Rebetez, Dobbertin, 2004). Finally, the relationship with pollinators can also be subject to influences from an atmospheric CO_2 increase, particularly in the timing and intensity of flowering and the quality of the nectar. The insects, however, appear to be more responsive than plants to climate changes, such that an altitudinal displacement of the species is not a great risk.

By concentrating on plants and their response, the research focuses on potential decline of the vegetation zones. One of the most recurrent themes is the raising of the average height of the limits of close forest (*timberline*) and the limits of tree species (*tree line*) on the Alpine slopes, both controlled by thermal rules in natural conditions. The anthropic capillary influence on Alpine vegetation, however, makes studying and modelling the tree line particularly complex due to the impact of abandonment of grazing activities in the summer pastures, triggering processes of secondary succession. Both these phenomena therefore act as the forces of a transition from herbal plant cover to arboreal cover. In one Swiss research study aimed at defining which of the two phenomena is most responsible for the rise of the treeline, Gehrig-Fasel, Guisan and Zimmermann show how the processes of recolonization following the abandonment of the pastures are predominant and how – theoretically – a rise in temperatures like the recent one will raise the tree line by at least 200 m, a figure decidedly greater than the reality of the evidence gathered (Gehrig-Fasel, Guisan, Zimmermann, 2007, p. 581). Yet the influence of climate change cannot be ignored, because elements of disturbance such as microclimates and frequent stochastic processes such as avalanches, snowfall, or discontinuity in the permafrost can force the limits of the wood above its own natural height limit. As a result, it becomes difficult to separate the effect of the climate, which would appear at higher altitudes, from reforestation of the grazing lands, which at this height becomes predominant.

The rise in the average height is not only, however, about the tree line, which is only part of a much vaster process, embracing all the high vegetation zones. Theurillat and Guisan point out how for a warming of 3.3°C there is a corresponding rise of 600 m, reducing the width of the zone of Alpine vegetation by 63%, while the lower zones would record minor shrinking. The extent of the zones' areas is not, however, the only important factor; the incline plays a determining role. The altimetric distribution of slopes with inclines of above 40% limits the capacity of the vegetational zones to migrate, due to their inability to sustain a compact mass of vegetation. Expected changes in the composition of the vegetation differ in cases of edaphic or climatic communities – with the latter more affected by changes in the meteorological variables – but the physiognomy of the terrain will determine, together with the migration of non-native species, the continuation of the plant associations or the displacement of the phyto-sociological classifications that we know today in the Alpine context. Keller, Kienast and Beniston, in an account of empirical evidence recorded at the Schynige Platte observation site in the Swiss Alps, show how thermophyle species have grown in numbers at the expense of microtherm species from 1930 to the present. The authors further highlight the temporal constancy of factors such as the availability of nutrients, so attributing the fundamental cause of the process to climatic variability (Keller, Kienast, Beniston, 2000, p. 76). On their part Theurillat and Guisan point out how the forecast models – both statistical and dynamic – are in agreement in forecasting an expansion of deciduous forest in the Alpine region, forcing the coniferous forest to migrate to higher levels, with particular zones that show a more marked susceptibility, as in the case of a number of subalpine forests of Swiss stone pine (*Pinus cembra*) and European larch (*larix decidua*). In the same way, increased temperatures in the south of the Alps is leading to a phenomenon of invasion of species that are typically absent in the mountain and hill vegetation zones, (Rebetez, 2009), in which species belonging to the evergreen laurel family replace characteristic species of the vegetation zones of the hills.

If documentary evidence of a potential or actual change in the composition and structure of vegetation in the Alps occurs frequently in the scientific literature, the phenological aspect has not been neglected; phenology is actually a useful tool for evaluating the impact of climate change on plants' growth and productivity (Theurillat, Guisan, 2001, p. 93), but also for understanding the consequences for animals' life cycles (European Environmental Agency, 2017). The detection of phenological data in the Alps is a scientific practice that has deep roots in Alpine research history[14]. On the whole the scientific community is agreed in observing a lengthening of the vegetative growing season, which begins early compared to the historical average in the spring and tends to come to an end later in winter (Rebetez, 2009), so attributing an overriding weight to the thermal factor. In a research studied carried out on the moraines of the Schwarzenberger-Seespitze glacier, in the Austrian Alps, Huelber confirms the dependence of phenological development on the temperature, but also highlights the influence of the role of the photoperiod, even if difficult to estimate (Huelber, 2006, pp. 101-102). The studies on the nival zone certainly do not exhaust the geographical variability on the research sites on phenological mechanisms, which are widely studied on a European scale. In a panorama focused on the collection of data from further European areas, Chmielewski and Rötzer (2002) identify a more marked trend towards warming for the central European area, while on the continental level there are seven days of lengthening of the vegetative growth season for every grade of warming.

1.5. The effects of the climate on the abiotic substratum

The overwhelming majority of more iconic images of climate change on the global scale are of the shrinking of the ice sheets and its consequences. Documentation linked to the melting of continental and polar frozen surfaces are part and parcel of scientific communication, as clear and appreciable evidence of changes in action in the climatic regime. The definition, widespread in scientific communication, of 'global warming' expresses perfectly the reaction of the glaciers to temperature variations and provides a successful metaphor for communication to the public at large. Yet the term has its roots in the historical use of the frozen environments in the scientific community as a source of *proxy data* for the reconstruction of the climate of the

[14] Carl Schröter was already estimating in 1926 how a growth in height of 100 m would be accompanied by a temperature drop of 0.55°C and a shortening of the vegetative growing season by nine days, basing his calculations on his studies of the Swiss National Park.

past, both more recent and remote. In this context, the Alps once more exhibit a high density of information, both on the recent glacial dynamic, for which recording tools exist, and for the study of glacial morphology, which allows the reconstruction of variations in the glacial fronts on a geological scale. As a result, scientific production on the glaciological environment occupies a significant percentage in the total of clusters linked to changes of the abiotic environment and can be briefly subdivided between *site-specific studies* and *regional studies* (Beniston et al., 2018, p. 765). The phenomenon of the melting of the ice can be traced back through the 19th and 20th centuries, although there were brief oscillatory periods, among them the cold period of 1950-1980, one indication of running counter to the long-term trend. This cold period was followed by consistent acceleration in the shrinking of the glacial masses, estimated at around 20% in the case of the Swiss glaciers in the period 1980-2000 (Rebetez, 2009, p.52). On the level of the phenomenon's spatial variability as well – present to a certain extent – comparative studies of different glacial areas show very similar behaviour: this is the case of the glaciers of Claridenfirn (Switzerland) and the Sarennes (France), monitored by Vincent (2004) on a scale of many decades, which exhibit similar mass balances, linked in both cases to summer melting, which is the primary cause of the annual contraction. Successive observation – carried out on a single site at the Sforzellina glacier in Valtellina – notes, from 2002, a net increase in the rate of melting compared to the average value (Cannone et al., 2008, p. 637), and more generally even exceeding the more pessimistic scenarios generated by the forecasting models in the 1990s (Rebetez, 2009, p. 53). In terms of measurements of area and volume, recent estimates on a national scale indicate that the Austrian Alps lost 17% of frozen surfaces in the years 1969-1998 (Lambrecht, Kuhn, 2007, p. 177), while for the Swiss Alps an estimate of the volume of ice lost from 1999 stands around 12% of the initial 74±9 km^3 (Farinotti et al., 2009, pp. 225-231). In general, the scientific community is in agreement in forecasting an almost complete disappearance of the minor glaciers by the end of the century, while scenarios based on a constant increase of 0.4°C per decade show a similar outcome for the majority of valley glaciers. Several studies on a regional scale forecast a disappearance of 76-97% of glacial volume by the end of the 21st century, showing once again how the Alpine glaciers – and more generally European ones – are off-balance compared to today's climate (Beniston et al., 2018, p. 766).

Unlike the mass of information describing the behaviour of the glaciers, the case of the permafrost is undoubtedly more problematic, since its behaviour following the rise in temperatures is less known, although its extensive area is comparable to that involved in the surface glacial phenomena. The larger part of the studies actually need to be based on indirect methodologies for the collecting of information, given the unfathomable nature of the permafrost for a visual analysis, as can be carried out for the glaciers. Geophysical surveys of surfaces intended to determine the physical properties of the terrain are joined to kinematic and geodetic measuring, aimed however at the identification of phenomena of subsidence, *creep* and slope instability, besides the obvious thermometric measures in boreholes[15]. What emerges is a clear indication that permanence and depth of the snowy cover, along with – as a consequence – the temperature of the ground, play the role of controlling factors for the formation and conservation of interstitial ice. The timing of the snowfall is another fundamental factor: heavy early snowfalls run the risk of isolating the ground and preventing the heat from leaving it; conversely, late snowfalls keep the temperature of the ground low, provided they persist throughout the winter season, which ideally should be drier. The snow cover, moreover, provides higher albedo levels, reflecting quantities that are decidedly more consistent with solar radiation than rock, which, although on the one hand allows the freeing of thermal energy arising from the ground depth during the period of snowfall[25], on the other transfers the thermal energy to the soil, above all during periods of thaw (Rebetez, 2009, p. 68). Studies based on forecast models show how in conditions of wetter winters followed by warmer and drier summers the permafrost can be hundreds of metres higher, leaving the lower levels subject to phenomena of rockslide following the melting of the ice, endangering the stability of the slopes (Beniston, Haberli, 1998, p. 258). The meltwater actually infiltrates the ground thanks to higher temperatures, reducing the ground's cohesion and creating slope distortions (Beniston et al., 2018, p. 766). To put the information given here into perspective, it is necessary to specify how the behaviour of the permafrost is differentiated on the basis of a combination of elements including the concentration of the ice, the gradient and orientation of the slopes, the composition of the soil, and, as given above, the albedo or solar reflection. In response to the lack of historical data and observations, there are today an increasing number of different projects linked to the study and modeling of the permafrost, above all the Swiss project PERMOS (*Permafrost Monitoring in Switzerland*), which operates on a national scale throughout the Swiss federation.

The melting of the ice, which in the Alps is only restricted in the high altitudes, contributes to determining further impacts on the abiotic mountain environment, being closely connected to the variability of the supply of water, although not being its primary control factor. The Alpine run-off is a

[15] The longest series of observations on the permafrost has been in the Alps, in the Swiss rock glacier of Murtèl-Corvatsch. The principle stated here is only valid in the case of rocky outcrops emerging from the snow cover.

direct result of precipitation – its timing and form – and the melting of snow – primarily – and ice during spring and summer and as a result is strongly regulated by the climatic regime. On the theoretical level the reduction in winter snow cover, coupled with the higher frequency of rainfall, leads to an increase in the volume of run-off in the winter and early spring, then to drop sharply between late spring and late autumn (Beniston et al., 2011, p. 734). In addition, the average rise in temperatures determines positive feedback, increasing the phenomena of spring melting and contributing to a greater run-off at that time. In one comparative study centred on different observation sites, comprising modeling of their future given behaviour from climatic simulations, Farinotti foresaw the advent of a phase of growth of annual flow, followed by one of contraction, above all for the fluvial basins fed by glacial meltwater; in these sites in particular there will be a transition from the glacial or glacial-nival regime to one preponderantly nival, that is, a concentration of the greatest flow no longer in summer but during the spring months. According to the same study the maximum of total volumes of flow will occur by 2050, while the maximum flow over the year will be earlier, at a rate of 4.4 ± 1.7 days per decade, in a projection to 2100 (Farinotti et al., 2012, p. 1909). Although the same authors suggest it is difficult to generalize from data on regional scales, the link between rainfall and flow remains of primary interest and will tend to be reinforced elsewhere in the Alpine region. In the basins linked to lower levels of glaciation (less than 40%) the estimates highlight a positive correlation between the runoff and precipitation, while it remains insignificant in the basins linked to greater levels of glaciation (between 40% and 70%) (Farinotti et al., 2012, p. 1921). The scientific community – excluding local indigenous differences – is therefore in agreement in depicting a future in which not only the volume of available water will vary in a non-linear manner, but the seasonal timing will also differ from the historical data gathered so far, actually projecting the water provision of the region in a situation of uncertainty.

Another argument of primary interest for the future of the Alps is linked to the frequency and severity of flooding, directly, although not exclusively, connected to the increase of the phenomena of extreme precipitation. The high temperatures and resultant rise in the snow's altitudinal limits actually lead to a drop in the water stored in solid form and therefore not contributing to the run-off; the result is direct participation in the precipitation run-off at high altitudes and hence a noticeable increase in the volumes of water affected (Rebetez, 2009, p. 73). Relatively more complex phenomena too, such as the increase in episodes of rain on snow (ROS) can have significant impacts on the frequency of Alpine flooding, as shown by studies conducted in the Sitter basin in the north-east of Switzerland. Being positively correlated with temperature behaviour, the frequency of similar episodes in the future has been modelled, resulting in an increased risk of around 50% in the case of a temperature increase between 2° and 4°C, when the snow reserves will have basically disappeared (Beniston, Stoffel, 2016, p. 228).

Finally in the case of phenomena of drought, we can expect a growth in frequency because of the greater temperatures, more intense evapotranspiration, and the drop in the frequency of rainfall precipitation, adversely affecting in particular the southern slopes of the Alps (Beniston et al., 2018, p. 772).

1.6. Alpine Climate change under the lens of social sciences

Even if with lesser numbers, social sciences and humanities are, in recent years, contributing actively to the ongoing effort to analyse, interpret, and cope with the changing of the climate. The discourse developed in the social science frame climate change as a structural problem that poses a set of deep threats to Alpine societies' economic, social, and cultural organization. As such, the conversation around the impacts of climate change is intertwined with the long-lived concept of "Sustainability" and its corollaries in the Alpine life. When coping with climate change, the idea of sustainability must face another key concept entailed by global warming, the one of "Adaptation", as any other effort to reimagine and design any possible future, must take account of the new climate regime. The IPCC proposes an idea firstly engineered in article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) adaptation as:

> The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, AR4, Annex II – Glossary).

Adaptation is a crucial object of interest for social sciences in its various forms. Interestingly, "adaptation science" is forming an interdisciplinary literature, combining perspective arising from economics with social and cultural accounts of how climate change morphs Alpine realities. Adaptive behaviours span from technical solutions, such as the adoption of snowmaking technologies in ski resorts and the intricate reworking of social constructions and management plans. The literature on the Alpine Region offers some overviews, alongside case studies on adaptive measures.

Socioeconomic analyses frequently tackle the emerging impacts that climate change entails on tourism systems and skiing activities in particular.

Several studies analyse what it takes to develop a "sustainable" management paradigm for Alpine tourism in a changing climate from a broad perspective. In a local scale perspective, Paunovic and Jovanovic (2017) offer a formulation of "sustainability" based on a set of interviews with heterogeneous stakeholders.

> In their perspective, sustainability in the German Alps is about the balance between ecological, economic, and social interests. On the one hand, it is important to develop in harmony with nature and the people, while remaining authentic and energy-efficient. On the other hand, economic sustainability means that investments made today should remain functional in the coming generations, in the long term (p. 5).

What this means from a climatic perspective is nevertheless complex to define. Hill et al. (2010) offer a comprehensive analysis of the mechanisms needed to implement climate adaptation in local Swiss touristic systems. The authors show how local stakeholders of two Alpine sites do not consider climate change adaptation to be of paramount importance for their families, villages, and businesses, as they identify competing or even more significant threats. At the same time, potential answers are mainly identified in technical measures (like snowmaking), and none of the interviewed stakeholders consider adaptation measures beyond the tourism sector as diversification options for Alpine economy. However, diversifying the alpine economy to move away from such a one-sided dependence is vital to creating more sustainable social, economic, and environmental structures. The authors conclude that, despite the improvement in awareness regarding climate change challenges in high-altitude areas, significant work needs to go into better monitoring, understanding, mitigating, and adapting to climate change in alpine areas in general well as improvements in the extent of knowledge sharing.

Given the current Alpine economy structure, the reduction of snow cover is the first obstacle to face on the path to a successful adaptation, as the current organization of the tourism systems relies heavily on the revenues coming from ski areas. The inherent climatic variability of the Alpine Region reflects on the reliability of the snow cover, which varies sensibly among different localities. Steiger and Abegg (2018) show how the picture is diverse, with subregions where most ski areas would turn nonsnow reliable in a 2 °C scenario. Hence, the Alps' foothills could lose most of today's existing ski areas, while the situation is less urgent in the centre of the Alps. This evidence suggests a foreseeable key role for snowmaking in the future of Alpine tourism. Narrowing the focus on the French sector of the Alps, Spandre and associates (2015) show that although snowmaking facilities have increased in number, snowmaking potential in the French Alps is limited and has declined since 1961. If the trends continue, likely, the need for water resources and suitable meteorological conditions for snowmaking will match (or even exceed) their availability. All resorts are not equally affected, but all will have to face increasing costs since they will have to produce snow in less ideal conditions.

Concerns for natural resources and their management are typical examples of how social sciences address the issue of adapting to a new climate outside the narrower realm of tourism. Forests are one of the most compelling examples in this regard. Irauschek et al. (2015) enquire about the capability of current management systems to endure the test of climate change. The current "business as-usual" is scrutinized, with its effect on the provisioning of timber production, carbon sequestration, nature and habitat conservation, and protection against gravitational hazards under historical climate and five climate change scenarios in a catchment of 250 ha in the Eastern Alps in Austria. The study does not provide any straightforward answer, as climate change reveals itself once again as a very complex phenomenon to cope with. In four out of five climate change scenarios, volume increment was increasing. Except for the mildest climate change scenario (2.6 C, no change in precipitation), all other analysed climate change scenarios reduced standing tree volume, carbon pools and the number of large old trees, and increased standing deadwood volume due to an intensifying bark beetle disturbance regime. However, increases in deadwood and patchy canopy openings benefitted bird habitat quality. The authors evaluated different management regimes against this background, providing information about the business-as-usual model's suitability for forest management.

Managing natural resources in a changing environment proves to be a complex endeavour. To manage such resources for the benefit of the many is even more challenging, as social sciences approach the topic of collective participation in environmental decision making. The case of water resources is particularly telling in the context of the Alps. The *water towers of Europe* will face significant water balance changes over the next few decades, and the management system should adapt accordingly. However, adaptation is not a strictly technical endeavour, as social acceptance plays a key role. Kellner (2019) illustrates how different stakeholders accept a multi-purpose reservoir in a recently deglaciated landscape in the Swiss Alps. The study, notably, highlights the presence of different trade-offs: first, a trade-off situation of nature protection between different scales and, second, between mitigation and adaptation. These situations require careful consideration of the advantages and disadvantages. From a perspective of sustainable development, the author remarks, it must be questioned whether social acceptance of a project should be based on an actual political process beyond the project itself. The dam in the Trift Glacier represents the first case in a glacier forefield and could be a legal precedent for other dam projects in new deglaciated landscapes. Such dams support the transition to renewable energy sources but transform a natural resource system into a hydroelectric region with impacts on nature, biodiversity, and the landscape.

Water resources are at the centre of converging attention, and an overview of such interests is needed in any planning initiative. Nonetheless, involvement needs infrastructures to be effective. To answer this need, a recent study (Bojovich et al., 2017) evaluated the effectiveness of an online platform supporting the analysis of adaptation measures in the Alps.

Such a form of *e-participation* shows the proposed methods, and the tool for participation would be an essential asset to a formal climate change decision-support process that would compare and combine experts' elicitation with information about public preferences in different locations and across various stakeholder groups.

Another realm of concern about climate change lies in land planning mechanisms and their capacity to incorporate climate change instances into their operative frameworks. Kruse and Pütz (2014) enquire on the adaptive capacity of spatial planning in the Alpine region regarding the emergence of climate change. The study displays how the inclusion of climate adaptation in spatial planning legislation and instruments is still far from being the norm and is only seldom addressed explicitly in planning objectives. To overcome this limitation, the authors suggest some strategies:

1. Improving the knowledge base for spatial planning so that adaptive capacities can be enhanced, which involves providing access to existing climate information, enhancing regional and sector-specific climate information, supporting regional spatial planning authorities with expert commissions, and fostering climate adaptation networks.
2. Mainstreaming adaptation within the institutional framework of spatial planning by providing legislation and instruments to strengthen political support for the planning and implementing adaptation measures. The authors identify a gap between planning and implementation when potentially strong and binding instruments for adaptation on the local level are not implemented accordingly.

Results show that climate change adaptation in spatial planning is a question of adaptive capacities and governance and institutions. Once again, the authors underline the need for further research on the topic.

To conclude, a more integrative approach is offered by Wilson (2018) in an accurate reconstruction of the resilience of an Alpine community to present and foreseeable drivers of change. *Community resilience*, a concept related to both sustainability and adaptation is defined as:

> […] the capacity of a community to absorb disturbance and reorganize while undergoing change to still retain essentially the same function, structure, identity, and feedbacks (Wilson et al., 2018, p. 372).

Among the many disturbances, Alpine communities must face the effects of a changing climate. Building on critical studies, the authors evaluate the resilience of a small village, Vent, located in the Öztal valley, Austria. The framework adopted broke down the concept of resilience in five domains (natural, cultural, social, political, and economic) and evaluated it in each domain against multiple disturbances. The study shows that the relative balance between the five domains precarious and may become more precarious due to several self-reinforcing cycles. Climate change is affecting tourism, but the village has continued to place considerable emphasis on skiing, creating a vulnerability factor (i.e. lowers adaptability and transformability of the community).

Nonetheless, compared to other tourism centres, the presence of a high proportion of summer tourism is positive for adapting to future climate change. Once the glaciers disappear altogether, Vent will find itself in a more advantageous position than communities that have continued to focus entirely on skiing. Nonetheless, climate change may prove particularly damaging for high Alpine communities such as Vent, although a more extended autumn season may benefit both eco-tourism, mountaineering, and farming. The future of Vent looks relatively bleak in light of continuing social and natural challenges, and current trends suggest that community resilience may decline further in the future.

2. *Epistemic geographies of climatic changes in protected areas*

2.1. Trapped in space: protected areas in a climate that is changing

Stationarity is dead.
(Milly et al., 2008)

A protected area is 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)

The formulation of a comprehensive definition of the meaning of 'protected area' is a less simple task than might appear. Over the arc of their history protected areas have accepted diverse tasks, cared for specific different objects, and changed their spatial area to pursue their own ends. Dudley's definition today provides us with a versatile tool that includes all the possible taxonomies developed by the International Union for Conservation of Nature (IUCN) over the years: from reserves of the biosphere to National Parks, from networks of natural reserves to areas that safeguard the landscape and sustainable use of resources. The history of conservation is full of examples of protected areas responsible for achieving very heterogeneous objectives. The most emblematic case is probably the dialectic of the 1920s and 1930s between the model of American conservation, realized in the Yellowstone National Park, and the Swiss model, embodied in the Swiss National Park. Although undeniable points of common interest were represented by the centrality of the wilderness, the guardianship of a form of *ur-Nature* (Kupper, 2014) which would act as a counterweight to the advance of modernity, and the "nationalization" of nature as a unifying symbol, the differences between the two cases remain profound. The common wording of 'National Park' conceals two radically different missions and two wide-apart ways of understanding conservation, which have finally polarized into true systems of reference. The American model, shaped by the romantic European ideal, focused on conservation for recreational ends of the human community. The institution of Yellowstone appeared before awareness of the environmental crisis, the action preceded the idea – as Roderick Nash (1967) notes – and as a result the park did not include ecological themes but only a naturalistic interest which equated the fascination of 'virgin' nature to that of the splendour of European castles and cathedrals. The Swiss model, by contrast, placed the scientific dimension at the heart of the National Park, creating an area of *Totalschutz* (Kupper, 2009, p. 62), of total preservation, in which to carry out the Grand Experiment of which Schröter was the visionary, completely excluding the human component.

If the purposes and missions have remained variables in the world of conservation and, in particular, in the protected areas, the boundary has, up until now, taken on the role of the constant. The boundaries of the protected area are what has made it such a successful, and at the same time contested, conservation tool. While on the one hand the exclusion of human activity from the exploitation of the natural resources has guaranteed the creation of a widespread archipelago on a global scale of protected areas of extremely varied dimensions, on the other it has generated a plethora of conflicts linked to access to the land and its resources, including the most fundamental: space. From the point of view of geographical science, the boundary has been widely studied in its relations to local communities. Dan Brockington, in a publication which has in its way become iconic, speaks of the concept of the protected area as a "Green Fortress", which excludes all human activities, in particular those concerning the local communities (Brockington, 2002). Brockington's aim is to highlight the extent of injustice in nature conservation, which in many geographical contexts has led to deprivation, above all for indigenous communities, excluded from access to natural resources. Along the same lines as Brockington, Zimmerer suggests exploiting the new conceptual instruments of nonequilibrium ecology in order to rethink the very paradigm of conservation by means of practices that are no longer exclusive and segregationary (Zimmerer, 2000). The perspective adopted by this train of thought concentrates above all on case-studies coming from developing countries, in which the rigidity of the boundary actually delineates an alien element that, often through supranational dictates, breaks the historical continuity of the man-environment relationships developed in the individual terrain. The geographers' interest seldom turns to analysis of the aims of the individual protected areas or a critique of the formulas of conservation adopted. Yet, as Kupper (2014) notes, the idea of insulation, of discontinuity of the territorial fabric as an instrument for the creation of spaces "other" than our own, has for years governed the rationale of conservation, stimulating at the same time a conceptual division between nature and culture, and presenting this with a material manifestation at a geographical level, a realized heteropia. As an exception in this panorama, a productive thematic nucleus has recently been developed among British geographers, focused on the search for alternative conservation formulas for protected areas and aimed at the creation of open-ended results rather than the benchmark static ecological communities (Lorimer, 2012), or on the search for interpretations of the geographical peculiarities of ecological connectivity and its consequences (Hodgetts, 2014). Although the necessity for alternative formulas in conservation is at the centre of a fruitful discussion, at least in the discipline of geography, the success of the protected areas in nature conservation has been shown to be high up until now, with the exception of local episodes of human intervention linked more to policy contingencies than to the limitations of the model. In this scenario of substantial acceptance of the model adopted as a tried and tested solution, the advent of climate change can be read as a problem so deep as to reach the paradigmatic level. The boundaries of the protected areas, for the first time, are an inefficient weapon of conservation because they cannot handle the effects of changes in the climate beyond the perimeters of protection. Whatever the type of area protected, its conservation aim and geographical position, climate change is an element that can deeply influence the success of the conservationist policies carried out, as a result of its capacity to influence diverse constituent elements of the protected areas. If in the modern history of conservation the constant (the boundary) has made possible the control of the variables (objects of interest, conservationist objectives), climate change shatters the paradigm in its very foundations. The existence of the boundary is no longer able to act as a necessary and sufficient condition for guaranteeing exclusive control of all the variables. The entrance of the independent variable – no longer another neutral constant – of the climate actually causes the ecological balances to alter, sometimes profoundly, and forces them to come to terms with a fundamental reality: nature cannot be frozen in a predetermined ecosystemic state. This means, in a certain sense, ceasing to consider the protected areas as a "*rethinking of our spatio-temporal conceptions capable of identifying which relicts of history and nature to maintain in the territorial dimension*" (Schmidt di Friedberg, 2004, p. 13), and instead beginning to reconceptualize them as a stage setting in which different elements – species, morphology, balances, and sometimes entire ecosystems – are no longer remains available to us, segregating them in the spatial dimension of 'there' and in the temporal one of 'for ever' in a little bit of land carved out of the country. The focus of every attempt at land conservation must therefore be modified in the face of climate change and incorporate in its own value system the old enemy: change.

In order to handle the complex subject of the impacts - measurable and potential – of climate change in the protected areas, the main spheres of influence can be briefly schematized as follows.

1) Effects on the species: the first element of basic importance for management concerns the movement of species associated with changes in the climate. The new thermo-pluviometric regimes determine changes in species' spatial distribution, substantially changing the species' composition within the protected area. This translates to the concrete possibility of discovering new species inside the protection boundary, as if the changes were helping to displace populations historically resident outside the perimeter (Parmesan, 2006). A limited capacity for dispersal or a fragmented habitat around the historical range can constitute fundamental obstacles to migration and could lead to contraction of the bio-geographic area (Mortiz, 2008; Wilson, 2011). The main point in this case is therefore the incompatibility of the protected area's spatial immobility with the species' heightened mobility, above all when the species were a cardinal element for the policies of conservation adopted.
2) Effects on the landscape: direct and indirect alterations to the physical environment of the protected area, that is, displacement of the biogeographic areas, new regimes of wildfires, melting of the glaciers, and depletion of the water basins, will lead inevitably to deep changes in the landscape of the protected areas, which could differ noticeably in the future from how they appear today (Thompson et al., 1998).
3) Effects on the ecosystems: the alterations in the protected areas' physical environment will, in many cases, lead to further important ecosystem adjustments, with estimates forecasting substantial differences to plant cover (Lemieux, Scott, 2005; Saunders, 2007). Changes in the rainfall and wildfire regimes could accelerate transitions from one ecosystem to another. In the case of rainfall, an alteration in the absolute volumetric value and in its temporal distribution could cause noticeable changes to the available water resources. In the protected mountain areas, as indicated in the previous chapter, an increase in rain precipitation at the expense of snowfall will necessarily lead to a different surface run-off, with directly related results for the ecological communities and the availability of water resources throughout the year. A greater frequency of wildfires, on the other hand, could redefine the plant cover of entire protected areas, facilitating the succession of fire-tolerant species. Where the wildfires also increase in intensity, they could even cause a change in the age and structure of vegetation in a number of regions, leading to the replacement of mixed forest with new, younger and more uniform forests, with potentially severe consequences for habitat connectivity and wildlife conservation.

5) Effects on human-environment interaction: the biotic and abiotic alterations which the protected areas must face will obviously also have repercussions on the human activities present within them and permitted by the conservation model adopted. In the North American parks this converts principally into potential changes in the performance of the recreational functions which the parks are expected to deliver, bearing in mind the seasonality of the influx of visitors. Equally, declines in some of the animal and plant populations, important landscape changes, and breaking of ecosystem integrity could lead to a fall in visitors' affection for the areas subject to change, due to the decreased adhesion to the aesthetic principles belonging to the historical ecological-environmental equilibrium (Scott, 2007; Lemieux, 2011). In the case of protected areas responding to different conservation criteria, the environmental changes could have a negative impact in ethno-ecological wisdom and the availability of resources (Turner, Clifton, 2009).

In the face of the numerous risks arising from climate change, the conservation community has broached the subject many times, with the aim of producing shared principles on the policies of adjustment to adopt. In 2016, the IUCN published guidelines for all the protected areas, consisting of a series of recommendations that are globally valid and can be scaled in accordance with the regional context, the type of area, and the network of shareholders involved. The IUCN aims to stimulate progressive incorporation of climate change into the planning of all protected areas by identifying a number of best practices (IUCN, 2016, p.14). The body identified different levels at which the new practices could be integrated, starting with a concept that could, to a certain extent, be called revolutionary: accept and accommodate the change. On the ecological and, in some sense, philosophical levels, the measure includes a fundamental move: accepting climate change means abandoning the claim of controlling its results, in place of being best able to channel it in the most desirable directions. On the level of management this means first abandoning every baseline of the historical example, actually removing the ideals of the ecological communities of reference: climate change is driving the ecosystems beyond their true equilibrium (or rather, beyond the state which we are accustomed to think of as equilibrium) and this forces us to come to terms with the fact that every point of historical ecosystem equilibrium is transitory. The equilibrium is therefore determined by a series of points in a temporal continuum, in which an ecological community of reference, a static point of arrival, cannot exist, just as we can no longer consider climate as a stationary element. With the death of the idea of a constant climate, even those concepts widely used in several conservationist contexts, such as historical allegiance as a founding principle of conservation policies, will count for less. The management must therefore incorporate the climate, but above all its variability, in the future direction of the protected areas, through an approach which reflects the idea of continuous change, cyclically embracing phases of resistance to change, resilience and realignment when it becomes necessary to facilitate the ecological transition and promote certain desirable features. The protected areas must thus adopt a proactive management viewpoint, able continuously to reconsider their own conservation objectives, from time to time evaluating their level of attainability according to the development of climatic-environmental conditions. The conservation objectives, therefore, must be flexible and the possibility of abandoning them whenever they become impractical should not be excluded. The objectives reflect the value system, and knowing how to adapt it is the first priority.

At this point it becomes necessary to make explicit, in the review of management strategies, what has until now been kept on an implicit level: the role of science. Even if the IUCN rarely mentions the subject directly, science's central status in the adjustment strategies is clearly appreciable. The construction of a management system involves a notable mass of scientific information, necessary to evaluate the intensity and direction of the processes in action: programmes of monitoring aimed at gathering information in the medium to long term are obviously fundamental elements, but are not on their own sufficient for successfully informing a plan of adjustment. Having to deal with climate change means today, above all, having to come to terms with the dimension of uncertainty (IUCN, 2016, p. 21), which can only be faced by producing a range of hypotheses within a given field of potential variables. Climate models and projections therefore become key tools, as are studies linked to ecological reactions to rising temperatures or alteration in pluviometric regimes and natural disturbances, not to forget the need for research studies linked to the response of human communities with direct relationships to the protected area. In the same way the spatial scale must be able to move from local to regional, from a specific site to the entire system, embracing not only the conservation principles of the ecosystem in its entirety in the protected area, but also between the protected areas, ensuring sufficient levels of connectivity to allow the movement of species between the different areas. All these needs mobilize studies arising from classic disciplines – ecology, glaciology, geomorphology, geology, hydrology, climatology, and geography – but equally require a functional integration of these competences in an application of "fringe science" between the traditional fields of knowledge, from the science of connectivity to scenario planning and risk management. The variability of the spatial-temporal scales of reference also requires the integration of approaches that are diametrically opposed on the level of geographical and methodological focus. The analysis of vast volumes of data linked to the scale of the landscape, needed for analysing the systems of the protected areas in their interactions, both realized and potential, must be integrated from studies at the local level, focused for example on the response of individual human communities to changes or to the migration of species that are locally important. This means, moreover, combining approaches based on statistical analysis on a wide scale (Big Data) with in-depth studies on a qualitative level (*Thick Data*[1]) to be able to monitor them as a whole and as their individual components.

The centrality of the scientific undertaking is being used itself not only in its traditional forms but also when translated into forms of boundary and transformation science. What remains to be verified is the level of effective collaboration between science and management on the direction of the protected areas, starting really from an evaluation of the level of scientific production. The aim of this chapter will therefore be that of defining the geography of the scientific contributions that can be used today by park managers and the entire conservation epistemic community in the study of climate change, by tracing the main geographical patterns in its production and examining the reasons for this specific distribution, then to focus on the Alpine macroregion and its role in this global circuit.

2.2. Climate change in the protected areas: a geography of scientific interest

2.2.1. Outlines of the geography of science and principles of regionalization

Just as none of us is outside or beyond geography, none of us is completely free from the struggle over geography. That struggle is complex and interesting because it is not only about soldiers and cannons, but also about ideas, about forms, about images and imaginings (Said, 1993, p. 6).

Out of so many theories on the circulation of knowledge developed in the international context, probably Edward Said's Travelling Theories (1991) are the ideal point of departure for explaining, from a theoretical viewpoint, what is meant in using the label "geography of science". Said expresses an

[1] The definition adopted here of *thick data* is a broad one. We apply the definition to qualitative informative materials, tools or techniques that help scientists and manager to gather granular, specific knowledge about their target regions or communities.

intuitive concept, an inherent ownership in ideas and theories, namely the capacity to circulate from person to person, from situation to situation, from institution to institution, and from one historical moment to another. Yet the process – and it is at this point that the discourse loses its apparent simplicity – is never that of a perfect migration from A to B, because the transfer necessarily involves a transformation. Circulation and translation are reciprocally constituent concepts, and so a pure replication of a theory does not exist. What Said wishes to elucidate is the finite nature of the theory, which must be understood in relation to the space and time in which it is formed. A theory is therefore a direct product of space and time and will always adapt to the space and time in which it is found (Livingstone, 1995, p. 7). Obviously, these considerations also apply to scientific theories.

Science is, first of all, a social undertaking (Finnegan, 2008). The exploration of the unknown and the construction of knowledge have never been exclusively technical projects, but should be read as challenges built by a community to give themselves rules and hierarchies. David Livingstone highlights how in the 17th century scientific production had specific geographies: the production of knowledge was not an a-spatial process but was deeply rooted inside the place within which the knowledge-based undertaking could be defined as legitimate. In this case, the laboratory assumed the role of the place of legitimization, a place in which the behaviour of scientific enquiry could be expressed and from which the final product – the discovery, or the proof of the theory – could be presented to an audience of the scientist's peers, effectively bringing it face to face with a community. In the same way, Livingstone also shows how science presents principles of regionalization. There are no scientific discoveries valid in Manchester which cannot be verified in Venice by following the same method, whenever this is rigorous and shared with the scientific community, but there were – and are – regions in which the combination of socio-political, geographical and economic factors made the development of determined scientific paradigms easier, faster, and more pervasive. Scientific communities differed from region to region, organizing themselves around different key problems, methods and interests.

Starting from these premises an entire thread of study appears in the field of historical geography, which explores the mechanisms that determine the emergence of scientific areas (Livingstone, 1995), the circulation of science across different lands and its reception and reworking in different scientific regions (Livingstone, 2003; Powell, 2007), the tight relationships between scientific paradigms and landscapes or entire bioregions, as in the case of the unfortunate link between the forest-gardens of Lesosad and the "scientific" trend of Lysenkoism (Fleming, 2014). The historical occurrence of this kind of research has moreover found fertile ground in ecology, the history of which discipline is today the subject of frequent studies on the spatiality which has allowed particular conservation theories, practices and policies that have fundamentally influenced research and its scientific paradigms. The literature has therefore no lack of examples of historical and geographical analysis of the different theories and methods of ecological science: from the duality of the French and American taxonomy systems, derived from the studies of Josias Braun-Blanquet on the one hand and those of Friedric Clements on the other (Livingstone, 1995), passing then to the study of the concept of scale in ecological studies and its role in the building of global knowledge (Vetter, 2017), to arrive finally at organized attempts to construct a thread of enquiry on the role of space and place in the history of ecology (De Bont, Lachmund, 2017).

The definition of "geography of science" does, however, also include a different approach to the study of spatiality, this time more markedly quantitative and directed towards an analysis of the distribution of research centres and publications with the help of software aimed at cartographic analysis of metadata (Small, Garfield, 1995; Leydersdorff, Persson, 2010; Bornmann et al., 2011; Bornmann, Waltman, 2011). This family of study was born as an offshoot of bibliometrics and scientometrics, with the aim of integrating a spatial dimension into this applied discipline, often with the objective of an evaluation of the research. Among the more recent research pointers, the integration of network analysis definitely marks an important progress for this type of study, because it provides the possibility of adding to the cartography generated with data in order to describe not only the objects but also their inter-relationships. If on the one hand the studies linked to spatial scientometrics allow the materialization visually and quantitatively of several of the theoretical elements belonging to the geography of science – laboratories, regional clusters, information circulation circuits – on the other the scope of the geographical analysis is no more profound, in this developmental stage, than a – necessary but insufficient – localized geography. The identification of patterns is rarely followed by a geographical, sociological or geo-historical analysis capable of lending meaning to the spatial arrangement derived from the treatment of the metadata. To use a fundamental quotation, "geography of science implies more than an acknowledgement of the locational context of science" (Driver, 1994, p. 338).

The English geographer Richard Powell, in tackling the wide discourse linked to the literature in the field of historical geography of science, draws attention to the possibility of going beyond the strictly historical dimension by embracing contemporaneity and the necessity for contemporary research, identifying a field of promising – and urgently necessary – application in the study of the geography of the geographical sciences (Powell, 2007, pp. 321-

322). Geographers' attention has often lingered inside their own discipline, seeking to gather from it a supposed special epistemological status or attempting to bridge the gap between the two spirits of geography. The possible application of a view of geography of science as a tool to mend the internal fractures of geographical disciplines is certainly a stimulating scientific undertaking for those who work within those disciplines, but the potentialities of the method could be extended beyond the individual academic boundary to embrace complex problems involving interdisciplinary interests. On this theme, among the great challenges that contemporary geography can and must face, climate change is perhaps the most important and complex. Mahony and Hulme describe the phenomenon as a prism out of which breaks an infinite variety of values, discourses and images (Mahony, Hulme, 2018, p. 397). Starting with this concept, the British geographers outline the "geographies of climatic sciences", which they define as "epistemic geographies", using the Foucauldian interpretation of the term and the concept of the epistemic community coined by Peter Haas (1992). Concentrating on the epistemological geographies of climate change means, to use the authors' words, "[to give attention] to the uneven geographies of scientific authority, the spatialities of the boundaries drawn between the scientific and the political, and the situated co-production of epistemic and normative commitments" (Mahony, Hulme, 2018, p. 396). The two authors therefore examine how the distribution of sites influences the building, inside the epistemic community, of scientific knowledge, how they form the regions of production of information, and how this information can travel from one region to another, meeting different openings for the reception and revision of its content.

Beginning with Livingstone's studies on the different receptions of Darwinism in diverse social contexts (Livingstone, 1995), the topic of reception and revision has taken on a central role among the possible paths of enquiry for the geography of science, summarized in what Livingstone defines as "scientific styles" (Livingstone, 1995, p. 16). Different institutional arrangements and socio-economic and political conditions are variables which actively influence the process of regionalization of science and its related distinct "styles". Among the different possible applications of the conceptual and methodological tools of the geography of science, one of the most interesting for the study of climate change is therefore the definition of the diverse scientific cultures developed in the various epistemic communities involved in the process of "knowledge-making" in the climatic sciences (Mahony, Hulme, 2018, p. 399).

From a theoretical viewpoint, the aim of this present study does not significantly differ from that suggested by Mahony and Hulme: the search for elements that can describe – "map" in a certain sense – the mechanisms of reception and review of climate sciences. There is a substantial difference, however, in the position of sciences on the climate. The object of study here will not be the internal mechanisms of building climatic knowledge, but its reception by a different epistemic-scientific community: that of nature conservation. The case provides an important opportunity to evaluate not only the capacity of scientific knowledge to circulate in different regions and scientific communities that differ in their geographical location (even although similar in their discipline), but also the effective capacity of different epistemic communities to incorporate rationales, scientific practices, and adaptive mechanisms that come from diverse scientific realities and diverse disciplines. In practice, the fundamental point will be to understand how scientific-epistemic communities that differ in the geographical position, study setting, scientific-conservationist culture, and specific ecologies in which they work, can receive, reinterpret and apply dictates coming from the climate sciences and boundary institutions, such as the IPCC – but in this case also the IUCN – which gather scientific information and enable it to have global and capillary circulation. It is hardly news that worry over climate change is unequally distributed over terrestrial surfaces (Orlove et al., 2014, p. 249), due to the practice of "selective recognition" deriving from the historical geographies of exploration, field work in a scientific environment, colonial exploitation, or post-colonial geopolitics (Mahony, Hulme, 2018, p. 401). The new-born – really as a result of the climate emergency – "adaptation science" is therefore the centre of attention:

> Adaptation science can be considered an epistemic 'trading zone' where global climate simulation intersects with field-based research on socio-ecological system and vulnerabilities (Mahony, Hulme, 2018, p. 401).

From this viewpoint, the protected areas are a perfect scenario for monitoring the spatial behaviour of these trading zones. Parks, reserves and national monuments, using an analogy with Livingstone's work, take on the role of laboratories for conservation science. The scientific literature warns against having excessive faith in the equivalence between the protected areas and ecological laboratories (Kupper, 2014), but in our case the protected areas serve as laboratories for a sociological analysis of scientific interest. It is not so much the bio-geo-ecological processes linked to climate change that are the centre of interest, but the relationship established between these objects of study, the fundamental scientific discourse on climate change, and the epistemic community of conservation in its local and regional geographical manifestations.

For the successful completion of such a study, it is indispensable to summon diverse tools of analysis belonging to the geography of science in all its guises: from scientometrics and spatial-scientometric analysis to qualitative analysis aimed at a rereading of the scientific-institutional discourse underlying research production, without forgetting the validation of the theoretical framework derived from geographical theory. The study should therefore also be understood as a testing ground for integration between different methodologies which until now have rarely crossed paths.

2.2.2. The study of climate change in the world's protected areas

Starting from the principles briefly listed in the foregoing, it is possible to provide a reading of the network of global research linked to the study of climate change in protected areas. For this end, the following provides an analysis of data extracted from the Web of Science to illustrate the current state of research (1985-2019). The dataset of articles (n=948) has therefore been read and analysed from different perspectives, allowing a panoramic observation of the diverse characteristics making up the network.

The first question when studying the dataset concerns in this case too the temporal dimension. Tracing the birth and development of scientific interest in the effect of climate change on conservation is once again useful for understanding its true effect by means of the curve that describes its growth.

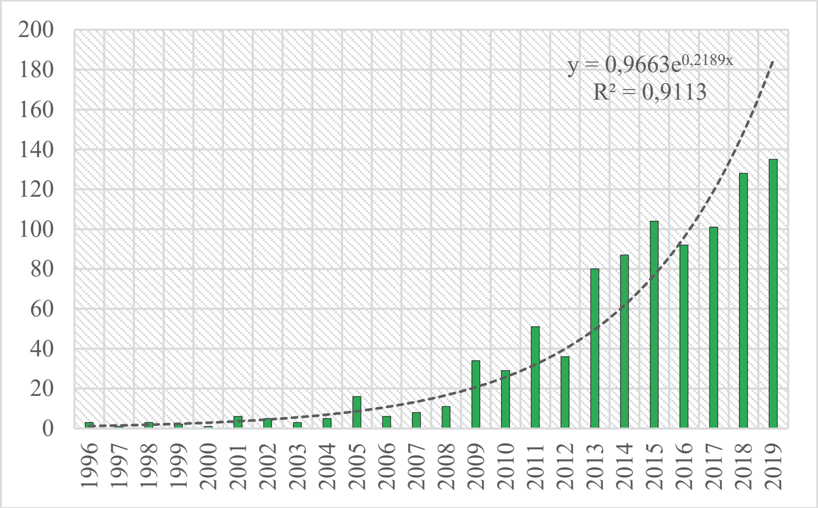

Figure 2.1 - Temporal evolution (1994-2019) of the number of research studies produced on the subject of climate change in protected areas. Developed by the author on data from the Web of Science. Search term TS=(protected areas) AND TI=(climate change)

The graph shown in Figure 2.1 highlights the marked quasi-exponential growth of the subject, above all from the beginning of the present decade. The seven years 2013-2019 have the greatest value of the entire series, so defining an argument that has become increasingly more important in the scientific community in those years, exceeding 130 publications in 2018 and 2019. After a strong growth spur (2013-2015) the number of new publications is gradually abandoning the exponential path, signalling a mature research question that is probably reaching a plateau.

The second question instead examines the actual composition of the scientific community. Who conducts the research? In this case, the answer is certainly more complex. From the geographical viewpoint, the first useful step for understanding the true spatial composition of the community can be identified in the national composition of the research products shown in the dataset, so searching for how many and which states are involved, and to what extent. Figure 2.2 shows, by country, the principal producers of research on the subject.

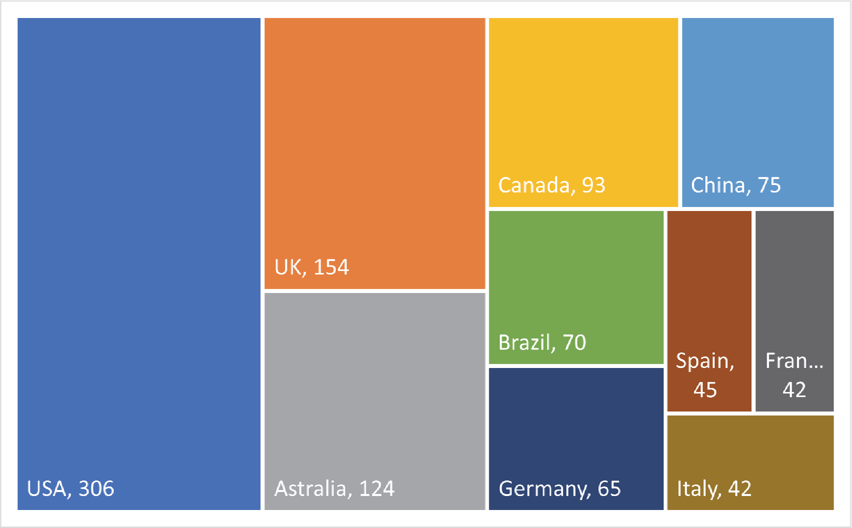

Figure 2.2 - The first 10 countries organized by gross output of scientific articles. Drawn by the author from Web of Science data

The international panorama is dominated by the anglophone countries, which produce the great majority of research articles, with the United States as the largest producer by a wide margin. Of particular interest for the purposes of this present discussion is the presence of three Alpine states – Germany, Italy and France – which, while not providing us with any indication of the centrality of the region within the international discussion, does give us an important piece of information on context: three of the countries that are signatories to the Alpine Convention are of world excellence in primary research production on climate change in protected areas. By widening the field of observation to the first twenty-five countries, we find new evidence worthy of note (figs. 2.3-2.4).

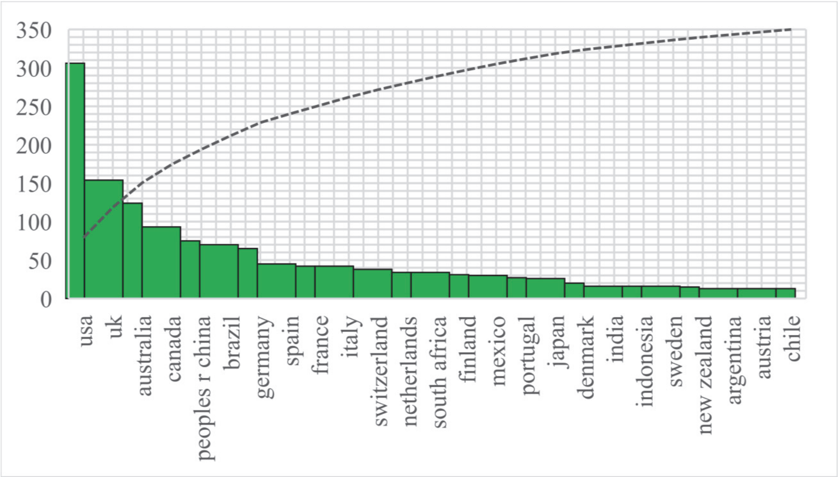

Figure 2.3 - The first twenty-five countries producing scientific articles in descending order. Developed by the author from Web of Science data.

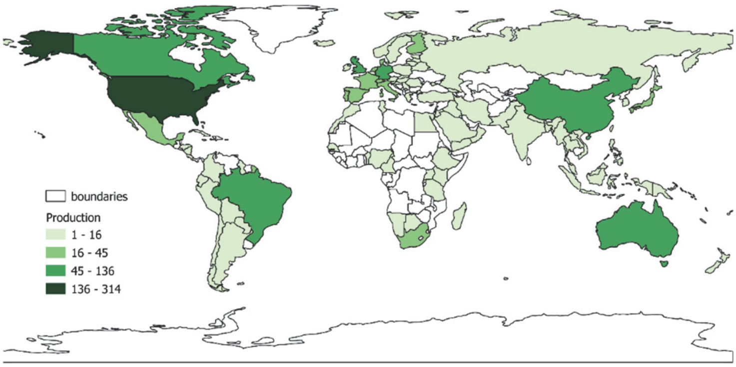

Figure 2.4 - Production per country. Data from Web of Science 1994-2019, drawn by the author on Web of Science data

The study of climate change can be defined as a "north-western" practice: the spatial pattern emerges around the centrality of the North American cluster, accompanied by a secondary one in Europe. The first four producing countries alone count for 60% of the scientific output. The global spread of the studies is therefore sparsely distributed and tends to conglomerate in macroregions, above all in the northern hemisphere. The southern counterpart ranks few countries among the major producers, and this fact is certainly not surprising: in the sample examined there is a positive correlation (p=0.8) between GDP (source: World Bank, 2016) and the number of research articles produced. For further confirmation of what is suggested by the great north-western cluster, it is clear that the southern countries which produce scientific research on the argument are those economically developed and with a higher GDP, on the whole comparable to the northern countries: China, Australia, South Africa, Brazil, Chile, and New Zealand. To some extent, the problem of climate change as a cause of disequilibrium for the protected areas seems to be a problem that can only be investigated in a given condition of economic well-being. However, we will focus on this aspect soon.

Once, therefore, the research hotspots have been identified, a further step can be made towards identifying the relationships between the different producing countries. Who engages in the greatest number of international relationships? Who is, by contrast, on the sidelines of international discourse? Which countries are most influential at a scientific level in international debate on the subject? What results do the metrics show in the case of the Alpine countries? To respond to queries such as those, a methodology has been chosen which has already been used in similar studies (Zuccala et al., 2016). The raw data extracted from the Web of Science were processed by means of the software VOSviewer's mapping algorithm (Van Eck, Waltman, 2010) and then extracted in the form of a Pajek (.net) file, to be processed further through the social network NetDraw's analysis software (Borgatti, 2002) by undertaking an analysis of the main measures of centrality (Degree centrality, Eigenvector, Betweenness centrality) on the whole dataset selected. For the purposes of this study, interest will be focused only on the results pertaining to the first ten producing countries and to the more significant metrics associated with them, as well as on the situation in the Alpine countries, so as to understand the scale of their importance in the network.

Before continuing to the analysis, the key point of this type of analytic methodology needs to be made clear: each item of data relates to the production of scientific articles within a determined country or research institute; this means that the data refer to the geographical position of the institutions, but do not take into consideration the setting of the research; what is drawn here therefore is the position of the subject that undertakes the research, but not the object studied. There is therefore no need to commit the error of thinking that the north of the world is more studied than the south, or any other inference about the location of the objects of interest. It is perfectly possible that the institutes of a given country have as their object of research the protected areas of a third country, or that international cooperation between advanced economies leads to the study of territorial reality in developing countries.

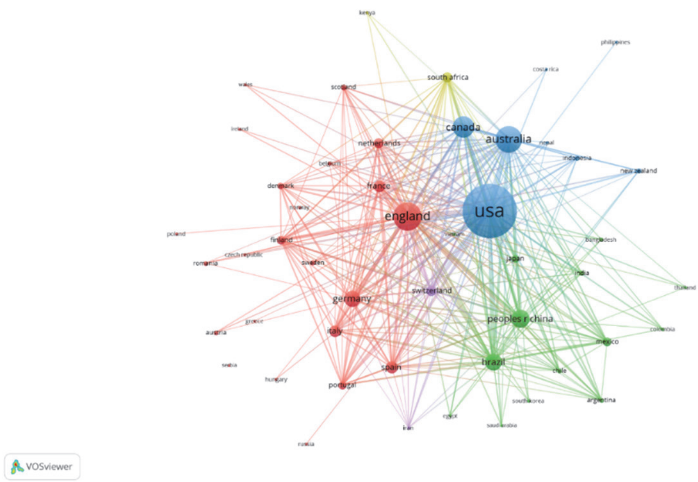

Figure 2.5 - Network map (bibliographic coupling) of the main producing countries. Developed by the author from Web of Science data.

From examination of the network we can extract new information, above all as regards international scientific relationships. The map in figure 2.5, structured around the data of *bibliographic coupling*, and the metadata associated with it, shows a complex phenomenon. The specialistic term *bibliographic coupling* indicates a procedure of analysis that use citations to calculate the similarity between publications. In bibliographic coupling, publications sharing many references, i.e., publications whose bibliographies largely overlap, are considered as more similar than publications sharing few or no references at all. Given the definition of similarity, we can interpret a high value of degree centrality in a node of our network (a high number of links) as a measure of influence. While the primacy of the United States remains clear in terms of volume production, the United Kingdom – and in particular England – shows the highest level of degree centrality and of connections with other producing countries (n=48). Among the peripheral nodes of England's cluster are aligned all of the Alpine country, except for Switzerland, sharing similar traits with US literature and forming a separate small cluster.

In order to give depth to the analysis, further metrics of centrality were applied, starting with the measure of eigencentrality, which gives us the capacity of one node to connect with the more important nodes inside the network. In this case too, the roles of the North American and Anglo-Saxon countries remain predominant, with England and the United States giving the greatest values. By combining the figure of centrality with that of raw production, it is clear how the United States are characterised by notably higher production than all the other countries incorporated in the network, but the figure of degree centrality (Dc=57) underlines how their capacity to enter into international cooperation is slightly lower than that of the English, as is also their propensity for collaboration with the network's most influential nodes (Ev=0.25). In the same way, the two countries cited above also show the highest level of betweenness centrality, highlighting their capacity for influencing the network and taking key positions in the circulation of scientific information. Values of lower centrality, but still within the highest of the entire dataset, are associated with Canada, Australia, and the four countries that are signatories of the Alpine Convention: Germany, France, Switzerland, and Italy. In the remaining cases, all the measures of centrality indicate marginal values in the overall economy of the network.

The raw data are a valuable source of information, but they do not tell the whole story. Raw data are, in fact, susceptible to the effect of scale. It is perfectly expected that anglophone universities such as the American or British may produce more papers on a given subject than smaller countries' scientific communities because of the sheer number of academics and researchers. If the researcher aims at identifying countries that produce the highest volume of scientific literature in proportion to its overall capacity, the data needs to be normalized. An intuitive way to treat our data would imply factoring the size of the research population into the picture. However, researcher populations are notoriously difficult to measure in their size: researchers work mainly in universities, but not exclusively. They work both in the public and private sectors. International institutions such as the World Bank aggregate data in the "Research and Development" (R&D) category and proceed with countries' estimations. Such estimations, nonetheless, are often inconsistent in their methodologies and asynchronous in their timespans. Therefore, employing such kind of data would introduce some distortion into our dataset. A more conservative approach could look slightly different, using once again publication data as a proxy. Web of Science categories have been retrieved for each article of the original dataset. Such categories define the disciplinary boundaries of every paper indexed in the database. Once defined the categories, we can formulate another string of research[2] to gather all the scientific production on the topic of climate change for every country which falls in the same categories of the original dataset. The solution allows us to normalize our data with a reasonable proxy of the academic population, assuming that production volumes for each country grow in functions of the number of researchers employed. With this new, larger, piece of information, we can now evaluate how much scientific production on the topic of climate change is devoted to studies revolving around protected areas. It is possible at this point to derive an index of centrality (Ic) for each country:

[2] SU=(ENVIRONMENTAL SCIENCES OR ECOLOGY OR BIODIVERSITY CONSERVATION OR ENVIRONMENTAL STUDIES OR MULTIDISCIPLINARY SCIENCES OR METEOROLOGY ATMOSPHERIC SCIENCES OR WATER RESOURCES OR FORESTRY OR GEOSCIENCES MULTIDISCIPLINARY OR MARINE FRESHWATER BIOLOGY OR GEOGRAPHY PHYSICAL OR OCEANOGRAPHY OR EVOLUTIONARY BIOLOGY OR GREEN SUSTAINABLE SCIENCE TECHNOLOGY OR GEOGRAPHY OR BIOLOGY OR ENGINEERING ENVIRONMENTAL OR PLANT SCIENCES OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR ZOOLOGY OR HOSPITALITY LEISURE SPORT TOURISM OR ENGINEERING CIVIL OR REGIONAL URBAN PLANNING OR AGRONOMY OR FISHERIES OR INTERNATIONAL RELATIONS OR URBAN STUDIES OR ENTOMOLOGY OR DEVELOPMENT STUDIES OR ENERGY FUELS OR LAW OR LIMNOLOGY OR MANAGEMENT OR REMOTE SENSING OR AGRICULTURE OR MULTIDISCIPLINARY ECONOMICS OR HORTICULTURE OR ORNITHOLOGY OR SOCIAL SCIENCES INTERDISCIPLINARY OR SOIL SCIENCE OR BIOCHEMISTRY OR MOLECULAR BIOLOGY OR ENGINEERING OCEAN OR AGRICULTURAL ECONOMICS POLICY OR ARCHITECTURE OR ENGINEERING MULTIDISCIPLINARY OR PALEONTOLOGY OR TOXICOLOGY OR AGRICULTURAL ENGINEERING OR AREA STUDIES OR ART OR BIOPHYSICS OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR BUSINESS OR CELL BIOLOGY OR CHEMISTRY ANALYTICAL OR COMPUTER SCIENCE INFORMATION SYSTEMS OR ENGINEERING ELECTRICAL ELECTRONIC OR ENGINEERING GEOLOGICAL OR GENETICS HEREDITY OR GEOCHEMISTRY GEOPHYSICS OR IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOGY OR INFECTIOUS DISEASES OR MEDICINE GENERAL INTERNAL OR PARASITOLOGY OR TROPICAL MEDICINE OR VETERINARY SCIENCES OR ANTHROPOLOGY OR AUTOMATION CONTROL SYSTEMS OR CHEMISTRY MULTIDISCIPLINARY OR COMMUNICATION OR COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE OR COMPUTER SCIENCE HARDWARE ARCHITECTURE OR COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS OR CONSTRUCTION BUILDING TECHNOLOGY OR DEMOGRAPHY OR ENGINEERING MARINE OR ENGINEERING MECHANICAL OR GEOLOGY OR HEALTH CARE SCIENCES SERVICES OR HEALTH POLICY SERVICES OR HISTORY PHILOSOPHY OF SCIENCE OR HUMANITIES MULTIDISCIPLINARY OR INFORMATION SCIENCE LIBRARY SCIENCE OR MATERIALS SCIENCE MULTIDISCIPLINARY OR MATHEMATICS INTERDISCIPLINARY APPLICATIONS OR NUCLEAR SCIENCE TECHNOLOGY OR PHARMACOLOGY PHARMACY OR PHILOSOPHY OR PHYSICS APPLIED OR PHYSIOLOGY OR SOCIAL SCIENCES MATHEMATICAL METHODS OR SOCIOLOGY OR STATISTICS PROBABILITY OR TRANSPORTATION OR TRANSPORTATION SCIENCE TECHNOLOGY) AND TS=(climate change).

$$Ic = \frac{Articles\ on\ climate\ change\ in\ protected\ areas}{Articles\ on\ climate\ change}\ x\ 100$$

Therefore, the result is expressed as the percentage of articles on climate change that focus on protected areas (related to the overall volume of literature produced on climate change). It is noteworthy that the index does not explicitly show a measure of absolute interest on the topic, but the relative importance of our field of research relative to all the other "competing" field of scientific enquiry in the domain of climate change. To avoid any statistical distortion due to small sample sizes, the normalization considers the countries with five indexed articles or more.

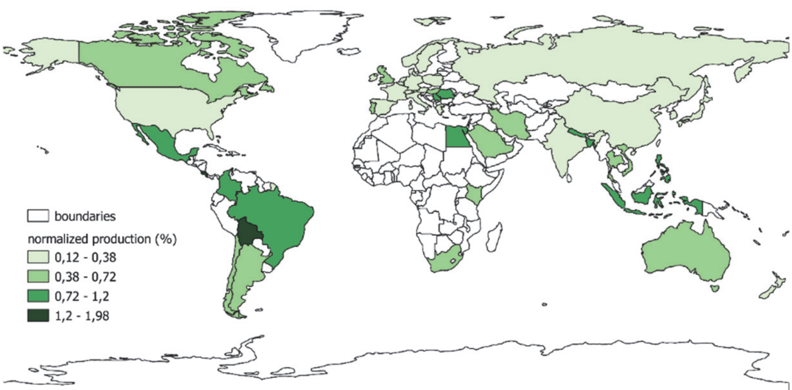

Figure 2.6 - Index of centrality for every country. Drawn by the author on Web of Science data

Normalized data (fig. 2.6) illustrate a new and interesting picture. Giants in gross production fall under the scrutiny of the normalization. Anglophone countries do not stand anymore head and shoulders over the pack: on the contrary, their normalized scientific production spans from average to low. The most compelling case among them is the one of the United States, whose production on our research question equals 0,33% of the overall research on the topic of climate change. Another giant, China, crumbles to low values (0,21%), testifying the influence of the research population's scale in its production. Other anglophone countries perform better: the UK display the higher percentage (0,62%), while Australia and Canada (0,5% and 0,41%) also fall under the average value of our dataset (0,6%). The UK's role stands out as the lone example of high production in terms of raw numbers accompanied by an average Ic value, the highest among countries with more than ten thousand articles indexed in the database. Narrowing our focus onto the

Alpine Countries alone, the interest on the topic remains lower than anglophone countries. Switzerland and Italy display the higher Ic values (0,38% and 0,35% respectively), while Austria (0,27%) Germany (0,24%) and France (0,24%) are all placed near the bottom of our sample. Once again, the geography of the scientific question outlined paints the Alpine Area as a less prominent region.

Surprisingly, developing countries assume a prominent role, as Bolivia (1,98%), Costa Rica (1,75%), Indonesia (1,2%), Bangladesh (1,16%), and Brazil (1,08%) the highest values of the dataset with values over 1%. However, this result might still be influenced by the small amount of scientific literature produced in such countries: except for Brazil and Mexico, the top ten percent-wise producers of the dataset count on small national literature on the topic of climate change (under 2000 indexed articles). To clarify the scale's influence on the dataset, we can correlate the number of articles produced by each country on the vast topic of climate change and the ratio expressed in the formula.

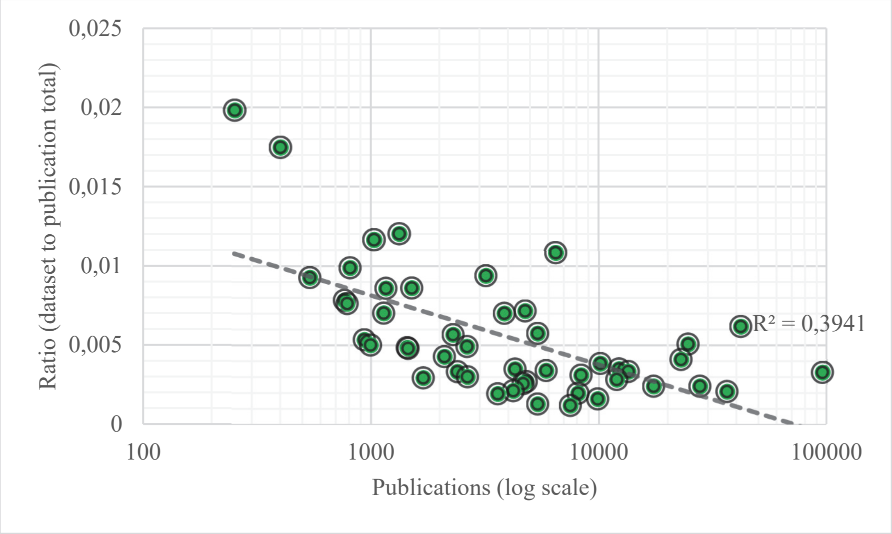

Figure 2.7 - Climate change in protected areas studies to climate change studies ratio against the number of total publications on climate change in each country

The plot (fig. 2.7) shows an interesting result. Size explains just a part of the variability, as the fit with the linear regression is sub-optimal (R2=0,39; note the log scale in x axis). The graph reflects the interest reserved to protected areas in the face of climate change by this group of countries: Bolivia and Costa Rica are outliers in our distribution, as their Ic is sensibly higher while the body of literature on climate change is rather small. Countries like Brazil, whose literature is fifteen to twenty times larger than the previous outlier, show comparable values of Ic. Similarly, values exceeding expectations of the linear model are sparse along the regression line. Taking consideration of all the points with a higher value than the model's expectations, Bolivia, Costa Rica, Indonesia, Brazil, the UK, and the US display the highest difference, exceeding by far the model's expectations. As a result, we can conclude that, even if a small size in the overall volume of literature plays a positive role in determining the share of protected areas studies, other decisive factors are in play.

Moving attention to the scale of single institutions, the network extracted from the dataset is shown in figure 2.8.

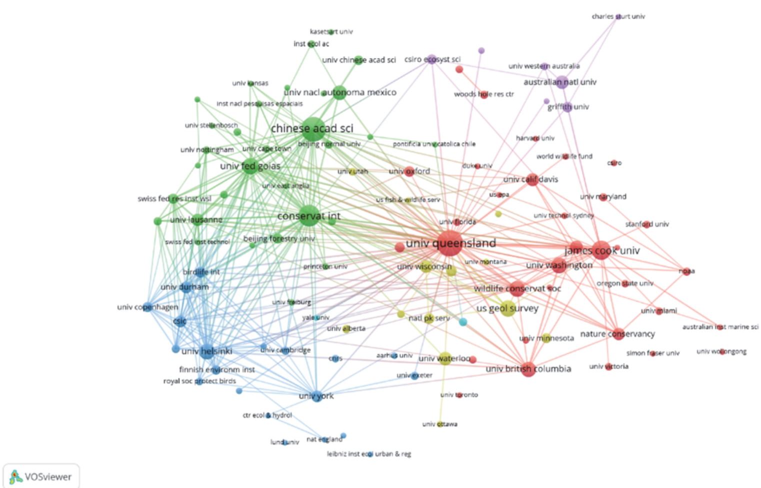

Figure 2.8 - Network map of the principal research institutions (bibliographic coupling). Developed by the author from Web of Science data

The network of institutions is dense, testifying the existence of an affirmed research field, where a large percentage of bibliographic foundations are shared among the institutions. The network also reflects, as expected, the predominance of the anglophone institutions, but has new material on the distribution of the principal sources of scientific information within the group of predominant countries.

From analysis of the composition of the clusters the absence of national or pseudo-national grouping becomes clear when talking of the creation of a network of scientific similarity, which assumes a strongly international direction. Starting from this argument, it becomes possible to take the first steps towards an analysis of metrics.

The most fruitful scientific production, in terms of indexed research documents, belongs to the James Cook University, to Conservation International, the Chinese Academy of Science, and to the University of Queensland (95th percentile). These institutions work as *hubs* and real centres of propagation for scientific contents across the network. To come across an Alpine institution, we need to descend to the 80th percentile, where we find the Lausanne and Grenoble 1 institutions.

Within the 90th percentile is recorded, once again, the dominance of the North American countries, Australia and England (twenty-one out of thirty institutions in total). Within the 90th percentile – an important piece of information for our case study – is found the University of Montpellier 2, geographically close to the Alpine regions and – together with the universities of Helsinki and Copenhagen – unique among the non-British institutions in Europe in reaching this percentile.

Focusing on the connections that build the network, however, the picture is quite different. Hub institutions as the Chinese Academy of Science, as well as strong producers of literature as the Federal University of Goias disappear from the highest percentiles, signalling how such institutions carry a slightly separated discourse from the bibliographic nucleus shared among the majority of North-Western countries. The University of Montpellier 1 enters the 90th percentile.

From the viewpoint of degree centrality, once again, one of the three institutions making up the 99th percentile is Australian, the University of Queensland, and one is Chinese, the Chinese Academy of Science, alongside with the international organization Conservation International. Within the dataset are seven different international institutions (The Nature Conservancy, Conservation International, Wildlife Conservation Society, World Wildlife Fund, Birdlife International, Joint Nature Conservation Community, Equilibrium Res), while the vast majority of the remaining institutions belong to anglophone countries, eight of them among conservation institutions and English universities. Some notable exceptions include the University of Copenhagen, the University of Evora, the University of Helsinki, the Federal University of Goias and the Autonomous National University of Mexico. It is, moreover, interesting to note how the larger number of universities included in the 90th percentile are English (n=8) and secondly Australian (n=4). Only one research institute belongs to the United States (US Geological Service) and none to Canada. To summarise, it is possible to state that on the level of relationships, the anglophone research institutes and the international institutions are the most active, with Australian universities being particularly prominent. As for the other measures of centrality, betweenness and eigenvector basically reflect the situation already described by the degree data, with the University of Queensland (Ev= 0.29; Bc=941) and Conservation International (ev=0.29; Bc=938) breaking away strongly compared to all the other values in the dataset, so giving a picture of a panorama in which two institutions maintain strategic positions inside the network and display active channels with the other influential nodes.

Finally, we can scale down our analysis to single authors and reconstruct their distribution in terms of locations and nationalities. For clarity and effectiveness, the analysis is focused on the *top authors* in terms of citation received overtime for their work on the topic of climate change in protected areas. At first, we should define how to spot a top author in the dataset. Citation distribution over a corpus of articles, like many other statistical distributions familiar to geographers, follows a power law, commonly known as the *Lotka Law*[3]. Similarly to the rank-size rule, widely employed to trace the distribution of city sizes, power laws can be fruitfully employed in bibliometric data, as the few top authors tend to concentrate the highest values of citations, the *head* of the curve, followed by a long *tail* of slowly decreasing values. Figure 2.9 shows the citations' statistical distribution per author in our dataset, considering only paper cited thirty or more times.

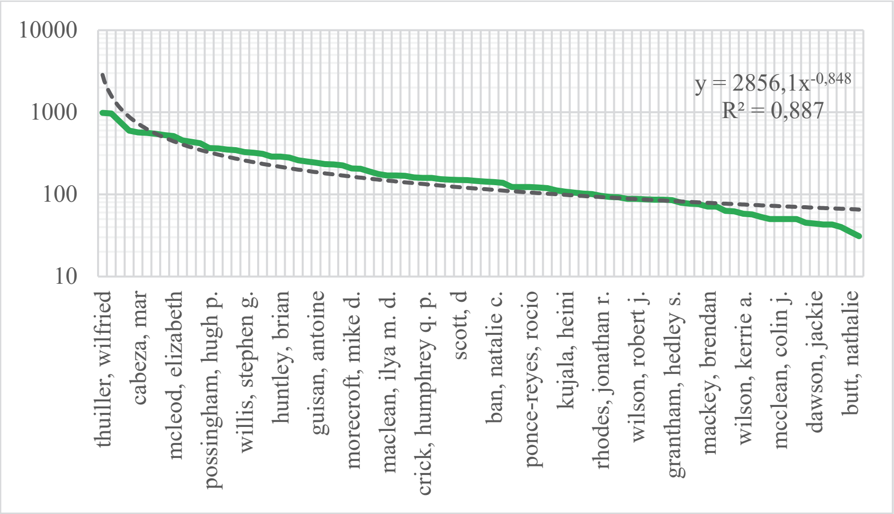

Figure 2.9 - Rank-size distribution author citations in the dataset. Drawn by the author on VOSviewer data

[3] A special application of the Zipf's law that describes the frequency of publication in a given field as an approximate inverse-square where the number of authors publishing a certain number of articles is a fixed ratio to the number of authors publishing a single article. As the number of articles published increases, authors producing that many publications become less frequent.

While the statistical distribution is aligned with the previously displayed results, it is interesting to dig into the geographic scope of the dataset, visualizing the distribution of the top authors. To enquire on this aspect, we retrieve affiliation data for the single authors from the Web of Science, process them via VOSviewer and then geocode[4] the name of the institutions to obtain a set of two coordinates (latitude and longitude) to be imported in a GIS environment (fig. 2.9).

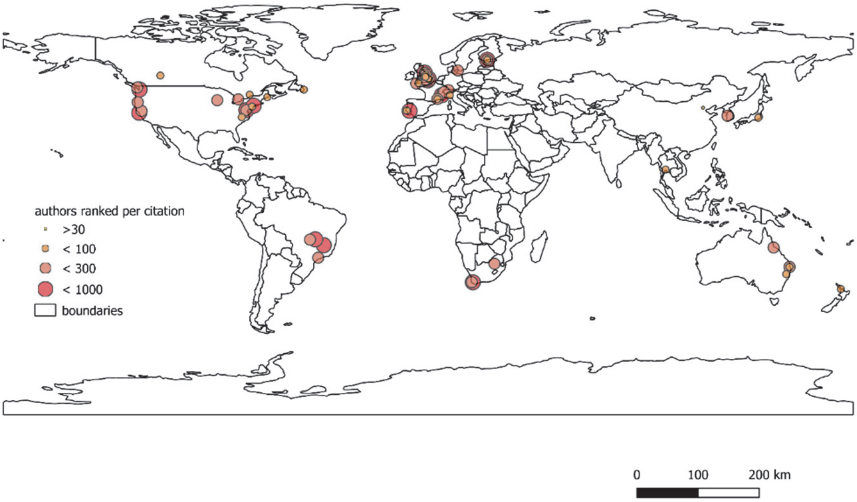

Figure 2.10 - Location (according to institutional affiliation) and ranking of the most cited authors in the dataset

In terms of affiliations, the distribution aligns with the pattern previously discovered. The North American and the European macro clusters are distinguishable as favourable locations for the production of scientific materials able to gather the attention of the scientific community. English and American institutes display the highest concentrations of top authors, and anglophone institutions produce a higher share of top-cited research papers. The map also reveals the existence of less expected clusters, as the Brazilian and the Swiss-French Cluster. The first piece of evidence pile up with the previous country-scale data to confirm the centrality of Brazil in the international endeavour around the study of climate change in protected areas: not only Brazil produce a higher proportion of articles on the topic than North

[4] Among many effective solution to perform a precise geocoding of location names: https://flowmap.blue/geocoding.

American and European countries, but its research products reach the highest scientific relevance in the field. Interestingly, the relatively small French-Swiss cluster (composed of five authors dislocated among the University of Lausanne, the IUCN headquarters, the University of Zurich, and the University of Montpellier) host the top author in term of citations.

From the point of view of the nationality, the top authors are once again distributed mostly across anglophone countries, while only six authors come from one of the Alpine countries (3 Italians, 3 Swiss, 2 French). Despite the small contribution to the pool of scientists, the top-cited author is French (Wilfred Thuiller) Figure 2.11 offers a graphical representation of the nationalities detected in the body of literature.

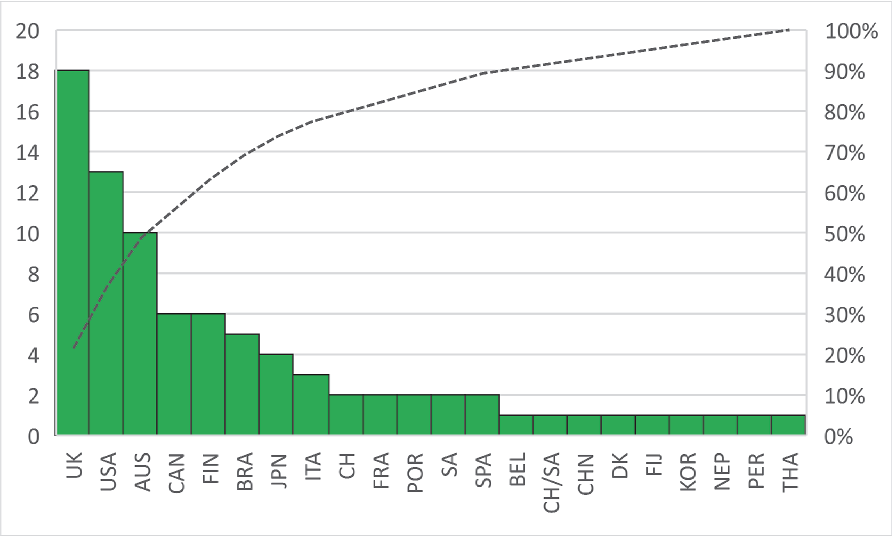

Figure 2.11 - Top authors grouped per nationality. Drawn by the author from Web of Science data

At this point it becomes necessary to summarize the main elements that constitute the geography of our scientific argument, before moving to a deeper interpretation. At a macroscopic level, the first fundamental element for the development of this type of research is given – intuitively – by the availability of investment in a scientific field, which largely excludes the institutions located in the southern hemisphere and a good number of developing countries. Once this fundamental prerequisite is established, the clearest data item consists of the centrality of the North American region, above all the United States, in terms of absolute production. From analyses of the networks extracted from the dataset, the measures of centrality have been calculated, all in agreement with the definition of that region as the true epicentre of the network. Other areas with strong scientific production are Australia and England, which in many aspects successfully overtake the North American region for their global impact on the functionality of the network, as does Canada, which with the United States joins to form the North American supercluster. Our dataset's informative foundations are shared between the vast North American and European superclusters from a bibliographic coupling viewpoint. However, normalized data draw a different picture, as some developing countries display the highest size-adjusted values, while anglophone and European countries lose their primacy. The focus shifts to countries like Bolivia, Costa Rica, Indonesia, Brazil, and Mexico, as they are actively developing a scientific discourse on the topic, although they are generally less productive. The effect of scale on normalized data plays a small role in predicting the number of articles published in relation to the dimension of national literatures on climate change, confirming the validity of the obtained values. What forces drive this result is still to be clarified, as much larger datasets of controlling, independent variables are to be analysed.

From an institution-scale analysis, the results are confirmed: the leading producers of scientific literature are either European or North American countries, alongside international organizations. The bibliographic foundations of the scientific discourse developed among these influential nodes of the network are widely shared, even if they are in lesser degrees for developing countries' institutions. In conclusion, the top-cited authors' distribution in the field is strongly centred around the North American, European and Australian clusters, with little space occupied by Asian researchers (Japan, China, and Fiji being the only countries represented).

Focusing briefly on the Alps scale, the majority of the Alpine states figure within the network, although with a marginal role. Scaling down the analysis to single institutions, two universities are centrality wise, part of the most influential group of producers: the University of Lausanne and the University of Montpellier 1. Alpine countries also host some of the top-cited authors in the dataset. Once this panorama has been defined, we should be mindful of our epistemological premises on the geography of science: science does not happen in a void. Bibliometrics need context to be significant and interpretable. The products of scientific enquiries are both premises and consequences of more profound, more extensive processes that influence society. As an example, the case of the North American cluster may be enlightening.

To respond to this question, it will be helpful to turn our attention to the actual leader with regard to the investigation of our research inquiry.

North America is the most important macroregion from the environmental conservation point of view: the first National Parks were created here, with Yellowstone acting as a forerunner and foundation stone for conservation – understood as a contemporary practice – throughout the world, and a large part of the scientific research linked to climate change in the protected areas has developed here, as is clear from the analyses of the network. This last element leads to further reflection on Livingstone's model used in the opening section: if in the past the scientific community was structured upon a network of peers, who shared access to places exclusively devoted to the building of knowledge and promoted a circulation of scientific products limited to members of this network, one of the principal effects of the transition towards contemporary Big Science, apart from the numerical increase discussed above, has been the inclusion of the scientific community in a far larger whole. The more restricted scientific community has been absorbed into a much wider epistemic community, composed of diverse actors: from policymakers to voluntary and professional conservationists, environmental journalists and to the scientists themselves.

In studying the practice of current conservation, the consequences of this epistemic community's heterogeneous composition cannot be ignored, since it is to all effects a complete ecosystem. Scientific discourse has been enriched by new facets and new perspectives which channel it into a political-cultural dimension.

To shed light on this complexity, it will be useful to follow a double track binary. On one side, we should enquire about the cultural dimension of climate change phenomena in protected areas. To do so, we turn to the analysis of practice outside the normal conduct of scientific practice, evolved in parallel to the enlargement of the world's scientific community, and the standardization of research products: scientific communication with the broader public. The case of the United States is better suited to this task because of a late growth of journalistic interest over the topic, undercovering some usually hidden facets of science and conservation practices. Environmental journalism offers a useful compendium of the technicalities, political currents, and cultural foundation that characterize the discourse developed around protected areas.

On the other side, scientific products, processes, and discourse are influenced, and influence, in turn, by the political domain. Conservation policies are often (and ideally) based on first-hand, reliable scientific information. At the same time, political choices might guide into specific direction the scientific endeavour. The case of the US and Canada are tailored for such exploration, being among the few countries to possess policy guidelines to face the effects of climate change in its protected areas.

2.3. The greatest of all threats. Analyses of scientific-cultural discourse on climate change in the American protected areas

From the 1980s on, scientists gradually came to accept that a new sort of change was under way. The glaciers in Glacier National Park were shrinking, wildfires in Sequoia were getting larger, and coastal parks were losing ground to rising seas. Shortly after the turn of the century, researchers in Glacier announced that by 2030 even the park's largest glaciers would likely disappear (Nijhuis, 2016).

> We manage the giant sequoia forests now in such a manner that they can reproduce, but do we know whether or not that particular niche will allow those trees to mature in the future? Is there a place in the Southern Cascades, as opposed to the Sierras, that we should be thinking about planting giant sequoias so that they'll still be around a thousand years from now? That's the way we've got to be thinking. We are in the perpetuity business here, so that's the space that we're beginning to explore (Than, 2016).

Science is no longer the occupation of a few, thanks to the increase in the number of those practising it, and the circulation of its results is no longer limited to the network of scientists actively engaged in research but extends to different external stakeholders, who range from the policymaker to the single individual. Scientific communication has become a necessary appendix in the process of construction, legitimization and socialization of scientific knowledge: only through communication can the scientific community's own processes of world making (Mahony, Hulme, 2018) be opened up beyond the fields in which they began. The narration of scientific practices is in this sense a tool for the excellence of the spread of information. Its analysis therefore gives us, in an indirect fashion, information regarding the world of research and its relations with the other spheres involved in the management of the protected areas and the practice of conservation. At this point it is interesting to initiate a discussion, bringing to the reader's attention a number of extracts from literature in the field of scientific communication of the phenomena of climate change in the parks, concentrating upon analysis of the discourse underlying several general publications. The ultimate aim of this exercise of qualitative analysis is to understand what the drivers are, scientific or not, that lead to the creation of a hotspot of research or indeed to an entire scientific region, what the techniques are for circulation of information beyond the strictly academic circuits, and what the repercussions are in terms of visibility for the research subject.

Addressing climate change with its implication for every conservation practice set in place in every corner of the world is a common trait of the contemporary environmental discourse. A simple web search on the news section of the main search engines provides access to an ample (hundred thousand news) body of information. Surprising news of scientific insights on the effects of a warming climate on biodiversity and landscape appear in European, South American, Australian, and Asian protected areas. Such news tends to be episodic, anecdotal, and with little or no degree of reflection on the profound consequences climate change poses for the very structure of conservation policies and practice. Among the few exceptions to this trend, a comprehensive and thoughtful journalistic review of climate change in protected areas found fertile soil in the United States. Analysing this small body of literature should not be regarded as a comprehensive review of what cultural values are embedded in the practice of conservation; on the contrary, the case study allows to take consideration of a very specific context that illuminates how research on climate change impacts conservation, and the context-specific value system entailed.

Between the spring and summer of 2016, on the occasion of the centenary of the founding of the National Park Service, various news media dedicated articles to climate change and its impact on American protected areas. In itself the choice to tackle the problem during a symbolic period of such significance expresses the importance that climate change had assumed in the ambience of American conservation. This does not constitute proof that climate change was necessarily the priority to be tackled among all the threats posed to the conservation of species and the environment, but it certainly shows how the subject evoked fervour in environmental journalism and met with significant findings in the scientific literature. Among the articles appearing in different media online, of particular interest are those in National Geographic (August 2016), Vox (May 2016), SmithsonianMag (August 2016), The Guardian (August 2016), together with an article appearing on the Nasa Earth Observatory (May 2016), the National Space Agency's organ of scientific dissemination. The main common ground in all the articles was dictated by the centrality that climate change would play in the near future in the American park system. In this respect, Greg Breining reported in Vox a statement released by Jonathan Jarvis, director of the National Park Service, in which he describes climate change as "fundamentally the greatest threat to the integrity of our national parks that we have ever experienced". Climate warming actually poses a variety of dangers that range from alteration in the composition of the species that inhabit the parks to threats for the integrity of a number of elements of the abiotic substratum – glaciers and permafrost most markedly – and for the conservation of architectural artefacts belonging to the cultural heritage of the parks involved. The phenomenon affects heterogeneous objects, just as its consequences for the various fields of conservation are heterogeneous. Oliver Millman, in the article published in The Guardian, writes in particular of topics linked to the archaeological and architectural consequences:

> Most people haven't thought about how climate change affects archeological sites. A site is a snapshot in time, it's not like we can pick it up and move it somewhere else. We are in danger of losing a great deal (Millman, 2016).

The immobility of archaeological sites at risk is a focal element in Millman's argument: they cannot be spatially moved, because their importance is linked to their localization. The author chooses to take examples connected to the most extreme environments of the United States' territory, Alaska and the states of the South-West. The selection of these two environments is in itself indicative of climate change's ability to edge its way – through various manifestations – into lands of climatic-environmental characteristics that are worlds apart. Alaska has twenty-four National Parks and is defined by Millman as "the front line" in relation to the advent of climate change, where the melting of the ice and the consequent raising of the sea level, joined to accelerated erosion because of increased intensity of storm wind, are reclaiming increasingly large sections of coast. With its coastal territory, Alaska also risks losing historical settlements of the Thule and Inuit cultures. The National Monument of Cape Krusenstern is reported above all to be a critical area, where archaeologists are carrying out a census of the area before the ocean floods the study sites. Similarly, the South-West reports equal urgency, but caused by decidedly different phenomena. In the Tumacàcori National Historic Park of Arizona, several clay buildings, left from missionary activity of the three preceding centuries, have collapsed following extreme rainfall. These are buildings in which the park invests more than two and a half thousand hours of annual labour and are one of the reasons for the very existence of the protected areas, but climate change, in the words of one who works on their maintenance, is an unprecedented and pressing threat:

> Meyer said there is a 'great urgency' to intervene and save cultural sites at risk from a rapidly warming planet. 'The longer we wait to act, the more history we lose,' she said (Millman, 2016).

The focal point – or at least among those more widely discussed – of all the other articles mentioned comes down to the bio-ecological consequences of climate change. The survival of several species is not guaranteed in a climate that is warmer and marked by temporal distribution of rain and snowfall different from today's. Over-severe thermal systems, more frequent drought periods, and early melting of the snow cover are all elements able to influence profoundly the composition of the ecological communities. Climate change will actually make some areas unfit for species settled in the protected areas, just as it will end up by benefitting others, some of which are not yet found in the parks. Kathryn Hansen is the author of the article most concerned with presenting the scientific evidence gathered from researchers working in the protected areas. She reports on numerous studies, connected to very varied geographical contexts, always calling attention, on the one hand, to the dimension of "measurability" of the current disturbances dictated by the climate and, on the other, to the dimension of modelling as a tool for visualizing possible futures in a panorama steeped in uncertainty. Hansen further highlights how the eastern forests of the United States are composed of a wide range of plant species, some common (*Acer rubrum*, *Fagus grandifolia*), others much rarer, but sources of sustenance and habitat (*Prunus serotina*, *Tsuga canadensis*), and the present complexities of foreseeing their future in terms of survival and possibility of competition with new species, which place the park managers involved in decision processes in difficult situations. In response to these uncertainties, Hansen's article refers to a study carried out by Patrick Jantz and Brendan Rogers of the Woods Hole Research Center based upon the development of a forecast model of the distribution of 40 plant species met within the protected areas of the Delaware Water Gap National Recreation Area (Pennsylvania and New Jersey), the Shenandoah National Park (Virginia), and the Great Smoky Mountains National Park (North Carolina and Tennessee). The model's results show how a number of species typical of the eastern forests of the United States, such as the silver maple (*Acer saccharinum*) and the Canadian hemlock (*Tsuga canadensis*) will lose part of their habitat, whereas some oaks (*Quercus marilandica*) and walnuts (*Carya texana*) will find optimal conditions in the warmer and drier new climatic regime and so more ideal areas for their propagation. On the western coast, in Yellowstone Park, the situation is not dissimilar in Hansen's narrative, with characteristic species such as the Douglas fir (*Pseudotsuga menziesii*), sub-Alpine fir (*Abies lasiocarpa*), or lodgepole pine (*Pinus contorta*) destined to lose part of their own distribution area, with a particularly grave situation for the whitebark pine (*Pinus albicaulis*). The probable victors in the new climatic niches will be in this case the population belonging to the juniper family.

Up until this point Hanson's approach to the subject does not differ from that of the scientific publications from which she derived the information cited, and she takes a careful look at the scientific community and their practices, without however widening the discourse to other stakeholders involved in conservation. Hansen's narrative is closely connected to the role that the scientific community should – and does – carve out in the management of conservation's future. To do this, Hansen describes in detail the tools developed and their practical application, examining above all their use as a planning instrument to respond to the emergence of management problems linked to climate change. The author stresses how the community of scientists belongs to a much greater whole, but never abandons her scientist-based viewpoint in favour of other members of the much wider conservation epistemic community. Her objective is that of showing what the scientist's role is and what it will be, just as she outlines its responsibilities and limits:

> You'll never find a decision of importance in the National Park System where you can simply say 'someone did this and it led to that,' Gross said. 'The problems we're working on are big, complicated, and involve a lot of people. We're not at the helm of the battleship. We're just one of a number of groups nudging it in the right direction (Hansen, 2016).

Hansen's treatment of the subject is kept, moreover, to a strictly professional level in outlining the figure of the scientist, without examining in depth what the mechanisms are that build a scientific interest – at a personal and community level – and how these influence the birth and development of research projects, something which, by contrast, is central to the next articles examined here. These tie themselves to the discussion of changes in the biological communities and to how scientific communication can be focused upon another type of information, not strictly dependent on technical data, but bound to the dominance of conservation policy and its fundamental values. To recall a term used by the British geographer Jamie Lorimer (2005), a fundamental consideration in the growth of the attention dedicated to themes of climate change is provided by the so-called "charismatic species", species which are immediately recognizable and particularly linked to existing conservation policies and the daily practices necessary for their implementation. The charismatic species play a key role not only in communicating the research results, but also in building scientific interest itself. To understand fully the concept of charisma associated with non-human organisms is therefore a fundamental prerequisite for further analysis of the interconnected narratives. Lorimer defines "non-human charisma" as "the distinguishing properties of a non-human entity or process that determine its perception by humans and its subsequent evaluation", and adds: «Non-human charisma emerges in relation to the parameters of different technologically enabled, but still corporeally constrained, human bodies, inhabiting different cultural contexts» (Lorimer, 2005, p. 915). In his analysis of the different types of charisma, Lorimer identifies three possible, and strongly interwoven, articulations of the concept: "ecological" charisma, "aesthetic" charisma, and "corporeal" charisma. The first is the basis for the development of a charismatic relationship of any kind whatsoever, because it is bound to the behaviour of the organism and its interactions with the environment, which together determine the "detectability" of the subject by the human. Form, colour, geographical distribution, temporal habits, and day-night ecology are all elements that regulate our effective capacity to "perceive" the organism, so creating the indispensable basis on which all other types of charisma are founded. The second type is intuitively linked to the physical appearance of the organism: aesthetic charisma does not bind itself unequivocally to one characteristic or a series of necessary physical characteristics, but ranges from a form of appreciative recognition for engaging traits to reverential admiration for forms of feral charisma. Finally, corporeal charisma refers to the emotions and affection that humans develop in contact with certain organisms, linking them therefore to their life experience (Lorimer, 2005, pp. 915-921). By using this concept and its articulations as a key to interpretation, the underlying discourse of the articles can be analysed more successfully, above all in relation to the work of Michelle Nijhuis and Ker Than.

Ker Than reported in the SmithsonianMag on the scientific campaign linked to the study of the vulnerability of the American pika (*Ochotona princeps*) in view of the rise in temperatures and shortages of snowfall. The five-year study of the National Park Service, begun in 2010 under the title Pikas in peril aimed to evaluate the winter risk for the population settled in the Lassen Volcanic National Park, in northern California. The pika, which only lives in rocky habitats, binds its survival in winter to the presence of a snowy stratum able to act as insulation, keeping its minimum temperature under control. The pika's susceptibility caused the National Park Service to examine the potential effects of climate change on the mountain ecosystems, exploiting the animal's popularity – unanimously appreciated for its aesthetic appearance – as a driver for research and the communication of the effects of climate change. It is the pika's aesthetic charisma, therefore, that enables the research and its use as a catalyst for interest in the theme of climate change on the ecosystems. Even where they do not become part of long-term scientific research, the charismatic species remain at the centre of the discussion on the conservation policies and practices carried out in the parks, posing concerns that range from local to national, depending on the species involved. Charisma is not actually an a-geographical concept but is instead subject to the effects of its explicit scale, outlining specific geographies. Than reports the case of the karner blue butterfly (*Piebejus melissa samuelis*), widespread in the recent past in the Indiana Dunes National Lakeshore but which after a particularly hot spring in 2012 suffered a severe decrease in its population because of an unexpected ecological mismatch : the high temperatures led to early hatching of the eggs and the caterpillars were deprived of their necessary sustenance, normally provided by the wild lupins on which they feed, due to the desynchronisation of the phenological cycles of the two species: the lupins' inflorescence should have already developed by the time of the hatching. The main fear today is of having to state that the butterfly, particularly loved by those who visit the protected area, is locally extinct. The numerous deaths through malnutrition left the park management powerless, and now forced to ask questions about the future oversight of the biomass in face of the threats from climate change.

If the story of the butterflies of the Indiana Dunes National Lakeshore tells of a serious conservation problem, but still only of local interest, Than, and also Michelle Nijhuis in the pages of the National Geographic, present a problem that is potentially similar in its nature but much greater in its magnitude, given the extremely charismatic dimension of the species involved. The Sequoia and Kings Canyon National Parks are home to these eponymous trees, recognisable titans throughout the world and the very symbol of the National Park Service, evergreen conifers at risk from the threats of climate change. Up until today, however, the threat remains more on the virtual level of forecasting models than in actual reality, in which only a number of episodes of water stress have been recorded. The species currently at risk are those which coexist today in the parks' forests, the Californian incense cedars (Calocedrus decurrens), pines and firs, above all at lower altitudes. Yet the National Park cannot do otherwise than face the problem and – at the very least – initiate a debate to arrive at a policy of shared conservation:

> What if Sequoia National Park became too hot and dry for its eponymous trees? Should park managers, who are supposed to leave wild nature alone, irrigate sequoias to save them? Should they start planting sequoia seedlings in cooler, wetter climes, even outside park boundaries? Should they do both – or neither? (Nijhuis, 2016).

The dilemma of the sequoia creates the preconditions at this stage for exploring in further detail the paradigm of conservation adopted by the American parks, discussed by all the articles cited. In 2012, the National Park Service published an updated document about the cornerstone of their conservation policies – the earlier "Wildlife Management in the National Parks", informally known as the Leopold Report – now entitled "Revisiting Leopold: Resource Stewardship in the National Parks", a version brought up to date and now required by the growth of the phenomena of contemporary environmental changes. The Leopold report, written independently in 1960 by the biologist Starker Leopold – son of the conservationist Aldo Leopold, among the founding fathers of American conservation, above all in his scientific dimension – and commissioned by the Secretary of the Interior, Stewart Udall, proved to be extremely influential. Leopold drew the attention of the Park Service to the necessity for maintaining the "biological associations" preexisting before European settlement; from that point the NPS engaged in controlled burning of forests in which wildfires had been systematically suppressed, and in the reintroduction of species that had disappeared but belonged to the "original" ecological community, such as wolves and the wild sheep of the rocky mountains. However, the final aim of Leopold's programme was not by nature ecological, but purely iconic: to recreate "*vignettes of primitive America*". This static vision is obviously invalidated by a basic error which Nijhuis recognises and highlights: Leopold considered the environment found by the first colonists as "virgin nature", ignoring the influence that the native Americans' hunting and "slash and burn" farming activities had on the environment of the parks. Similarly, Leopold's ecological vision ignored the fact that nature left to herself does not tend towards static equilibrium; ecosystems and landscapes undergo continuous change from the disturbances of fire, drought, flooding, and indeed biotic interactions. The iconography of the parks was what ought to be conserved, and with it, but only as an indispensable instrument for the success of the undertaking, the ecology of the equilibrium associated with that type of landscape and setting, so as to reclaim the idea of virgin nature, untouched and uncorrupted by human activity. Anyhow, despite its ultimate purpose, the Leopold report led to a series of practices aimed at maintaining the ecological equilibrium associated with the natural landscapes of which the individual protected areas are the custodians, from controlled burning to the reintroduction of a number of species. All the authors cited here consider revision of the Leopold report as a key moment for providing the NPS with the conceptual and operational tools for restructuring the very idea of conservation. The static settings yield to continual change, the ecology of equilibrium, with its unchangeable landscapes, gives way to ecological integrity and cultural and historical authenticity, the idea of the park considered and administered as an island, a discontinuity in the land's fabric, is replaced by the concept of the park as the node inside an interconnected network. Nijhuis, Than and Breining take advantage of these paradigmatic revolutions to introduce problems of management linked to conservation practices which should emerge from the new policy theories. The focal point is probably to be sought in the sphere of conservation ethics: the introduction of practices for managing continual change has proved to be complex and without unanimous solutions. To accept the change – at all its levels, from the smallest biological communities to the scale of the landscape – also means not having complete control over the transition from one state to another, just as it compels definite choices to be made about objects of specific interest for which there is no longer a clear standard of custodianship. As Than says, "There was a time when the notion of letting prized native species die out seemed heretical. Now the agency is bracing for the possibility that some of the species under its care simply won't make it". The discussion enters fully into a background narrative linked to "winners and losers of climate change" which has become central to the communication of scientists, conservationists and park managers. For the first time, the NPS accepts the possibility of seeing some of the species under their protection disappear and therefore, as a result, changes to the ecosystems and protected landscapes. The response of the conservation epistemic community, however, is not unanimous. There are views that disagree with the non-intervention position, which find substance above all in the practice of "assisted migration", an argument touched upon by all three authors and significant in a relocation handbook for the target species.

The thought experiment described by Nijhuis and reported above centres on one of the most charismatic species of North America, obliging the reader to face the limitations of the earlier Leopold report, but also the ambiguity inherent in the new conservation model proposed by the NPS: how can a conservation that embraces change as an inevitable phenomenon manage the risk of the disappearance of one of the very symbols of the NPS? Should it assume positions of intervention and go straight to planting seeds beyond the species' normal dispersal range, in more suitable climatic conditions? Or should it leave the ecological equilibrium to find a solution on its own, possibly causing the sequoias to disappear from the protected area, without, moreover, any guarantee that they will unassisted find a usable climatic niche?

Nijhuis' example, exploiting the charisma and iconicity of the species, expresses with considerable effect a doubt that whichever species populate the protected areas, they can be thought of indiscriminately, by forcing them into the spatial trap. Obviously the "correct" solution for resolving the thought experiment does not exist, just as the debate on the new practices of adaptation to climate change remains open and contains various possible solutions, but it is important to note how the debate has become central to the formulation of NPS policies:

> Among all the federal land management agencies, they are probably paying the most attention to climate change – says Bruce Stein, the National Wildlife Federation's associate Vice-president of conservation science and climate adaptation – That isn't to say that they are doing uniformly well, but there are a lot of people within the park service who are really being thoughtful about this…they are openly having those conversations and engaging in the kind of scientific investigations that are going to be essential for answering tough questions (Than, 2016).

Among the conservationists' proposals there is also a triage procedure, of which both Breining and Than make explicit mention. By means of this procedure the community can state which of the species is potentially worth concentrating the conservation efforts on, and which, by contrast, should be considered beyond the NPS' practical possibilities. A cornerstone of the decision-making procedure is obviously the scientific research applied in the individual parks, unique in providing the necessary information for an internal debate, which, however, will prove insufficient if viewed as the sole conveyor of objective data, of the thresholds, of the boundaries beyond which every conservationist effort is considered pointless. "We did not say 'here is the point at which you give up something'. What we did say is that there is going to be a need to have those hard conversations and to review what our conservation goals are or should be" (Than, 2016). Implementing choices with a strong ethical value can be difficult for the public to understand, as they will consider it unjust that a conservation agency does not try to safeguard a species resident in a protected area and indeed paradoxical that its members sit around a table to decide which species should be helped in their fight for survival and which should instead simply be "left to go".

If examined in parallel, the articles show common points in the narrations developed. The first common factor is the personal scale of the treatment: all the articles cite directly, and with the same words, the experiences of the scientists involved in research linked to the climate. If some of the articles analysed limit themselves to reporting the scientists' descriptions and statements, others enter into the personal dimension, telling of the daily practices that structure the researchers' days in the field:

> There he goes, there he goes!'. Michael Magnuson lowers a battered pair of binoculars, pointing to a rocky debris field a short distance away from a visitor parking lot in Northern California's Lassen Volcanic National Park. The National Park Service wildlife biologist has just spotted his quarry: a small, round, rodent-like mammal that darts between boulders and tufts of red mountain heather while clutching a leafy branch between the boulders, a rocky sanctuary against the hot July sun. […] Having a cool shelter is crucial for pikas in the summer in account of their thick fur. 'If they sit in the sun too long, they get too hot' Magnuson explains. He points out a typical pika home that he has identified based on the mounds of scat surrounding the entrance. 'They typically prefer the bigger rocks, because there is more space underneath them' he adds. 'If you stick your hand under, it's several degrees colder. It's pretty cool, literally'. […] Questions of species conservation are complex, and thus there are no easy answers. Irrevocable changes are already sweeping across the parks, and freezing them in time to echo a bygone era is no longer possible, if it ever was. For now, even though the Pikas in Perils project has ended, Magnuson continues to survey Lassen's pikas yearly. He visits about 100 sites every fall, scanning the landscape for signs of little haystacks. 'I'm just making it a priority to keep the project going (Than, 2016).

The extract above shows a rhetorical strategy based upon publicizing the daily life of the experts directly involved in conservation. By telling Magnuson's story, Than highlights how the problem of climate change is pervasive for those addicted to this work: not a theoretical and solely speculative interest, but a reality dropped into working life that reorganizes the very practices that make up the professionalism of the conservationists. They cannot do otherwise, in the face of the overpowering entrance of climate change, then dedicate their competencies to it. The author also points out how the scientist's or conservationist's devotion is strongly dedicated to their project, to the point of making it a priority, even after their official deadline: a priority that remains in this ambiguous intersection between the scientific level and the emotional one. Nijhuis pushes this intersection into the spotlight, working out the ambiguity and showing almost explicitly the emotional dimension, that which Lorimer defines as resulting from a process of "learning to be affected" (Lorimer, 2015, p. 54) on the part of the conservationist about the object of interest.

> High in Sierra Nevada, floodlit giant sequoias tower into the night sky. They can live 3000 years, but California's historic drought has tested them. 'We are treating this drought as a preview of the future' says ecologist Nate Stephenson. […] When Nate Stephenson was six years old, his parents fitted him with boots and a handbuilt wooden pack frame and took him backpacking in Kings Canyon National Park. For most of the 53 years since Stephenson has been hiking the ancient forests of Sierra Nevada. 'They are the center of my universe' he says. Soon after he graduated from UC Irvine, he packed up his Dodge Dart and fled Southern California for a summer job at Sequoia National Park. Now he's a research ecologist there, studying how the park's forest are changing. While park managers are often consumed by immediate crisis, researchers like Stephenson have the flexibility – and the responsibility – to contemplate more distant future. In the 1990s this long view became deeply disturbing to him. He had always assumed that the sequoia and foxtail pine stands surrounding him would last for longer than he would, but then he considered the possible effects of rising temperatures and extended drought, he wasn't so sure – he could see the 'vignette of primitive America' dissolving into an inaccessible past. That realization threw him into a funk that lasted years (Nijhuis, 2016).

In this case Stephenson's personal story is not treated from the viewpoint of the redefinition of the daily practices that structure his expertise, but rather on the level of the emotional link that connects him to the protected area and its forest. Stephenson is an expert, but in this article – unlike the treatment by Hanson in particular, but also by Breining and Millman – it is not the viewpoint of the technical scientist that the journalist is interested in writing of, but his capacity to care deeply about the future of these species, this ecosystem, this landscape, because he has learnt, thanks to his training and his life, to connect himself to the characteristics of the environment. Nijhuis is approaching the scientific subject of conservation as a social practice, in which the knowledge of techniques and technology is connected to the socio-cultural dynamics of the research community. The scientific interest is not presented as a merely technical curiosity, that is to say as a "pure science", but is a mixture of experience, fear, hope, worry, and satisfaction that these feelings can be traced back to the realm of the personal and their own lives. In these circumstances, the quotation marks are bound perfectly to Tuan's theories on affection for places (Tuan, 1990) like Lorimer's theories on affection for certain species, which is formed on the basis of a significant meeting, often in one's youth (Lorimer, 2015, p. 51). Nijhuis' ultimate aim is to show the reader the pervasiveness of climate change, its capacity to penetrate inside the scientific community not only on the technical level but invading it on more intimate dimensions. By presenting the scientist as, first of all, a human being connected to everyday places and ecosystems, Nijhuis means to indicate the priority that climate change constitutes for conservation: not a scientific priority, but a civil priority, linked to conservation of the common weal, which can be bound to anyone's personal experience, including those outside the community of scientists.

The second point in common in all the articles examined arises from this awareness of the pervasiveness of global warming: the view of climate change as a cultural object, which enters into the realm of conservation, not only penetrating the scientific practices and lives of the individual researchers, but also the policy that regulates the conservation. In recalling the Leopold Report the authors mean to show how this management tool is culturally out of date as regards the emergence of the problem. Climate change needs an effort from the community of conservationists in redefining the paradigms of their tools: technological, technical, legislative, and – above all – cultural. In their treatment of the problem there is therefore no lack of references to the inter-connections between the scientific world and that more strictly of policy. If on the one hand the articles belong to a corpus of shared scientific literature, they end up by presenting, each to a different extent, thoughts that are linked to a value-driven framework. Science can be – and ought to be – a principal instrument of enquiry for understanding the profound transformations that will invest the protected areas in response to changes in the climatic regime, but will not necessarily be the solution to the problems posed, because the most important game will be played on the field of shared values that the parks and protected areas should represent and defend in a climatically unpredictable future. In order to convey this message, the articles are accompanied by images with a strong iconic content: glaciers in phases of advanced melting, forests hit by drought, protected monuments with new structures built against the rise in sea levels. This all contributes to the formation of a specific iconography that materializes the problem unequivocally, demonstrating its effects on culturally precious scenes, whose protection is key to the mission of the NPS. We are not talking here simply of a spatial relocation of objects of conservation interest, of species moving north or to higher altitudes, or of a future with uncertain water supplies, but of the cultural power that the images associated with these processes have in "materializing" climate change. To cite the American philosopher Timothy Morton in his Hyperobjects, "stand under a rain cloud and it's not global warming you'll feel" (Morton, 2013): to convey climate change in its entirety is a formidable challenge for geographical sciences (Marini, Tolusso, 2016, p. 10), but first describing it through some of its local manifestations lays the basis for it to be represented and put across, taken outside its strictly scientific dimension and rendered as, indeed, a recognisable cultural phenomenon.

The discussion merits particular attention with reference to Kathryn Hansen's article. The author introduces an element of division from the other articles in the corpus examined, replacing (largely) the images of iconic landscapes put at risk by climate change with visualizations of data and scientific tools. Hansen's is a choice which allows observation of the typical iconography with which scientists visualize and rationalize the effects of climate change and the observation of a phenomenon of world making which originates from a part of the epistemic community, then to radiate through all its parts. Just as Nijhuis and Than use images loaded with a recognizable significance for the majority of the population in order to convey successfully the tangibility of climate change as a (physical-)cultural phenomenon, Hansen discloses a cultural representation belonging to a more specific, more authoritative, and for these purposes more legitimate group, in that they are a fundamental part of the decision-making process linked to its management. The author introduces elements of a graphic alphabet which normally does not enjoy the same circulation capacities as naturalistic-landscape photography, but actually add to the narrative and provide new elements with which to characterise the climatic phenomenon on a cultural scale. At the same time, Hansen implicitly credits science and its mechanisms as an indispensable tool for the management of protected areas in response to current climate change.

The third common factor is the geographical extent. Considering the five articles analysed, the number of protected areas from which the source information was extracted (twenty-four) is not inconsiderable, giving us an indication – broadly and far from being complete, but still significant – of the geography of science linked to climate change in the protected areas in America (fig. 2.12). The distribution of the protected areas cited is polycentric, including above all areas of the two coasts, no matter what the latitude, such as Alaska. The spatial distribution of the points of interest makes yet more explicit the capacity of climate change to exercise an influence on very disparate environments: if in the coastal areas the problem of fundamental management is determined by the rising of sea levels and in the areas of the extreme North the melting of the permafrost creates structural problems for historic buildings, at the intermediate latitudes the fundamental questions range from alteration in the composition of species to alteration of the frozen landscapes of the Rocky Mountains. So it emerges clearly how the geographical dimension of climate change embraces the interest of the American parks system in all its territories and how it is able to connect to different themes, linked from time to time to specific traits of the individual areas protected. The map derived does not allow the tracing of true climatic hotspots; although several of the National Parks are cited in more than one article, such as the Glacier National Park or the Joshua Tree National Park – both examples in which climate change constitutes a threat for the very raison d'être of the two areas protected – the majority of the areas mentioned are cited in only one article. The map cannot therefore be understood as a tool for creating hierarchies of places of the greater or lesser influence of climate change with reference to conservation priorities, but as a revelation of different localities which, to greater or lesser extents, contribute to the creation of a scientific-cultural discussion which is geographically anchored but which because of the capillarity of its spread has become international, combining cases of National Parks of almost worldwide reputation to examples of protected areas of local importance.

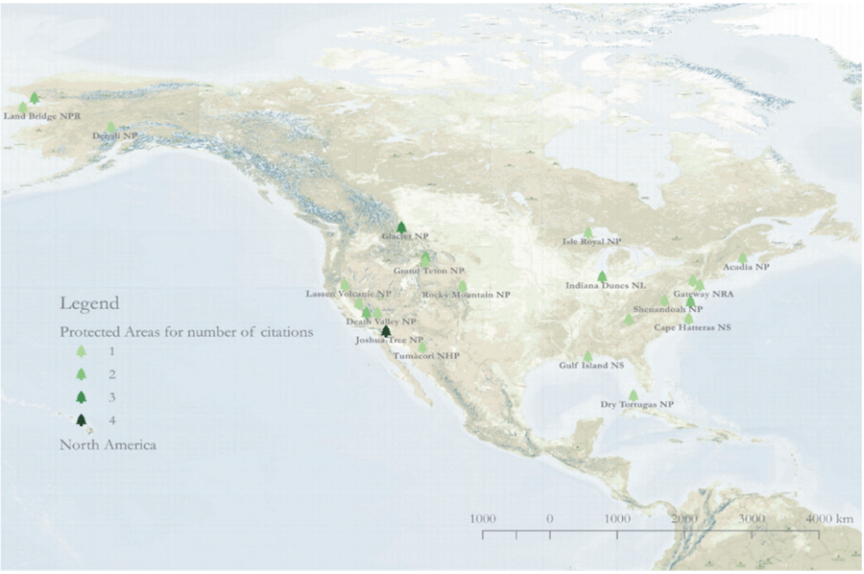

Figure 2.12 - Distribution of protected areas cited in the articles analysed. Developed by the author.

A further point of the analysis is linked by contrast to the fundamental narrative that the articles produce on the unfolding of climate change, on the central message conveyed. The geographer Jerilynn "M" Jackson, in a publication of 2015, highlights how the narrative of the melting of the glaciers on a global scale tends to equate glaciers in strong phases of ablation with the idea of "ruins", an object beyond equilibrium as regards its own climate and so in a phase of disappearance, in which what is visible today is already interpreted as a ruin.

> Ruins are thus broken bits of former bodies, reminiscent and recognizable of what once was, cannot be separated from their original location and, importantly, are quite power-laden (Jackson, 2015).

The result is a narrative of resignation, in which the figure of the glacier – in the singular, because the narration itself tends to unite the complex reality of thousands of glacial bodies with their geographical peculiarities into one ideal body – is fated to be lost in time, assuming tones of inevitability. Jackson further emphasises how this type of narration is diametrically opposed to that which surrounds the species at risk: they are not considered "lost" and the discourse that develops around the node of their conservation calls for action, for protection, for active opposition to save them (Jackson, 2015, p. 480). From this point of view, the protected areas contain both the objects of interest, just as they contain – potentially – both the narratives that conflict with each other, without necessarily finding a point of equilibrium. From the articles both perspectives emerge, anchored to the new strategies of management of the parks system, which embrace the dimension of change as necessary: assisted migration, climatic zoning and refuges all constitute active measures to counter the losses, which however are not excluded from the range of managerial possibilities. The glaciers of the Glacier National Park are probably destined for disappearance, and yet the park will remain in custodianship of scenes of value. In the same way, the possible disappearance of the eponymous trees of the Joshua Tree National Park will not decree the end of the park, which will instead remain in protection of something new and inevitably different. The dimension of the loss is strongly rooted in the discourse perpetuated by the authors, as is the necessity to prepare for its inevitability. Yet the scenarios of uncertainty that characteristic climate change and its management do not allow us to establish what the victims of the process will be with any clarity. The rhetoric of these articles, therefore, is not comparable to the resigned tone of that surrounding the glaciers but stresses the centrality of management and the active role that it will have in the future of the protected areas. The authors highlight the challenges of the future, seeing in them the potential devastating effect for the conservation policy adopted until now, but they all agree in visualizing a future in which, despite environmental and administrative changes that climate change will bring, the American parks will still be present and central to the American people's lives. Once the consequences of the composition and distribution of species, of glacial melting, and of the conservation of individual monuments have been analysed, the focus of the argument therefore shifts to the scale of the individual park, if not the entire system of the protected areas. The authors have made public the message of uncertainty that is linked to climate change, and therefore continue the discussion on a more settled level, highlighting how the parks, while profoundly changed on biological and geomorphological levels, will still exist physically and will still play an active role in community life, in the training of the public, in fulfilling their recreational and conservationist functions. What will change profoundly will be the objects which the protected areas will be expected to safeguard and the messages which they will be able to convey.

> Even then, he says, 'the parks won't cease to exist'. In a Glacier without glaciers, people will still watch the grizzlies. Parks altered by climate change will still protect wide swaths of wild land, harbor a variety of wildlife species, and protect valuable cultural sites. But the loss of familiar or namesake resources, such as Glacier's glaciers, he says, 'will provide a teachable moment (Breining, 2016).

> Like the Park Service, visitors must learn to accept that their favorite park might change. "People ask, 'Will I still be able to enjoy it? Will my kids and grandkids be able to enjoy it?" Davis says. "The answer is yes, they will. They might not enjoy it in the same way, and they might not get here the same way. But they will still be able to enjoy it (Nijhuis, 2016).

> NPS director Jarvis says that if the parks are to survive another century, there is no question they will have to change. He gives the example of the iconic Joshua Tree National Park in California. 'We may not be able to maintain Joshua trees in Joshua Tree National Park, but that doesn't mean that Joshua Tree National Park is somehow devalued,' he says. 'It will just become home to something new (Than, 2016).

In conclusion, the analysis of the discussion provides a useful tool for understanding different characteristic features of ways of approaching the public on the problems of climate change in the parks, starting from the narrative that gives uniform significance to the data, images and experience derived from extremely heterogeneous geographical contexts. The channels through which the message is conveyed already offer indications of the importance that it carries for the scientific and epistemic conservation community: international newspapers and publications, whose catchment area extends well beyond national boundaries and which serve as fundamental platforms for focusing media attention on climate change and its effect on the natural and cultural heritage that the parks system is called upon to protect. From analysis of the discourse it is also possible to extract information regarding the rhetorical strategies used in telling the stories linked to global warming and to understand how they disclose information about the object of the study but also about the people who are actively studying it, giving insight into several means by which interest – scientific and subjective – becomes trained at an individual and community level. In the same way – and perhaps still more successfully – the discourse analysis reveals the heterogeneous nature of the debate on climate change, which is based equally on scientific, political and cultural concerns. To obtain information on a problem such as climate change through the analysis of public discussion enables us to acquire essential preliminary information that can best guide a deeper analysis of the sources that must be considered in the study: sources of a scientific nature and sources of a political-cultural nature. From this subdivision arise the next steps towards understanding the epistemic geography that characterizes the study and management of climate change at different levels and in different regional contexts. Should the scientific, cultural and policy concerns already cited, on which the debate on climate change is based, be considered constants or variables in geographical analysis? And again, how and to what extent should the two realms of information – science and policy – interact in defining different regional geographies?

2.4. Conservation policies and catalysts of scientific interest

From the discourse analysis, therefore, is drawn the detailed picture of a geographical singularity, which can be used as a standard for the search for elements that can be held in common.

From the viewpoint of decision making, the authors show how administrators and conservationists have need of two basic classes of information: scientific data and (political) values. If the first are a necessary tool for monitoring the consequential direction of the change, the second constitute indispensable indications on the objectives for which science must play an instrumental role. The discourse analysis has clearly highlighted how the value systems involved are not linear and not even necessarily consistent with each other. The conservation policies, from a certain viewpoint, are required to gather the whole complexity of values that characterise conservation and its practices and codify them in programme documents. Moreover, in spite of the division between the two information classes, in practical terms a separation into discrete elements is complicated: conservation science and policy do interact and influence each other. The policy can organize the scientific project around the two cardinal themes and indicate strategic direction of development. The results, the instruments and processes of research construction, for their part, can indicate to the policy which paths will be the most productive, achievable, and compatible with resources and competencies. This is why understanding the reason for a particular regional geography in contemporary science also involves the policy dimension in a way that is difficult to separate from the purely scientific realm, above all in the case of conservation, understood both as a practice and as science. The theme of relationships between environmental science and environmental policy – not only those of conservation – is not new for geography: the case of the IPCC has already been widely studied, highlighting how institutions of this scale play a fundamental role by indicating which instruments and paradigms are policy relevant (Turnhout et al., 2015). Being policy relevant is inextricably bound to the epistemic dimension, which shows us which science is important not from the policy view but from that of knowledge making. The influence in this case begins from the policy dimension, which directs research towards themes and usable tools in the processes of power production. Turnhout, Dewful and Hulme use precisely the example of the IPCC. Among its actions towards globalization, the IPCC seeks an aggregation of scientific data and the provision of a spatial scale of reference for the different studies, a world scale. By creating a number of benchmarks for the realization of policy, relevant science parameters are also formed that decide which research studies and knowledge forms are epistemologically legitimate and important (Turnhout et al., 2015, p. 66): this is the case in the IPCC's average temperature indicators and its Global Circulation Models (GCMs) which veer towards a scientific perspective rather than that of other potential competitors in knowledge making. A contemporary geography of science should fully consider these implications on the link between the importance of research to policy and the forms of epistemic legitimacy generated by it, just as it ought – as a priority – to overcome the globalizing tendencies promoted by the boundary institutions to understand what the diverse regional geographies of science and the scientific policies regulating them are. The biology of conservation, moreover, was born as a "science of the crisis" (Soulé, 1985) and as such operates at all levels, including value judgements, by actually defining a discipline that cannot, to some extent, avoid being value-laden (Baumgaertner, Holthujizen, 2016). In this attempt to configure in a measurable way the relation between humans and nature and to safeguard those natural and anthropic elements that are facing risk situations, the negotiation over which scientific tools and paradigms are most important at the epistemological level becomes complex.

The policy is a holder of values which the community – any community, from local ones to epistemic-scientific or whatever other communities are thought of – projects upon a given object and which, if broken down into its basic parts, can replace other prime elements that in their turn provide a catalyst for the formation of a precise scientific interest. The geographical variability of the value systems associated with conservation can therefore be a key to understanding the different concentrations of scientific studies within geographical regions that do not together show important imbalances among the socioeconomic parameters of development.

Turning therefore to the case of the United States, the first salient point underlined in the policy document is to be found in the cultural dimension which the environment occupies within American discourse, a direct legacy of the country's environmental history. The protected areas, although restructured within a coherent ecological discourse, maintain a dimension of monumentality: their specific iconography is made of centuries-old sequoia, of glaciers, of charismatic species. By acting on their presence, persistence and geographical distribution, climate change is claimed as a force able to change structurally several of the environmental characteristics that contribute to the process of the importance of place. This awareness is reflected in the policy document widely cited by the authors, the Leopold Report, which introduces ecological variability as a condition that cannot be deferred in the process of environment conservation, which must, however, maintain those same aims that were expressed in the original Leopold report:

> The overarching goal of NPS resource management should be to steward NPS resources for continuous change that is not yet fully understood, in order to preserve ecological integrity and cultural and historical authenticity, provide visitors with transformative experiences and form the core of a national conservation land- and seascape (NPS Advisory Board Committee, 2012, p. 11).

The forces pushing the NPS to a reform that embraces the change are not limited to climate change, which, however, is explicitly a fundamental part of this need. The document further states the centrality of science in the processes of adjustment and management of the values which the NPS is there to guard, actually calling on the scientific community to concentrate upon policy relevant research:

The NPS needs a specific and explicit policy for park stewardship and decision making based on the best available sound science. […] Best available sound science is relevant to the issue, delivered at the appropriate time in the decision making process, up-to-date and rigorous in method, mindful in limitations, peer-reviewed, and delivered in ways that allow managers to apply its finding.

From this detectable state of affairs at the policy level we can, indirectly, also detect some of the reasons for the United States introducing this business of concentrating on research linked to the effects of global warming on the protected areas.

Therefore, the policy documents' analysis can reveal the fundamental reasons for a cluster, hotspot, or entire scientific region arising and developing. European protected areas are starting to face similar questions: the case of the LIFE project NatureAdapt, born in 2018 as a coordinated effort among French conservation institutions and EUROPARC, stands as an example. The project aims to create pilot sites for testing management prototypes for climate change in protected areas based on the best available scientific information.

Still looking within the American cluster, however, we can find the most mature experience in the field: the Canadian case is probably a yet more significant example of policies of adjustment to climate change, because it is endowed with a very structured planning document with particular commitment to the IUCN areas Ia, Ib, II, and III. The conservation policies initiated here all have a double objective, attainment of which is imperative: to preserve the integrity and ecosystem representativeness (Lemieux et al., 2010). Canada depends on a huge proportion of national territory destined for conservation, estimated at around 10.6% (CCEA, 2008), there to care for the strong environmental range of the land, home to ecosystems that extend from the Arctic to Carolinian, following the latitudinal axes from north to south. The richness of the ecological systems has therefore been assumed as a founding value for the whole architecture of conservation policies, albeit with diversity in the aims and functions linked to individual sites. For this reason the processes of adjustment to climate change are focused on a plan on the scale of the country – understood as a network of ecosystems – of a bioregional type, in which the protected areas are connected in the form of a network to guarantee integrated management of the biological legacy and the exchange of information (Lemieux et al., 2008). The structure of the areas in the network has been adapted to the reasonable needs of a climate that is changing, forming guidelines for future planning around the creation of areas of stricter biological conservation (core areas) and less rigorous areas to guarantee access to natural resources (buffer zones). A similar division, laid down by the IUCN in their guidelines, joined to the creation of other "infrastructures for biodiversity", will allow a management adapted also to different geographical areas. The idea of adaptive management is set out clearly and embraces bold measures of geographical flexibility for the protected areas, to the point of introducing innovative proposals within the categorization of land use, such as the floating protected areas, temporary protection areas, and temporal corridors, which can be used to allow migration in a given period. Experimentation also finds a place in the Canadian proposals, such as the Evolutionary Baseline Parks, protected areas intended for the study of the transition between ecological balances and ecosystems (CCEA, 2008). The dynamic planning will provide a new instrument for combatting climate change and maintaining ecological integrity and representativeness:

> Comprehensive, physiographically-based representation schemes should manifest more resilience as shifting species and biotic communities may have greater opportunity to re-colonize sites in new protected areas similar to those lost to invading climate regime in their place of origin (CCEA, 2008).

From the viewpoint of scientific production, it is acceptable to expect that Canada will develop productive lines of research on the link between populations and climate change, dynamics of the metapopulations, movements of the biogeographical areas, monitoring – or at least programmes for monitoring – of the ecological integrity and representation, which are the key values of the entire conservation policy. A first look at the scientific production is given in Figure 2.13.

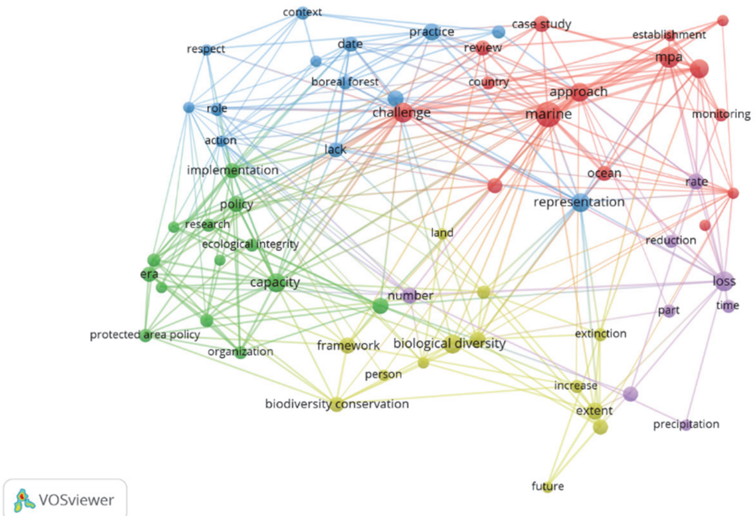

Figure 2.13 - Term-map of the Canadian literature. Data from Web of Science. Visualization in VOSviewer

From a first visual analysis, the map highlights all the key-terms that summarize the Canadian programme document (ecological integrity, representation, biological diversity, biodiversity conservation), showing fundamental harmony with the scientific community's research directions. The centrality of the protected marine areas stands out in a quite marked way, dominant compared to the land reserves and the typical environments of continental Canada: the sole example inside the network is represented by the boreal forests. Several of the terms linked to the hypotheses of management of the Canadian park system are missing: there are no traces of floating protected areas, temporal corridors, or other innovative infrastructures but there are nevertheless references to policies and practices. Also interesting is the tight connection between research and policy. Obviously, the analysis only provides preliminary indications that are insufficient for appropriate descriptions of the explicit case, which falls outside the specific interest developed in the present study, but it is useful for confirming a reality already clearly seen in the American case: a specific policy towards climate change is shown by the scientific community's particular attention to the subject under consideration. Clarifying the nature of the link between policy and epistemic importance, in the Canadian case too, is not appropriate for this present study.

With this first, general cartography to portray – or at least to sketch out – the particular geography of science linked to enquiries on the effects of climate change in the protected areas on a global scale, it is possible to pass to analysis of the Alpine case. In doing so, all the considerations that have been expounded up until now need to be borne in mind, on the conditioning of scientific interest and its catalysts, and on the sources that can be investigated to give meaning to the spatial configurations obtained from analyses of the data. This is therefore the moment to ask: who conducts research on climate change in Alpine areas? What are the objects most studied? And where is research particularly concentrated? Which protected areas are studied?

3. *Putting (climate change) science in its place*

3.1. Climate change and Protected Areas from Europe to the Alps

The complex discourse developed by the IUCN around the challenges that climate change brings to the future of PAs (see paragraph 2.1) is obviously scalable to the case of the Alps. The new climate regime can be a threat to species and ecosystem protection, as well as to the normal conduct of conservation practices. The IUCN World Commission for Protected Areas (WCPA) addressed the general policy lines drawn by the IUCN, which have already been downscaled to macroregional levels, including the continental scale. Other than the already mentioned example of Canada, Australia displays articulated policy documents regarding the effects of climate change in PAs (Dunlop, Brown, 2009), intended as assessments of climate change's effects on the Australian PAs' system. The reports provide overviews of the state of knowledge for policymakers, thanks to the combined efforts of the Climate Change Department and Parks Australia. The positive correlation between the existence of policy documents addressing the topic and a strong body of research records has already been highlighted in the previous chapter. Despite the wealth of different assessments of climate change and summaries for policymakers provided by NGOs and other institutional bodies, addressing different spatial scales, comprehensive policy documents, especially guidelines, are uncommon.

At the European level, such a document is represented by the publication "Guidelines on Climate Change and Natura 2000. Dealing with the impact of climate change On the management of the Natura 2000 Network of areas of high biodiversity value", edited by the European Commission. This report, building upon the foundations laid down by the Commission White Paper on Adapting to Climate Change – Towards a European Framework for Action (2009) and the EU Strategy on Adaptation to Climate Change, stressed the role of ecosystems in tackling climate change, while analysing the impacts of the new climate regime on biodiversity in the Natura 2000 site. Coherently with the IUCN guidelines, the document focused on the implementation of adaptive management in these sites and policy strategy addressing the problem on a higher spatial scale, comprising a concept that is proving to be significant and highly policy-relevant for the Alpine macroregion: the creation of ecological connectivity. The central dimension of adaptive management is clearly a testament to the role of science in the PAs' future, as all of the proposed measures need strict scientific support and monitoring in order to be effective.

However, before coming to the case of the Alps, it should be acknowledged that the document, even if probably the most structured, is not the only expression of a growing interest towards the topic of climate change in PAs. The Europarc Federation promoted a meeting in 2017 on the topic of "Changing climate – changing parks", hosted by the Julian Alps Transboundary Ecoregion. The meeting, involving – among others – members of the European Parliament and Commission, widely addressed the topic of climate change in Parks and PAs. Nevertheless, the Europarc federation's interest in climate change took a more concrete form in the same year, but in a different region. Europarc Spain published a manual on adaptation to climate change for PAs. The publication, "The protected areas in the context of climate change. Incorporating adaptation to climate change in planning and management", while highlighting how little, if any, attention is given to climate change, focuses on the existing scientific data that can drive adaptation processes:

> The implications of climate change for the operation of ecosystems are already perceptible and extremely abundant evidence is available in the scientific literature. […] that evidence has been collected on the effects of global change at all organizational levels: changes in genetic variability, in physiology, in demographic structure, in phenology and the lifecycles of many species, in distribution patterns, or in ecological processes such as productivity, material cycles and, in short, changes in the provision of services to society (Mezquieda et al., 2016, p. 22).

The document stresses, step by step, how "the entire process must be based on the best scientific evidence available" in order to be effective.

Even if of evident importance in the development of a comprehensive approach to climate change in European Parks, the work carried on by the federation is neither the only nor the first example. In particular, signs of concrete concern came three years earlier from the Alps.

In 2014 the Alparc federation organized a workshop in Gran Paradiso National Park titled "Monitoring biodiversity transformation to document climate change impacts in Alpine protected areas". The workshop gathered scientists and PA managers and stressed the centrality of the topic of biodiversity monitoring in regard to climate change. In this context, the need of international cooperation in the field of climate change impacts on biodiversity has been highlighted, together with the laboratory role that PAs can assume for research addressing the topic (Alparc, 2014). The availability of trained staff for observation and samplings, of monitoring infrastructures and long-term visibility of monitoring plots were considered the main reasons for the prominence of these geographical contexts in climate change research. Moreover, the workshop consisted of a series of presentations highlighting the work of the scientific monitoring network. Alparc also published its own introductive guide to managing biodiversity in a time of climate change in PAs. The document, entitled "Biodiversity in time of climate change: management or wilderness?" and published in 2010, comprises a short theoretical analysis with some practical examples of adaptation in the conservation domain, and some interviews with park managers and scientists. However, the guidelines have yet to assume a more systematic, encompassing form.

Despite this significant manifestation of interest, climate change is not at the centre of a unified guideline for the Alpine microregion. It is evident that climate change is today an integral part of many general management and policy guidelines, but still, a central, unified focus on formulating a strategy is missing for the macroregion. However, the prominence of climate change in the Alpine context is clearly visible in one of its most central and comprehensive steering documents, Alpine Nature 2030. Creating [ecological] connectivity for generations to come, published by the German Federal Ministry of the Environment. The document revolves around the need for fostering connectivity among otherwise isolated PAs, which would otherwise witness diminishing results in their efforts to conserve nature. Among a plethora of causes are the genetic isolation of species populations, the reduction of suitable habitats, and the fragmentation of the matrix in which small patches of protected land are located. The document does not address the issue of climate change directly, but many of the contributions consider climate change as one of the main drivers fostering the need for adaptation (see Svadlenak-Gomez, p. 13; Plassmann, pp. 21-31; Tabor, McClure, p. 44; Scheurer, p. 86; Walzer, p. 106; Santolini et al., p. 107) as they try to introduce a paradigmatic shift in the ways conservation has been practised and managed for the last 100 years. The macroregional initiative can be ascribed to the broader movement of landscape-scale conservation, which aims at the redefinition of the entire scale in which conservation is today taking place, overcoming the model of the island in favour of the "whole ecosystem". This paradigm introduces the need to conserve the land between reserves as well as the PAs themselves, taking account of species migration, gene flows between different populations, the integrity of the environment, and ultimately, the inclusion of people in nature protection initiatives (Adams, 2006). In the Alps, ecological connectivity is not only alive on paper, but is at the centre of projects and frameworks of implementation, as in the case of the Ecological Continuum Initiative promoted by the joint work of CIPRA, ISCAR, ALPARC, and WWF. On an operational level, the alliance promotes the development of an on-the-ground-project, named “Econnect. Restoring the web of life”. This project, nearing its end in 2018, aims at enhancing ecological connectivity across selected regions of the Alpine range. Climate change adaptation plays a role in the whole project since it is centred on fostering the possibility of species migrations, especially in the light of climate change.

The growth of policy documents and conservation initiatives is an obviously unmistakable sign of how much climate change awareness enters into different social worlds and does not stay confined to the scientific domain. However, the Alpine macroregion still has to provide unified guidelines for climate change adaptation in PAs. At this point, we shift our interest back to the main concern of this work: what is the state of climate change research in Alpine PAs, especially in the light of its policy-relevant status?

3.2. Scientific research in Alpine Protected Areas

The role of science in PAs is recognized as central by many documents addressing the contemporary policy of conservation (IUCN, 2016). Additionally, scientific research is an integrated task for most managed PAs in Europe, with the goal of creating the necessary knowledge for the implementation of evidence-based management (Scheurer, 2016, p. 242). The task is particularly important in the light of undergoing global and regional changes. However, previous reviews have often underlined the gap between the theoretical role of science in the management of PAs and the actual relevance the role holds, despite notable exceptions (ibidem). On a normative level, science should be expected to play the role of the innovator in processes of adaptation to global and regional changes, but, as noted by Scheurer (pp. 242-243), in order to fulfil this task, science must “be focused on fundamental questions related to global and regional change, and should be interdisciplinary and long-term in design”, and additionally “the interface between science, park management and regional governance has to be strengthened in order to enhance exchanges of knowledge and mutual learning. However, it should be noted that the relationship between science and PA management can be handled materially in many forms, from the establishment of a scientific department, in charge of conducting research and fostering co-operation with external scientists, to the organization of scientific councils or boards, in charge of steering and overviewing research conducted in PAs. Despite the existence of such organs, we still lack a solid understanding of the dynamics they promote at this interface. In a recent study, Arpin et al. highlighted how the Alpine landscape is characterized by the coexistence of different organs working at the interface between science and management. Scientific departments, as well as scientific councils, display an uneven distribution in the Alpine range; nevertheless, "there is no overview or general assessment to their contribution to bringing together scientists and PAs practitioners and to fostering boundary science" (Arpin et al., 2016, p. 5). Additionally, the very definition of a scientific council is a broad one: scientific councils of Alpine PAs can be situated along a gradient between science and management, as some of them are strictly concerned with proposing and evaluating scientific activities, while others are more involved in advising managerial boards on management issues (Arpin et al., 2016, p. 8). Hence, it is challenging to understand univocally their role in selecting and promoting policy and management relevant science, and, more precisely, their role in promoting climate change research.

As an integral part of the global change process, however, climate change can be regarded as one of the main fundamental questions in the future of PAs, and consequently an enquiry into the state of climate change research should constitute a valid benchmark if we are to test the commitment of PAs to managing some of the main effects of global and regional changes.

As a first step, climate change research can be analysed by mining data from the Web of Science core collection. First, some descriptive statistics can be derived, in order to help to better grasp the scope of scientific efforts in the Alps and the main disciplinary composition of research on climate change, and put this information in an international perspective, comparing neighbouring and morphologically-similar geographical regions to the Alps.

From the point of view of the research articles indexed, Alpine PAs are the most studied among the major mountain ranges worldwide, proportionally to the data highlighted in the previous chapters on general research on climate change conducted in mountainous regions. The research records set within the boundaries of the Alpine macroregion often outweighs the number of records addressing the national-scale of the most part of the signatories of the Alpine convention itself. A preliminary look to the data indexed reveals that among the countries with a dataset overlapping partially the Alpine one from a spatial standpoint, only Italy can count on a larger body of literature (n=66). It is clear that Alpine PAs are a very prominent setting for climate change research in Europe (fig. 3.1).

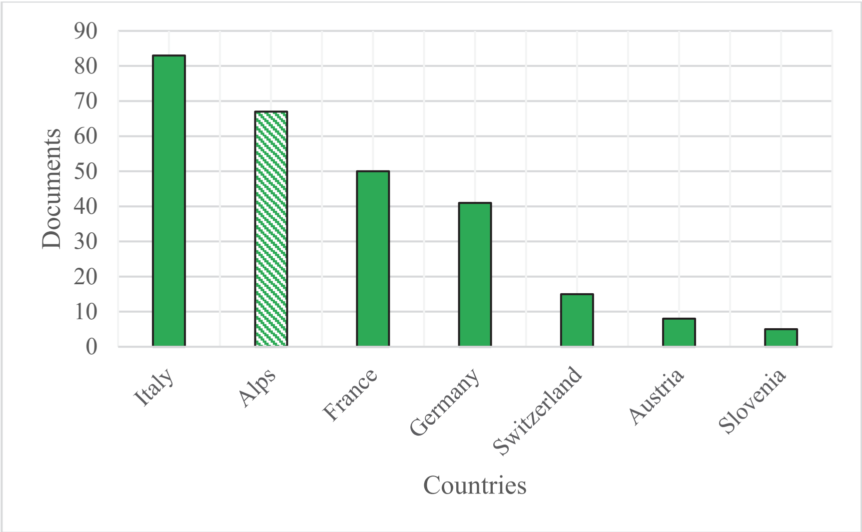

Figure 3.1 - Climate change research records in PAs across different regional scales

However, as already discussed in chapter 2, the dataset is rather small if compared to the world's most important producers of climate science records, i.e. the USA, Canada, Australia, and the UK. Additionally, it has to be noted that some of the most iconic or largest PAs of the World are deviating sensibly from the norm. The dataset related to Yellowstone National Park, for instance, exceeds in size the one related to the entire Alpine range (n=100), while the Ross Sea Marine Protected Area, the second largest on Earth, nears Italy's dataset (n=83).

These data provide a helpful introduction to the relative dimensions of the dataset we are to work with. However, the deepening of the analysis could take many paths at this point, considering the body of data available for processing. The next sections display the main tools and research strategies adopted in this chapter with the task of understanding in greater detail the composition, scope, and geographical diffusion of the indexed data.

3.3. Mapping climate change studies in Alpine Protected Areas

The central focus of this chapter is the scientific dimension of the Alpine macroregion, in order to understand how climate change is gaining space among the research interests of different scientific and disciplinary domains. Clearly, many different qualitative and quantitative methodologies can be followed in order to accomplish this task. We have already employed techniques born in the fields of scientometrics and science mapping over the course of this work, with the task of visualizing and synthesizing data. Science mapping is a young undertaking and is still forming a strong core of reference literature able to guide the inquiry. In the case of the Alpine macroregion, we have not found similar methodologies already applied to another case study, while in the case of conservation, we have met articles adopting the methodology a very few times (Kratzer, 2018). However, we believe that, given the exploratory dimension of this endeavour, we should be looking at more efficient ways to gather data that can serve as a basis for further, more in-depth analysis. Bibliometric analysis is today widely employed in the task of mapping the development of science for its ability to highlight hotspots and trends (Zhang et al., 2016). To employ it with the goal of shedding some light on the overall scientific literature produced in the Alps is an opportunity not to be missed.

We believe science mapping should be regarded as an ideal approach to fulfill the task of producing a reliable overview on the Alpine scale, but its reaching potential is bound to the level of data availability. In the case of research in PAs, the samples are often small, and hence we are testing the methodology at the limits of its effectiveness. This fact is to be taken into serious consideration when interpreting results and looking for significant trends.

Despite the epistemological limitations, we believe this methodology offers a series of key advantages in analysing the main features of bodies of literature if we accept some of the main assumptions it implies. Even if already discussed in the previous chapters, we schematize the central assumptions at the core of the methodology. First, scientific progress is expressed as a function of the accumulation of literature (Kratzer, 2018, p. 37). Second, more central to our case, the co-occurrence of words represents a reliable index of the centrality of the specific terms employed in the literature. The terms that co-occur the most are the most likely to define particular branches of literature. Third, links and relative distance from one node to another are a direct function of their relatedness in the literature. These assumptions are just a fraction of the more complex set of rules that govern science-mapping undertakings, but are, in our view, the fundamental guidelines the reader should keep in mind when approaching the results and interpretations provided.

Additionally, it has to be remarked that metadata derived from the articles can be employed in the construction of different kinds of map: from network maps linking together terms or authors to maps binding together different geographical contexts, like PAs. In our study, both kinds of network map have been employed.

3.3.1. Main limits of the methodology and the research strategy

Even if the methodology applied to the research question displays evident advantages in a geography of science inquiry, its limitations need to be addressed, with a particular focus on the scope of the analysis. The analysis is indeed based on a fixed database – Thompson Reuters' Web Of Science – that allows keeping track of the publications distributed to the scientific community by the main journals in the respective disciplinary fields. As a consequence, every research product published in journals outside the database is not detectable by the methodology. It is crucial to note that the exclusion of a research product from the database is not a direct result of the content and quality of the article itself, but is a function of the evaluation system that the database employs to steer the quality of the journal itself. In the light of this mechanism, it is possible that some research products might be undetectable. This fact can be connected with a wider issue of the exclusion from the reach of these scientometric tools, namely, the phenomenon of *grey literature*. The term can be defined as follows:

> Information produced on all levels of government, academia, business and industry in electronic and print formats not controlled by commercial publishing, i.e., where publishing is not the primary activity of the producing body' (Bonato, 2016).

The case of PAs is effectively described by this definition, since their primary role is different from publishing. Moreover, the publishing activity itself might be conducted in a way that does not perfectly overlap the academic procedures, especially regarding the stage where the publication is presented. Journals may not be the most preferred target of research in PAs since the main goal of such research is often to generate useful and operationally practical information for the PA[1]. For this reason, part of the scientific literature produced by PAs, and in PAs, takes the form of reports or working papers.

To overcome the separation between the two bodies of literature is a very complex task since there are no universally recognized tools to mine the grey literature's universe. Theoretically, a different database, namely Google Scholar, can potentially be used to track other sources of information, such as reports or conference papers. Even if it lacks the transparency and authoritative stature of the more widely used Thompson Reuters' Web of Science or Elsevier's Scopus, Google Scholar depends on a larger database, often comprising conference articles not detectable using other tools. Nevertheless, research has

[1] The question of the means of research production in PAs is addressed in chapter 4, in the form of an expert interview that helped in identifying the issue.

already shown that Google Scholar cannot be considered dependable, testing its detection ability on conference papers (Bonato, 2016, p. 254). Moreover, reports are still difficult to find if not published in any journal.

In order to overcome this situation, and work with the available data, the dataset has been analysed in two studies, from two different standpoints.

The first study, based completely on the Web of Science dataset, is focused on the analysis of the content of the scientific literature, looking for the main thematic features of the Alpine scientific corpus. The central aim is to recall the earlier ideas around which Livingstone constructed the entire architecture of his Geography of Science approach. First, that distinct regions hold distinctive "cultures", and second, that some places can serve as recognizable and socially accepted "venues" of science. We tested these ideas in the field of research in PAs. This field of research can be seen as an odd benchmark since science can be regarded as "bound" to some key interests that are common to every PA. We highlighted how ecological research is dominant in the records, and the reason is self-evident. Science plays the role of the informer for policies and practices in these contexts (Scheurer, 2016), and hence its capacity of roaming free of external constraints is reduced since it needs to address present – and sometimes pressing – issues and possible future scenarios. In a more pragmatic view, science embraces an applied dimension, and, as the most evident example, the allocation of funding bound to specific objects of interest might shape research. However, our main interest is to understand which factors catalyse or prevent the formation of scientific interest around the topic of climate change in PAs, and such a task demands science to be treated in its relationship with external, interacting forces, and not the tracking of its "evolutive" directions *in vitro*, without any interference coming from the outside. Livingstone himself was concerned with "*how provincial science may be shaped by the forces of political and social geography"* (Livingstone, 2003, p. 106), and Mahony and Hulme stressed the relationship between epistemic relevance and policy relevance in contemporary climate and climate-related studies. In the light of these helpful insights on the relationships between geography, society, and science, mapping scientific undertakings in Parks and PAs is an even more interesting challenge. Ecological research may take different directions in different settings. Glaciological research may be taken into higher consideration by some PAs rather than others. Research in forestry could be more appealing for PAs with higher or more valued wood-related resources, and so forth.

Once this framework for our task has been acknowledged, analysing science in this context can be particularly revealing: physical, environmental, and social geography can potentially exert a force in shaping the "scientific culture" of the region. Just to provide a more detailed example in the domain of ecological science, a particular research focus on different species, charismatic or not, might be revealing about the relationships between the species and the social community, and could define the scale at which this relationship takes place. However, the fundamental questions are many at this point. What are the main thematic features of research in Alpine PAs? Can Livingstone's theories stand against the connecting (and homologating?) effects of an infinitely more efficient science circulation? Can we talk and write about "scientific regions" in a context where the globalization of conservation policies are promoted by the IUCN and other influential boundary organizations? Note that all these questions can be answered only after addressing a more pragmatic and inescapable question. How do we operationalize concepts coming from a theoretical field of geography into something measurable? In the first study, we focus on looking for answers to these questions by testing a semantic analysis of the key features indexed in the metadata, namely keywords.

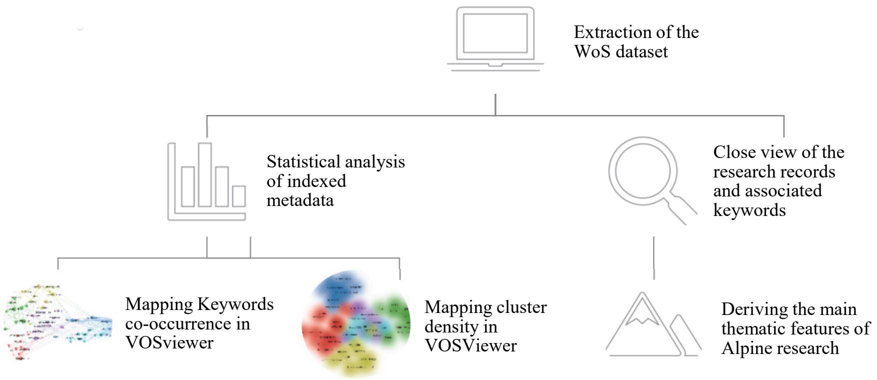

Figure 3.2 - Workflow of study 1

After dealing with the immaterial "culture" of the region, the second study will focus on the spatial distribution of research on climate change in Alpine PAs. The dataset employed in study one is, as already remarked, a limited one, that can represent just a part of the literature circulating on an Alpine scale. However, it can be nonetheless employed for analysing the spatial dimension embraced by research published in international journals, assuming that these publication contexts represent the top-quality level as research products. Nevertheless, we are aware that this dataset might misrepresent the real composition of research in the Alps. In order to face the possibility that (1) some research projects may currently be under development, even without material traces of research products, and (2) some publications can escape the reaching capacity of Web of Science, the focus shifted from a "distant reading" methodology to a close reading one. In the final session of the study, we look for active, or at least recent, research networks and projects in other databases or Park's websites. Even if this integrative methodology cannot display the same systematicity of the first one employed, it can nevertheless be a source of reliable information regarding new research projects that still have to present published products or have already published outside the main online infrastructure of science circulation. In both cases, the data obtained have been organized in a small database and mapped.

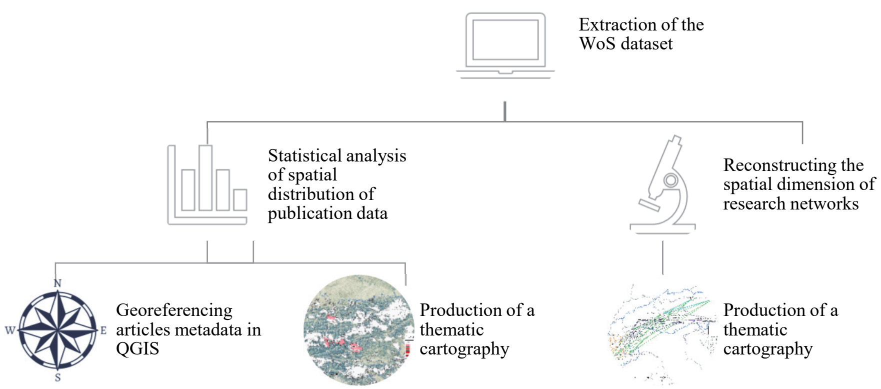

Figure 3.3 - Workflow of study 2

3.3.2. A small dataset and the Triglav's anomaly

The initial query applied to the Web of Science database[2] provided an initial dataset of 69 research records. An additional manual checking of the setting of every research was needed in order to exclude some misplaced records, as well as some records not directly concerning PAs[3]. Even with this multistep approach, an anomaly has been detected. Considering the Triglav

[2] The queries were multiples. From a more generic "TS=(climate change AND alps AND protected areas)" to site specific queries TS=(climate change AND alps AND Swiss National Park"). The multiplicity of the queries allowed to detect more research records and integrate the initial one, that needed to be cleaned of a number of misplaced research records, most of them regarding Australian Alps.
[3] The final dataset is shown in the supplementary materials.

National Park in Slovenia, no research records dealing with climate change have been found. However, further interrogation of the dataset was able to find three glaciological research records conducted in the Triglav glacier. These records are not indexed as research conducted in the PA since they never cite directly the National Park, but just the glacier's toponym. This fact opens up the possibility that a similar situation might be repeated in other PAs. When read in this light, the particular case of the Stelvio National Park, which will be addressed later, is probably the real anomaly, where the research – funded directly either by the park management or the Region of Lombardy – actively cites the park among the metadata[4]. Wherever this official economic – or another form of institutional – relationship is not present, the Triglav's anomaly might reproduce itself, and studies carried on within the PA will not be indexed as such. The anomaly reveals the fact that PAs might represent the wrong reference scale in these cases. Regarding the Triglav toponym, it refers simultaneously to a mountain, a glacier, and a PA. It is clear that from a strictly scientific standpoint, glaciological records have to be stored and labelled in databases with the name of the glacier, or the toponym of the mountain. At the same time, without active interaction between the researchers and the park's managers, there is no point in considering the PAs while indexing the research record. Hence, research projects will not automatically recognize the PA as a stakeholder, without explicit expressions of interest by the PA, which might commit to the research project, as in the case of Stevio. The anomaly is, in Triglav's example, linked to glaciology and glaciers, but could be virtually extended to other disciplines that focus on other objects of interest. However, it is to be noted that ecological research, at least within the limits of our dataset, often addresses spatial distribution issues in order to test the capacity of PAs and non-PAs to retain specific populations, or to analyse the impacts of climate change on a prized protected species, and that research in conservation biology and related fields are more naturally linked to the main tasks and interests of PAs. The Triglav anomaly, in light of this consideration, can have an impact on the indexing of glaciological rather than biological or ecological research.

What are the implications of this misplaced literature for the aim of the study? Should we include it in the original one or filter the new data out of the final mapping outputs? Even although this decision potentially reduces the volume of the dataset, we must keep these research records out of the further processing, in order to maintain the integrity of the relationship between research and PAs. Research conducted in the PA should be made with

[4] The source for this data is Web of Science itself, since among the metadata are often indexed funding agencies.

the explicit reference of the PA's tasks and scopes. If research "just happens" to be carried on within the boundary of a PA, but does not address this spatial entity directly (in the title, keywords, abstracts or any other metadata field), it could still be considered as meaningful data for every PAs' administration. However, in a research study aiming at a quantitative and qualitative analysis of the relationship between science and PAs, only science conducted in partnership – or at least with a reciprocal interest – should, in our view, be considered. The reader should acknowledge at this point that the dataset considered in this work is a direct consequence of this choice.

3.4. Study 1: Provincial science, cosmopolitan science. A thematic analysis of the dataset

3.4.1. Methodology

The main task of this study is to define what constitutes research in Alpine PAs from a thematic standpoint. As anticipated in the previous section, the initial idea that we wanted to address with the study deals with some of the main ideas that structure David Livingstone's work, i.e. the concept of "scientific cultures" linked to particular geographical areas. In Livingstone's own words, what constitutes the geography of science are "*ideas and institutions, theories and practice, principles and performances*" (Livingstone 2003, p. 12). However, these concepts can be difficult to translate on an operative level. The collection of metadata associated with scientific articles in the WoS database can serve as a viable starting point. Among the metadata stored qualitative data can be particularly helpful in identifying the main features that shape research in a region, especially in the case of the co-occurrence of particular terms. However, approaching this kind of analysis one has to be mindful of the fact that our questions can seldom be answered directly. Even although we entered this study with a set of theoretical questions in mind, the research turns, when dealing with relatively large (numerically and geographically) bodies of data, into a data-driven one, where new questions can arise from the analysis of the dataset and old questions might remain unsolved. In this case, we looked for descriptors of different features of research, namely the clusterization of different research topics, the temporal dimension of research development, and the topology of the network. Hence, the methodology adopted can be tested here in its information-mining capacity, and then the results confronted with the initial theoretical questions.

With this goal, the Web of Science database has been mined, and the dataset extracted. For the first study, our interest focuses on defining the thematic composition of research. The WoS disciplinary composition category, used in the introductory section, is too rough as a proxy to map effectively the main features of research. The fact that the discipline of ecology appears as the main discipline in the study of climate change in this area is not particularly meaningful. In order to overcome the limitations of the potential reach of our instruments of analysis, we employed the software VOSviewer, which allows us to visualize via social network the co-occurrence of terms extracted from the articles' metadata: titles, abstracts, and keywords.

As a starting point for describing research carried on in Alpine PAs, an analysis of the keywords co-occurrence has been performed in the VOSviewer environment. Keywords can be seen as the most synthetic index of the contents of research, since they do not need a manual clean-up of the data, unlike the more generic terms derived from abstracts and titles (Yeung et al., 2018).

The literature corpus was processed via VOSviewer and divided into different clusters. The keywords selected were filtered: in order to be taken into consideration, keywords must have occurred at least twice. Consequently, the analysis considered 158 keywords.

The results of the analysis are visually synthetized by figures 3.4, 3.5 and 3.6.

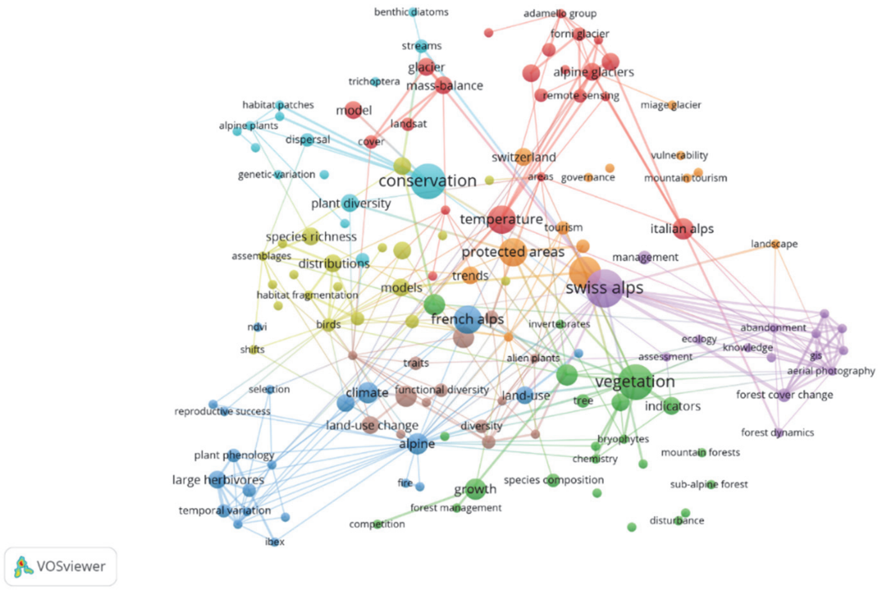

Figure 3.4 - Co-occurrence map of the keywords

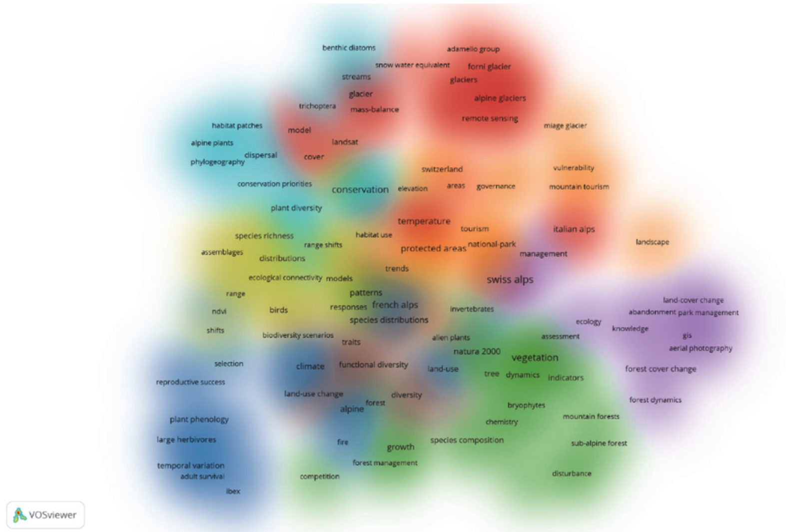

Figure 3.5 - Density Map of the different clusters

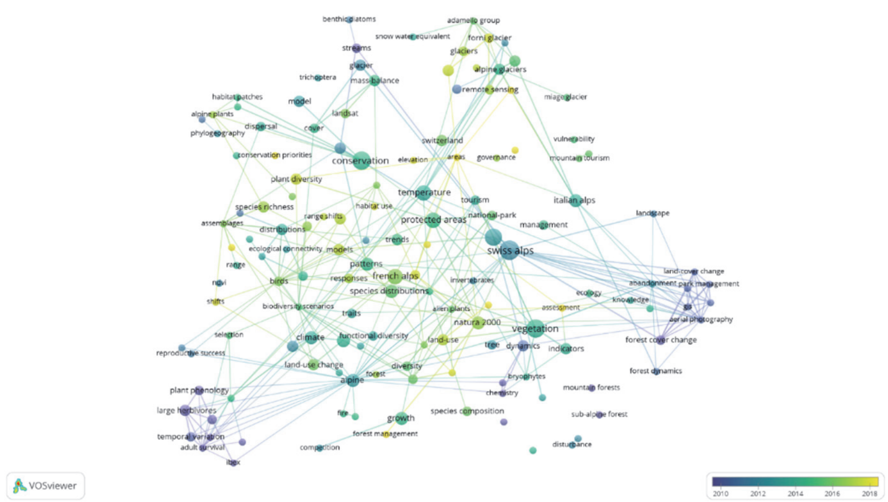

Figure 3.6 - Overlay visualization of the network highlighting the average publication year of every keyword. The results are normalized by subtracting the mean value of the dataset to every term's publication year

The keyword map in figure 3.6 highlights eight clusters of research, with a core structure composed of four clusters, and four additional clusters lying on the periphery of the network. The semantic analysis of the keywords allows reconducting the cluster to the central thematic core around which it revolves. Cluster 1, coloured in red, revolves around glaciology. The cluster is the only one highlighting toponyms among the keywords, since Mont Blanc massif, Forni glacier, and Adamello group are all constituent parts of the cluster. Of special interest is the explicit reference to the Stelvio National Park as one of the most recurrent terms of the entire group of items (n=4). Connected to this first knot of glaciological information, cluster seven (orange) faces the effects of climate change on winter tourism, comprising the consequences of shrinking glaciers. Cluster two, marked in green, focuses on a precise spatial scale, i.e. Natura 2000 network, and some of the main conservationist issues related to the network, as in the case of specific habitat conservation. Cluster three, highlighted in blue, is dealing with the case of ibex population dynamics and, more generally, large herbivores' populations and habitats. Even if not part of the keywords, the setting of these research studies is detectable via metadata close reading: all these keywords, in fact, refer to articles produced by research carried out in Gran Paradiso National Park. Cluster four (yellow) explores the ways species, biological communities, and assemblages deal with climate change. Cluster five (purple) put climate change in perspective with reflections on longer timescales and the feedbacks it entails with converging phenomena (abandonment,land-use change). The sixth cluster, coloured in light blue, deals with biological communities' conservation, with a particular interest for terms arising from freshwater ecology, benthic diatoms, and *Trichoptera.* Finally, cluster eight (brown) brings generalist keywords on ecological matters.

From the point of view of the dominance of some set of keywords in the network, it should be noted that the network lacks recognizable centres (i.e. keywords with noticeably higher occurrences). The median value of the entire dataset in terms of occurrences of a single term equals 2 and coincides also with the lowest value. Conversely, the highest value is 10. Hence, the range of variability is restricted and no clear centre of the map appears.

From the point of view of centrality measures, degree centrality (labeled as "links" in the table) does not show significant evidence, since the terms belonging to the 90th percentile (Avg. Dc=15.8) are either very broad terms (e.g. biodiversity, conservation, temperature) or general toponym (e.g. Italian Alps, French Alps). An exception to the rule is given by the keyword "large herbivores" that constitutes a centre for cluster 1, a factor that will be further developed in the discussion of the results.

Considering the temporal dimension, the dataset is relatively recent: the minimum value is 2005, while the average year of publication rests on 2014. Research on the topic is active today since the latest publication year is 2019. A closer look at the different "age" of the clusters reveals that cluster 2, the "Gran Paradiso cluster" is the oldest one, followed by some of the keywords of cluster 1. However, the contemporary research front is not part of any specific cluster, since the newest keywords are distributed between cluster 3 and 5. Interestingly, Stelvio National Park is one of the keywords displaying the highest average publication year, highlighting how the setting of research is productive in this particular moment. If read in contraposition to the other geographically distinguishable, and most peripheral cluster of Gran Paradiso, this visualization helps us understand how the two hot-spots are temporally not aligned one to the other, since cluster 2 represented the first body of literature addressing the problem of climate change, while cluster 3 is temporally the last.

At the beginning of the analysis, we defined some clusters as more "peripheral", but did not further develop the claim. More peripheral edges in a network can be detected from a centrality standpoint (degree centrality) or from a topological standpoint, by considering the geometrical shape of the whole network and its spatial properties. Hence, the network has been further analysed from a topological standpoint, looking for meaningful spatial relationships. More precisely, we addressed the question of the centre–periphery relationship, since from preliminary observations, the maps highlighted an accumulation of "specialist terms" on their outer edges. Our interpretation of the adjective "specialist", however, is not based on the disciplinary context in which the terms are usually employed. The semantic domain might reveal a slippery ground in defining the degree of specialism of a term. Consequently, we defined a keyword as "specialist" if it addresses a topic that holds a central dimension in one research record, or in just a few research records. In other words, a term can be seen as specialist if it is not shared among several research records. We considered the hypothesis of a strong centre–periphery relationship, where most common terms are concentrated in the centre of the map, while the more specialist terms gather in the peripheries. In order to test this hypothesis, we calculated the distance of every single node from the centre of the network, coincident with the origin of the Cartesian axes. Starting from the single coordinates values of x and y, we derived the Euclidean distance of the point from the centre (R). Detailed results are shown in the supplementary materials, while the relative distance of the keywords, grouped per cluster, is shown in figure 3.7.

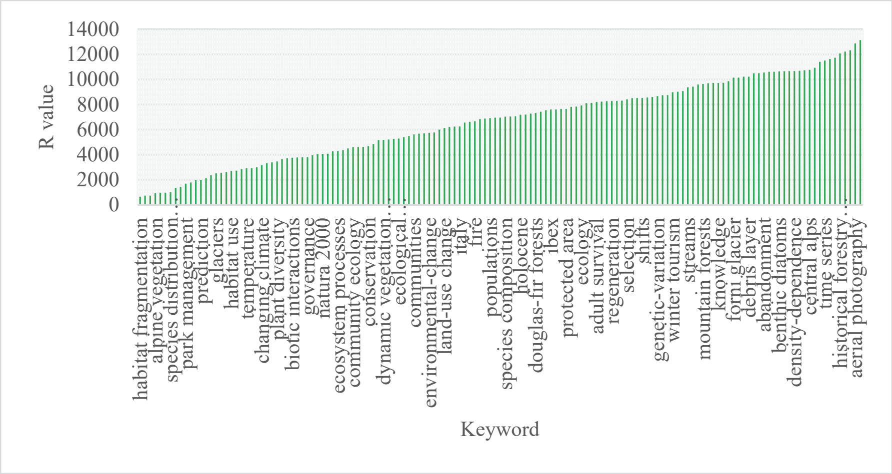

Figure 3.7 - Euclidean distance (R) from the centre of the Network

The initial hypothesis is reinforced from a close view of the data and the associated R values; such a metric can identify research-specific terms. In order to calculate which cluster value occurred most in every quartile, we calculated the frequencies of the values composing the single clusters. Clusters one to four have right-skewed distributions, highlighting a concentration of high R values associated with each keyword; hence, they are the more specialized[5]. On the contrary, clusters five to eight distribute the most of their keywords on low R values, defining more central and generalist clusters.

3.4.2. Discussion of the results

The most interesting results of the analysis arise from the clusters identified and their spatial arrangement, together with their connections. If the core of the network gathers more general keywords, the two most peripheral clusters disclose particularly meaningful information, since they explicitly or implicitly address a spatial dimension and narrower research fields. In cluster one, all the keywords entail easily recognizable connections with the field of glaciology, either toponyms or technical terminologies. Cluster three shapes very similar situations, as the object of interest – the ibex, or more generally large

[5] Note that the two centralities do not necessarily overlap. From a topological standpoint, an edge can be peripheral even if it displays a high value of degree centrality. High R values in topologically peripheral edges define the presence of a node that is particularly important in its vicinity, but do not form any connections outside its small circle.

herbivores – is the centre around which the entire cluster revolves. To a lesser, but still recognizable extent, part of cluster six shows a similar trend, since it focuses on high-altitude environments, namely alpine springs, and their fauna assemblages. Cluster eight, finally, develops an independent discourse on management of different climate-related or concurrent phenomena.

The highest values of degree centrality are associated with general terms located in the centre of the map or in peripheral nuclei located in the outer structures of the network. The relative positions of the terms coming from the glaciological lexicon or from large herbivores' population dynamics clearly show that highly specialized research is positioned on the edges of the network, posing an interesting consideration on the centre–periphery relationship. Among the terms with the higher outset from the centre, there is no continuity in terms of research subjects, apart from independent "families" of specialized keywords. With the term "specialization" we are referring to these families of research studies: the groups are distinct from the rest of the network; their keywords co-occur frequently, but their ties with terms outside their cluster are weaker; their separation is recognizable on a mathematical level by the high R values associated with each keyword and with the lower reach of the links connecting the edges to the rest of the network. As an example, the term "large herbivores", around which cluster two revolves in terms of connectivity, belongs to the 90th percentile considering the totality of the keywords indexed centrality-wise. The keyword defines a highly connected node, but the reach of its connections does not extend beyond the immediate neighbouring terms.

Additionally, the semantic analysis of the keywords suggests that on the one hand, cluster one is strongly linked with the geographical region of Stelvio National Park, while on the other cluster three suggests exclusive links with Gran Paradiso National Park, since it is the only one dealing with the study of the ibex in relation to climate change. It is also particularly interesting for the aims of this study to note that the one of two most central clusters in topological term is associated with research focused on the Natura 2000 network.

From an interpretative standpoint, this two bodies of evidence – the georeferencing of particular research interests and their relative separation from the larger body of literature – echo Livingstone's view of different scientific cultures associated with the different places where science is conducted. Science obviously remains a large social undertaking, in which peculiar traits cannot be limited to the scale of the single PA. However, the specialization of a PA in a particular field of inquiry is nonetheless an interesting feature from a geographical perspective, since it can characterize different spaces of science. To be able to recognize the geographical origins of a thematic nucleus of keywords is significant, since it means that the research field is not diffused across multiple spatial entities. If Stelvio is a laboratory for glaciological research, and Gran Paradiso serves as an observatory for the Alpine ibex, we could legitimately think that place still matters in the conduct of science, at least in our case study. Nevertheless, it would be a mistake to generalize this specialization trend to every PA, since a more precise geographical analysis of the sources of scientific literature – the places where the indexed studies have been carried out – is at this point necessary to push the inquiry further. In particular, this new aspect of the analysis could help to shed light on the dynamics that formed the structure of the central clusters of the network, made by keywords more widely shared among different clusters and research records. An answer to our set of theoretical questions, despite some new insights coming from the data, should be postponed to the end of study 2, crossing the information obtained.

Before moving on, however, it has to be noted that a piece of evidence of secondary importance is related to time. The temporal dimension shows that the literature has developed in recent times and at different rates. Additionally, the front of the research extends temporally up to 2018, demonstrating the vitality of the research question.

3.5. Study 2: reconstructing the geography of the Alpine records

3.5.1. Methodology

After defining the dataset, we geo-referenced the research records in a GIS environment, in order to obtain points representing the location of every research record. However, the geographical information associated with the available metadata does not allow for a constant level of detail beyond the spatial scale of the administrative boundaries of the PA. As a result, some research studies could have been referenced at the spatial scale of a precise PA, valley or locality, while others were at the level of the entire PA. In the light of this fundamental inhomogeneity of the data, the spatial scale selected was the one that guaranteed a constant level of data availability. At this point, the associated geometries were highlighted with graduated colours.

3.5.2. Results from Web of Science analysis

From the coupling of every research record with a defined set of spatial coordinates, research records tend to aggregate in just a few PAs, a minimal fraction of the entire protected surface of the Alpine range. Only a few of these PAs serve as hotspots for climate change research, as immediately visible in the case of Stelvio National Park in Italy, which counts the higher number of climate change research records. The complete distribution of research records is schematized in figure 3.8.

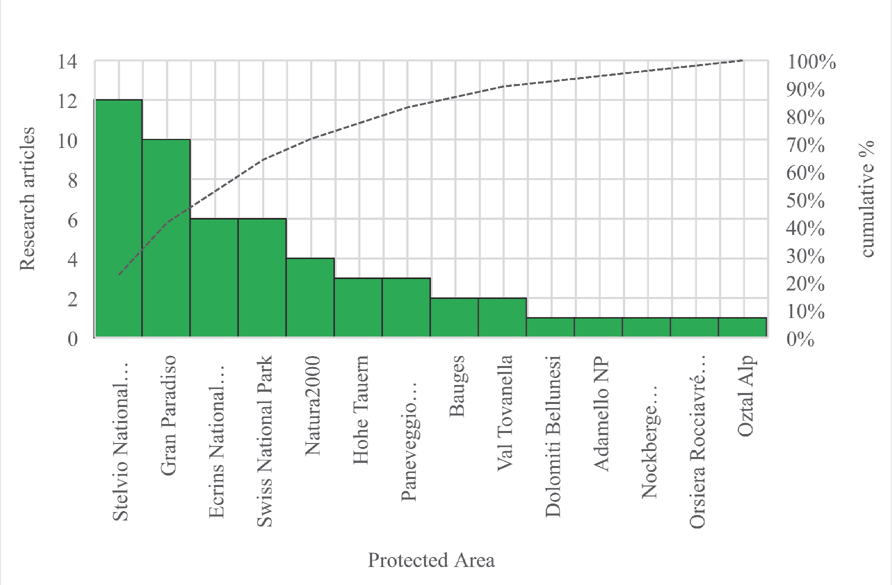

Figure 3.8 - Distribution of climate change research records in Alpine PAs. From Web of Science data

Considered the great number of PAs of different categories located within the Alpine Convention perimeter, climate change research is strongly concentrated in very few Parks and PAs. As a matter of fact, just thirteen Parks have been objects of scientific investigations, either National Parks or Regional Nature Park.

If taken together, four National Parks – Stelvio, Ecrins, Gran Paradiso, and SNP – aggregate 65% of the research indexed in the dataset. In addition, a fifth hotspot could be identified as the sum of all the research carried on in the setting of Natura 2000 sites. In this regard, Natura 2000 can be defined as a "mobile hotspot": these sites effectively work as "spaces of climate science", especially in relation to a broader context that does not produce scientific research on the topic. However, a cartographical representation of the areas coherent with the methodology adopted is difficult to achieve, since the articles do not state clearly the location of the observations conducted. All the other PAs represented on the map (fig. 3.9) host either one or two research records.

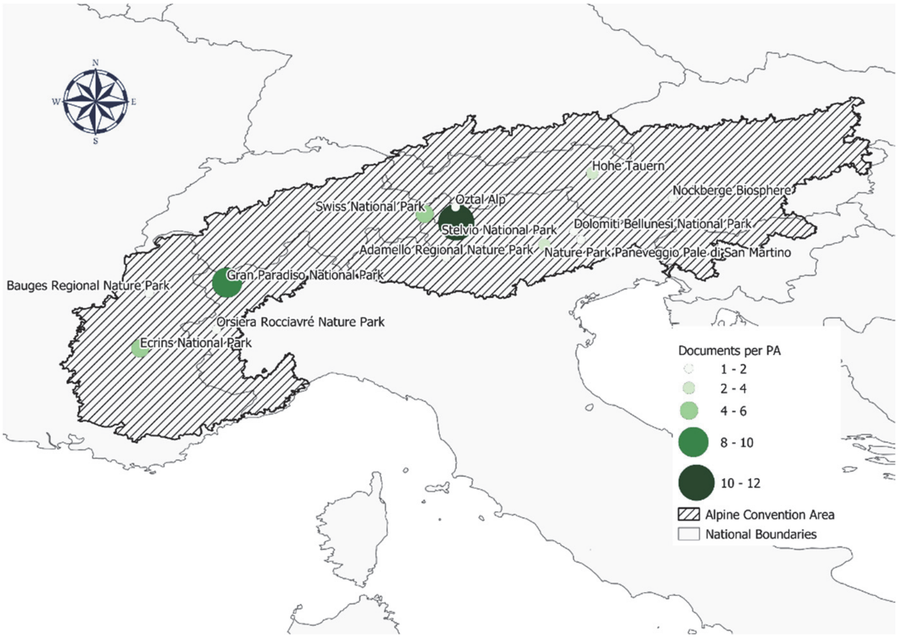

Figure 3.9 - Overview of the distribution of research records

3.5.3. Pushing the boundaries of the inquiry: overcoming the obstacle of grey literature via research networks detection

As already remarked, generating a map based solely on Web of Science indexed publications is not enough if we are to draw a complete geography of scientific undertakings. The problem of grey literature is still to be overcome, and a systematic, encompassing methodology to successfully complete the task is yet to be defined. However, an attempt can be made following the lines of international scientific cooperation projects. These projects, especially if in the early stages, may leave no traces on the official scientific corpus of articles, but they obviously produce literature in the form of reports, working papers, conference presentations, and articles in non-indexed journals. Collecting these secondary traces of research is a rather unsystematic exercise since no database can be queried[6]. Trying to

[6] A comprehensive database of research in Alpine PAs, the European Mountain Pool, has been recently shut down to comply with the General Data Protection Regulation (GDPR). The resource will be relaunched in the future, but the actual timing depends on the administration of the Swiss Academies of Arts and Sciences in Bern (Astrid Wallner, research coordinator for Swiss Alpine PA, personal communication).

fulfil the task of gathering reliable information poses challenges in the conduct of research, since online research in PAs' websites, the official websites of research networks, and research institutions has to be carried on without the help of any comprehensive database. Starting from this situation of unsystematized data, in the following section we focus on the detection of the different research networks operating currently – or, at least, whose functions ended recently – which address topics related to the effects of climate change. Where possible, literature associated with the networks will be presented, but their further analysis is beyond the scope of this study, since the methodology cannot be employed on non-standardized metadata.

In order to develop coherently a research strategy, a good starting point is checking international research projects on climate change encompassing the largest possible geographical scope. Looking for wide intercontinental research networks can be seen as a good entry strategy for this research task since they enjoy the highest visibility. In our case, obviously, these projects have to be focused on mountain environments. An attempt to gather and organize the data found is made in the following section.

Amongst all the different networks, one of the best known and established is the Global Observation Research Initiative in Alpine environments (GLORIA). The programme operates on a worldwide long-term observation network with permanent plot sites in alpine – broadly intended as an ecosystem, without a particular geographical focus – environments, monitoring vegetation and temperature in every site.

> GLORIA focuses on the alpine life zone (or high mountain area), which is defined here as the area above the low-temperature determined forestline and includes the treeline ecotone, the alpine, and nival elevation zones. The alpine life zone represents the only terrestrial biogeographic unit with a global distribution (Pauli et al., 2015, p. 15).

The final goal of the programme is to collect trends in "*species diversity, composition, abundance, and temperature, and to assess and predict losses in biodiversity in these fragile ecosystems which are under accelerating climate change pressures*" (GLORIA official website, https://www.gloria.ac.at/). The programme focuses especially on vascular plants and vegetation, but, where funding and workforce are available, it extends to other organism groups, such as bryophytes, lichens, vertebrates, and arthropods. Quantification of the changes occurring in species and vegetation patterns are resurveyed cyclically every five or ten years and all the surveys are conducted with standardized methods, in order to ensure the spatial comparability of the data obtained. The purpose of GLORIA's multi-summit approach is to build world-wide indicators of the impacts of climate change on the biodiversity of natural or semi-natural environments and to assess regional to large-scale risks of biodiversity losses. In the bigger picture, GLORIA aims at estimating the vulnerability of high mountain ecosystems under climate change pressures (Pauli et al., 2015).

The Alpine range contributes to the realization of this programme with multiple target regions. However, the sites located within PAs are few, with the most important of them being the Swiss National Parks, with two different summits, a siliceous and a carbonatic peak (Haller et al., 2013). Each of them has already been surveyed three times since their establishment, back in 2002. The surveys have already contributed to the publication of 4 research records, indexed in the Digital Object Repository of the WSL.

Another observation site is located at Mont Avic, in the Italian western Alps, part of the Mont Avic Natural Park, established in 2002, and, like the case of SNP, surveyed three times. One international publication in indexed in the Web of Science, although the previous searches were not able to detect it[7].

The network comprises other National Parks from different Alpine countries: the Austrian Gesäuse National Park has devoted a site to GLORIA programme observations since 2009 which has been surveyed twice. Nevertheless, research records showing results are not available.

In France, the National Park Mercantour observation site, established in 2001, has been surveyed only once in seventeen years; however, the scientific strategy for the period 2018-2022 highlights the necessity for a new survey in 2022 (Stratégie Scientifique du Parc National Mercantour, 2018-2022, pp. 28-29). A similar situation can be found in the case of the Berchtesgaden National Park, in Germany. The target region was set in 2004, and surveyed just once, without leaving detectable traces of research records stored in the local, national or international databases, outside the basic metadata displayed on the GLORIA programme's official website.

At a lower geographical level, other research networks can be found in the Alpine macroregion, for Alps-specific studies – research networks based solely on sites located within the Alps – or trans-regional studies, where groups of phenomena related to climate change are studied across a gradient of different environments and ecosystems, from mountainous to coastal. Within the latter group, a cross-border project, developed in an Interreg framework, was launched in 2010 and ended in 2013. The project was composed of nine partners – four in Slovenia and five in Italy – under the leading

[7] The publication does not cite the term "protected area" in any of the metadata field. Title, abstracts and keywords do not show the use of the term; hence, the research record was undetectable using the main string of research.

direction of the Triglav National Park. Of the total group of PAs involved, three of them belong to the Alpine range (Triglav, Dolomiti Friulane Nature Park, and Prealpi Giulie Nature Park), while the others range southward, following the coastline of the Adriatic Sea. The CLIMAPARKS project was intended as something more than a pure research project conducted in different environments for purely scientific causes and involved management contribution into the different work-packages into which it was split. From a scientific standpoint, the value of the project is found in its capacity to set a "year zero" for different monitoring – and associated research – projects in different parks that did not count in research and monitoring data before the beginning of the project (Vranješ, 2013, p. 7), a testament to the effectiveness of this kind of geographical cooperation across wider geographical scales. The research conducted under the coordination of the project did not result in WoS-indexed publications; however, a detailed report has been published on ISSUU, an open publishing database (Vranješ et al., 2013).

On the border between Italy and France, another research network formed in recent years. The e-Pheno programme (2012-2014), follow-up of the older PhenoALP Interreg project (2008-2011), gathered phenologic data from a network of PAs and non-PAs in the western section of the Alps. The central idea of the research network was to monitor potential changes in phenological rhythm due to climate change. Phenology, in this case, is taken as a valid proxy for monitoring the evolution of climate change. The monitoring focused on grassland and subalpine larch forests ecosystems (Filippa, 2014). The programme officially involved the Ecrins National Park, Gran Paradiso National Park, Nature Park Mont Avic, and Massif des Bauges Nature Park, even if the latter, included among the partners of the programme, does not show any monitoring site within the area[8]. The official website of the research initiative displays a section with all the publications directly linked to the data gathered by the project. However, the majority of them cannot be linked to the literature regarding PAs. Most of the sites involved in the studies are located outside PAs, while some of them do not directly address topics related to climate change, as they aim to test different observation methodologies. Only one of the research records indexed in the webpage satisfies our criteria of eligibility (Bocca et al., 2013).

The project is wide, from a geographical standpoint, but is not the only one to take place in this section of the Alpine range. On the same boundary between France and Italy, another project, still active in this case, is the LIFE project "PastorAlp", addressing pasture vulnerability and possible adaptation

[8] In the official website of the ePheno programme, a map of the currently operating station shows all the parks involved, without taking consideration of the Massif de Bauges Nature Park.

strategies in the Alps (http://www.pastoralp.eu). The project combines biophysical and socioeconomic research in an attempt to face the undergoing changes in pasture environments, and involves Gran Paradiso and Ecrins National Park. The project is very recent, since it started its operations in late 2017, and still has to produce scientific publications[9]. However, PastorAlp is an ambitious project, as it aims at the definition of management guidelines during the expected five years of operations.

Even if not actively working yet, another transboundary monitoring project is currently being structured in the Alps. On the occasion of the 2018 edition of the *Forum Alpinum*, held in Breitenwang, Austria, a project focusing on monitoring spring ecosystems has been launched. Springs are seen as delicate ecosystems that can face substantial changes in species composition due to climate change since the species inhabiting the ecosystems are highly specialized[10]. The project will take place in different locations, within the boundaries of four PAs: Biosfera Val Mustair and Swiss National Park (Switzerland), Gesäuse National Park (Austria) and Berchtesgaden National Park (Germany). The project, despite being in very early stages, can already count on some WoS-indexed publications (already comprised within the initial dataset), that served as the cornerstone for the development of the transboundary interest.

Shifting our focus to research networks working on a national level, two monitoring programmes are currently developing in the French Alps. The networks *Reseau Lacs Sentinelles* and *Reseau Alpages Sentinelles* are monitoring the effects of climate change on different ecosystems. The former addresses the changes in high Alpine lakes from a multidisciplinary point of view, while the latter focuses on the effects recorded in Alpine pastures. Both networks involve the Ecrins, Mercantour and Vanoise, the totality of French National Parks in the Alps. However, while the *Lacs Sentinelles* extends to the Natural Reserve Haute Savoie, the *Alpages Sentinelles* network is wider, touching the Regional Nature Parks Chartreuse, Vercors, Ventoux, and Luberon.

The last project addressed in this overview is found in Italy, where an ecological monitoring project focused on the measurement of biodiversity comprising many different PAs has been developed since 2005. Arising from a pilot study conducted on two altitudinal gradients in Gran Paradiso National Park, the monitoring initiative aims at spreading a standardized method for collecting observations in order to (I) collect data on animal

[9] One publication has already been produced, consisting of a poster presented at the European Geosciences Union General Assembly, held in Vienna, 8-13 April 2018. The poster showed a presentation of the project and its main goals.

[10] Personal communication of one of the leading scientist involved in the project, Stefanie Von Fumetti, ecologist from the University of Basel who chaired a session dedicated to the project at the 2018 Forum Alpinum.

biodiversity along altitudinal gradients and identify the main factors determining the current species distribution, (II) estimate the future risk of biodiversity loss, also applying climate change scenarios. and (III) identify species or groups more sensitive to environmental and climatic changes in order to determine new biodiversity and ecological indicators. In 2006 the project was incorporated into the Interreg programme "Gestalp", and between 2007 and 2008 extended to two additional PAs, Orsiera Rocciavré Nature Park, and Alpe Veglia Devero Nature Park, both in Piedmont. The programme was further developed due to new funding coming from the Italian Ministry of the Environment in the period 2012-2014. On this occasion, the first surveys in the initial PAs were repeated, while the network embraced three additional National Parks: Val Grande, Stelvio, and Dolomiti Bellunesi. The project led to four research articles over the years, but these contributions are written in Italian and not indexed in the Web of Science database.

All these scientific networks make the wide jigsaw of research activities on climate change that characterize the Alps and actively produce – in different publishing contexts – the literature that serves as an informative basis for adaptive management of the natural heritage.

3.5.4. Discussion of the results

The data deriving from the two separate analyses can provide some useful insight for an overview of the research panorama. Research conducted on the topic of climate change in Alpine PAs is, from the point of view of indexed research records, an occasional activity. It seems that no consistent effort can be clearly traced on a macroregional level, since the spatial distribution of research products is very concentrated in few hotspots, while the majority of Alpine PAs range from one research record indexed to none at all. At this scale of the analysis, it is difficult to understand what the forces shape the geographical distribution. The only phenomenon that is possible to note is that research on climate change tends to occur more and more often in those National Parks which are usually a historical and geographical entity with a long environmental history. This positive correlation between the historicity of the institution and the number of climate research records may suggest that these places can count on internal factors influencing positively the conduct of research. The most explicate cases are perhaps Stelvio National Park and Gran Paradiso National Park. The former has developed an almost pure cluster of glaciology. When the records are closely analysed, the research cluster shows signs of a structured interest in its approach to the area. Most of the contributions are focused on the Forni Glacier, in the Ortles-Cevedale group, and different methodologies are used for collecting observations. In this regard, the glacier serves as a functioning space for science, where methodologies are tested and new research of potential interest to the Park is generated. However, the scientific dimension of the Park goes beyond serving as a benchmark for validation of scientific methodologies; one of the research records addresses long-time observations (D'Agata et al., 2014), while another deals with the geomorphological consequences of the glacier shrinkage (Smiraglia, Diolaiuti, 2010). The variety of records suggests that this cluster can be regarded as an autonomous research programme completely developed in the PA. In the same light, Gran Paradiso displays another interesting example. The research records associated with the PA are all coming from ecology, as they focus on the potential impact that climate change can exert on the ibex population. The ibex, one of the most charismatic species of the Alpine range, historically finds a home in Gran Paradiso National Park. In particular, how the Gran Paradiso's population served as source population for different operations of reintroduction is widely addressed in the scientific and generalistic literature. Research on the ibex is obviously a core topic in Gran Paradiso, and climate change here finds fertile ground as a topic of study.

From these two examples, and more generally from the distribution highlighted, it appears that – *ceteris paribus* – a long history of scientific research in a PA increases the chances of the rise of new research. Put briefly, research already stored in the PA might have a positive feedback effect on the growth of new research. In particular, the two examples highlights how a core cluster of accumulated research on a topic (that entails strong interest for the PA) might serve, borrowing a term from Conservation Biology's vocabulary, as *keystone research*[11], the presence of which is able to influence strongly the capability of the PAs to inquire into the effects of climate change in their territories and on objects of particular interest for the PA.

However, the second part of the study has led to better understanding of one of the main infrastructures for the co-construction and circulation of research, i.e. the scientific networks. The utility of this approach was twofold. First, it helped to keep track of research records not indexed in WoS core collection. The contributions found through smaller and less known internationally channels, and often not written in English, are obviously to be

[11] Keystone species, in ecology, a species that has a disproportionately large effect on the communities in which it occurs […] derived from the practice of using a wedge-shaped stone to support the top of an arch in a bridge or other construction. Just as other stones in the construction depend on the keystone for support, other species in a biological community depend on the presence of a keystone species to maintain the community's structure (Encyclopaedia Britannica).

considered meaningful and – from a PA's perspective – helpful information, but it is to be noted that the circulation potential of these data is sensibly reduced, in particular, if we are to compare data inter-regionally. Second, highlighting climate change research networks helped the visualization of possible paths that research can travel in the Alpine range. If the first part of the study considered the PAs as islands, where research activities develop independently of one another, the second part of the study showed how this archipelago is actually interconnected, and different islands can cooperate to construct research activities together and exchange standardized data.

Scientific projects in a PA can be autonomous in their development, and the Web of Science dataset analysis showed that smaller PAs can also produce research in this way, even if in reduced amounts in the case of climate change. Nevertheless, the reconstruction of the networks highlights how the involvement in wider geographical entities can foster the developing of the process, and probably counter the effect of previous research accumulation on the rise of new research. However, the networks traced cannot cover the entire Alpine range, since even this particular geography cannot display either a constant density of edges, nor a stable number of links connecting the edges. In particular, the northern part of the central section of the range is evidently disconnected, resulting in a quasi-isolation of the Swiss subregion, with the exception of the research-hub constituted by the Swiss National Park. Additionally, it is clear that many networks do not cover the entire surface of the Alpine Convention. Outside the GLORIA programme, which displays the longest paths through the Alps and crosses the highest number of boundaries, the majority of the edges are organized in sub-regional networks, with a stronger concentration around the border between France and Italy. As a consequence, from a centre-periphery relationship standpoint, the general network is decentralized. The majority of the transboundary networks cross just one border, while two networks operate on a national level. Hence, just one component (GLORIA) of the larger network is truly operating on the macroregional level. The map overviewing the networks is shown in figure 3.10.

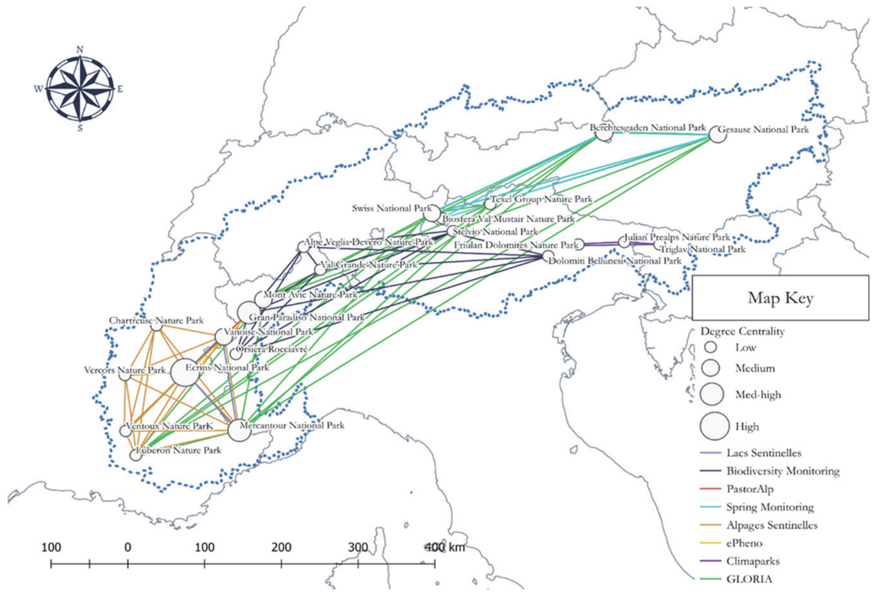

Figure 3.10 - Overview of the research networks

3.6. Venues of science, circulation of research, and scientific cultures

Using once again Livingstone's terminology, different PAs are serving as "venues of science" for climate research. However, it is possible to trace an uneven geography in the distribution of these venues. Just a small part of the PAs' system actively hosts research projects on the topic. At the same time, both the circulation of research products and the design of monitoring networks on the effects of climate change suggest different degrees of involvement in the scientific task.

Crossing the results of the two separate studies on the Web of Science database, an interesting pattern emerges. Research records indexed in the Web of Science show a particular spatial arrangement, based on the primacy of historical National Parks. These parks' footprint is visible on a geographical level – since the distribution of research data source is highly concentrated – but also on a content level.

From an operative point of view, Parks and other PAs represented in the Web of Science dataset serve as repositories of scientific records. The analysis of the data stored helped to chart the association between particular spaces and specific research interests, or, conversely, scientific projects shared by multiple PAs. In particular, the data allows some trends to be visualized:

(I) Study 1 underlines how research conducted in historical National Parks can show traces of a strong thematic coherence, forming research clusters with multiple inner connections between research records. From the ibex focus of the Gran Paradiso, to the accumulation of glaciological studies in the Stelvio, National Parks leave evident traces of their own scientific styles and interests in the general map of climate change research. The case of Stelvio is particularly striking in this regard. The PA has the highest number of Web of Science research records, but its degree of centrality in international networks is very low. As a result, research conducted in the Park is highly recognizable and forms a strong, relatively close, cluster since the records indexed in Web of Science are all focused on glaciological analyses.

(II) On the other end of the spectrum, some National Parks carry out research focused on multiple objects of interest and are part of observations networks working on different ecosystems, species communities or disciplines, as in the case of the Ecrins or the Swiss National Park. In particular, in the case of the Ecrins, the research carried out is indistinguishable on the keywords map, since its terms are shared widely among the dataset, and the co-word analysis cannot help to identify the site-specific cluster, despite the high number of records. The fact is certainly positively correlated with the high degree of inclusion in research networks of the PA, which shows the higher degree centrality in the dataset of the second study. Ecrins conducts research with a different, more thematically open, and collaborative style.

Additionally, the reconstruction of scientific networks highlighted three main factors:

(I) Research indexed in the Web of Science is just a sample of the total population, since research records resulting directly from the operations of networks are often published in non-indexed scientific journals. Whether or not this sample can be considered representative is still to be determined, since the volume of the non-indexed literature cannot be estimated precisely, but should be inquired into in depth. Nevertheless, the grey literature detected clarified a point: PAs associated with highly-specialized research can be conducting projects on different objects of interest as well, but the publication of the results might take place at different stages. The case of Gran Paradiso, for example, can be particularly telling. The Park is involved in other research projects apart from the ibex monitoring displayed by the Web of Science, and its level of degree centrality in the PA network is rather high thanks to the many monitoring projects it is part of. This fact does not diminish the importance of the Park as a hub for research on the ibex and the impact of climate change. On the contrary, of the many research studies carried out so far, the ibex research is the only one published in international journals and circulating worldwide.

(II) From the perspective of the process of making climate change science, the analysis highlighted how research networks act as infrastructure for the widening of research projects toward new PAs. Parks with no research tracks recorded in the database are getting involved in broad programmes and become part of a network where scientific information – in the form of data know-how and shared methodologies of work – can travel from place to place. However, these networks differ from one another in geographical location, scope, size and level of internationality, and only one of them – the GLORIA programme – operates at the scale of the whole macroregion. Additionally, wide sections of the Alps are underrepresented among the edges of the network. Switzerland, as the most evident example, is not included in any monitoring programmes outside the Swiss National Park.

(III) Smaller and more recent Parks do not, on the whole, share the same channels of research diffusion as larger, older and more scientifically affirmed PAs. The circulation of research products does indeed happen through different channels, with different potentials of diffusion.

Research conducted in National Parks is written in English, enjoys global accessibility thanks to the inclusion in wider research databases, and plays the role of the calling card for the entire body of "official" and "grey" literature. The analysis of the scientific network studying climate change in the Alps highlighted how minor PAs, even when involved in climate change research projects, more rarely publish in peer reviewed international journals, and the knowledge they produce frequently circulates only at a sub-regional level. Research studies, it turns out, have different degrees of "mobility" and accessibility.

From a geography of science standpoint, the analysis provides much useful information. National Parks today play the role of science venues, and their traces are detectable quantitively, since they gather the majority of scientific records and form the largest nodes of monitoring networks. Their traces are also visible in the literature, where they form the bulk of indexed research, whether forming very specific research programmes or creating strong networks that contribute to diversifying research. If the first study highlighted the strong, easily identifiable footprint of Stelvio and Gran Paradiso National Parks, the second study highlighted how Ecrins and Swiss National Parks display a different, but equally fundamental, research composition. At the same time, the circulation of climate change knowledge is influenced by the whereabouts of scientific research. More precisely, research conducted within historical, widely recognized PAs enjoys a wider diffusion.

The concept of "scientific culture" can take different forms. It ranges from the selection of particular objects of research interest to the number of scientific connections that a PA has built on the topic of climate change, as well as its capacity to promote its research on a world-wide circulation network such as the Web of Science, or regional network and journals. All these elements are still rather unsystematic, and still do not provide a solid baseline that describes the scientific culture associated with different PAs. In order to do so, these elements have to be verified on the ground with scientists, park managers and practitioners, but they at least provide some insights into how research is conducted and how different social forces shape scientific projects within the boundaries of the PAs.

These results open many new questions. First, on a purely geographical level, what are the reasons behind the spatial distribution of research products and networks? Why do some sub-regions produce more research than others? Why do the networks not extend to some subregions of the Alpine range?

Secondly, attention could be directed towards the grey literature. If we are to overview the complete landscape of climate change research in PAs, what is the role of grey literature in the story? How could this new information change the research landscape previously mapped? What are the factors that prevent research produced in smaller PAs from circulating its results on higher spatial scales? Can we trace pieces of grey literature outside the research networks? Do the contents of grey literature overlap with the Web of Science dataset, or do the two contents differ?

And from an operational, park-centred perspective, is the availability of previous research records or data really a *conditio sine qua non* for the development of climate change research programmes? Can we trace other limiting or favourable factors?

In order to address at least some of these questions, the next chapter will shift the focus to a new geographical scale. The analysis will explore some of the factors that shape research at the sub-regional level. Hence, the case of Switzerland will be studied from a close perspective. Switzerland, as previously highlighted, shows a distinctive geographical pattern of production, since the Swiss National Park is the only PA with a tangible track of research records on the topic. Switzerland will serve as a laboratory in which we can verify how scientific cultures work and come to be shaped. The absence of publications in the Web of Science sample, together with the exclusion from the main monitoring networks suggests starting from the simplest of the questions. Is research on climate change a topic of research that differs in Swiss PAs from research in the National Park?

4. *The making of a scientific subregion: constructing climate change science, conserving nature in Swiss protected areas*

4.1. Protected areas and scientific research in Switzerland

Despite being historically and traditionally associated in common understanding with ideas of respect for the land and care of the country's natural heritage, Switzerland displays a more complex relationship with conservation than one might expect. The history of Swiss contemporary conservation is actually quite recent, since almost all the protected areas were founded in the first decade of the 21st century. The first ideas, however, of setting aside a piece of land in order to spare it from the growth of modernity are traced back to the beginning of the 20th century, when Paul Sarasin led the national conservation movement towards the creation of the Swiss National Park (Kupper, 2014), a groundbreaking event in the history of protected areas worldwide. At that time, protected areas represented a completely new concept for Europe, and the Swiss National Park played the role of the pioneer, paving the way for the proliferation of the concept throughout the continent. However, Switzerland itself did not take part in this growth spurt, leaving the National Park as the only stronghold of nature conservation in the whole country[1]. Things changed dramatically with the revision of the *Nature and Cultural Heritage Act* almost a century later, in 2007 (Galland, 2011). With a much-needed update in legislation, Switzerland opened its doors to the rise of new categories of protected areas: the Regional and National Nature Parks. If the Swiss National Park had stood for more than a century as a temple for science, an open-air laboratory, with its long history of success, inspiration, struggles and malfunctions, these areas were born in response to a different need from that of their famous ancestor and serve as multifunctional spaces, where sustainable local development aims to meet cases of conservation and democratic inclusion. These new Swiss protected areas are

[1] During this century-long timespan, Switzerland did actually see some new forms of protection for particular biotopes or landscapes, from the Federal Inventory of Landscapes and Natural Monument of national importance (1977) to the *Rotothenturm Initiatve*, but did not establish new protected areas, as happened widely in the rest of Europe.

the result of bottom-up processes, where the initial input for the foundation process comes directly from the local population, and the multiplicity of goals is indicative of their complex nature as instruments of regional development. Together with this new form of land protection, Switzerland has seen the creation of ten UNESCO World Heritage sites – three of them natural areas – and the capillary penetration of Ramsar sites and Federal Hunting Reserves. As a result, conservation is today played on an intricate jigsaw of lands and territories, all serving different purposes and varying greatly in size. The total number of Parks and World Heritage natural sites amounts today to twenty, comprising one National Park, *Naturparks* and suburban parks.

The task of inquiring about the role of science in these heterogeneous land units is an intricate one. To find, foster and structure a dimension for science in these land units is the responsibility of a dedicated office in the Swiss Academy of Arts and Science in Bern, the Swiss Park Research, founded by the Federal Office for the Environment (FOEN). As stated in the official website:

> Because of their special status the parks of national importance gain increased importance as reference and preference areas for comparative research of different research topic of national and international interest. Swiss Park Research aims to support the parks of national importance and other protection areas (for example, UNESCO World Heritage Sites) in the field of research and to enable their collaboration on priority themes.

In the office's view, protected areas (henceforth PAs) should act as reference and preference areas for scientific projects. The function of the office itself is to support the development of research programmes and projects in the contexts of the PAs.

The office's work in recent years has resulted in the definition of a thematic catalogue that highlights the main foci of inter and transdisciplinary research to be developed in the parks[2]. Interdisciplinary topics have been proposed, spanning from the parks' identity to landscape development, from ecosystems services and biodiversity to comparative studies with non-parks area, from parks governance to regional and economic development (Wallner, 2012). Under the control of the same office, an online resource has been made available in order to keep track of all the research carried on in the parks, both in recent times (three years or less) and in historical times in the case of the older protected areas like the Swiss National Park. The online resource enables the researcher to enquire about the distribution of research activities in the parks and understand their geography, consisting of historical hotspots, new areas of scientific monitoring and multisite comparative research projects.

[2] Research themes belonging to single disciplines were excluded by the catalogue, not because of lack of need for this kind of scientific interests. Disciplinary research, in fact, is regarded as the basic instrument needed to set up systematic monitoring programs (Wallner, 2012, p. 39).

Table 1 - Research in PAs divided per single PA (column), number (#) of research records and percentage (%) of research produced on the total volume of research records stored in the database. Data from Parkforschung.ch.

Protected Area	*Recent (>3 years) research (#)*	*Recent (>3 years) research (%)*	*Total research (#)*	*Total research (%)*
Regional Nature Park Beverin	3	0.8	10	0.7
Regional Nature Park Binntal	1	0.3	11	0.8
Regional Nature Park Biosfera Val Müstair	39	9.9	90	6.4
Regional Nature Park Chasseral	9	2.3	19	1.4
Regional Nature Park Diemtigtal	4	1.0	17	1.2
Regional Nature Park Doubs	6	1.5	9	0.6
Regional Nature Park Ela	29	7.4	72	5.1
Regional Nature Park Gantrisch	19	4.8	47	3.3
Regional Nature Park Gruyère Pays-d'Enhaut	7	1.8	13	0.9
Regional Nature Park Jura Vaudois	9	2.3	35	2.5
Regional Nature Park Jurapark Aargau	4	1.0	13	0.9
Regional Nature Park Pfyn-Finges	11	2.8	114	8.1
Regional Nature Park Schaffhausen	5	1.3	6	0.4
Regional Nature Park Thal	9	2.3	21	1.5
Swiss Alps Jung-frau-Aletsch UNESCO World Heritage Site	22	5.6	83	5.9
Swiss National Park	135	34.4	553	39.4
Swiss Tectonic Arena Sardona UNESCO World Heritage Site	7	1.8	35	2.5
UNESCO Bio-sphärenreservat Engiadina Val Müstair	6	1.5	10	0.7
UNESCO Biosphere Reserve Entlebuch	24	6.1	146	10.4
Wildnispark Zurich	43	10.9	94	6.7
Total	393	100.0	1403	100.0

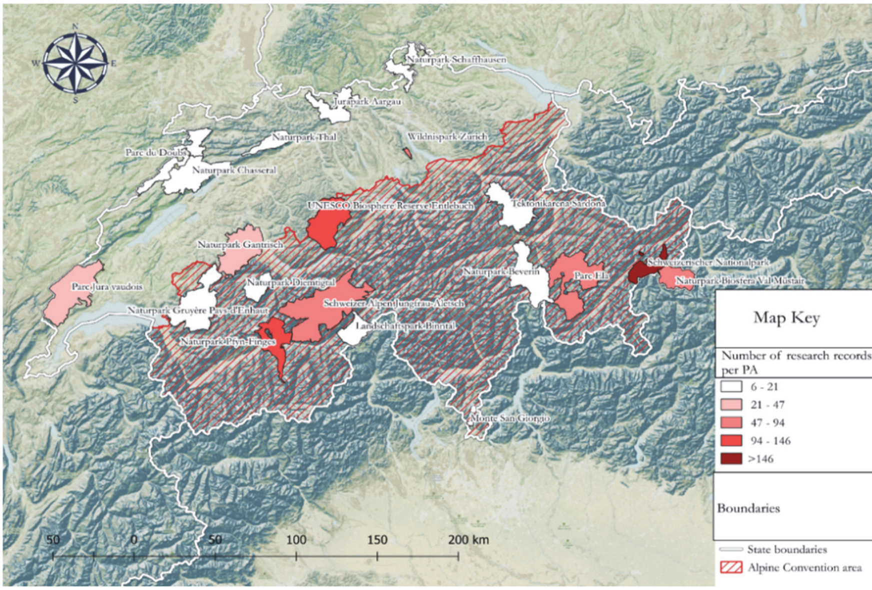

Figure 4.1 - Number of total research records filed in every Park in Switzerland. Data from Parkforschung.ch

From this general overview is possible to understand the degree of scientific activities taking place in the parks. Swiss parks are – to different extents – all involved in scientific research projects and some of them have large archives of stored research. If the Swiss National Park's role as the leading figure (39.4% of the overall volume of research produced in the Swiss parks, 34.4% of new research projects) remains unquestioned, the general research landscape highlights the rise of new protected areas involved in the search for science-based answers to questions regarding the impact, aims and governance of Swiss parks. In particular, the highest concentration of research in these relatively new protected areas is to be found in the UNESCO Biosphere Reserve Entlebuch (n=146, 10.4% of the total amount) and the Regional Nature Park Pfyn-Finges (n=114, 8.1%), while the most scientifically active parks in the last three years are the Wildnispark Zurich (n=43, 10.9%) and Regional Nature Park Biosfera Val Mustair (n=39, 9.9%). Clearly, this kind of online resource, as provided by the Swiss Park Research office, represents an escape from the problem of gray literature and allows us to keep track of every scientific undertaking, regardless of the formal requirements that tools like the Web of Science pose.

Coming back to the principal focus of this work, the task of quantifying the actual volume of climate change research stored in the database reveals an interesting configuration. Regardless of the growth rate of scientific research in Swiss parks, and the high policy-relevance on climate change topics in the Swiss context[3] the question of the impact of climate change on protected areas remains largely unanswered, and significantly, even often unasked. In order to understand the precise spatial distribution of climate research in protected areas, in the present work the database has been mined, looking for terms related to the domain of climate change in titles, abstracts, and descriptions[4] of every park's digital archives in the site. The results are summarized in figures 4.2 and 4.3.

It is apparent that climate change is not part of the core scientific interests of the protected areas, despite the high level of relevance that the scientific topic has gained on a national level[5]: nine of them do not show any sign of climate change research, and six of them display just one inquiry on the topic. By contrast the Swiss National Park and its surroundings – the Naturpark Biosfera Val Mustair and the UNESCO Biosphärenreservat Engiadina Val Mustair – form the main geographical cluster of research, defining a hotspot of research interest in our scientific question that gravitates around the work of the National Park. Breaking down the composition of research by typology, the Swiss National Park's scientific production is almost equally divided between research projects and doctoral dissertations or master degree theses. Interestingly, of the 7 total research studies indexed, 3 are long-term monitoring programmes, the only exponents of this kind present in the whole database, probably the only sources of long climate data series that are a necessary condition in order to inquire about the evolution of climate at the scale of a protected area. Considering the whole protected areas system, there are 14 research projects: 8 masters theses, 3 doctoral dissertations, 2 management oriented projects and 1 bachelor's thesis. Given the particular distribution, it is difficult to make sense of the spatial pattern formed, and outside of the Swiss National Park cluster the data has little informative meaning and does not show definite trends, other than the means of monitoring, in binary fashion, the presence or absence of the topic among the research interests of the single protected area.

[3] Switzerland is particularly well equipped in the fight for mitigation and adaptation to climatic changes throughout society as a whole. For more in depth information on this topic see the Federal strategy for climate change adaptation: https://www.bafu.admin.ch/bafu/de/home/themen/klima/fachinformationen/anpassung-an-den-klimawandel/strategie-des-bundesrates-zur-anpassung-an-den-klimawandel-in-de.html

[4] In particular, the terms used were multilingual. The query of research focused on the terms "climate change", "climate", "klima", "klimawandel", "climat", "environnement", "réchauffement climatique", "clima", "cambiamento climatico".

[5] The relevance of climate science at policy level is best explained by the recent publication (2016) of a report published by the Swiss Academies of Sciences titled "*Coup de projecteur sur le climat Suisse. Etat des lieux et perspectives*".

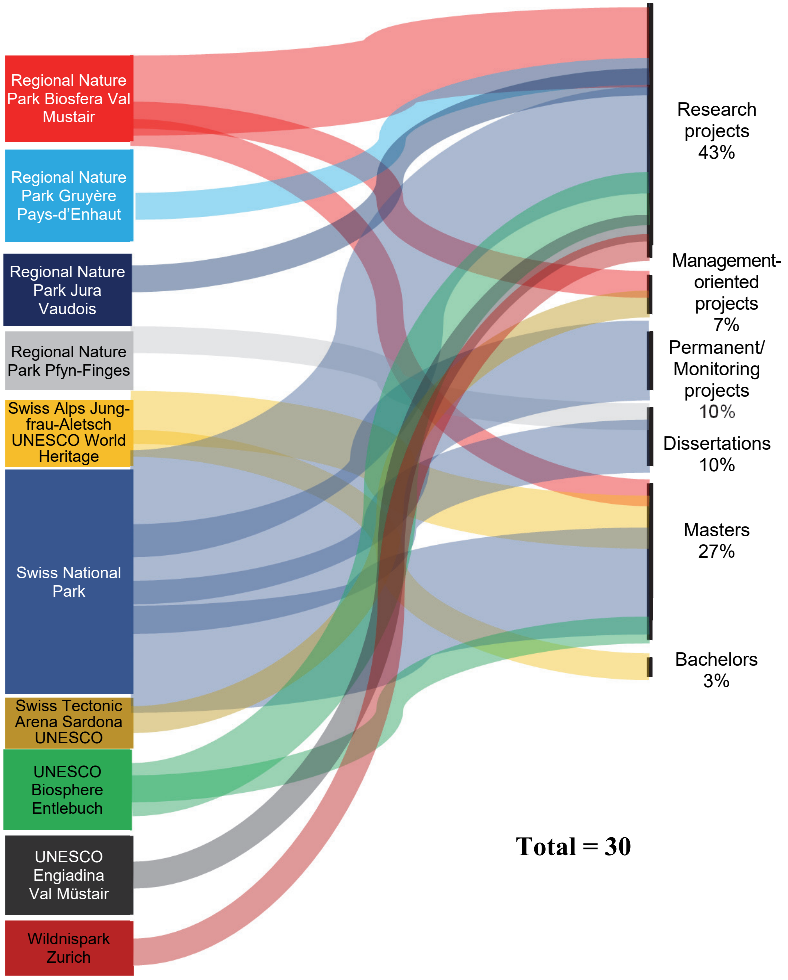

Figure 4.2 - Climate change research in Swiss Parks divided per typology of research (Sankey chart). Data from Parkfoschung.ch. Last update on 08-29-2018

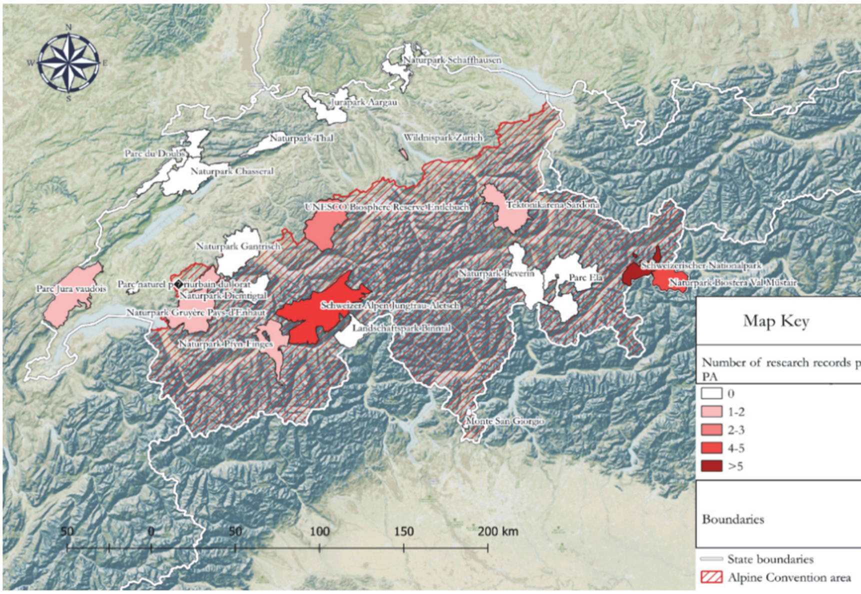

Figure 4.3 - Climate Change research records filed in every PA. Data from Parkforschung.ch

In this context of relative data scarcity, bibliographical and bibliometric analyses lose their explanatory power. As a matter of fact, these kinds of methodology are suitable for the analysis of data and very profitable in conditions of data richness, but the presence of a large body of information is the only sufficient and satisfactory condition to engage a problem with this framework. The methods employed so far are not fitted to carry the inquiry any further if we are to understand what the reasons, drivers, and constraints are of this particular geography of science. For this reason, the focus of the entire discussion shifts at this point from the products of science – counting and mapping articles and research projects – to the process of making science, speaking directly with the people involved in research and conservation projects, in order to understand which dynamics are involved in the making of scientific research, and how climate change is catching the interest.

4.2. The epistemic community and the structure of experts interviews

In order to shed light on this particular situation, a set of semi-structured interviews was organized between January and June 2018. The research design was informed by the notion of "epistemic community" defined as a "*group of professionals, often from a variety of different disciplines, which produce policy-relevant knowledge about complex technical issues*" (Haas, 1992, p. 16). This framework is intended not only as a way to overcome data scarcity but also as a means to understand how policy and management relevant knowledge is formed and interacts with members of the community. The notion of "epistemic community" is usually employed in the fields of science and technology studies (STS) and political ecology as a key to understanding how environmental information is formed and how it flows from science to policy domains, often highlighting how the naïve vision of a science straightforwardly informing policy cannot be empirically verified, and suggesting models of co-construction of both science and policy in the process of knowledge production (Kamelarczyk, Smith-Hall, 2014). Epistemic communities allow research in the geography of science to analyse not only the inner dynamics of the research community but also the relationship of the scientific communities with other groups of stakeholders.

If "*ideas would be sterile without carriers*" (Haas, 1992, p. 27), then policies, management measures, and scientific research – or the lack thereof – can be better understood in their complexity through adopting a variety of different actors' standpoints. This claim proves especially true in the case of conservation, where communities are formed by an assemblage of scientists, practitioners, managers, and policymakers (Lorimer, 2015). At this scale of observation, and with the contextual absence of a strong macroregional environmental policy regulating research and adaptation to climate change in protected areas, it is very difficult to understand how information flows between the domain of science and that of policy at a national scale, or lower. Despite this fact, protected areas still maintain their dimension of boundary objects, "*able to bound together local needs and national or international dimensions, as well as different social actors"* (Kamelarczyk, Smith-Hall, 2014, p. 21). A population belonging to different social worlds inhabits these objects, as scientists, local managers, and practitioners form a community that cannot be defined as strictly scientific, nor administrative, but are widely considered epistemic, as they share a substantial set of beliefs about the role of science as an informative force for the management of protected areas. As anticipated in chapter 2, parks and PAs can be understood as trading zones where the conservation community intercepts and reworks concepts coming from a different scientific and political community, namely the community of climate and climate change study and management.

Talking about an epistemic community is an efficient way of synthesizing the heterogeneity and making sense of the different worldviews that actors might present. However, it is worth noting that this label does not shed light on the actual dynamics that animate the community. As already highlighted by Patrick Kupper in his reconstruction of the birth and development of the Swiss National Park, the history of conservation cannot be analysed from a perspective of a pure history of scientific ideas, or, conversely, a material history made by different institutions working their way into the definition of the field of conservation as we know it today. Hence, the history of the Swiss National Park is analysed by Kupper as the history of the development of a network of different actors: from conservationists and park managers to scientists, from wardens to community leaders and journalists. The complexity of the landscape is even higher in Kupper's account, because of the necessity of taking account of the non-human actors as well: animals with their movement and their agency played a determinant role in the definition of the Park's history[6]. Moreover, scientific ideas were also an integral part of the network: the overarching idea of equilibrium ecology served both as a scientific framework and a target for the development of nature in the Park's grand project.

The same arguments hold true in contemporary conservation. Conservation as a social undertaking can be understood only by acknowledging the great diversity of human and nonhuman actors involved in the process. The discourse perpetrated by American nature journalists, as seen in section 2.4, touches scientists and conservationists, colliding ideas of a fixed and ever-changing nature, the relationship between scientists and non-scientists, the role and behaviour of much-valued species in response to climatic changes, and is filtered through the lens of trained storytellers that become part of this network by promoting certain meanings and messages with their own writings, inside and outside the epistemic community. Hence, the goal of the following sections will be to analyse the constitutive components of the scientific discourse and its interaction with the management domains, starting from the particular geography of scientific information sources.

With the purpose of pursuing these goals, interviewees were partly selected with the help of two experts on the topic of research in protected areas in the Swiss Academy of Natural Science (ScNat) and then joined lately by other experts suggested by the first initial group, in a *snowball* selection process. For the task of analysing the data, the whole body of interviews was divided into four groups (table 2): scientists currently (or in the recent past) conducting a research project on climate change in protected areas (1), research coordinators or members of a research council (2), conservationists or

[6] Kupper shows how some of the main struggles in the management of the park were caused by maintenance of the boundaries. Boundaries might have been an effective tool in order to realize the utopic "boundary object", keeping out poachers and adverse land uses, but their effectiveness did not apply perfectly to animals. It was the biopolitics implied in deciding which species should live inside the boundaries and which outside, and the maintaining of this order, that created trouble for the Park. The author stretches the importance of the role played by some charismatic species, especially the Ibex. The Ibex, absent at the beginning on the land of the park, was at the centre of different attempt to establish a population in the protected area. The attempts made were not always successful, because the ability of the ibex communities to move and chose their *umwelt* undermined the effors made by managers and scientists to create spaces where they could live and thrive (Kupper, 2014).

administrative managers (3), and external social or natural scientists with particular perspective and expertise on the issue addressed (4).

Table 2 - Interviewees divided by name, group, function carried, area of expertise and institution

Name	Group	Function	Area of expertise	Organization
Laudo Albrecht	3	Conservationist	PA's administration	ProNatura
Bruno Baur	1	Scientist directly involved in climate change research	Ecology	University of Basel
Alice Brambilla	1	Scientist directly involved in climate change research	Ecology	University of Zurich
Matthias Buergi	4	Expert on wider topics connected to climate change	Landscape Ecology	WSL
Thomas Hammer	1	Scientist directly involved in climate change research	Geography	University of Bern
Felix Kienast	4	Expert on wider topics connected to climate change	Landscape Ecology	WSL
Florian Knaus	2	Research coordinator	Research coordination	UNESCO Biosphere Entlebuch
Christoph Kull	4	Expert on wider topics connected to climate change	Climatology	ProClim
Patrick Kupper	4	Expert on wider topics connected to climate change	Environmental History	University of Innsbruck
Thomas Scheurer	2	Member of research council	Research coordination	Iscar, Swiss National Park
Stefanie Von Fumetti	1	Scientist directly involved in climate change research	Ecology	University of Basel

The interviews were designed and carried out between January 2018 and September 2018. Given the diversity of the expertise involved in the interviews, the topic addressed changed slightly from one interview to another, in order to cover the majority of topics related to the issue of climate change in protected areas. Because of the heterogeneity of the topics discussed during the interviews, the data have been aggregated in several sections. The first section is exclusively dedicated to the analysis of climate research in the Swiss National Park, taken as an example of how a geographical hotspot of research can be generated. The following section describes the main obstacles toward a development of a research focus on climate change, aggregates all the opinions and perspective on the particular distribution of research projects, historical research studies, and monitoring initiatives, and is divided into two subdomains. The first will address obstacles lying at the interface between science and management that impede the development of research projects, while the second will focus on the purely scientific factors that slow down research. A third section will analyse possible ways of fostering climate change research, starting from the capability of international research projects to boost the economic and scientific interest around climate change inquiry. Finally, the last part of the analysis will consider the main reasons why some highly common climate change research topics in the field of climate research are not found in the research agendas of the PAs and why they have potential to become new catalysts for scientific interest in Swiss PAs. The final section will summarize the data and highlight some of the main features of the geographical scientific region emerging from the representation given by the community members.

4.3. Unpacking the cluster: the Swiss National Park as a scientific hub for climate change monitoring

It is probably counter-intuitive to start with the exception to the general rule in order to analyse the factors shaping the particular geographical distribution, but the isolation of the different factors allowing the Swiss National Park to evade the trend is probably the most effective way to make sense of the whole body of qualitative data gathered through the interviews, as well as to understand the effects that the absence of these factors plays elsewhere in the country. The PA historically displays its own distinct research concept, which makes the Park, on an international level, one of a kind. As already noted in the previous chapters, the Swiss National Park is first and foremost a space – and actually a place – for science. The primacy of scientific research allows the National Park to be an ideal context in which to study the full development of climate change effects, not just in relation to a particular ecosystem, species or disturbance but covering the entire spectrum of the possible changes that ecosystems might face in consequence of climatic alterations. Climate change is not a threat for the park, but rather an occasion to study climate change ecological dynamics in a secluded environment. In Thomas Scheurer's words:

> The SNP offers the best opportunities to study climate change effects, as natural processes are not influenced or managed in the Park. In this regard, climate change is a "neutral" external driver of natural processes and "observed" by research. Strict protection as an ideal laboratory! In this perspective, climate change does not affect conservation. If species are extinct in the Park due to climate change, this has to be accepted, if new species migrate into the Park, this has to be accepted (Scheurer).

In the Swiss National Park, the scientific and the management perspectives merge into one another. Science is not an instrument but the goal of the entire conservation paradigm. The dimension of the open-air laboratory, an evergreen metaphor that describes the Park from its foundation, is playing again, more than one hundred years later, a fundamental role. However, as pointed out by environmental historian Patrick Kupper, the fundamental scientific conception of nature has changed and is more open-ended, embracing more tightly the sometimes-unforeseeable effects of climate change:

> Two weeks ago I took part in a radio interview [and was asked] about how climate change affects protected areas and the management policies of National Parks in particular. My answer is that it depends on what you are protecting, what are your goals. If the goal is always protecting natural processes, and that is indeed what they did in SNP from the beginning, there are no substantial changes. What changed really is the idea of a natural equilibrium that was the original target of the Park. Basically now they still want to understand processes while not disturbed by humans, but it is a more open-ended process. In the past [in the case of SNP], scientists got kind of frustrated because nothing happened: changes were so slow they needed years and years and years just to actually see small shifts. Probably with climate change it will be faster (Kupper).

The very distinctive research and management concept of the National Park represents an ideal setting for monitoring the effects of climate change, without any possible interfering interest other than science:

> It is possible that a political discussion can lead to management measures, if surroundings or infrastructures are threatened, e.g. regarding natural forest fire or debris flows (Scheurer).

Even if the primacy of science came to know some forms of constraint in the past, and could face some more of them in the future, the special attention given to science by the Park's administration allows the flourishing of different climate change monitoring initiatives. In this context, different scientific disciplines, untied from any administrative constraints, frequently find interest in observing the unraveling of climate change and its effects on the ecosystems.

> Climate change issues are at the top of relevance, together with the evolution of wildlife. Most of the disciplines work on topics related to climate change. Research provides a large range of facts concerning effects of climate change. Most of the research profits from earlier studies, like resurvey studies on snakes, butterflies, macroinvertebrates, summit plants, millipedes, etc. On the other hand, there is no concerted research programme on climate change effects in the Park and its ecosystems (Scheurer).

It is of capital importance to highlight the fact that the deep historical roots of the parks have a direct and positive influence on the possibilities of inquiry. In fact, in virtue of the abundance of historical scientific observations, the National Park is in a position to study climate change effectively with a methodology that would be unsuitable anywhere else, namely, the repetition of earlier surveys on the distribution of plants and animals. These kinds of study, focusing on mapping range shifts or contractions, have been extensively used in scientific literature to assess the impact of climate change on ecosystems' species composition (Parmesan, 2006), and the possibility of repeating them in a context undisturbed by human activities – a condition that enables the researcher to exclude other independent variables from the observation.

> There are many studies that document an effect of climate change on specific habitats or species. Most of such research projects are related to long-term monitoring and research or resurvey of old data samplings (Scheurer).

The practice of resurvey of old data samplings sheds light on one of the main scientific needs in climate change research, namely, historical data series. The availability of previous observations can play a strong role in shaping the geography of scientific inquiries by allowing comparative practices. These kinds of consideration will be further developed in the next sections.

Another important enabling factor is the internationality of research monitoring undertakings. From an international cooperation standpoint, the Swiss National Park signals substantial involvement in a wider network of research, reunited around particular objects of observation. The PA is, in fact, a fundamental part of wide international monitoring networks focusing on climate change's effects, as in the case of the GLORIA programme, and GLOCHAMOST. Additionally, interviewees highlight that the park is in contact with other, smaller regional geographical networks of ecologic monitoring, such as *Lacs sentinelles* or *Spring Monitoring*[7] and is an integral part of wildlife monitoring programmes that can be instrumental in climate change impacts assessments. However, when asked about the centrality of the role that will be played in the near future by the international network in the creation of scientific interest in climate change, Thomas Scheurer raised a significative consideration:

> Such projects have to be designed in a way they can initiate research, as GLORIA. In the SNP a couple of projects are related to the GLORIA approach, focusing on different aspects that are not covered by GLORIA, as thermal variations, decomposition of organic materials, etc. (Scheurer).

The mere embeddedness of a PA in a wider network does not constitute a necessary and satisfactory condition. In order to develop scientific interest around the topic of climate change, these wide projects must stimulate new research, able to undertake related phenomena and gain impetus from the original research project. This claim resonates with the wider hypothesis described in chapter 3 on *umbrella researches* and their role in the promotion of climate change research projects. The context of the SNP obviously represents a very fertile ground for the multiplication of research on the topic since the entire National Park is devoted to scientific inquiry and there is no substantial obstacle or higher priority to follow. However, despite the growth in scientific projects aiming at observing some effects of the changing climate, there is no sign yet of a concerted research programme about climate change.

4.4. The boundaries of climate change research

4.4.1. Some obstacles at the science-management interface

Starting from the first concrete evidence gathered in the data analysis, the question of the scarcity of records of climate change research is obviously central. The low density of data has to be explained by considering the parks' attitude towards the increase in climate change phenomena. With the notable

[7] As remarked in chapter 3, this research network is not operating yet, but it is uniting researchers and scientific materials from different geographical realities as a starting point.

exception of the Swiss National Park, interviewees agreed with the claim that Swiss PAs tend to be reactive rather than proactive in their behaviour towards climate change monitoring, since projects on climate monitoring are still to be developed. From the analysis of the few data available, a hypothesis has been expressed. If climate change does not alter – or at least threaten to do so – some of the conservation objects or goals of the single PA or meet the interests of a particular research concept, a dedicated research focus is not taken into consideration. The latter claim, already analysed, is best described by the case of the Swiss National Park. Conversely, the first hypothesis could be helpful in explaining the particular geographical pattern outside the cluster centred around the National Park. Whenever a particular object of interest for a PA could be endangered by climatic changes, scientific interest can be triggered. The case of ProNatura's reserve of the Aletsch epitomizes this distinctive attitude. This well-known NGO is the most important non-governmental actor involved in nature conservation and is the owner of 700 reserves nationwide (https://www.pronatura.ch/fr/decouvrir-des-reserves-naturelles) as well as hosting visitors in two centres set up for the purpose of nurturing environmental awareness. The NGO's entire mission is directed around the need to conserve nature and integrate governmental efforts to increase the total surface of protected areas. Narrowing the focus on one of its reserves, the case of the Aletschwald poses an interesting perspective for testing the centrality of climate change considerations in conservation discourse. This area, which is a part of the bigger "Aletscharena", hosts one of the two visitor centres managed by the organization, and, given its geographical position, holds a favoured view of one of the most dramatic and best known cases of glacial retreat, that of the longest glacier of the Alpine range, the Aletsch. Moreover, the NGO manages the neighbouring forest, the Aletschwald, home of some of the oldest trees in Switzerland, all of the microthermal species *Pinus cembra*. The small region is full of natural elements potentially touched by climate change, also in a harmful way. In order to understand what degree of centrality climate change has in the mind of the administration, an interview with the director of the local ProNatura Centre of Villa Cassel, Laudo Albrecht, was set in place.

In his own words:

> We cannot say we have precise observations or scientific results of changing because of climate change (Albrecht).

Nevertheless, Albrecht claims to have at least some empirical observations – not scientific evidence coming from structured research programmes – about changes in some of the distinctive aspects of the area:

We have the Black Grouse (Tetrao tetrix) and Rock Ptarmigan (Lagopus mutus) which are here in this region. We can observe the tendency of the Tetrao of going higher, and also the Lagopus mutus is going higher. Then you have here the Great Aletsch Glacier, and here we have the end [of the glacier] but in 1860 the end of the glacier was here [points to a higher spot on the map]. So you can see the glacier receding. This is normal, but the speed of the retreat is something new, and it is getting faster and faster. We think this is a very good evidence of climatic changes. This is one thing. And then the other thing you see is a growing problem of stability [of the slopes]. On this side, you can see the glacier and on the other the Aletschwald. The glacier is retreating and so the slopes became unstable, so you have landslides. In 2016, two years ago, we saw in this region a faster retreat: 80 cm per day. This retreat will have consequences on the whole landscape and on the PA. We think this is also related to climate change. With the retreating of the glacier, the slopes became unstable. We had to install sustaining structures against the instability of the slopes to protect our own structures. I think this installation and the retreat of the glacier are the most visible signs of climate change (Albrecht).

The empirical observations listed by Albrecht extend to many topics widely addressed in the scientific literature: from glacial retreats and related slopes' instability to species' range shift. Nevertheless, when asked about the capacity and the willingness of the PA actively to face these changes, in particular regarding the possible changing in the species' composition of the prized forest, Albrecht analysed the threats posed by climate change at the moment as follows:

I do not think we are going to see significant changes in the next twenty-thirty years. Not only the temperature is important, but also how much snow and rain you have in the summer, how long is the winter, all the factors that are important for the trees, not only temperature. Normally we can see when you have risings in temperatures – three degrees or five as extreme temperatures – I think that we will have influences on the trees. Perhaps we will have more Picea, but Arolla pine and Larix decidua will stay here. In the higher zones we do not have many trees at the moment, but probably forest will rise higher. But again, no scientific results, it is just a guess (Albrecht).

Climate change is not perceived as a possible threat to species composition in a mid-term future. The arrival of new species – or at least the population growth of some species different from the most valued ones – is not seen as a real threat either for the ecology or for the iconicity of the forest. Moreover, when asked about the possibility of an investigation on the changing of the populations in the forest, the interviewee responded as follows:

> We have some scientific material concerning the forest. This forest is 2000 m above sea level and processes are happening very slowly. Every 20 or 30 years we make an inventory, counting the trees. But this time span is almost irrelevant for such a forest, which is thousands of years old. It needs a very long time to see changes (Albrecht).

In other words, changes are expected, but the pace will be slow. It is safe to assume that changes in the species composition do not constitute at the moment a threat for the PA, since they are not showing direct influence on the valued species, but just minor effects on some population dynamics.

> Not concerning the diversity of the species, not at the moment. When you speak with experts, probably they will be focused on the future scenarios and might have some concerns. It would be normal that with higher temperatures you can have new plants coming in the areas, but we have no evidence now. […] We can see changes, but not related to climate change. I can't say there are no changes [due to climate change], but we just cannot see them right now (Albrecht).

In such conditions, the possibility of having an effective policy can easily be perceived as problematic.

> It is impossible to have one, we do not know what is coming. We must observe the development and then decide at the moment (Albrecht).

In addition, a set of questions regarding tourist behaviour regarding the effects of climate change and the environmental education activities organized by the PA was addressed. The final goal was twofold. The first aim was to understand how much the physical and ecological dynamics triggered by climate change are perceived and known by the general public visiting the PA, and secondly, this topic was instrumental in understanding the PA's degree of investment in the topic of climate change on an educational level.

> It is very difficult to say because we do not have any study on tourist behaviour. I cannot say precisely why they are coming to visit the region. We have – and I cannot claim to be scientific – the impression that there are a lot of people coming to see the Aletsch glacier while it is still here. I think visitors are generally more aware of nature protection. However, when I look at the whole region called "Aletsch Arena", then I do not think climate change is an important reason for interest in the region. The people coming to visit us [the ProNatura Centre] are more aware; perhaps these events are making other people more sensitive to climate change and the things which can happen, but I do not think they are already. When we have people here, we have many school classes coming to camps. They stay from Monday to Friday, with guided excursions: for example,

> when we have excursions on the Aletsch Glacier we have discussions about climate change and how can we see climate change through the glacier, what are the reasons of climate change and so on, but people in the neighbouring villages are just coming for holidays. This is not something you discuss during holidays. For the people who are coming to our centre, we have discussions aimed to make them more aware of the problem. But we only have a small part of the visitors of the Aletsch Arena. In addition, our tours are not just focused on climate change, but also on the natural beauty of the region in general (Albrecht).

From the evidence gathered by this point, it is legitimate to see climate change as a problem lurking in the background, very present in science communication programmes and currently at the centre of attention from the PA's administration, but for some scientific and management reasons scientific research aimed at gathering evidence of changes and forecasting future scenarios as a guideline for managing the PAs is not taking place. The purely scientific reasons will be addressed in the next section, focused on groups 1 and 2 of interviewees. From a management standpoint, the topic is complex, but as a first hypothesis, it is possible to state that climate change is not scientifically analysed here because it does not directly touch any object of strict interest for the PA. In this case, the PA's protection responsibilities are centred around the forest, and do not comprise the glacier. The main goal at this point is to find examples of damage or substantial change to some core conservation interest of one PA that can act as the spark that ignites interest toward the topic. The problem of the landslides might be an ideal entry point for scientific research in the area of the Aletschwald, but the hypothesis cannot be tested empirically.

An interesting benchmark to test this hypothesis is the research project on moorlands and climate change (*Moorhabitate der UNESCO Biosphäre Entlebuch im Wandel des Klimas*) developed in the UNESCO biosphere reserve Entlebuch, which is able to shed light on the great complexity lying behind this simple relationship. Moorlands are at the centre of different research and management initiatives at the European scale, both for ecological reasons and the carbon sink functions they can perform[8], but are also climate-sensitive ecosystems. On a Swiss scale, moorlands are constitutionally protected ecosystems, defining a unicum in Europe and the Entlebuch represents the territorial unit hosting the highest number of moorlands in the whole

[8] The Moorlands Indicators of Climate Change Initiative (MICCI) is probably the best example of the role played by such habitats in climate change research and environmental discourse creation (www.nationalparks.gov.uk/students/micci-project). The project, UK-wide, has been developed to give secondary school students the opportunity to take part in real world climate science, and is based on National Parks as monitoring sites. It was used as a benchmark during the interviews addressing the moorlands as the centre of discussion.

country, with a surface of almost 2000 Ha[9] As a matter of fact, moorlands are rare and valued ecosystems that might be an ideal candidate as an attention catalyst around the topic of climate change, and – coherently with the hypothesis – are at the centre of a research initiative.

The research project is led by Thomas Hammer, professor of Geography at the University of Bern, and has resulted in a publication not indexed in the Web of Science. When asked about the main features of the Swiss moorlands, and especially Entlebuch's, Hammer described a scientific and managerial situation slightly different from the one that might be envisioned following the lines drawn by the international discourse:

> Climate change will harm those residual landscapes that are very peripheral and not quite as iconic as Scottish moorlands or German moorlands. They have a value as near natural–cultural landscape, but they are really small in size and do not count as an important carbon sink. These are residual landscapes, since 90% of them are gone, and are conserved most of all for aesthetic and ecological reasons. Only a part of moorland landscape is made by high mires, that are important records of environmental change. In relation to climate change, they will be affected in their ecological equilibrium (Hammer).

It is apparent that the international discourse on moorlands as carbon sinks has no gravitational pull on Swiss moorland conservation, which does not align with the more famous examples of Scotland or Germany. The local conservation of moorland habitats follows its own path[10] and has its own distinctive rationale. Nevertheless, the ecosystem is highly valued and the threats posed by climate change have become a matter of research concern. Despite this fact, Hammer reports the substantial lack of cooperation between science and policy in relation to the topic of the effects that climate change might have on the conservation status of the moorlands, suggesting their lack of iconic dimension and geographical extension as possible explanations:

> There is no general discourse around the moorlands, despite their status of protection. I am surprised too since they are nationally protected. There is no important discussion going on, either in science or in society. It is a surprising thing. The high mires are few and small in size, while the flat mires are more extensive, but without the same value. Probably their extension and rarity,

[9] The source of information regarding the total surface of protected moorlands is the official website of the UNESCO biosphere: http://www.biosphaere.ch/de/natur-landschaft/moore.

[10] Moorlands conservation in Switzerland is a practice deeply rooted in history, starting from the Rothenthurm Initiative, a legal framework created to protect the upland moor of Rothenthurm and also other moors scattered through the whole country. This moorland area provides a habitat for many species that are threatened with extinction.

combined with their low iconic value, make them neglected in some way. Of course, we have the Alps as a categorical landscape. I think we have no perception that this typical landscape exists in Switzerland. The Alps are extensive and always in the centre of the discussion about the landscape. We are far from the situation of Germany or Scotland, where moorlands are recognized as beautiful and iconic landscapes (Hammer).

It appears that moorlands have the capacity of summoning scientific interest around their potential changes in response to climate change, but due to a fundamental lack of iconic value, neither science nor society are particularly keen on a close analysis; hence the topic is prevented from becoming the centre of a robust scientific effort.

In order to understand better the research and management dynamics underlying the lack of a stronger interest, an additional interview was set up, this time with the coordinator of research in the UNESCO Biosphere Entlebuch, Florian Knaus. The topic of the moorlands was addressed alongside more general considerations on the management constraints that limit the development of research on the wide topic of climate change. On the situation involving moorlands, he helped to explain some of the issues raised by Hammer, and listed some of the main obstacles management has to face in order to realize effective monitoring programmes. Regarding the topic of climate change, the discussion was rooted in the substantial absence of climate change in the monitoring system:

> It is not a topic that has been much investigated. There was an additional [in respect to Hammer's research] student research on climate change and wetlands, but it was something really small. […] We are trying to make the monitoring initiatives more systematic. We have not really included monitoring aspects specifically related to climate change, but we have two climate stations here in the Entlebuch. We are collecting data also from the river, so we could have data on the runoff. But that is it. We would be generally interested, but it is a matter of finances whether and how climate change could be monitored by us (Knaus).

The allocation of scarce economic resources is obviously a matter of urgency in the need for investment, and at the moment the Biosphere has no particular need for this kind of inquiry in order to strengthen decision making related to climate change.

> Entlebuch is a region with extremely high precipitation. Let's say that if the temperature goes a little bit up and rainfall goes a little bit down, this is not particularly bad. It is a region with extremes. If precipitations during the summer decrease – and this is what is expected – that does not have an extreme effect in terms of how the landscape will change […] We had bigger issues with landslides

from heavy precipitation for example. If this increases, it would be more problematic, that would make us think more about climate change. Precipitation in summer and higher temperatures are not a problem. One topic that was particularly popular was linked with bark beetle infestations in summers, but it is not so much of a topic any more. Forest management has to change in a way that is more efficient and relies more on tree species that are not affected by bark beetles. This has already been implemented starting about 10 years ago (Knaus).

The geography and climatic envelope of the Entlebuch make the area resistant to possible changes, and no adaptation strategy is needed. Hence, it is plausible for efforts and resources to be directed towards different scientific projects. Nevertheless, the question regarding moorlands is still extant at this point, given their special status of protection and potential for climate-driven changes.

> Something we are not sure of is how peatlands are influenced by climate change. We have seen in extreme dry summers of the past few years that they are dry and there might be changes, but we don't know how, we don't have monitoring there.[11] Generally, we can say it is not a huge issue yet, but it can be problematic if peatlands run dry in summer, there might be additional CO_2 issues (Knaus).

At this point we can already understand more clearly why the effects of climate change on moorlands are not addressed by other research projects: the effects of climate on the moorland ecosystem are still uncertain. It is clear that a situation of relative ignorance on some ecological processes will be seen from a PA as an opportunity of scientific inquiry, but this might be undertaken only if based on monitoring systems. Hence, it is now necessary to update the original hypothesis. PAs start research projects on climate change if the phenomenon already influences some of its core conservation objects and the PA has the capabilities to monitor climatic and ecological evolutions over time.

Addressing the question of the possible problems that the future climate might hold for moorland conservation and carbon sink properties, Knaus aligned himself with the general international discourse surrounding moorlands, acknowledging the possibility of changes in the carbon retention capacity. In addition, and on a very practical level, he cites the Entlebuch's natural heritage feature and its connections to some works by external institutions that might prove useful in addressing future issues. In a way, this can be regarded as a testament of the management and research sectors' awareness of the latent potential of climate change phenomena:

[11] In a first follow-up, Knaus states that a Master Thesis was bound to be completed on the topic by the end of the year 2019. In 2020, in another follow-up communication, Knaus tells about the setting of a long term monitoring schemes of the Entlebuch's raised bogs.

We do not have the only cluster but we have a specially high density of peatlands and this is just a fraction of the original distribution. What we know is that 80% of the intact raised bogs of Switzerland are in our region. We have not yet approached the theme of the CO_2 sequestration, i.e. how much CO_2 is sequestered in peatlands in the biosphere reserve. There is a woman in charge at WSL who is working on standards to calculate carbon balance for restoration projects and cooperate with a compensation company. They set a standard in which they calculate how much money to invest in restoration. We are in contact with them. We have plans to put the question in place. When you do a restoration and climate change is starting to be more severe, even more than expected, in summers when the overall precipitation is lower than the mean, it could be a problem to keep this vegetation in place (Knaus).

In the end, with regard to the possibility of bringing together the international discourse around climate change adaptation and mitigation and the local needs of the PA, Knaus raised an interesting observation.

These peatlands are 80% or 90% privately owned. If climate change exerts such pressure that there are real money allocations towards CO_2 sequestration – these peatlands are carbon sinks – and we find a mechanism to allocate money to the people who own the lands, there will be a chance. I think that there is potential to bring these two levels closer. Here [points at the map] the greenish and yellowish parts are areas where the land is used, but it is a nature conservation kind of use, sustained with subsidies. In that case, the land still has a value for them. The blueprint is here, but it is not related at the moment to any CO_2 sequestration initiative. There is a good chance these [CO_2 sequestration initiatives] will have an influence on land use in the future, but not at all at the moment because currently there are no CO_2-payment-schemes (Knaus).

This claim reveals the complexity of the relationships between science and management. Noting the lack of climate change research among the most common research topics in Swiss protected areas is unavoidably linked with the absence of management actions undertaking adaptation to climate change at the PA level. The relative lack of research projects is matched by an absence at the policy level, identified with the contingency of the lack of CO_2 payment schemes, and this impedes, in turn, the presence of management actions or guidelines for action. The interest around a particular topic might take different forms, from political to scientific, but its different manifestations are seldom to be taken independently. Whereas the parallelism might be self-evident, the difficult task is to understand the mechanism of influence between the two spheres. It is true that the presence of a scheme of payment for CO_2 sequestration services might have triggered scientific interest around the topic and in turn on moorlands ecosystems, but it is also true that an opposite mechanism might be realistic, where the birth of scientific interest could lead to new understandings that inform policy and management, triggering interest in different domains than science. It is a very demanding task to understand the main direction of the influence between these spheres, but it is nonetheless important to note their strict intertwining and the feedback mechanisms underlying this relationship.

Following the same line of inquiry, the discussion was taken from the particular to the general, searching for other possible explanations or integrations to the original hypothesis. Agreeing on the validity of the initial hypothesis, Knaus added some remarks on the concrete possibility of intervening effectively by the PA as an important factor in the scientific and management attitude:

> It is also to consider the concrete possibility of doing something about it [a hypothetical change]. The Aletsch glacier is retreating anyway, there is nothing you can do. But if you have species conservation problems or problems with the trails where people cannot walk any more, then you start being active. For instance, we have references to climate change in our research concept, but we have just never done anything specifically to research it (Knaus).

The possibility of materially doing something in response to changes is seen as a determinant factor in the formation of interest from the point of view of the management and, consequently, in potential scientific inquiries. Moreover, in the case of the Entlebuch's moorlands, Knaus highlights again that even the research projects already undertaken have struggled to find definite answers. Hence, possible management interventions are left without guidance.

> It is true that there is a gap. We have been approached a few times from people wanting to do something about climate change, like projects on how potentially peatlands can change when climate change stresses them. This is something you can ask yourself, but nobody has an answer. Thomas Hammer's group of students, in the end, had to ask an expert who had no answer to give. I find it interesting because the only thing you can really do is adaptation. Of course, we can contribute by conserving our peatlands, but this is something we already want to do [independently from climate change] and we have side effects of helping a bit with CO_2 sequestration, but you know, these few hectares won't save the world. From a conservation point of view, the only thing you can do is approach it intergenerationally. You restore the peatlands and you make sure you have done what you could have done (Knaus).

These insider's perspectives on the problem of monitoring and addressing climate change issues in PAs effectively portray the main issues that are preventing the formation of a strong interest from the management domain. Climate change might be seen as a difficult research field for protected areas for reasons of conflicting interest in other topics, perceived as more urgent. This might change only if the alteration of some climatic parameters shows direct influence on an object – a species, biotope, ecosystem or landmark – that is part of the core conservation interests of the PA. However, the detection of these kinds of ecological or biophysical transformations can be far from granted, especially in the absence of monitoring structures and programmes. Even if fulfilling all these pragmatic constraints, the actual possibility of intervening and influencing the phenomenon under consideration plays a role, as some PAs may allocate funds and workforce elsewhere, especially to research projects capable of actively informing conservation practices.

These issues might be related to the broader communication struggle that climate science faces in effectively translating some of its main scientific perspectives and instruments to the policy and management spheres. To verify the central hypothesis and its relatedness with more general trends, a discussion with ProClim's deputy director Christoph Kull[12] was set in place. As first, Kull pointed to a fundamental issue: Parks and PAs, in general, are heterogeneous objects, with different goals and priorities.

> You have correctly said that this question is important in the Swiss National Park. You must know that the other projects of the Swiss parks are, in my view, the results of an economic-political demand. The work "park" is full of different interests. I believe that actors such as ProNatura or other NGOs have an important function in putting these demands within the parks' agendas. It seems to me that the structures are organized around economic facts: the interests of the population and above all economic interests, and the environmental interest may then arise later (Kull).

In Kull's view, environment conservation is just one of many processes that the parks should promote, and probably not the first-ranked for importance. This claim is in line with the previous consideration expressed by Florian Knaus, stating that local populations and steering committees

[12] ProClim- is a forum for climate and global change issues, which seeks to facilitate both integrated research activities and the necessary linkages among scientists, policy makers and the public at home and abroad. Based in the Swiss Academy of Science (ScNat) its mission is to actively promote interdisciplinary scientific collaboration, to assist with the development of coordinated research projects, to ensure links with international global change programs and to facilitate the exchange of information on global change science within Switzerland (http://4dweb.proclim.ch/4DCGI/proclim/en/Detail_Program?proclim-).

sometimes saw in nature conservation an obstacle in their way to development. Nature conservation, even if an integral part of every PA's official goal, might be overshadowed by different interests. By the same token, research on the possible impact of climate change might be slowed down by the need to address socio-economic problems. Discussing the main problems highlighted by the previous interviewees, Kull recognized some common traits between this particular case and one of the more general difficulties that climate science is facing in the task of structuring robust communication with society in the Swiss context. In particular, he stresses the need to communicate climate change as a problem to address in the present, rather than in the future.

> [What you are citing] is a problem involving all of society. Switzerland is very organized and starting to change something is difficult. The response that you are quoting to me is typical, because a change is only possible if there are agreements. There is a need to feel that something really would change. These are weighty organizations, difficult to change. I have discussed the fact with Thomas (Scheurer) that it would be good to have structures that were able to adapt, to find new possibilities. But in the end the capillary organization really makes it difficult to change anything (Kull).

The task of effectively spreading the concept of uncertainty, a key feature of climate science, has proven difficult to accomplish:

> This is something which we have been trying to do for ten years, to communicate the notion of uncertainty. It is a difficult concept to communicate even in scientific circles. We have a discussion group that organizes meetings three or four times a year in which we speak of the current themes in this context. But uncertainty is really difficult to communicate. In the end it seems to me that in Switzerland the weight of the organizations makes everything difficult: everything works so well, why change it? This sense of inertia is strong, and it is difficult to communicate the need for flexibility (Kull).

Kull sees in heavy structures like PAs nonflexible objects, which are difficult to connect to ideas of uncertainty. These difficulties might have a direct effect on research, since climate change science is based on future projections, with their margin of errors and different scenarios that need to be addressed with flexibility. Combining this need with the point raised by Knaus on the necessity or at least the possibility of actually doing something in order to cope with the changes, one can easily have a sense of the perceived difficulties of the implementation of climate adaptation and even monitoring. Additionally, the question of the availability of the monitoring structure was raised, given the fact that it was originally established for different purposes.

The infrastructure developed according to a different thinking. The first places for gathering data were in the mountains, in the St Gotthard or the St Bernard. The discussions on new observation points came from private companies who exerted pressure for the meteorological network to be widened. I do not think this discussion [on climate and the ecological change network] ever entered into the network planning. The network was built on the basis of indications of population. The network exists, but it was born in a different context […] I think that in the mountain above all, however, it will need to be developed, however (Kull).

In general, even if – as highlighted at the beginning of the chapter – climate science accounts for a high degree of policy-relevance on a national scale, communication between climate experts and different branches of society is not necessarily smooth.

It is clear that climate change is there, just as are the effects that come at a cost. There are questions, but we do not yet know what the best response is, also on the political level. For many people, the best response is to do nothing (Kull).

Kull confirmed the central hypothesis and embedded it in a more general overview of the difficulties in conducting and communicating climate science to different administrations, even in Switzerland, where climate science has already reached a high level of policy relevance.

However, a last step towards the confirmation of the hypothesis took the direction of the ecological evidence supporting the need of climate-related studies. On this topic, interviewees from both the management and science domains showed a reasonable degree of agreement around the need of gathering more information describing the effects of climate change on ecosystems in order to undertake any adaptation measures. Moreover, it has been highlighted explicitly how a more precise body of scientific information would be crucial in order to understand better how climate change can affect not only the composition, but also the structures and functions of ecosystems.

These [ecological processes] are very slow processes. Just the migration of some species does not indicate that ecosystems are changing. We have to be careful in the interpretations of climate-induced changes. What we need are analysing climate-related changes in different "segments" of ecosystems: soil, air, water, forest, grassland, etc. It is to these days not evident, if evolution has the same direction in all "segments". Expostion or block dumps can offer retreats for arctic species even if temperatures are increasing. In this regard, mountain ecosystems are very resilient to climate change (Scheurer).

As mentioned earlier, there is no evidence available demonstrating substantial influences of climate change on the ecosystem's structure and function; hence it is crucial to stimulate new basic research on these topics, in order to enhance the capability of detecting actual threats to ecosystems deemed worthy of legal protection. Another interviewee belonging to group 1, Stefanie Von Fumetti, researcher at the University of Basel and part of the nascent spring monitoring network, aligned herself with the position expressed by Scheurer on the absence – and necessity – of data regarding ecosystems' response to climate change, but also of basic research on the functioning of ecosystems:

> I think for scientists climate change is a compelling phenomen, there a lot of things to research (…) We need more research on structure and functions. We need to understand how food webs function, how they may change if some parts of the food webs vanish or become less, food availability changes and so on. We need first to know how it works now in order to project it in the future (Von Fumetti).

In order to deepen our understanding of this last points, an interview with ecosystem specialist Bruno Baur, from the University of Basel, has been organized. Baur explained in detail what are the obstacles towards the formation of research on the impacts on ecosystems' structure and function.

> There are various studies going on climate change affecting ecosystem functioning. This is a rather complicated question. You might have direct and indirect effects. For example, climate change allows a better development of invasive species. In the past, when we had cold winter, it pealed many invasive species. We have now warmer winters and invasive can develop better. The problem is serious and depending strictly to climate change. In my group we are finalizing a study on Himalayan balsam: where the species occurs, you have half of the root biomass in the soil. Root biomass is directly or inversely correlated with soil erosion. Less roots equals erosion and viceversa. Ecosystem functioning avoiding erosion is depending on the amount roots. A typical way of indirect effects of climate change on soil stability. These systems are complex, not easy to communicate to wider audience and lay persons. So it is difficult to communicate these projects, but it is also easier to record changing in species distribution, but studying the responses of ecosystems is a demanding task, that cannot be by a single person. They are just more demanding questions. There are few groups willing to di this kind of research, because you have to invest more time, money and manpower to get ecosystem results. It is easier to have results in species distribution with a lower-investment research. Saying that we need more data is a superficial answer. One should ask why we need more, and I am trying to do this (Baur).

At this point is clear that some of the main issues regarding the management domain cannot be answered by science alone but need to be tackled by the joint interest of science, management and policy. However, as the last quotations show, substantial lack of knowledge of ecosystems' structures and functions are seen as an obstacle to a more comprehensive scientific view of the problem. For this reason, further interviews focused on the main scientific obstacles that prevent the formation of climate change research in Swiss protected areas.

4.4.2. Factors hindering research by the scientific community

From the point of view of science, the task of organizing and conducting climate change research poses significant challenges. Most of the interviewees belonging to categories 1 and 2 highlighted how the need for a historical series of data constitutes an obstacle for monitoring the development of climate change and its physical and ecological consequences. This is especially true in recent PAs, where scientific projects may be entirely new. From springs to moorlands, ecological monitoring initiatives suffer from the absence of reference data gathered in the past. While the case of moorlands has already been documented, Stefanie Von Fumetti drew attention to the same topic of data unavailability, scarcity, or, similarly, to the incomparability of data stored from past observations.

> There is plenty of data from the sixties, but it is not easy to do a comparison. The first data on springs that went to the direction of climate change was from the Berchtesgaden National Park in Germany, but it was not a long-term monitoring, just 6 springs for 10 years. That is not enough. we do not have a continuous data series. […] So it is not that we have data series, we have it, but not continuous. You need continuously to have the personnel to monitor. It is also a financial issue (Von Fumetti).

On the same lines, Knaus remarked that in the case of moorlands without precise data from the past, any monitoring initiative would suffer from the absence of a baseline comparison.

> We have to try to compare the situation of the peatlands in the 1980s and today, 40 years later. It might be useful to have insights into what changed, but we do not know yet (Knaus).

The absence of these kinds of epistemological constraints constitutes, as already highlighted in section 4.3, the good fortune of the Swiss National Park, and hence one of the main reasons it stood as the only hub of climate change research in protected areas in Switzerland. Given these particular conditions, it is fair to suspect that not only park administrations might find little interest in addressing a topic perceived as temporally distant or of little practical importance as climate change, but also researchers might see parks as unappealing settings for these kind of studies:

> It is not so urgent for Naturepark to undertake research on climate change. And conversely, researchers don't need to go to parks to investigate impacts of climate change. For us [researchers participating in the spring network] parks, national parks especially, are important, because that is where you can find pristine springs, so it is more obvious (Von Fumetti).

Von Fumetti pointed implicitly to factors of scale mismatch between the physical and scientific capabilities of the PAs to study effectively climate change and the unavoidable needs that have to be satisfied in order to produce robust evidence and, as a consequence, effective scientific findings. If the temporal scale mismatch has already been stressed, the researcher hypothesizes also a potential spatial mismatch:

> Maybe the topic of climate change is just wider than Natureparks and you have to look to whole countries or regions (Von Fumetti).

In the absence of historical data describing the past climate, the attention in climate research can be turned to spatial variability. The latter practice, however, might be as problematic as the former, because spatial variability can be grasped in wider spaces than the simple PA.

On the same line of inquiry, Alice Brambilla, a postdoctoral researcher at the University of Zurich, points out some of the main scientific problems that researchers have to face while addressing a problem as complex as climate change. Brambilla is a long-term research collaborator in the oldest PA of the Italian Alpine range, Parco Nazionale del Gran Paradiso, where she has carried on research on ibex populations. Brambilla is not actively working in Swiss protected areas at the moment, but her experience on assessing the needs, obstacles and problems underlying climate change research practices is highly relevant to understanding better the difficulties that Swiss protected areas have to overcome. During her work, she became familiar with the potential effects that climate change might entail in ibex population dynamics and stresses the importance of the availability of long data series, or, at least, proxy data able to give useful insights on past climate.

> The long-term area [of research] in which I work began its own activity around twenty years ago, with an initial aim that was different from the study of climate change but was to have more general long-term observations which would provide deeper knowledge of the species. The observation of a number of

particular phenomena, among them a drop in the population of ibex from the mid-1990s, then led the research to be directed towards the causes. Climate change was obviously one of the possible hypotheses. From that point began a series of monitoring over time, because obviously the problem of climate change is the impossibility of reconstructing the variability of the past where there is no progressive data, and there is no alternative to looking at the future. The ibex has the advantage of having horns that are able to be kept and function like the rings of a tree, therefore the data from the ibex can enable climatic reconstructions of the past, even before 2000, the official beginning of the surveys. We can date back to around the 1980s. There are also methods linked the analyses of satellite images which allow us to work on reconstructions linked to parameters of the environment and not just an individual species. Our research now is moving in different directions, but I will limit myself here to those areas linked to climate change. There are counts on the number of animals and the dynamics of the population, a measure of the population's physical parameters, such as the size of the animals or their horns, which tell us of the environment's trophic availability in the long term, and there are supplementary studies into the quality of the environment itself: we have digital images with which we can measure the quality of grazing and the trophic resource – today we can also find this with sample of vegetation at a seasonal level to see how the trophic resource changes over time. Our hypothesis relating to the ibex is that the main conservation problem is the synchronization between the plant season and the species' biological cycle. Among our methods we have animals who are marked and individually recognizable and we conduct censuses throughout the park. We also have areas of intensive monitoring. The historical series of the censuses begins from 1956 and is very valuable, even with all its limits of homogeneity. The hypothesis linked to the phenology in detail is that with the advance of the vegetation growing season, linked to the reduction of snowfall and higher winter temperatures, the phenological seasons of richer nutrients, with the sprouting of the vegetation, is coming before the birth of the fawns. The time of parturition and the peak of trophic availability are no longer synchronised. As a result the fawns do not reach autumn in conditions of health that are adequate to survive their first winter, which is the critical time for their life expectation. We think therefore that the direct cause of the fall in the population is a fall in the fawns' survival rate. Pathological cases have been excluded, to some extent it was initially linked to a physiological fall given the high density, but the decrease went beyond what was expected, and from that point arose the interest in the fawns (Brambilla).

Despite the long research history of the ibex populations and of the PA, uncertainty in ecological responses to climate change still plays an important role in the research activities:

Another possible cause is the species lack of ability for thermo-regulation. The ibex suffers from the heat and climbs to higher levels, but risks distancing itself from its food sources. The work which we are undertaking in the long term shows us that actually the adult male ibexes are fatter. This is understandable, since there is less snow and they begin to eat earlier in the spring: the adult makes are not delicate. We don't yet have any clear answers, but the long-term studies will give us these (Brambilla).

Focusing on the main scientific needs that play an important role in climate change research, she indicates not only historical data series, but also forecasting models:

> There are two problems: the need for long series of data and the reliance of forecasting models which prevents us from giving correct results about the future. Gran Paradiso has worked with CNR[13] to have climate models; there is interest. But everything is poorly organised and the connections often link to contingencies and so to research networks (Brambilla).

These models materialize the limitations related to scientific uncertainty, which Kull has already addressed on a theoretical level. Brambilla stresses the absence of a systematic way of addressing climate change at research level. Research on climate change might need different expertise, bound together by a structured network. Even in the case of Gran Paradiso, its cooperation with other research institutions is a direct consequence of contingencies and fruitful occasions of network-building. However, the capacity for networking of large, historical institutions might not be the same as that of recent PAs, as in the Swiss case.

Addressing the wider issue of research distribution in the case of climate change and PAs, Brambilla notes another problem that could prevent climate change research from blossoming: in her experience, defining what constitutes "climate change" can be problematic.

> We noticed how the ibex horns got smaller over the years. We attributed this to the effect of climate change, but something did not add up. We have now realized that the animals have become larger, in terms of weight, while the horns became smaller in the the past, only to stabilize in recent years. The dynamic is probably extremely complex. The difficulty in carrying out research into climate change is a difficulty of definition: what is meant by climate change? Do we mean increases in temperature? Changes in trophic supply? Changes to the environment at a geomorphologic level? There is ambiguity in publishing a work explicitly dedicated to the effects of climate change, when in fact only the effects of temperature on the spatial behaviour of the ibex will be monitored. One can talk in a certain way when giving information, but when presenting research results, temperature and spatial behaviour are not equivalent to climate change (Brambilla).

[13] Founded in 1923, Consiglio Nazionale delle Ricerche (CNR) is the largest public research structure in Italy (https://www.cnr.it/it).

In other words, the problem might be an issue of attribution, where the correlation of some factors is not seen as enough evidence for speaking of climate change. This problem adds to the already large pile of scientific difficulties and is directly linked to the availability of long data series or forecasting models. It also can prevent some publications from explicitly linking their findings to climate change, giving new possible explanations for the relative lack of research records in Alpine PAs, where the dimension of applied research might be overweighting basic research interests and discouraging research that cannot produce definite results.

In conclusion, the few and often incomparable historical data deriving from past climate and environmental monitoring, united with the need for different expertise able to deal with uncertainty, even in the form of climatic models, are the main factors that limit the possibility of research in the field. Additionally, a problem of attribution might hinder scientific research, as in the absence of historical data and forecasting models, the correlation of phenomena to climatic variables might be seen as insufficient for ascribing the causal relation to climate change.

4.5. The role of International scientific monitoring programs in the future of climate change research

The role of international monitoring programmes has been evaluated with every interviewee belonging to category 1 and 2. Even if the obstacle of data scarcity is unavoidable, because the temporal gap in data collection cannot be fixed, PAs might nevertheless serve as climate change observatories if involved in broader monitoring projects. Interviews highlight how this kind of scientific practice can be useful not only for small protected areas with little or no historical data available, but can serve as benchmarks also for large and historical PAs:

> The replicability (of the data) is not perfect. In the case of the ibex the is much variability between different areas. Among animal communities there can be young populations and older ones, with different dynamics and histories. This is not only connected to the peculiar characteristics of Gran Paradiso, but to the age of the population. There would need to be analogous conditions elsewhere to be able to replicate the studies. We would be pleased if there were other areas that could replicate the studies, obviously not in an abstract way in which we took any area at all of the Alps and made the comparison, but in a way where the same characteristics would be looked for elsewhere. Yet account has to be taken of the reality; we don't have a possible comparison with our data. For historical, political and human reasons we have this concentration of data in this place. For our future research

directions it would also be very valuable to be able to compare the data – ideally, three or four similar situations with long-term data, so as to be able to best understand the variability. I am in favour of promoting replicability because it is the best way of promoting a fundamental scientific principle (Brambilla).

If the importance of monitoring networks has already been stressed as an effective way to include small PAs into larger monitoring organizations, Brambilla highlights how even historical PAs would benefit from the inclusion of multiple PAs in the same network:

> Speaking of inertia, the world of European research and institutions is quick to accept new concepts. From the perspective of individual institutions there is more inertia, more difficulty in reception. Gran Paradiso is very receptive from this viewpoint. Certainly, no-one is asking to change the census methods, but there is participation in PhenoAlp between France and Italy, and those of us working on the ilex are participating in an Interreg France–Italy project. The institution is keen to widen its perspectives, but I understand that a smaller area with fewer resources can struggle to collect external input. It is also true that today to attract investment and resources you need to jump at these opportunities, which are handed down from above but can still work. Gran Paradiso, from this point of view, could, by this type of scientific initiative, drag along other areas too (Brambilla).

In concurrence with this statement, Switzerland is showing some signs of involvement in these transboundary networks. Von Fumetti highlights how the formation of a specialist network focused on National Parks is a constituent part of the wider research network on springs:

> At the beginning we had a loose network of researchers in National Park Gesäuse and of course another group of people working on springs in Germany, but not focused on National Parks. We are now starting a specialist network on National Parks. We will probably have a network of 4 national parks [Gesäuse, Berchtesgaden, Val Müstair and Swiss National Park] (Von Fumetti).

When questioned directly on the future role of international scientific cooperation in promoting climate change research, interviewees from category 2 and 4 agreed in principle on the projected centrality of international cooperation, but highlighted two crucial aspects deemed to be necessary in order to increase the number of research studies on the topic, one from a purely scientific standpoint and one related to the policies and practice of the ecosystem's conservation.

First, as Scheurer recalled (7) international research projects have to be designed and conducted in a way that can generate new research in the PAs involved, following, for instance, the blueprint of GLORIA's ancillary projects designed in the Swiss National Park. International research projects should act as an umbrella under which new parallel projects can be organized and conducted. Following this direction, the lack of preceding observations and data might be overcome by a wider spatial dimension that opens the possibility of data comparisons throughout different geographies and integrates the research protocol with new observations outside international research schemes.

Second, especially in PAs where science is not at the core of conservation programmes, or where it shares a central role with local sustainable development goals, research can be translated into effective conservation practices only if accompanied by mechanisms of resources allocation towards all the stakeholders, comprising private landowners, with the final task of conserving endangered, rare or highly-valued ecosystems from the threat that climate change might pose in the foreseeable future. From this perspective, the future development of research projects could be dependent on the possibility of constructing conservation interests among all the stakeholders towards climate-sensitive ecosystems, landscapes, and habitats.

4.6. Of melting ice, migrating species and scientific relevance

By this point, some of the main obstacles slowing the development of climate change research have been detected by the interviews. Many interviewees underlined how interest in climate change might rise with the occurrence of more threatening phenomena, such as water scarcity or landslides. This attitude demonstrates how already developing – and detectable – phenomena, such as species migration and range shifts, or glacier melting, are not considered highly problematic (or simply not manageable) from a management standpoint. However, if the presence of active scientific monitoring projects is dependent on the importance that is given by the PA to these processes, it also tells of the distinctive "scientific culture" of the region under the lens. Scientific regions are formed in the interaction of scientific and managerial interest with epistemic constraints, including funding, policy or management issues. From a management standpoint, Swiss parks are boundary objects that have to fulfill many tasks, one of which is nature protection. However, it is indeed interesting to investigate what objects PA managers and scientists select as their protection (or research) goals and, in the end, what nature they feel they should protect, and how they should study it. For this reason, the topics of ecosystem composition, species migration and glacier melting have been discussed, as some of the few clearly detectable signs of climate change effects. The goal was to gain a better understanding of their peripheral position in respect to the main lines of inquiry.

In the case of the Aletschwald, the PA could be regarded as an interesting setting for studies on species distribution and ecological composition. The policy regulating nature management has been clearly defined as a nonintervention one, but only for as long as climate change does not constitute a real threat to some core conservation target.

> For us now the policy is very clear: we let nature develop. Nature can develop, we are not influencing the development in some precise direction. When we see developments that are disturbing animals, for example, we normally do not think "what can we do to help". Seeing the Tetrao tetrix going higher in this region, we let them adapt their behaviour. We have problems with the red deer […] there are too many of them and they are disturbing the forest. So, we are looking to begin a study to monitor the movement of the deer to discover how to react to their density in the Aletsch forest. But we cannot say anything until we have results. Take another example. If we have a fire, it disturbs the natural development. We have never had a great fire, but when we do it is not clear [what we will do]. Probably we would let the fire consume the forest and see the natural processes start anew. Normally we do nothing in terms of intervention to influence natural development (Albrecht).

The example of fire, as already shown by the Swiss National Park, is usually the most problematic, since if left unmanaged, the consequences might be bigger than the PA itself. However, even in the specific case of species composition issues, i.e. new species colonizing the protected forest habitat, the policy is uncertain and, once again, postponed to the future.

> The problem will be present when we have new plants in the forest. At that moment we will probably decide to do something against [the process], but we cannot take decisions now. We will take a decision when a real problem is there (Albrecht)

However, it is interesting to see that the PA Aletschwald does not completely rule out the possibility of active intervention in the future. From this point of view, future research on invasive species and neophytes would become policy relevant, at least at the scale of the single PA. Nevertheless, species composition issues cannot claim to be yet at this stage on the bigger picture, taking the entire PA system into consideration. From a management standpoint, an initial answer to the question of why species composition or glaciological research is not yet considered relevant for the single PA can be given regarding the expectations of tourists visiting the PAs.

> For general tourists, I think their view of the glacier and the forest is naïve. They see the glacier and the forest and they are ok, but they don't detect changes.

A view of the glacier, a walk in the forest, the smell of the pines. I don't think they wonder about ecological or physical changes. Perhaps somebody can ask about [the most] apparent changes, and then we can explain and speak about climate change. When I show them old pictures of the glacier, they are shocked. But still, at the moment, we have a 23 km-wide glacier that is here, so there is no problem for them (Albrecht).

Albrecht included issues related to glaciers and ecologically valued species in his general discourse on touristic behaviour towards environmental evidence of climate change effects, stressing their fundamental inexistence in the eye of the casual observer:

At the moment we can see, with the retreat of the glacier, the tourist will see little lakes that are a very nice sight. I do not know if they see a problem with the glacier retreat. We will have other problems, like landslides, permafrost etc. But we are still far away. Problems of water availability for hydroelectric functions, they will arise too. When you have such problems, everybody will be more aware, but it will be too late. For us, it is important to show people every day what is at stake with climate change. Many people will not care about the species of the trees you can see here. Arolla pines or other trees are the same to them. The problem will be present when we have new plants in the forest. At that moment we probably will decide to do something against [the process], but we cannot take decisions now. We will take a decision when a real problem is there (Albrecht).

On the same line of inquiry, Hammer sees the problems of species composition as an issue that cannot be dealt with using a rigid set of goals, as conserving a species in a specific geographical location. He also stresses the political choice undertaken by Switzerland, dealing with ecological connectivity as the only possible solution to conserve species at risk of local extinction.

We know we must protect the habitats, but we can see that some of the species originally included in the habitat are moving out and others are moving in. The only solution is to be open. Habitats are changing, but still, they must be protected, not just because they host one or two species, but as a fundamental part of the landscape. But what happens if habitats do not fulfil the criteria to retain legal protection? We do not have a solution here in Switzerland, just a discussion. Our proposition is to connect different biotopes and ecosystems. To connect habitats on the local level, but also on a national level. We must promote connectivity at each and every level (Hammer).

Addressing the same topic, Baur stresses the potential consequences of this choice for highly specialized, rare species:

> You cannot fight against climate change, it is mainly a political issue. In most PAs they will have a new species assemblage. Where specialized species will stay in the future? In Switzerland in the next two decades biodiversity is probably going to increase. But these new species are common, generalist species, able to live in different situations. Our concern should be on the rare, highly specialized species. They can move relatively, most of the specialist will not able to migrate from one site to the other. Of the PAs they should think more of these species, because they could have refuge for them. Some of them will probably become extinct with the competition of colonizing species, but there actually is the key question: what to do we do for rare and specialized species? You can try to figure out tools for particular species, but a general answers is beyond me. It is a large question mark (Baur).

Even in this connectivity framework, the possibility of losing some species is not ruled out of the question. As Von Fumetti highlights for the case of springs:

> If they are not able to adapt to higher temperatures or to shift then they are gone. At least in some regions, even if probably not everywhere (Von Fumetti).

At this stage of the inquiry, it is unavoidable to ask why – in a large, transboundary conceptual framework like connectivity, designed for allowing species to migrate and break free from isolation and related risk of extinction – species-specific research on spatial mobility and population dynamics in relation to climate change struggle to find their way into research agendas. From the point of view of the single PA's management, the fight against the effects of climate change could be seen as an integral part of "nature protection". With the goal of discussing this task, two experts on landscape ecology, Felix Kienast and Mathias Bürgi from the WSL, were consulted. The alleged centrality of climate change tackling operations has been widely discussed, and it reveals some ideas that animate the debate at the scale of the landscape. This particular scale has been selected because of the centrality it shows in the context of the connectivity framework, where a good amount of territorial planning is performed. Discussing the role of parks and PAs in the "fight" against climate change effects, Kienast remarks how the task and the main focus of conservation should be different from "fighting" changes.

> The strong emphasis on conservation is on fighting? No, there is nothing to fight. Species arrangement will change, and new species assemblages will form. The big task is to design a kind of future landscape which people can be attached to and where species can find new habitats. The strict conservation aspect will fail. You cannot find new localities – either for humans or for plants and animals – that are identical to the ones where conservation issues were implemented originally (Kienast).

Even downscaling the focus from the wider landscape to the single PA, Kienast's arguments follow the same reasoning:

> I think that protected areas have some meaning for what they stand for. For example, in National Parks in the USA, you have a topic that is compatible with the landscape characters. So for example, if in Glacier National Park the glacier was gone, the meaning will be necessarily different. Let's think along the line of a disappearing glacier. Even if they disappear, they can have a meaning. Even if a glacier vanishes, the moraines will be there and remind people what used to be there, and people will visit the area the same. I think meanings don't disappear, they are replaced. I think it is wrong to fight for the one and only meaning of a place or landscape in the light of climate change (Kienast).

On the same position Bürgi addresses the question of the symbolic meanings associated with the environment, its ecosystems, and species assemblages:

> Talking about symbolic meaning, maybe it is a matter of defining what stories places might hold. We get rid of something that has not fitted, but we generate something new and meaningful. There is a lot of work to do […] The question is very practical: why do you want to keep telling these stories? We must get rid of some stories. Also, with the glaciers, seeing the traces witnessing the past presence of the glacier, you will have very relevant stories to tell. When a story loses the meaning, you must get rid of it. It is not static, stories have a meaning for people, and meaning changes (Buergi).

The only caveat expressed is that the speed of the process might pose some troubles to the PA («Probably losing things in a small-timespan might be the problem. It makes thing less acceptable», Kienast).

In the two scientists' interpretation, it is easy to see why species composition is not addressed as a problem for the PAs, as they should be concerned with pursuing other adaptation goals, such as learning to cope with a changing environment and generating new relationships between ecosystems, landscapes and local populations. The position assumed by the majority of Swiss PAs is more understandable, under this light, waiting for climate change effects to happen in order to actively adapt.

At that point, climate change research might increase. In the case of glaciological research, the reason for such a substantial lack of research may be found by looking more widely than only in Switzerland. Looking back at chapter 3, it is easy to see that the overall distribution of glaciological research in protected areas is strongly concentrated in the hotspot of Stelvio National Park, while outside it there is little contact between research and PAs. Glaciological research of climate change effects does not need to focus on PAs in order to gather evidence. Conversely, the viewpoint of the two landscape ecologists clarifies why Swiss PAs do not see glacial retreat as a priority in their research efforts. The phenomenon is very similar to the one described by Von Fumetti, where PAs and scientists may lack interest in each other.

However, the lack of policy and management importance given to research on topics such as species composition and migration, as well as their postposition in the future of scientific research in protected areas, still clashes with the central political position assumed by the international discourse on connectivity. How can a highly impactful theme on the political sphere not be supported by a core research focus? The point of view of research coordination organs, as in the case of the Entlebuch, may help to find some insights:

> If a species is isolated genetically it is probably just gone. Can it survive, does it have enough genetic variability? We have the example here of a plant that occurs in two places, here and in northern countries. Some restoration projects have been done, but one night a deer decided to eat some of the plants. Can it now survive? If you take these two points [on map] they have different subsoils, one is dry, and one is not. How can you create connectivity? Sometimes it is just impossible – from a theoretical point as well. […] it is all still highly conceptual-hypothetical. The fact that species might move upwards is something people can grasp. Initiatives like connectivity network are difficult to understand. […] If you want to do a connectivity network for this plant how do you do it? This species would most likely not go anywhere else. Hence, it is nice to think about building up networks, but illustrating what this means in practice and from the perspective of concrete species, it can get difficult to explain and justify (Knaus).

It is probably the perceived hypothetical dimension of the whole project that is deterring these kinds of scientific project from development. From an analysis of the available scientific literature, it seems that the research initiatives are all born on higher spatial scales than the single PA[14]; hence, research on the spatial mobility of the species, as well as inquiries on changes in the ecosystem composition, might be seen as a concern for a higher spatial level of research than the single PA. However, analysing the current research on connectivity also from a temporal point of view, it is clear that a core research programme still has to be developed, although an initial – and indeed very small – cluster of research saw the light at the beginning of the century, while a second cluster, slightly larger, was formed between 2015 and 2018. It is probably a matter of time until the growth of connectivity allows it to affirm itself as a scientifically-epistemically relevant research

[14] All the research records indexed in Web of Science point at regional scales, taking into consideration wide landscapes, as in the case of the ECONNETC project.

topic, able to spread through different PAs since its policy relevance status is already a steady reality. Nevertheless, the topic needs further research in order to confirm the hypothesis and actually monitor how the status of policy-relevance translates to the scientific domain.

Another point of interest is formed by the analysis of the potential role that the notion of iconicity entails. The role of iconicity and charisma as properties of some organisms or even landscapes has already been addressed in the previous chapters as one of the main drivers of conservation processes. Migrations and issues of species composition, as well as glacier retreats in fact, can surge to a new relevance status if taken outside their strict naturalistic dimension and analysed as a social phenomenon. In the case of iconic landscapes – like the ones ideally protected by UNESCO under the "World Heritage site" label – the PAs can do very little in order to limit the changes that climate variations can impose: receding glaciers, less snow cover or water availability. However, these changes can be studied – in a strongly "applied research" focus – together with the touristic and local population behaviour and perceptions toward the new landscape, as in the case of Canada (Groulx et al., 2017). The case of iconic or charismatic species traces its influence back to the past. The example of the Swiss National Park represents an interesting benchmark in this regard. The successful management paradigm adopted here came to know its limitations in the past, especially with the management of wildfires – which still represent the social limits of the non-intervention rule – but also occasionally of some debated species reintroduction[15].

> Extinction is a natural process and specific species conservation has never been a target, but still, the case of the Ibex broke out of the official paradigm of non-intervention with natural processes. There are limits to this concept and charismatic species are probably sitting at the edge. But the history of SNP has some other examples of the limits of this conception as a non-intervention space, like in the case of wildfire. It is interesting to explore where the concept gets intertwined with other dimensions. To map the border in order to understand where the social limit is, where the problem stops being scientific and starts being social (Kupper).

It is exactly in the intertwining between the natural and the social that climate change might find a way into the scientific agendas of the PAs. If parks and other PAs are to be "beautiful promises for the future" and models of sustainable development, then research inquiring into the relationships between physical, biological and ecological changes and the social consequences of these changes cannot be anything but a central topic of the future. In Felix Kienast's word: «the big task is to design a kind of future landscape

[15] See Kupper, 2014.

which people can be attached to». When read in this light, climate change research could find another way – independent from international monitoring undertakings and strictly place-dependent – into the research focus of the PAs. Not with the final task to arm PAs for an unwinnable war against inevitable climate-induced evolutions in ecosystems and landscapes, but by addressing the task of generating new spaces for migrating species, and new meanings in the various form of human-environment relationships that will take place in the future of parks and PAs. This hypothetical research programme could also bypass the need for long series of data describing the past evolution of climate or climate-related variables, since its focus should be on the present and future dimension of these relationships between natural and social worlds. Neither the preliminary data analysis, nor the interviews, however, could highlight potential areas able to display substantial alteration of the landscape character. As a result, the whole discussion remained highly hypothetical.

4.7. Synthesis of the data

The analysis of research practices of the Swiss subregion is helpful in forming an idea of how the patterns of research distribution highlighted in chapter 3 hide complex dynamics at the interface between science, management, and policy. If the research has been carried so far on a indexed data analysis basis, shifting the focus to the network of actors behind the data allows a different kind of information to be obtained. The methodology of the expert interviews has allowed light to be shed on the dynamics that form scientific and managerial interest toward climate change, which today remain largely uncodified. Moreover, the qualitative data are particularly well fitted for the task of inquiring into the travel capacity of science on a (sub)regional level, where the low density might undermine the explanatory capacity of the data.

From a perspective encompassing science and management, some issues in addressing effectively climate change arise. It appears that when heavy economic, social and political organizations like PAs allocate interest, funding, and workforce, they seldom do so without concrete evidence of a threat towards their core interests. Up to this point, from an ecological view, the lack of research data and substantial knowledge regarding the structures and functions of the ecosystems reduces the possibilities of tracking changes. In the Swiss context, in particular, the young age of the majority of Swiss PAs probably forces them to focus on monitoring acceptance within local populations or other more urgent issues. Even when they already empirically face some degree of change that is considered tolerable from the PA's administration, climate change is apparently regarded as a phenomenon to be addressed in the future. This attitude is mostly explained by the need to face issues regarding land use, land-owning rights, and concessions. Even if some signs of change in ecosystems composition might be empirically detectable, their relatively low current impact is preventing the formation of keen interest.

Additionally, interviewees belonging to category 2 highlighted how the physical capability to cope with changes is influencing research. Scientific projects in protected areas have to embrace the dimension of applied research. The retreat of a glacier and the upward migration of a particular species do not constitute phenomena that can be managed or controlled and they – probably – pose no threat to the integrity of the PA. By contrast, an increase in the number or intensity of wildfires or landslides might be perceived as a physical threat. Given the low density of research distribution in the PA system, it is probably safe to assume that climate change does not yet constitute a physical threat to protected areas' infrastructures or to the integrity of the ecosystems they host.

Critical considerations on the spatial and temporal necessities of a hypothetic climate change research project led some of the interviewees to advance hypotheses of a scale mismatch between the problems related to climate change and the inquiry capabilities of PAs, both in relation to time and space. The absence of historical data means that the acquisition of useful information could take decades to show meaningful trends, and the limited geographical scope of the PAs might not be an ideal setting to monitor the unraveling of ecological changes. Researchers also highlighted the necessity of networking in climate change monitoring, since some of the necessary tools, such as forecast models, could be developed only in cooperation with external research institutions. These cooperative projects are easier to arrange for large, historical and socially affirmed PAs, while smaller and more recent areas might face substantial difficulties.

The result of such a combination of limiting factors is the drop in climate change research in the background of research and monitoring efforts in almost every PA.

Additionally, the viability of international monitoring networks as a solution for fostering climate research in protected areas has been evaluated and some of the potential benefits addressed. However, the solution can be effective only if the international research programmes are able on the one hand to stimulate the creation of new, ancillary research studies on a local level and on the other – in PAs where sustainable development goals are part of the mission – mobilize resources to allocate to the different stakeholders involved in conservation of valued or endangered ecosystems.

Moreover, the issues regarding the composition of ecosystems are not currently seen as phenomena of paramount importance for the maintaining of the mission of any PA. The same considerations can be applied to the case of receding glaciers, where the impossibility of actively taking management measures to compare the rates of melting is also seen as a factor determining the lack of dedicated research efforts, especially considering that the majority of the PAs are not entirely focused on the study and protection of nature, but share its resources with socio-economic development goals. With the development of climate change effects and the translation of the foundational concept of connectivity from the political to the scientific domain[16] and the concrete definition of research programmes, more studies may be seen dealing with – even if not necessarily in an exclusive manner – climate change effects on species. At the same time, and potentially even on a local level, the interviews highlighted how the mission of PAs in the face of a changing climate should be focused on the creation of new meanings and new ways to generate attachment between people and landscapes or environments. In the light of this task, and coherently with the necessity of applied research that might be immediately useful for the management, new research directions can be developed in monitoring the perceptions and behaviour of tourists and local populations toward the changing landscapes and ecosystems.

In conclusion, the young age of the Swiss PAs affects negatively their capacity for effective enquiry into climate change, both from a managerial and scientific standpoint. The relatively short existence of the institutions forces some PAs to focus on local acceptance and more urgent issues, while the lack of long-term data suitable for climate research hampers the PAs' capacity to conduct research. Additionally, it should not be forgotten that Swiss Natureparks are born out of the need of creating areas where the goal of nature conservation shares a central role with sustainable development, and hence research efforts are not limited to the natural science domain, but involve socio-economic sciences that focus their interests on different phenomena. However, international cooperation in the form of scientific monitoring networks and the intertwining of social and natural phenomena that climate change will probably cause in the future could potentially bring new attention to an otherwise peripheral scientific topic.

[16] Note that the issue of habitat connectivity was born as an exclusively scientific problem in the domain of ecology. However, the adoption of the term in the political sphere and promoted the centrality of the topic in the general discourse around conservation. When we forecast the translation of connectivity from the political to the scientific sphere, we are referring to the scale of the PAs, where scientific records are still lacking. Hence, it will be a mistake to generalize and assume that ecological research on connectivity *in toto* has been made epistemically relevant because of political interest. The case of connectivity provide an interesting example of the feedbacks that animates the relationship between science and policy in conservation.

5. *Conclusions*

5.1. Overview of the main results

Our journey led us throughout different geographies, from the global level to the sub-regional level of Switzerland, trying to find the factors shaping the distribution of research and some of the main features that are characterizing different scientific regions. In order to synthesize the main findings and limitations of the research, the paragraph will address, step by step, what the different chapters highlighted.

The introductory chapter reconstructed some of the key historical moments and central concepts that characterize the Alps as a scientific region" and pointed at the current state of the art in climate change science across different disciplinary fields from the natural and the social sciences. The numbers obtained in a scientometric review testify the prominence of the Alps as a scientific region. In historical terms, the Alpine scientific dataset's reconstruction mirrored the paradigmatic perspective enucleated by the French geographer Bernard Debarbieux: climate change is a pervasive reality able to touch every aspect of science, as the social sciences slowly flank the natural science in addressing the issue in the Alpine reality.

Chapter 1 showed how climate change science is widely distributed in protected areas worldwide, even if the majority of the indexed research is produced in North America, the UK, and Australia. Raw data proved that English-speaking institutions dominate the indexed research. However, normalizing the data with the total amount of climate change literature produced in each country provides a new picture. Developing countries show a more substantial interest in the research question, even if their indexed literature's relative size plays a role in inflating some of their numbers. The growing reality of Bolivia, Costa Rica, Bangladesh, Indonesia, and Brazil present compelling cases of strong prominence of our research question in national scientific agendas. The role of major scientific literature producers is diminished in this new perspective, as giants like China and the USA crumble to low normalized values. The Alpine countries follow the same trend, displaying a relatively high production volume, but a small share concerning the overall climate literature indexed. On the other side, the UK is the only country to show a high volume of production combined with a remarkable normalized rate.

For the particular case of the United States, we have dived in the public discourse developed around the effects of climate change in protected areas and noted how climate change is deeply rooted in the everyday practices of conservation and scientific research. As the phenomenon deepens its roots in the scientific culture of American PAs, its identity changes. Climate changes become a cultural object that cannot be contained in the domain of the natural sciences and probably of science in general. The articles we addressed showed clearly how climate change effects, even if inquired on a scientific level, are strengthening connections with scientists' life histories and personal feelings towards precise environments and ecosystems. The analysis of two policy documents, namely the *revisiting Leopold* guidelines and the Canadian guidelines for protected areas, highlighted that, in particular regions, the interest of science in climate change effects in protected areas is connected to the presence of particular policy guidelines. The interconnections between the two spheres have been only highlighted, mostly through the lens of the Canadian adaptation policy, without further developing the analysis of the nature of the relationship. However, for the scope of the analysis, the presence of dedicated policy documents has been assumed as a reliable proxy of a robust volume of scientific literature addressing the problem.

Coherently with the last finding, we looked for encompassing policy documents in our specific region of interest. However, we could not find a single, large-scope policy guideline.

The regional geography of scientific endeavour has also been tendered as a fruitful focus for work on science spaces, enabling identification of features of scientific culture positioned between the local and the global. Hence, in chapter 2, we discussed the specific case of Alpine PAs and tested a more in-depth bibliometric and science-mapping analysis of the regional literature. The results highlighted how climate research in Alpine protected areas is circulating across and beyond the region on different "railways". Four National Parks are producing more than half of the total body of literature indexed in Web of Science. These Parks are leaving their marks in the literature on a content level since they are driving research conducted in monitoring networks or developing their own research program. Smaller, younger protected areas contribute less in the general research landscape, even if global and regional networks of research involve progressively more parks and protected areas. On the other side, a parallel analysis in the grey literature highlighted how a reasonable degree of additional literature rests outside of the most known science database. This research body enjoys a lower degree of mobility, since it is often written in local languages and is not published in international journals. In Livingstonian terms, we can say that some Parks are serving as primary laboratories for conservation in light of climate change, as they often conduct and produce more research, and promote a broader, more efficient circulation of research products.

In critical terms, our focus touched two of the pillars of the geography of science thus far, namely the construction of *science in situ* and the principle of *science in motion* (Livingstone, 2003; Finnegan, 2008). The results align with the general theoretic claims of the framework. Scientific products' spatiality testifies the very own essence of science itself as a situated and social enterprise. Climate change intercepts different scientific agendas from different angles: research varies in space according to different economic, socio-cultural, and historical traits. As a result, climate science selects its object of interest on a local level accordingly to these factors. In Finnegan's words:

> field sites might be approached not as fixed points in space but as 'working objects' differently constituted in different spaces of inquiry and fashioned by 'practices of place' such as pinpointing, demarcating, describing and samplin (2008).

Alpine protected areas are not an exception.

At the same time, the scientific history and credibility of National Parks play a determinant role in disseminating scientific endeavours. Traditionally, we are thoroughly keen to believe that scientific knowledge travels the world with constant efficiency and scientific practitioners harbour ambitions that patently extend beyond local, peripheral contexts. Still, our case study highlights how the circulation of scientific knowledge is ineluctably bound to questions of trust; trust, in turn, flourishes in specific sites, where scientific history and tradition, funding, and workforce are to be found.

In the last chapter, we analysed from a close distance what are the main factors that are preventing the formation of a robust body of literature on climate change in protected areas. Switzerland was an ideal stage for understanding the limitations that climate science must overcome to spread in the majority of managed protected areas. Additionally, the presence of national databases provided guidance in exploring the otherwise dark depth of grey literature. Expert interviews highlighted the centrality of different factors that are impeding research development, ranging from the absence of historical data to a lack of monitoring systems in place. Experts also stressed how research endeavours are subjects to funding and workforce constraints and how climate change can be penalized whenever economic interests are at stake in the competition for resources between research projects. Moreover, some experts underlined that climate change could be perceived as a problem "waiting to happen", a future concern. This perception could be the results of the inertia that is typical of heavy, slow structures when facing changes, but it also stresses the dimension of uncertainty, the "uncertainty monster" as has been recently defined (Curry, Webster, 2011), that constitute an obstacle to climate change adaptation.

Diving into an epistemic community proved to be a fruitful source of qualitative, *thick* data that provided both contextualization and explanation for our quantitative evidence. Climate science's globalizing message (top science metric-wise, or advertised science) must face the struggles that come with epistemic and political quarrels. The regional reality enquired shows distinctively how models and narratives are telling just a part of the story. Coherently with our initial stance, science has been treated as a social endeavour and explored with a constructivist approach. Experts shared their expertise, their points of view on key elements that influence science-making processes as an everyday practice, and a long-term policy investment. Qualitative data were instrumental in undercover the limitations of standard bibliometrics exercises when applied to small regional contexts, but also displayed the necessary explanatory power to interpret the body of information available, or conversely, not available.

5.2. Further lines of research

The results of this exploratory analysis can stimulate new questions of research that could constitute new lines of inquiry in the same field. In epistemic terms, PAs are attractive trading zones where climate science is transmitted across different scientific communities. In their own, distinctive way, National Parks, Regional Parks, Nature Reserves, and Natura 2000 sites constitute places of translation for different epistemic languages, shared among academics coming from different disciplinary fields, park managers, and conservationists. Such rich and diverse and lively assemblages are worth the geographical community's attention and pose a compelling case for more research, suggesting new and even deeper questions.

1. Once defined the main feature of the literature produced in Alpine protected areas, new insights on the regional identity of research can be obtained by comparing different regional literature. On the same line of reasoning we employed in the introduction and third chapters, it could be interesting to compare the Alpine literature with the ones produced in the other main mountain ranges of the world. In a geography of science

perspective, this exercise could constitute a valid benchmark of the existence of different "cultures of science" in approaching the problem of climate change in protected areas on a macroregional level.

2. Building on point (I), more questions of "how" need to be answered. Experts interviews highlighted many otherwise invisible processes, acting behind the world of publications. The different opinions and sometimes contrasting readings of experts helped give more voice to the science mapping and bibliometric analysis. It could be fruitful to test this methodology in other Alpine subregions again. In the alternative, with a different geographical scale, next interviews could focus on the functioning of research hotspots to shed light on the specific interests that move Ecrins, Stelvio, Gran Paradiso, and Swiss National Parks.
3. As already stated clearly in chapters 2 and 3, the world of grey literature cannot just be ignored. On the countrary, it can reveal the existence of a complex underwood that is made invisible by the towering trees of international publications. Is the content of these two bodies of research similar? Do they differ? Why this imbalance in publication practices exists? All these questions can be answered only after dealing with a methodological problem: how can we systematically explore this universe without comprehensive databases, without recurring to a slow and often inefficient close reading approach? It is possible to aggregate different databases, and different languages, into a comprehensive corpus of information?
4. Simultaneously, a multiregional enquiry on climate change research in protected areas could offer the chance to evaluate which different research programs create epistemic relevance to inform conservation policies and practices. Is the top-quality, Web of Science-indexed literature influencing policymaking on a macro-regional scale? Is the grey literature involved in the formulation of adaptative behaviours on a local scale? Keeping track of the citational flows between policy documents and scientific articles might present a compelling new direction of research in a Geography of Science perspective.

5.3. Some concluding remarks on the geography of science and the conceptual and methodological instruments employed

From an epistemological standpoint, the application of science mapping and scientometrics, combined with expert interviews constituted a fair strategy for integrating quantitative descriptors with qualitative insights on the mechanisms that regulate the pattern of distribution. The results are confirming the potential of this kind of integrative method. Expert interviews helped us to save the dimension of "science in action" (Latour, 2003), moving from the documental level (the publications) to the processes of science-making.

Nevertheless, everything comes with a cost, and some issues had to be faced in projecting and writing this research. A source of struggle came to form the integration of the two methodologies. The methods are radically different in their capacity to address precise questions. Qualitative experts' interviews are easily directed towards the object of interest. Hence, we can say that the method is rather "question-driven". Conversely, data mined from the scientific databases are hardly bending to the pure curiosity of the researcher. In this case, the research approach is "data-driven" since the initial questions that led us to employ the methodology are not finding ready-made answers. To integrate both methodologies in question-driven research is not easy, as the data provided by the database could miss the point of the discussion. As a result, this work is the outcome of a long-fought battle to maintain an equilibrium between the more instinctual and innate search for answers to our leading questions and the analysis of what data structures and patterns can tell.

This last point can be particularly hostile for a human geographer, used to employ mainly qualitative methods. Network maps are characterized by "the independent life of mathematical objects" (Petrovich, 2018). Statistical measures that helped us describe the network's main feature are many, describing the mathematical properties of the edges and links that compose the network. One can easily lose sight of the original question that led to this methodology's choice since many questions can arise, exploring the different functional relationships between the data.

Despite these difficulties, we believe that this path can be a fruitful one if we are to apply the framework and the leading questions of the geography of science to new research questions, like climate change. We hope that this work can constitute a small contribution in geography to reconstruct a beneficial interest toward the spatial dimension of science, as a means to disentangle the complexity that characterizes global problems.

After all, we could discover that geography, even in this universalizing, fast traveling world, still matters.

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Charting the uncharted

Making space for climate change science in Alpine protected areas

Protected areas are among the most common and successful instruments for conserving the environmental features of different regions. Basing their effectiveness on the paradigm of spatial segregation, or their capacity to block out of their borders undesired environmental pressures, they carved their space into the fabric of lands and territories worldwide. However, climate change is leading the scientific community to a turning point in designing conservation plans and practices: no matter how tall the fences are, how deep the helms, and how strict the laws, protected areas cannot held climate change on the edge of their borders, but need adaptation pathways to the new climatic conditions. Adapting to climate change is, first and foremost, a science-driven endeavour, that should embrace the best scientific information available. Interestingly, the genesis, mobilisation, and circulation of science all display spatial variability, as space plays a role in creating scientific knowledge that is notably unrecognized. Building on the literature inherited by the field of the geography of science, the research experiments an array of computational and qualitative methodologies to reconstruct the landscape of science making in protected areas. The final goal is to shed light on the geography of scientific information that shapes the Alps, one of the most crucial conservation regions in Europe, in the face of the looming changes that global warming entails.

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